Analysis of Internal Force and Deformation of Existing Crane Girder Structure Under Large Tonnage Crane Loads

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Abstract: In the theoretical calculation of crane beams, the influence of the stiffening ribs of the web plate on its load carrying capacity and deformation is not considered, which leads to a large discrepancy between the theoretical calculation results and the measured data. Taking the example of upgrading a small-tonnage crane to a large-tonnage crane in the assembly workshop of a single-story light steel structure plant as the background, a correction method is proposed based on the field test results of the structural internal forces and deformations of crane beams under the loads of large-tonnage cranes. The method considers the influence of web stiffening ribs on the load carrying capacity and deformation of the crane girder, and adjusts the established deformation theory and stress calculation of the crane girder accordingly, as well as corrects the deflection theory and stress theory. The purpose of the correction is to solve the problem of neglecting the influence of web stiffening ribs in the theoretical calculation of crane beams. The analysis results show that the crane girder is still in the elastic working stage after the small tonnage crane is upgraded to large tonnage. The corrected theoretical calculation values are more in line with the test values, but some crane girders still have small errors, which may be due to the existence of other influencing factors not considered in the actual measurement process.

Key words: Crane Beam; Load Test; Theoretical Analysis; Modification Method

1. Introduction

The crane beam is one of the main components of the plant, and there have been many scholars who have done some research on it.

At present, Wang et al [1] took the opportunity of upgrading the original design crane of the assembly plant to a large tonnage crane to conduct a test study on its crane beam. Teng et al [2] who conducted a relevant study on the generation of weld cracks, it is pointed out that the generation of cracks is a result of a complex and multi-factorial role. Eccentric torque, track unevenness or small deviations in the fabrication of the crane bridge, transient impacts generated when the crane passes through the rail joints, transient tensile stresses generated during the welding process, deviations during installation, and defects in construction are all factors that lead to a reduction in the fatigue life of the beam. Many scholars in China have also studied and analyzed the fatigue performance of crane girders under various conditions and given methods to evaluate the fatigue performance of crane girders [3-6]. Zhang [7] conducted fatigue strength test and static load test on two crane girders with more serious corrosion, and found that they were still in the elastic working stage under multiple fatigue loads and were in good condition under static loads. Yin [8] analyzed the deformation, cracking and bearing performance of large-span T-beams under different loads by combining the field test of crane beams in a water diversion project. Shang [9] carried out two-point loading on a pre-stressed concrete fish-belly crane girder prefabricated in the field and observed the deflection and deformation of the girder during the test. The crane, as an accessory member of the crane girder, does not belong to the crane girder system, but it has a synergistic relationship with it, and when the crane girder is subjected to the repeated action of the crane load, the resulting dynamic response will also have a certain effect on this type of accessory member. In recent years, the failure and damage of the accessory members of the crane girder system have been occurring continuously, which has caused a large safety hazard to the structure and production safety of the plant [10].

Because of the modification of the production process, it is necessary to replace the original cranes in the plant with large-tonnage cranes. In order to understand whether the replaced crane beam meets the requirements under the newly designed crane load. By comparing the test and theoretical analysis of the crane beam, it was found that the difference between the theoretical value and the measured data was equally large, because the theoretical calculation did not consider the influence of the stiffening ribs of the crane beam web on its bearing capacity and deformation, which led to a large difference between the theoretical calculation results and the results of the measured data. With the background of replacing the original crane of a single-story light steel structure plant assembly workshop with a tonnage crane, a correction to the deflection theory and stress theory is proposed, aiming to solve the problem of not considering the influence of the stiffening ribs of the crane beam web on its bearing capacity and deformation in the theoretical calculation of the crane beam. The research results provide reference for similar projects.

2. Structural Overview of the Project

The project was built in 2003, with a floor area of about 10885m2, which is a single-story light steel structure plant. Localized two-storey structure, beams, columns cross-section form are used I-beam, the plant is equipped with a number of cranes, the initial design of the maximum lifting capacity of cranes for 2T ~ 16T [1]. The crane girder A with a span of 8m and a weight of 30T, the crane girder B with a span of 16m and a weight of 30T, and the crane girder C with a span of 16m and a weight of 25T.

3. Internal Force and Deformation Analysis

Through the field test, the deflection deformation and strain results of the crane beam in its span under the specified load grading loading were measured. And the theory of deflection and stress is used to calculate and analyze the calculated selected crane beam, the displacement analysis results are shown in Figure 1, and the stress analysis results are shown in Figure 2.

From Figure 1, it can be seen that with the gradual increase of loading weight, the theoretical vertical deformation of crane beam A, crane beam B and crane beam C is obviously larger than the experimental value, but the theoretical vertical displacement and deformation, the experimental vertical displacement and deformation and the load increment are all linearly related. The measured displacements obtained from the tests under each condition fluctuate under different loading conditions due to the data differences caused by external factors during the field tests.

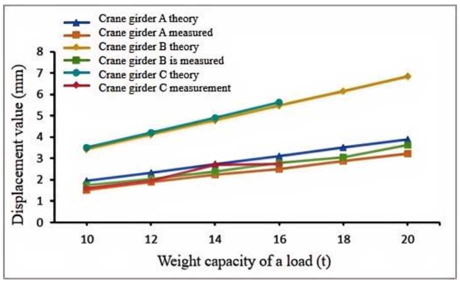

Figure 1. Displacement Curve

Using the calculation theory of stress to carry out theoretical calculations on the crane beams selected for the test, and comparing and analyzing the calculation results with the measured results obtained from the test.

As can be seen from Figure 2, the stresses of the three selected crane beams all show a stable upward trend with the increase of loading weight, and the theoretical values of the stresses of the crane beam A, beam B and beam C are obviously larger than the experimental values, but the theoretical and experimental stresses are all linearly related to the increment of loading. And the measured displacement of crane beam A changed the most when the loaded weight was 16 tons, the reason may be caused by external factors during loading.

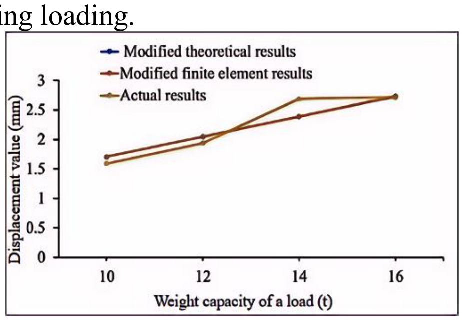

Figure 2. Stress Curve

4. Study of Deformation and Internal Force Correction

4.1 Deflection Correction

Since the influence of the stiffening rib of the crane beam web on its bearing capacity and deformation is not considered in the theoretical calculation of the crane beam, it leads to a large difference between the results of the theoretical calculation of the deflection and the results of the measured data. In order to accurately analyze the influence of the crane beam web stiffening ribs on the deformation not considered in the theoretical calculation of the crane beam deflection, a correction is proposed namely:

$$\omega = \beta \frac{pl^3}{48EI} \tag{1}$$

Where: β is the deflection correction factor considering the effect of ribbed I-beams on the deformation.

Finite element analysis was applied to the three crane beams selected for the test, and the finite element results were obtained. And compared and analyzed with the theoretical results previously calculated and the measured data obtained from the test, the analysis results of the displacement of the crane beam A after correction are shown in Table 1. According to the analytical results of the modified displacement of crane beam A in Table 1, the theoretical values, experimental values and modified results of beam A are further compared and analyzed, and the analytical results are shown in Figure 3.

Table 1. Corrected Displacement Values of Crane Beam A

load(t)	Theoretical results (mm)	Finite element results (mm)	Actual results (mm)
10	1.58	1.599	1.526
12	1.896	1.919	1.901
14	2.213	2.24	2.24
16	2.529	2.431	2.514
18	2.845	2.888	2.878
20	3.161	3.138	3.224

As can be seen from Figure 3, the theoretical displacement values of crane beam A and the finite element displacement values are very close after correction, and the data match very well. The measured displacement, on the other hand, changes significantly when the loaded weight is 16 tons, which is due to the external factors during loading, which is not considered by the theory.

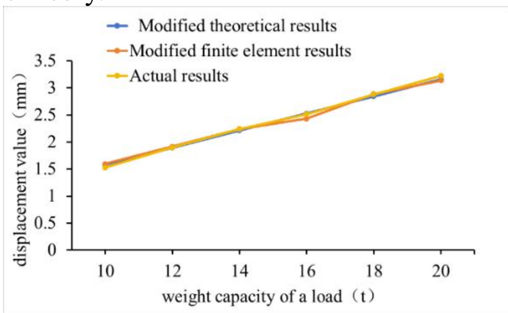

Figure 3. Comparison Curve of Displacement of Crane Beam A

Table 2. Corrected Displacement Values of Crane Beam B

load(t)	Theoretical results (mm)	Finite element results (mm)	Actual results (mm)
10	1.735	1.734	1.759
12	2.083	2.081	2.038
14	2.43	2.428	2.376
16	2.777	2.775	2.784
18	3.124	3.122	3.06
20	3.471	3.469	3.629

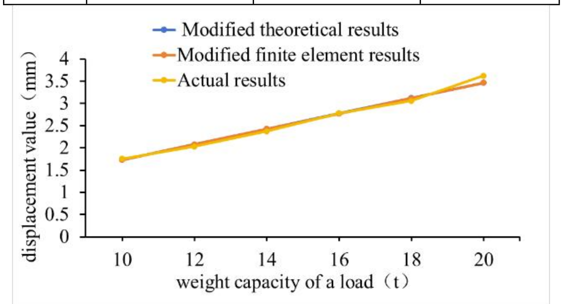

Figure 4. Comparison Curve of Displacement of Crane Beam B

The analyzed results of the modified displacement of the crane beam B are shown in Table 2. According to the analytical results of the corrected displacement of crane beam B in Table 2, the theoretical value, experimental value and the corrected result of the beam B are further compared and analyzed, and the analytical results are shown in Figure 4. It can be seen from Figure 4 that the errors of the theoretical and finite element displacement data after the correction of the crane beam B are extremely small, and only when the loaded weight is 20 tons, the measured results show obvious changes due to the influence of external factors.

The analyzed results of the modified displacement of the crane beam C are shown in Table 3. According to the analytical results of the modified displacement of the crane beam C in Table 3, the theoretical value, experimental value and the modified results of the beam C are further compared and analyzed, and the analytical results are shown in Figure 5.

Table 3. Corrected Displacement Values of Crane Beam C

load(t)	Theoretical results (mm)	Finite element results (mm)	Actual results (mm)
10	1.706	1.709	1.592
12	2.048	2.051	1.941
14	2.389	2.393	2.691
16	2.73	2.735	2.721

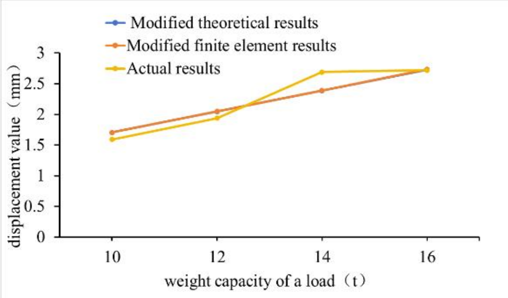

Figure 5. Comparison Curve of Displacement of Crane Beam C

As can be seen in Figure 5, the theoretical and finite element displacements of the crane beam C corrected are in excellent agreement, while the measured displacements change at loaded weights of 10, 12, and 14 tons, with the most significant change at 14 tons.

4.2 Stress Correction

As the actual I-beam crane beam is with web stiffening ribs, it has certain influence on its load carrying capacity, which leads to a large difference between the results of the stress theory calculations and the results of the measured data. In order to accurately analyze the stress calculation of the crane beam without considering the effect of the web stiffening ribs of the crane beam on the deformation, it is proposed to amend that:

$$\sigma_{max} = \frac{M_{max}(\beta)}{W_z} \quad (2)$$

Where: $M(\beta)_{max}$ is the positive moment repair of the I-beam with stiffening ribs considered.

The theoretical calculated stresses of the crane beams were fitted to the measured stresses by a single function to obtain their correction factors, and the corrected stresses were calculated.

The analyzed results of the modified stresses of the crane beam A are shown in Table 4. According to the analytical results of the modified stress of crane beam A in Table 4, the theoretical, experimental and modified results of the stress of beam A are further compared and analyzed, and the analytical results are shown in Figure 6. As can be seen from Figure 6, the corrected three results with the increase of the loaded weight, the stress value also increased, and the measured results in the 14t to 18t between the stress change is more obvious, the remaining two results tend to be stable.

Table 4. Corrected Stress Values for Crane Beam A

load(t)	Theoretical results (MPa)	Finite element results (MPa)	Actual results (MPa)
10	9.235	9.212	9.682
12	11.082	11.074	11.124
14	12.923	12.912	11.948
16	14.776	14.749	17.51
18	16.623	16.611	15.45
20	18.47	18.449	16.48

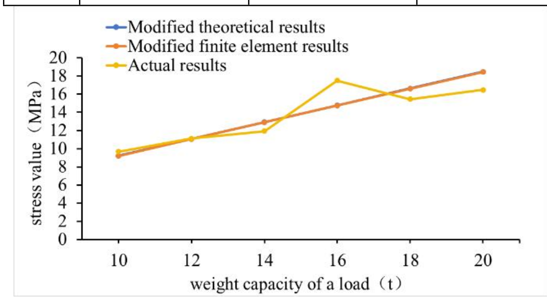

Figure 6. Stress Comparison Curve of Crane Beam A

Table 5. Corrected Stress Values for Crane Beam B

load(t)	Theoretical results (MPa)	Finite element results (MPa)	Actual results (MPa)
10	9.97	9.968	9.682
12	11.96	11.965	11.942
14	13.95	13.955	13.802
16	15.945	15.952	16.068
18	17.94	17.946	18.128
20	19.93	19.936	20.6

The analyzed results of the modified stresses of the crane beam B are shown in Table 5. According to the analytical results of the corrected stresses of the crane beam B in Table 5, the theoretical, experimental and corrected values of the stresses of the beam B are further analyzed in comparison, and the analytical results are shown in Figure 7. From Figure 7, it can be seen that the corrected stress values increase with the increase of loading weight, and there is almost no difference between the values before 18 tons, and there is a little difference between the corrected theoretical results and the measured results when loading to 20 tons, and the corrected finite element results are almost the same as the corrected theoretical results.

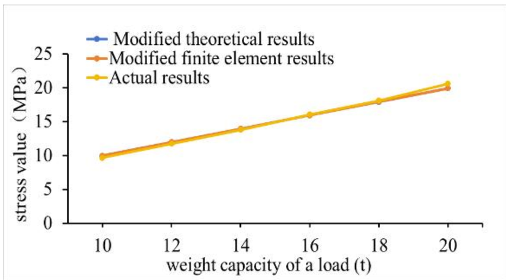

Figure 7. Stress Comparison Curve of Crane Beam B

The analyzed results of the modified stresses of the crane beam C are shown in Table 6. According to the analytical results of the corrected stress of crane beam C in Table 6, the theoretical value, experimental value and the corrected result of the stress of beam C are further compared and analyzed, and the analytical results are shown in Figure 8.

Table 6. Corrected Stress Values for Crane Beam C

load(t)	Theoretical results (MPa)	Finite element results (MPa)	Actual results (MPa)
10	6.92	6.937	8.034
12	8.2	8.325	8.24
14	9.69	9.714	9.27
16	11.07	11.099	9.88

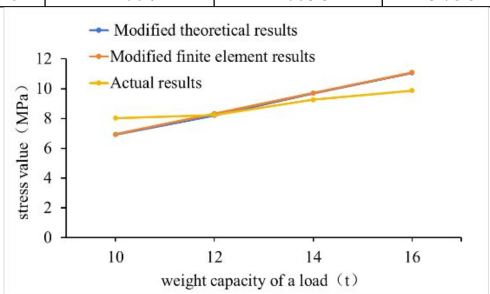

Figure 8. Stress Comparison Curve of Crane Beam C

As can be seen from Figure 8, the corrected stress values all increase with the increase of loading weight, and the theoretical results are in excellent agreement with the finite element results, while the measured results are greater than the theoretical and finite element results before 12 tons, and are less than both after 12 tons. And the comparison difference is largest at the maximum and minimum loading weight.

5. Conclusion

The original design crane of a single-story lightweight steel structure plant assembly shop is taken as the background after replacing it with a large tonnage. A combination of field test and theoretical method is used to conduct the study, and the following main conclusions are drawn:

(1) The crane girder work is in the elastic stage after the replacement of the existing small-tonnage crane with a large-tonnage one.

(2) A correction method for the deformation theory and stress of the existing crane girder considering the influence of the stiffening ribs of the crane girder web on its bearing capacity and deformation is given.

(3) After the correction, the error between the theoretically calculated values and the test values is obviously reduced and the agreement is significantly improved, but some crane girders still have small errors, which is due to the fact that there may be other influencing factors in the actual measurement.

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