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Study on Fire Resistance of Two-Span Continuous Steel-Concrete Prestressed Composite Beams

Zhiyuan ZHENG [a], Yongqiang ZHAO [b,1], Jie GAO [a] and Huanxin CHEN [b]
[a] *School of Urban Construction, Hubei Business College, Wuhan 430070, China*
[b] *Infrastructure Construction Department, Guangxi Normal University, Guilin 541006, China*

Abstract. In order to study the fire resistance of prestressed continuous composite beams and master the finite element simulation method, a set of two-span steel-mixed continuous prestressed composite beams were designed and tested, and the finite element model of material and geometric nonlinear forces was established by ABAQUS finite element software. By investigating the characteristics of the composite beam under high temperature, such as failure form, deflection change, reaction change at the support, curvature change of key section and internal force change of cable, comparing the test and finite element simulation results, the results show that: Under the standard heating mode, the temperature distribution of each component of the composite beam is different, and the temperature rise rate of the lower flange of the steel beam is the fastest, followed by the web, the upper flange of the steel beam, and the concrete slab. The failure form of the composite beam at high temperature shows that the mid-span deflection is too large, and the web plate and flange of the middle support are distorted. The mid-span deflection decreases gradually with increasing temperature, and the rate starts to accelerate when the temperature is about 450 degrees. The relative tension of the cable decreases first and then increases slowly with the increase of temperature. The relative reaction of the support decreases first and then increases with the increase of temperature. The nonlinear finite element simulation model of two-span prestressed continuous steel-concrete composite beams is obtained after comparison and verification, which provides technical support for further engineering.

Keywords. Prestressed continuous composite beam, finite element simulation, experimental research, fire resistance

1. Introduction

As the main stressed component of building and bridge structure, the mechanical properties of prestressed steel-concrete composite beams directly affect the overall performance of the structure [1-2]. At present, prestressed continuous composite beams will take certain fire protection measures in structural applications, but their fire performance will be weakened due to late maintenance negligence or human accident factors, so the study of fire resistance of prestressed continuous beams has certain

[1] Yongqiang ZHAO, Corresponding Author, Infrastructure Construction Department, Guangxi Normal University, China; E-mail:83247563@qq.com.

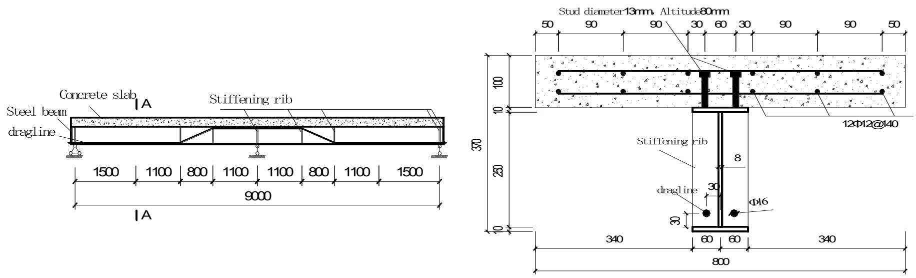
practical significance [3]. Domestic and foreign scholars have made a series of studies on prestressed composite beams and achieved certain achievements. For example, Fisher et al. studied the influence of beam end link mode and steel bar continuity on the fire resistance of composite beams through experimental methods [4]. ZHOU H T studied the influence mechanism of load ratio and prestress ratio on fire resistance of prestressed simply supported composite beams through experiments [5].

It can be seen that there is no relevant research on the fire resistance of prestressed continuous composite beams. Therefore, in order to fill the gap in this research, this paper designed a set of specimens of two-span steel-mixed continuous prestressed composite beams for testing, and adopted ABAQUS finite element software to establish its material and geometric nonlinear force finite element model simultaneously, fully combining the two means of test and finite element simulation. The mechanical mechanism of prestressed continuous composite beams under high temperature is studied.

2. Finite Element Model Establishment

2.1. Geometric Structure

The structure of the prestressed continuous composite beam is shown in figure 1, that is, the two ends are simply supported, and the three points in the span are equally loaded. The fire mode is the bottom surface of the beam and the sides of the two sides.



(a) Elevation of composite beams (b) Composite beam A-A cross-section

Figure 1. Prestressed continuous composite beam structure (unit: mm).

2.2. Finite Element Model Establishment

In the temperature field model, three-dimensional solid grid element (DC3D8) is used for the concrete slab, shell grid element (DS4) is used for the I-beam, and truss grid element (DC1D2) is used for the steel mesh and prestress reinforcement in the slab. In the mechanical model, the concrete slab adopts three-dimensional linear solid grid element (C3D8R), the I-steel beam adopts three-dimensional shell grid element (S4R), and the reinforcement and prestress reinforcement in the slab adopt three-dimensional truss grid element (T3D2). The grid element division of the whole component is shown in figure 2 below. Among them, the concrete type is C35, the I-beam and steel bar type is Q235, and the prestressed tendon type is S1860 steel strand. The interface slip effect between concrete slab and steel beam is simulated by linear connection element. The anchorage points at both ends of the cable are connected with the stiffening ribs through spring joints, and the initial prestress is applied by equivalent cooling method. The double-layer steel mesh arranged in the slab is coordinated with the concrete slab through embedding.

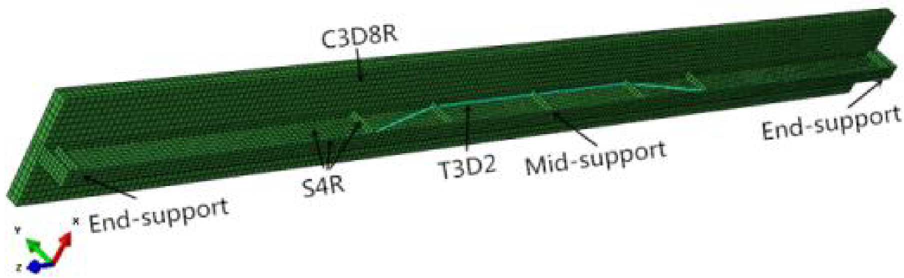
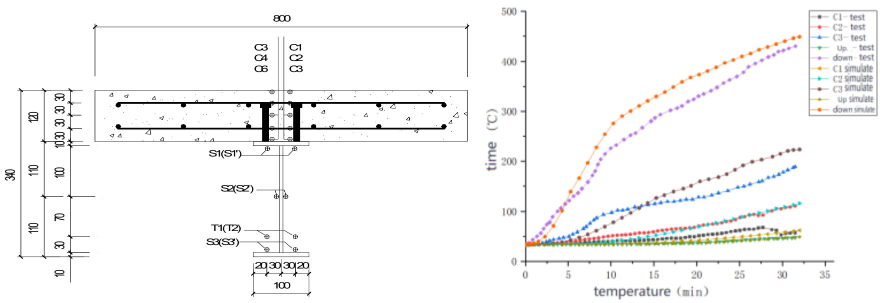


Figure 2. Grid division of prestressed continuous composite beams.

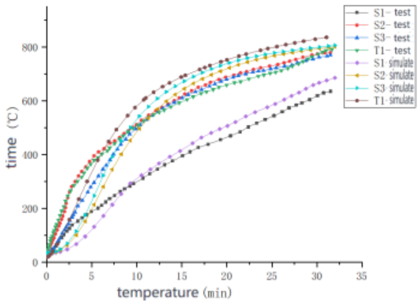
3. Comparison of Finite Element Simulation and Test Results

3.1. Comparison of Temperature Field Results

The test beam load ratio is 0.5, the prestress ratio is 0.6, the steel beam material property is Q235, the concrete is C35. Figure 3a is the measuring point at the temperature of the test beam, and figures 3b and 3b reflect the comparison between the actual temperature at the measuring point of the beam and the finite element simulation temperature results. As can be seen from the figure, the temperature of the steel beam (figure 3b) is generally higher than that of the concrete (figure 3a), and the temperature of the composite beam presents a certain gradient along the section direction. Among them, the temperature rise rate at the "S3" measuring point at the lower flange of the steel beam is the fastest, and the temperature rise rate at the "middle and upper" measuring point on the surface of the concrete roof is the slowest. In addition, the test temperature curves at each measuring point basically coincide with the finite element simulation temperature curves, which indicates that the finite element temperature field simulation results are reliable.



(a) Temperature measurement point (b) Concrete slabs temperature

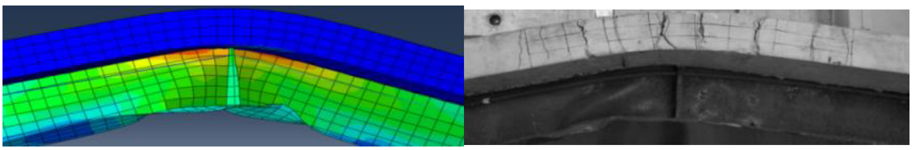


(c) Cable and steel beam temperature

Figure 3. Comparison of temperature field results of PCCB1 beam.

3.2. Comparison of Failure Forms

Figure 4 shows the comparison between the finite element and test results of the deformation at the middle support of the beam. According to the analysis of the test results, the simulated deformation of the finite element is consistent with the deformation of the test beam.

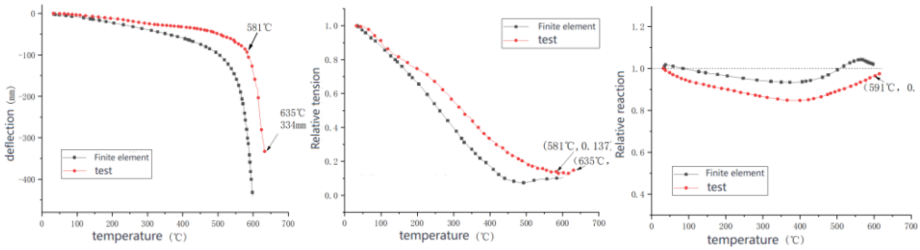


(a) Finite element simulation (b) Test results

Figure 4. Beam deformation at PCCB1 middle support.

3.3. Comparison of Structural Stress Behavior

(1) Comparison of mid-span deflection variation



(a) mid-span deflection variation (b) cable tension variation (c) Side support reaction variation

Figure 5. Comparison of structural stress behavior.

As can be seen from figure 5a, the curve change process can be divided into two stages: In the first stage, the mechanical properties of steel and concrete materials are reduced less by temperature, and the overall bending resistance of the beam is strong, so the deflection of the beam is slowed down. In the second stage, the temperature of some parts of the steel beam has reached 400℃, its elastic modulus and yield strength are significantly affected by temperature, and the bending resistance of the composite beam is greatly weakened, so the curve deflection decreases sharply with the rise of temperature.

(2) Comparison of cable relative tension changes

Figure 5b shows the curve of the relative tension of the cable changing with temperature. The relative tension is the ratio between the tension of the cable at high temperature and its initial tension at normal temperature. The temperature is taken as the temperature of the lower flange of the steel beam in the middle section of the beam span. In the first stage, the relative tension of the cable gradually decreases with the increase of temperature, which is because the temperature rise rate of the cable is faster than that of the composite beam, and the deformation of the composite beam is relatively slow, so the reduction amplitude of the cable stress due to the temperature effect is greater than the increase amplitude due to the coordinated deformation. In the second stage, the tension of the cable gradually increases with the increase of temperature, but the rise rate is slow, this is still because the composite beam deformation is large due to excessive temperature at this stage, and the stress of the cable also increases due to coordination deformation greater than the reduction due to temperature deformation.

(3) Comparison of the relative reaction force of the support

Figure 5c shows the curve of the relative reaction of the side support changing with temperature. The relative reaction is the ratio of the support reaction of the composite beam at high temperature to that at normal temperature. The deformation process of the curve is still divided into two stages: In the first stage, due to the superposition of the negative bending moment formed by the temperature gradient effect on the cross section of the composite beam and the negative bending moment generated by the external load on the cross section of the middle support, the bending moment of the cross section of the middle support increases with the increase of temperature, while the bending moment of the middle span cross section decreases gradually after the superposition of the negative bending moment generated by the temperature gradient effect on the cross section of the composite beam.

4. Conclusion

Through the study of the fire resistance of the two-span prestressed continuous steel-concrete composite beams, the following conclusions are obtained:

(1) The failure form of the composite beam at high temperature shows that the mid-span deflection is too large, and the web plate and flange of the middle support are distorted.

(2) The mid-span deflection gradually decreases with the increase of temperature, and the rate begins to accelerate when the temperature is about 450 degrees; The relative tension of the cable decreases first and then increases slowly with the increase of temperature. The relative reaction of the support decreases first and then increases with the increase of temperature.

(3) The nonlinear finite element simulation model of the two-span prestressed continuous steel-concrete composite beam is obtained after comparison and verification with the test, which provides further technical support for the project.

Fund Project

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