Research on Simulation Method of Steel-Concrete Composite Beam with Finite Element

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Abstract. The performance of composite girder double element model and composite cross-section model in the finite element analysis of composite beam were introduced, and three simulation method of the interface in the composite beam was studied, and then the three finite element modeling method of were adopt to analysis a composite beam under different load, and two simulation models including shrinking and the creep effect were computed. It is concluded from the computational results, when the mesh of dual element model is refined, the difference between the calculation results of the dual element model and the transformed section model remains very small, which means that dual element model can meet the requirements of calculation accuracy in case of the fine mesh size.

Keywords. Composite beam, bearing capacity, finite element model, transformed section element, dual element.

1. Introduction
The steel-concrete composite beam is composed of concrete deck and steel beam. The two materials transmit force through shear keys under load. Building an accurate analysis model is the efficient way to obtain the reactions of composite beam under the loads [1, 2]. The solid element is the most accurate model in composite beam analysis among those method [3], in which steel beam and concrete element are divided into small solid element and connected at common node, but it is not efficient and require tremendous storage. Therefore, A more efficient and reasonable method [4-6] is necessary to analyze the state of composite structure. Beam element model is usually used to calculate and analyze composite structure bridge in the engineering design [7, 8]. The commonly used steel-concrete composite beam finite element adopts the transformed beam element to simulate the steel-concrete composite beam (Shown in figure 1), in which the slip between steel and concrete is no under consideration, and the beam are taken as a uniform material. On the other hand, the concrete shrinkage and creep calculated with steel transformed into equivalent concrete after conversion, so it is difficult to evaluate the shrinkage and creep of concrete deck alone.

Figure 1. Diagram of transformed element method.
As shown in figure 2. In the dual element method, the layered beam elements are used to simulate the concrete bridge deck and steel beam respectively. The two-layer elements are connected by the rigid arm at the node. The slip effect of the composite beam can also be simulated through the longitudinal stiffness of the rigid arm. The deformation of the steel beam and the concrete in the element is only connected at the node, so the element should be refined to ensure accuracy.

Figure 2. Diagram of dual element.

The more accurate method is to simulate the steel-concrete composite beam with the combination of beam and plate element. In this method, steel beam is built with beam element, and concrete bridge deck is simulated with shell element. The shear lag effect and the partial load effect of the concrete deck can be taken into account accurately in this method, although the computational efficiency is not as high as the former two methods.

2. Comparative Analysis of Transformed Section and Dual Element Model

The following will compare the results of structural internal force, displacement and stress of composite beam element model and dual element model when simulating composite beam.

Different with the transformed section model, the dual element model is that the shear force transfer mode of the interface between steel beam and concrete deck is different. The shear force at the interface of the transformed section element model is uniformly distributed, and the deformation is always consistent along element. The deformation is constraints on the interface only the at node in the Dual element model, so the shear force on the interface is transferred by the rigid arms on both sides. This difference will affect the continuity of axial force in the finite element model, and the calculation error of the dual element model mainly comes from this.

2.1. Analysis Composite Beam under Uniformly Distributed Loads

A 20 m + 30 m + 20 m continuous composite beam is shown in figure 3. The beam section with single box double chamber section is composed with two box steel girder and concrete bridge deck. The beam height is 1.5 m and the width is 6 m. among them, the steel beam height is 1.3 m, the concrete height is 0.2 m, the steel box bottom plate thickness is 24 mm, and the web thickness is 16 mm. See figure 3 for the section form and size. The steel grade is Q345qD, the elastic modulus is 2.06 × 105 MPa, the unit weight is 78.5 kN / m³, the concrete strength grade is C50, its elastic modulus is 3.45 × 104 MPa, and the unit weight is 25 kN / m³.

Figure 3. Section of the beam.
Research suggests that if the ratio of element length to span is controlled between 0.01 and 0.05, the calculation accuracy can be guaranteed [9], and the element length is 0.5 m. As shown in figure 4, in the process of composite beam bridge erection, steel beam is often used as the support of concrete pouring. After the concrete solidifies to form composite beam, the two will bear the force together. Therefore, the construction stage is divided into erection of steel beam, combination of concrete slab and uniform load of 50-200 kN /m (load increment of 50 kN/m), and steel beam bearing its own weight and wet weight of concrete slab are considered in the stage of steel beam erection. After getting the internal force of the composite beam, the transformed section model calculates the stress based on the conversion section principle, and evaluates the final stress state of the composite beam by the way of stress superposition.

![Figure 4. Continuous beam under uniform load.](image)

As shown in figures 5 to 8, the difference between the internal force of steel beam and concrete deck calculated by the dual element model and the transformed section is small, and the computational results of stress are very close. The steel beam computational bending moment and concrete deck bending moment of dual element model are greater than that of transformed section model.

![Figure 5. Bending moment of steel beam section.](image)

![Figure 6. Bending moment of concrete beam section.](image)

![Figure 7. Deflection under uniform load.](image)

![Figure 8. Stress of steel beam top deck.](image)

With the increase of uniform load, the relative error of steel beam bending moment calculated by the two models increases gradually. Both are with a small error, and the relative error of concrete bridge deck bending moment is nearly maintained unchanged (shown in table 1).
Table 1. Comparison of computational results at midspan with two models under distributed loads.

| Load Internal Force | 50 kN/m | 100k N/m | 150 kN/m | 200 kN/m |
|---------------------|---------|----------|----------|----------|
| Ms/kN·m             | TM      | DM       | Error    | TM       | DM       | Error    | TM       | DM       | Error    |
| 2296                | 2302    | 0.3%     | 2690     | 2701     | 0.4%     | 3083     | 3098     | 0.5%     | 3477     | 3499     | 0.6%     |
| Mt/kN·m             | 10.94    | 10.98    | 0.4%     | 21.88    | 21.96    | 0.4%     | 32.81    | 32.99    | 0.5%     | 43.75    | 43.98    | 0.5%     |
| N/kN                | 1634    | 1631     | -0.2%    | 3269     | 3263     | -0.2%    | 4903     | 4890     | -0.3%    | 6538     | 6520     | -0.3%    |
| v/mm                | -30.4   | -30.4    | 0        | -35.6    | -35.6    | 0        | -40.9    | -40.9    | 0        | -46.1    | -46.1    | 0        |
| σs/MPa              | 35.7    | 35.7     | 0        | 50.4     | 50.4     | 0        | 65.1     | 65.1     | 0        | 79.8     | 79.8     | 0        |
| σt/MPa              | -1.64   | -1.64    | 0        | -3.27    | -3.27    | 0        | -4.91    | -4.91    | 0        | -6.54    | -6.54    | 0        |

Note: TM denotes Transformed Section Model; DM denotes Dual Beam Model.

2.2. Comparison Composite Beam with Creep Effect

In order to study the influence of the creep to the stress and deformation of composite beam structure[10-12], the finite element models are established based on the dual element and the transformed section model respectively for above continuous beam with characteristics and construction stage settings of the structure the same as those in the section 2.1. The following two simulation methods are given to calculate the deflection, internal force and stress of concrete bridge deck caused by creep at different ages (7, 30, 90, 180 days).

As shown in figures 9 to 12, the error rule and load effect evaluated with the two models are basically the same when the concrete creep effect is counted in the computation. The bending moment of steel beam and concrete deck in the dual element model is slightly larger than that of transformed section model, while the calculated value of axial force is slightly less than that of transformed section, but the error between them is very small. The displacement and stress results calculated by the two models are close. In addition, the change of the initial age of concrete bridge deck does not affect the relative error of structural response calculated by the two models as shown in table 2.

Figure 9. Bending moments of steel beams at different loading ages.

Figure 10. Stress of steel beam bottom plate at different loading ages.

Figure 11. Bending moments of concrete deck at different loading ages.

Figure 12. Stress of concrete deck at different loading ages at different loading ages.
Table 2. Comparison of results with two models under different loading ages at support position.

| Load Internal force | 7d    | Error | 30d    | Error | 90d    | Error | 180d   | Error |
|---------------------|-------|-------|--------|-------|--------|-------|--------|-------|
| Ms/kN·m             | -416.1| 1.6%  | -323.2 | -3.2% | -266.7 | 1.6%  | -236.3 | 1.6%  |
| Mt/kN·m             | 12.23 | 0.5%  | 11.25  | 0.5%  | 10.12  | 0.5%  | 9.28   | 0.5%  |
| N/kN                | 2452  | -0.3% | 2020   | -0.3% | 1603   | -0.3% | 1288   | -0.3% |
| σt/MPa              | 10.9  | 0.5%  | 9.24   | 0.5%  | 7.22   | 0.5%  | 5.56   | 0.5%  |
| σs/MPa              | -2.35 | 0.3%  | -1.97  | 0.3%  | -1.59  | 0.3%  | -1.31  | 0.3%  |

3. Conclusion

The differences of calculation results of composite beam modeled with the two methods under different conditions are analyzed based on examples. The simulation results of the two models are compared with the simulation results of the plate shell model. Finally, two fine transformed section model with different interface simulation methods are established.

It is concluded from the computational results, with the increasement of uniform load acts on the composite beam, the error of internal force between the two models also increases gradually. When the mesh of dual element model is refined, the difference between the calculation results of the dual element model and the transformed section model remains very small, so the dual element model can meet the requirements of calculation accuracy in many cases of engineering with the fine mesh size. When the creep is taken into account, the response of the transformed section model is also close to that of the other under uniform load.

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