Finite Element Modeling Method and Analysis of Self-Compacting Concrete Prestressed T-Beam

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Abstract. Self-compacting concrete could be poured under the action of gravity, without vibration, and has good working performance. It could reduce the noise during production, and reduce the labor of workers. In recent years, more and more scholars begin to study the concrete. In this paper, ABAQUS finite element software is used to simulate the self-compacted concrete prestressed T-beam under different parameters, using the self-compacting concrete constitutive model. The cooling method is used to simulate the prestress applying, and the performance of beam is analyzed. It is found that the bearing capacity of the member improves with the increasing of the reinforcement ratio, the prestress increases the stiffness of the member, and reduces the deflection of the member, but the ductility is reducing with the increasing of prestress.

Keywords. Self-compacting concrete, finite element analysis, ABAQUS.

1. Introduction
In 1988, Okamura of Tokyo University successfully prepared a kind of concrete with high fluidity. This kind of concrete was named self-compacting concrete. It shows excellent working performance, could fill the formwork and wrap the reinforcement without vibration [1]. In the process of pouring, it flows freely and fully fills the space in the formwork with its own weight, forming a uniform compact structure. Compared with ordinary concrete, self-compacting concrete has the following advantages: (1) excellent liquidity and self-filling performance, and no concrete bleeding. (2) need not vibration process, reducing construction noise, improving the workers and residents environment. (3) solving the problem of that some parts are not easy to be vibrated during the concreting process. (4) improving the efficiency of construction [2]. Many scholars have studied the concrete. Surong Luo [3], Hu Qiong [4], Huang Hui et al. [5] have studied the flexural performance of self-compacting concrete beams. It is found that the bending failure process of self-compacting concrete beams also has three stages: elastic stage, strengthening stage and yield stage, and its flexural bearing capacity is greater than that of ordinary concrete. Buratti N [6] found that fiber can improve the anti-crack performance of self-compacting concrete beams, and it can effectively reduce the crack width of self-compacting concrete beams. Hassan A et al. [7] studied the shear strength, cracking performance and deflection of self-compacting concrete beams. Mohamed L et al. [8] studied the influence of corrosion on the shear performance of self-compacting concrete beams. Nadim W et al. [9], studied the flexural performance of self-compacting prestressed concrete beams under monotonous cyclic loading. Mohammad M et al. [10] analyzed the ductility of the prestressed concrete beams. However, for the
advantages of self-compacting concrete, it has a good application prospect. In this paper, the finite element modeling method and the properties of the self-compacting concrete prestressed beam is studied.

2. Establishment of Nonlinear Finite Element Analysis Model
In this paper, a self-compacting concrete prestressed T-beam model is established by ABAQUS finite element analysis program. The main parameters include: Stress-strain relation of concrete, prestressed stress and reinforcement ratio, and the properties of the concrete beam is studied.

2.1. Model Size and Material Parameters
The model size, material parameters and reinforcement of self-compacting concrete prestressed T beam are shown in figure 1, figure 2 and table 1.

![Figure 1. Self-compacting concrete prestressed T beam.](image1)

![Figure 2. Cross section and reinforcement.](image2)

| Specimen number | Concrete grade | Prestressed reinforcement | Common reinforcement | Stirrup | Control stress |
|-----------------|----------------|---------------------------|----------------------|---------|----------------|
| 1               | C50            | φ1*7(15.2)                | 4A8+2A10             | A8@100  | 0.75fpy        |
| 2               | C50            | φ1*7(15.2)                | 4A8+2A16             | A8@100  | 0.45fpy        |
| 3               | C50            | φ1*7(15.2)                | 4A8+2A10             | A8@100  | 0.45fpy        |
| 4               | C50            | /                         | 4A8+2A10             | A8@100  | /              |

ABAQUS finite element software provides three constitutive models of concrete: the damage plastic model, the dispersion crack model and the crack model of concrete. Plastic damage model of concrete can be used for one-way loading, cyclic loading and dynamic loading, it uses the non-affiliated hardening plasticity and isotropic damage to describe the concrete damage [11], this
model has better convergence. In this paper, self-compacting concrete constitutive model are taken from [12, 13], and the parameters are shown in table 2. The constitutive model of reinforcement adopts double linear model.  

| Concrete grade | Cube compressive strength/(MPa) | Axial compressive strength/(MPa) | Splitting tensile strength/(MPa) | Modulus of elasticity/(×10⁴MPa) |
|----------------|---------------------------------|---------------------------------|---------------------------------|-------------------------------|
| C50            | 56                              | 33.8                            | 2.94                            | 3.76                          |

2.2. Model Building  
In order to prevent the local damage of the concrete beam, steel spacers are set at the support and the stress point. During the model creation process, tensile longitudinal reinforcement, compression longitudinal reinforcement, stirrup, prestressed reinforcement, concrete support gasket, prestressed rib gasket, concentrated force gasket and concrete are created independently. Each part is created in its own local coordinate system, which is independent of each other in the model. Since the reinforced concrete simply supported beam is composed of multiple components, it must be assembled in an overall coordinate system. While defining constraints, the steel skeleton is embedded in the concrete element to simulate the bond relationship between the steel bar and the concrete; The reference point and the steel spacer are selected as the coupling constraint; the constraint relationship between the spacer and the reinforced concrete beam also needs to be defined. It is assumed that they are tightly glued together during the simulation, so the binding constraint relationship is selected. The boundary condition at the support is hinged restraint, which acts on the center of the steel gasket at the left and right ends. Refer to the reference [14] for more specific methods. The model is shown in figure 3.  

![Figure 3. Self-compacting concrete prestressed T beam.](image)

2.3. Application of Prestress  
At present, the prestressing methods of finite element models includes equivalent load method and integral cooling method, etc. The equivalent load method could satisfy the design accuracy and more simple But it does not consider the deformation coordination between the prestressed member and the whole structure, and can not really consider the actual stress and strain of the prestressed member under the action of various external loads. The integral cooling method is to make the temperature dropping on the unit of the prestressed member and analyze the force of the prestressed member and the whole structure as a whole, to simulate the prestressed effect of the prestressed member on the whole structure. This method can flexibly control the value of prestress at different positions and simulate the loss of prestress. In this paper, the cooling method is used to simulate the prestress applying.  

2.4. Meshing  
In ABAQUS, there are three basic grid partitioning technologies: Structured, Sweep and Free. In this paper, neutral axis algorithm of the sweep partitioning technology to the concrete is adopted, and 8-node linear hexahedral unit is used to the concrete and T3D2 is used to the reinforcement.
3. Results Analysis
The influence of concrete strength, control stress and reinforcement ratio on the self-compacting prestressed concrete T beams is analyzed in the paper. Figure 4 shows the damage cloud diagram of specimen 1 concrete beam. The damage refers to the generation and development of micro-defects, leading to the failure of the unit. It could be described with damage coefficient. The value of the damage coefficient ranges from 0 to 1, where 0 is the initial state and 1 is the complete damage. Figure 4 is the damage coefficient cloud map of the component at the limit state.

![Damage coefficient cloud map of self-compacting concrete prestressed T beam.](image)

Figure 4. Damage coefficient cloud map of self-compacting concrete prestressed T beam.

ABAQUS finite element software could simulate the bending performance of self-compacting concrete prestressed T beam well. From the simulation results, it is found that the beam bearing capacity could be improved by increasing the reinforcement ratio of reinforcement. With the increasing of the non-prestressed reinforcement, the flexural capacity of the beam increases obviously. The prestress has little influence on the ultimate bearing capacity of the member, and it could increase the stiffness of the member, and the deflection corresponding to the maximum load is greatly reduced, but the ductility of the member is poor. Figure 5 is the Load-deflection (mm) curves of specimens.

![Load-deflection (mm) curves of specimens.](image)

Figure 5. Load-deflection (mm) curves of specimens.

4. Conclusion
1) The cooling method could simulate the application of prestress well.
2) The stress-strain relationship of the self-compacting concrete in literature [12] can be applied to simulating the self-compacting prestressed concrete beam.
3) The ratio of non-prestressed reinforcement and the prestress have an effect on the bearing capacity and stiffness of the beam. The bearing capacity of the member improves with the increasing of the reinforcement ratio, and the prestress increases the stiffness of the member, and reduces the deflection of the member, but the ductility is reducing with the increasing of prestress.

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