Experimental Test and Numerical Simulation of the Initial Crack Reinforced Concrete Beam in Bending

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Abstract. Based on the concrete constitutive relations provided by the concrete structure design specifications, a three-point bending beam numerical analysis was performed by introducing a damage plastic damage model and using ABAQUS to add a concrete parameter plug-in. The three-point bending test of the beam was carried out by the fatigue test machine, and the results of theoretical calculation and numerical simulation were compared to verify the correctness and reliability of the plastic model of concrete damage (CDP model). At the same time, the shortcomings of the theoretical calculation were pointed out, which can be used as a reference for the later engineering calculation and the research of concrete.

1. Introduction

Damage mechanics is a branch of continuum mechanics developed over the past 30 years. It systematically discusses the influence of microscopic defects on the mechanical properties of the material \cite{1}, the stress distribution of the structure, and the evolution of defects. It can be used to analyze the entire process of structural failure, that is, the evolution of microcracks, the formation of macroscopic cracks, and the complete destruction of components. Suppose that $A$ is the cross-sectional area of the cross-section of the element normal to the $n$. After the unit is loaded, the effective bearing area is reduced to $\tilde{A}$ due to the existence of micro cracks, micropores, the interaction of the defects, and the micro stress concentration caused by the micro defects. It is assumed that microcracks and micropores are evenly distributed in all directions of the space, which are independent of normal $n$, and all isotropic damage variables $D$ can be defined as:

$$D = \frac{(A - \tilde{A})}{A}$$

In fact, the orientation, distribution and evolution of micro defects are closely related to the direction of loading. Therefore, material damage is essentially anisotropic. The anisotropy of the damage has been proved by experiment. For example, creep crack propagation and ductile fracture experiments show that the anisotropy of the damage has significant influences on the type of crack propagation \cite{2}, fracture time, fracture load and so on. In order to describe the anisotropy of damage, the 2 or 4 order tensor $D$ is usually used to define the damage. Based on the plastic damage model of concrete, the bending bearing capacity of beams with initial cracks in mid span is analyzed by means of experiment and numerical simulation.
2. Damage Mechanics and CDP Model
The concrete damage plasticity constitutive model was developed by (Lubliner et al., 1989) and was elaborated by (Lee & Fenves, 1998). It is a modification of the Drucker–Prager strength hypothesis. The irreversible damage that occurs during the fracturing process can be described by the combination of non-associated multi-hardening plasticity and scalar (isotropic) damaged elasticity. It is assumed that the main two concrete failure mechanisms are the tensile cracking and compression crushing of the concrete material. The CDP model can analyze the concrete structures under monotonic, cyclic, and dynamic loading. It takes into account stiffness recovery effects in cyclic loading.

The evolutions of the damage components \( d_c \) and \( d_t \) are linked to the corresponding plastic strain. It is determined proportional to the inelastic strain using a constant factor, which both are experimentally determined. (Fig.1)

![Fig.1 Damage Evolution in CDP model](image)

3. Reinforced simple supported beam Experiment with initial damage
In order to determine the test load of reinforced concrete beam with initial crack, the ultimate bearing capacity of the non-crack reinforced concrete beam is calculated by using the structural design principle, which is the basis for the test and numerical simulation.

The theoretical bearing capacity of reinforced concrete beam is calculated by the method of structural design. The bending moment value can be used to obtain the load of the test beam.

\[
M_u = f_y A_s (h_0 - a') = 13.58 \text{kN} \cdot \text{m}
\]

Under the action of bending moment, the displacement of the cross section is as follows:

\[
\omega_{\text{max}} = \frac{FL^3}{48EI} \quad \omega = 0.73 \text{mm}
\]

There is an error between the calculation result and the actual situation, and it is because that the calculation process is according to the ideal computational model. Moreover, the calculation of bearing bending moment is based on the assumption of flat section, which is different from the actual situation. It is necessary to test the bearing capacity of reinforced concrete under the displacement loading.

Concrete materials: Concrete mainly consists of cement, stone and sand. Cement with strength grade C35 is used. The mixing ratio is as follows: cement 14.80kg, water 7.40kg, sand 24.36kg and stone 49.44kg. Types of reinforcement: steel bar is HRB335 steel (nominal diameter 12mm (pressure) and 14mm (tension)). The diameter of the stirrup is 6mm, and the spacing is 200mm, with a total of 9. At the same time, the standard concrete blocks were also made for the determination of the basic mechanical parameters of C35 concrete.
When the mid span deflection is 0.73mm, the loading force is converted to bending moment of 10.519 (kN·m), which is basically consistent with the numerical simulation and theoretical calculation. The test structure was compared with the numerical simulation structure in Figure 12.

4. Numerical simulation by nonlinear finite element method

The full-scale model is established according to the geometric dimensions of the simple beam, and the finite element model is established separately. The concrete element is made of three-dimensional hexahedral reduction element C3D8R in ABAQUS, and the steel reinforcement is made up of two nodes linear three-dimensional frame element T3D2 in ABAQUS. Modeling can be achieved by defining the bond between steel reinforcements and concrete by means of Embedded region. In order to avoid stress concentration, an elastic steel shim is arranged at the bearing and the loading point.

The model is loaded by displacement. According to the solution of bending moment in mechanics of materials, for a simply supported beam under concentrated load, when the concentrated load acts on the midspan section of the simply supported beam, the bending moment is the maximum and the maximum bending moment occurs in the midspan.
Because the force applied in this test is relatively small, the compression damage of concrete is small (Figure 10), however, for tensile damage (Figure 11), from the stress nephogram, it can be seen that the tensile damage starts from the mid position and extends gradually to both ends of the beam, extends from the bottom of the beam to the top of the beam, consistent with the basic theory, and the simulation is more reliable.

In the model experiment established by ABAQUS, it can be seen that the maximum bending moment appears in the middle position, which is consistent with the theoretical analysis, and the maximum bending moment is 9.720 kN.m. The results are somewhat different from those calculated by theory. Fig. 9 gives the bearing capacity of the particle with time, it can be see that the bearing capacity is changing with time, advice, as time increases, the particle force increases in line with the actual situation.

Based on the experimental data obtained, the results are compared with the numerical simulation data.

Figure 12 gives the numerical simulation and experimental data comparison chart. It can be seen that the general trend of the bearing capacity curves is basically the same. In this experiment (numerical simulation), the bearing capacity shows a gradually increasing trend with the increase of time,
meanwhile, the actual results and numerical simulation results are well verified.

5. Conclusion
The experimental results have the same trend as the numerical simulation results. The experimental results are similar to those of numerical simulation, which shows that the CDP model can simulate the bearing capacity of concrete beams with initial cracks. Compared to the perfect concrete beams, the concrete beams with 0.2mm wide and 3cm deep initial cracks are cracking early in the cracks, but have little influence on the ultimate bending moment value of the beams. The possible reason for this phenomenon is that the contribution of the tensile capacity of the concrete to the bearing capacity of the members is generally not considered according to the theory of concrete structure\cite{8}. At the same time, the initial crack width and extension height of this paper are too small, which is one of the reasons for the limited bearing capacity of reinforced concrete members.

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