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Structural Behavior and Damage of Reinforced Concrete Beams Under Cyclic Loadings Using ABAQUS Implicit Code

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1. Introduction

The finite element analysis technique is a widely used approach for analyzing the flexural behavior of reinforced concrete (RC) structures [1]. In this study, the preliminary finite element analysis is carried out to perform an analytical evaluation of the flexural behavior, concrete cracking pattern, and damage under cyclic loadings using the ABAQUS implicit code [2].

2. Numerical modeling

2.1 Concrete and steel model

The concrete damage plasticity (CDP) model is used to account for isotropic concrete damage caused by tension and compression as well as the effect of strength recovery under load history [3]. To simulate the nonlinear properties of reinforcements, the isotropic hardening model in ABAQUS is also used [2]. Details of the material properties for concrete and reinforcements can be found in Cha et al. [1] and Ha [2].

2.2 Finite element modeling

The sectional geometry of the RC beam is 150 mm width, 205 mm height, and 1,400 mm length [2]. The beam is reinforced with two main reinforcements of 13 mm diameter and transverse reinforcements of 10 mm diameter spaced at 80 mm intervals [2]. C3D8R elements with a 20-mm element size are used to model the concrete, while T3D2 elements with a 20-mm element size are utilized to model the reinforcements [2].

Figure 1 shows an FE model of a RC beam with loading and boundary conditions [2]. As shown in Fig. 1, the left support is pinned (constrained in T_x, T_y, and T_z directions), whereas the right support is a roller support (constrained only in T_x and T_y directions). The RC beam is subjected to cyclic four-point bending loadings, and the load is applied steadily in accordance with the five loading steps based on the experimental setup [2].

3. Simulation of RC beam under cyclic loadings

3.1. Comparison of the displacement

Figure 2 compares experimental data to load-deflection curves generated by finite element analysis using an isotropic hardening and a CDP model [1]. The finite element analysis shows a yield load of 93.69 kN, which is slightly higher than the experimental result by 1.82 kN (about 2 % difference) [2]. The peak load determined by finite element analysis is 99.58 kN, which is slightly less than the experimental data by about 8.66 kN (8 % difference) [2]. The comparison of predicted load carrying capacities to experimental data reported by Cha et al. [1] is summarized in Table 1.

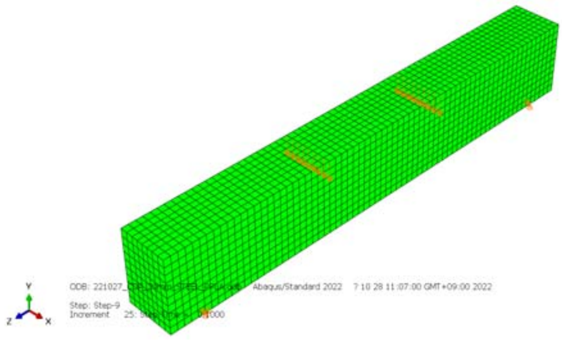


Fig. 1. FE model of a RC beam with loading and boundary conditions [2]

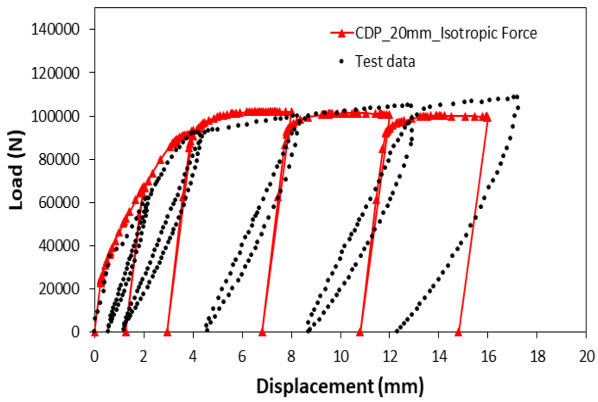


Fig. 2. Load-displacement history of the RC beam during cyclic four-point bending loadings [2]

Table 1. Comparison of the predicted load carrying capacities to experimental data [2]

Type	Yield load (kN)	Peak load (kN)
Test data [1]	91.87	108.24
Numerical results	93.69	99.58
Difference ratio (%)	1.98	8.00

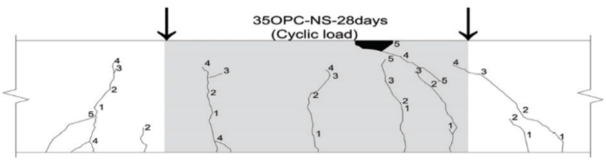
3.2. Comparison of the concrete damages

Figure 3 depicts the contour results for the DAMAGET (tension damage index) and DAMAGEC (compression damage index) with the CDP model [2].

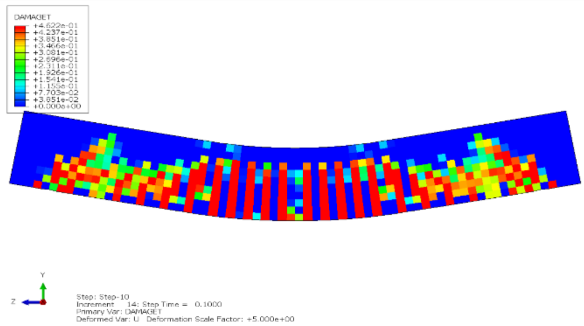
Flexural cracking was found in the pure flexural region in the early stages of loading, as shown in Fig. 3(a), and thereafter transverse-flexural fractures formed in response to increased load, as indicated by the flexural-shear cracking pattern [1].

Flexural cracking occurs in the DAMAGET between the support points, as illustrated in Fig. 3(b), and transverse-flexural fractures develops in response to higher loads. This cracking pattern is comparable to the concrete cracking pattern seen in the test results [1].

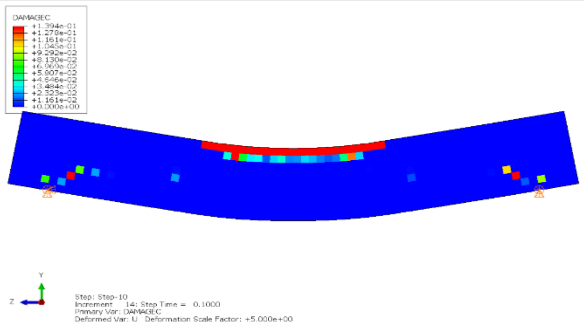
The DAMAGEC contour result reveals concrete crushing due to compression, as seen in Fig. 3(c), which is similar to the crushing of concrete observed in the experimental findings [2]. The cracking pattern and damage of a RC beam subjected to cyclic loading can be accurately predicted by the CDP model. [2].



(a) Test results [1]



(b) Tension damage index (DAMAGET)



(c) Compression damage index (DAMAGEC)

Fig. 3. Comparison of crack pattern and damage between test data [1] and numerical results [2].

4. Conclusions

In this study, flexural behavior, concrete cracking pattern, and damage under cyclic loadings are analyzed using the ABAQUS implicit code [2]. It is concluded that the CDP model with the isotropic hardening model can accurately estimate the cracking pattern and damage of a RC beam subjected to cyclic loadings [2]. More research are needed to evaluate the structural behavior and damage of RC beams subjected to cyclic loadings using various concrete and steel material models.

Acknowledgements

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