Diagonal crack propagation analysis of reinforced concrete beams using XFEM

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ABSTRACT

This paper deals with the analysis of crack propagation in longitudinally reinforced concrete beams without transverse reinforcement. Based on the previous test results of diagonal cracks of concrete beams according to shear span-to-depth ratio, we compare the crack propagation using a XFEM model of a general purpose finite element program. During the numerical analysis, tensile stress distribution and failure cracks are checked according to the calculated shear span-to-depth ratios. The location of cracks and the final crack distribution according to the ultimate load are compared carefully.

Keywords: XFEM, crack propagation, concrete beam, span to depth ratio

1. Introduction

Recently, many papers have been published on cracking of composite materials rather than single materials in academia. It is expected that the cracks of reinforced concrete beams can be interpreted by the extended finite element method (XFEM), and it is expected to be able to reinforce the location of the fragile parts. Unlike the Cohesive Element Behavior, which can analyze defects as well as the extended finite element method (XFEM), there is an advantage in that it is not necessary to use a complicated method of specifying an initial crack and a predicted crack location. A study of multiple cracks using extended finite element method (XFEM) has been performed by Belytschko (2004) and Rabczuk (2006).

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Therefore, this study aims to apply the extended finite element method based on the analytical results and the results of the study on the diagonal crack propagation of the concrete beams of Marta Slowik (2012) and Tomasz Nowicki (2012).

Based on the test results of the comparative analysis using the shear span-to-depth ratio (a/d), the results are compared with the analytical results. Finally, the extended finite element method is applied to the nonlinear analysis of reinforced concrete, which is a composite material, to compare the fracture pattern and final fracture cracks.

2. Test information

2.1 Test setting and specimen

In Marta Slowik (2012), the specimens used in the study are as shown in Fig. 1 (Marta Slowik (2012)) and the concrete beams were classified into 4 types according to the a / d ratio. Experiments were carried out at 4 node bending test. The test effective span, l_{eff} = 1.80 m, the width b of all beams is 0.12 m and the total height h is 0.25 m. The effective depth d is 0.22 m. The a / d ranges from 2.7 to 3.4 and shows two cases. Figure 2 shows the free object of the specimen. Table 1 shows the a / d ratio and the load-bearing position for each specimen. The overall specifications of the specimens are the same.
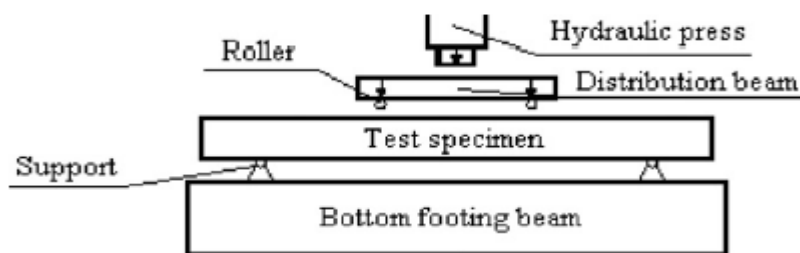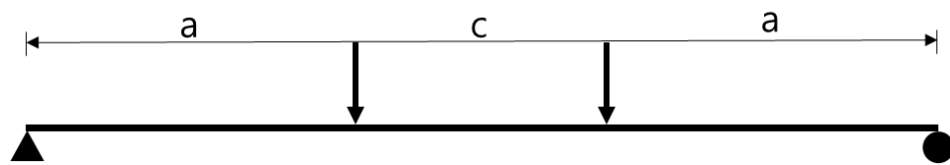

Fig. 1 Test setting (Marta Slowik(2012))

Fig. 2 Test specimen FBD

Table 1 (Marta Slowik(2012))

Specimen	L_{eff}, m	c, mm	a, mm	a/d
S2	1.80	0.3	0.75	3.4
S3		0.6	0.60	2.7

The a / d ratio represents the ratio of shear span to depth.

2.1 Experiments result

In this paper, we do not consider the moment and shear force because we are going to compare the fracture behavior of the specimens tested in Marta Slowik (2012). Figure 3 (Marta Slowik (2012)) is the result of cracking of the specimen.

It is still impossible to implement all the cracks in the test results with XFEM. However, since the aim of this study is to roughly simulate the initial cracks and the position of the main cracks by XFEM, the test results and the analyrical results are compared with each other with emphasis on the location of the cracks and the direction of propagation . In addition, many studies have not applied concrete plasicity model to XFEM, so applying it to concrete plasticity model is also the key of this study. A detailed of the firing model is provided in the finite element analysis material properties description.
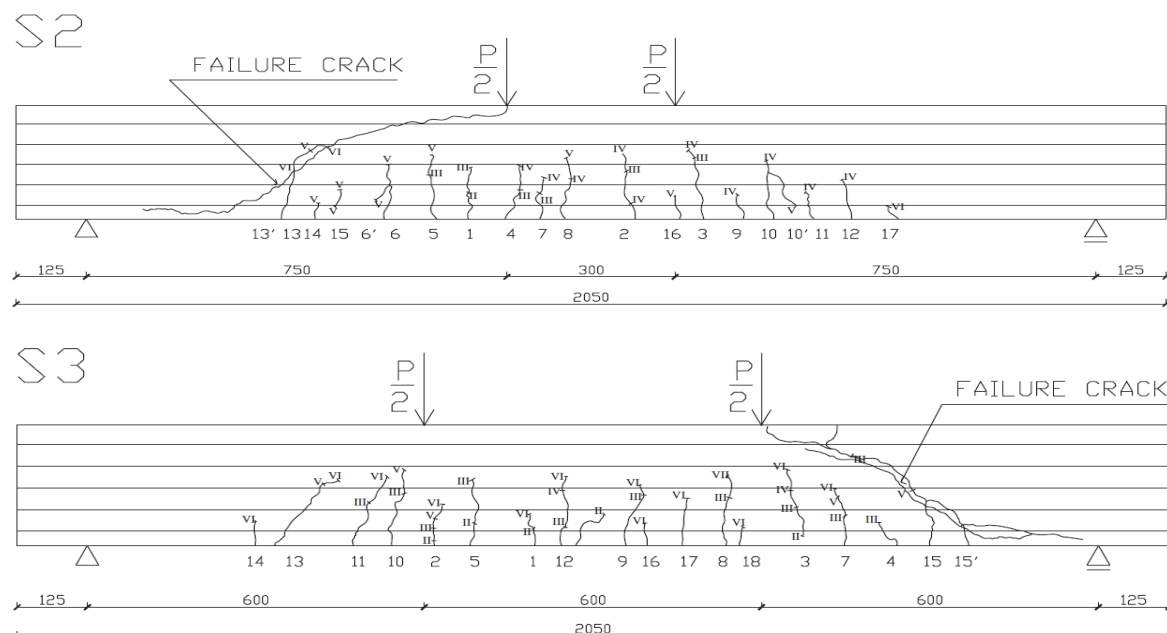

Fig. 3 Test result (Marta Slowik(2012))

3. Finite element analysis

3.1 Material Properties

In order to simulate the cracks of the specimens, the analysis was carried out using the general purpose finite element analysis program Abaqus 6.10.1. Damage was also defined using a concrete damage model to confirm crack propagation in reinforced concrete beams reinforced longitudinally and without transverse stiffeners. The reinforcing bars assumed perpect plastic behavior. In order to apply XFEM, fracture was defined as main stress and Damage evolution was defined by calculating G_f value using Rots (1988) equation. G_f is fracture energy. G_{f0} related to the maximum aggregate size (d_{max}). Aggregate size-G_{f0} table is below table 2(Rots (1988)). Rots (1988) is the following equation (1). The physical properties of concrete and steel are shown in Tables 3 and 4 below.

$$G_f = G_{f0} \ (f_c/10)^{0.7} \qquad (1)$$

Table 2 Aggregate size-based fracture coefficients

Maximum aggregate size, d_{max} (mm)	G_{f0} (J/m^2)
8	25
16	30
32	58

The concrete plasticity model used the Concrete Damage Plasticity model (CDP). Many studies have used concrete smeared cracking model to study smeared cracks. In this study, we tried to implement concrete behavior of concrete more precisely by using CDP model. CDP model can define both compressive and tensile behavior of concrete and define the behavior of concrete after the elastic section as nonlinear. When the nonlinear analysis is applied by applying the CDP model, the problem of convergence often occurs. Therefore, the purpose of this study is to see the propagation of the cracks, so we did not finish the analysis until the end.

Table 3 Concrete Property

	value	Unit
Compressive Strength, F_c	32.7	MPa
Splitting Tensile Strength, $F_{ct,sp}$	3.34	MPa
Tensile Strength,$(0.9*F_{ct,sp})$,F_t	3.0	MPa
Young's Modulus, E_c	37,650	MPa

Table 4 Steel Property

	value	Unit
Yield Stress, F_y	453	MPa
Young's Modulus, E_s	200,000	MPa
Poisson Ratio	0.3	-

3.2 Finite Element Model

The finite element model is shown in Fig. 4 below, and the load control is displacement control to improve convergence. The boundary conditions were hinge and roller as in the test conditions. All elements were made the same size to reduce the dependence of the mesh shape. Four - node bending analysis was applied to the finite element model for numerical analysis. Unlike Marta Slowik (2012), which performed 1/4 model analysis, the whole model 3-D FEM analysis was performed. This is because there is a possibility of cracking at the cut surface.
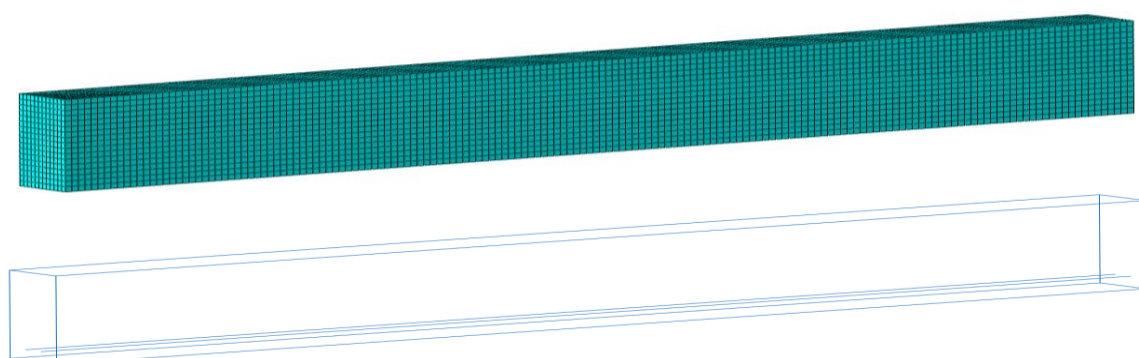

Fig. 4 Finite Element Model

4. Analysis results

4.1 Finite Analysis Results

Figures 5 and 6 show the results of each specimen crack analysis. Unlike the actual test results, all the cracks at the center of the span could not be expressed. However, the direction of the cracks of the signature cracks in the 4-node test is generally similar to that of the actual test results. However, the propagation patterns of the main cracks occurring at almost the same position as the load point are almost the same. In this conference paper, an analysis was carried out for a rough comparison of the propagation pattern of cracks and the location of occurrence.
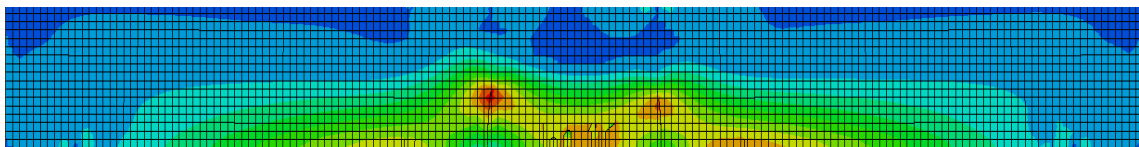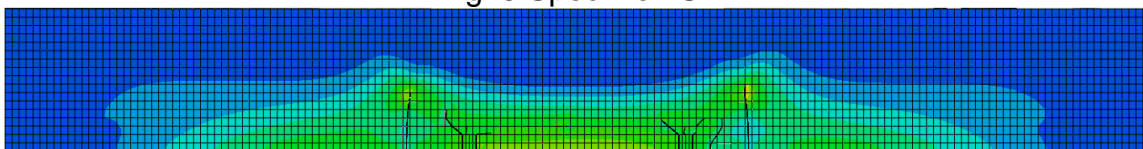

Fig. 5 Specimen S2

Fig. 6 Specimen S3

5. Conclusions

XFEM was applied to the concrete plasticity model and the analysis was carried out with the aim of confirming the crack propagation behavior of the actual reinforced concrete. Because of the nonlinear analysis of concrete, there is a disadvantage that the analysis time is prolonged. The most important problem is that the neighboring elements are cracked and locked around the degree of freedom. This results in no cracks in the center of the S3 model. Therefore, in order to see the crack propagation in the center part and the final progress of the cracks occurring, we are investigating a method to solve the degree of freedom locking in the surrounding elements after cracking. The number of comparative test specimens and data variables are increasing for clear comparison. The data variables are the initial stress and energy values of the damages that cause cracks, and the enrichment partition for the initial location of the cracks is also being analyzed. As a result, it is somewhat predicted about the position of cracks and the direction of propagation. However, in order to obtain more detailed results, it is necessary to understand the theoretical and functional parts of XFEM. Based on this analysis, many cases need to be analyzed.

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