Flexural Behavior Prediction of SFRC Beams Using FE Analysis and X-ray Images

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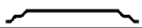
1. INTRODUCTION

Steel fiber reinforced concrete (SFRC) is a material characterized by an enhanced post-cracking residual strength due to the crack-bridging stress of fibers. For design or analysis of SFRC members in bending, it is necessary to deduce the post-cracking tensile strengths for identifying the tensile post-cracking opening laws or softening curve. However, numerous researches have demonstrated that the post-cracking tensile strength is a material property significantly affected by the fibers' distribution and orientation (i.e., Ferrara et al, 2010). Many parameters in the fabrication process cause different fiber distribution and orientation in each SFRC specimen, which leads to a large scatter of post-cracking responses of SFRC members (di Prisco et al. 2009). This phenomenon causes discrepancy in deriving the tensile softening curve and results in an overestimation or underestimation of flexural capacity of SFRC beams (DE Montaignac et al. 2012). This paper presents a novel prediction method to estimate the flexural behavior of SFRC beams using X-ray image and finite element (FE) analysis. The tensile softening curve is determined by an integrated approach of FE inversed analysis and digital process of X-ray image. In the FE method, the variability of fiber dispersion in each SFRC beam was considered by determining different stress-strain relations in each mesh based on its distinctive fiber reinforcement in X-ray image. The FE predicting method provides results in good agreement with those of the test beams.

2. EXPERIMENTAL PROGRAM

To achieve the above objective, 3 series of 6 SFRC prisms and cylinders (100 mm × 200 mm) were produced with different fiber contents 20 kg/m^3, 30 kg/m^3, and 40 kg/m^3 for the material characterization tests. For the structural test, a series (BF30) of 2 large SFRC beams with the height of 300 mm were also fabricated. The fiber used for reinforcing specimens is 60 mm long and has a diameter of 0.9 mm. Table 1 show the details of test specimens and shape of the fiber. The bending test setups of the prism and beam are illustrated in Fig.1 and Fig.2, respectively. Before the bending test at 28 days, X-ray radiography was performed on each prism and beam to take its X-ray image of fiber dispersion (see Fig.1 and Fig. 2 for the area of acquired X-ray image). The compression and splitting tests using 3 cylinders were conducted to determine the compressive and tensile strengths of SFRC material.

Table.1 Details of specimens

Notation	#	Dimension (mm)	Fiber content (Kg/m^3)	Fiber Shape
P20	6	550 × 150 ×80	20	
P30	6	550 × 150 ×80	30	
P40	6	550 × 150 ×80	40	
BF30	2	1360 × 300 × 80	30	

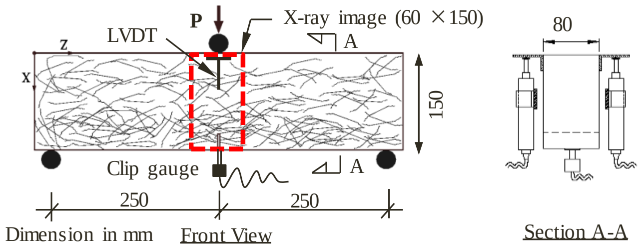


Fig. 1 Bending test setup of notch prisms.

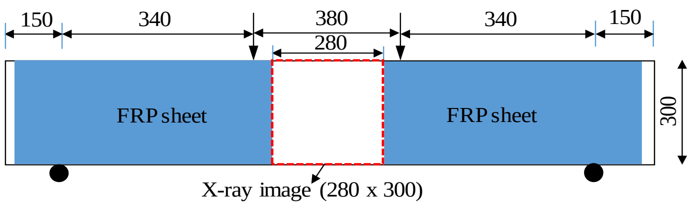


Fig. 2 Bending test setup of large beam BF30.

3. FLOWCHART FOR THE FLEXURAL PREDICTING METHOD FOR SFRC BEAM

Figure 3 illustrates the flowchart of the predicting method of flexural behavior for SFRC beam using FE analysis and X-ray image, which consists of six steps. The first step is to determine the dimensionless parameter called *RNF* which is proposed herein to take into account the variability of fiber in each SFRC members. To determine this parameter, firstly, the X-ray image at the middle part of the SFRC prism are divided into four meshes; and the distribution properties (i.e., the orientation α_i and embedded length Le_i) of each fiber that lies across the assumed cracking line were measured in each mesh. Next, the roughly estimated of pull out performance score is assigned to each fiber considering its orientation and embedded length. *RNF* is defined as a summation of the product of the orientation and embedded lengths' scores for the total number of fibers in a mesh. In step 2, the bending test of prisms is conducted to obtain the P-δ responses of each SFRC prism. In the third step, a FE inversed analysis is used to deduce the post-cracking tensile strengths from the P-δ responses of prisms. The input values of post-cracking tensile strengths (σ_1 and σ_2) and crack width w_2 are altered until a

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main criterion is reached: the difference between the areas under experimental and computed curves smaller than 5%. In addition to this criterion, effort is also made to maintain good fits of two important points (i.e., points (e) and (f) on the experimental curve). The fourth step is to establish the relationship of post-cracking strengths (σ_1 and σ_2) and *RNF* by regression analysis. Note w_2 is found to have a relationship with σ_2. In step 5, the X-ray image of beam is divided into meshes in which the values of *RNF* are determined. Next, through the three relationships established in step 4, different tri-linear tension softening curves can be identified in each mesh using numerical values of *RNF* that is determined in the X-ray image. Next, each tri-linear crack-opening curve is converted into stress-strain (σ-ε) by using a relationship $\varepsilon = w/lcs$ in which ε is a strain corresponds to a crack width and *lcs* is a characteristic length). In step 6, for the 2D FE model, the middle part of SFRC beam that takes X-ray is divided into meshes in the same as X-ray image is meshed in step 5. Finally, stress-strain relationships can be determined in the meshes according to the numerical values of *RNF*, and FE analysis of the beam can be performed.

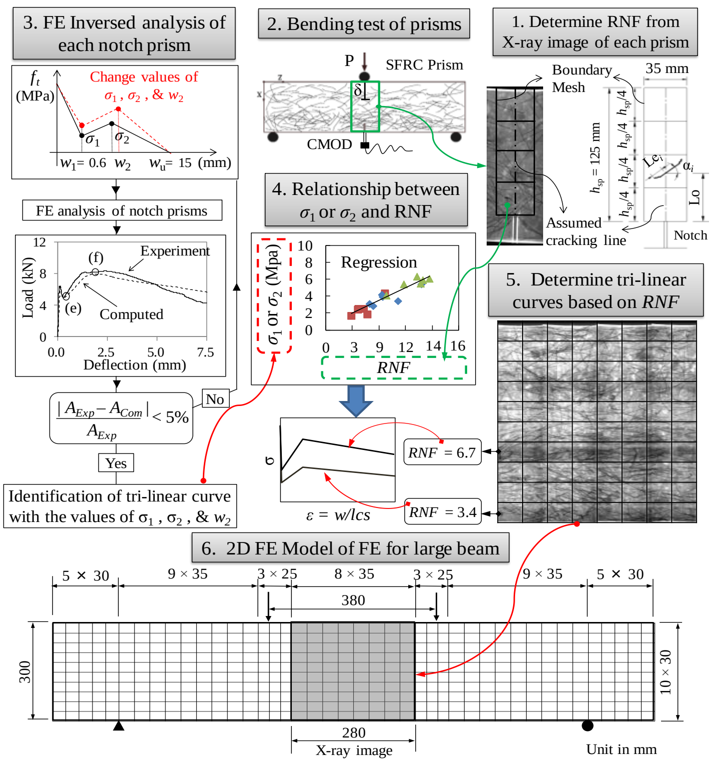

Fig. 3 Flowchart for flexural prediction method of SFRC beam.

4. VALIDITY OF PRDICTED METHOD

Fig. 4 shows the FE numerical versus experimental P-δ responses of the two large beams. The long-dash curve represents a response of the simulated beam using different σ-ε curves based on *RNF* while the short-dash curve represents a response of the simulated beam using only an average tension softening curve that is deduced from the 6 prisms in the series P30. From Fig. 4, it can be seen that the FE results using *RNF* (i.e., with X-ray images) are compared very well to those of test beams while the FE result using average tensile curve (i.e., without X-ray images) overestimate the response of the test beam.

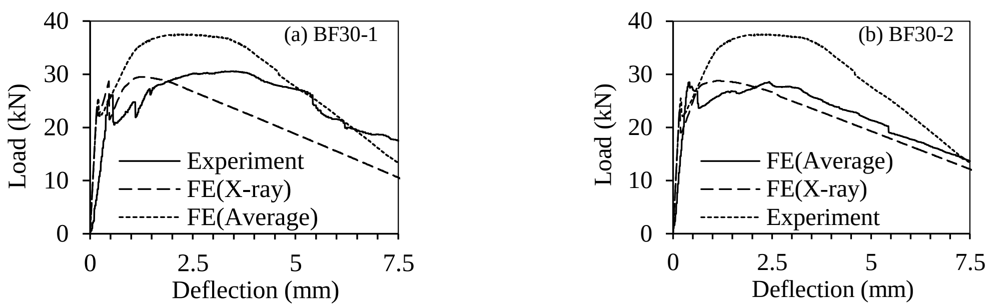

Fig. 4. FE numerical versus experimental *P*-δ responses

5. CONCLUSIONS

A novel method to predict the flexural behavior of SFRC beams using X-ray images and FEM analysis has been established in this paper, and its validity is also verified. Based on the findings in this paper, it can be concluded that FE method using the proposed parameter *RNF* to consider the variability of fiber dispersion provides satisfactory results with the test beams and far better results than FE method using only the average tension softening curve.

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REFERENCES

DE Montaignac, R., Massicotte, B., Charron, J-P.: Design of SFRC Structural Elements: Flexural Behavior Prediction, *Materials and Structures*, 45, 2012, pp. 623-636.

di Prisco, M., Plizzari, G., and Vandewalle, L.: Fiber Reinforced Concrete: New Design Perspectives, *Materials and Structures*, 42, 2009, pp. 1261-1281.

Ferrara, L., Park, Y.D., and Shah, S.P.: Correlation among Fresh State Behavior, Fiber Dispersion, and Toughness Properties of SFRC. *Journal of Material Civil Engineering*, 2010, 20, pp. 493-501.