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Ultimate Pressure Capacity Assessment of R-FRC PCCV based on the Tension Stiffening Tests

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1. Introduction

The use of fibers in concrete or cement composites can enhance the performance of structural elements. Fibers have been used for a cement mixture to increase the toughness and tensile strength, and to improve the cracking and deformation characteristics. The addition of fibers into concrete can improve the ductility and increase the tensile resistance of concrete structures. Recently, the application of fibers to prestressed concrete containment vessels (PCCVs) has been a major research topic. However, the tensile stiffening behavior of reinforced - fiber reinforced concrete (R-FRC) is not fully developed yet especially for specimens using large diameter rebars. In nuclear power plant (NPP) PCCVs, large diameter rebars are applied. Therefore, the tensile stiffening behavior model should be developed to assess ultimate pressure capacity (UPC) of R-FRC PCCVs. In this study, we modeled the tensile stiffening behavior of R-FRC PCCVs by using recently developed model [1], and assessed the UPC of R-FRC PCCVs. To do this, we performed tension stiffening test of R-FRC with large diameter rebar.

2. Methods and Results

2.1 Tension Stiffening Model of R-FRC

To model the tension stiffening behavior of R-FRC, firstly, we tested the R-FRC specimen as illustrated in Fig. 1. The size of rebar and reinforcement ratio are determined based on the data of APR1400 NPP.

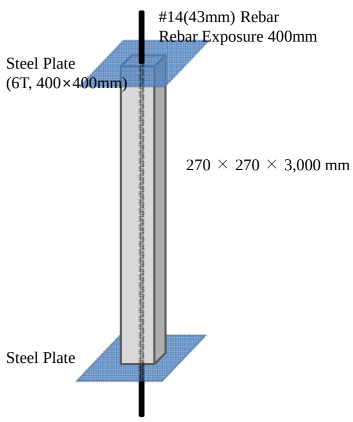

Fig. 1. Layout of tension stiffening test specimen.

The basic material properties of concrete & steel fibers are listed in Table I. Where, d_{sf} and l_{sf} are diameter and length of steel fiber, respectively.

Table I: Basic material properties of concrete and steel fiber.

Property	RC20	SF20	SF13
f'_c (MPa)	61.80	41.23	38.08
E (MPa)	29,309	24,833	20,492
d_{sf} (mm)	-	0.5	0.5
l_{sf} (mm)	-	30.0	30.0

Lee et al. proposed modified tension stiffening model for R-FRC as follows;

$$f_{c,TS} = \frac{f_{cr}}{1+\sqrt{3.6\,c_f M\ \varepsilon_{t,avg}}} \tag{1}$$

where, c_f is the coefficient to consider the effect of steel fibers. $f_{cr} = 0.33\sqrt{f_c^{'}}$ in MPa. $\varepsilon_{t,avg}$ represents average tensile strain of rebar or R/FRC member. The bond parameter is calculated from $M = A_c/\left(\sum d_{bs}\pi\right)$ in millimeters. A_c and d_{bs} mean cross-sectional area of concrete and diameter of rebar, respectively. For each prediction model, the basic material properties in Table I are used. The Axial force of test result, predicted model and bare rebar for RC20 specimen is illustrated in Fig. 2. It can be seen that the test result is well approximated by the proposed predict model. In Fig. 3, the tensile stiffening models of each R-FRC are depicted.

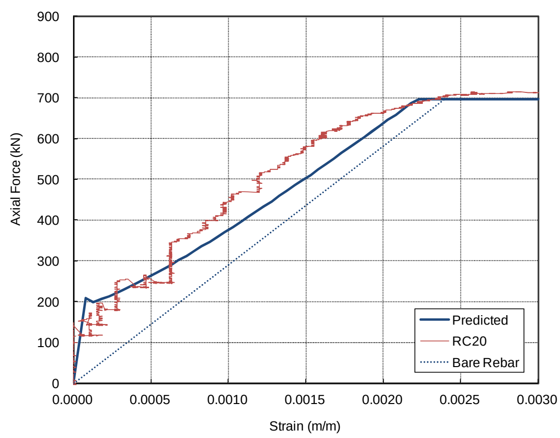

Fig. 2. Axial force of test result, predicted model and bare rebar for RC20 specimen.

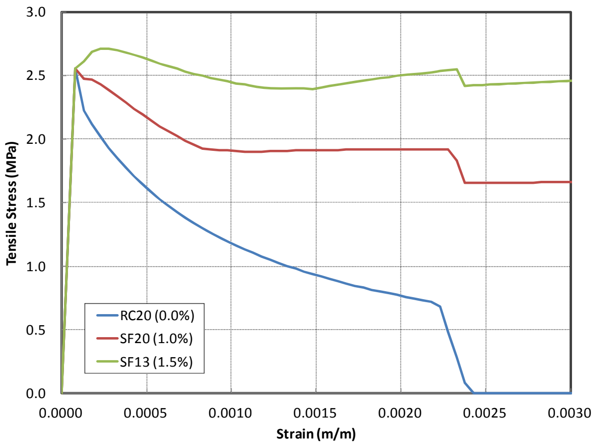

Fig. 3. Predicted tension stiffening model of R-FRC.

2.2 UPC Assessment of R-FRC PCCVs

By using the proposed R-FRC tension stiffening model, we performed. Even though the KSNP type PCCV used a conventional normal reinforced concrete, we assumed that it is constructed using R-FRC. The model is developed by using the general-purpose FE analysis program, ABAQUS. We modeled the behavior of concrete after experience of damages by using the concrete damaged plasticity model [2], which is a continuum, plasticity-based, damage model for concrete. For the modeling of the main concrete structure, we adopted the solid element which is able to describe embedded tendons discretely modeled by using truss elements. The 3-dimensional model of KSNP type PCCV includes the large penetrations such as an equipment hatch and an airlock. Tendons are modeled discretely by using truss elements. To simplify the modeling and analysis procedure, the slippage of a tendon within the tendon sheath is neglected so that the bond effect between the concrete and the tendon steel is not considered in this study. The rebars are modeled by using the embedded surface elements considering its reinforcement ratio. Fig. 4 depicts the deformed shape of wall & tendons of R-FRC PCCV. In Fig. 5, preliminary UPC analysis results of R-FRC PCCV are represented.

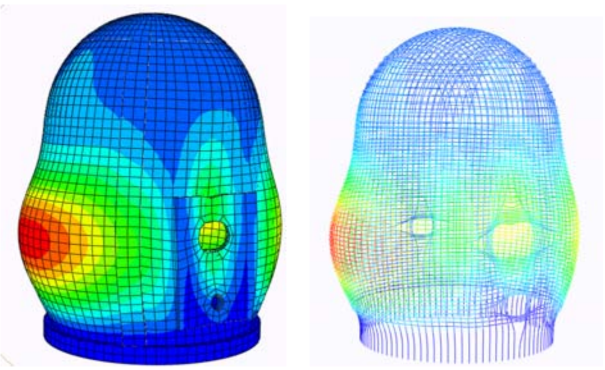

Fig. 4. Deformed shape of wall & tendons of R-FRC PCCV.

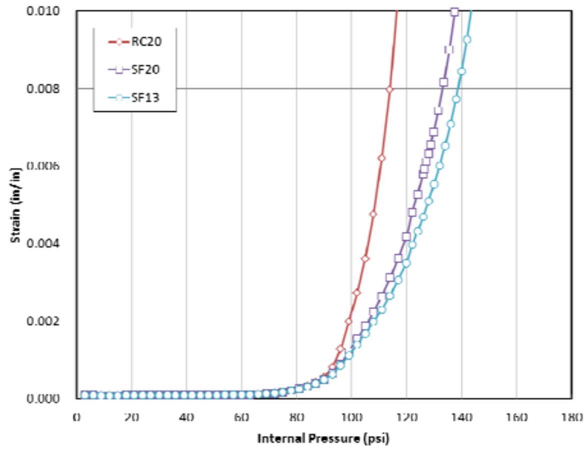

Fig. 5. Preliminary UPC analysis results of R-FRC PCCV.

3. Conclusions

The addition of fibers into concrete can improve the ductility and increase the tensile resistance of concrete structures. Recently, the application of fibers to prestressed concrete containment vessels (PCCVs) has been a major research topic. In this study, we modeled the tensile stiffening behavior of R-FRC PCCVs by using recently developed model [1], and assessed the UPC of R-FRC PCCVs. To do this, we performed tension stiffening test of R-FRC with large diameter rebar. Then, we adopted the prediction model of tension stiffening behavior of R-FRC member. Compare to the test results, the proposed predict model shows well agreement. UPC assessment for KSNP type PCCVs is also performed by using the proposed R-FRC tension stiffening model. From the UPC assessment results, we concluded that the adoption of steel fiber to a conventional PCCVs can improve the internal pressure capacity considerably.

Acknowledgement

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