Ultimate Pressure Capacity of Prestressed Concrete Containment Vessels with Steel Fibers

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1. Introduction

The ultimate pressure capacity (UPC) of the prestressed concrete containment vessel (PCCV) is very important since the PCCV are final protection to prevent the massive leakage of a radioactive contaminant caused by the severe accident of nuclear power plants (NPPs). The tensile behavior of a concrete is an important factor which influence to the UPC of PCCVs. Hence, nowadays, it is interested that the application of the steel fiber to the PCCVs since that the concrete with steel fiber shows an improved performance in the tensile behavior compared to reinforced concrete (RC). In this study, we performed the UPC analysis of PCCVs with steel fibers corresponding to the different volume ratio of fibers to verify the effectiveness of steel fibers on PCCVs.

2. Methods and Results

2.1 Tension Stiffening Model of FRC

The tension model of concrete proposed by Okamura and Maekawa [1] is widely used for the analysis of concrete structures. This model is formulated as:

$$f_t = f_{tu}\left(\frac{\varepsilon_{tu}}{\varepsilon}\right)^c \qquad (1)$$

where ε_{tu} is the strain that the tensile softening /stiffening starts, f_{tu} is the tensile strength, and c is the tension stiffening factor. In RC, it was shown that a value of c=0.4 correlated well with a wide range of tests [1]. In concrete with steel fibers, it is expected that the fibers can provide an extra average tensile stress due to fiber bridging at cracks. Adopting Eq. 1, this can be accommodated by lowering the c value (Fig. 1).

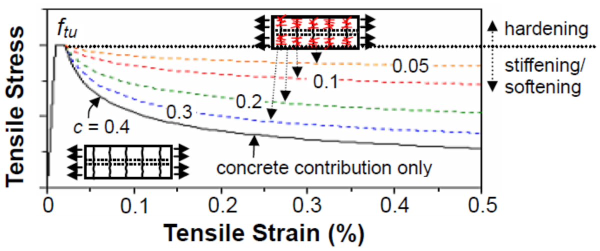

Fig. 1. Tensile stress-strain relationship of FRC.

Suryanto et al. [2] revealed the relationship between the fiber volume ratio and the parameter in the tension, c (tension stiffening factor) from the results of the shear panel experiments of concrete with steel fibers. It can be seen that the tension stiffening coefficient (c) decreases as the ratio of fiber volume increases. This indicates clearly the advantage of adding fibers to improve the ability of the concrete to resist tension. Nevertheless, it is expected that the improvement is effective until a certain fiber volume only (Fig. 2). From this test results, we adopted the tensile softening model of concrete with steel fibers corresponding to the fiber volume ratio as depicted in Fig. 3.

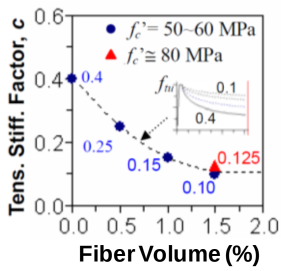

Fig. 2. Relationship between tensile stiffness coefficient and steel fiber volume ratio.

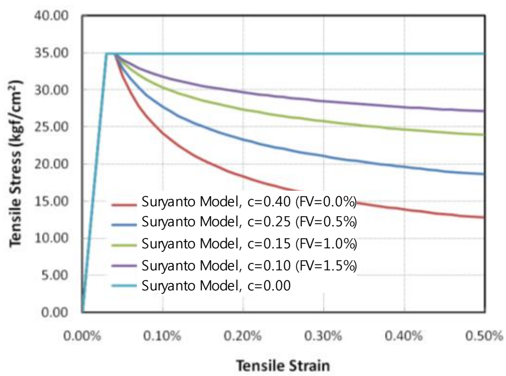

Fig. 3. Adopted tension softening model of concrete with steel fiber.

2.2 Modeling of PCCVs

We modeled the behavior of concrete after experience of damages by using the concrete damaged plasticity model [3], which is a continuum, plasticity-based, damage model for concrete. For the compression region, a piecewise linear curve considering confinement effect of stirrup in the softening region is modeled using Mander's model [4] (no plastic strain up to $0.4\,\sigma_{cu}$). We constructed the reinforcement steel model by using the 1-directional stress-strain relationship according to the resistance corresponds to the uniaxial loading. The monotonic envelop of embedded steel is idealized as a bilinear curve with 1% hardening ratio both in compression and tension regions. The stress-strain relationship of tendon does not have a distinct yield point compared to that of reinforcement steel. For the modeling of material nonlinearity of tendons, we make a tri-linear piecewise linear stress-strain plasticity model including the important points such as the proportional elastic limit, the yield point and the failure point.

In this study, we take into consideration a typical type of containment that has been operated in South Korea: PWR type. Among various kinds of PWR type containments, KSNP type, which is currently the most widely used in Korea nowadays, is a main concern. We modeled KSNP type containment by using the general-purpose FE analysis program, ABAQUS [3]. 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.

2.3 UPC Analysis

We performed the internal pressure analysis of the target PCCVs with steel fibers which have fiber volume ratios of 0.0%, 0.5%, 1.0% and 1.5%. Each fiber volume ratio is modeled in terms of the corresponding tensile stiffening coefficient, *c*. To define the UPC, we assumed the limit state of the failure of PCCVs with steel fibers as a maximum global membrane strain of 0.8 percent [5]. This strain limit is applicable to all materials which contribute to resisting the internal pressure (i.e., tendons, rebars, and liner (if considered)).

Fig. 3 represents one of the results of the internal pressure capacity analysis of PCCVs with steel fibers, i.e., the maximum strain responses of tendons corresponding to the internal pressure loading with respect to the fiber volume ratios. It can be easily seen that the internal pressure capacity increase as the amount of added steel fiber increase.

It is summarized that the results of UPC analysis of PCCVs with steel fibers in Table 1. As fiber volume ratio increases, the UPC also increases significantly (about 20% for 1.5% fiber volume ratio). From the results, it can be inferred that the PCCVs with steel fibers will have an improved internal pressure capacity compare to a PCCVs without any fibers.

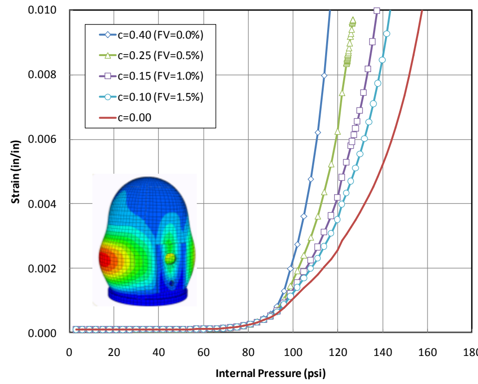

Fig. 3. Strain responses of tendons corresponding to fiber volume ratios.

Table 1: UPC of PCCVs with steel fibers against to Leak Failure Mode

Fiber Volume (%)	Ultimate Pressure Capacity (psig)	Increase (%)
0.0	115	-
0.5	123	7.0
1.0	133	15.7
1.5	139	20.9

3. Conclusions

In this study, we performed the UPC analysis of PCCVs with steel fibers to verify the effectiveness of steel fibers on PCCVs in the viewpoint of the tensile performance improvement of concretes. From the result, we found that the appliance of 1.0% volume ratio of steel fiber will improve the UPC more than 10%.

ACKNOWLEDGEMENT

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