Influence of Steel Fibers on the Structural Performance of a Prestressed Concrete Containment Building

Young-Sun Choun [a*], Daegi Hahm [a], Junhee Park [a]
[a]*Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Daejeon, 305-353, Republic of Korea*
[*]*Corresponding author: sunchun@kaeri.re.kr*

1. Introduction

The addition of steel fibers into a plain concrete improves the material properties such as flexural toughness, impact resistance, and flexural fatigue endurance, and increases the structural performance of concrete structures. A large number of previous experimental investigations indicate that the use of steel fibers in conventional reinforced concrete (RC) can enhance the structural and functional performance of prestressed concrete containment buildings (PCCBs) in nuclear power plants [1,2,3]. A prevention of through-wall cracks and an increase of the post-cracking ductility will improve the ultimate internal pressure capacity, and a high shear resistance under cyclic loadings will increase the seismic resisting capacity. In this study, the effects of steel fiber reinforced concrete (SFRC) on the ultimate pressure and seismic capacities of a PCCB are investigated.

2. Experimental Programs

The tension responses and shear behaviors of structural members constructed using SFRC were investigated by the axial tension and cyclic load tests.

2.1 Concrete Mix Proportions

For test specimens, concrete mixes with compressive strength of 42 MPa are given in Table I for the plain and fiber concretes. The maximum size of coarse aggregate was 19 mm. For the fiber concrete, a 1.0% volume fraction of hooked-end steel fibers were added. The fibers had a length of 30 mm and a diameter of 0.5 mm, giving an aspect ratio of 60. The tensile strength of the fibers was 1,100 MPa. All of the reinforcing bars had a nominal yield strength of 400 MPa.

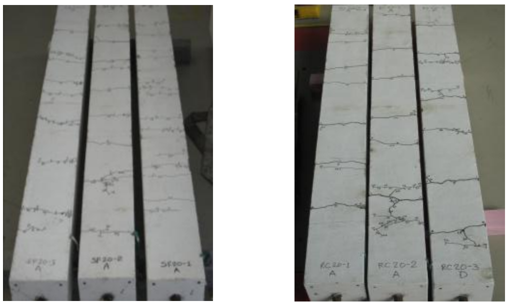
Table I: Mix Details of the Concrete Used in Specimens

Mix proportions (kg/m^3)	Plain concrete	Fiber concrete
Cement	325.50	325.50
Water	162.75	162.75
Coarse aggregate	938.77	938.77
Sand	748.89	748.89
Fly ash	81.38	81.38
Steel fibers	-	79
Water-reducing agent	2.60	3.66
Air-entraining agent	0.15	0.15

2.2 Axial Tension Test

All of the specimens for an axial tension test had a cross section of 270 mm by 270 mm, and a length of 3,000 mm. A single D41 steel bar was provided in each specimen. The load was applied to the steel reinforcing bar through a set of tension grips at the top and bottom, and therefore the applied load transferred from the steel reinforcing bar to the concrete section. Two linear voltage differential transducers (LVDTs) were placed between steel plates at a both ends of the concrete to measure the total elongation of the concrete specimen.

Fig. 1 shows crack patterns in SFRC and RC specimens after axial tension test. In the SFRC specimens, the transverse cracks were smaller and more closely spaced than the RC specimens, and no splitting cracks occurred. Fig. 2 shows tension responses of the specimens. A slight increase in initial stiffness and cracking load is observed in an SFRC specimen. After cracking, the SFRC specimen shows more tension stiffening than the RC specimen.



(a) SFRC specimens (b) RC specimens

Fig. 1. Crack patterns in tension specimens.

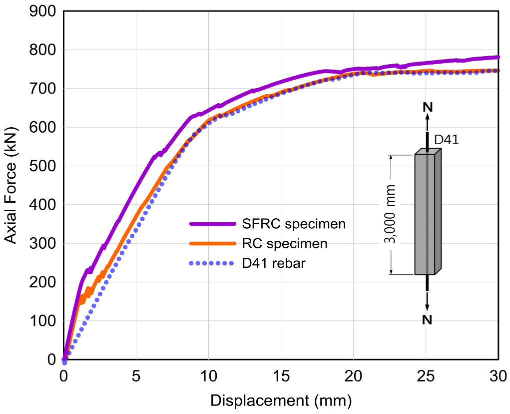


Fig. 2. Axial force versus displacement responses.

2.3 Reversed Cyclic Load Test

For the cyclic test of structural walls, lateral displacements were applied through a 3,000 kN hydraulic actuator connected to the loading beam of a specimen at one end and a strong reaction wall at the other end. The specimen consists of a loading beam, wall, and base. The height-to-width ratio of the wall is 1.15 as shown in Fig. 3.

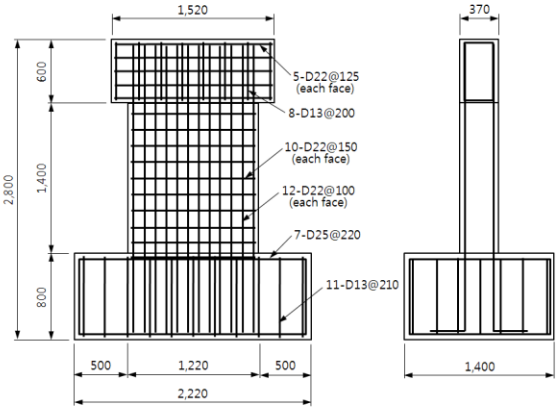


Fig. 3. Detail of wall specimen for a reversed cycle test.

The failure of the SFRC specimen, which contains steel fibers at a 1.0% volume fraction, was governed by a shear-friction, whereas the RC specimen was governed by a diagonal tension (Fig. 4). The SFRC specimen has a larger shear force, draft capacity, and energy dissipation than the RC specimen (Fig. 5). It was revealed that the addition of steel fibers in a RC wall can enhance its shear resisting capacity significantly.

(a) SFRC specimen at 3.5% drift (b) RC specimen at 2.5% drift

Fig. 4. Cracking patterns at failure in cyclic load test specimens.

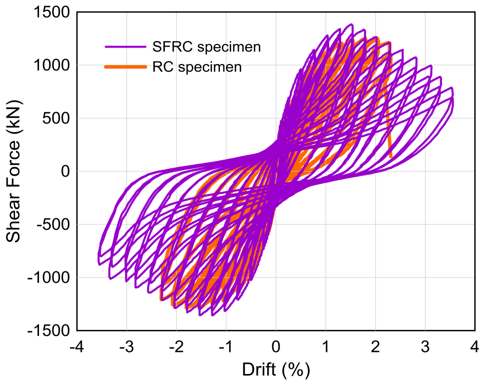


Fig. 5. Shear force versus drift responses.

3. Evaluation of Structural Performance of a PCCB

3.1 Ultimate Pressure Capacity

The ultimate pressure capacity is evaluated for the KSNP (Korean Standard Nuclear Power Plant) type PCCB. Even though the PCCB has been built using a conventional RC, we assumed that it is constructed using the SFRC for comparison purposes only. The tension stiffening models were obtained from Fig. 2. The general-purpose FE analysis program, ABAQUS was used. The ultimate pressure capacity for a PCCB constructed with steel fibers at a 1.0% volume fraction was approximately 16% higher than that for a conventional PCCB.

3.2 Shear Resisting Capacity

For a shear capacity analysis, the PCCB was represented by a lumped-mass stick model, which has a different eccentricity between the mass center and rigidity center at each level of lumped masses. OpenSees was used for obtaining the structural response. The pinch factors for the Hysteretic model were derived based on the hysteretic response of walls as shown in Fig. 5. The maximum shear strength and lateral displacement for a PCCB constructed with steel fibers at a 1.0% volume fraction were approximately 8% and 64% greater than those for a conventional PCCB, respectively.

4. Conclusions

The effects of steel fibers on the ultimate pressure and shear resisting capacities of a PCCB are investigated. It is revealed that both of the ultimate pressure capacity and the shear resisting capacity of a PCCB can be greatly enhanced by introducing steel fibers in a conventional RC. Estimation results indicate that the ultimate pressure capacity and maximum lateral displacement of a PCCB can be improved by 16% and 64%, respectively, if a conventional RC contains hooked steel fibers in a volume fraction of 1.0%.

Acknowledgement

This work has been achieved with the financial support of the research project granted by Korea Institute of Energy Technology Evaluation and Planning (2010161010004K). All support is gratefully acknowledged.

REFERENCES

[1] ACI Committee 544, State-of-the-Art Report on Fiber Reinforced Concrete (ACI 544.1R-96), American Concrete Institute, Michigan, USA, 2001.

[2] P. H. Bischoff, Tension Stiffening and Cracking of Steel Fiber-Reinforced Concrete, J. Materials in Civil Engineering, ASCE, Vol.15, pp.174-182, 2003.

[3] B. A. Canbolat, G. J. Parra-Montesinos, and J. K. Wight, Experimental Study on Seismic Behavior of High-Performance Fiber-Reinforced Cement Composite Coupling Beams, ACI Structural Journal, Vol.102, pp.159-166, 2005.