Evaluation of Shear Resisting Capacity of a Prestressed Concrete Containment Building with Steel or Polyamide Fiber Reinforcement

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1. Introduction

Fibers are effective as shear reinforcement because the random distribution of fibers improves the tensile strength, ductility, and fracture toughness of plain concrete. Therefore, the addition of fibers into plain concrete can increase the shear performance of structural concrete. Conventional reinforced concrete (RC) members generally show a rapid deterioration in shear resisting mechanisms under a reversed cyclic load [1]. However, the use of high-performance fiber-reinforced cement composites provides excellent damage tolerance under large displacement reversals compared with regular concrete [2].

Previous experimental studies have indicated that the use of fibers in conventional RC can enhance the structural and functional performance of prestressed concrete containment buildings (PCCBs) in nuclear power plants [3,4]. This study evaluates the shear resisting capacity for a PCCB constructed using steel fiber reinforced concrete (SFRC) or polyamide fiber reinforced concrete (PFRC).

2. Hysteretic Behaviors of Shear Walls

The shear behaviors of structural walls constructed using RC, SFRC, and PFRC were investigated through the reversed cyclic load tests. Using the test results, the hysteretic models for a dynamic analysis were derived.

2.1 Concrete Mix Proportions

For the test specimens, concrete mixes with a compressive strength of 42 MPa are given in Table I for plain and fiber concretes. For SFRC, a 1.0% volume fraction of hooked-end steel fibers was added. The steel 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 steel fibers was 1,100 MPa. For PFRC, a 1.5% volume fraction of polyamide fibers were used. The polyamide fibers had a length of 30.28 mm and a diameter of 2.31 mm. The tensile strength of the polyamide fibers was 650 MPa. All of the reinforcing bars had a nominal yield strength of 400 MPa.

2.2 Reversed Cyclic Load Test

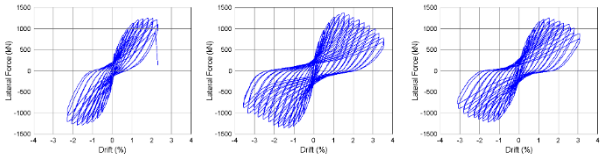
For the cyclic test of concrete wall specimens, lateral displacements were applied through a 3,000 kN hydraulic actuator connected to the loading beam of a specimen at one end and a strong reaction wall at the other. The specimen consists of a loading beam, wall, and base. The height-to-width ratio of the wall is 1.15 [4]. The specimens were subjected to a lateral displacement cycle with the drift of up to 3.5%.

Table I: Mix Details of the Concrete Used in Specimens

Mix proportions	Plain concrete	SFRC	PFRC
Cement (kg/m^3)	325.50	325.50	376.00
Water (kg/m^3)	162.75	162.75	188.00
Coarse aggregate (kg/m^3)	938.77	938.77	722.00
Sand (kg/m^3)	748.89	748.89	883.00
Coarse aggregate size (mm)	19	19	20
Fly ash (kg/m^3)	81.38	81.38	94.00
Water-reducing agent (kg/m^3)	2.60	3.66	-
Air-entraining agent (%)	0.15	0.15	0.2
Superplasticizer (%)	-	-	2.0
Viscosity agent (%)	-	-	0.15
Water/cement ratio (%)	40	40	40
Fibers (%)	-	1.0	1.5

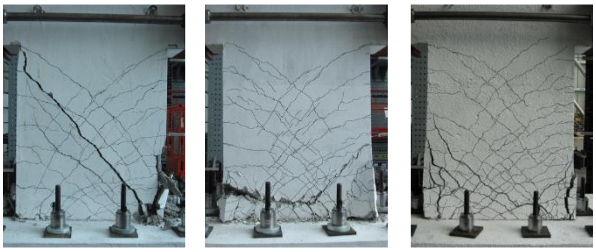
2.3 Drift Hysteresis Responses

Figs. 1 and 2 show the hysteresis responses and failure cracking patterns for RC, reinforced-SFRC (R-SFRC), and reinforced-PFRC (R-PFRC) specimens. It was revealed that the addition of fibers in an RC wall can enhance its shear resisting capacity significantly, and



(a) RC (b) R-SFRC (c) R-PFRC

Fig. 1. Shear force versus drift response for different concrete walls.



(a) RC (2.25% drift) (b) R-SFRC (3.5% drift) (c) R-PFRC (3.0% drift)

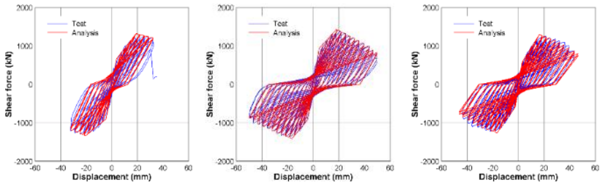
Fig. 2. Failure cracking patterns for different concrete walls.

the failure mechanism in the RC and fiber-reinforced specimens is totally different.

3. Shear Resisting Capacity

3.1 Hysteretic Models

Based on the hysteresis responses of the test specimens shown in Fig. 1, the hysteretic models for the RC, R-SFRC, and R-PFRC members were derived as shown in Fig. 3 and Table II.



(a) RC (b) R-SFRC (c) R-PFRC

Fig. 3. Hysteretic models for RC, R-SFRC, and R-PFRC members.

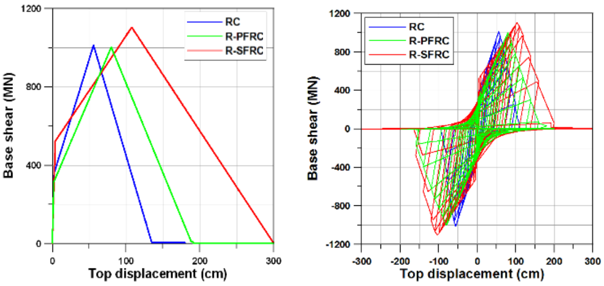
Table II: Strength and displacement properties of hysteretic models

Property	RC	R-SFRC	R-PFRC
Crack strength (kN)	668	959	578
Crack displacement (mm)	3.54	4.14	2.52
Yield strength (kN)	1,368	1,572	1,389
Yield displacement (mm)	12.46	11.40	12.24
Maximum shear strength (kN)	1,323	1,442	1,306
Maximum shear displacement (mm)	32.12	49.58	46.20
Ductility	2.57	4.35	3.77

3.2 Shear Resisting Capacity

For a dynamic 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. The mass of the model includes all of the mass of the walls, slabs, and heavy equipment. As a material model, the Hysteretic model of OpenSees [5] was used to simulate a degradation of the strength and stiffness. The pinch factors used for the Hysteretic model were derived based on the hysteretic response of walls under a reversal cyclic load. For the element modeling, the nonlinearBeamColumn element was selected from the OpenSees elements library.

Table 4 and Table III show the dynamic responses of the PCCB stick models. The maximum shear strength and lateral displacement for a $\mathrm{PCCB}_{\mathrm{R\text{-}SFRC},1.0\%}$ were approximately 9% and 120% greater than those for a $\mathrm{PCCB}_{\mathrm{RC}}$, respectively, and the maximum lateral displacement for a $\mathrm{PCCB}_{\mathrm{R\text{-}PFRC},1.5\%}$ was approximately 40% greater than that for a $\mathrm{PCCB}_{\mathrm{RC}}$. The energy dissipation capacities were approximately 182% and 106% larger in a $\mathrm{PCCB}_{\mathrm{R\text{-}SFRC},1.0\%}$ and $\mathrm{PCCB}_{\mathrm{R\text{-}PFRC},1.5\%}$, respectively.



(a) Pushover analyses (b) Cyclic analyses

Fig. 4. Dynamic responses for PCCB models.

Table III: Maximum resisting capacity of PCCBs for a lateral force

Type	Maximum shear strength (MN)	Maximum lateral displacement (cm)	Energy dissipation capacity (MN-cm)
$\mathrm{PCCB}_{\mathrm{RC}}$	1,009	136	454,640
$\mathrm{PCCB}_{\mathrm{R\text{-}SFRC},1.0\%}$	1,104	299	1,282,916
$\mathrm{PCCB}_{\mathrm{R\text{-}PFRC},1.5\%}$	1,000	191	935,091

4. Conclusions

The effects of steel and polyamide fibers on the shear performance of a PCCB were investigated. It was revealed that steel fibers are more effective to enhance the shear resisting capacity of a PCCB than polyamide fibers. The ductility and energy dissipation increase significantly in fiber reinforced PCCBs.

Acknowledgement

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