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Experimental study on the cyclic behavior of steel fiber reinforced high strength concrete columns and evaluation of shear strength

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ABSTRACT

In this paper, the effectiveness of steel fiber inclusion on the structural performance of steel fiber reinforced high strength concrete columns was investigated with test of 7-high strength concrete specimens with and without steel fiber. All test specimens were subjected to axial load and reversed cyclic lateral loads. It was shown that test steel fiber inclusion significantly increase the structural performance. Steel fiber inclusion was remarkably effective than the transverse reinforcement about structural performance such as strength and energy dissipation capacity. Steel fiber reinforcement was more effective with high volumetric ratio of transverse reinforcement. Compressive strength of matrix affect to the strength and ductility. High strength matrix column specimens showed better performance than normal strength matrix column specimens. In order to verify the safety of existing strength estimation equations, test results were compared with estimated values. Most of the estimation equations were over estimated the shear strength of concrete. Therefore, in this study, for the safe design of steel fiber reinforced high strength concrete columns, newly developed estimation equation was suggested.

1. Introduction

Reinforced concrete columns are subjected to compression, shear and bending simultaneously. Under repeated cyclic loading, such as seismic loads, it is necessary to give adequate confinement stress to column core and adequate shear strength should be guaranteed, for the safe structural behavior with flexural mode of failure. Recently, the use of high strength concrete has been increased, but relatively low confinement effect was observed, and researches for resolving this problem have been continuously carried out for the safe design of high strength reinforced concrete columns. And many researchers tried to solve this problem with inclusion of steel fiber to the high strength concrete [1–4]. However, these researches about steel fiber reinforced concrete columns were focused on the compressive behavior under concentric compression. It is hard to find the research results about the steel fiber reinforced high strength concrete (SFRHSC) columns subjected to the axial and lateral loads simultaneously.

There were many researches about reinforced concrete columns and many models to describe the behavior of columns under repeated cyclic loading. Priestley et al. [5] suggested shear strength reduction according to the ductility of member using test results of Ang et al. [6] and Wong et al. [7]. This model shows high accuracy at low displacement ductility ratios but low accuracy at high displacement ductility ratios because the proposed method assumes that the residual shear strength is independent to the compressive force subjected to column and aspect ratio of column. Shear strength model suggested by Watanabe and Ichinose [8] considered the rotation of crack but cannot predict accurately the shear strength of reinforced concrete columns under high level of axial load. Sezen and Moehle [9] tested the columns simulating the existing structures which have not designed about seismic action. And they collected test results from other researchers. They suggested the shear strength prediction method based on the internal stress distribution and it was evaluated by collected test data. There are many kinds of test and analysis about the reinforced concrete column behavior, except researches mentioned above. However, very limited number of researches about high strength steel fiber reinforced concrete columns have been carried out.

Lee [10] tested 6 SFRC columns and 2 RC column under repeated cyclic loading. The main variables were transverse reinforcement ratio and fiber volume fraction. Steel fiber increase the shear strength and ductility of RC columns. The maximum increase rate of shear strength according to the inclusion of steel fiber was observed from the test

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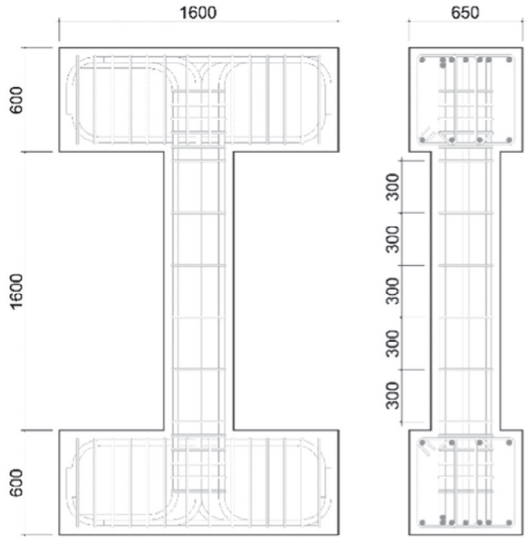

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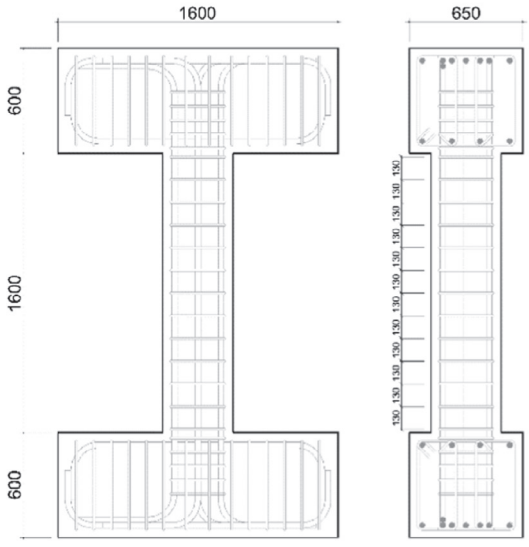
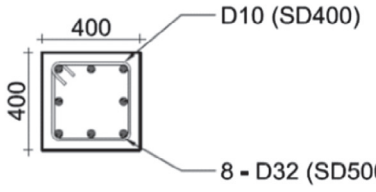


(b) T series



(c) Section of test specimens

Fig. 1. Details of test specimen.

results about specimens with 1.5% of steel fiber. Lee also evaluated the RC column shear strength prediction equations. Equation suggested by Priestley et al. [5] had shown good agreement with test results. Using this equation, Lee suggested new prediction equation for SFRC column shear strength. The maximum compressive strength of test specimens which were used for regression analysis were 69 MPa. Nagasaka [11] tested SFRC columns and collected other test results. Steel fiber can increase the shear strength, ductility and energy dissipation capacity preventing the bond failure and spalling of column. Using collected test results, regression equation was suggested which considers the effect of steel fiber inclusion directly to shear stress. The maximum compressive strength of test specimens which were used for regression analysis were 42 MPa.

Because high strength concrete have shown different behavior under compression compared with normal strength concrete and limited number of tests were carried out about SFRC columns, for the safe design of high strength SFRC columns, the behavior of SFRHSC column should be investigated.

As mentioned earlier, high strength concrete member had shown different behavior compared with normal strength concrete. Especially, test results of high strength-steel fiber reinforced concrete columns were very limited. It was hard to generalize the behavior of high strength-steel fiber reinforced concrete columns. Therefore, in this study, SFRHSC columns were tested. The structural behavior and performance of SFRHSC columns were investigated compared with steel fiber reinforced normal strength concrete columns. And for the safe design of SFRHSC columns, existing shear strength prediction equations were evaluated and new prediction equation was suggested.

2. Literature review

As mentioned earlier, lateral load resistance of SFRC column are not sufficient to design SFRC column, compared with normal reinforced concrete columns. Therefore, in this study, applicability of shear strength prediction methods based on normal RC columns to the HS-SFRC members were evaluated. And applicability of limited number of SFRC column shear strength equations and SFRC beam shear strength equations to SFRHSC column were evaluated.

2.1. Shear strength model for normal RC columns

ACI318-14 [12] model considered that the shear strength of RC columns were consists of contribution of concrete, V_c, and contribution of shear reinforcement V_s. This model based on the 45-degree truss model. Nominal shear strength of RC columns and contribution of each component can be calculated as,

$$V_n = V_c + V_s \tag{1}$$

$$V_c = 0.17\left(1 + \frac{N_u}{14A_g}\right)\lambda\sqrt{f'_c}\,b_w d \tag{2}$$

$$V_s = \frac{A_v f_{yt} d}{s} \tag{3}$$

V_c cannot be greater than the V_c calculated by Eq. (4).

$$V_c = 0.29\lambda\sqrt{f'_c}\,b_w d\sqrt{1 + \frac{0.29N_u}{A_g}} \tag{4}$$

where V_n is nominal shear strength of member, V_c is nominal shear strength provided by concrete, V_s is nominal shear strength provided by shear reinforcement, A_v is area of shear reinforcement within spacing s, f_{yt} is specified yield strength of transverse reinforcement, d is distance from extreme compression fiber to centroid of longitudinal tension reinforcement, s is center-to-center spacing of transverse reinforcement, N_u is factored axial force normal to cross section occurring simultaneously with V_u, A_g is gross area of concrete section, λ is modification factor to reflect the reduced mechanical properties of lightweight concrete to normal weight concrete of the same compressive strength, is specified compressive strength of concrete, b_w is web width of section.

Shear strength model for RC columns suggested by Priestley et al. [5] is consisted of three components, contribution of concrete, V_c, contribution of shear reinforcement V_s and arch action V_p. Especially, V_c considered the effect of displacement ductility. Contribution of shear concrete on shear strength reduced with increasing displacement