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Improving fire performance with steel fibers for internally anchored square composite columns

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ABSTRACT

This study focuses on mixing steel fiber in the concrete to improve the ductility and toughness of the columns. The purpose of the study is to evaluate the load capacity and deformation capacity associated with the amount of steel fiber and loading condition and to analyze the interplay between the steel fiber reinforced concrete and the welding built-up square tube in terms of structure and fire resistance performance. Reinforcement of concrete with steel fiber, when cross-section shape and boundary condition (load ratio) remained unchanged, improved fire resistance performance by 1.1–1.3 times. It is deemed that the area resisting thermal load increased and fire resistance performance was improved since the concrete reinforced with steel fiber restrained cracking. In addition, the fact that the cross-sections of the concrete were barely damaged indicates that load share capacity was greatly improved.

1. Background and purpose

Studies on concrete filled steel tube (CFT) columns have been made since the early 1990s. The rise in steel prices and the development of high-strength materials led to the efficient use of construction materials and the reduction in steel amount. Local buckling is likely to occur when thin steel plates are used in a CFT column, which results in the deterioration in cross-sectional efficiency because steel tube cannot confine concrete. Stud bolts or anchor bolts are used to induce composite effect and counteract the loss in confinement effect and ductility. Studies on CFT columns with internal or external stiffeners started in the late 1990s in this context. Choi et al. [3]) suggested a new type of square tube made of 4 bent steel plates as shown in Fig. 1 to induce composite effect between the tube and concrete as well as to enhance workability and avoid stress concentration at the corners. Suggested in 1997 and chosen as a new technology in 2009, this type of welded built-up columns named advanced construction technology columns are actively used in construction field. Water press test [4] was conducted to evaluate the safety of the throat depth of internally anchored square columns.

In many studies, CFT columns were proved to provide fire-resistance performance even without fireproofing protection. Those CFT columns in high-rise buildings provide required fire-resistance performance that is, however, not a safe proposition. In order to deal with this issue, the idea of reinforcing the concrete with steel fibers or steel bars was suggested. While the ribs of a column play the role of interior anchors and improve cross-sectional efficiency, they tend to deteriorate the fire resistance performance of the column when exposed to high temperatures. In other words, the ribs accelerate concrete cracking when thermal deformation occurs. A test was conducted with full-scale internally anchored columns under loaded heating condition to see the influence of steel bars in concrete on the fire-resistance of the columns. The cross-sections of the columns were 612 mm × 612 mm. The effective heating length of the tubes made of 10 mm thick steel was 4550 mm. Internally anchored columns with reinforced concrete satisfied fire-resistance requirement of 180 min, while those with plain concrete resisted fire for 50 min. As shown in Fig. 2, approximately 40–50% of the cross-section of the plain internally anchored column was damaged. Since the steel tube directly exposed to high temperatures was of higher thermal conductivity than the concrete, it underwent thermal deformation from the early stage of heating. Then the ribs deformed rapidly and caused concrete cracking. In spite of the storage effect, the concrete could not resist thermal load.

In order to improve the fire-resistance performance of internally anchored columns, the toughness of concrete should be increased enough to resist the thermal deformation of ribs as suggested in Fig. 3. This study suggests increasing the toughness of internally anchored columns without fireproofing protection by mixing steel fibers in concrete.

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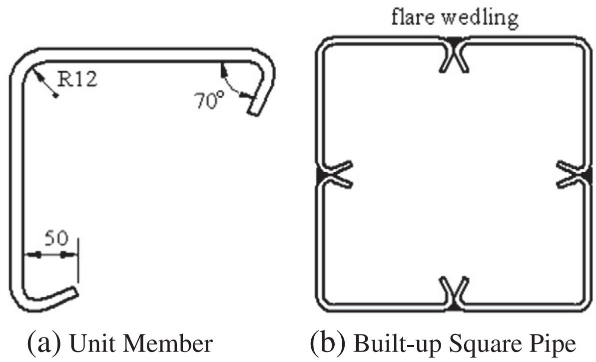

Fig. 1. Internally anchored square column.

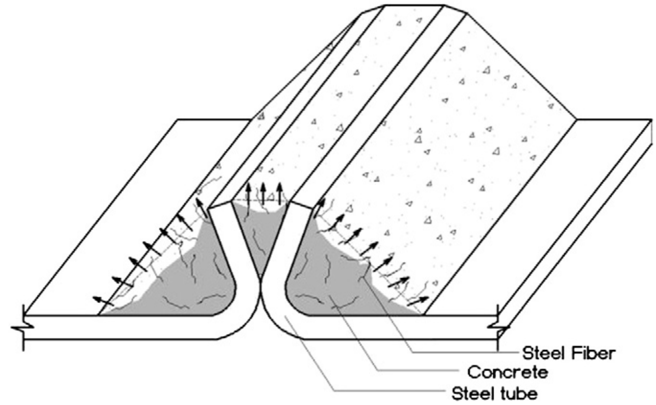

Fig. 3. The interaction between SFRC and steel rib.

2. Previous studies

Only a few studies have been made on the fire-resistance performance of steel fiber reinforced concrete (SFRC) columns. Starting in the 1990s, the studies focused on reinforcing concrete with fibers such as steel fibers and polypropylene fibers to prevent concrete spalling when exposed to high temperatures. V. K. R. Kodur was the major figure in studies on the fire-resistance performance of SFRC square columns. Table 1 shows the specimen details and parameters of the 7 studies conducted between 1996 and 2004. The steel fibers used in the tests were hook-ended type (lf: 50 mm, df: 0.9 mm) and mixing ratio was 1.77%. Numerical analysis model was drawn from the result of the tests. Finally, designed formula was suggested based on the test and the analysis. The formula published in the AISC Steel Design Guide-19 is the cornerstone of the fire resistance design for concrete-filled columns.

2.1. Fire resistance of SFRC-filled steel tube column

A total of 58 cylinders or square CFT columns were tested for the evaluation of fire-resistance performance. Plain concrete (PC), reinforced concrete (RC) and steel fiber reinforced concrete (FC) were used. Loaded heating tests were in compliance with the time–temperature curve prescribed in the ASTM E119-88 or ULC S101-89. Hollow steel tube columns resisted fire for 15–20 min, while the columns filled with plain concrete resisted for 1–2 h. The columns with reinforced concrete (RC) and steel fiber reinforced concrete (FC) resisted fire for 3 h. Unlike plain concrete filled columns which failed due to sudden contraction, the failure of RC and FC columns was caused by gradual compression.

2.2. Fire-resistance performance formula

Most of the studies on the fire-resistance performance of concrete-filled columns were conducted by [1,2,5,6,7], NRCC (National Research Council of Canada) and Fuzhou University, China which were sponsored by CIDECT (Comité International pour le Development et l'Étude de la Construction Tubulaire). NRCC conducted standard fire-resistance tests with plain, reinforced and steel fiber-reinforced CFT columns under axial loads. Its researches also included the fire-resistance of concrete-filled columns under combined loads involving eccentricity. All of the CFT columns without fireproofing protection had fixed ends. The studies conducted by NRCC showed that although the fire-resistance performance of the reinforced concrete filled columns was improved, drawbacks such as the rise in cost and limited column size were accompanied. Reinforcing concrete with steel fibers was found to counteract the disadvantages of plain concrete and steel bar-reinforced concrete. Kodur and T. T. Lie [7,8] identified the thermal and dynamic

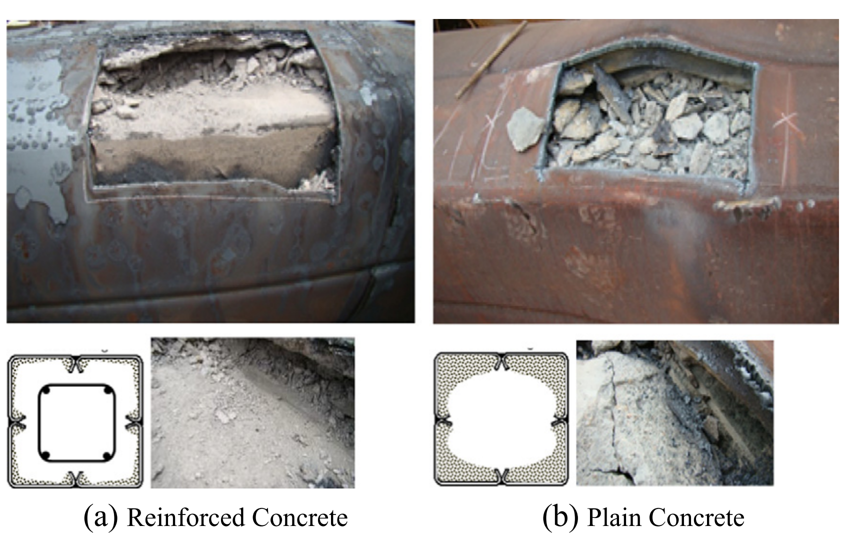

Fig. 2. Concrete damage by high temperatures.