Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(11) (2022) 1061-1064
DOI: 10.22060/ceej.2021.18604.6905

Replacement Effect of High-Performance Fiber-Reinforced Cementitious Composite with Ordinary Concrete on Improving the Experimental Behavior of Two Fixed-Ends Concrete Beams

A. Ghods, M.K. Sharbatdar*

Faculty of Civil Engineering, Semnan University, Semnan, Iran.

ABSTRACT: In this paper, the effect of high-performance fiber-reinforced cementitious composite (HPFRCC) with 1 and 2% of steel fibers on the flexural behavior of two fixed-ends concrete beams was investigated. Four beams were cast and tested under concentrated load, two conventional beams, and two HPFRCC beams (with 1 and 2% steel fibers) with two different stirrups spacing in the plastic zone. The average compressive strength is 55 MPa in HPFRCC beams and 50 MPa in conventional concrete beams, and the mixing design was considered so that the strengths of all samples were the same. The type of loading was statically and in the middle of the span. Two fixed-end beams were arranged with a beam of 1.85 m in the middle and two rigid columns of 0.3 m on the sides, which were connected to the frame by using 16 bolts of 22 mm to ascertain the rigidity of the problem, during the test, this rigidity was regularly controlled by the use of measures. The results of the experiments indicated that the use of 1 and 2% fibers in the HPFRCC concrete increased the ductility and absorption of energy. As the displacement ductility increased by 54 and 100% in HC1 and HC2, increasing in energy ductility was 74 and 200% due to the use of more fibers and causing smaller cracks in concrete, and improving its strength properties. By adding fiber, the length of the plastic hinge of the beams was increased 35 to 47%.

Review History:

Received: Jun. 15, 2020
Revised: Sep. 05, 2020
Accepted: Dec. 20, 2020
Available Online: Jan. 10, 2021

Keywords:

Two fixed-end
High performance
Reinforced concrete
Steel fibers.

1- Introduction

In recent years, incredible advancements have been made in concrete technology which has led to the production of high-performance cements (HPCs). HPC is a special type of composite cement in which separate fiber is added to the normal concrete. One of these highly efficient concretes which has become prominent in recent years is HPC. In 1960, researchers studied the effect of steel fibers on the reduction of the brittleness of the concrete [1]. Naaman and Reinhardt (2013) introduced materials that had a strain hardening in tensile stages in the stress-strain curve and called it high performance. High-performance fiber-reinforced cementitious composite (HPFRCC) was classified in a manner that was separated from concrete (FRC). Therefore, HPFRCC was a special type of FRC composite whose characteristic was strain hardening behavior under tensile loading after the first cracking, which was accompanied by several cracks until reaching large strains [2].

Hemmati et al. (2016) conducted parametric experiments to study the effects of compressive strength, loading type, and the ratio of tensile reinforcement on ultimate deformation properties of the HPFRCC beams. It was shown that if the concentrated load in the middle of the span is changed to a uniform load, the plastic hinge rotation capacity will increase [3]. The effect of the conditions of the joint between the concrete bed and the HPFRCC layer [4], the volume fraction of the fiber and the properties of HPFRCC mixture [4], growth and development of cracks [4], optimization and flexural performance [5, 6] and the tensile strain-hardening behavior [7] are the important issues investigated by the researchers in recent years. The first experimental researches about ductility and moment distribution in a continuous beam were first conducted by Mattock in 1959 [8] and were followed by Cohn in 1964 [9]. It has been concluded that moment redistribution up to a maximum amount of 25% does not cause considerable changes in cracking and the beam curvature, and this bending moment is under the elastic theory.

Hemmati et al. (2014) investigated the flexural behavior of high-performance concrete beams by considering the effect of the thickness of the HPFRCC layer in the cross-section of the beam under a two-point flexural test. The results of the study showed that the beams produced with HPFRCC are more ductile than beams manufactured with normal concrete (reinforced concrete beam) [10]. In recent decades, the focus has been on high performance materials such as high-strength concrete (HSC), using different types of fibers and modern polymers, etc., to improve the behavior of the reinforced concrete structures [11, 12].

*Corresponding author's email: msharbatdar@semnan.ac.ir

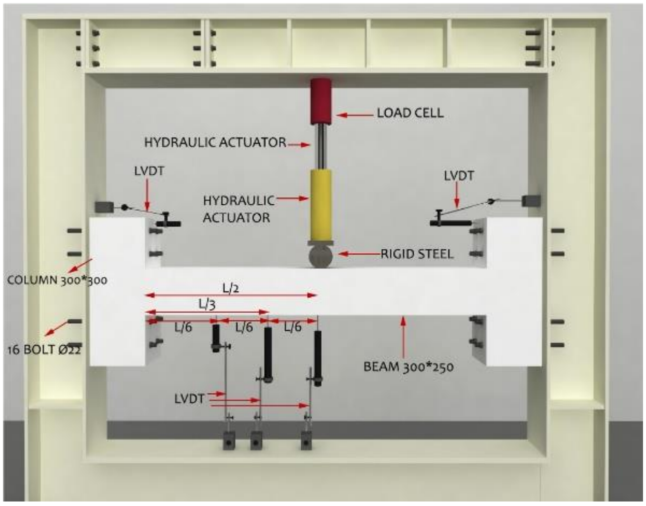

Fig. 1. Experiment's setup.

2- Experimental Programs

To investigate the behavior of fixed beams at both ends, 4 beams were considered. Two of these were made from high-strength concrete and 2 beams were of high-performance concrete. One of the high-performance concrete beams was manufactured with 1% of volume steel fiber and the other one had 2% of volume steel fiber. A 1000 kN hydraulic jack was used to apply a concentrated load in the middle of the beam. To measure the total applied force by the hydraulic jack, a 1000 kN load cell was employed. Moreover, the beam's deflection was measured using LVDTs at three locations, one in the middle, one at the 0.333, and the other at the 0.666 of the span lengths. Electrical strain gauges (ESG) that are 10 mm long and have electrical resistances of 120 Ohms were connected to the surface of longitudinal rebars and stirrups at 17 points. Fixed beams at both ends were prepared as a beam with a span of 1.82 m in the middle and two highly rigid short columns at the sides. These short columns were connected to the frame using 16 powerful bolts to meet the assumption of a fixed end problem, and they were checked constantly during the experiment using some measures. The beam section is 30×25 which is connected to the frame from both sides by two rigid short columns with sections of 30×30 cm and 16 grade-20 bolts. The complete beam specifications can be observed in Fig. 1. To investigate the effect of fiber volume on the mechanical performance of HPFRCC, the dog bone tensile test was conducted. Using standard JSCE (Mattock 1959), the displacement transducer was adjusted by a length measuring device at 80 mm. Loading was controlled according to displacement. For unilateral tension tests, dumbbell-shaped specimens were used [8].

3- Results and Discussion

The results of the experiments shown in Fig. 2 indicated that the use of 1 and 2% fibers in the HPFRCC concrete increased the ductility and absorption of energy. The displacement ductility increased by 54 and 100% in HC1 and HC2, while these numbers were 74 and 200 for energy ductility. Also, the use of more fibers caused smaller cracks in concrete and improved its strength properties. By adding fiber, the length of the plastic hinge was increased 35 up to 47% in beams with congested stirrups and 1 and 2% steel fiber, HC1 and HC2, respectively.

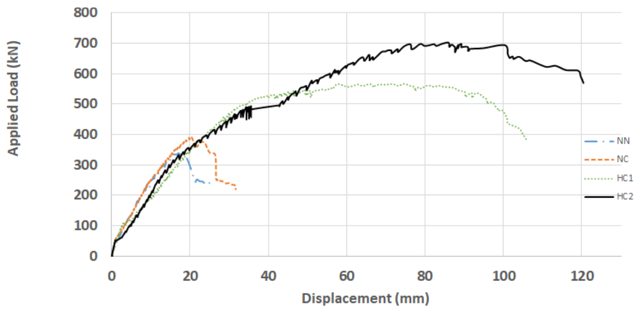

Fig. 2. Load-displacement curves of the beams.

4- Conclusion

1. Replacement of HPFRCC fiber-reinforced composite concrete with 1% steel fibers with ordinary concrete in a beam with the same percentage of longitudinal reinforcement and arrangement and the same distance of compacted stirrups and almost the same compressive strength of two types of concrete, increases 48 and 40% in yield and ultimate load and also, displacement ductility and energy increased by 54 and 74%, respectively.

2. Increasing the volume percentage of steel fibers from 1 to 2% in HPFRCC concrete in two ends fixed beam caused a 12.5 and 26% increase in yield and ultimate load. The displacement ductility increased by 46% while the ductility of the energy increased by 126%, and the effect of increasing the fibers on this ductility is obvious.

3. Reducing the stirrup distance from one-half to one-quarter of effective height of two ends fixed beam with conventional concrete increased only 5% of the length of the plastic hinge while replacing the reinforced fiber concrete increased the length of the plastic hinge up to 46% at the end of the beams. And the moment redistributed and more microcracks were produced and the failure mode of normal concrete beams changed from bending-shear to complete bending in reinforced concrete beams.

4. Comparison of theoretical and laboratory moment capacity of beams showed that the theoretical value of normal concrete beam with uncompressed stirrups was more than the experimental value and in compressed stirrups beam these two values were almost equal but significant difference between these two values in reinforced concrete beams. It was observed that the experimental value of flexural moment was up to 40% more than the theoretical value, which shows the very high impact of replacing this concrete with normal concrete in improving the flexural behavior of two ends fixed beams.

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HOW TO CITE THIS ARTICLE

A. Ghods, M.K. Sharbatdar , Replacement Effect of High-Performance Fiber-Reinforced Cementitious Composite with Ordinary Concrete on Improving the Experimental Behavior of Two Fixed-Ends Concrete Beams, Amirkabir J. Civil Eng., 53(11) (2022) 1061-1064.

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