AN EXPERIMENTAL INVESTIGATION OF THE STEEL FIBER ADDITION TO THE REINFORCED CONCRETE CANTILEVER BEAMS UNDER A CYCLIC LOAD EFFECT

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Abstract

The cantilever beams are widely used in reinforced concrete structures. Due to the deflections in a cantilever, cracks occur. The formation of a crack is unfavourable for the behaviour and it decreases the bearing capacity of a reinforced concrete member. The use of steel fiber in a reinforced concrete is widespread since it prevents the formation of a crack and increases the ductility. The significance of this study is its experimental report of the use of steel fibers in reinforced concrete cantilever beams and its contribution into the behaviour. Therefore, reinforced concrete cantilever beam samples with and without steel fiber additions were produced. As cyclic loads were applied, the behaviours of the samples were examined. As a result of the study, it is experimentally found that with the addition of steel fibers into the reinforced concrete cantilever beams, the crack widths decreased and their ductility increased. The decrease in stiffness occurred less in the reinforced concrete cantilever beams with steel fiber addition and it was concluded that use of steel fibers is favourable for the behaviour.

Key words: Reinforced concrete cantilever beams, hysteretic behaviour, pushover analysis, crack.

1. Introduction

An earthquake is a dynamic force which has an effect on structures. Because of the structural damages that occur under an earthquake effect, there is a great loss of life. This also results in an irreparable loss of property for the national economies.

In the reinforced concrete structures, cantilever beams are usually used to broaden the floor area of the floors after the ground floor. Cantilever beams of bearing systems are constructed on one or four side of buildings. Cantilever beams are subject to uniform wall loads. Due to the deflections in the cantilever beams, cracks occur. The formation of cracks becomes more pronounced, particularly under an earthquake effect. With an increase in the depth of the cracks, permanent damages occur during an earthquake. These damages are in the form of a collapse of the cantilever beams.

The strength and other mechanical qualities of the concrete material are improved by means of various additive materials. To that end, as well as chemical additives, steel fibers in various sizes are used in a concrete. The addition of steel fibers into the concrete increases its bearing capacity, its resistance against deformation and its tensile strength; decreases the crack width; provides crack control and it shows a higher resistance against dynamic and sudden loadings [1]. The use of steel fibers in the reinforced concrete as an additive material becomes interesting and significant as it improves the behaviour.

In recent years, steel fiber added concretes are widely used in highways, tunnel linings, concrete pipes, reinforced concrete frames, reinforced concrete beam members, shell roof systems, skyscrapers and pre-tensioned concrete, thin shell structures, domes and folded plates [2,3].

The functions of reinforced concrete steels and steel fibers in a concrete should not be confused with each other. In a great many structural applications, reinforced concrete steels and steel fibers may serve the same functions to a degree. However, one basic difference between them is how and when they perform their functions and crack controls in a concrete. In measurements, a steel fiber, as a homogeneous material, should not be considered as a reinforced concrete steel which builds up the bending moment. Instead, steel fibers can be considered as a material which changes the structure of the concrete and which forces it towards a plastic behaviour. The characteristic of a concrete with steel fibers is its ability for an increased elastic behaviour and to hold energy [4].

The basic characteristic of a steel fiber added concrete is its behaviour under a bending effect. With the addition of fibers, the concrete’s resistance to bending increases. In the concretes which make better bonding with the fibers, the increase in the bending resistance is greater. The amount and slenderness of the fibers have an important role in this increase. With better orientation along the samples, longer fibers lead a greater increase in the strength. Steel fibers perform the greatest effect when the cracks first occur by transferring the stress on the crack ends to themselves and firm areas [5].

In the studies on cantilever beams, the behaviours of reinforced concrete cantilever beams with T cross-sections were analyzed as they were reinforced with carbon fiber reinforced polymer (CFRP) for stirrup. In the studies, 6 reinforced concrete cantilever beams produced were tried under the cyclic loading effect. At the end of the experimental study, it was concluded that the stiffness and energy consumption capacity of the samples increased with CFRP application [6]. In another similar study, 6 pieces of T cross-sectional reinforced concrete beam samples were produced by using the

CFRP material as diagonal winding. At the end of the study, it was found that the strength and stiffness of the beams increased [7].

In another study in which the cantilever beam behaviours were examined, an experimental study was conducted to determine the behaviours of reinforced concrete cantilever beams on the systems equipped with carbon fiber reinforced polymer (CFRP). In this study, which aims to suggest a new design, three node point samples were produced in the experiments and then earthquake loadings were applied and hysteresis curves were obtained. At the end of the study, it was found that the suggested design may be favourable for the behaviour [8,9].

The behaviours of reinforced concrete beams and columns resulting from the addition of steel fibers were also analyzed. Steel fiber addition to reinforced concrete beams and columns increased the ductility of the member and limited the crack formation [10,11].

The significance of this study is its presentation of the performances of the reinforced concrete cantilever beams produced with the addition of steel fibers of varying ratios under cyclic loading effects. It was experimentally analyzed what contributions were made by the steel fibers into the bearing capacity and crack formation of the reinforced concrete. To that end, reinforced concrete cantilever beams in actual sizes were produced and their force-displacement curves and crack formations were determined. At the end of the study, it was found that the increasing ratio of the steel fibers increased the ductility of the reinforced concrete cantilever beams and control the crack widths.

2. Experimental Study

2.1. Test Specimens

In the study, a single type of steel fiber was added in varying ratios into the reinforced concrete cantilever beams with same concrete strengths. Reinforced concrete cantilever beams were produced in three groups; a group without any steel fiber addition (B1), 30 kg/m^3 steel fiber added (B2) group and 60 kg/m^3 steel fiber added (B3) group. The cross sections of the samples were 300x300 mm and bending span for each was 2360 mm. The longitudinal reinforcement of the reinforced concrete cantilever beams was chosen as 8ø14 and the confinement reinforcement was ø10/100 mm. In the samples, S420 rebars were used. Average compressive strength of concrete is 21.2 N/mm^2. At the ends of the stirrups, hooks were made in accordance with the regulations [12,13]. The lateral reinforcements were placed with 100 mm intervals along the span of the sample. In the remaining part at the top of the cantilever beams which amounted to 20 %, the confinement reinforcement intervals were reduced to 50 mm and densification was made. At this point to which the lateral loads would be transferred, brittle damages resulting from smash were prevented. Reinforcement details of the samples are presented in Figure 1.

In structural members, steel fibers with circular cross-sections and hooks have been used. Debonding behaviours of the steel fibers which were produced with hooks at their ends were more positive when compared with the flat-end ones. In the study, Dramix RC 80/0.60 BN type steel fibers of 60 mm length and 0.75 mm diameter and with a slenderness value of 80 were used. Minimum tensile strength of the steel fibers was 1050 N/mm^2. The steel fibers were added into the transmixer with a 20 kg/min rate in a way to create a homogeneous mixture and the mixture was spun at maximum speed for 5 minutes. The dosages of steel fibers were selected so as to create a homogenous distribution within the concrete. The selected dosage is important for the concrete behaviour [3].

2.2. Experimental Setup

The experiments on the reinforced concrete cantilever beams were conducted 28 days after the samples were produced. Lateral force was applied to the peak points of the samples and they were exposed to damage until they reached the collapse mode. While applying the lateral loading, cyclic loading was performed by pushing and pulling. The application of loading on the sample was at first conducted with load control and with displacement control before the peak point. At the first phase of the experiment, load value was applied as 2kN for each step and the resulting displacement values were obtained. At the second phase, the loading values resulting from the displacement values of 10 mm were recorded on a computer by a datalogger. The displacement values were calculated using a linear displacement scalar (LVDT).

During the experimental study, the restraints points, mid-spans and unrestricted point of the cantilever beams were displacement values measured. The measurements in the restraint areas were taken in order to have a control on restraint movements. As for the mid-span displacement measurements, they were taken so as to create an elastic curve. Peak point displacement values were used to draw the force-displacement curves of the cantilever beams. Figure 2 shows the loading mechanism and the points from which displacement values were taken.

3. Experimental Results and Discussion

In evaluating the performance of reinforced concrete members, the relative floor displacement value was used as a damage intensity scale. In the samples, immediate occupancy limit was 23.60 mm and for the 3 samples these limits were reached under 18kN load value. Life safety limit is 70.80 mm and this limit was obtained at 29 kN load value for sample B1, 28 kN for sample B2 and 32 kN for sample B3. Collapse prevention limit is 94.40 mm and this limit was obtained at 25 kN load value after the peak point for the sample B1, 30 kN for the sample B2, and 31,84 kN for the sample B3 [12,14,15]. Figure 3 shows the damage appearance and crack pattern after the loading on the samples.

When the cantilever beam damages are investigated, it is seen that the cracks centre around the restraint areas and continue along the beam span. In advanced damages, there occurred openings in the stirrups in the restraint areas and buckling in the longitudinal reinforcement. In the restraint area where hinges appeared, the longitudinal reinforcement exuded. In the sample B1, the concretes of the restraint area were smashed and dispersed. The node point damage of the sample is given in Figure 4. Samples B2 and B3, the concrete in the restraint area did not dispersed due to the steel fiber effect. Keeping the crack spans smaller due to the steel fiber effect was influential in such a behaviour.

Figure 5 shows the peak point force-displacement hysteresis curves obtained during the pulling and pushing processes in the experiment. It is seen that the behaviours while pulling and pushing are similar. When the curves are analyzed, it is seen that the increasing fiber ratio also increased the ductility.

Figure 6 shows the stiffness-cyclic loading curves depending on the loading phases of the stiffness change which was calculated from the hysteresis curves of the samples B1, B2, and B3. Following the cracks formed in the sample B1, stiffness decreased steadily. However, with the interference of the reinforcement, the decrease in rigidity slowed down. Due to the steel fiber addition, crack formations were prevented. Thus, the decrease in the stiffness of the sample slowed down depending on the steel fiber ratio. As for the sample B3, the prevention of the decrease in stiffness due to the ratio of the steel fiber used was more pronounced.

The force-displacement curves drawn for the samples are given in Figure 7. The curve was drawn with attention to the peak point values of the hysteresis curve cycles in pushing. In an analysis on the curves, it is seen that the decrease in the loading capacity after peak point due to the steel fiber ratio slowed down. As the steel fiber ratio increased, the ductility of the beams B1 and B2 increased respectively by 28 % and 40 % when compared with the sample B1. The increase in the capacity for energy consumption was measured as 28 % in the beam B2 and 39 % in the beam B3 when compared with fibreless sample. Table 1 shows the experimental displacement ductility and energy consumption capacity of the cantilever beam samples.

4. Comparison of Experimental and Analytical Results

The below stated order was followed while calculating the theoretical bearing capacity of the reinforced concrete cantilever beams. The compression force on the concrete compression block and tensile force on the tensile reinforcement were equalized and force balance equation was obtained as the first equation. Building up the moment according to the weight centre of the reinforcement or concrete, the moment balance equation was found as the second equation. From the equality of the equation, the height of concrete compression block was measured. With the help of compression blocks, the force on the concrete and the longitudinal reinforcement area of the cantilever beams were calculated. The controls over the longitudinal reinforcement ratios were performed in a way to make tensile breaks possible. According to the longitudinal reinforcement area of the reinforced concrete cantilever beams, the number and diameter of the tensile reinforcement were chosen. Theoretical M_{cal} bearing capacity of bending moment was calculated for the reinforced concrete cantilever beams designed in a way to make tensile failure possible. The stirrup range in the samples was chosen to be Φ10/100 mm for the samples so as to reach the bearing capacity under bending effect and to avoid shear failure. The cantilever beam is modelled with finite element samples and were analysed. The cantilever beam model and the stress distribution are given in Figure 8. Table 2 shows the measured theoretical bearing capacity moment of the reinforced concrete cantilever beam [13,16,17].

The experimental measurement results were all above the theoretical values calculated. Addition of steel fibers prevented the formation of cracks and contributed into the bearing capacity with regard to the increasing fiber ratio. The increase in the bearing capacity was by 6 % and 25 % respectively for the samples B2 and B3 when compared with the sample without steel fiber addition. Table 2 shows the beam moment values resulting from the measurement and experiment.

5. Summary and Conclusions

The study experimentally states the contribution of steel fiber usage in the reinforced concrete into the cantilever beam behaviour. As the steel fiber ratio increased, there was an increase in the bearing capacity of the reinforced concrete beams by 6 % in the sample B2 and by 25 % in the sample B3. The ductility value increased by 28 % and 40 % respectively for the samples B2 and B3 in comparison to the sample B1 as the steel fiber ratio increased. The increase in the energy consumption capacity was by 28 % for the beam B2 and 39 % for the beam B3 when compared to the sample without fibers. Consequently, when the experimental data are assessed, it can be said that steel fiber addition is influential on ductility, bearing capacity, energy consumption capacity, and stiffness alterations. Particularly, the decrease in the formation of cracks in the samples with steel fiber additives and low levels of crack width improve the behaviour of reinforced concrete. Experimental data demonstrated that the use of steel fibers in reinforced concrete cantilever beams is favourable for the behaviour. Particularly in the reinforced concrete cantilever beams with critical spans, use of steel fibers should be preferred. The increase in the performances of the reinforced concrete cantilever beams in the samples with steel fibers indicates that steel fiber effect should be taken into consideration in measuring the bearing capacity of the reinforced concrete.

6. Acknowledgement

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7. References

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List of Tables

Table 1. Experimental results of reinforced concrete cantilever beams

Sample no	Flexural cracking load (kN)	Flexural yield load (kN)	Failure load (kN)	Yield disp. δ_y (mm)	Failure disp. δ_u (mm)	Ductility ratio δ_u/δ_y	Energy dissipation capacity (kN mm)
B1	10	26.00	28.37	42.40	190.07	4.48	4428.28
B2	14	26.50	29.90	37.30	214.40	5.75	5677.54
B3	10	27.30	35.33	36.10	226.60	6.28	6157.08

Table 2. Comparison of experimental and calculated results

Sample No	**Experimental strengths $M_{exp.}$ (kN m)**	**Calculated strengths $M_{cal.}$ (kN m)**	**Experimental/ Calculated $M_{exp.}$ / $M_{cal.}$**
B1	66.95	44.51	1.50
B2	70.56	44.51	1.59
B3	83.38	44.51	1.87

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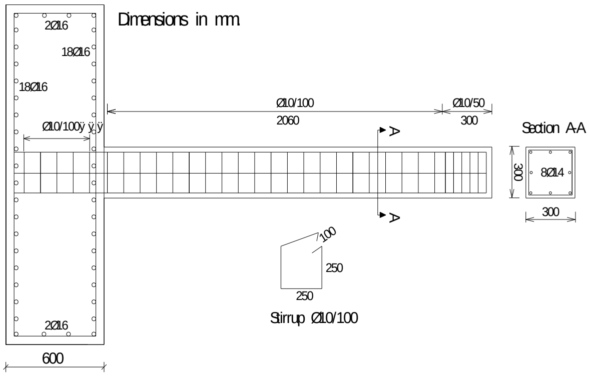


Fig. 1. Reinforcement details of specimens

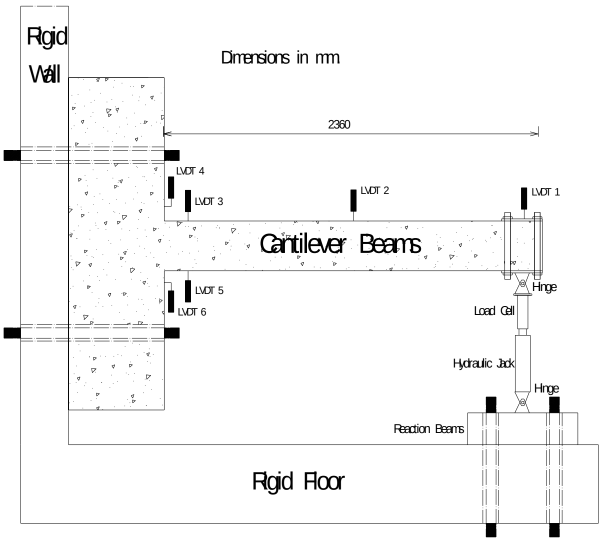


Fig. 2. Test setup

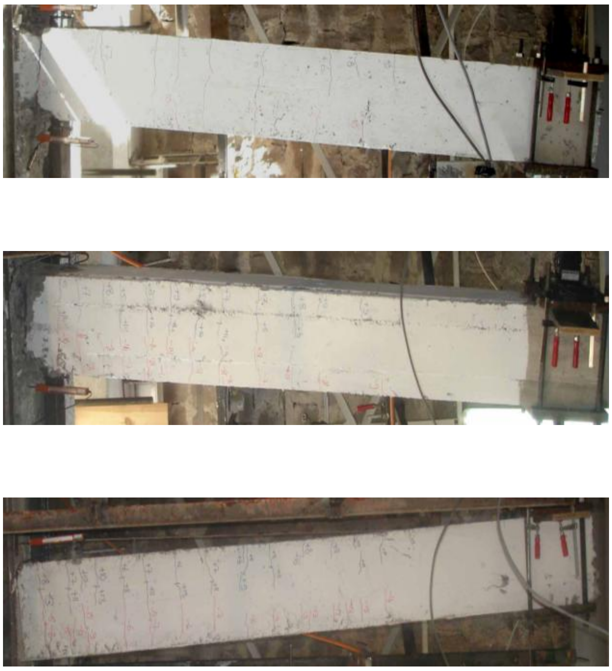
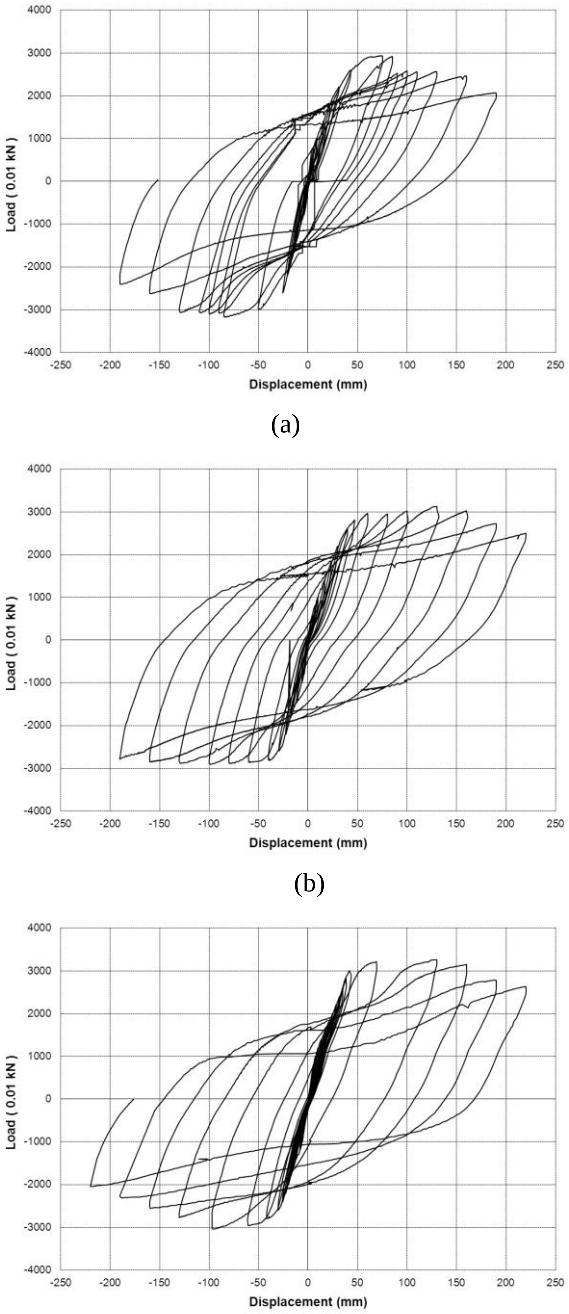


Fig. 3. Damage and crack pattern of specimens views

Fig. 4. Restraints damage of specimens (Plastic hinge)



(a)

(b)

(c)

Fig. 5. Load-displacement hysteretic curves of test specimens: (a)-B1, (b)-B2, (c)-B3

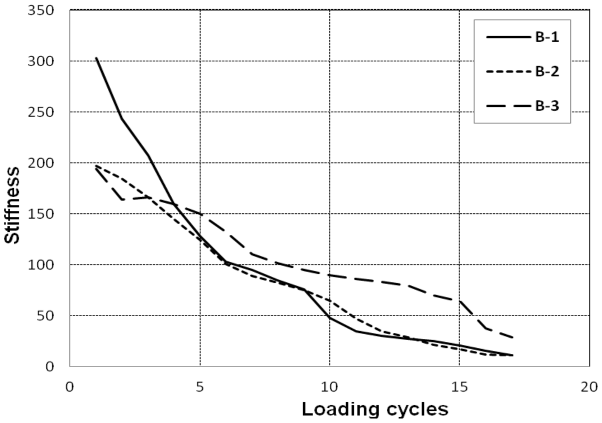


Fig. 6. Stiffness-Loading cycles curves of test specimens

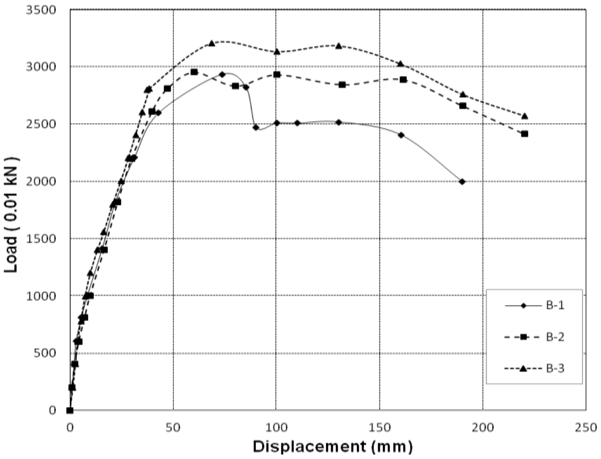


Fig. 7. Load-displacement curves of test specimens

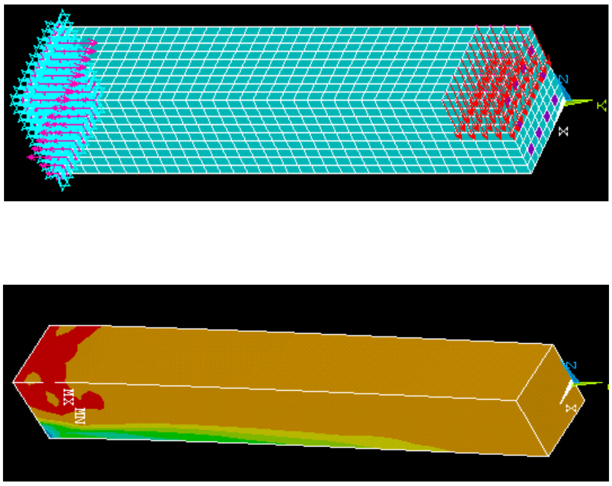


Fig. 8. The cantilever beam model and the stress distribution