International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 4
April 2018

Study of Steel Fiber-Reinforced Concrete Beams through Cyclic Loading

Durgesh Nandan Verma
Assistant Professor In Civil Engineering Department
Gateway Institute Of Engineering And Technology, Sonipat
Ganesh Chauhan
Gateway Institute Of Engineering And Technology, Sonipat

ABSTRACT

A practical study has been operated to study the cyclic characteristics of reinforced concrete beams in that steel fibers were mixed to the concrete. Seven relevant geometrical specimens with entire scale were examined under four- point bending test through slow cyclic loading. One specimen as a control sample was involute without steel fibres or 0% volume fraction and six other with 1, 2 and 4% of of steel fibres in twin models. The maximum and ultimate resistance, ductility, degradation of loading and unloading stiffness, absorption and dissipation of energy and equivalent viscous damping were studied in this examination and the effect of steel fibres on the cyclic behaviour was compared with each other. Generally, the addition of steel fibres up to a certain limit value (vf = 2%) improves the cyclic behaviour of reinforced concrete beams and results in the increase of maximum strength and ultimate displacement.

KEYWORDS

Steel fiber-reinforced concrete · Volume fraction · Damping · Secant stiffness · Practical study

INTRODUCTION

The idea of mixing the fibres to brittle materials to enhance ductility goes back to old times (Felekoĝlu et al. 2007). Ancient times in Egypt, straw was mixed to mud brick but now different types of fiber are used; for sample, in concrete structure the most prevalent is steel fiber. Various researches have been made on steel fiber-reinforced concrete (SFRC) (Sahoo et al. 2016, 2015a, b; Ozcan et al. 2009; Nataraja et al. 1999; Vandewalle et al. 2003; Ganesan et al. 2007). Concrete reinforcement with steel fibres has many advantage such as decrease and control of cracking, enhancing of durability and age of concrete, toughness, tensile, flexural and shear strength of concrete, and many disadvantages like corrosion of fibres, decrease of workability of concrete, irregularity of distribution and accumulation around the local area. The fibres varies in size and shape such as straight, hooked and corrugated (Wang 2006). It has been displayed that steel fibres through low volume fraction (< 1%), in SFRC, have a non-significant impact on compressive strength, but improve sheltering tensile and flexural strength and toughness (Sahoo and Kumar 2015; Holschemacher et al. 2010; Mohod 2012). Cho and Kim (2003) showed that the addition of steel fibres to concrete beams enhanced the initial stiffness and ultimate strength and also the ductility in specimens in which failed in shear–flexural and flexural are higher than those which failed dominantly in shear. The results display that the end-hooked fiber types lead to more residual load-bearing capacity for more deformation in four-point bending test, but corrugated fibres lead to high load-bearing capacity for lower deformation and there is a decrease of capacity with increasing deflection (Holschemacher and Muller 2007).

The experimental study of fiber-reinforced concrete through cyclic compressive loading displays that its behaviour is similar to plain concrete or concrete confined thru steel spirals, indicating that the fibres primarily influence the envelope curve (Otter and Naaman 1988).

The cyclic response of non-ductile reinforced concrete frame was studied by Oinman et al. (2014). They displayed that the addition of steel fibres in the critical location of beam–column joints increased the lateral load resistance capacity and corresponding lateral drift. Also, the lateral stiffness increased and degradation of the lateral stiffness occurred at a high level of drift. There is no significant difference in energy absorption between specimens with and without steel fibres. Due to significant damages examined in the columns of model without steel fibres, a higher damping was observed as compared to the SFRC.

Biolzi and Cattaneo (2017) examined the shear–flexural response of steel fiber-reinforced concrete beams with longitudinal and transverse reinforcement under four- point bending test in the form of monotonic behaviour. They displayed that the inclusion of steel fibres in concrete beams causes an important increase in shear and bending strength and also ductility and stiffness. Beams failed due to the crushing of the compressive zone in a ductile manner, displaying the yielding of the longitudinal reinforcement. In beams with steel fibres, one main crack was usually localized in the central part of the beam

EXPERIMENTAL INVESTIGATION

The details of specimens, materials, setup of samples and imposed loading history are presented in the following sections.

MATERIALS AND SPECIMENS

Seven reinforced beams of concrete mix with 0, 1, 2 and 4% volume fraction of steel fibers were fabricated in the laboratory of Semnan University. One sample was without steel fibers and the rest of the samples were twin models with the same property because of the probable scatter of results. The shape of the fibers is hooked and the size of the fibers is 60 and 0.8 mm in length and diameter, respectively.

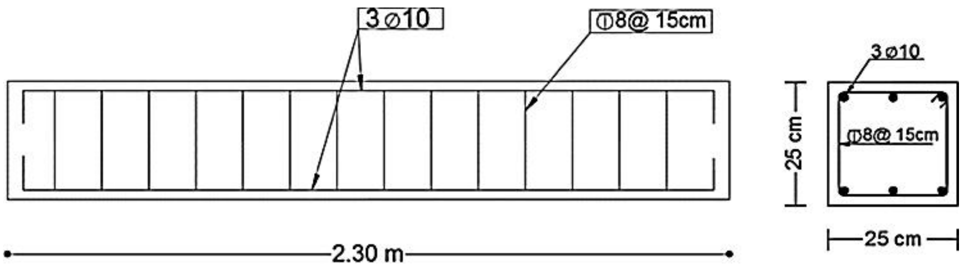
The dimensions of the specimens are 2300 mm and 250*250 mm^2 in length and cross section, respectively. The top and bottom longitudinal and transverse armatures are 3Φ10 and Φ8@150 mm, respectively. The corresponding yield strength is 4000 and 3000 kg/cm^2, respectively. The length of the cover to concrete is 50 mm.

Portland cement type II was used in the concrete mix and liquid polycarboxylate super- plasticizer, due to increase of workability, and micro silica, due to modification of physical properties of concrete, were added to the concrete mix.

Three cube compressive strength tests (15 × 15 × 15 cm^3 and 28 days) were conducted to measure the compressive strength of concrete. The compression strength of concrete with 0, 1 and 2% vf of steel fibers are 34.69, 36.18 and 24.17 MPa, respectively. Similarly, it is observed in other published test results that the addition of fibers does not significantly affect the compressive strength of concrete. (Mohod 2012; Bencardino et al. 2008).

SETUP OF EXPERIMENTAL MODELS

Four- point bending test in the form of slow cyclic loading was conducted by two hydraulic actuators at the top and bottom of the simple support specimens. The segments which impose the force at 0.25 length of the beams were located at the top and bottom of the beams and anchored to each other by eight studs.



International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
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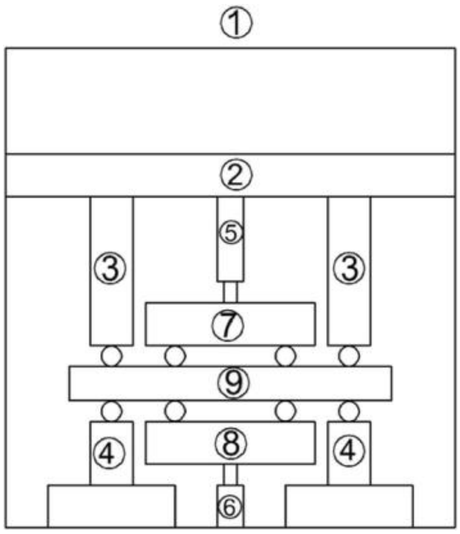
The equipment of the setup of the experimental models consist of: reaction frame, two hydraulic actuators with 250 kN capacity and 30 cm of maximum displacement at the top and bottom of the specimen, two load cells for the measurement of load, two LVDTs for the measurement of displacement at the mid-span of the specimen. The schematic shape of the setup of the experimental models is shown in Fig.

Gravel	Sand	Cement	Water	W/C	Micro silica	Super plasticizer
106.5	159.7	50	30.76	0.61	3.5	0.44



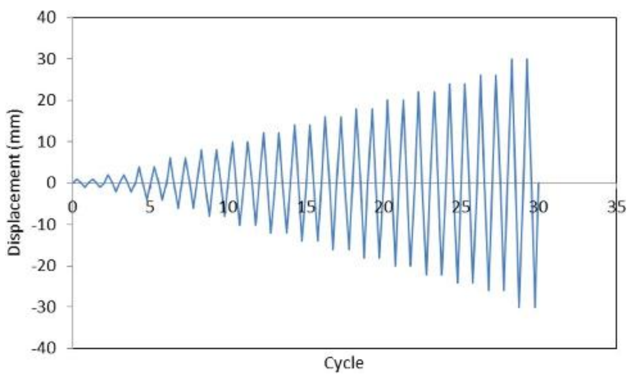


Fig. Setup of the experimental model. 1—reaction frame, 2—moving and adjustable beam in which the top actuator and supports are connected, 3, 4—top and bottom supports of the beam, 5, 6—top and bottom actuators and load cells, 7, 8—segments to transmit force to the beam in 0.25 length, 9—beam under test

Fig. Imposed loading history

ITEMS OF INVESTIGATION

The obtained results in the experimental models are presented in this section. The hysteretic behavior of specimens which clarifies their nonlinear behavior, capacity curve, maximum and ultimate strength, ductility and ultimate displacement, absorption and dissipation energy, damping and deterioration of stiffness are studied in this investigation. These results are compared between specimens with and without steel fibers to identify the influence of steel fibers on the cyclic behavior of reinforced concrete beams and also the effect of value of vf of steel fibers on the items of this investigation.

HYSTERETIC BEHAVIOR

The hysteretic behavior is shown in the form of load from the top and bottom actuator versus displacement at mid-span of specimens. Figure shows the cyclic response and fracture mechanism of specimens.

The cracking pattern was studied in SFRC with stirrups by Biolzi and Cattaneo (2017). Beams without steel fibers were characterized concrete crushing in the compressive zone and a large number of cracks with branching led to failure, but in beams with steel fibers one main crack was usually localized in the central part of the beam (Fig. below).

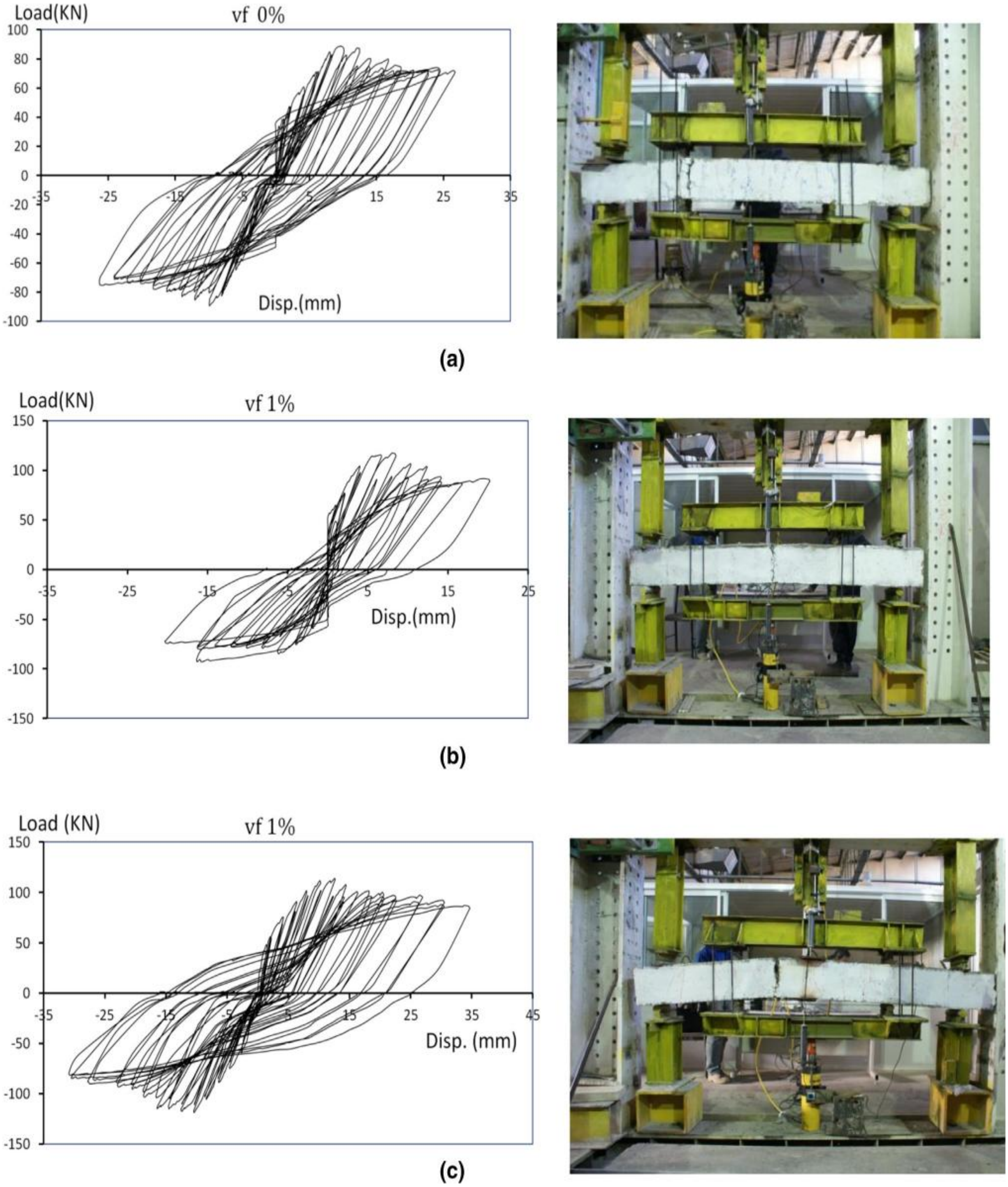
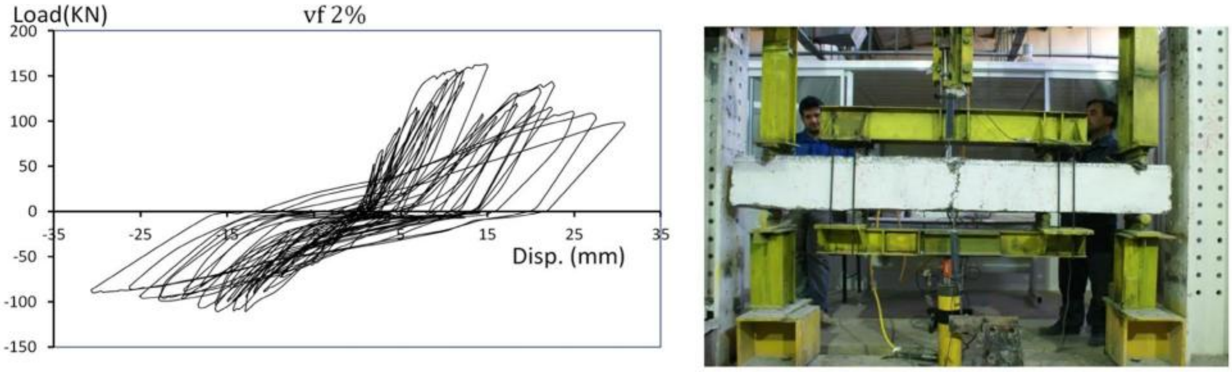
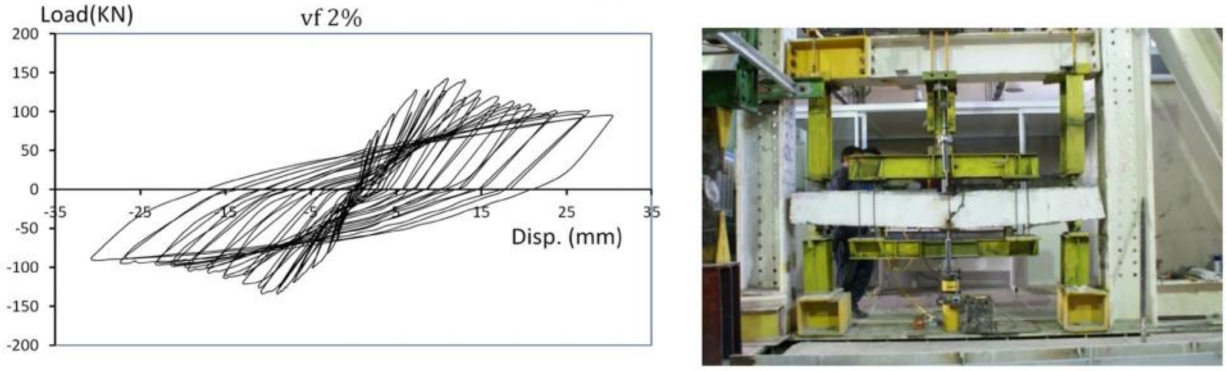


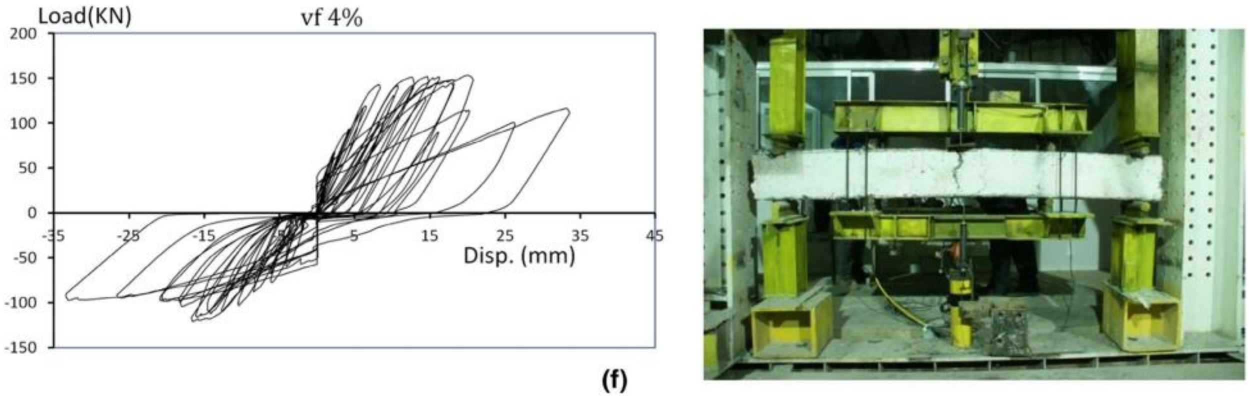
Fig. Hysteretic behavior and failure mechanism corresponding to various vf of steel fiber, **a** 0%, **b, c** 1%, **d, e** 2% and **f**, **g** 4%



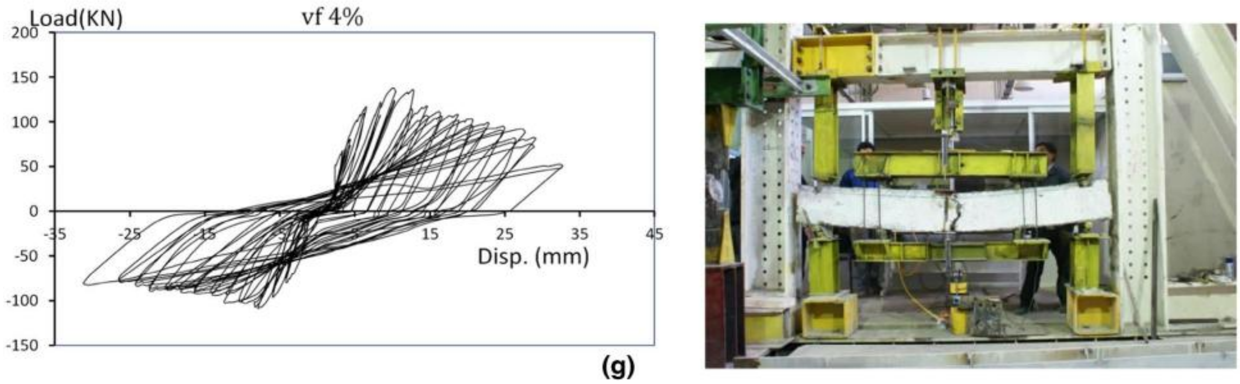
(d)



(e)



(f)



(g)

Fig. (continued)

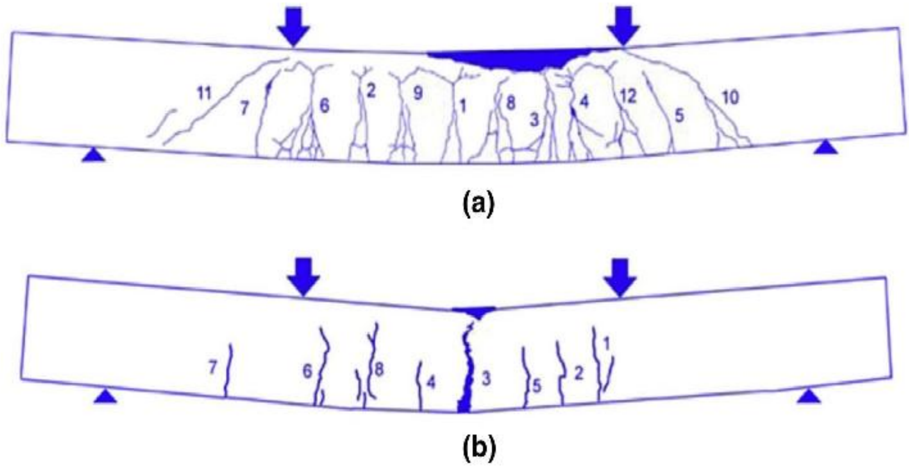


Fig. Typical crack patterns:
a without steel fibers, **b** with steel fibers (Biolzi and Cattaneo 2017)

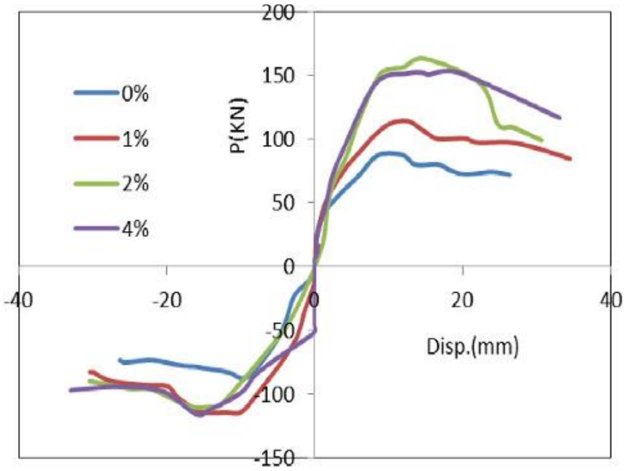


Fig. Comparison of capacity curves of specimens

Table Characteristic values of capacity curves of specimens

vf (%) (1)	*y* (mm) (2)	max (mm) (3)	Pmax (KN) (4)	Pult (KN) (5)	ult (mm) (6)	Ki = Pmax/*y* (KN/mm)	μ=max/*y*
0	3.54	9.61	88.66	70.92	27.38	25	2.71
1	4.72	12.57	113.99	91.19	30.98	24.15	2.66
2	6.49	14.85	163.11	130.49	23.69	25.13	2.29
4	5.71	20.66	151.98	121.58	30.91	26.61	3.62

(1): volume fraction of steel fibers
(2): yield displacement
(3): maximum displacement in the plastic range
(4): maximum strength

International Journal of Engineering Technology Science and Research
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www.ijetsr.com
ISSN 2394 – 3386
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(5): strength corresponding to 80% of maximum strength

(6): displacement corresponding to ultimate strength

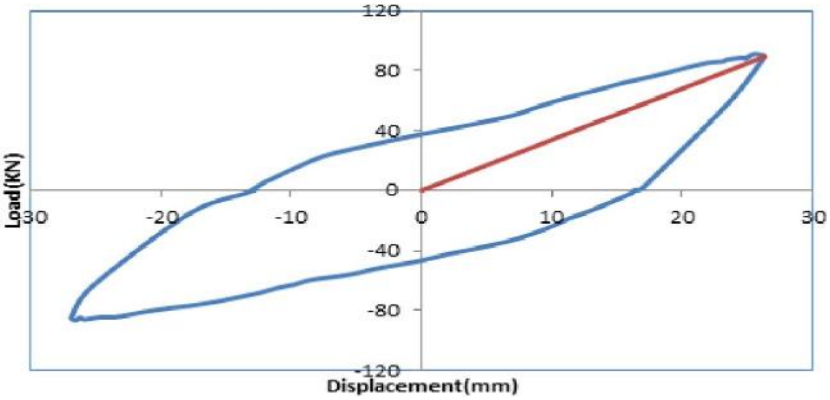

Fig. Description of loading secant stiffness

DISCUSSION

According to the results of experimental models, all of them fail in the flexural mode. However, the addition of steel fibers to concrete results in the concentration of damage at the zone of maximum displacement of specimens, whereas in the specimen without steel fibers the cracks spread in the total length of the beam and finally the model fails at the zone of imposed force. The steel fibers bridge the micro cracks and prevent their opening. At the mid-span by increasing displacement, the steel fibers in the mouth of the crack elongate, yield and finally tear at the ultimate state of the beams. This mechanism results in the increase of capacity of ultimate load and displacement but it seems by increasing the content of fibers from 2 to 4% the efficiency of steel fibers is affectless, it can relate to the reduction of workability of concrete and local behavior of concrete. Reinforcing concrete with steel fibers does not affect the stiffness considerably, but the stability of models in loading and unloading increases. As expected, by the addition of steel fibers to the concrete mix, the absorption and dissipation of energy increase, but because of the limitation of damage at the length of the specimens the viscous damping decreases.

CONCLUSIONS

In this experimental investigation, the effect of steel fibers is studied on the cyclic behavior of reinforced concrete beams.

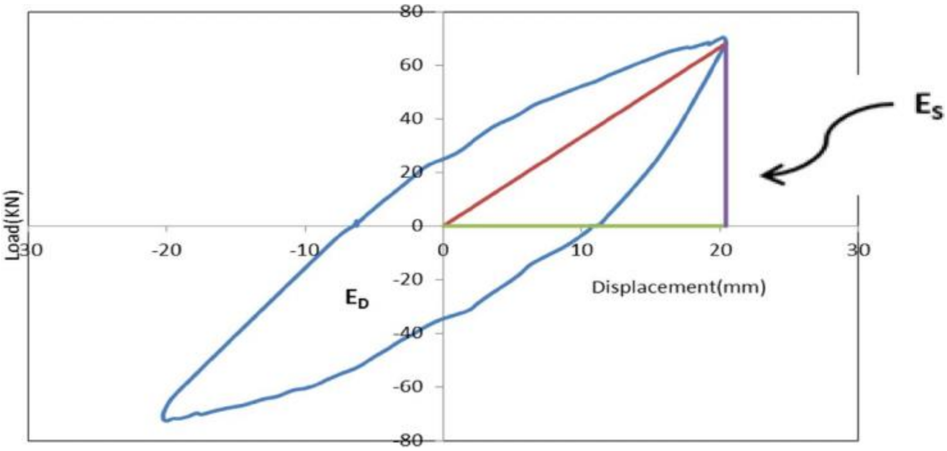

Fig. Description of hysteresis and strain energy

1. Generally with increasing steel fibers, the maximum strength and displacement increase, although this increment has limitation with the volume fraction of steel fibers.
2. It seems with volume fraction of steel fibers, more than 2% of the efficiency of the concrete mix decreases and the maximum strength could be decreased.
3. By addition of steel fibers to the concrete mix, the main crack is localized in the central part of the beams and the number of cracks is less in comparison with the specimen without steel fiber.
4. Generally with increasing volume fraction of steel fibers, the secant stiffness in loading and unloading increases. In other words, with increasing steel fibers in the concrete mix, damage in the specimen decreases and the cyclic behavior is more stable in comparison with specimens without steel fibers or less volume fraction of steel fibers.
5. At smaller displacement, there is no significant difference between the hysteresis energy of specimens. For larger displacement, this difference is considerable, but with increase of steel fibers more than 1% of the difference decreases.
6. At smaller displacement, there is no significant difference between the equivalent viscous damping of specimens. At larger displacement, the equivalent viscous damping of specimen without steel fibers is higher than specimen with steel fibers. More damage before failure in the specimen without steel fibers can result in higher value of equivalent viscous damping.

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