COMPARISON OF METALLIC FIBERS AND STEEL BARS AS REINFORCEMENT IN IMPROVING ENERGY DISSIPATION CAPACITY OF CONCRETE

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ABSTRACT: Energy released by the earthquake gets injected into the structure as ground motion which has to be dissipated for safety reasons. To release the seismic energy, the structure should damage in such a way that, on one hand, collapse of structure should not occur and on the other hand, damage should be economically feasible to repair. Cracking of concrete and yielding of steel reinforcement mainly contribute in energy dissipation in RC structures. In case of reinforced fibrous concrete, friction between fibers and concrete matrix and fiber yielding also contribute importantly in energy dissipation. In this paper, results of an experimental study carried out to compare the ability of ordinary steel reinforcement and metallic fibers as reinforcement to dissipate energy are presented. Form this study; it is found that it is more convenient to use metallic fibers instead of increasing ratio of classical reinforcement if only improvement in energy dissipation capacity of RC is required.

Keywords: Beam; steel reinforcement; metallic fibers; reverse cyclic test; energy dissipation

INTRODUCTION

It is well known that during an earthquake seismic energy enters into the structures through ground motion, and structures are subjected to reverse loads which induce both severe tensile damage of concrete and bond deterioration. The seismic energy must be dissipated to avoid collapse of the structures (Atimtay *et al*, 2006, Daniel *et al*, 2002).

Energy dissipation capacity has been used as a measure of the ability of a structural member to withstand cyclic inelastic loading (Sinha *et al*, 1991). To enhance the structural performance under seismic loading, use of steel fiber has been the subject of many research projects in last recent years (Filiatrault *et al*, 1995, Kimura *et al*, 2007). Under reverse cyclic loading, concrete is subjected to severe damage since it is subjected to tension and compression alternatively. The presence of fibers reduces the strain magnitude and arrests the cracks (Daniel *et al*, 2000). Major benefits of addition of steel fibers in concrete are hindrance in the development of micro-cracks, delay in propagation of micro-cracks to macro-cracks and improved ductility after the development of micro-cracks (Holschemacher *et al*, 2007).

Earthquake resistant design methods available these days involve developing the structural configuration; determining the size and shape of various elements; the materials of construction; and the method of fabrication (Durgesh, 2000). Being restricted to the scope of this paper, the discussion remains limited to the materials of construction. Today, fiber reinforced concrete has made inroad into earthquake resistant construction. Steel fibers are added in the concrete to modify the force-displacement response of structural component and/or enhance their capacity to dissipate a larger part of the inject energy during an earthquake.

Under the scope of a comprehensive experimental program, reinforced fibrous concrete (RFC) beams (beams reinforced with both longitudinal steel and fibers) were tested under reverse cyclic flexural loading. Two types of metallic fibers (FibraFlex and Dramix fibers) were studied. Both fibers were tested at low dosage of 20 and 40 kg/m^3 taking into account the cost of resulting composite. The aim of the experimental program was to find out the response of the following three questions: 1) how the mechanical behaviour of the RC beams under alternate bending is changed when metallic fibers of different types (FibraFlex and Dramix fibers) are added at low dosage?; 2) is there any beneficial effect on the global behaviour of reinforced concrete beam when two different metallic fibers are used in hybrid form?; 3) among metallic fibers and ordinary steel reinforcement, which one is more effective to increase energy dissipation of RC beam?

Based on the findings of experimental testing of RFC beams under reverse cyclic loadings, the discussion on the response to first two queries has been published in Hameed *et al.* (2011). To find response to third query, energy dissipation of RC beam with 0.19% tensile reinforcement ratio (reference beam) was compared with RC beam with tensile reinforcement ratio of 0.33% (73% more than the reference beam) and RC beam with same tensile reinforcement ratio as in reference beam (i.e., ρ = 0.19%) but containing metallic fibers. For the purpose of comparison, reinforcement detail of each type of beam is shown in Fig.1.

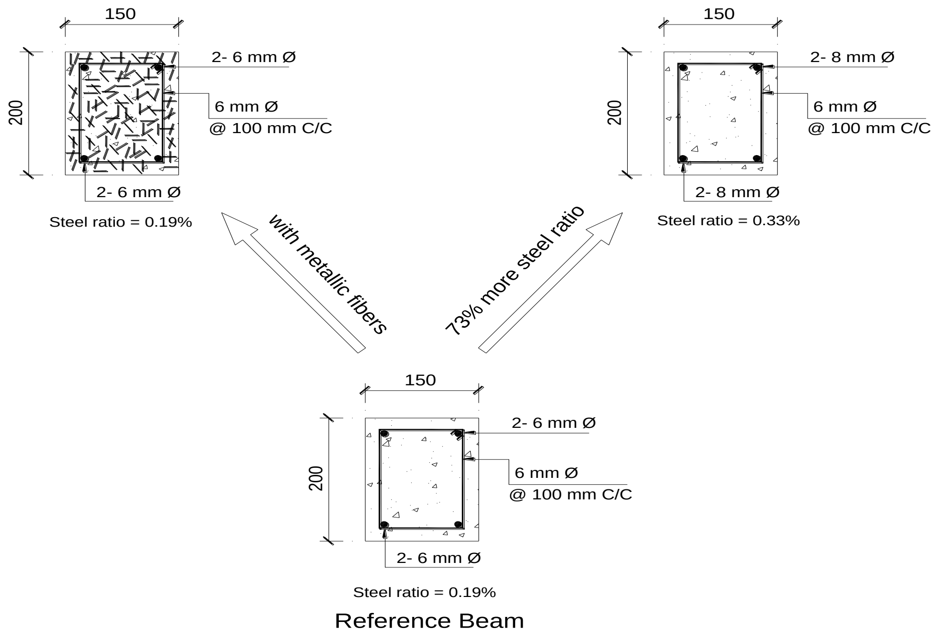

Fig.1: Comparison of the reinforcement

MATERIAL AND METHOD

Concrete Composition: Six different concrete mixes, two without fibers and four mixes containing different contents of metallic fibers were studied. For all concrete mixes, CEM I 52.5 R type cement has been used. Locally available sand with maximum particle size of 4 mm was used. Round gravels with size range of 4 -10mm were used as coarse aggregate. A Super-plasticizer was used as an admixture to improve the workability of the mix in the presence of metallic fibers. Table 1 show the mix proportion of control concrete.

Table 1: Control concrete mix proportion (kg/m^3)

Cement	Sand	Gravel	Water	Super-Plasticizer
322	872	967	193	1.61

Type of fibres used: Two types of macro-metallic fibres were used: 1) FibraFlex fibres (designated in this study as F fibers) are amorphous metallic fibers. They are composed of iron and chromium (Fe, Cr) 80% and Phosphorous, Carbon and Silicon (P, C, Si) 20% by mass (Saint-Gobain Seva, 2012). Due to their rough surface and large specific surface area, F fibres are characterised by high bond strength with concrete matrix (Hameed et al 2010). 2) Dramix fibers (designated in this study as D fibers) are made using carbon steel wires, and are characterised by a weak bond with the matrix compared to FibraFlex fibres due to smooth surface and less specific surface area. They have circular cross-section and hooked-ends. The characteristics of these two types of metallic fibres are given in Table 2, where L, W, T, D and E represents length, width, thickness, diameter and modulus of elasticity respectively.

Table 2: Fibres investigated in this study

Fiber	Fiber Type	Dimension (mm)				E, GPa	Tensile strength (MPa)
		L	W	T	D		
FibraFlex	amorphous metal	30	1.6	0.03	-	140	2000
Dramix	carbon steel	30	-	-	0.5	210	1200

Test Specimen: Cross section of test specimen (Beam) was 150 x 200 mm and length of 1260 mm. Characteristic yield strength of reinforcing steel bars was 500 MPa. Flexural failure of beam was ensured by providing the required shear reinforcement. Details of all tested beams regarding concrete type, steel ratio, fiber type and dosage are given in Table 3.

Nomenclature of Tested Beams: Regarding nomenclature of tested beam, for B6-cont, "B6" stands for beam with 6 mm diameter reinforcing steel bars and "cont" stands for control (without fibers), similarly, B8-cont, "B8" stands for beam with 8 mm diameter reinforcing steel bars. For B6-F20, "F" stands for

FibraFlex fibers and "20" is quantity of fibers in kg/m^3, similarly B6-D20, where "D" stands for Dramix fibers.

Table 3: Details of tested beams

Beam Type	Concrete	Steel ratio ρ, Ø	Dosage of Fibers, kg/m^3		Total quantity of fibers, kg/m^3
			FibraFlex	Dramix	
B6-cont	Control	0.19 % (6 mm)	--	--	--
B8-cont		0.33 % (8 mm)	--	--	--
B6-F20	FRC	0.19 % (6 mm)	20	--	20
B6-F40			40	--	40
B6-D20			--	20	20
B6-D40			--	40	40

Experimental Setup: Cyclic tests were performed using SCHENCK Standard (PS 3007 B) Hydroplus Machine with maximum capacity of 100 kN in static loading and 80 kN in dynamic loading. The experimental setup is shown in Fig.2.

Fig. 2: Experimental setup for reverse cyclic bending test on beam

Testing Procedure: Since seismic action is simulated by series of alternating cycles of bending load with variable amplitude (Buyle-Bodin and Madhkhan, 2002). In this study, displacement controlled reverse cyclic bending tests were performed. Amplitude of reverse cyclic displacement was gradually increased and was applied on the middle of the beam. A cycle for a given displacement amplitude was repeated three times. The loading rate of imposed displacement was fixed as 0.2 mm/second.

RESULTS AND DISCUSSION

Load-displacement hysteresis loops of the RC beam with 0.33% tensile steel ratio (B8-cont) is presented in Fig.3. Load-displacement hysteresis loops of all tested RC beams with ρ = 0.19% and with or without fibers have been presented in Fig.4 to Fig.6.

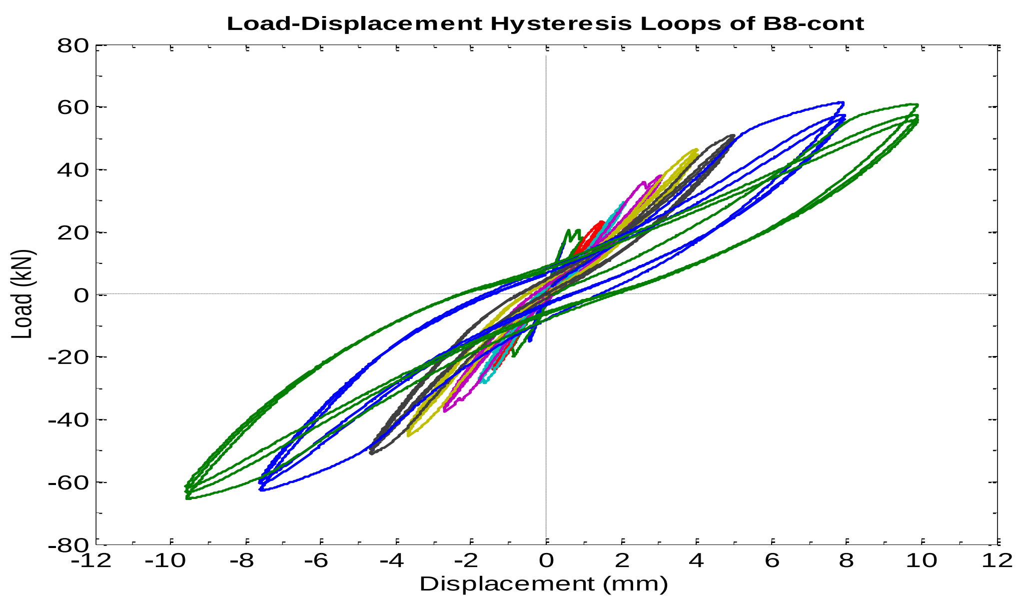

Fig.3: Load-Displacement hysteresis loops of B8-cont

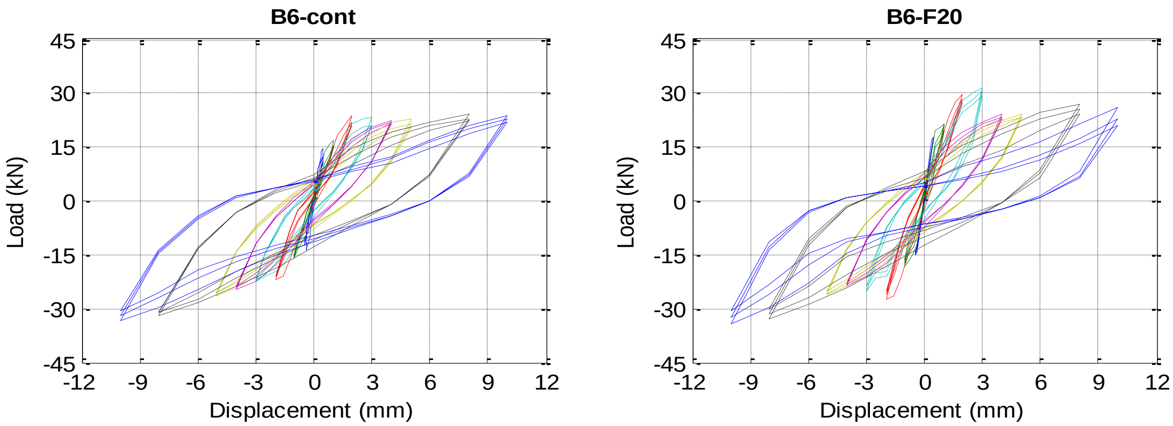

Fig.4: Load-Displacement hysteresis loops (B6-cont and B6-F20)

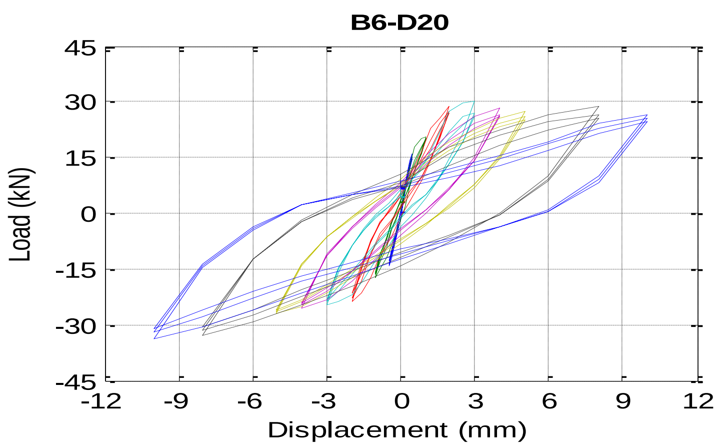

Fig.5: Load-Displacement hysteresis loops of B6-D20)

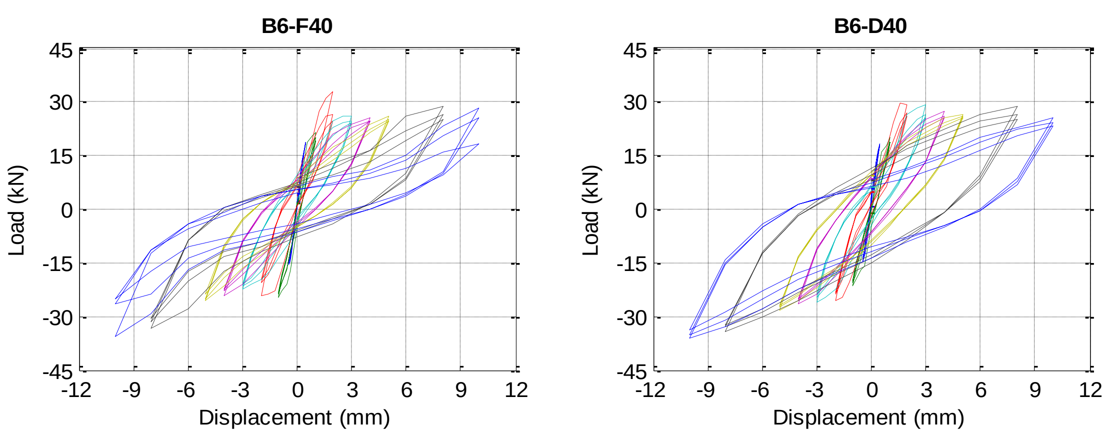

Fig.6: Load-Displacement hysteresis loops (B6-F40 and B6-D40)

The effect of each type of reinforcement (tensile steel reinforcement and metallic fiber) is separately discussed at different values of imposed displacement amplitude. In Fig.7, it can be observed that at 1 mm displacement, increasing tensile reinforcement ratio from 19% to 0.33% provided gain of 54% in energy dissipation. Addition of Fibra Flex fibers in reference beam at 40 kg/m^3 provided almost the same gain in energy dissipation while Dramix fibers at 40 kg/m^3 increased the value of energy dissipation by 45%

compared to reference beam. On the contrary, addition of FibraFlex and Dramix fibers at content of 20 kg/m^3 provided significantly less gain compared to the gain provided by beam with increased tensile reinforcement ratio. The results show that addition of both metallic fibers (FibraFlex and Dramix) at content of 40 kg/m^3 improves energy dissipation in the similar way as RC beam with 73% increased tensile reinforcement ratio does. It is important to mention here that at 1 mm displacement level, apparently no macro cracks were observed in case of B8-cont beam and therefore, greater energy dissipation value is perhaps due to the high load value attained at this displacement amplitude compared to other beams with fibers resulting in more area under load displacement curve.

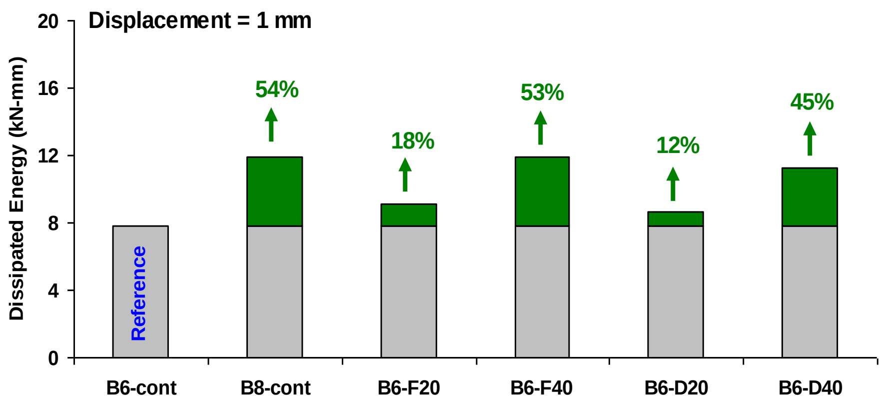

Fig.7: Comparison of energy dissipation at 1 mm displacement

At 2 mm displacement, maximum gain in energy dissipation was provided by FibraFlex fibers at 40 kg/m^3 as shown in Fig.8. Energy dissipation of B8-cont beam was less than the reference beam (B6-cont) by 39%. It can also be observed that Dramix fibers at both contents (20 kg/m^3 and 40 kg/m^3) also increase the energy dissipation. This shows that for improving energy dissipation capacity of RC structural element, adding metallic fibers is a good way rather than increasing tensile reinforcement ratio. Increase in tensile reinforcement ratio results in increased global stiffness of the beam and as a result, up to this displacement level (i.e., 2 mm), less damage occurs in the beam and consequently less energy dissipation is registered.

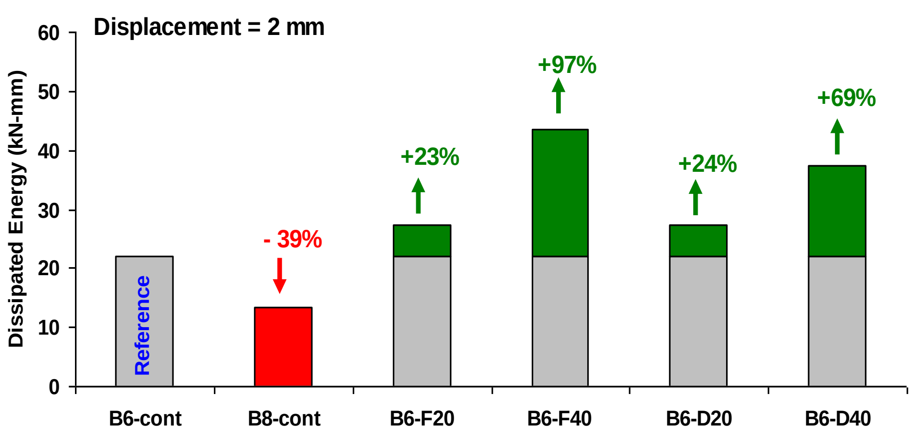

Fig.8: Comparison of energy dissipation at 2 mm displacement

At 3 and 4 mm displacement, almost similar effect on energy dissipation by the two types of reinforcement is observed (Fig 9 and Fig. 10) as it was at 2 mm displacement amplitude: energy dissipation of beam B8-cont was less than the reference beam while both fibers increased energy dissipation of RC beam. It is observed in the load-displacement hysteresis loops of B8-cont that even up to 4 mm displacement, yielding of steel bars did not start, as a result, damage level in the beam is not so high which could cause much of the absorbed energy to dissipate. On the other hand, in beams with tensile reinforcement ratio of 0.19% and containing fibers, yielding of bars was already started at 2 mm displacement and due to increased damage and action of fibers, energy dissipation was significantly increased.

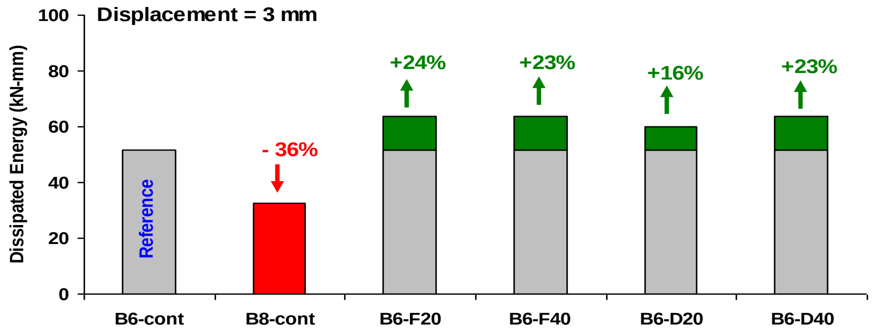

Fig.9: Comparison of energy dissipation at 3 mm displacement

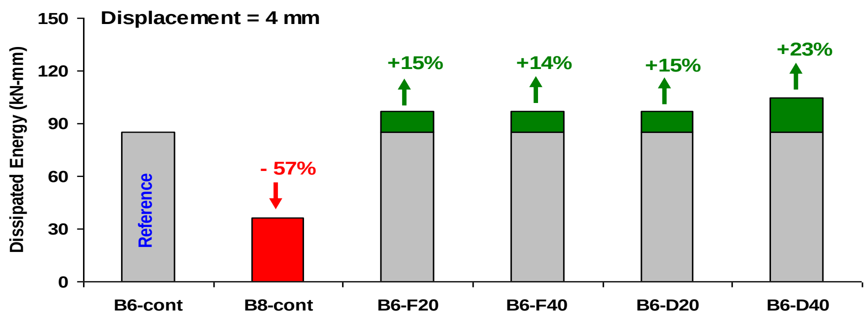

Fig.10: Comparison of energy dissipation at 4mm displacement

With the increase of displacement, gain in energy dissipation by the fibers compared to reference beam was decreased. At 5 mm displacement, as shown in Fig.11, maximum increase in energy dissipation of 26% was registered by B6-D40. Energy dissipation of B8-cont was 47% less than the reference beam. Indeed, in case of B8-cont, steel bars are not plasticized up to this amplitude level and energy dissipation occurs only due to concrete cracking. On the contrary, at this displacement level in reference beam, besides concrete cracking inelastic deformation in steel bars is also another factor which increases the energy dissipation.

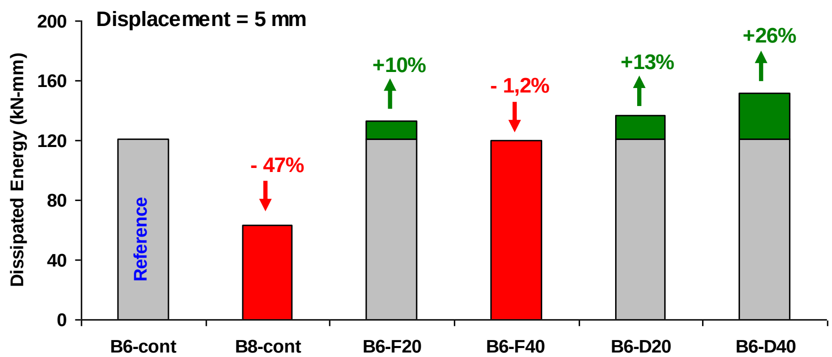

Fig.11: Comparison of energy dissipation at 5mm displacement

Effect of each type of reinforcement at displacement amplitude of 8 mm and 10 mm is shown in Fig.12 and Fig.13, respectively, where it can be noticed that energy dissipation of B8-cont was almost similar to that of B6-cont. at 8 mm displacement, beam containing 20 kg/m3 of FibraFlex fibers exhibited only 5% increase compared B6-cont while energy dissipation of beam containing 40 kg/m3 of FibraFlex was 14% less than the reference beam. Similar observation made at displacement of 10 mm also demonstrated the negative effect of FibraFlex fibers. On the contrary, the energy dissipation capacity of RC beam containing Dramix fibers was always greater than the reference beam even at large displacement values.

Conclusions: Results of comparative study carried out to investigate the effectiveness of ordinary steel reinforcement and metallic fibers have shown that addition of metallic fibers have an important positive influence on the energy dissipation of RC structural members. Since the fibers act once the crack is opened so generally they do not affect the initial secant stiffness of the structural members and after cracking of concrete, they act as energy dissipator and improve dissipation of energy.

Based on the findings of this experimental study, it is concluded that to enhance the energy dissipation capacity of reinforced concrete structural element, it is more convenient to use metallic fibers instead of increasing ratio of classical reinforcement.

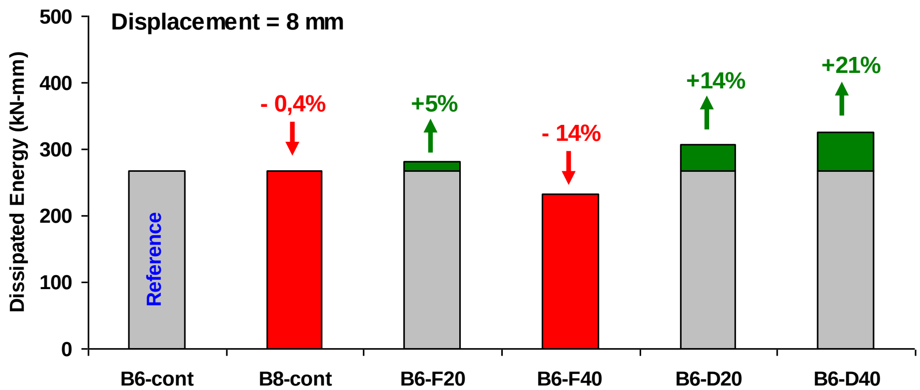

Fig.12: Comparison of energy dissipation at 8 mm displacement

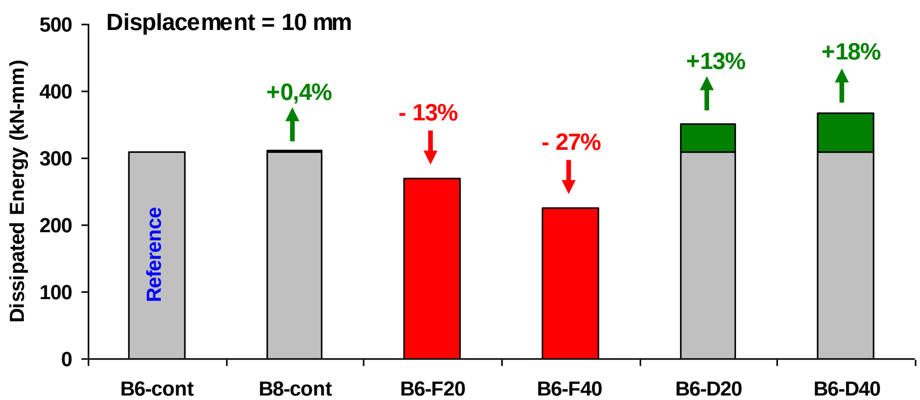

Fig.13: Comparison of energy dissipation at 10 mm displacement

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