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Energy absorption of fibrous self compacting reinforced concrete system

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Abstract. The objective of the present work is to evaluate the influence of two different methods of improving the ductility of Reinforced Concrete Frames and their influence on the full range behavior of the frames with M40 grade of concrete. For this purpose one fourth scale reinforced concrete square frames are experimentally tested subjected to static cyclic loading for three cases and monotonic loading for one case. The parameters are varied as method introducing ductility to the frame viz. (i) by using conventional concrete (ii) adding 1% of steel fibres by volume of concrete at hinging zones (iii) using self-compacting concrete with fibres at hinging zones. The energy absorption by ductile and non-ductile frames has been compared. The behavior of frames tested under cyclic loading have revealed that there is a positive trend in improvement of ductility of frames when fibrous concrete is used along with self-compacting concrete.

Keywords: ductile frame; non-ductile frame; fibrous concrete; self-compacting concrete; monotonic and cyclic loading; energy absorption characteristics

1. Introduction

In recent times it is witnessed that many people have been killed during the occurrence of earthquakes. The loss of life of people is not due to earthquake but, due to lack of construction and detailing aspects to make the structure to behave in a ductile manner. Lakshmipathy (2003) has carried out investigations on reinforced concrete sub-assemblies, elements and frames with three different methods for improving ductility, namely, use of conventional reinforcement as suggested by IS Code (13920 : 1993), provision of inclined bar reinforcement at the joints and use of fibrous concrete at joints. It was observed that the use of fibrous concrete at joints improves the ductile behavior of frames to the maximum level. Anitha and Jaya (2005) investigated the effect of Self Compacting Concrete in improving the ductility of reinforced concrete frames. It was concluded that the Self compacting concrete frame had more ductility than the ordinary concrete frame. Said and Nehdi (2007) carried out experiments on full scale beam column joint specimens to compare the performance of normal concrete (NC) and self-consolidated concrete (SCC). They concluded that the SCC beam column joint specimen performed adequately in terms of the mode failure and

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ductility requirements. Shatarat *et al.* (2007) conducted four different computer programs to evaluate the seismic response of a simple two-span highway bridge. The seismic response was evaluated using two force-based methods of analysis (response spectrum and time-history) and two displacement-based methods (capacity spectrum and inelastic demand spectrum. The experience gained by utilizing the computer software revealed that some programs are well suited to displacement-based analysis, both from the point-of-view of being efficient and providing insight into the behavior of plastic hinges. Mehmet and Hayri (2006) and Shatarat (2012) conducted pushover analysis of two highway bridges built with little attention to seismic forces was performed in an effort to evaluate the difference in global response predicted by using the user-defined nonlinear hinge properties or automated- hinge properties in the software SAP2000. The results demonstrated that user-defined hinge model is capable of capturing the effect of local failure mechanisms, in the plastic hinge region, on the global response of the bridge; while the automated-hinge model cannot capture this effect. Aslani and Natoori (2013) conducted analytical investigation for estimating the mechanical properties of Steel fiber reinforced self-compacting concreteand steel fiber reinforced concrete since steel fibers improve many of the properties of SCC elements including tensile strength, toughness, energy absorption capacity and fracture toughness. Kamal *et al.* (2013) conducted experiments to evaluate the potential of self-compacting concrete (SCC) mixes to develop bond strength. The results showed that the bond strength was reduced due to Portland cement replacement with dolomite powder. Also the test results demonstrated inconsistent normalized bond strength in the case of the larger diameter compared to the smaller one. Ashtiani *et al.* (2014) studied six beam-column joint specimens made of high-strength self-compacting concrete, conventionally vibrated high-strength concrete, and normal strength conventionally vibrated concrete. These specimens were designed, fabricated, and tested under reversed cyclic loading. All specimens showed a relatively ductile behavior as opposed to the general notion of brittle failure in high-strength concrete. Ganesan *et al.* (2014) carried out an experimental investigation to study the effect of steel and hybrid fibres on the strength and behavior of high performance concrete beam column joints subjected to reverse cyclic loads. They found that the combination of steel fibres and polypropylene fibres gave better performance with respect to energy dissipation capacity and stiffness degradation than the other combinations. The design recommendation (ACI-ASCE Committee 352, 1985) stipulates to provide reinforcement cage with closely spaced vertical and horizontal reinforcement in the critical zones. But this results in congestion at the joints in real three dimensional multi-storey frames where three or more members at the joints, leading to construction difficulties. Boudjellal *et al.* (2016) conducted experimental study on a self-compacting polymer concrete called isobeton made of polyurethane foam and expanded clay. Application of the Linear Elastic Fracture Mechanics (LEFM) and determining the toughness of two isobetons based on Belgian and Italian clay, was conducted to determine the stress intensity factor KIC and the rate of releasing energy GIC. The material considered was tested under static and dynamic loadings for two different samples with 10×10×40 and 10×15×40 cm dimensions. The result obtained by the application of the Linear Elastic Fracture Mechanics (LEFM) shows that is optimistic and fulfilled the physic-mechanical requirement of the study.

Based on the literature survey, the beam column joints in a reinforced concrete frame are found to be critical. To avoid damage in the joints, closely spaced stirrups called special confined reinforcement are provided. So congestion of reinforcements occurs, resulting in poor compaction of concrete. This problem of placing and compaction of concrete in beam column joints can be solved if self-compacting concrete is used instead of conventional concrete. The objective of the

Table 1 Materials and mix proportions

Description	Conventional Concrete (BFC)	Fibrous Concrete (BFF)	Fibrous self-compacting concrete (BFSF)
Mix Ratio	1:0.63:1.56	1:0.63:1.56	-
Water/Cement Ratio	0.30	0.30	0.40
Cement (kg/m^3)	676	676	50 %
Fine Aggregate (kg/m^3)	423	423	840
Coarse Aggregate (kg/m^3)	1058 kg/m^3	1058 kg/m^3	715 kg/m^3
Main reinforcement and stirrups (mm)	4	4	4
Fibre	-	1%	1%
Fly Ash	-	-	25%
GGBS	-	-	20%
Micro Silica	-	-	5%
Super Plasticizer	-	-	7.8 kg/m^3

present study is to investigate the influence of structural concrete such as steel fibrous concrete and fibrous self-compacting concrete at hinging zones of the frame on the ductility of frames, in comparison with conventional concrete frame. The behavior of one-fourth scale RC frames studied under static monotonic and static cyclic loading and to measure ductility performance of frames by adopting conventional reinforcement, using fibre reinforcement in joint regions and using SCC with fibre reinforcement in joint regions. The behaviors of the frames are compared with respect to energy characteristics.

2. Experiemtnal investgations

The materials used in this work are tested to find their suitability according to relevant standards. Ordinary Portland cement confirming to IS 12269-2013 is used throughout this investigation. Locally available clean river sand passing through 4.75mm sieve is used for this investigation and IS 383:1970 is followed. Machine crushed hard blue granite broken stones of 10 mm, angular in shape are used as coarse aggregate. The fibres used for the present investigation are crimped steel fibres with length of 36 mm and diameter of 0.45 mm. The steel fibres used in the present study are 1 % by volume of concrete. Mix design is carried out for M40 grade concrete based on Indian Standard 10262-2009. The self-compacting concrete mix for M40 grade is adopted from the work carried out in the laboratory and the mix ratio has been shown in Table 1.

The dimension of the frame is 600×600 mm with 85×60 mm cross section which is kept constant for specimens such as conventional bare frame with monotonic loading (BFC1), conventional bare frame with cyclic loading (BFC2), bare frame with fibrous reinforced concrete (BFF) and bare frame with self-compacting concrete cum fibrous concrete (BFSF). The mould used for casting is arranged on a clean flat and non-absorbent surface. The reinforcement cage is placed inside the mould and cement mortar cover blocks, see Fig. 1. The exact quantities of materials are kept ready on another platform for preparing specimen and after mixing the concrete is filled as 3 layers in the mould, see Fig. 2. After that all the frames except BFC2 are cured under

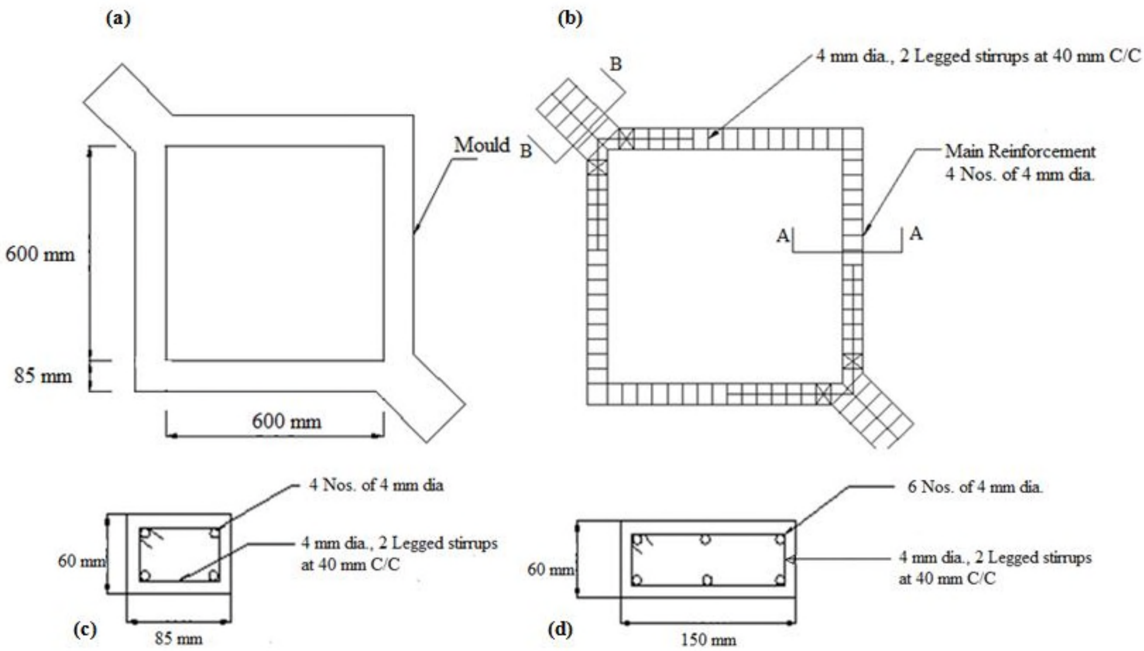

Fig. 1 Schematics of (a) mould (b) reinforcement (c) cross section AA and (d) cross section BB

Fig. 2 Specimens concreting and vibrating

clean water in the curing tank for 14 days until they are taken out for testing while the frame BFC2 cured only for 10 days. In general, the concrete achieves 90% of the strength at 14 days and the structural systems are under serviceable conditions. For instances, structural concrete de-shuttering period is 10-14 days are applicable in practical. After 14 days of casting concrete, concrete gains only 9% in next 14 days.

Fig. 3 Typical test setup for testing the specimens and marking cracks

Table 2 Compressive strength of concrete cubes

Frame designation	Individual compressive strength , N/mm^2			Average compressive strength, N/mm^2
	Sample 1	Sample 2	Sample 3	
BFC1	33.5	40.4	36.5	36.8
BFC2	28.5	25.5	27.1	27.0
BFF	34.0	37.0	36.0	35.6
BFSF	37.0	29.0	32.6	33.0

The specimen was wiped off its surface moisture and grit on the previous day of its testing date and it is white washed. After the white wash the surface was dried, the surface of the frame was marked with lines to study the crack pattern. The points where the dial gauge readings are to be taken are cleaned well and adhesive is applied over the frame surface to which *L* shaped aluminum plate was fixed. The vertical and horizontal displacements are observed by using four dial gauges, two along the vertical diagonal for vertical displacement and other two along horizontal diagonal for horizontal displacement measurement. In the present study, horizontal displacement of the frames was not discussed. The frame is erected on the loading frame vertically and the frame is adjusted such that loading is through the diagonal, see Fig. 3. Dial gauges are fixed at position where displacement should be measured. Load is applied gradually through the head and hand operated hydraulic jack in increments and at each stage of loading deflection of the frames are taken.

The compressive strength of the specimens was measured after the concrete cubes are cured under clean water in the curing tank for 10-14 days. Here, along with each frames, three cubes of size 150×150×150 mm are cast on the same day with the same mix which is used in the corresponding frame. The accompanied specimens are tested and cube compressive strength is determined on the same day on which the corresponding frames are tested, Table 2.

3. Results and discussions

The scheme of experimental work is aimed at quantifying the difference in the behavior of frames with provisions for improving ductility and without it. The results of the experimental program carried out as described in the previous Section are presented in the following sections.

The behavior of the conventional bare frame (BFC1) is discussed in terms of its load corresponding deflection behavior, crack pattern and failure load. The vertical deflections recorded during the experiment at each load interval are plotted against corresponding load and a graph as shown in Fig. 4. From this graph the initial stiffness of the frame is calculated as 4.62 kN/mm. The progressive loading of the frame has resulted in cracking of concrete at load level of 6 kN at the corners of the frame. On further loading the cracks increased in their length and width at the same sections. The monotonic loading of the frame from zero loads to ultimate load caused cracking of the frame, the consequent loss of stiffness and failure to take incremental load characterized by increased deflections without increase in load carrying capacity. The ultimate load is reached with formation of plastic hinges at the four corners of the frame at a load level of 12 kN for conventional bare frame (BFC1).

A half cyclically loading sequence was carried out to understand post-yield behavior of conventional bare frame, BFC2. The lower limit of loading is fixed to be the first cracking load level of the frame, that is, 6 kN and the upper limit is fixed to be the ultimate load of the frame, i.e., 9 kN. The ultimate load capacity of BFC1 is higher i.e., 12 kN and that of BFC2 only 9 kN.

This can be attributed to the fact that the BFC1 has been cured under water all the 14 days after casting whereas the frame BFC2 has been cured only for first 10 days after casting. This is also

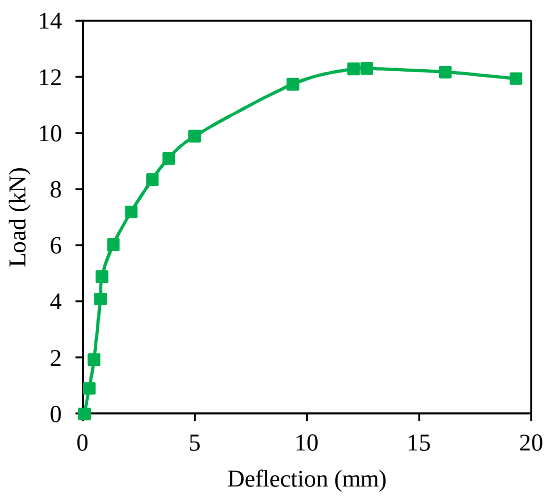

Fig. 4 Load-displacement profile of BFC1 specimens

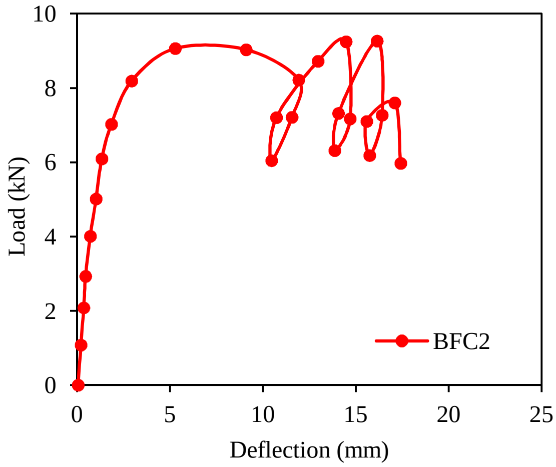

Fig. 5 Load-displacement profile of BFC2 specimens

confirmed by the average values of cube compressive strength of BFC1 and BFC2 is 36.8 and 27 N/mm^2 respectively. The load versus deflection curve of the frame BFC2 is plotted in Fig. 5 and the initial stiffness of the frame is obtained as 5.0 kN/mm. Further, the slope of the ascending curves of each cycle is calculated for BFC1 frame corresponding load-deflection curve, see Fig. 6. The slope of the hysteresis loops of BFC2 frame are 2.0, 1.67 and 0.86 for first, second and third cycle respectively. The loading sequence on the frame is such that the loading is of monotonic type till the ultimate load is reached and the value of load is varied between the first cracking load and the ultimate load for five half cycles.

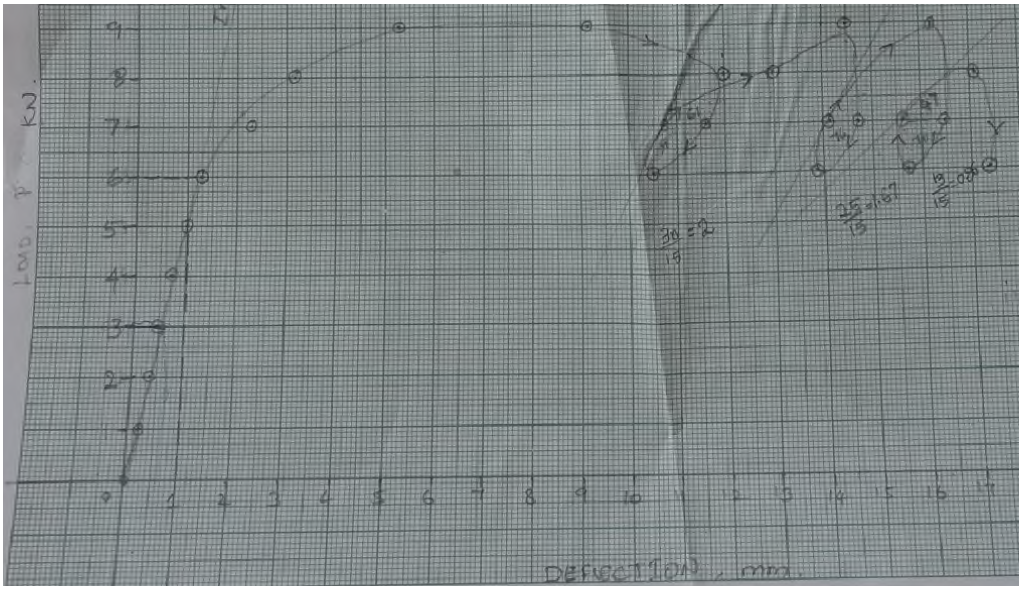

Fig. 6 Plot showing Initial stiffness, slope and ultimate load of BFC2 specimens

The frame BFF is similar to the conventional bare frame in terms of cross sectional dimension reinforcement and concrete mix used except for the fact that the frame is cast with fibrous concrete having 1% of steel fibre as a measure to improve the tensile cracking strength of concrete. The loading sequence is similar to that of conventional frame described previously. The load versus deflection curve of the frame BFF is plotted in Fig. 7 and the initial stiffness of the frame is obtained as 5.71 kN/mm. Further, the slope of the ascending curves of each cycle is also calculated for BFF frame, see Table 3. The slope of the hysteresis loops of BFF frame are 3.02, 2.67, 2.71 and 1.23 for first, second third and fourth cycles respectively. The loading sequence on the frame is similar to that of non-ductile frame BFC2. It is observed that the frame has failed with formation of four hinges at corners and typical hinge formation at the joints is shown in Fig. 8.

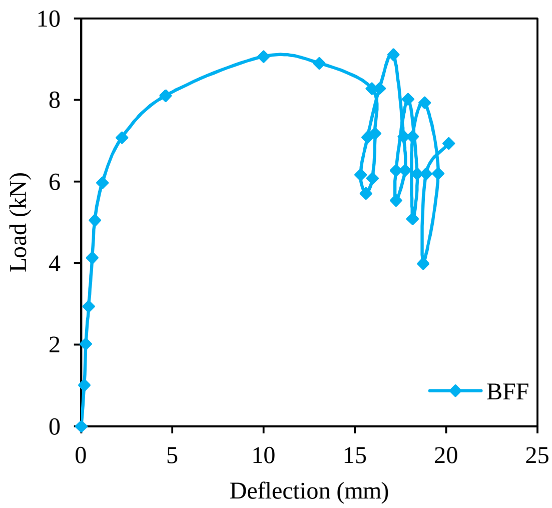

Fig. 7 Load – displacement profile of BFF specimens

Fig. 8 Typical plastic hinge pattern

The load versus deflection curve of the frame BFSF is plotted in Fig. 9 and the initial stiffness of the frame is obtained as 6.0 kN/mm. Further, the slope of the ascending curves of each cycle is also calculated for BFSF frame, see Table 3. The slope of the hysteresis loops of BFSF frame are 1.25, 1.20, 1.09, 0.93 and 1.10 for first, second third, fourth and fifth cycle respectively. The loading sequence on the frame is similar to that of non-ductile frame BFC2. It is observed that the frame has failed with formation of four hinges at corners. In order to evaluate the energy absorption characteristics of ductile and non-ductile frames using two different strategies of improving ductility the following sections bring out the comparison of the frames tested with respect to the above parameter.

The energy absorbed by the specimens BFC2, BFF and BFSF are compared in Fig. 10: The energy absorption capacity of the specimens were estimated as the total area enclosed by the hysteresis loop (load-deflection curve) in each cycle. Fig. 10 shows the use of fibrous concrete in hinging zone of the frame BFF as resulted in a slight increase of 16% in the energy observation capacity when compared to non-ductile frame. The ratio of the values of energy absorption capacity of BFSF and BFC2 is 1.63. This indicates the superior performance of fibres in combination with self-compacting concrete.

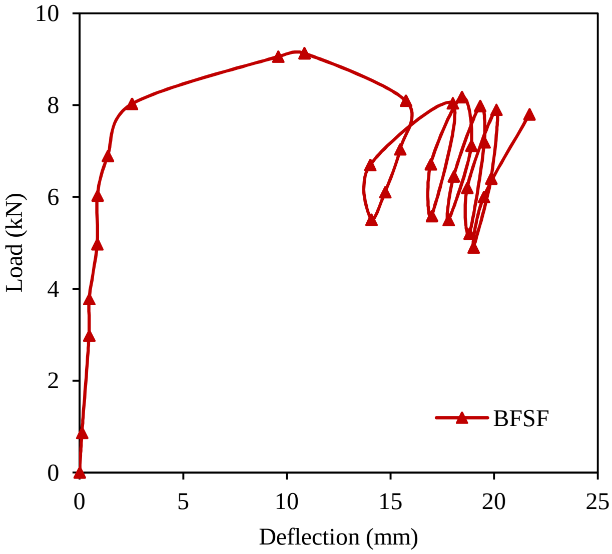

Fig. 9 Load - displacement profile of BFF specimens

Table 3 Slope of the ascending curves of ductile and non-ductile frames

Number of cycles	Slope of the ascending curves		
	BFC2	BFF	BFSF
Cycle 1	2.00	3.02	1.25
Cycle 2	1.67	2.67	1.20
Cycle 3	0.86	2.71	1.09
Cycle 4	-	1.23	0.93
Cycle 5	-	-	1.10

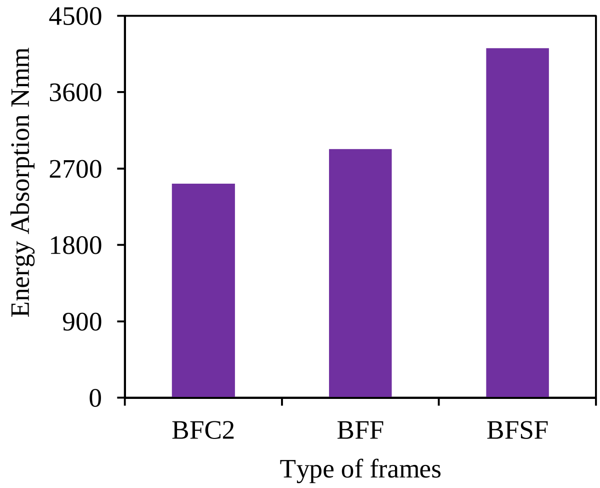

Fig. 10 Comparison of energy absorption by ductile and non-ductile frames

4. Conclusions

The full range behavior of ductile and non-ductile frames have been evaluated under monotonic and cyclic loading and the following conclusions are drawn: The energy absorption capacity of self-compacting concrete with fibres at hinging zone has resulted in increase of 63% when compared to non-ductile frame. This indicates the superior performance of fibres in combination with self-compacting concrete. Therefore, the behavior of frames tested under cyclic loading have revealed that there is a positive trend in improvement of ductility of frames when fibrous concrete is used along with self-compacting concrete. The frame BFC2 is unable to support the cyclic loading beyond three cycles but the frame BFF and BFSF frame went upto four and five cycles respectively. Therefore, the behavior of BFSF is highly preferable since the amount of load shedding is minimum even after five cycles.

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References

ACI-ASCE Committee 352 (2002), *Recommendations for design of beam-column connections in monolithic reinforced concrete structures*, (ACI 352R-02); Farmington Hills, Mich., U.S.A.

Anitha, D.N. and Jaya, K.P. (2005), “Behaviour of reinforced concrete frames with self compacting concrete under lateral cyclic loading”, *Proceedings of International Conference on Recent Advance in Concrete and Construction Technology*, December 7-9, 275-285.

Ashtiani, M.S., Dhakal, R.P. and Scott, A.N. (2014), "Seismic performance of high-strength self-compacting concrete in reinforced concrete beam-column joints", *J. Struct. Eng.*, **140**(5), 04014002.

Aslani, F. and Natoori, M. (2013), "Stress-strain relationships for steel fibre reinforced self-compacting concrete", *Struct. Eng. Mech.*, **46**(2), 295-322.

Boudjellal, K., Bouabaz, M. and Belachia, M. (2016), "Mechanical characterization of a self-compacting polymer concrete called isobeton", *Struct. Eng. Mech.*, **57**(2), 357-367.

Domone, P.L. (2006), "Self-compacting concrete: An analysis of 11 years of case studies", *Cement Concrete Compos.*, **28**(2), 197-208.

Ganesan, N., Indira, P.V. and Sabeena, M.V. (2014), "Behaviour of hybrid fibre reinforced concrete beam–column joints under reverse cyclic loads", *Mater. Des.*, **54**, 686-693.

Inel, M. and Ozmen, H.B. (2006), "Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings", *Eng. Struct.*, **28**(11), 1494-1502.

IS 10262 (2009), *Concrete mix proportioning-guidelines*, Bureau of Indian Standards, New Delhi.

IS 12269 (2013), *Specifications for 53 Grade Ordinary Portland Cement*, Bureau of Indian Standards, New Delhi.

IS 13920: 1993 (Reaffirmed 2003), *Ductile detailing of reinforced concrete structures subjected to seismic forces*, Bureau of Indian Standards; New Delhi.

IS 383:1970 (reaffirmed 2002), *Specification for coarse and fine aggregates from natural sources for concrete*, Bureau of Indian Standards, New Delhi.

Kamal, M.M., Safan, M.A. and Al-Gazzar, M.A. (2013), "Steel-concrete bond potentials in self-compacting concrete mixes incorporating dolomite powder", *Adv. Concrete Constr.*, **1**(4), 273-288.

Lakshmipathy, M. (2003), "Study on improving ductility behaviour of frames", *Post Seminar Proceedings of National Seminar on Futuristic in Concrete and Construction Engineering*, December 3-5, 21-32.

Said, A. and Nehdi, M. (2007), "Behaviour of reinforced self-consolidating concrete frames", *Proceedings of the ICE - Structures and Buildings*, **160**(2), 95-104.

Shatarat, N. (2012), "Effect of plastic hinge properties in nonlinear analysis of highway bridges", *Jordan J. Civil Eng.*, **6**(4), 501-510.

Symans, M.D., Shattarat, N.K., McLean, D.I., Cofer, W.F., Zeldenrust, R.P. and Engineer, S.S.B. (2003), *Evaluation of displacement-based methods and computer software for seismic analysis of highway bridges*, Washington State Department of Transportation.

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