Study on size effect of RC deficient beam-column joints with and without retrofitting under cyclic loading

A.M.Choudhury[1], A.Dutta, S.K.Deb[2,3]

[1]National Institute of Technology, Silchar, India, Email: munimchoudhury@gmail.com; [2]Indian Institute of Technology, Guwahati, India; [3]Indian Institute of Technology, Guwahati, India

Reference Number: 6-12-1-144
Name of the Presenter: A.M.Choudhury

Abstract

Available theories of material behavior that predict size effect are receiving increasing attention in the technical literature nowadays. Beam-column joint is one of the vital elements, whose behaviour during earthquake is very critical. No study has been done till today to establish the existence of size effect on beam-column joint. Hence, in the present study, an experimental programme was undertaken by considering shear deficient beam-column joints. Three geometrically similar specimens were considered as control specimens and three corresponding specimens were retrofitted by FRP (fiber reinforced polymer). Cyclic loading with a constant axial load on the beam-column joint was applied during testing. The recorded data were plotted to draw hysteretic response, envelope curve, energy dissipation etc. Comparisons of results were made between control and retrofitted specimens in term of all the above-mentioned properties and conclusions were drawn regarding the benefit derived out of retrofitting. Further, the percentage gain in capacity due to retrofitting, energy dissipation etc were correlated with size of specimens. To compare the energy dissipation of specimens having different sizes, a new parameter, viz. energy dissipation per unit volume (e_N) was introduced for the first time in the context of evaluation of size effect. e_N was correlated with the size of the specimen at different drift angles. Stresses for all the specimens were calculated and bi-logarithmic plots were drawn. It was observed that most of the properties follow principle of size effect. The most important finding is that- the bi-logarithmic plot of unit strength follows the established law proposed by Bazˇant.

Key words: Beam-column joint, size effect, retrofitted, cyclic load, bi-logarithmic

1. Introduction

The principle of solid mechanics supports that material properties like tensile or compressive strengths are not scale dependent. Such properties measured by testing standard laboratory samples of the material are usually assumed applicable in all the engineering practices. It may happen that the size of the field structural elements may differ from those of the test samples. Many researchers conducted tests on retrofitted beam-column joints without varying the sizes of tested specimens (Ghobarah and Said 2002; Ghobarah and amoury, 2005; Li and Chua, 2009). Some tests results are available for scaled models for a particular deficiency (Gergely *et al.*, 2000; Mosallam, 2000; Mukherjee and Joshi, 2005; Mahini and Ronagh, 2010). These results are unlikely to reflect the behaviour of full size specimens as the size of the specimen plays an important role for various properties. Available theories of material behavior that predict size effects are receiving increasing attention in the technical literature nowadays. It has been demonstrated that the size of the specimen plays an important role. Thus, the use of test results from standard laboratory specimen should be judiciously used in practice giving proper weightage to the existence of size effect. Upon loading a concrete structure, which is heterogeneous, micro cracks stars propagation. The accumulation of all such micro cracks may lead to the development of major cracks and subsequently failure may occur. The mathematical modeling of such materials should be based on the principles of fracture mechanics. Material models based on fracture mechanics can predict a size effect when geometrically similar specimens of different sizes are considered (Bazˇant and Planas, 1998).

Literature survey shows that tests were carried out for full-scaled and scaled down specimens by different researchers. Research was done to see the effect of curing process, FRP layout and surface preparation and conclusions were drawn. However, no research was reported on study the scale effect of the tested specimens. Further, literature survey shows that though study on size effect was carried out for RC basic structural elements (Sener *et al.*, 2002; 2004; Coc and Sener, 2009), yet no study on size effect on beam-column joint was reported. Further, literature survey also shows that in RC structure very few researches were reported on size effect for retrofitted specimens using FRP. It may be mentioned that the only work was done by Leung *et al.*, 2007 for beam and the study was conducted for monotonic loading. Some of the past devastating earthquakes proved that beam-column joints, especially the exterior ones can act as one of the weakest links. To combat the future earthquakes, though various developed countries implemented the principle of strong-column weak-beam, yet the under developed countries are reluctant to practically adopt the same principle. The proposed Indian draft code of ductile detailing IS: 13920 (1993) has given lot of emphasis on this principle. However, many of the constructed beam-column joints in those countries are of waek-column strong-beam nature. These constructed weak-column strong-beam can be retrofitted by FRP to make them fit for the future earthquakes. To study the behavior of waek-column strong-beam and to observe the enhancement achieved in properties by retrofitting the present research was initiated emphasizing the size effect aspect. One of the objective of the work is to strengthen beam-column joints against future earthquakes; hence, all the specimens were tested under cyclic loading in this study. The deficient joints were properly retrofitted using Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). Strengthening was done with unidirectional CFRP and bidirectional GFRP. Retrofitting was done as per the requirement for all the three sizes. Total six specimens consisting of control and retrofitted involving different sizes were tested. A typical residential building with floor to floor height as 3.3 metres and the beam of 3.0 metres effective span was considered for selection of full scale models. The retrofitted specimens were designed for enhanced load carrying capacity. All the three dimensions of two third and one third scaled specimens were selected by proportionately scaling down the dimensions of full scaled specimen. The diameter of the reinforcing bars, development length, cover of reinforcement etc. was also scaled down appropriately. Thus, in the present work, the various aspects that had been tried to cover for plain (referred as control specimen) and FRP retrofitted RC beam-column joints were as follows-

- To study the size effect and possibility of correlating the size effect with any established law for plain and retrofitted RC beam-column joint in term of various properties like stress, stiffness, ductility and energy dissipation etc.
- To study the change in various properties of the specimens due to retrofitting and possibility of correlating this change with size of the specimens tested.

2. Data and Material

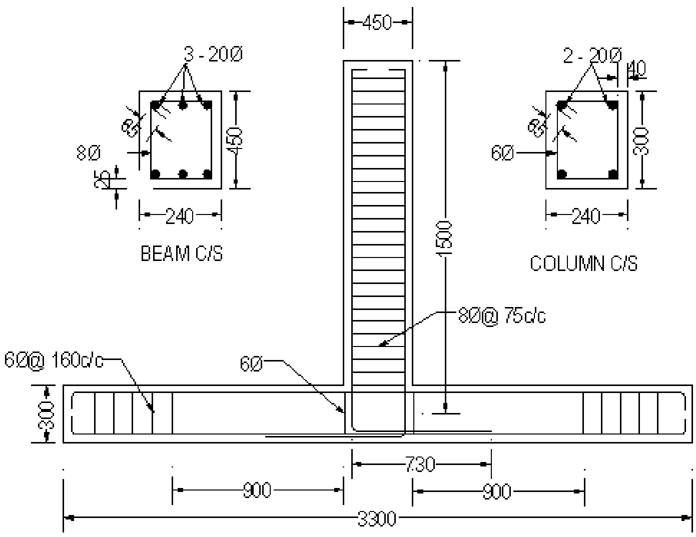
In the present study, Two types of specimens, namely, Beam-column joint with column weak in shear : control and Beam-column joint with column weak in shear : retrofitted, were considered. In each type, three geometrically similar specimens of full scaled, two third scaled and one third scaled sizes were considered. The naming of the specimens was done with five alphabets, the first three alphabets cover the deficiency type, the fourth for size and the fifth for type of specimens, which can be either control or retrofitted. For example, CWSLC stands for *column weak in shear large control* specimen, similarly CWSMR stands for *column weak in shear medium retrofitted* specimen.

2.1 Column weak in shear: control specimen

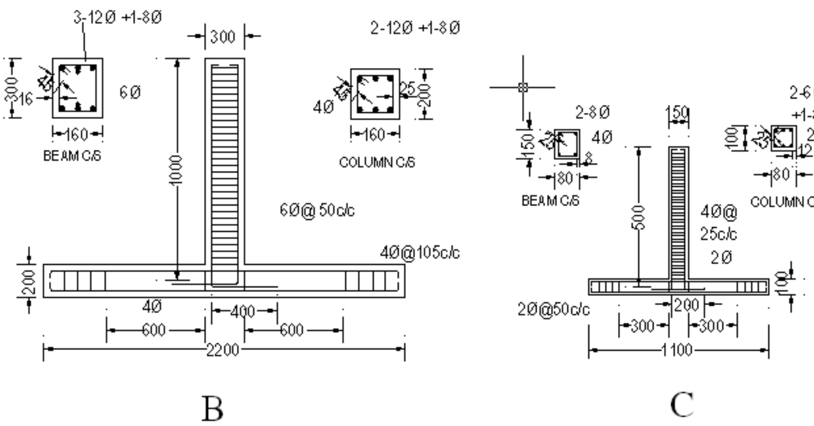
The detailed drawings for these specimens are shown in Fig.1. The cross section of the column was chosen smaller than cross section of beam to make the beam-column joint as a strong beam-weak column joint (with column weak in shear). Concrete of target strength of 25 N/mm^2 was used for casting. The main reinforcements in column were also less in comparison to that in beam. Spacing for the lateral ties in the columns were increased than relevant codal provision to ensure the shear weakness of these specimens in column. The flexural capacities of the column and beam has been calculated and the ratio of column-to-beam flexural capacity was worked out to ensure a weak-column weak-beam condition. In LC specimen, 2-legged 6 mm diameter mild steel bars with a spacing of 900 mm c/c were provided as lateral ties. To maintain a pre-defined failure location the spacing was decreased to 160 mm c/c for the remaining part of the column. For the full model, the cross section of the column was chosen as 240 mm × 300 mm and that of the beam as 300 mm × 450 mm. Four numbers of high strength deformed bars (Yield strength : 500 MPa) of 20 mm diameter in column and six numbers of 20 mm diameter in beam were used as reinforcement. In the beam, shear reinforcement of 8 mm diameter bars with spacing of 75 mm c/c were used over the entire span. Two third and one third scaled specimens were proportionately reduced in all the three dimensions. The diameters of the reinforcing bars were also scaled down.

2.2 Column weak in shear: retrofitted specimen

The retrofitting schedule for these specimens has been furnished in Fig. 2. In order to strengthen the column weak in shear : control specimens, the retrofitting in the column were done using GFRP. In CWSLR specimen, three numbers of strips each with one layer of GFRP having width of 90 mm was wrapped around both sides of the joint with spacing 360 mm c/c (type B). Geometric similarity was maintained for two scaled models. This scheme of retrofitting enhanced the shear capacity of the column making it higher than the flexural capacity. Hence at this level the column was expected to fail at the flexural capacity of the control specimen, resulting a slight increment in the overall capacity. Hence, flexural retrofitting was also carried out to achieve an appreciable increase in capacity of the specimen. The flexural strengthening was carried out in column by providing CFRP. One layer of CFRP of width 240 mm was fixed on column at either side of the joint over 450 mm length for the specimen CWSLR (type A). The joint was also adequately strengthened with one layer of GFRP (type C). Geometrical similarity was strictly maintained for other two scaled down models during retrofitting.



A

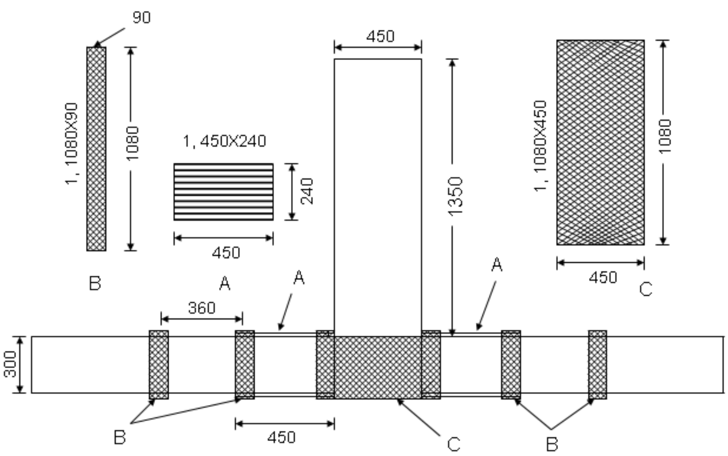


A- CWSLC; B-CWSMC; C-CWSSC

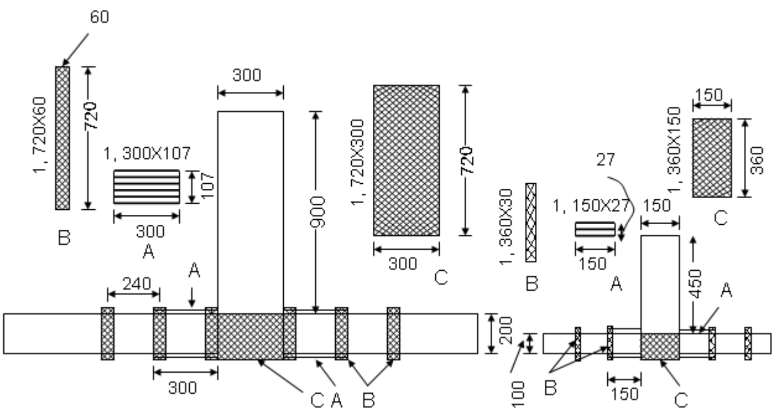
Fig. 1 Detailing of column weak in shear : control specimens

3. Research Methodology

A constant axial load on the column was maintained by hydraulic jack during testing to simulate gravity loading. An "A" frame was fabricated to facilitate the application of axial load. During testing, the column was placed in horizontal position while the beam was placed in vertical position. The actuator with capacity of 250 kN was used for large and medium specimens, while the actuator of 100 kN capacity was used for small specimens. In the experimental investigations, cyclic load was applied to all the specimens with the help of hydraulic actuators. Displacement controlled loading system with a frequency of 0.025Hz. was adopted and was applied to all the specimens till failure. Displacement amplitudes were scaled down to two-third and one-third magnitude of that of full scaled models for two-third and one-third models respectively. Fig. 3(a) and Fig. 3(b) show the view of a typical specimen at the starting and at the end of testing respectively.



P



Q R

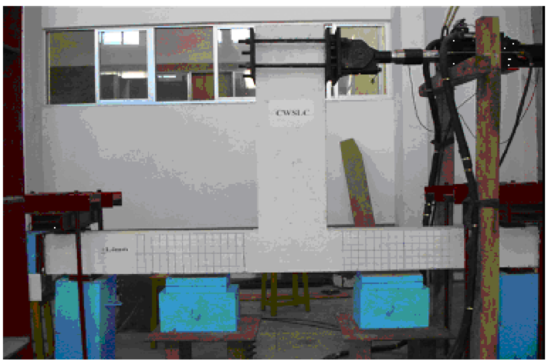
P-CWSLR specimen, Q-CWSMR specimen, R-CWSSR specimen

Fig. 2 Detailing of column weak in shear : retrofitted specimens

4. Results and Analysis

The recorded data were plotted to find hysteretic response, envelope curve, energy dissipation etc. Comparisons of results were made between control and retrofitted specimens in term of all the above-mentioned properties and conclusions were drawn regarding the benefit derived out of retrofitting. One of the hysteretic loops for a typical control specimen as well as for the corresponding retrofitted specimen it is shown in Fig. 4.

From the envelope curves the ultimate load carrying capacity of all the specimens were found out. The percentage gains in ultimate load carrying capacity due to retrofitting for all the tested specimens were calculated and presented in Fig. 5. This Figure shows that the percentage gains in ultimate load carrying capacity due to retrofitting increases as the specimen size decreases, supporting the existence of size effect.



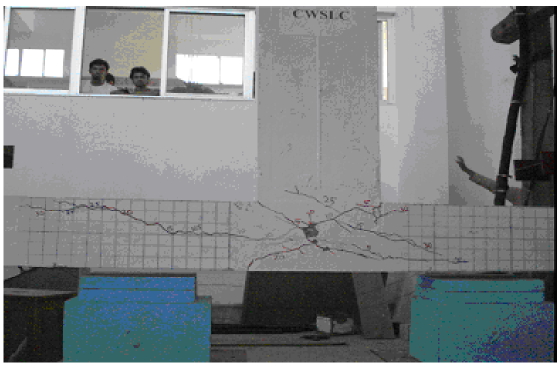
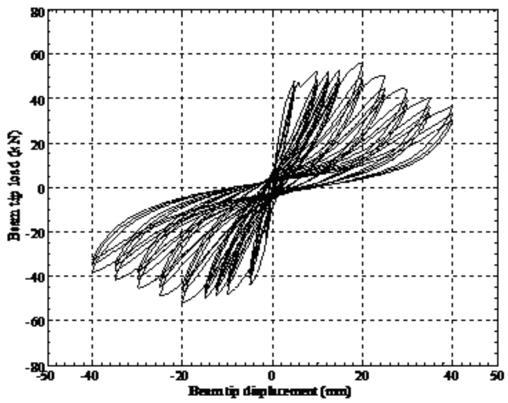
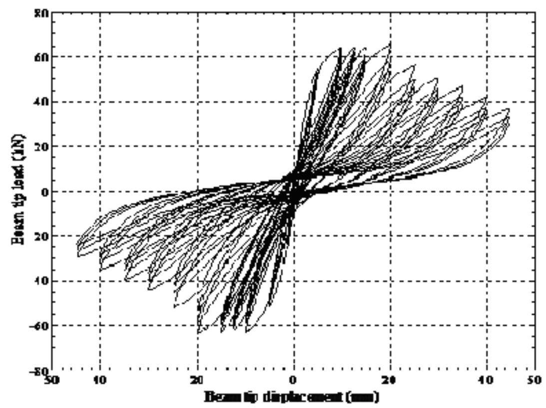


Fig. 3(a) Typical specimen at starting Fig. 3(b) Typical specimen at end of test

The ability of a structural element to resist an earthquake depends to a large extent on its capacity to dissipate the energy. The plot of energy dissipation versus drift angle for typical control and corresponding retrofitted specimens reflects that the cumulative energy dissipated by retrofitted specimen is always higher than that of control specimen. The gain in cumulative energy dissipation due to retrofitting was calculated for all the cases and was found in accordance with size effect principle.





4. (a) Hysteretic response for BWFLC 4(b) Hysteretic response for BWFLR

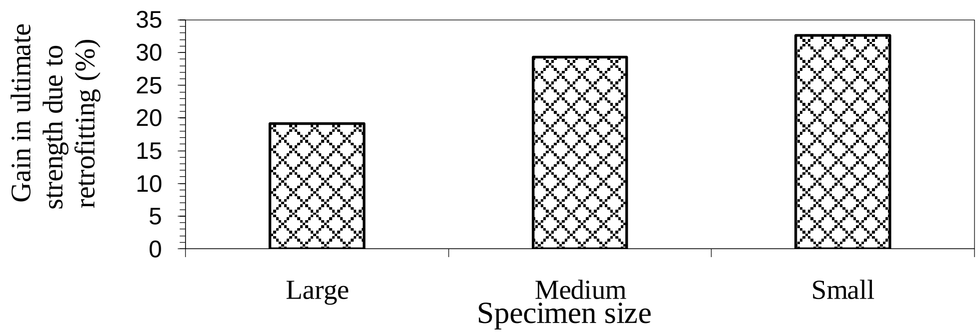


Fig 5: Percentage gain in ultimate load carrying capacity due to retrofitting

Failure shear stress denoted by σ_N, for all the specimens were calculated and bi-logarithmic plots were drawn for both control and retrofitted specimens. For the purpose of statistical regression of data, the size effect law proposed by Bazˇant and Planas (1998) was used. Bazˇant's law can be expressed as $\sigma_N = \dfrac{Bf_t^{/}}{\sqrt{1+D/D_0}}$. The unknown constants *B* and D_0 were determined by statistical regression analysis. Bi-logarithmic plot was drawn with Log (*D/D₀*) in the X axis and $Log(\sigma_N / Bf_t^{/})$ in the Y axis. The various parameters needed for plotting bi-logarithmic graph is shown in table 1. The bi-logarithmic plot of control specimens is shown in Fig. 6. It is observed from the graph it shows presence of significant size effect and it supports closely Bazˇant's size effect law. The retrofitted specimens also show the similar trend of graph.

Type of specimen	Name of specimen	Shear stress, σ_N (N/mm^2)	Depth of specimen, D (mm)	$\left(\frac{f_t^/}{\sigma_N}\right)^2$	Log (D/Do)	$Log(\sigma_N / Bf_t^/)$
control	CWSSC	0.662	100	11.96616	0.243668	-0.24227
	CWSMC	0.628	200	13.29694	0.544698	-0.26517
	CWSLC	0.458	300	25.0000	0.720789	-0.40226
Retrofitted	CWSSR	0.878	100	6.80271	-0.0593	-0.15512
	CWSMR	0.811	200	7.973138	0.241732	-0.1896
	CWSLR	0.545	300	12.60525	0.417823	-0.28906

Table 1 Parameters for plotting bi-logarithmic graph

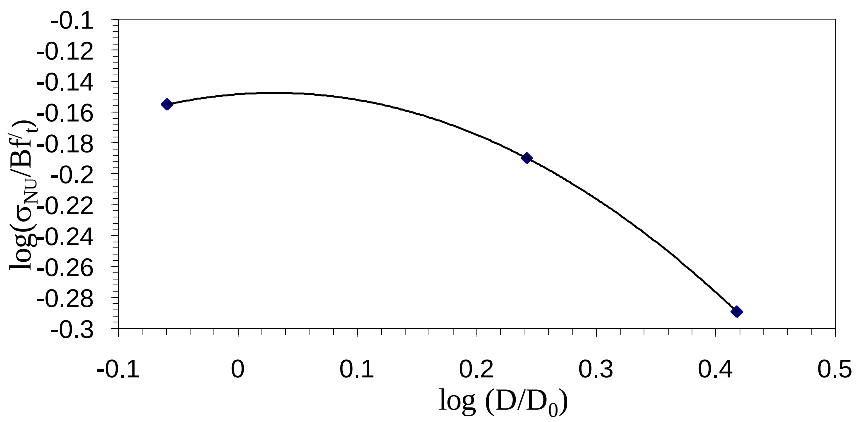


Fig 6: Bi-logarithmic plot for control specimens

To compare the energy dissipation of specimens having different sizes of beam-column joint, a new parameter, viz. energy dissipation per unit volume (e_N) was introduced. e_N was correlated with the size of the specimen at different drift angles and accordingly graphs were plotted between e_N versus drift angle for different sizes of specimens. Both retrofitted as well as control specimen were considered for plotting the graph. It has been observed from both the plots that the uppermost curve is for the smallest specimen, middle curve corresponding to the medium size specimen and lowermost curve for the largest specimen. The plot for control specimens also follows the same trend. This is an indication for the existence of size effect.

5. Conclusions

In this paper, the results of beam column joints with column weak in shear and corresponding retrofitted specimens were tested and interpreted for various parameters. Total six specimens, covering both control and retrofitted of geometrically similar sizes were tested. Hysteretic responses for all the specimens were plotted. Various graphs like envelope curve, cumulative energy dissipation curve were drawn to study the relative improvement in various properties due to retrofitting with respect to size of specimens. The plotted graphs shows that, all the above mentioned properties got improved due to retrofitting supporting the existence of size effect. The gain in capacity due to retrofitting is minimum for the largest specimen and maximum for the smallest specimen; which proves the existence of size effect. The gain in cumulative energy due to retrofitting also follows the same trend.

The results were plotted in bi-logarithmic form and cumulative energy dissipation per unit volume of joint (a newly coined parameter). The plotted graphs show the bi-logarithmic plot for both control and retrofitted specimens follows the size effect law proposed by Bazˇant. The cumulative energy per unit volume of the joint at every drift angle for small specimen is the maximum and it decreases as the specimen size increases. I.e. the energy dissipation capacity of beam column joint per unit volume of joint increases as the specimen size decreases for both the cases. This is an indication for existence of size effect.

Based on the interpretation of various graphs the following conclusions can be drawn –

1. The bi-logarithmic plot for both control and retrofitted specimens follows the size effect law proposed by Bazˇant.
2. The gain in strength due to retrofitting increases considerably supporting the existence of size effect.
3. There was remarkable enhancement in cumulative energy dissipation for all specimens due to for retrofitting.
4. The cumulative energy per unit volume of the joint at every drift angle indicates the existence of size effect.

References

Coc, V., & Sener, S. (2009). Size effect in normal- and high-strength concrete with different notches under the axial load. *ASCE, J of materials in civil Engineering.,* 21(9), 433-445.

Gergely, J., Pantelides, C.P., & Reaveley, L.D. (2000). Shear Strengthening of RCT-Joints Using CFRP Composites. *Journal of Composites for Construction*. 4(2), 56-64.

Ghobarah, A., & Said, A. (2002). Shear Strengthening of Beam-Column Joints. *Elsevier, Engineering Structures*. 24(7), 881-888.

Ghobarah, A., & El-Amoury, T. (2005). Seismic Rehabilitation of Deficient Exterior Concrete Frame Joints. *ASCE, Journal of composites for construction*. 9(5), 408-416.

IS 13920 (1993). *Ductile detailing of reinforced concrete structures subjected to seismic forces- Code of Practice*. Bureau of Indian Standard, New Delhi.

Jain, S.K., & Murty, C.V.R. (2006). *Proposed draft provision and commentary on ductile detailing of RC structures subjected to seismic forces*. Document No. :: IITK-GSDMA-EQ11-V-3.0 :: IITK-GSDMA-EQ16-V2.0.

Leung, C., Chen, Z., Lee, S., Ng, M., Xu, M., & Tang, J. (2007). Effect of Size on the Failure of Geometrically Similar Concrete Beams Strengthened in Shear with FRP Strips. *ASCE, Journal of composites for construction.* 11(5), 487-496.

Li, B., & Chua, H.Y.G, (2009). Seismic performance of strengthened reinforced concrete beam-column joints using FRP composites. *ASCE, J of structural engineering*. 135(10), 1177-1190.

Mahini, S.S., & Ronagh, H.R. (2010). Strength and ductility of FRP web-bonded RC beams for the assessment of retrofitted beam-column joints. *Composite Structures.,* 92(6), 1325-1332

Mosallam, A.S. (2000). Strength and Ductility of Reinforced Concrete Moment Frame Connections Strengthened with Quasi-Isotropic Laminates. *Composites Part B-Engineering*. 31(6-7), 481-497.

Mukherjee, A., & Joshi, M. (2005). FRPC reinforced concrete beam-column joints under cyclic excitation. *Composite structures*. 70, 185-199.

Paulay, T. (1989). Equilibrium Criteria for Reinforced-Concrete Beam-Column Joints. *ACI Structural Journal*. 86(6), 635-643.

Sener, S., Begimgil, M., & Belgin, C. (2002). Size effect on failure of concrete beam with and without fibre. *ASCE, J of materials in civil Engrg*. 14(5), 436-440.

Sener, S., Barr, B.I.G., & Abusiaf, H.F (2004). Size effect in axially loaded reinforced column. *ASCE, J structural Engrg*. 130(4), 662-670.

Bazˇant, Z.P., & Planas, J. (1998). *Fracture and size effect in concrete and other quasibrittle materials*. CRC Press, Boca Raton: Fla,