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Seismic Performance of Ground Granulated Blast Furnace Slag Reinforced Concrete Beam-Columns

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Abstract: **Cement is a very energy intensive material and its manufacture releases large volumes of carbon dioxide into the atmosphere. Sustainable development focuses on the reducing consumption of energy, carbon emissions and utilization of waste materials. Blast Furnace Slag is a waste product in the steel industry whose disposal is a major concern for the steel industry. Ground granulated blast furnace slag (GGBS) is obtained by cooling the blast furnace slag and grinding it. GGBS contributes to the strength development of concrete and can replace a considerable percentage of cement. Utilizing GGBS as replacement cement solves the problems of both cement and steel industry. This paper investigates the suitability of GGBS as a replacement to cement in seismic areas. It presents the experimental study performed on reinforced concrete six beam-columns with 40% GGBS as a replacement for cement. The beam-columns were subjected to a constant axial load and reversed lateral loads and tested on the 28th and 56th day. The investigations revealed that reinforced concrete beam-columns with GGBS exhibit almost similar behaviour as the control specimens in terms of load resisting capacity, ductility and energy absorption capacity. This suggests that GGBS can be used as a replacement to cement even in seismic regions.**

Index Terms- **GGBS, slag concrete, cyclic behaviour, beam-column, lateral loads, hysteresis, energy absorption.**

I. INTRODUCTION

Cement manufacture is very energy intensive and it releases one tonne of carbon dioxide into the atmosphere for every tonne of cement produced. Cement industry is responsible for 6% of all man-made carbon emissions, so immediate efforts have to be taken by the construction industry to reduce the consumption of cement by finding alternatives to cement. This will reduce the carbon imprint and lead to sustainable development of the construction industry.

Emission reduction is feasible by using locally available materials that are generated as wastes in industry and agriculture. They should to be pozzolonic in nature and suitable for usage as replacement to cement. Fly ash, Blast furnace slag rice husk ash etc are three well known examples of waste materials that are ideal for replacing cement.The behavior of structures when new materials are used as replacement to cement has to be studied in detail through experimental investigations and the results should be validated.

Blast furnace slag is obtained as the major waste product during smelting of iron, its disposal is raising environmental concerns. When blast furnace slag is quenched in water forms granules, these granules when ground results in Ground Granulated Blast furnace slag (GGBS). GGBS is very close to cement in chemical composition and can replace up to 50 percent cement. Several researchers have studied the feasibility of GGBS as a replacement to cement and established that it improves strength and durability of the concrete.

II .LITERATURE SURVEY

Karim et al. [1] suggested that cement manufacture emits huge volumes of CO_2 into the atmosphere and hence it has to be replaced as much as possible by various supplementary cementitious materials like fly ash, GGBS, bottom ash etc.

Vejmelková et al. [2] referred to studies done by Bijen [3], Aldea et al. [4], Atis et al. [5] and reported that GGBS is a waste product in blast furnace. Utilising GGBS as a replacement for cement is an excellent initiative to reduce carbon emission and to obtain sustainable concrete. GGBS can be used as a supplementary cementitious material, by replacing cement up to 60% as it increases workability, improves strength, reduces heat of hydration, permeability, porosity, etc.

Pal et al. [6] concluded that products of hydration of GGBS are denser than Ordinary Portland Cement (OPC). Cheng et al. [7] explained that GGBS concrete exhibits higher resistance to corrosion.

Oner and Akyuz [8] established that strength contribution of GGBS increases with age and the optimum dosage of GGBS is around 55%. Johari et al. [9] concluded that when tested between 28 days and 90 days GGBS concrete mixes exhibit almost same strength as control concrete.

Shariq et al. [10] found that 40% cement replacement is the optimum percentage for GGBs concrete tested at 56 days. Investigations by Gu and Liu [11] reveal that the flexural fatigue performance of GGBS concrete with 50% replacement level is better than that of control concrete. Several studies have concentrated on the influence of GGBS, on properties like, workability, durability, compressive and flexural strength of concrete. Volumes of literature are available on the durability studies of GGBS concrete, however research on the structural behaviour of GGBS concrete is scanty.

In the present study 40% of the cement was replaced with GGBS and Glenium B-233 was used as superplasticiser. Four beam-columns with GGBS and two without were cast and tested on the 28th and 56th day. The experiments were carried out to explore the seismic performance of GGBS concrete beam-columns subjected to reversed lateral loads. Their performance is presented in terms of hysteresis curves, ductility and energy absorption capacity.

III. EXPERIMENTAL INVESTIGATION

In this experimental programme, tests were conducted on six reinforced concrete beam-columns with and without GGBS to determine their seismic loads when subjected to reversed lateral loads.

A. Materials and mix design

In the present investigation, Ordinary Portland Cement (53Grade) and Glenium B1-233 (BASF) superplasticiser were used. Glenium B1-233 is a commercial high range water reducing agent suitable for GGBS concrete. It is free of chloride and has low alkali. It is compatible with all types of cements. The concrete beam-columns were cast using water binder ratio of 0.40 and 0.7% of Glenium B1-233 superplasticiser. M40 grade of concrete was designed as per the Indian Standard 10262-2009 and the mix ratios are provided in Table 1. Fe 415 grade steel was used for the stirrups and longitudinal rebars.

B. Specimen details

Six beam-column specimens were tested, out of which two were control specimens and four specimens were with 40% GGBS as replacement for cement. The height of the column was 1000 mm with a cross section of 150 mm x150 mm. The beam was of span 1500 mm with a cross section of 150 mm x 200 mm. The specimens were designed based on the Indian Standard 456-2000 and detailed as per Indian Standard 13920-1993.Two control and two GGBS specimens were tested after curing for 28 days and two GGBS specimens were tested after 56 days of curing in the laboratory. The dimensions and reinforcement details of the specimens are illustrated in Fig. 1 and the details of the specimens tested are given in Table 2.

Table 1: Mix Ratios

Concrete Strength	Replacement %	Unit Mass kg/m^3					
		w/c	C	GGBS	F.A	C.A	Water
M40	0	0.4	416.64	0	677.066	1221.44	166.656
M40	40	0.4	249.98	166.5	677.066	1221.44	166.656

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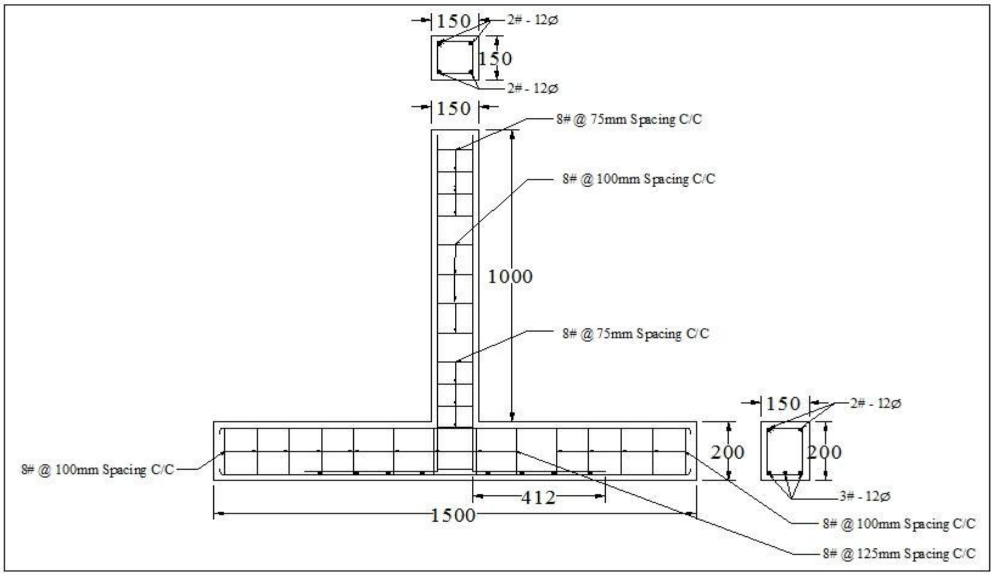

Figure 1. Reinforcement details of beam-column specimens

Table 2: Specimen Details

Sl. No.	Description of Beam-column number	Testing of Beam-columns (days)	Reinforcement in beams			Reinforcement in columns	
			Nos. and size at top	Nos. and size at bottom	Diameter (mm)	Nos. and size at top	Diameter (mm)
1	BC0%-1-28	28	2#10	3#12	8	4#12	8
2	BC0%-2-28		2#10	3#12	8	4#12	8
3	BC40%-1-28		2#10	3#12	8	4#12	8
4	BC40%-2-28		2#10	3#12	8	4#12	8
5	BC40%-1-56	56	2#10	3#12	8	4#12	8
6	BC40%- 2-56		2#10	3#12	8	4#12	8

BC0%- control beam-column specimens BC40%- 40 % GGBS beam-column specimens

IV. EXPERIMENTAL SETUP

The test set-up consist of a reaction frame, a hydraulic actuator of capacity 200 kN with a stroke length of ± 100mm and a loading frame with hydraulic jack of 200 kN to apply axial compressive loads to the test specimens. A 200 kN actuator was used to apply reversed lateral load on the specimens. Linear voltage displacement transducers actuator was used for the measurement of reversed cyclic loads. LVDT was connected to a data logger from which the displacements were captured in a computer at every load intervals until the specimens failed. Also, a load cell recorded the reversed lateral loads. A loading frame was used to apply a vertical constant axial load was applied through steel rollers placed with the support of steel plates in between the jack and the column head. The vertical load was chosen to a design compression rate of 20% axial resistance found in the analysis. The experimental set-up is shown in Fig. 2.

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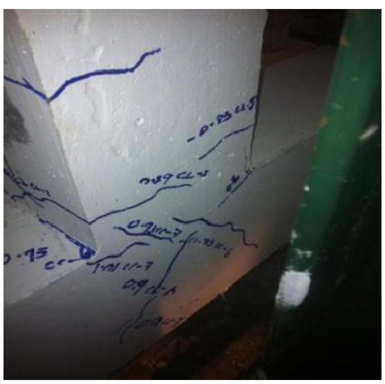
Figure 2. Experimental Setup

V. BEHAVIOUR OF THE SPECIMENS

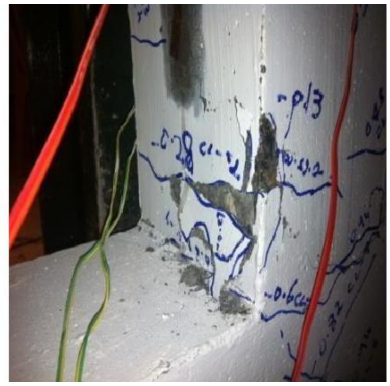
A. General Observations and Failure Patterns

The initial crack loads were noted. As the lateral load was increased gradually, more and more cracks appeared at the junction of the beam and column. With further increase in load the cracks already present increased in length and width. As the number of cycles increased the cracks progressed and finally resulted in spalling of concrete. Cracks formed after each cycle was marked. Figure 3 gives the failure patterns in the beam-column specimens.

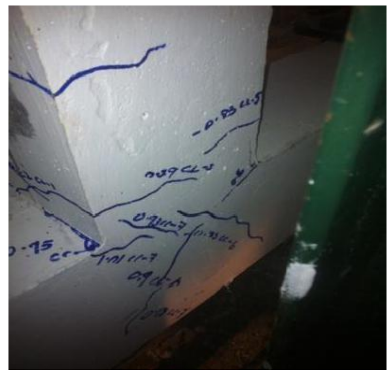


a. BC0%- 1-28

b. BC0%- 2-28



c. BC40%- 1-28



d. BC40%- 2-28

e. BC40% 1-56

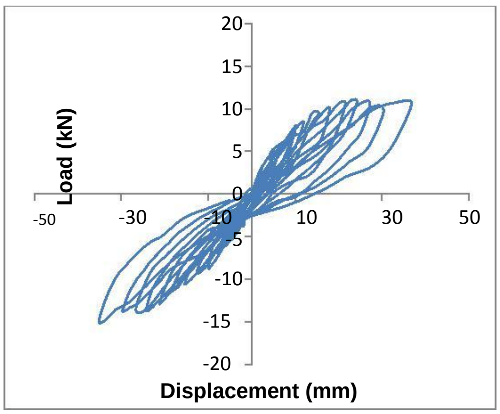
f. BC40%- 2-56

Figure 3. Failure Patterns in beam-column specimens subjected to reversed lateral loads

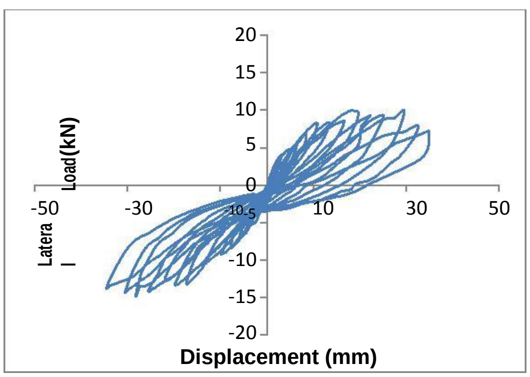
VI. RESULTS AND DISCUSSIONS

A. Hysteresis Curves

The hysteretic behaviour of structure when subjected to reversed lateral loads predicts the behaviour of the structure when subjected to earthquakes. The hysteresis curves were plotted for the variation of lateral displacement with that of the lateral load for all the specimens. The experimental hysteresis curves plotted for the beam-column specimens with and without GGBS tested on the 28th day and GGBS specimens tested on the 56th day are shown in Figure 4, Figure 5 and Figure 6 respectively.

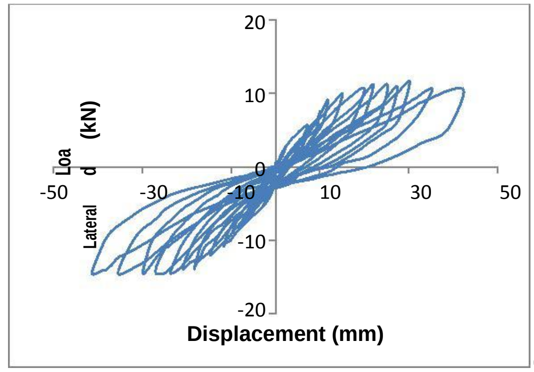


(a) BC0%- 1-28

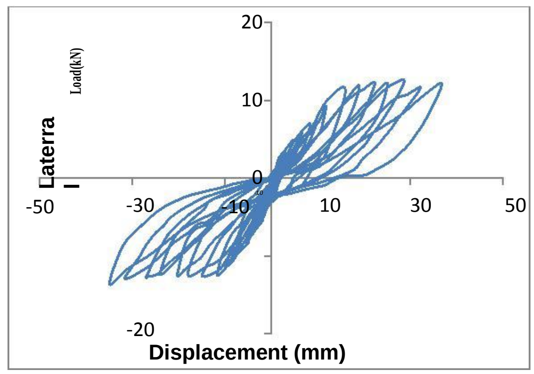


(b) BC0%- 2-28

Figure 4. Hysteresis curves for control beam-columns tested on the 28th day

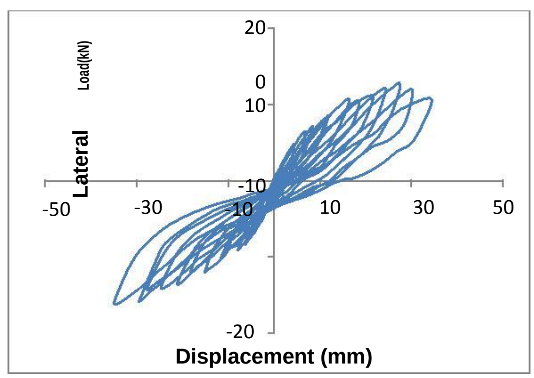


(a) BC40%- 1-28



(b) BC40%- 2-28

Figure 5. Hysteresis curves for GGBS beam-columns tested on the 28th day



(a) BC40%-1-56

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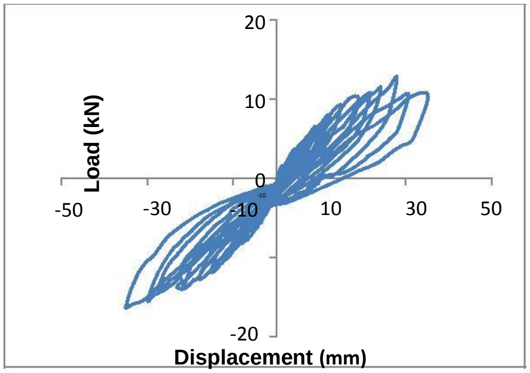

(b) BC40%- 2-56

Figure 6. Hysteresis curves for GGBS beam-columns tested on the 56th day

B. Strength Capacity of the Specimens

The envelope curves of the peak load-displacement for all the beam-column specimens tested on the 28th and 56th day are represented in Figure 7 and Figure 8. The average ultimate loads for the specimens without and with 40 % GGBS are 14.65 kN and 14.55 kN respectively on the 28th day and 16.1 kN for GGBS specimen tested on the 56th day. The average ultimate load of the GGBS specimens on the 56th day is 10% greater than the specimens tested on the 28th day.

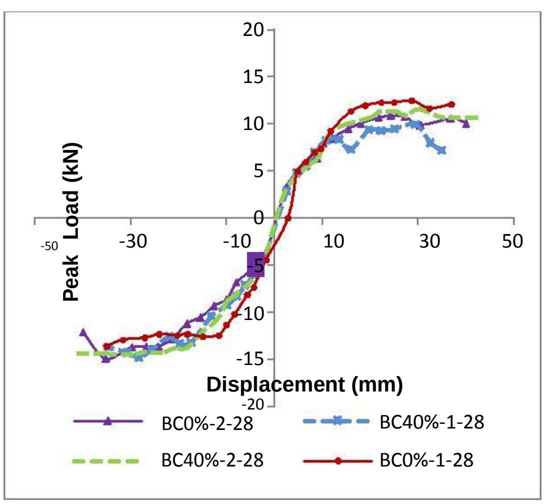

Figure 7. Peak load-displacement curves of specimens on the 28th day

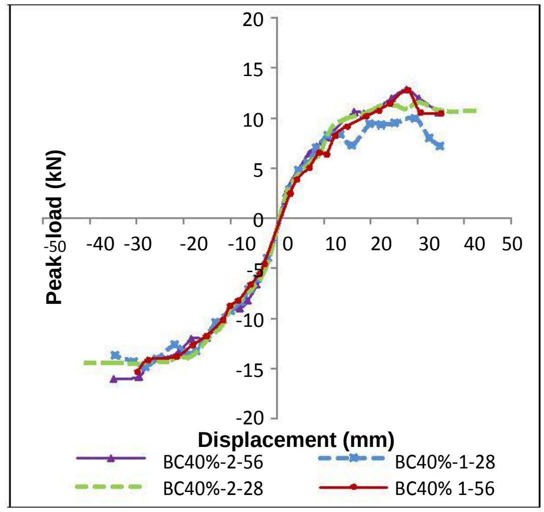

Figure 8. Peak load-displacement curves of the GGBS specimens

C. Stiffness Degradation

Secant stiffness of the specimens is an index of the response of the beam column specimen from one cycle to the succeeding cycle. It is the slope of the line joining the maximum positive displacement and maximum negative displacement of a single load displacement cycle. The stiffness degradation in the concrete is due to the opening and closing of cracks and the slipping of bars at the anchorage zone, when the specimen is subjected to repeated lateral loads.

Figure 9 illustrates the stiffness degradation of control and GGBS specimens on the 28th day. Figure 10 compares the stiffness degradation of the GGBS specimens on the 28th and 56th day of testing. The plot shows that the stiffness degradation is almost the same for both control and GGBS specimens on the 28 day. It was observed that the stiffness of the GGBS specimens is slightly higher than the control specimens.

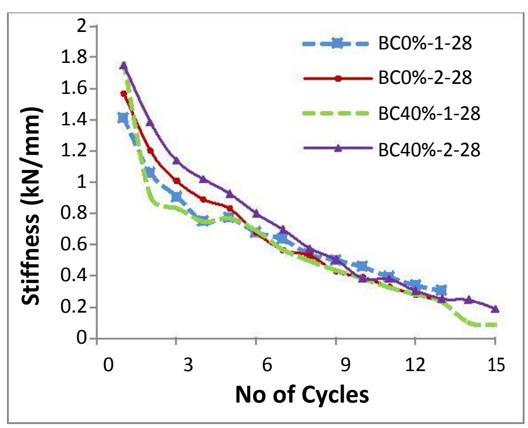

Figure 9. Stiffness Degradation curve of beam-column specimens on the 28th day

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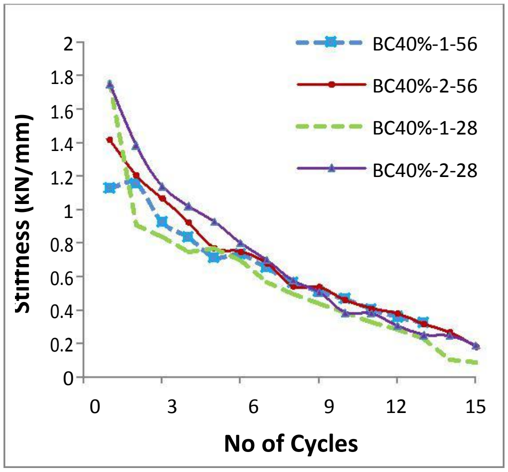

Figure 10. Stiffness Degradation curve of GGBS beam-column specimens

D. Ductility of the Beam-Columns

Ductility is the ability of a structure to undergo large deformations without losing its strength.

Ductility of the beam-column specimen is design as the structure has to deform in a ductile manner expressed in terms of ductility factor. Ductile behaviour is very essential in earthquake resistant when subjected to lateral loads. Displacement ductility is considered as the ratio of ultimate displacement to that of the yield displacement. The ultimate displacement and yield displacement were obtained from peak lateral load versus lateral displacement curves. Table 3 shows the yield displacement and ultimate displacement of the test specimens. The displacement in the positive side was considered as upward displacement and on the negative side was considered as downward displacement. The average ductility ratio obtained for the various beam-column specimens ranges from 3 to 6. Displacement ductility in the range of 3 to 6 is adequate for structural members subjected to large displacements caused by sudden forces like earthquake according to the literature available (Ashour, S.A. (2000) and Ma, H. et al (2013)). More information can be found in Agarwal, P. and Shrikande, M. (2006).

Table 3: Ductility of Test Specimens

Specimen Series	Lateral Displacement (mm)				Displacement Ductility Ratio		Average Ductility Ratio
	Yield		Ultimate		Upward direction	Downward direction	
	Upward direction	Downward direction	Upward direction	Downward direction			
BC0%-1-28	8	6.5	24.2	29.8	3.025	4.585	3.8
BC0%-2-28	6.25	6.25	29.4	28.3	4.704	4.528	4.6
BC40%-1-28	5.25	5	30.2	29.9	5.752	5.98	5.9
BC40%-2-28	7	7.5	28.6	35.1	4.086	4.68	4.4
BC40%-1-56	9	8	27.9	30	3.1	3.75	3.4
BC40%- 2-56	8	8	27.5	35.1	3.438	4.388	3.9

E. Energy Absorption

The seismic performance of a structure is the ability of the structure to absorb the seismic energy released during the ground motion. The energy absorbed by the structure is estimated as the area enclosed by the hysteresis loop when the structure is subjected to lateral loads. In the present Investigation the beam-columns with and without GGBS were subjected to reversed lateral loads and the hysteresis loops were plotted, the energy absorbed in each cycle was estimated. Figure 11 and Figure 12 show the extent of the energy absorbed at different displacement levels.

It was observed from the plot that the energy absorption capacity of the GGBS beam-columns tested on the 56th day was slightly higher than the energy absorption capacity on the 28th day specimens. This establishes the fact that beam-columns with GGBS as a partial replacement for cement have good seismic performance and they can be recommended in earthquake prone areas also.

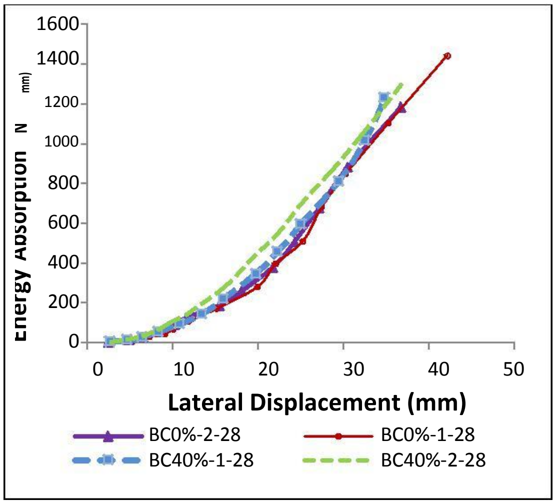

Figure11. Energy absorption curves of the beam-column specimens on the 28th day

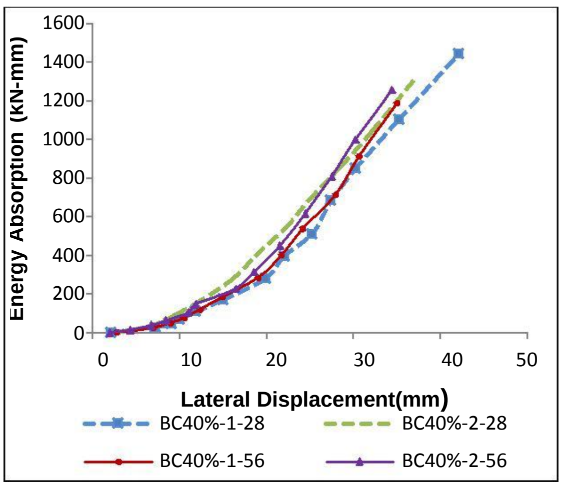

Figure 12. Energy absorption curves of GGBS beam-column specimens

VII. CONCLUSIONS

In this paper an effort was made to compare the seismic performance of RC beam-columns with 40% GGBS as replacement for cement with Ordinary Portland Cement RC beam-columns. Six beam-column specimens were cast and tested on the 28th and 56th day. Based on the experimental investigations the following conclusions are arrived at:

- All the beam-columns developed similar failure patterns under the lateral loads irrespective of the presence of GGBS.
- The hysteresis curves and stiffness degradation patterns of the GGBS concrete beam-columns were comparable to the control specimens. This implies that properly designed and detailed GGBS concrete beam-columns have adequate seismic performance.
- The Lateral load carried by GGBS specimens on the 56th day was adequate. Energy absorption capacity of the GGBS specimens was found to be ample.
- The ductility ratios of the beam column specimens were in the range of 3 to 6. This suggests that the GGBS concrete beam-columns are capable of resisting earthquake if they are properly designed and detailed. Therefore, GGBS can replace cement up to 40% in earthquake prone regions

From the present investigation it can be concluded that with proper design and detailing RC beam-columns with 40% GGBS can exhibit good seismic performance with adequate load resisting capacity, ductility and energy absorption capacity. Usage of GGBS will increase the sustainability of the structures while reducing the carbon emissions and providing buildings with sufficient seismic performance.

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