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Seismic Investigation of Self-Compacting Concrete Beam – Column Joint

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Abstract: The construction activities in the last few decades have increased many folds in almost all the developing countries of the world. Cement is becoming a scarce commodity globally because of its growing demand day by day. It is the need of time to search such alternative waste materials that would partially or fully replace cement and sand used in concretes without affecting its quality, strength and other characteristics. In order to reduce time and to improve the filling capacity of highly congested structural members by its own weight without any vibration self-compacting concrete (SCC) is adopted. The primary aim of this study is to explore the feasibility of SCC using Ground Granulated Blast furnace Slag (GGBS) and foundry sand as a replacement for cement and fine aggregate respectively. Here Portland cement is replaced by 10%, 15% and 20% by GGBS and fine aggregate is replaced by 10%, 15% and 20% by foundry sand in combinations. The w/p ratio is kept constant throughout the investigation as 0.40. Super plasticizer known as Conplast SP430 is used. Since there is no standard method of mix design available for SCC hence the mix proportion is obtained as per the guidelines given by European Federation of producers and contractors of special products for structure (EFNARC). This paper presents an experimental investigation on strength aspects like compressive and split tensile strength and the workability tests. The compressive strength and split tensile strength of the cubes and cylinders at 7 days, 28 days are obtained and it was found that the mix having 10% replacement of cement with 20% replacement of foundry sand gives the best results. Furthermore to investigate on this topic the beam column joint is the crucial zone in a reinforced concrete when it comes to seismic load. It is subjected to large forces during severe ground shaking and its behaviour has a significant influence on the response of the structure. The assumption the of joint being rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions. This offers a unique area of application of self-compacting concrete which can flow through every corner of extensively reinforced area without any vibration and more effective for seismic load. So for this reason SCC with the optimum replacement percentage which has been arrived is cast into two reinforced concrete beam column joints and tested for seismic loading.

Keywords: *Self Compacting concrete, Material Properties, Fresh Concrete Properties, Hardened Concrete Properties, GGBS and Foundry sand, beam-column joint.*

1. Introduction

Present-day self-compacting concrete can be classified as an advanced construction material. As the name suggests, it does not require to be vibrated to achieve full compaction. This offers many benefits and advantages over conventional concrete. These include an improved quality of concrete and reduction of on-site repairs, faster construction times, lower overall costs, facilitation of introduction of automation into concrete construction. An important improvement of health and safety is also achieved through elimination of handling of vibrators and a substantial reduction of environmental noise loading on and around a site. The composition of SCC mixes includes substantial proportions of fine-grained inorganic materials and this gives possibilities for utilization of mineral admixtures, which are currently waste products with no practical applications. Mineral admixtures such as GGBS and Foundry sand are used as a replacement for cement and fine aggregate respectively. In this paper, different replacement percentages of GGBS and foundry sand are comparing and then the optimum combination is arrived.

2. Literature Review

Concrete is a mixture of Cement, fine aggregate, coarse aggregate, water and also sometimes with the addition of chemical and mineral admixture. Due to increase in construction now a day the demand of concrete is increasing and at a certain point of time the availability of cement and other constituents of concrete might be exhausted. This can be reduced by the use of waste materials (or) by-product from the industries as a replacement material which will not affect the concrete properties. Past research have concluded that the use of GGBS and foundry sand increases the mechanical properties of concrete and also by addition of these materials in Self Compacting Concrete the properties won't change much. In [1,2,3] the cement is replaced with GGBS by a maximum of 40% and it has shown that the addition of GGBS increases the and strength parameter of the Self-Compacting Concrete. From [4,5,6] fine aggregate is replaced with foundry sand up to 15%. It has been found out that with an increase in replacement percentage of fine aggregate with foundry sand the compressive strength and split tensile strength increases. To maintain the same replacement percentage for cement and fine aggregate the replacement percentages are kept as 10%, 15% and 20%. The replacement percentages are kept within 30% so that we can achieve best results as much as possible. To make a more extensive study on this topic based on [10,11,12] it is found out that the use of SCC in beam column joints satisfies the minimum required result or sometimes gives even better results when compared to the usage of normal concrete in beam column joints when it is under seismic loading. Hence the optimum replacement percentage is incorporated into the beam column joint to achieve the best result.

3. Material Properties

The properties of materials used in the concrete are discussed below:

3.1. Cement

Ordinary Portland cement of 43 grades available in local market was used. The physical properties are given in table Table 1.

Table 1.*Physical Properties of Cement*

S.No.	Physical Properties	Values
1.	Specific gravity	3.14

3.2. Fine Aggregate

Natural fine aggregate available from locally available market is used. [7] The sand which is sieved through 4.75 mm sieve is used. The physical properties are given in Table 2.

Table 2.*Physical Properties of Fine aggregate*

S.No.	Physical Properties	Values
1.	Specific gravity	2.6

3.3. Coarse Aggregate

Locally available coarse aggregate is used. The physical properties are given in Table 3.

Table 3.*Physical Properties of Coarse aggregate*

S.No.	Physical Properties	Values
1.	Size	10-12.5 mm
2.	Specific Gravity	2.67.

3.4. GGBS

GGBS is used as a replacement for cement. The physical properties are given in Table 4.

Table 4.*Physical Properties of GGBS*

S.No.	Physical Properties	Values
1.	Colour	Grey
2.	Specific Gravity	2.58.

3.5. Foundry sand

Foundry sand is used as a replacement for fine aggregate. The physical properties are given in Table 5.

Table 5.*Physical Properties of Foundry sand*

S.No.	Physical Properties	Values
1.	Colour	Grey
2.	Specific Gravity	2.58.

3.6. Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Potable water available in the laboratory was used.

3.7. Super plasticizer

Sulphonated Napthalene Formaldehyde based super plasticizer was used with the brand name Fosroc Conplast SP430 DSI. Dosage of super plasticizer is 1% of cementations material. The specific gravity of super plasticizer is 1.145. It is a dark brown liquid

3.8. Mix Proportion

The mix composition is chosen to satisfy all performance criteria for the concrete in both fresh and hardened state. There is no standard method for SCC mix design and many academic institutions, admixture, ready – mixed, precast and contracting companies have developed their own mix proportioning methods. However, to obtain the required properties of fresh concrete in SCC, a higher proportion of ultrafine materials and the incorporation of chemical admixture are necessary. The components shall be coordinated one by one so that segregation, bleeding and sedimentation are prevented. A rational mix design process should be used, to reduce the number or trial tests in laboratory.

Based [8] on the EFNARC guidelines mix proportion for M_{30} grade is achieved. The following Table 6 gives information about EFNARC guidelines.

Table 6.*Typical ranges of SCC suggested by EFNARC*

Constituent	Typical ranges by mass (kg/m^3)	Typical ranges by litre (lit/m^3)
Powder	380-600	
Paste		300-380
Water	150-210	150-210
Coarse aggregate	750-1000	270-360

Fine aggregate	Constituents balance the volume of other constituents, typically 48%-55% of total aggregate weight.
Water/Powder ratio by volume	0.85-1.10

4. Experimental Investigation

In this investigation the fresh and hardened properties of self-compacting concrete for various replacement percentages of GGBS and Foundry sand are determined.

4.1. Fresh Properties

In order to find the fresh properties of SCC slump, V-funnel, L-box and U-box were conducted for each combination. The fresh concrete test results are given in Table 7 and Table 8

Table 7.*Slump tests and V-Funnel test for SCC with GGBS and foundry sand*

S.No.	% of replacement		Fresh Concrete Test	
	GGBS	Foundry Sand	Slump (sec)	V-Funnel (sec)
1.	0	0	5	10
2.	10	10	6	11
3.	10	15	6	11
4.	10	20	6	12
5.	15	10	7	13
6.	15	15	9	14
7.	15	20	9	14
8.	20	10	8	13
9.	20	15	9	14
10.	20	20	12	16

Table 8.*L-Box tests and U-Box test for SCC with GGBS and foundry sand*

S.No.	% of replacement		Fresh Concrete Test	
	GGBS	Foundry Sand	L-Box	U-Box
1.	0	0	0.82	29
2.	10	10	0.82	32.5
3.	10	15	0.84	36.7
4.	10	20	0.85	37
5.	15	10	0.85	34
6.	15	15	0.86	35.7
7.	15	20	0.86	37.1
8.	20	10	0.84	33.8
9.	20	15	0.84	34.4
10.	20	20	0.85	35.1

4.2. Hardened Properties

In order to find the mechanical properties Compressive strength tests were conducted at 7 and 28 days of cube (150 X 150 X 150 mm) specimens. For each combination, two specimens were tested.

In order to find the split tensile strength of concrete 7 and 28 days of cylinder (150 X 300 mm) specimen are cast. For each combination, two specimens were tested. The test results are discussed in the following Tables.

4.2.1. Compression strength

Compressive strength of concrete is the capacity of concrete to withstand axially directed pushing force. When the limit as reached, the brittle material (Concrete) will be crushed. Compressive strength of cubes were determined using a Compression Testing Machine. Cubes are tested for their 7 days and 28 days strength. Compressive strength is calculated by the formula,

Compression strength = Load/Area of cube

Compression strength of cubes was found on cubes size 150 x 150 x 150mm using a 2000 kN compression testing machine. The rate of loading was maintained at a level of 14 $N/mm^2/min$. Fig.1 shows the Compression strength testing.

Figure 1: *Testing of Compression strength*

4.2.2. Split Tensile strength

This test is carried out by placing cylinder specimen horizontally between loading surface of Compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. Split tensile strength was calculated by,

Split Tensile Strength = 2P/πDL

Where, P - load in kN.
D - Diameter of Cylinder in mm.
L - Length of Cylinder in mm.

Fig. 2 shows the split tensile strength of Cylinder. Split tensile strength of cylinder specimen was found out using specimen of 150mm dia and 300mm length using 2000kN compression testing machine.

The test results are discussed in the following Tables. Graphs are plotted to compare the 7 days and 28 days compression strength of SCC with GGBS and Foundry Sand. Fig. 3 and 4 shows the comparison of 7days and 28 days split tensile strength of SCC with GGBS and Foundry Sand.

Figure 2: *Testing of Split tensile strength*

Table 9.*7 Days Compressive strength of SCC with GGBS and Foundry Sand*

S.No.	Replacement percentage		7 days Compressive strength (N/mm^2)
	GGBS	Foundry Sand	
1.	0	0	24
2.	10	10	23.55
3.	10	15	25.3
4.	10	20	27.1
5.	15	10	25.65
6.	15	15	28.2
7.	15	20	32.8
8.	20	10	21.9
9.	20	15	21.15
10.	20	20	19.55

Table 10.*28 Days Compressive strength of SCC with GGBS and Foundry Sand*

S.No.	Replacement percentage		28 days Compressive strength (N/mm^2)
	GGBS	Foundry Sand	
1.	0	0	33.76
2.	10	10	34
3.	10	15	35.8
4.	10	20	37.6
5.	15	10	36
6.	15	15	39
7.	15	20	43.3
8.	20	10	32.4
9.	20	15	31.65
10.	20	20	30.2

Table 11.*7 Days Split Tensile strength of SCC with GGBS and Foundry Sand*

S.No.	Replacement percentage		7 days Split Tensile strength (N/mm^2)
	GGBS	Foundry Sand	
1.	0	0	1.8
2.	10	10	2.2
3.	10	15	2.4
4.	10	20	2.65
5.	15	10	2.57
6.	15	15	2.83
7.	15	20	2.9
8.	20	10	2.46
9.	20	15	2.65
10.	20	20	2.7

Table 12.*28 Days Split Tensile strength of SCC with GGBS and Foundry Sand*

S.No.	Replacement percentage		28 days Split Tensile strength (N/mm^2)
	GGBS	Foundry Sand	
1.	0	0	2.3
2.	10	10	2.765
3.	10	15	3.035
4.	10	20	3.28
5.	15	10	3
6.	15	15	3.4
7.	15	20	3.57
8.	20	10	3.17
9.	20	15	3.29
10.	20	20	3.35

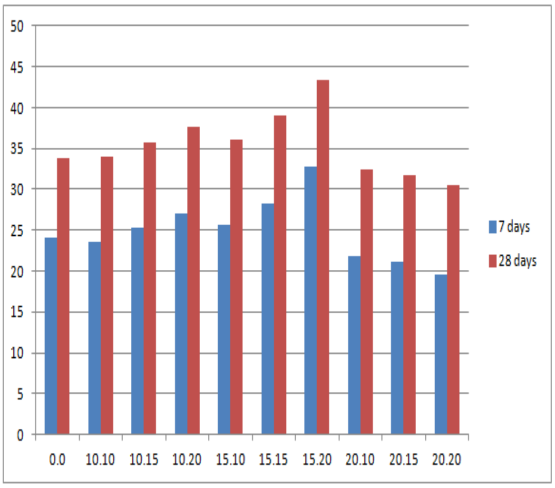

Figure 3: *Compression of 7 days and 28 days Compression strength of SCC with GGBS and Foundry Sand*

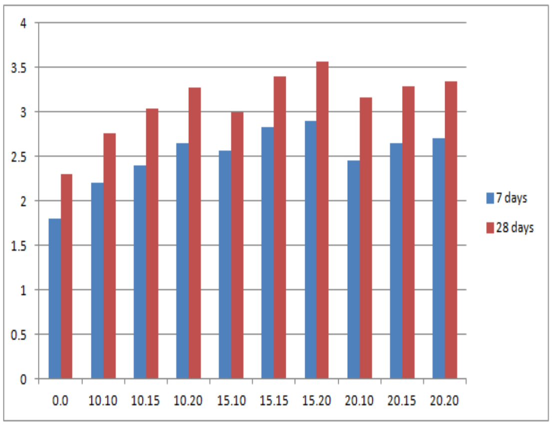

Figure 4: *Compression of 7 days and 28 days Split Tensile strength of SCC with GGBS and Foundry Sand.*

4.3. Beam Column Joint

The experimental program included two specimens (C1 & C2) where C1 is the specimen with normal concrete and C2 is the specimen with SCC with opimum replacement. Both the specimens C1 & C2 were conforming to IS 13920. The size of the beam was 800 mm x 200 mm x 250 mm and column 1000 mm x 200 mm x 250 mm. The dimensions and reinforcement details of test assemblages are shown in Fig.5. The reinforcement cages that were prepared for both the specimens are shown in Fig.6.

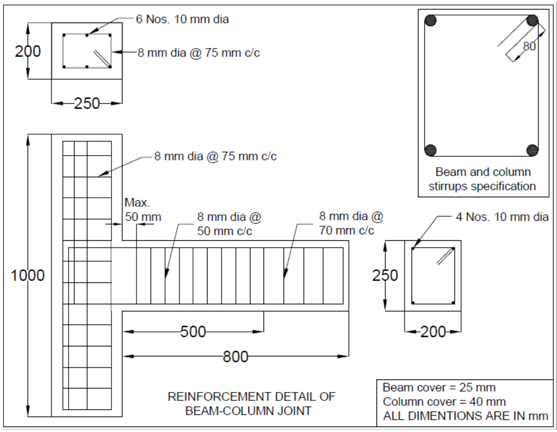

Figure 5: *Reinforcement details for Specimens C1 & C2*

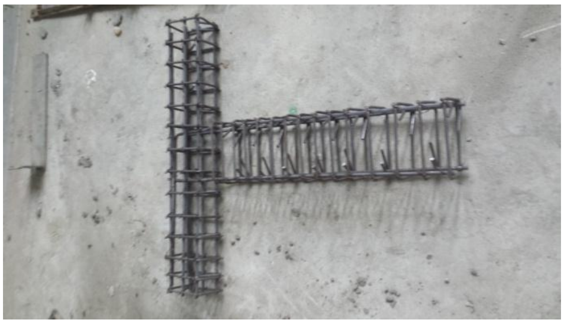

Figure 6: *Reinforcement cages for Specimens C1 & C2*

The specimens were tested in an upright position and static reverse cyclic loading was applied. Both ends of the column were hinged properly within the self-straining test frame. A deflection control test was conducted in which the specimen was subjected to an increasing deflection with increments not exceeding 2.5 mm up to the failure. The specimens were instrumented with hydraulic jacks, LVDTs, dial gauges and strain gauges to monitor the behavior during testing. Lateral loading, at deflection increments of 2.5 mm was applied in a cyclic manner by means of hydraulic jacks having a capacity of 100 kN and 200 kN for downward and upward loading respectively. It was applied at a distance of 100 mm from the free end of the beam until failure of the specimens. One dial gauge was placed at the loading point of beam to control deflection at the point of application of load.

The crack patterns in different specimens are shown in Fig. 7 and Fig. 8. For specimen C1 and C2, the initial diagonal and column beam interface hairline cracks occurred in the third cycle of loading in positive direction and fifth cycle of loading in negative direction. For specimen C2, further cracks were developed at the column beam interface only after sixth cycle in both positive and negative direction. C2 specimen exhibited the best performance.

Figure 7: *Crack pattern Specimens C1*

Figure 8: *Crack pattern Specimens C2*

The ultimate load carrying capacities of all the specimens were observed and fig.9 shows the comparison of the same. For the specimen C1 detailed as per is 13920: 1993, the ultimate load is 37 kN, but for specimen C2 detailed as per is 13920: 1993, the ultimate load is 32 kN.

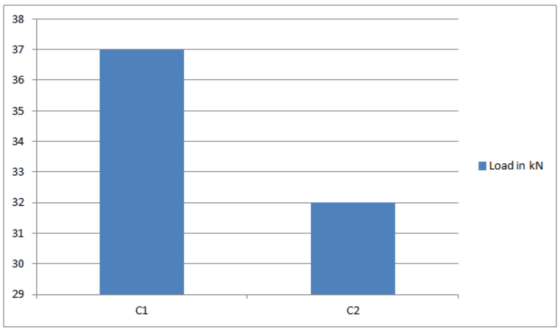

Figure 9: *Comparison of ultimate load carrying capacity of specimen C1 and C2*

5. Conclusion

The following conclusions have been derived from the above study:

- Replacement of concrete with admixtures such as ground granulated blast-furnace slag (GGBS) and foundry sand will retain the original strength of concrete.
- When the replacement of cement with ground granulated blast-furnace slag (GGBS) is kept within 30% it gives good results.
- The mix design for self-compacting concrete with M30 grade has been calculated keeping the replacement percentages of ground granulated blast-furnace slag (GGBS) and foundry sand as 10%, 15% and 20%.
- It has been found out that when the replacement percentage of foundry sand is increased the compressive strength also increased, but when the replacement percentage of GGBS is increased more than 15% the compressive strength reduces. So the optimum replacement percentage is found out to be a combination of 15% replacement of cement with GGBS and 20% replacement of fine aggregate with foundry sand.
- The usage of SCC in beam column joints with cement and fine aggregate replaced with GGBS and foundry sand respectively gives better results than the usage of normal concrete in beam column joints under seismic loading.

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