International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2585
Volume 3, Issue 08, August-2017

EFFECT OF ARTIFICIAL SAND ON MECHANICAL PROPERTIES OF SELF COMPACTING GEOPOLYMER CONCRETE

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ABSTRACT

Self compacting geopolymer concrete (SCGC) is an advanced concrete that doesn't require both cement and compaction. In this research, SCGC mixes were prepared using class F fly ash (FA) and ground granulated blast furnace slag (GGBS) in 50:50 proportions with artificial sand (ARS) as fine aggregate. According to EFNARC guidelines mix design was prepared with 8M, 10M and 12M of NaOH. After successful evaluation of various fresh properties like slump flow, T_{50cm} slump flow, V-funnel, L-box, the present experimental investigation was carried out on mechanical properties like compressive strength and flexural strength after 28 and 56 days of ambient room temperature curing. Performance aspects such as first crack load, ultimate load, ultimate deflection, crack patterns and failure mode of reinforced SCGC (RSCGC) beams were studied. The mechanical properties are evaluated and get a conclusion that curing time gives better strength in all molarities and also found that the increase in NaOH molarity decreased the fresh properties, however it increased the compressive and flexural strength of SCGC.

Key words: Self compacting geopolymer concrete, class F fly ash, ground granulated blast furnace slag, artificial sand, compressive strength, and flexural strength.

INTRODUCTION

Concrete is the resolution of all the construction and development activities around the world. The prime ingredient of conventional concrete is OPC. From environment point of observation, making of OPC is not environmental friendly view as it takes huge quantity of natural resources and releases a major quantity of green house gases [1]. So as to decrease the manufacture of OPC which effect the pollution to the environment alternate binders are introduced. Special types of concrete are being developed based on the purpose in the construction industry. Among special types of concrete being produced, SCGC is proven to have excellent engineering properties with reduced green house gases diffusion. It not only decreases the greenhouse gas diffuses but also utilizes a huge amount of industrial waste materials like fly ash and slag. Considering these positive attributes, it is becoming an increasing and popular construction material. Davidovits introduced geo polymeric binders showing promising region of study in construction industry as alternate binders to OPC. A polymeric reaction of alkaline liquids with the Si and Al source materials of naturally existing resources or industrial by-products such FA, GGBS, rice husk ash (RHA) etc., develops these geopolymers [2].

In SCC amount of sand should be more than half of the whole aggregate [3]. Sand can be artificial or natural sand has to be of uniform grading and absorption characteristics should be intimately observed [4]. Therefore amount of sand required for SCGC is higher than that of CC. If natural sand is used in huge quantity, it not only affects environmental problems but also lack of natural resources and usage of artificial sand is the solution for this problem. Researchers have shown that use of artificial sand gives the superior strength than with river sand [5&6].

GuruJawahar and Mounika observed that at room temperature FA and GGBS blended GPC mixes attained enhances mechanical properties [7]. Sujatha et al. concluded that stiffness, ductility and high load carrying capacity and exhibited by geopolymer concrete columns until failure [8]. Anuradha et al. pointed that tensile strength of GPC manufactured with artificial sand is lower than that of GPC manufactured with river sand [9].

Palmo et al. concluded that mechanical properties of the fly ash based GPC significantly affected by the curing temperature. However, current studies declared that GPC mixes can be improved for ambient room temperature [10]. Hardjito et al. [11] noticed that SP was create to be used to attain sufficient workability as fresh GPC was extremely viscous with low workability. Generally, in the geopolymer technology, the mixture of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate solution can be considered as alkaline solution [12&13]. Raise in NaOH concentration and curing time results superior compressive strength values of fly ash based GPC mixes [14]. Vijai et al. built up an articulation that to compute 28 days compressive strength, splitting tensile strength and flexural strength of steel fiber reinforced geopolymer concrete composites [15]. This makes SCC especially valuable wherever putting is required in complicated formwork or heavily reinforced concrete members [16].

SCGC is an advanced concrete that primary two overlay issues, for example, using the industrial by products and putting the concrete in complicated formworks. Memon et al. presumed that impact of curing temperature on strength of fly ash based SCGC that compressive strength was enhanced with the rise in temperature from 60^0C to 70^0C, but beyond 70^0C strength was decreased [17]. Memon et al. inferred that compressive strength of fly ash remains based SCGC upgraded with the ascent in NaOH molarity from 8 M to 12 M, however additionally rise in moloarity 14 M decreased the strength of SCGC. They also observed that the fresh properties of SCGC get decreased with rise in molarity [18]. Nuruddin et al. reasoned that the to get enhanced workability of SCGC, alkaline solution, SP and additional water ought to be premixed before addition to the dry mix of concrete [19].

In the present research, SCGC was prepared with available ingredient materials and investigated its basic fresh and mechanical properties. The present work is investigated SCGC properties by varying the molarity of NaOH from 8M, 10M and 12M. In this research, class F fly ash and GGBS were proportioned equally at 50% replacement level. Artificial sand was used as fine aggregate. Test methods such as compressive strength on cubes and flexure strength on beams were conducted on SCGC after 28 and 56 days of ambient room temperature curing.

2. EXPERIMENTAL STUDY

2.1. MATERIALS

In this investigation the materials utilized were FA, GGBS, ARS and coarse aggregate, alkaline solution, SP, water and reinforcement. FA got from Rayalaseema Thermal power plant, Muddanur, A.P [20]. GGBS created from Vizag steel plant, A.P were utilized as a part of making of SCGC. The chemical and physical properties of FA and GGBS are shown in Table-1. Artificial sand having specific gravity of 2.61 and fineness modulus of 2.69 was used as a fine aggregate. Locally accessible crushed coarse aggregate of maximum size 12mm having specific gravity of 2.66 and fineness modulus of 7.0 used for all mixes.

The mixture of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution was used as alkaline solution. The Na_2SiO_3 solution (Na_2O=13.7%, SiO_2=29.4% and H_2O=55.9% by mass) was purchased from Astrra Chemicals, Chennai, T.N. The NaOH pellets were used and purchased from a local supplier. NaOH solution concentration was varying from 8M, 10M and 12M. The alkaline solution was readied 24 hrs before to utilize. To attain superior workability of the fresh concrete, financially accessible SP (SKY 8630) was utilized. It is a blended version of both SP and VMA. Properties of SKY 8630 are given in Table-2. A specified quantity of extra water was also used in the preparation of SCGC. The reinforcement used for the casting of beams are taken from the local supplier and its arrangement as shown in figure-1.

Table-1.Chemical and Physical properties of class F fly ash and GGBS

Chemical properties (%)	Class F Fly ash	GGBS
Silica(SiO_2)	65.6	30.61
Alumina(Al_2O_3)	28.0	16.24
Iron Oxide(Fe_2O_3)	3.0	0.584
Lime(CaO)	1.0	34.48
Magnesia(MgO)	1.0	6.79
Titanium Oxide (TiO_2)	0.5	-
Sulphur Trioxide (SO_3)	0.2	1.85
Loss on Ignition	0.29	2.1
Physical properties		
Specific gravity	2.13	2.9
Fineness (m^2/kg)	360	400

Table-2.Properties of SKY 8630

Chemical admixture	SKY 8630
Main component	Polycarboxylate ether
pH	≥6
Relative density	1.08
Chloride content	<0.2%

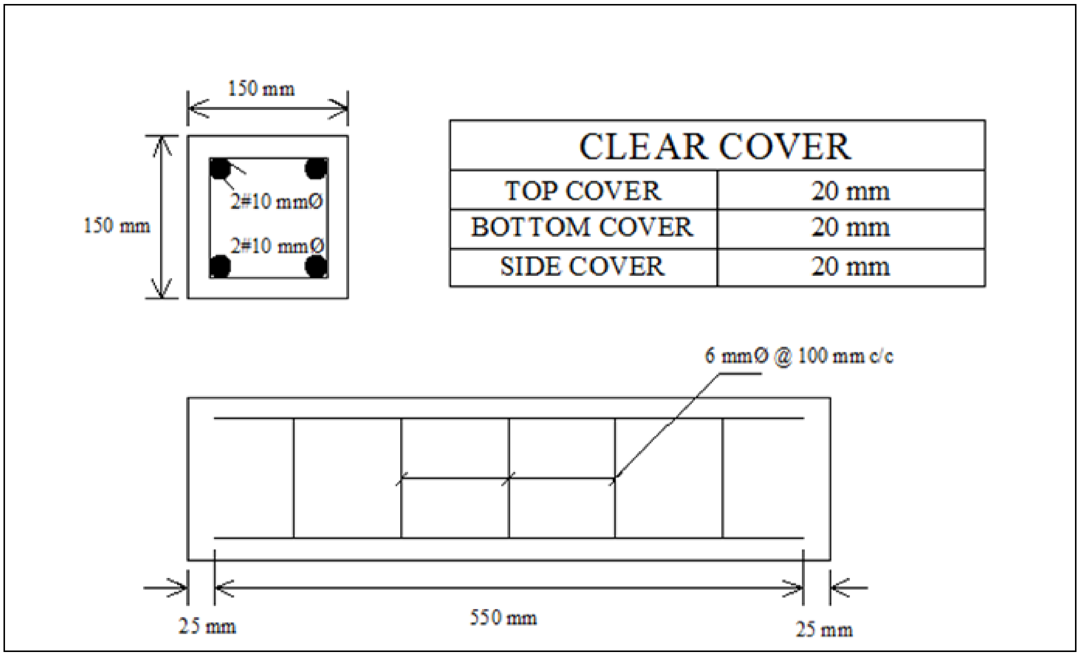

Figure-1.Reinforcement Arrangement

2.2. Mix proportions of SCGC

In this research work, to study the impact of NaOH concentration on fresh properties and mechanical properties of SCGC three different mixtures with the similar binder (FA+GGBS) content of 450 Kg/m^3 were prepared. The NaOH solution was raise from 8M, 10M and 12M. The alkaline solution to binder ratio was kept at 0.45. All mixes had fixed at water to geopolymer solids ratio of 0.4 by mass, whereas the ratio of Na_2SiO_3 to NaOH was kept at 2.5. According to SCC guide lines, coarse aggregate content was maintained at 30% of concrete volume [16]. In order to obtain the required fresh and mechanical properties of SCGC, a water content of 25% and SP dosage of 2% by mass of the binder were also used. The mix designations and mix details of SCGC are given in Tables 3 and 4 respectively.

Table-3.Mix designation of SCGC

Mix	AS/B	Binder (kg/m^3)	AS (kg/m^3)	CA (kg/m^3)	Molarity	NaOH solution (kg/m^3)	Na_2SiO_3 Solution (kg/m^3)	Extra water	SP (%)
M1	0.45	450	960.96	786.24	8	58	145	25	2
M2	0.45	450	960.96	786.24	10	58	145	25	2
M3	0.45	450	960.96	786.24	12	58	145	25	2

Table-4.Mix details of SCGC

Material	Content
Class F fly ash (Kg/m^3)	225
GGBS (Kg/m^3)	225
Artificial sand (Kg/m^3)	960
Coarse aggregate (Kg/m^3)	790
Sodium hydroxide solution (Kg/m^3)	58 (8M,10M,12M)
Sodium silicate solution (Kg/m^3)	145
Extra water (%)	25
Super plasticizer (%)	2
Alkaline solution /binder	0.45
Na_2SiO_3/NaOH by mass	2.5
Water/geopolymer solids(by weight)	0.4

2.3. Mixing, testing, casting and curing of SCGC

Mixing process was prepared in two phases, artificial sand, coarse aggregate on SSD condition and binder were mixed together in 100 liter capacity concrete mixer for 2.5 minutes. Toward the finish of this dry mixing, a well-shaked and premixed alkaline solution, SP and extra water was added in the concrete mixer and the wet mixing was proceeded for an additional 3 minutes [19]. To ensure the good homogeneity in the mix, fresh concrete was mixed for another 2 to 3 minutes. To assess the characteristics of SCGC, a freshly prepared wet mix was utilized to test the workability. According to EFNARC [16], test methods such as slump flow, T50cm slump flow, V-funnel and L- box were done to evaluate the fresh properties of SCGC. The fresh concrete mixture was then cast in 150× 150 × 150 mm size cube moulds and 150× 150 × 600 mm size beam moulds. After demoulding, the specimens were kept at ambient room temperature curing for different curing periods. The test specimens were tested for compressive and flexural strength as per IS 516 [21] after 28 and 56 days of curing.

3. RESULTS AND DISCUSSION

This section discusses the effect of NaOH concentration on fresh and mechanical properties of SCGC.

3.1. Effect of NaOH concentration on SCGC fresh properties

The SCGC fresh properties were tested by as per SCC guidelines [16]. The experimental results of various fresh properties are given in Table-5.

Table-5.Fresh properties of SCGC mix

Mix No.	Molarity (M)	Slump flow (mm)	T_{50cm} slump flow (sec)	V-funnel (sec)	L-box ratio (h_2/h_1)
M1	8	690	3.5	9.5	1.00
M2	10	680	3.8	10.2	0.95
M3	12	665	4.2	11.2	0.90
SCC acceptance criteria as per EFNARC [13]	Minimum	650	2	6	0.8
	Maximum	800	5	12	1

It is noticed from the Table -5 that the three mixes M1 (8M), M2 (10M) and M3 (12M) have met the SCGC acceptance criteria [13]. Hence, it is concluded that the raise in NaOH molarity in the mix reduced the fresh properties of SCGC and no adverse effect of artificial sand is observed.

3.2. Effect of NaOH concentration on SCGC mechanical properties

From the result obtained in fresh properties of SCGC as shown in Table-5, the mixes were considered as successful SCGC mixes. The mechanical properties of SCGC are compressive strength and flexural strength.

3.2.1. Compressive strength of SCGC

The compressive test was conducted on 150×150×150 mm concrete cubes as shown in figure-2. Compressive strength results of SCGC mixes after 28 and 56 days of curing at ambient room temperature are presented in the Table-6. Compressive strength results of SCGC mixes and their comparisons in their molarity are shown in figure-3.

Compressive strength f_c in Mpa=Maximum load/cross sectional area of the cube

Figure-2.Compressive test on SCGC cube

Table-6.Compressive strength values of SCGC

Mechanical property	Age (days)	Molarity		
		8M	**10M**	**12M**
Compressive strength f_c (Mpa)	28	40.44	43.11	45.77
	56	46.17	49.64	51.2

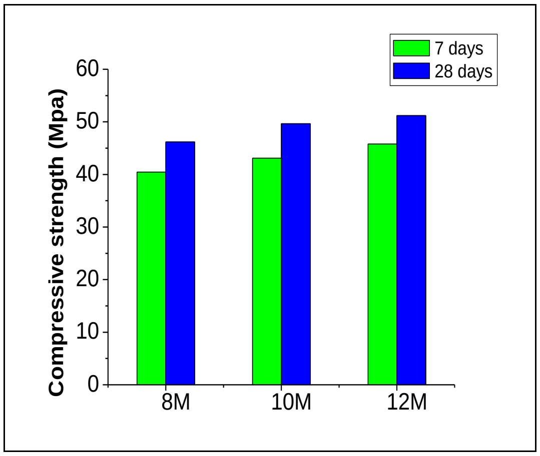

Figure-3.Compressive strength results of SCGC

Figure-3 represents compressive strength results of SCGC. Test results shown that the rise in molarity increased the compressive strength of SCGC. All the mixes have attained excellent values of compressive strength at all curing periods at ambient room temperature.

3.2.2. Flexural strength of SCGC

All the beams were tested under two point loading. The beams were tested in a loading frame of about 50kN capacity. The flexure load was applied on the test beam through a distributing steel beam by a hydraulic jack. The test specimen was properly instrument for load application and measurement of load and deformations at the mid span. The experimental set up for beam is shown Figure-4. The test was carried out on 150 x 150 x 600 mm beam size, Figure-5 shows the Flexural Test on self compacting geopolymer concrete beams. Each beam was tested to failure by applying loads in series of regular increments and deflection noted using deflectometers. Performance aspects such as first crack load, ultimate load, ultimate deflection, crack patterns and modes of failure of beams were observed. Flexural strength results of SCGC mixes after 28 and 56 days of curing at ambient room temperature are presented in the Table-7. Flexural strength results of SCGC mixes and their comparisons in their molarity are shown in figure-6.

Figure-4.Experimental set up for beam in loading frame

Figure-5. Flexural Test on SCGC beam

Table-7.Flexural strength values of SCGC

Mechanical property	**Age (days)**	**Molarity**		
		8M	**10M**	**12M**
Flexural strength f_r (Mpa)	28	6.07	7.09	8.10
	56	6.58	7.84	9.09

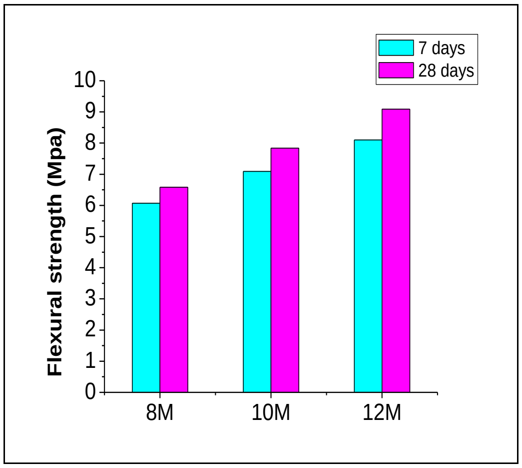

Figure-6.Flexural strength results of SCGC

Figure-6 represents flexural strength results of SCGC. Test results shown that the increase in molarity increased the flexural strength of SCGC. All the mixes have attained excellent values of flexural strength at all curing periods at ambient room temperature. From the results, it is revealed that the increase in NaOH molarity decreased the fresh properties, but however it enhanced the mechanical properties of SCGC, and no adverse effect of artificial sand. Thus, successful SCGC mixes can be achieved using artificial sand and there by natural resources can be saved.

3.2.2.1. First crack load, Ultimate load and Ultimate deflection of RSCGC beams

The values of first crack load, ultimate load are given in Table-8. The values of ultimate deflection are given in Table-9 and also these values are using drawn from the figures 7, 8 and 9.

Table-8.First crack load and Ultimate load at 28 and 56 days

Molarity (M)	28 Days		56 Days	
	1st crack load in KN	Ultimate load in KN	1st crack load in KN	Ultimate load in KN
8	10.80	25.334	12.92	27.97
10	12.92	30.125	15.07	33.35
12	15.07	34.42	18.30	38.72

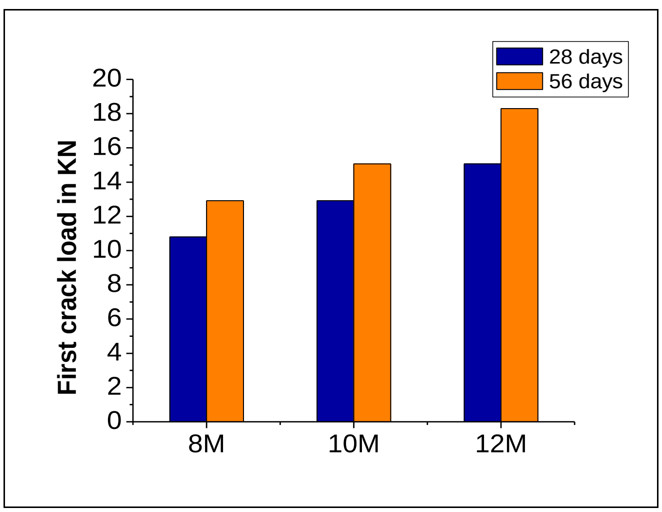

Figure-7.First crack load results of SCGC

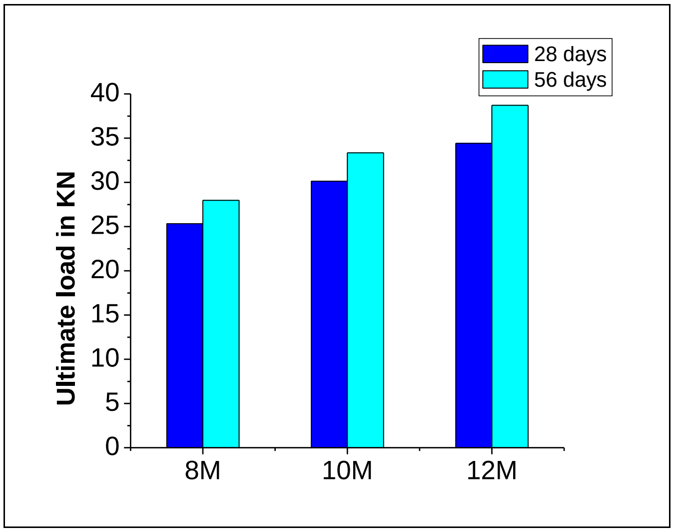

Figure-8.Ultimate load results of SCGC

Table-9.Ultimate deflection at 28 and 56 days of curing

Molarity (M)	Ultimate deflection in mm at 28 days	Ultimate deflection in mm at 56 days
8	1.99	2.14
10	2.28	4.51
12	2.62	4.70

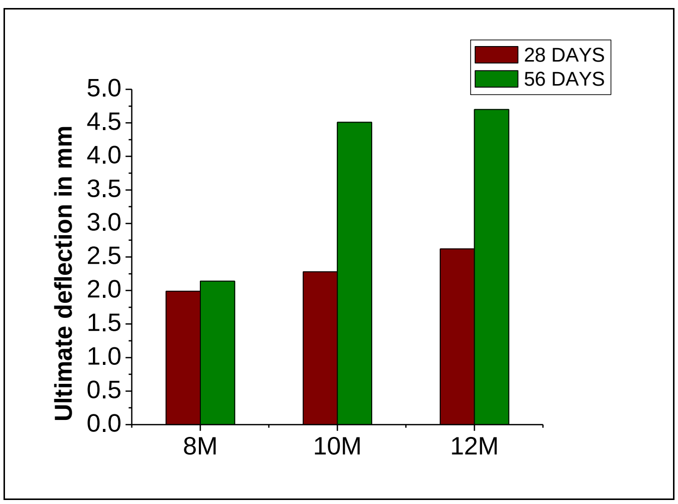

Figure-9.Ultimate deflection results of SCGC

Figure-7 represents the first crack load results of SCGC. It is observed that the 12M of NaOH has higher the value of first crack load when compared two molarities. Figure-8 represents the ultimate load results of SCGC. It is observed that the 12M of NaOH has higher the value of ultimate load when compared to other two molarities. Figure-9 represents the ultimate deflection results of SCGC. It is observed that the 12M of NaOH has higher the value of ultimate deflection when compared to other two molarities. It is observed that 12M of NaOH RSCGC beams have higher load carrying capacity and the larger deflections when compared to other two molarities (8M & 10M) of NaOH.

3.2.2.2. Crack patterns and Failure mode

Cracks were not observed initially when the load was increased linearly at the beginning of the test. As expected, flexure cracks initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. The width and the spacing of cracks varied along the span. At ultimate stage, most of the cracks traversed up to the beams. In all, the crack patterns observed for reinforced Self compacting geopolymer concrete beams (RSCGC) were similar to those reported in the literature for reinforced conventional concrete beams (RCC). The cracks at the mid-span opened widely near failure. The final failure of the beams occurred when the concrete in the compression zone crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that of an under-reinforced concrete beam. The crack patterns and failure mode of test beams are shown in Figure-5.

4. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusion can be obtained

- The raise in the concentration of sodium hydroxide with 8M, 10M and 12M enhanced the viscosity and reduced the fresh properties of SCGC mixes, nevertheless, all the three mixes still met the prerequisite of SCC suggested by EFNARC.
- By comparing three mixes, M1 mix with 8M of NaOH has excellent fresh properties among the other two mixes which are M2 mix with 10M of NaOH and M3 mix with 12M of NaOH.
- Increase in NaOH molarity decreased the fresh properties, but however it enhanced the mechanical properties of SCGC.
- No adverse effect has been observed when SCGC mixes prepared with artificial sand (AS).
- The first crack load and ultimate load of 12M RSCGC beams have higher values when compared to other beams (8M and 10M). The load carrying capacity and the deflections of 12M RSCGC beams were higher when compared to other beams (8M and 10M).
- The crack patterns observed for SCGC beams were similar to those reported in the literature for RCC beams. All beams failed in flexural mode in a ductile manner accompanied by crushing of the concrete in the compression zone.

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