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Computation of Modulus of Elasticity of High Strength Concrete using Silica Fume

V.S. Sethuraman[1,*], K. Suguna[2]

[1] Research Scholar, Department of Civil & Structural Engineering,
Annamalai University, Annamalainagar, Tamilnadu

[2] Professor, Department of Civil & Structural Engineering,
Annamalai University, Annamalainagar, Tamilnadu

[*] *Corresponding author's email: sethuramanvs [AT] gmail.com*

ABSTRACT---*The modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically. In order to utilize the full compressive strength, the structures using high strength concrete tend to be slimmer and require a higher elastic modulus to maintain its stiffness. The mechanical properties of HSC are mostly dependent on the properties and proportions of binders and aggregates. Therefore, knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation providing satisfactory serviceability and avoiding the most cost-effective designs. This paper presents the results of experimental study of modulus of elasticity of M60 grade concrete using standard cylinder specimens tested with compressometer under axial compression. Based on the test results, it is observed that the stress-strain behaviour exhibits non-linear variation from which the initial tangent modulus is plotted to arrive at modulus of elasticity values.*

Keywords*:* Modulus of elasticity, High-strength concrete, Compressive strength, Axial compression, Compressometer, Stress-strain, Initial tangent modulus.

1. INTRODUCTION

The mix-proportioning procedure for normal-strength concrete cannot be used to proportion high-strength concrete involving both chemical and mineral admixtures. The American Concrete Institute method (ACI 211.4R-93) can be used to proportion both normal and high-strength concrete. High strength concrete has a compressive strength generally greater than 40Mpa. High strength concrete is made by lowering the water-cement (W/c) ratio to 0.35 or lower. Often Silica Fume (SF) is added to prevent the formation of free calcium hydroxide crystals in the cement matrix, which might reduce the strength at the cement-aggregate bond. Low W/c ratios and the use of silica fume make concrete mixes significantly less workable, which is particularly likely to be a problem in high-strength concrete applications where dense rebar cages are likely to be used. To compensate for the reduced workability, high range water reducers like superplasticizers or hyperplasticizers are commonly added to high-strength concrete mixes. Extreme dosages of dispersing agents are used to overcome the surface tensions, permitting dense particle packing. Very low water demand is obtained and thus, pastes of very low water-cement ratios can be produced.

In some applications of high-strength concrete the design criterion is the modulus of elasticity rather than the ultimate compressive strength. The mechanical properties of the concrete can be improved by obtaining a denser packing of the solids. Aggregates must be selected carefully for high-strength mixes, as weaker aggregates may not be strong enough to resist the loads imposed on the concrete and develop failure to occur in the aggregate rather than in the matrix or at a void, as normally occurs in regular concrete. A dense cementitious matrix is not sufficient by itself to obtain HSC since the aggregate-matrix bond may not be strong enough. In NSC the interfacial zone is often a weak link, since it tends to be more porous and heterogeneous than the bulk paste matrix.

The addition of SF can drastically change the microstructure of the paste at the interface, causing it to be as dense as that of the matrix. This provides a much more efficient bond between the aggregate and the matrix. This effect of SF is associated with its ability to pack densely at the aggregate surface, as well as to reduce the internal bleeding of the concrete. The paste aggregate bond can also be improved. The size and spherical geometry of SF particles allows them to fill effectively the voids between the larger and angular cement grains. Due to these interfacial effects, the aggregates in high strength silica fume concrete are becoming active load-bearing components in the concrete, contributing to the overall strength, and not first inert mechanical fillers as in NSC.

Yaqub and Bukhari reported that smaller sizes (10 mm and 5mm) and rounded shape of coarse aggregates should be used to obtain the high strength concrete than other sizes and shape respectively. It is reported that to overcome the unfavorable effect on workability, higher percentage of super plasticizer would be used in silica fume concrete for higher percentage of cement replacement by silica fume. Katkhuda, Hanayneh and Shatarat experimented to observe the isolated effect of silica fume on compressive, flexural and tensile strengths on high strength lightweight concrete and showed that the compressive, flexural and tensile strengths enhanced with silica fume incorporation but the optimal replacement percentage is not invariable because it depends on the water–cementitious material (w/cm) ratio of the mix.

Shannag (2000) stated that the addition of 15% pozzolan and 15% SF to concrete resulted in a 26% increase of the 28-day compressive strength of concrete. For mixes with a w/c ratio of 0.35, the strength of the SF concrete was found to be higher than the strength of the concrete without SF. Toutanji and El-Korchi (1996) documented a test where 16 and 25% of cement used in the paste and mortar, measured by mass, was replaced by SF. Four different water/cement ratio mixes were tested: 0.22, 0.25, 0.28 and 0.31 with the proper addition of super plasticizer amount. Their results showed that the partial replacement of cement by SF increased the compressive strength of the paste.

Mostofinejad and Nozhati (2005) attempted to extract some experimental models to predict the modulus of elasticity of HSC. The maximum compressive strength of HSC was achieved by a 10% substitution of SF for cement when w/c ratio was 0.4 and by a 15% substitution of SF for cement when w/c ratio was 0.24 or 0.30. The optimum SF percentage that produced maximum modulus of elasticity is not necessarily equal to that for achieving the maximum compressive strength. Benefits of utilizing SF to the hydration in concrete reported by Langan et al.(2002) included substantial increase in compressive strength of concrete, reduction in the required cement content for specific target strength and durability increase for hardened concrete when added in paste containing 20% SF exhibited the highest strength.

2. MODULUS OF ELASTICITY

Modulus of elasticity is one of the most important mechanical properties of concrete. Modulus of elasticity is defined as the ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of a material. It is a key factor influencing the structural performance of reinforced concrete structures and is particularly important as a design parameter in predicting the deformation of tall buildings.

The modulus of elasticity of concrete is largely governed by the properties of the coarse aggregate. Increasing the size of coarse aggregates or using stiffer coarse aggregates with a higher modulus of elasticity increases the modulus of elasticity of the concrete. Being a composite material composed of paste and aggregate, the modulus of elasticity of concrete in compression is closely related to the mechanical properties of the paste relative to that of the aggregate particles. As the elastic moduli of paste and aggregate particles approach each other, the resulting concrete tends to exhibit a more linear stress-strain relationship and increased brittleness.

3. MIX PROPORTIONING

In this experimental study the mixes of concrete were intended as per the guidelines specified in ACI 211.4R-93 though some restriction is mandatory by restricting the amount of cementitious material content and is equal to 450 kg/m^3. Table 1. shows the mix proportions of concrete.

Table 1: Results of Mix Design

Grade of Concrete	M_{60}	
Water cement ratio	0.36	ACI 211.4R IS 456-2000 Table 5
Cement	450 Kg	OPC 43 grade, IS 8112-1989
Fine Aggregate	730 Kg	IS 383-1970
Coarse Aggregate 20mm 12mm	680 kg 450 kg	IS 383-1970
Water	160 Litre	
Mineral Admixture Silica Fume @ 8% by weight of cement	36 Kg	IS 456-2000 Cl,5.2.1.2 (5 to 10%)
Chemical Admixture Hyper Plasticizer- CLASSIC SUPERFLOW PC 8860 @ 1% by weight of cement	4.5 Litre	IS 456-2000,Cl,10.3.3 (0.5 to 2%)
Design Mix Proportions	1:1.62:2.51	ACI 211.4R

4. EXPERIMENTAL PROGRAMME

4.1 Materials

In this experiment for development of the workability of concrete, hyperplasticizer CLASSIC SUPERFLO PC8860 with base as polycarboxylate ether polymer in compliance to IS: 9103-1999 and ASTM C494 type B,D & G was used. CLASSIC SUPERFLO PC8860 was specially formulated to report high range of water reductions upto 40% without losing workability or to turn out high quality concrete of lesser permeability. The properties of hyperplasticizer are shown in Table 2.

Table 2: Properties of Chemical Admixture - Hyper Plasticizer

Hyper Plasticizer (HP) – CLASSIC SUPERFLO PC 8860 e		
1	Base	Polycarboxylate ether polymer
2	Appearance	Amber coloured liquid
3	Specific Gravity	1.15± 0.01
4	pH value	7±1
5	Solid content	45%
6	Chloride content	Nil (BS:5075)
7	Solubility	Water Soluble
8	Dosage	400 to 1200ml per 100kg Cement (0.4 to 1.2% [V/W])
9	Particle size	0.25 to 0.35 micrometers (µm)
10	Water reduction in concrete	Upto 40%
11	Gives high slump with W/c ratio	< 30%
12	Slump retention(maintain fluidity)	About 4 hours at 35^{o}C
13	Conforming to Standards	IS 456:2000 (cl: 10.3.3), IS: 9103-1999, ASTM C 494 Type B, Type D and Type G.

Finely divided mineral admixtures like silica fume were widely used in HSC. Silica fume is a by-product of the melting process used to produce silicon metal and ferro silicon alloys. Because of its spherical shape, extreme fineness and high silica content, silica fume is a most effective pozzolonic material. The silica fume reacts pozzolonically with the lime during the hydration of cement to form the stable cementitious compound Calcium Silicate Hydrate (CSH).

Silica fume improves compressive strength, bond strength and abrasion resistance. It reduces permeability and therefore protects reinforcing steel from corrosion. It also combines with calcium hydroxide during hydration of cement to improve concrete durability. As micro filler, the extreme fineness of the silica fume helps to fill the microscopic voids between cement particles thereby reducing permeability and improving the paste to aggregate bonding. The properties of silica fume are given in Table 3.

Table 3: Properties of Mineral Admixture

Mineral Admixture – SILICA FUME (SF)		
1	Type of material	Amorphous (Non-crystalline material). SiO_2 ranging from 85 to 98%.
2	Obtained as by-product in manufacture of	Silicon, ferrosilicon, quartz and carbon in electric arc furnace.
3	Reactive material content	Silicon dioxide (SiO_2)
4	Additional material content	Trace elements
5	Particle size	95 % < 1 micrometer (µm). Approximately 100 times smaller than average cement particle
6	Particle shape	Spherical
7	Bulk density	130 to 430 kg/m^3 (as produced) 480 to 720 kg/m^3 (densified)
8	Specific gravity	2.2
9	Specific surface	15,000 to 30,000 m^2/kg
10	Dosage	5 to 10 % of cement content of a mix
11	Conforming to standards	IS 456:2000(cl: 5.2.1.2), ACI 234R-96, ASTM C 1240, ASTM C 618, AASHTO M 307

4.2 Workability

To measure the mobility or flowability of concrete, slump test was carried out and measured in quantitative terms. Several factors affect the workability of concrete. They relate to the properties of aggregates, cement, water and entrapped air. Workability was mainly affected by aggregates. The properties of aggregates that affect workability include their maximum size, grading type, shape and texture.

The workability of concrete when added with silica fume found to be decreased. By the addition of hyperplasticizer @1% by weight of cementitious material, the workability was improved and a maximum slump of 85mm was achieved.

4.2 Test conducted

The modulus of elasticity was determined by subjecting the cylinder specimen to uniaxial compression and measuring the deformations using dial gauge fixed between the guage length of 200mm as shown in Figure 2. The test was conducted using compressometer as per IS 516-1959. The cylinder specimens of standard size 300mm height and 150 diameter were placed on CTM of 2000kN capacity without eccentricity and uniform load was applied till the target load failure of the cylinder. The target load and deflection were noted. The deflection readings are calculated in the form of strain through change in length. Dial guage readings divided by guage length will give the strain and load applied divided by area of cross-section of cylinder will give the stress.

For finding Young's modulus of concrete, the deformation of various loads was observed and the results were plotted graphically against the stress. In the stress-strain curves, tangent was plotted and modulus of elasticity was determined from the slope of the initial tangent modulus.

Diameter of the cylinder, D	= 150mm
Height of the cylinder, H	= 300mm
Cross-sectional area, A	= 17671mm^2
Capacity of CTM	= 2000kN

Figure 2. Compression Test of Cylinder Specimens

5. RESULTS AND DISCUSSIONS

The modulus of elasticity of concrete is generally related to compressive strength. The modulus of concrete under static loading conditions is generally known as its static modulus. The value of the static modulus (E) for concrete is determined on the basis of the uniaxial stress-strain curve obtained from a standard test cylinder. The stress-strain behaviour of HSC depends on material parameters such as aggregate type and experimental parameters that include age at testing, strain rate and interaction between specimen and testing machine. The stress-strain characteristics of concrete are non-linear from the beginning. The initial tangent to the stress-strain curve is regarded as the initial tangent modulus. The modulus of elasticity is determined from the slope (dy/dx) of initial tangent drawn. The modulus of elasticity varies with the load level, as well as with the rate of loading as shown in Table 4 to 6. The corresponding stress-strain behavior is shown in Figure 3 to 5.

Table 4. Test Results of Specimen-1

Load	Deflection	Strain	Stress	Modulus of Elasticity (E)
kN	mm	mm/mm	N/mm^2	N/mm^2
0	0	0.0E+00	0	0
50	0.01	4.9E-05	2.83	5.80E+04
100	0.03	1.5E-04	5.66	3.87E+04
150	0.04	2.0E-04	8.49	4.35E+04
200	0.05	2.4E-04	11.32	4.64E+04
250	0.06	2.9E-04	14.15	4.83E+04
300	0.08	3.9E-04	16.98	4.35E+04
350	0.11	5.4E-04	19.81	3.69E+04
400	0.13	6.3E-04	22.64	3.57E+04
450	0.16	7.8E-04	25.46	3.26E+04
500	0.19	9.3E-04	28.29	3.05E+04
550	0.22	1.1E-03	31.12	2.90E+04
600	0.26	1.3E-03	33.95	2.68E+04
650	0.3	1.5E-03	36.78	2.51E+04
700	0.35	1.7E-03	39.61	2.32E+04
750	0.39	1.90E-03	42.44	2.23E+04
800	0.42	2.05E-03	45.27	2.21E+04
850	0.48	2.34E-03	48.10	2.05E+04
900	0.56	2.73E-03	50.93	1.86E+04
950	0.62	3.02E-03	53.76	1.78E+04

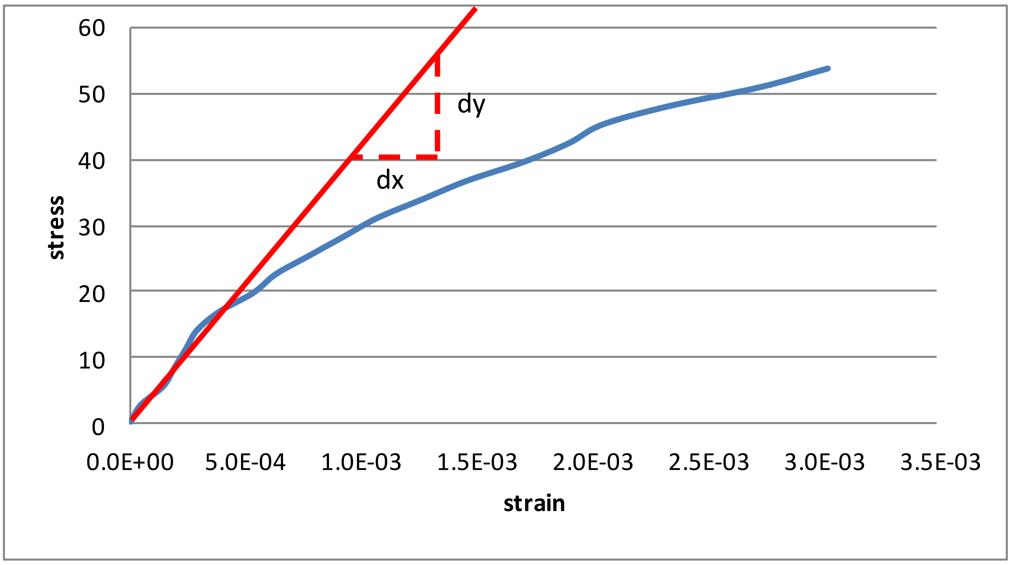

Figure 3. Stress-Strain behavior for Specimen-1

Table 5. Test Results of Specimen-2

Load	Deflection	Strain	Stress	Modulus of Elasticity (E)
kN	mm	mm/mm	N/mm^2	N/mm^2
0	0	0.0E+00	0	0
50	0.01	4.9E-05	2.83	5.80E+04
100	0.02	9.8E-05	5.66	5.80E+04
150	0.04	2.0E-04	8.49	4.35E+04
200	0.05	2.4E-04	11.32	4.64E+04
250	0.06	2.9E-04	14.15	4.83E+04
300	0.08	3.9E-04	16.98	4.35E+04
350	0.1	4.9E-04	19.81	4.06E+04
400	0.13	6.3E-04	22.64	3.57E+04
450	0.15	7.3E-04	25.46	3.48E+04
500	0.18	8.8E-04	28.29	3.22E+04
550	0.22	1.1E-03	31.12	2.90E+04
600	0.25	1.2E-03	33.95	2.78E+04
650	0.29	1.4E-03	36.78	2.60E+04
700	0.33	1.6E-03	39.61	2.46E+04
750	0.38	1.85E-03	42.44	2.29E+04
800	0.42	2.05E-03	45.27	2.21E+04
850	0.46	2.24E-03	48.10	2.14E+04
900	0.5	2.44E-03	50.93	2.09E+04
930	0.58	2.83E-03	52.63	1.86E+04

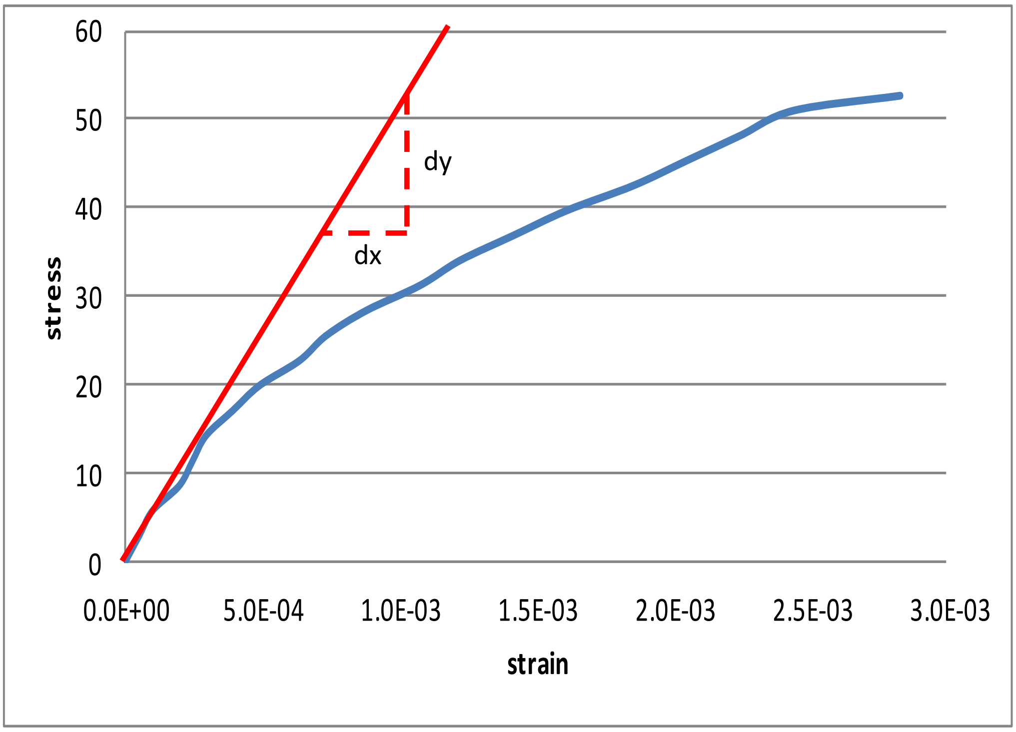

Figure 4. Stress-Strain behavior for Specimen-2

Table 6. Test Results of Specimen-3

Load	Deflection	Strain	Stress	Modulus of Elasticity (E)
kN	mm	mm/mm	N/mm^2	N/mm^2
0	0	0.0E+00	0	0
50	0.01	4.9E-05	2.83	5.80E+04
100	0.03	1.5E-04	5.66	3.87E+04
150	0.04	2.0E-04	8.49	4.35E+04
200	0.05	2.4E-04	11.32	4.64E+04
250	0.06	2.9E-04	14.15	4.83E+04
300	0.08	3.9E-04	16.98	4.35E+04
350	0.11	5.4E-04	19.81	3.69E+04
400	0.13	6.3E-04	22.64	3.57E+04
450	0.16	7.8E-04	25.46	3.26E+04
500	0.18	8.8E-04	28.29	3.22E+04
550	0.22	1.1E-03	31.12	2.90E+04
600	0.26	1.3E-03	33.95	2.68E+04
650	0.31	1.5E-03	36.78	2.43E+04
700	0.35	1.7E-03	39.61	2.32E+04
750	0.39	1.90E-03	42.44	2.23E+04
800	0.43	2.10E-03	45.27	2.16E+04
850	0.48	2.34E-03	48.10	2.05E+04
900	0.56	2.73E-03	50.93	1.86E+04
940	0.6	2.93E-03	53.19	1.82E+04

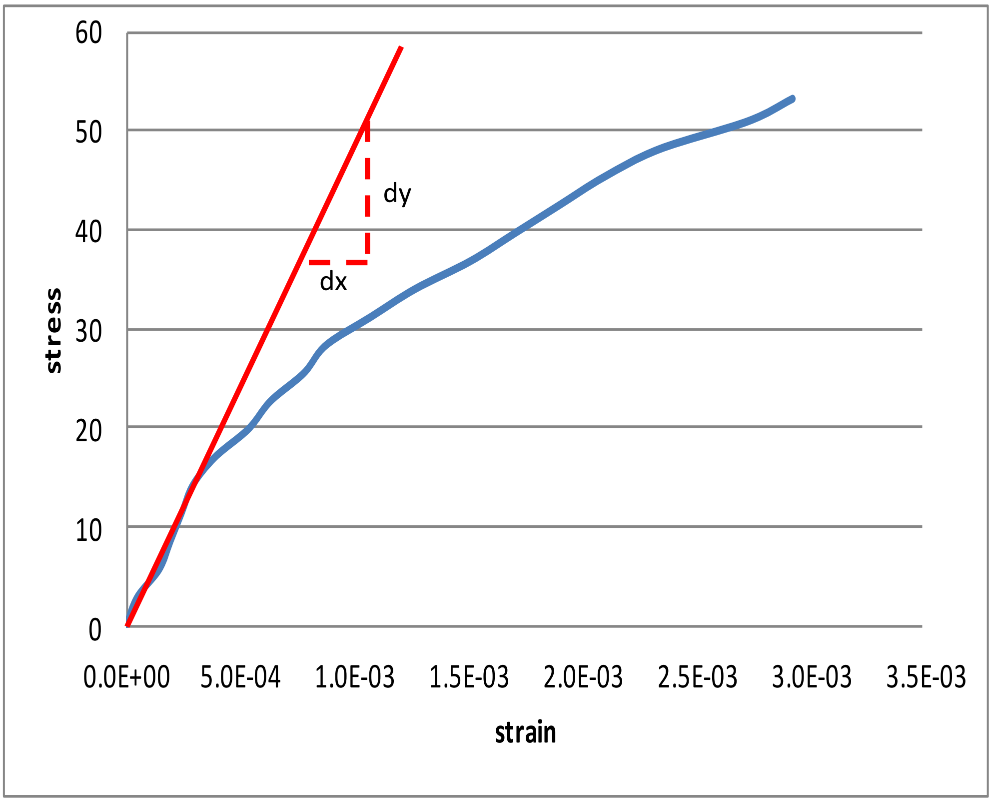

Figure 5. Stress-Strain behavior for Specimen-3

From the above stress-strain curves, taking slope (dy/dx) from the initial tangent modulus plotted, the values for modulus of elasticity are determined and tabulated in Table 7.

Table 7. Modulus of Elasticity of Specimens

Specimen No.	Modulus of Elasticity E (N/mm^2)	Average Modulus of Elasticity E (N/mm^2)
1	34. 21x10^3	34.39x10^3
2	33. 82x10^3	
3	35. 13x10^3	

From the above test results of the 3 specimens, it was observed that the stress-strain variation is non-linear. The modulus of elasticity E of specimen ranges from 33 to 35 MPa which is correlated with the theoretical modulus of elasticity E=38.73x10^3 N/mm^2 as per IS 456-2000.

6. CONCLUSION

Based on the results presented, the following conclusions are drawn:

* The properties of concrete, compressive strength (cylinder) and modulus of elasticity increases by addition of silica fume at 8%.

* For the mix proportion of 1:1.62:2.51 and with a w/c ratio of 0.36 along with the addition of 1% hyperplasticizer a desirable slump of 85mm has been achieved.

* The stress-strain relationship for the high-strength concrete indicates a non-linear variation which gives an average modulus of elasticity value as 34.39x10^3 N/mm^2

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