

**HIGH
VOLUME**

FLY ASH

**CONCRETE
TECHNOLOGY**

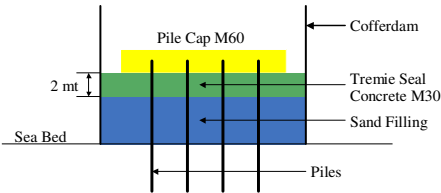
**BANDRA-WORLI SEA LINK
PROJECT, MUMBAI**



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INTRODUCTION



Schematic sketch of pile cap arrangement

High volume fly ash concrete (HVFA) technology was developed at CANMET, Canada in the 1980s. In HVFA, up to 55-60% of portland cement could be replaced by fly ash. Over the years, large numbers of research projects were carried out on HVFA, and the results show excellent long-term durability and mechanical properties of this concrete.

This report highlights one such application of high volume fly ash concrete in underwater construction of tremie seal concrete so as to provide impermeable working platforms for pile cap construction. The work was carried out as a demonstration project under the CANMET-CII-CIDA HVFA implementation project in India with the goal of reducing the green house gas emissions in the construction industry.

Bandra-Worli Sea Link Project is a prestigious project, which envisages construction of a 5.86 km long eight lane free way to be built across the sea. Most of the concrete specified is high strength, high performance concrete.

The distinctive features of Bandra-Worli Sea Link Project are:

- Out of 5.86 km length, the length of bridge portion is 4.0 km including 500 m cable stayed portion,
- The 500m long cable stayed portion rests on 150m high single pylon,
- The bridge will be supported on friction piles. The piles will be drilled and concreted in the sea bed, 8-10 m below the depth of water,
- There are two curves on the sea link, for which different types of trapezoidal segments (in plan) are necessary,

THE PROJECT

- **CASE STUDY 1- TREMIE SEAL CONCRETE**

The use of HVFAC was proposed for Tremie seal concreting to be done under the pile cap. For concreting of the pile cap, a cofferdam was driven into the ground and the depth filled with sand up to a level 2 meter below the level of the bottom of the pile cap. This two meter high area was filled with Tremie seal concrete of M30 grade. The basic purpose of this tremie concrete is to provide an impermeable working platform for the pile cap construction.

- *REQUIREMENT OF TREMIE SEAL CONCRETE*

As per the project specification, the compressive strength requirement was 30 MPa after 28 days. As the concrete is required to be placed underwater, the concrete was required to be cohesive enough with the needed workability in order to be placed with Tremie pipe/pump. The pouring location, which is in deep sea, and the placing procedure for tremie seal concrete required a slump of 170 ± 10 mm after 3 hours.

THE SELECTION OF MIX DESIGN

Initial mix proportions as recommended by CANMET were modified so as to incorporate available local materials. Accordingly various lab trials were conducted in order to arrive at an optimum combination of the material for achieving the desired fresh and hardened state properties. The details of various lab trials conducted are attached as annexure A.

MATERIAL

- *ORDINARY PORTLAND CEMENT:*

L&T OPC 53 Grade cement conforming to IS 12269 was used in concrete. The chemical and physical properties of the cement are listed in Table 1.



Table1: Chemical & Physical properties of L&T OPC

Particulars	Test Results	Requirements IS: 12269-1987
Chemical Requirements		
$\text{CaO} - 0.7\text{SO}_3$ $2.8\text{SiO}_2 + 1.2\text{Al}_2\text{O}_3 + 0.65\text{Fe}_2\text{O}_3$	0.908	0.8 to 1.02
% Al_2O_3 / % Fe_2O_3	1.06	0.66 Min
Insoluble Residue (% by mass)	1.49	3.0 Max.
Magnesia (% by mass)	1.06	6.0 Max.
Sulphuric Anhydride	1.51	3.0 Max.
Total loss on Ignition (%)	1.92	4.0 Max.
Chloride (%)	0.028	0.1 Max.
Physical Requirements		
Fineness (m^2/kg)	297	225 Min.
Normal Consistency	28.25%	
Setting time Initial (min.)	190	30 Min.
Setting time Final (min.)	275	600 Max.
Soundness – Le Chatelier Expansion	0.2	10 Max.
Soundness – Autoclave Expansion	0.01	0.8 Max.
Compressive Strength		
3 days	42	27 Min.
7 days	51.6	37 Min.
28 days	61.2	53 Min.

- *FLY ASH*

Class F Fly Ash confirming to the requirements of ASTM C-618 from field 3 of Dahanu Thermal Power Plant was utilized after conducting the necessary, physical and chemicals tests. Table 2 highlights the properties of fly ash used for the works.

Table 2: Chemical and Physical Properties of Fly Ash

POWER PLANT – DAHANU			
Description	IS 3812 - 1981 (Grade I)	Results	Std. Dev.
Chemical Properties			
Silicon Dioxide, SiO_2 (%)	Min 35%	59.48	1.18
Ferric Oxide, Fe_2O_3 (%)		4.53	0.52
Alumina Al_2O_3 (%)		29.53	0.66
$\text{SiO}_2 + \text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ (%)	Min. 70%	93.54	0.82
Calcium Oxide (%)		1.29	0.26
Sulfur trioxide (%)	Max. 2.75%	0.10	0.07
Loss of Ignition (%)	Max. 12%	0.79	0.18
Potassium Oxide (%)		0.77	0.05
Sodium Oxide (%)		0.40	0.18
Total alkali, Na_2O Eqv. (%)	Max. 1.5%	0.89	0.18

- *AGGREGATE*

A crushed Basalt rock with a maximum size of 20 mm was used as coarse aggregate. Crushed sand and Natural sand from Ambika river in Gujarat were used as fine aggregate. The individual aggregates were blended to get the desired combined grading. The specific gravity and water absorption of the aggregates are given in table 3. The individual grading of aggregate is given in table 4.

Table 3: Properties of Aggregates

Properties	Specific Gravity	Water Absorption
Coarse aggregate 20mm	2.78	0.36
Coarse aggregate 10mm	2.78	0.54
Crushed Sand	2.71	1.91
Natural Sand	2.70	3.54

Table 4: Grading of Fine and Coarse Aggregate

Sieve Size	20mm	10mm	Natural Sand	Crushed Sand
40 mm	100.00	100.00	100.00	100.00
20 mm	90.20	100.00	100.00	100.00
10 mm	7.60	87.30	100.00	100.00
4.75 mm	1.20	8.10	98.57	99.82
2.36 mm		1.20	93.76	79.21
1.18 mm			64.03	39.60
0.6 mm			39.16	26.30
0.3 mm			16.04	17.99
0.15 mm			4.48	12.41
0.075 mm			1.84	11.99

- *CHEMICAL ADMIXTURE*

Sulfonated Naphthalene Formaldehyde based high range water reducing Admixture confirming to ASTM C494 Type G was used.

CONCRETE MIXTURE PROPORTIONS AND LAB TRIAL OBSERVATION

The mixture proportions per cubic meter of concrete selected from trial mixtures along with fresh and hardened concrete properties of trials are as given in Table 5.

Table 5: Concrete Mixture Proportions

		Proposed Mix
Cement		180
Fly Ash		220
Water		135
W/Cm ratio		0.3375
20 mm		550
10 mm		450
Crushed Sand		465
Natural Sand		465
Admixture		2.5% HRWRA
Slump	Initial	Collapse
	After 3 hours	180 mm
Strength	3 days	9.67 MPa
	7 days	13.58 MPa
	14 days	18.35 MPa
	28 days	29.52 MPa
	56 days	37.57 MPa
	91 days	41.11 MPa
Permeability (As Per DIN1048)		Nil

FINDINGS AND RESULTS OF TREMIE SEAL CONSTRUCTION

The workability of concrete at field was determined using slump cone and Flow table. 150mm size cubes were cast for testing at various ages in order to study the strength development behavior of this concrete. Also samples were cast for determining the Water permeability as per DIN 1048 and the modulus of elasticity. The permeability of concrete to chloride-ion penetration was determined as per ASTM C1202. This series of specimens were cast from three batches of concrete made during one and half years. Some samples were tested in two different laboratories i.e. a site laboratory and in an external laboratory. Some samples were cored from the tremie seal concrete after one year to determine the compressive strength of the concrete in the field. The test results are presented in Table 6.

Table 6: Mechanical Properties and durability characteristics of TREMIE SEAL concrete

	Batch 1	Batch 2		Batch 3		
	Site lab	Site lab	Ext. lab	Site lab	Ext. lab	
Compressive Strength, MPa	3 days	10.2	-	-	-	-
	7days	15.0	17.4	-	18.5	-
	14days	20.3	-	-	-	-
	28days	31.2	32.4	30.6	36.5	-
	56days	38.9	37.8	-	47.2	50.6
	91 days	43.5	-	-	-	63.9
	180 days	-	-	-	n.y	n.y
	365 days	-	n.y	-	n.y	-
	(cores) 365 days	55.9	-	-	-	-
Water Permeability, mm (as per DIN 1048)	28 days	40.0	42.5	45	-	-
	91 days	Nil				
Chloride Ion penetration, Coulombs (AS Per ASTM 1202)	28 days	Low	-	Moderate	-	-
	91 days	-	-	-	-	Very low
	365 days	-	-	n.y	-	-
Modulus of elasticity, GPa	28 days	-	26.1	22.0	-	-

N.Y NOT YET DETERMINED

- *COMPRESSIVE STRENGTH*

The concrete used for tremie seal was designed for M30 grade, the results presented in Table 6 show that the 28-d compressive strength ranged from 31.2 to 36.5 MPa. This shows that the concrete has met the requirement of M30 grade, and that the values concurred between different batches and different laboratories, demonstrating the excellent reproducibility and the quality control of the concrete. Due to the use of high volumes of fly ash, this concrete kept gaining strength with time and reached a 91-d compressive strength of 63.9 MPa. At this age, a huge difference was noticed between the compressive strengths determined on samples casted from batch 1 (43.5 MPa) and batch 3 (63.9 MPa). This could be due to the difference in ambient temperature during the period these batches were made. It is known that the curing temperature has a significant effect on the strength development of fly ash concretes i.e. strength increases with increasing curing temperature. The compressive strength determined on

samples cored from the batch 1 tremie seal concrete was 55.9 Mpa. This confirmed the fact that HVFAC keeps gaining strength with time even in the field. Fig. 1 shows the strength development of HVFAC made from batch 1.

- *PERMEABILITY*

The permeability of the concrete was determined by the following two methods: the chloride-ion permeability as per ASTM C 1202 and the water permeability as per DIN 1048 standard. Results of the first method show that HVFAC developed moderate to low permeability at 28 days and low permeability at 91 days. This means that HVFAC will be more durable with time to the ingress of water or any chemicals found in the seawater. The results also show that the 28-d water permeability of HVFAC ranged from 40 to 45 mm, and that at 91-day was negligible. Published data have shown that a water permeability of less than 25 mm is equivalent to very low chloride-ion permeability (i.e. less than 1000 Coulombs).

- *MODULUS OF ELASTICITY*

Table 6 shows that HVFAC developed a 28-d modulus of elasticity ranging from 22.0 to 26.1 GPa. This is rather low compared to the published value of around 30 GPa as the 28-d modulus of elasticity of HVFAC.

- **Case Study 2 - M60 Pile Cap Concrete**

The pile cap constructed on top of tremie seal concrete is of M60 grade. The raw materials and the placement methodology is same as that of the tremie seal concrete except that this concrete was placed in dry condition, achieved with the impermeable tremie seal concrete below.

Requirement of Pile Cap Concrete:

- Grade of Concrete – M60
- Target strength to be achieved in laboratory – 74 MPa
- Open time – 3 hours
- Maximum temperature of concrete – 70 °C

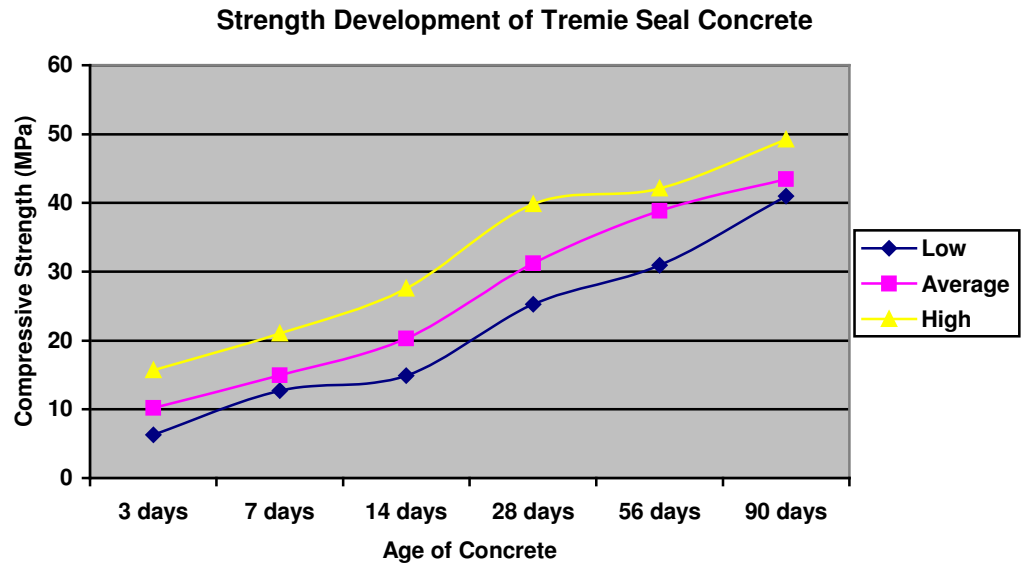


Fig. 1: Strength Development of Tremie Seal Concrete

CONCRETE MIXTURE PROPORTIONS

The concrete mixture proportions used for the pile cap are presented in Table 7.

Table 7: Concrete Mixture Proportions and properties of HVFAC used for Pile Cap

Ingredients (kg/m ³)	Proposed Mix
Cement (L&T 53 Gr)	300
Fly Ash (Dahanu)	196 (40%)
Micro silica	40
Total Water	136
W/cm ratio	0.25
20mm	577
10mm	500
Natural Sand	423
Crushed Sand	327
Admixture	2.5%HRWRA
Properties of Hardened Concrete	
3 days strength	39.31
7 days strength	55.91
28 days strength	75.40
56 days strength	78.23
Permeability (DIN)	0 mm
Max. temperature of concrete	68 °C

FINDINGS AND RESULTS

The same series of test done for the tremie seal concrete was also done for the pile cap concrete. The results are presented in Table 8.

Table 8: Mechanical Properties and Durability Characteristics of HVFAC used in the pile cap

	Batch 1	Batch 2		Batch 3		
	Site lab	Site lab	Ext. lab	Site lab	Ext. lab	
Compressive Strength, MPa	3 days	39.3	-	-	-	-
	7days	55.9	53.5	-	54.8	-
	28days	75.4	62.6	68.5	74.7	-
	56days	78.2	75.1	-	80.9	83.5
	91 days	-	-	-	92.2	82.6
	180 days	-	-	-	n.y	n.y
	365 days	-	n.y	-	n.y	-
	Max. temperature of concrete, °C	68	-	-	-	-
water Permeability, mm (as per DIN 1048)						
	28 days	0	8.8	7.0	-	-
Chloride Ion penetration, Coulombs (AS Per ASTM 1202)	28 days	-	-	Very low	-	-
	91 days	-	-	-	-	Very low
	365 days	-	n.y	n.y	n.y	n.y
Modulus of elasticity, GPa	28 days	-	36.3	31.4	-	-
	91 days	-	-	-	40.6	40.5

- *COMPRESSIVE STRENGTH*

The concrete was designed to develop a 28-d compressive strength of around 74 MPa. Table 8 shows that concretes from both batch 1 and 3 developed a 28-d compressive strength of around 75 MPa., except batch 2, which had strength values ranging from 62.6 to 68.5 MPa. However, at 56 days, the latter concrete developed a compressive strength of around 75 MPa, while, the 56-d compressive strength of concrete from batch 1 and 3 ranged from 78.2 to 83.5 MPa. This illustrates that the 28 strength requirements usually applied for normal concrete, could be changed to later ages (56 or 91 days) for HVFAC, since the strength gain of this type of concrete is substantial with time as shown in Fig.2.

- *PERMEABILITY*

HVFAC developed low chloride-ion permeability and a water permeability ranging from 7 to 8.8 mm at 28 days. This shows the high resistance of this concrete to the ingress of water or any type of ions found in the seawater.

- *MODULUS OF ELASTICITY*

The 28-d modulus of elasticity of HVFAC ranged from 31.4 to 36.3 GPa., and that at 91 days was around 40.5 GPa.

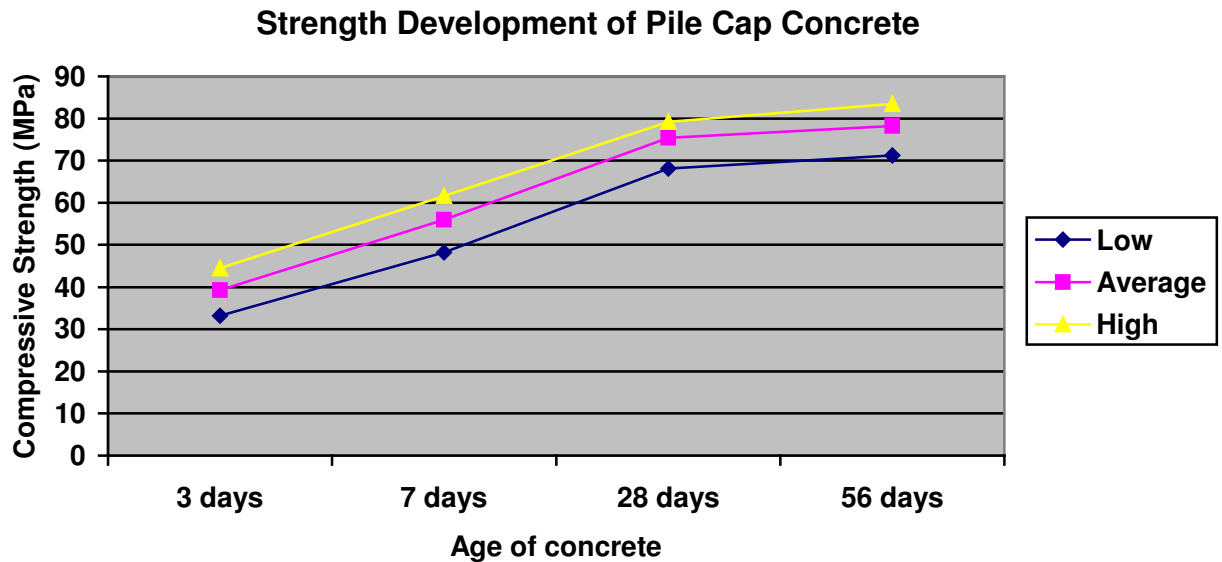


Fig. 2: Strength Development of Pile Cap Concrete

GHG REDUCTION

The total Tremie seal and pile cap concrete for the project is 20000 and 55000 cum. In general, M30 and M60 grade concrete when made with portland cement only requires a cement content of around 400 & 420 kg/m³ respectively. Tremie Seal concrete was made with 180 kg/m³ of portland cement only, whereas the pile cap concrete was made with 300 kg/m³ cement. This would result in a saving of 0.22 & 0.12 tones of CO₂ for each m³ of concrete for Tremie seal & Pile cap, respectively. The whole project will result in approximately 11000 tones of CO₂ reduction.

CONCLUSION

- High volume fly ash concrete is an economical and durable option for structural as well as general concreting purposes.
- High volume fly ash concrete doesn't require any special efforts in terms of mixing & placing; this concrete can be mixed, transported and placed

using conventional means.

- The high volume fly ash concrete can be effectively utilized in under water concrete applications where concrete is required to be cohesive enough to have anti washout resistance.

The rise in temperature of concrete particularly in case of mass concrete can be effectively controlled with high volume fly ash concrete.

ACKNOWLEDGMENT

This report has been prepared based on information provided by officials from The Hindustan Construction Company Ltd. Special thanks are extended to Mr. Mohamed Ashraf and Mr. Manish Mokal from HCC

REFERENCE

- a. ACI 211.1-97 "Standard Practice for selecting Proportion of Normal, heavy weight and Mass Concrete"
- b. ACI 304.2 R-96 "Placing concrete by pumping methods"
- c. ACI 211.3 R "Guide for selecting proportions for No Slump Concrete"
- d. High Volume Fly Ash Concrete – V. M. Malhotra

ANNEXURE A

Date	28/01/04	28/01/04	29/01/04	29/01/04	30/01/04
Location	BWSL Lab	BWSL Lab	BWSL Lab	BWSL Lab	BWSL Lab
Lab Trial Mix No	TM-518 B	TM-518 D	TM-523 A	TM-523 B	TM - 524A
Total Cement	400	400	440	440	400
W/C Ratio	0.337	0.337	0.337	0.337	0.337
OPC 53 Grade	180	180	198	198	180
Flyash	220	220	242	242	220
CA 20 mm	577	577	577	577	660
CA 10mm	385	385	385	385	430
Crushed Sand	467	467	467	467	420
River Sand - COARSE	467	467	467	467	420
River Sand - FINE	0	0	0	0	0
Free Water	135	135	135	135	135
Admixture	8	6	11.44	11.44	10
Dosage %	2.00%	1.50%	2.60%	2.60%	2.50%
Admixture Name	SP 430 SRV	Superplast HS	SP 430 SRV	SP 430 SRV	SP 430 SRV
Supplier	FOSROC	SWC	FOSROC	FOSROC	FOSROC
Slump (mm) / Flow (%)					
Initial	220 / 182%	200 / 140%	210/145%	210/145%	Collaps/200 %
1 Hour	200 / 145%	190 / 110%	200/137%	200/140%	Collaps/200 %
2 Hour	100 / 50%	150 / 92%	200/137	200/140	Collaps/200 %
3 Hour	x	100 / 65%	190/135%	190/137%	220/187%
Compressive Strength (Mpa)					
3 Days	9.8	9.8	11.86	10.73	10.91
7 Days	14.29	14.11	15.67	15.98	15.94
14 Days	19.6	18.6	23.07	23.31	20.77
28 Days	26.64	26.62	31.38	30.58	26.95
56 Days	31.42	x	36.89	33.89	27.00
90 Days	x	45.09	52.02	44.09	x

ANNEXURE A(Contd.)

Date	30/01/04	02/02/04	03/02/04	02/07/04	03/07/04
Location	BWSL Lab	BWSL Lab	BWSL Lab	BWSL Lab	BWSL Lab
Lab Trial Mix No	TM - 524C	TM - 532A	TM - 532C	TM - 533A	TM - 533B
Total Cement	400	400	400	400	400
W/C Ratio	0.337	0.337	0.35	0.355	0.3625
OPC 53 Grade	180	180	180	180	180
Flyash	220	220	220	220	220
CA 20 mm	660	550	550	580	580
CA 10mm	430	450	450	460	460
Crushed Sand	420	279	465	445	356
River Sand - COARSE	420	651	465	445	534
River Sand - FINE	0	0	0	0	0
Free Water	135	135	140	142	145
Admixture	8.8	10	2.4+2	2.4+ 2.0	2.8+2.0
Dosage %	2.20%	2.50%	0.6% + 0.5%	0.6% +0.5%	.07% +0.5%
Admixture Name	SP 430 SRV	SP 430 SRV	Gleni + Retard	Gleni + Retard	Gleni + Retard
Supplier	FOSROC	FOSROC	MBT	MBT	MBT
Slump (mm) / Flow (%)					
Initial	Collaps/200%	Collaps/200%	Collaps/152%	170/90%	190/125%
1 Hour	Collaps/200%	Collaps/200%	120/115%	70	95
2 Hour	Collaps/195%	Collaps/200%	100/100%	x	x
3 Hour	220/187%	210/182%			
Compressive Strength (Mpa)					
3 Days	10.03	10.27	11.62	12.33	11.48
7 Days	13.98	14.2	16.07	17.44	17.75
14 Days	19.89	20.64	21.74	x	x
28 Days	25.9	27.24	29.53	28.38	26.44
56 Days	x	37.07	39.21	44.62	x
90 Days	45.27	48.51	48.53	x	46.6

ANNEXURE A(Contd.)

Date	17/02/04	19/02/04	19/02/04	19/02/04
Location	BWSL Lab	BWSL Lab	BWSL Lab	BWSL Lab
Lab Trial Mix No	TM - 534A	TM - 537B	TM - 538A	TM - 538B
Total Cement	400	400	400	400
W/C Ratio	0.337	0.337	0.325	0.337
OPC 53 Grade	180	180	180	180
Flyash	220	220	220	220
CA 20 mm	691	550	570	595
CA 10mm	460	450	470	485
Crushed Sand	0	650	630	850
River Sand - COARSE	768	280	260	0
River Sand - FINE	0	0	0	0
Free Water	135	135	130	135
Admixture	8.8	10.8	10	10
Dosage %	2.20%	2.70%	2.50%	2.50%
Admixture Name	SP 430 SRV	SP 430 SRV	SP 430 SRV	SP 430 SRV
Supplier	FOSROC	FOSROC	FOSROC	FOSROC
Slump (mm) / Flow (%)				
Initial	Collaps/187%	Collaps/200%	Collaps/200%	Collaps/200%
1 Hour	210/187%	Collaps/200%	220/192%	210/200%
2 Hour	190/160%	Collaps/200%	220/190%	190/187%
3 Hour	165/97%	220/200%	210/182%	180/182%
Compressive Strength (Mpa)				
3 Days	11.44	11.99	13.3	9.1
7 Days	18.22	19.67	21.89	18.73
14 Days	27.33	22.53	23.95	22.62
28 Days	29.68	31.7	32.91	30.98
56 Days	43.93	47.15	45.73	47.75
91 Days	Awaited	Awaited	Awaited	Awaited