Efficient Use of Superplasticizers for Durable Concrete Construction

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High-range water reducers

1st generation: Lignosulphonates at high dosages

2nd generation:
Polysulphonates
- Sulphonated melamine formaldehyde (SMF)
- Sulphonated naphthalene formaldehyde (SNF)

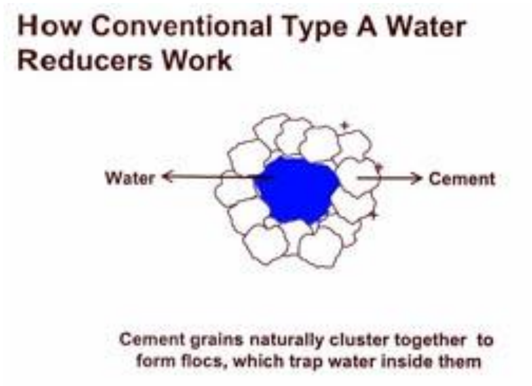
3rd generation:
- Polycarboxylates
- Polyacrylates
- Monovinyl alcohols

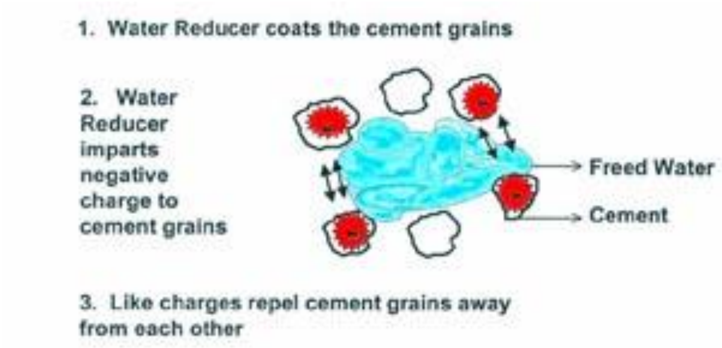
Typical dosage: 0.7 – 1.0% by weight of cement.
Also called ‘Superplasticisers’

Mechanism of action - old

- **Lowering of Zeta Potential (leading to electrostatic repulsion) after surface adsorption**

- **Substances with functional groups**
  - Lignosulfonates
  - Sulfonated condensate of naphthalene formaldehyde
  - Sulfonated condensate of melamine formaldehyde
  - Sugar refined lignosulfonates



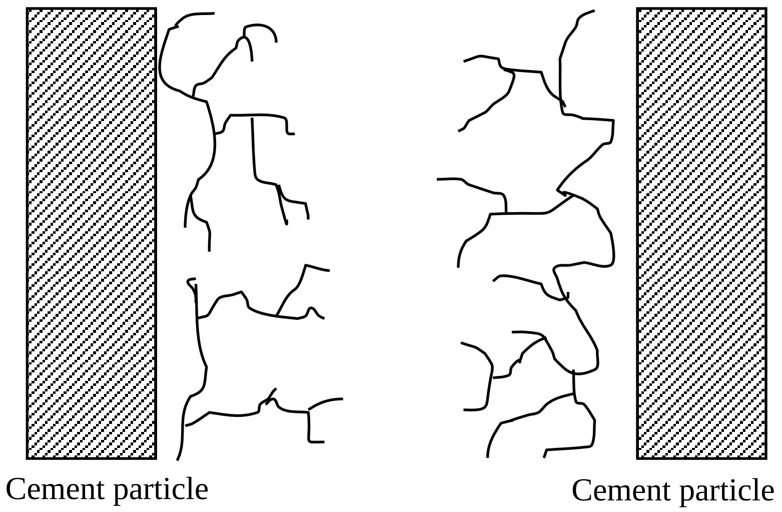


http://www.carolinapumping.com/education/elementary/admixtures.html

Mechanism of action - new

- **Steric hindrance**

- **Polymers with backbone and graft chains**
  - Polycarboxylic ether (PCE)
  - Carboxylic acrylic acid with acrylic ester
  - Cross linked acrylic polymer



Up to 40% water reduction possible!!

Santhanam, 2011

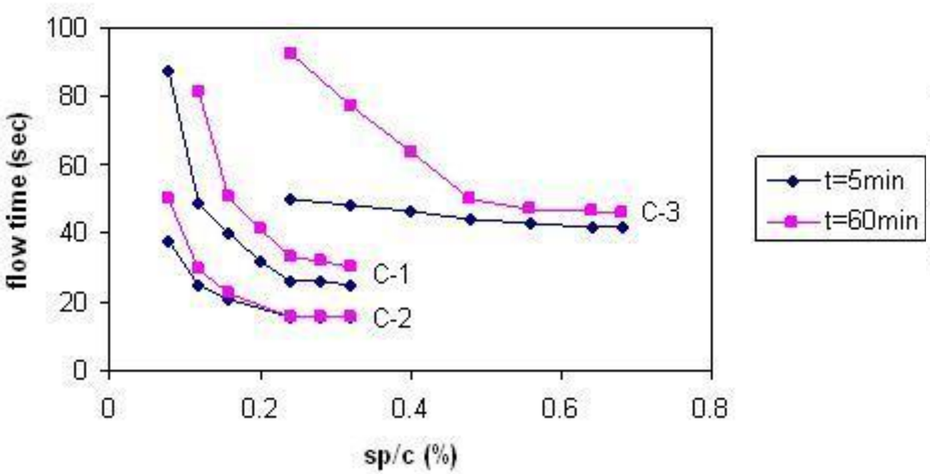
Range of action

The 1st generation HRWRs need a slump of around 75 mm for action (~0.45 w/c). The slump is increased up to 150 – 200 mm.

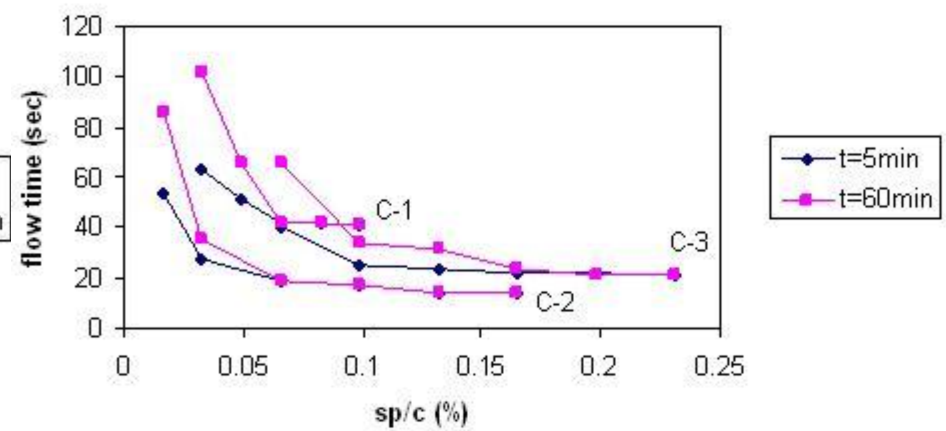
The 2nd generation admixtures can work at reasonably low slumps (25 – 50 mm, corresponding to w/c of 0.35 – 0.40) to increase the slump to ~ 250 mm.

The 3rd generation HRWRs, on the other hand, can even be used with no slump concrete (0.29 – 0.31 w/c), and the slump is increased to more than 250 mm.

Paste tests with different cement – SP combinations



SNF



PCE

	C-1	C-2	C-3
PCE	0.066, 162	0.066, 155	0.165, 175
LS	0.266, 114	0.228, 80	0.760, 125
SNF	0.240, 150	0.240, 139	0.640, 158
SMF	0.266, 153	0.228, 138	0.456, 129

PCE more compatible than SNF
Optimum dosages for PCE lowest among four families of SPs

Santhanam, 2011

Lab investigations on concrete

	w/c	Slump values (mm)				Compressive strength (MPa)	
		0min	30min	60min	90min	3 days	7 days
Control mix	0.45						
C-1		170	70	10	0	20.0	25.3
C-2		180	70	10	0	20.3	26.0
C-3		120	40	0	0	27.3	28.5
With PCE	0.35						
C-1		180	140	80	20	34.0	36.9
C-2		190	140	80	20	36.0	39.0
C-3		190	130	60	20	40.4	40.7
With LS	0.35						
C-1		110	80	10	0	16.2	26.3
C-2		100	60	0	0	17.3	26.5
C-3		80	10	0	0	18.7	28.3
With SNF	0.35						
C-1		150	80	0	0	32.8	39.0
C-2		140	60	0	0	33.4	38.4
C-3		200	130	40	0	38.8	41.8
With SMF	0.35						
C-1		140	100	70	20	32.4	38.5
C-2		190	130	40	0	31.0	38.8
C-3		100	40	0	0	34.2	40.0

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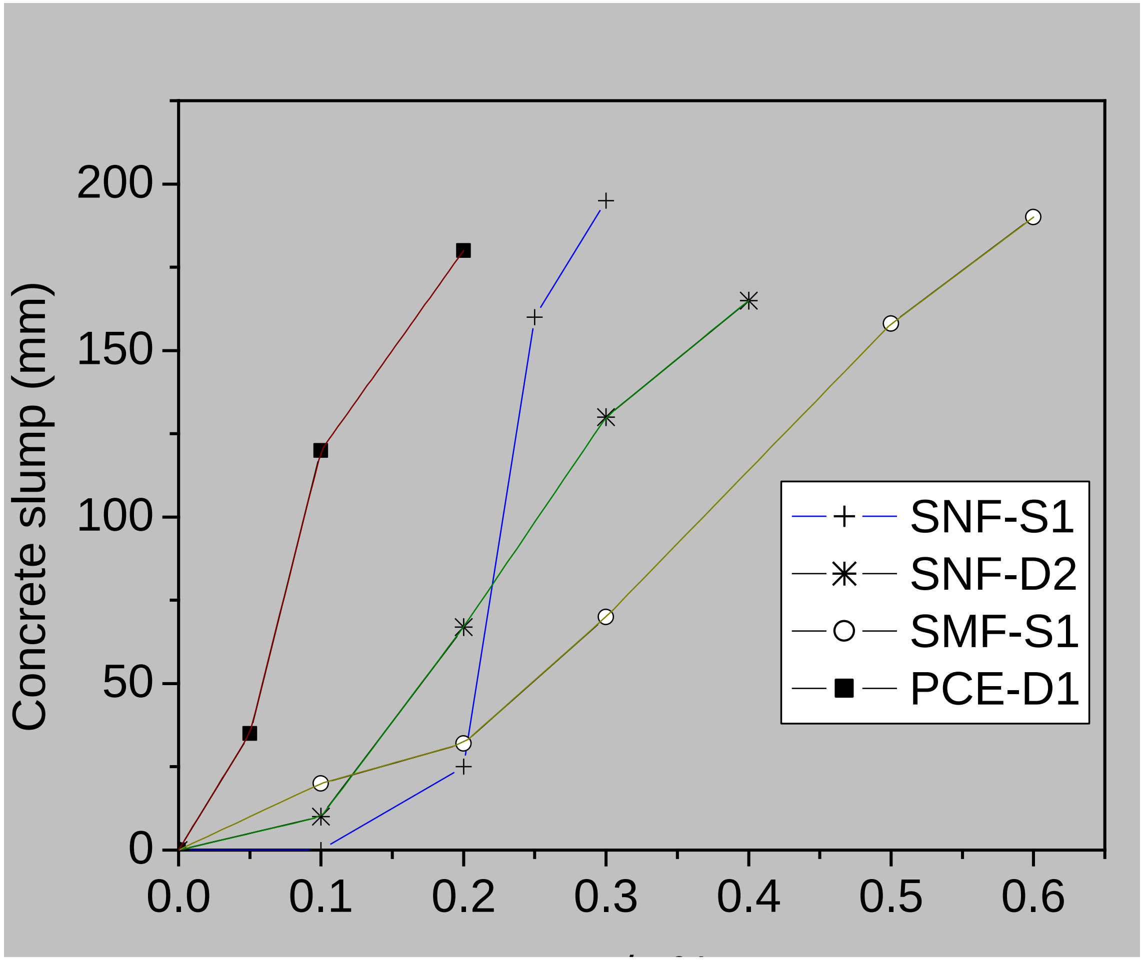
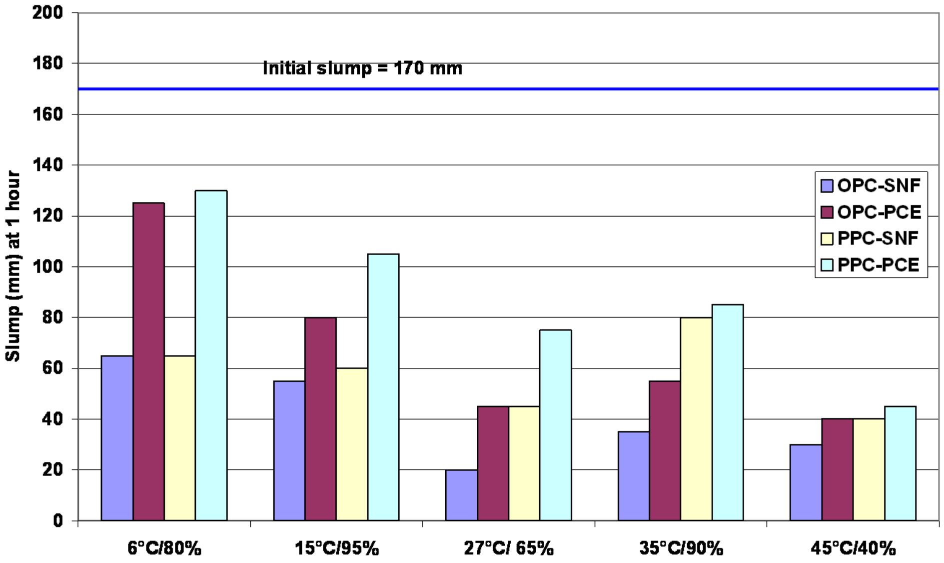
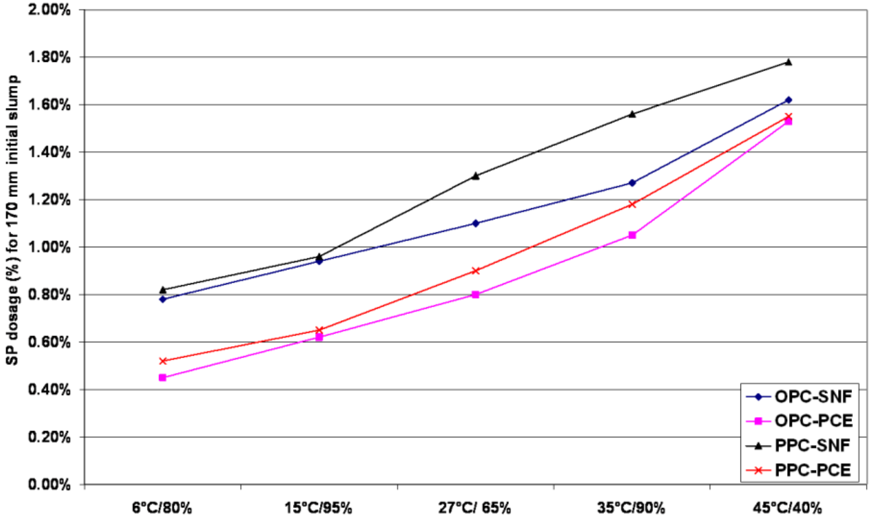
Concrete performance with SPs



Jayasree and Gettu, 2009

Temperature effects on concrete





PCE based concrete shows less sensitivity to temperature effects
Admixture dosage changes with temperature!
PPC based concrete better

Santhanam, 2011

Mixing related effects

- PCE based concrete workability not sensitive to time of addition of the SP, while SNF mixes do show some dependence – late addition maintains workability for longer time; however, slower strength gain when PCE added later
- Mix size – Initial slump increases with increasing size of mix at same dosage! Higher mixing speeds also lead to higher initial slump → goes to suggest that admix dosages fixed based on lab trials will have to be adjusted at site

Case Study of HPC at Chennai Airport

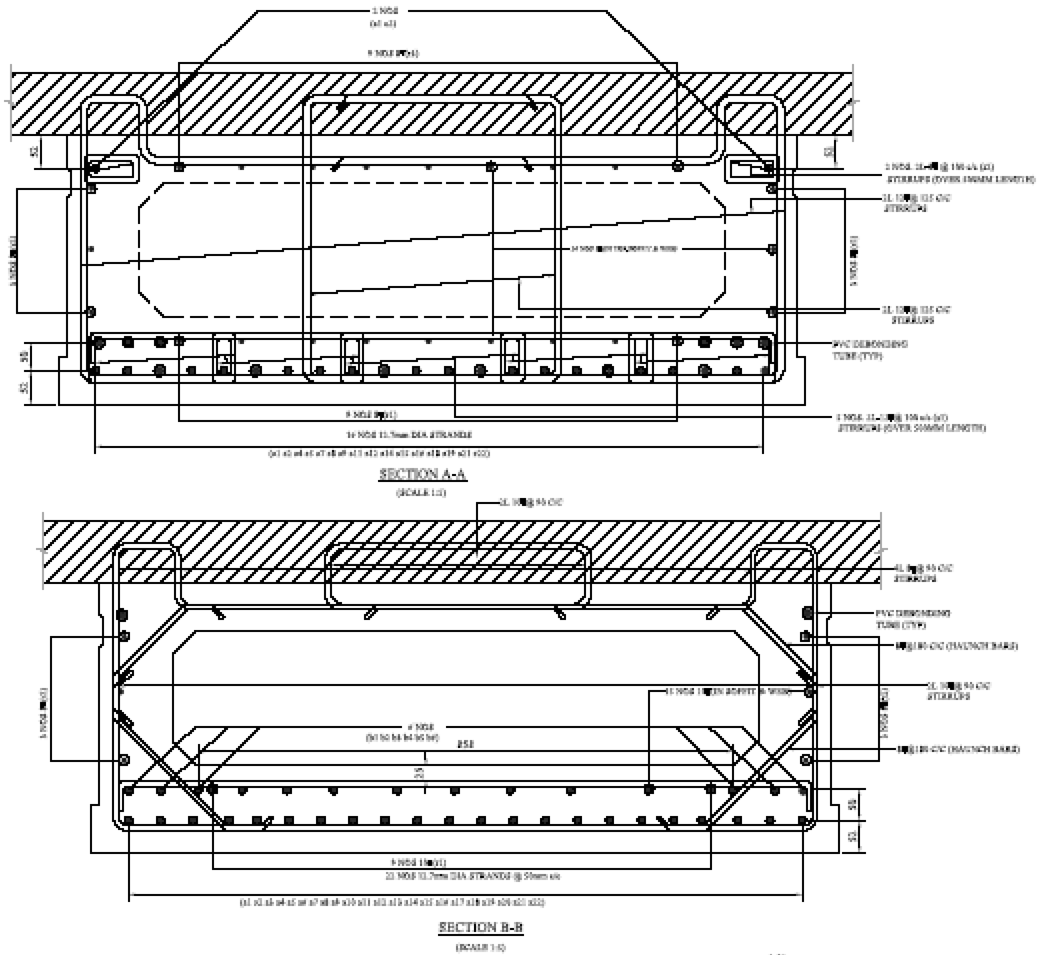
Box girder: M45 steam cured

4 winged pier: M50 normally cured

Cap beam: M65 normally cured

I-girder: M60 steam cured

Box Girder

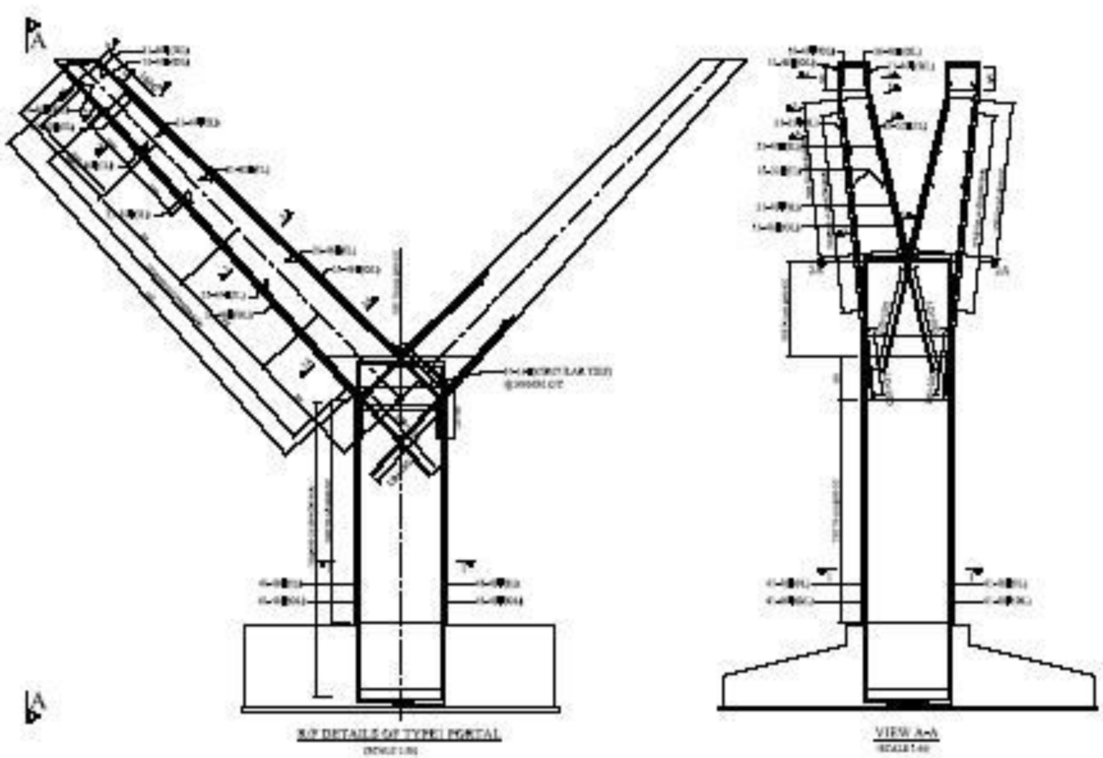


Highlights:

- M45 steam cured concrete
- OPC 43
- PCE based superplasticizer
- >100 mm slump requirement at time of placing
- Requirement of 35 MPa at the end of steam curing cycle
- Base concrete placed first, followed by polystyrene box for the central section, and then sides and top concreting

Santhanam and Balasubramanian, 2010

4-winged pier



Highlights:

- M50 moist cured concrete
- OPC 43
- SNF based superplasticizer
- >100 mm slump requirement at time of placing
- 50 MPa strength required at 7 days
- Extreme congestion of reinforcement at the junction of vertical and slanted elements
- Difficult to place concrete

Santhanam and Balasubramanian, 2010

Santhanam and Balasubramanian, 2010

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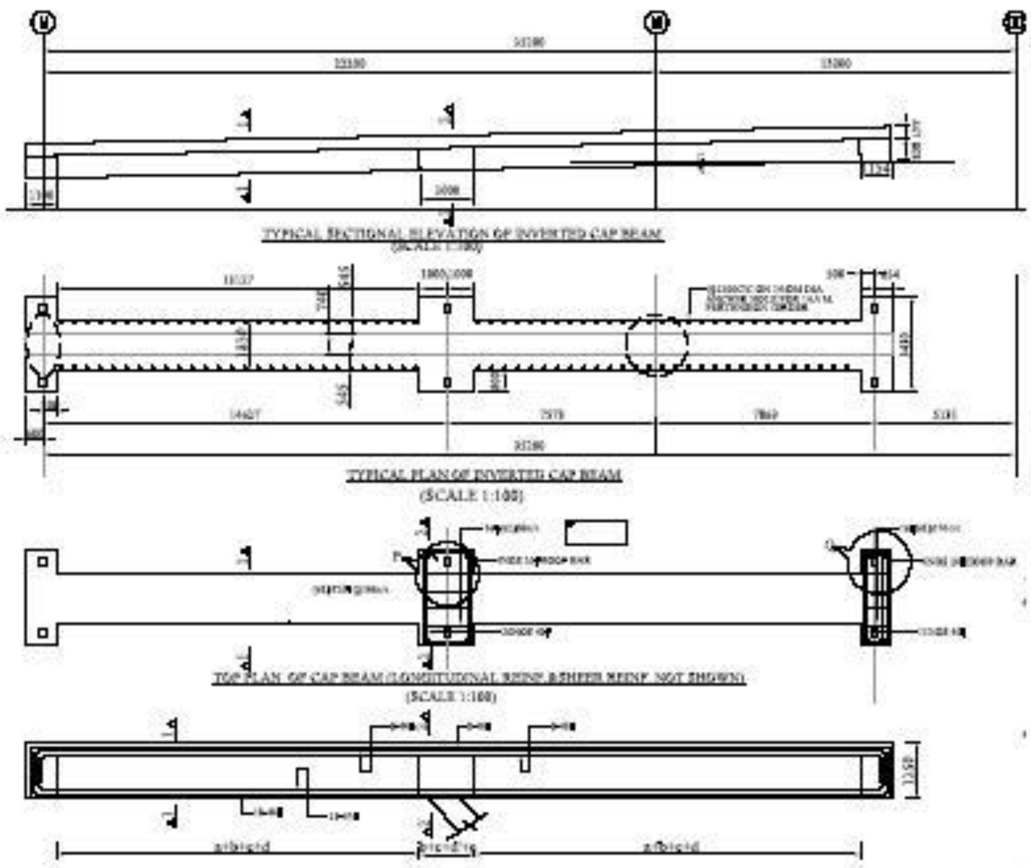
Cap Beam

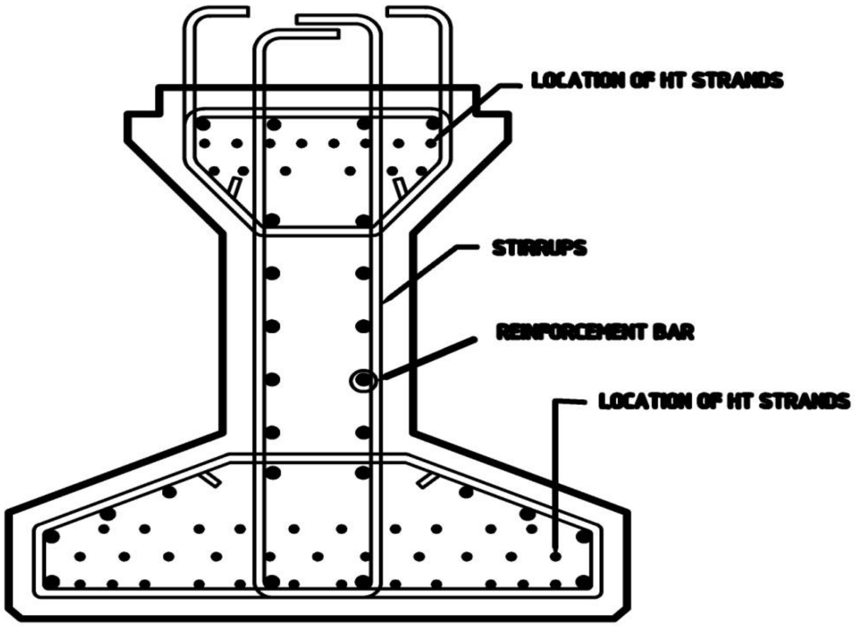


Highlights:

- 65 MPa moist cured concrete
- OPC 43 and silica fume
- PCE based superplasticizer
- >100 mm slump required at time of placing

Santhanam and Balasubramanian, 2010

I-girder



CROSS SECTION OF FULL STRENGTH GIRDER

Highlights:

- 60 MPa steam cured concrete
- OPC 53 and silica fume
- PCE based superplasticizer
- 60 MPa strength requirement at the end of steam curing cycle
- >100 mm slump required at time of placing

Santhanam and Balasubramanian, 2010

Santhanam and Balasubramanian, 2010

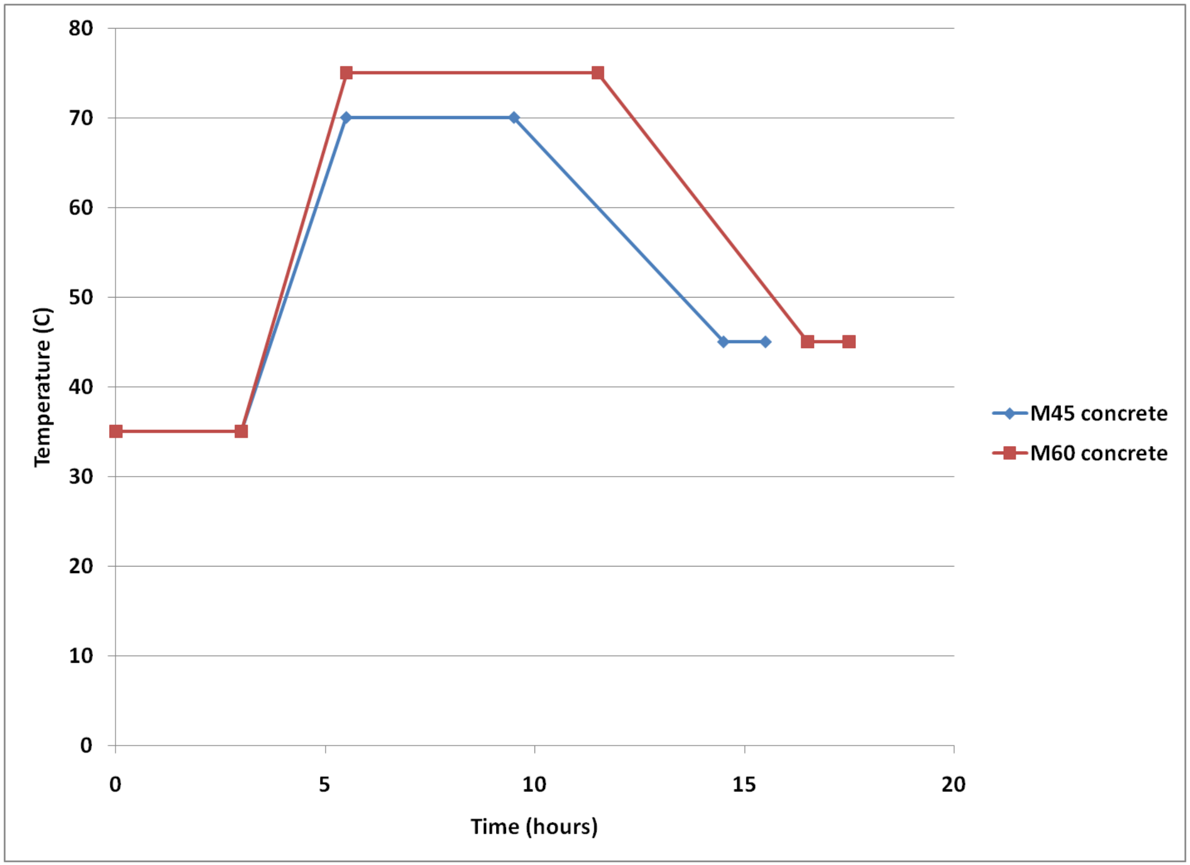
Parameters for lab designs

- Initial slump (with no bleeding) of 150 – 180 mm, and 1 hour slump in excess of 100 mm desired
- M45 steam cured concrete – 35 MPa required after 16 hour steam curing cycle
- M50 moist cured concrete – 65 MPa required at 28 days (and 50 MPa at 7 days)
- M60 steam cured concrete – 60 MPa required after 18 hour steam curing cycle
- M65 moist cured concrete – 80 MPa required at 28 days (and 65 MPa at 7 days)

Finalized mixture designs

Mix Designation→	M45 SC	M50 MC	M65 MC	M60 SC
Cement (kg/m^3)	450	450	450	500
Silica fume (kg/m^3)	-	-	45	50
Sand (kg/m^3)	730	715	703	768
12 mm CA (kg/m^3)	547	536	527	469
20 mm CA (kg/m^3)	547	536	527	469
Water (kg/m^3)	126	162	148.5	143
w/cm	0.28	0.36	0.30	0.26
Coarse to Fine Aggregate	60:40	60:40	60:40	55 : 45
20 mm : 12.5 mm aggregate	50:50	50:50	50:50	50 : 50
Superplasticizer (% bwoc*)	1.0% (PCE)	0.9 % (SNF)	0.9 % (PCE)	1.16 % (PCE)
Room temp. (^oC)	32.0	34.0	34.0	32.0
Concrete temp. (^oC)	31.0	33.0	32.5	34.0
Slump (mm) Initial 60 min	 160 120	 220 150	 220 165	 190 120
Compressive strength (MPa)				
Required target	35 (after 16 hours)	65 (at 28 days)	80 (at 28 days)	60 (after 18 hours)
Achieved	45 – 50	65 – 70	80 – 85	70 – 75

Steam curing cycles adopted



Highlights:

- Careful control of maximum temperature required – when T > 80 C, possibilities of delayed ettringite formation
- Need to ensure that steam reaches all sections of the segment properly
- Delay period (before temperature rise) extremely important – it is loosely equal to the initial setting time

Field trials

- Mix designs CANNOT be finalized without field trials
- 'LABCRETE' ≠ 'FIELDCRETE'!!
- Some parameters that could be vastly different include SP dosage, time of mixing, specimen preparation (!!), curing quality and duration
- Even on site, SP dosage estimations can be performed using mini slump and Marsh cone tests on paste

Lessons Learnt

- Retention of workability – A parameter not given due consideration
- Redosing of admixture on site
- Sequence of mixing – Particularly when Silica fume and PCE based admixture are involved → concrete mixing schedules should be adjustable…

Design and steam curing issues

- Mix design should be dynamic with minor variations in the sand content and proportion of the 20 and 12 mm- due to source change in materials
- Complicated shapes of structural members with congestion of reinforcement - SCC should be used
- Max temperature during steam curing- be restricted to 70 – 75 ^{o}C to counter DEF

Summary

- Limitations of the type of superplasticizer must be clearly understood
- PCE presents distinct benefits
- More than 1,00,000 cubic meters of High strength concrete laid successfully in the airport project - No reported failure
- Extremely low water contents used in the design of the mixes - executed well at site