BENEFIT COST ANALYSIS OF SELF COMPACTING CONCRETE OVER CONVENTIONAL REINFORCED CEMENT CONCRETE

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Abstract

Self-compacting concrete offers numerous advantages over conventional cement concrete, however it has not been largely used in the construction industry. Self-compacting concrete (SCC) can flow under its own weight and we can have compacted concrete even in congested reinforcements. Due to high workability, it reduces the labor & machine component thereby increasing productivity, It also reduces the need of vibrator for compaction thus reducing the cost component for compaction and also noise pollution caused by it. Super-plasticizers are essentially needed to increases the workability which increases the cost of SCC over conventional concrete. This research paper aims to perform a benefit cost analysis of self-compacting concrete and list down the process and criteria of selection of SCC. It can also help in drafting guidelines for the selection of Self Compacting Concrete.

Keywords: *Self-Compacting Concrete, Cement Concrete, Selection Process, Benefit-Cost Analysis.*

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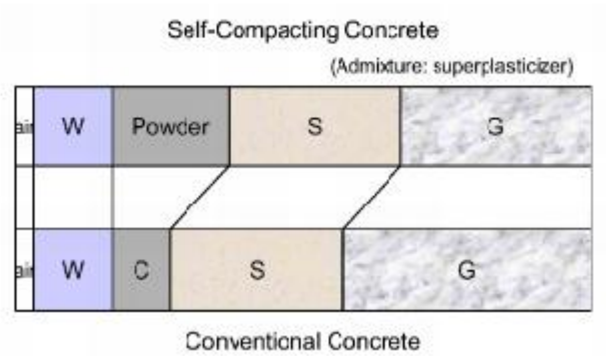
1. INTRODUCTION

Self-compacting concrete or self-consolidating concrete or self levelling concrete as the name suggests is that concrete which is flowable and compacts under its own weight. It has the ability to flow on its own and can reach deep even in dense reinforcement filling up the formwork completely. It does not need any external source of compaction such as mechanical vibrator and has the ability to maintain homogeneity. The main principle of self-compacting concrete is *"the sedimentation velocity of particle is inversely proportional to the viscosity of the flowing medium in which the particle exists"* (Tande S.N., 2007). Some of the characteristics of SCC are low yield stress, higher deformability and moderate viscosity. A well designed SCC mix does not segregate, gives excellent stability and high deformability characteristics. This type of concrete was developed in Japan in year 1988 by Prof H. Okamura in Tokyo University. Shortage of skilled labor and defective workmanship lead to development of SCC by Prof. H. Okamura. Today most of the concreting works in Japan are done by SCC only.

The three key parameters for classifying any concrete as self-compacting concrete are (EFNARC, 2002):

- Filling Ability – SCC should be able to fill the formwork completely by going into each and every corner on its own.
- Passing Ability – SCC should have the capability to pass the congested reinforcement without the need of external compaction like vibrator.
- Segregation resistance – SCC like other concrete is made up of several constituent materials having different specific gravities, so it is possible that at the time of placing materials having heavy mass tend to settle causing segregation. The mix should be made such that it should be able to resist segregation and maintain its homogeneity.

A comparison between constituents of conventional concrete and self-compacting concrete can be seen in figure 1.



W – Water, C – Cement, S – Sand, G – Gravels

Fig 1 : Comparison between constituents of conventional concrete and self-compacting concrete. Courtesy: Okamura H et al, 2003

SCC contains a higher dosage of fines (passing 100 microns) and super-plasticizers in unit content of concrete as compared to conventional concrete. The content of fine aggregates is almost same whereas the quantity of coarse aggregates required for SCC is less than conventional concrete.

In India, Self-compacting concrete is not widely used. Some of the projects in which SCC is used are Nuclear Power Corporation of India Ltd. at Tarapur, Kaiga, Rajasthan Atomic Power Project (RAPP), Delhi Metro etc. (Sood et

al., 2009). A factor which may have caused its less acceptance in Indian markets may be its high cost associated when compared to conventional concrete. This high cost is due to additional super plasticizers and admixtures which make self-compacting concrete behave like fluid. At the same time it offers advantages which is not offered by the conventional concrete. So, there is a need to study whether SCC should be selected despite having high cost which could be determined by one of the factors known as benefit/cost ratio. A benefit-cost ratio greater than 1 would suggest the use of self-compacting concrete is an economical option. The high cost of SCC when compared to conventional concrete is counteracted by the benefits it provides. Similarly, benefit-cost ratio less than 1 would suggest that use of SCC is not economical when compared to conventional concrete but at the same time there are conditions when use of SCC would have to be done or to take the benefits that conventional concrete cannot provide.
This paper lists the advantages and disadvantages of using SCC in construction projects along with the conditions in which SCC should be used. The results mentioned in this paper can be achieved only when desired quality assurance and control is maintained while designing the mix and executing the work. Paper has derived criteria of use of SCC, where in conventional concrete would not be a suitable option. Finally benefit-cost ratio has been worked out considering the advantages that SCC provide over conventional concrete.

2. ORIGIN OF SELF COMPACTING CONCRETE

Starting from the year 1983, Japan saw that the durability of their structures were decreasing mainly because of lack of skilled workers. Skilled workers were needed to perform compaction of concrete. With the decline of skilled workers the quality of construction started deteriorating. There was need of concrete which could compact because of its own weight and fill the formwork completely by going into each and every corner. Okamura came with such type of concrete in 1986.

Self-compacting concrete was first made in 1988 using materials available in the market. The mix performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties. This concrete was named as "High Performance Concrete." and had the following three stages (Okamura, H et al., 2003):

- Fresh, self-compactable
- Early age: avoidance of initial defects
- After hardening: protection against external factors

Professor Aitcin at almost the same time defined "High Performance Concrete" as a concrete with high durability due to low water-cement ratio. So, the term high performance concrete came to be known in the world as high durability concrete. Therefore, Okamura changed the term for the concrete proposed by him to "Self-Compacting High Performance Concrete" (Okamura, H et al, 2003). Later in 1990s the research and development for SCC began in Sweden (Europe) and now nearly all countries do some research for this material (Goodier, C.I., 2003).

3. LITERATURE REVIEW

- In 2005, H Azamirad et al published a paper "A criticism of Self-Compacting Concrete" which talks about the problems in using SCC such as segregation and roles of different materials which affect it. It talks about the economic problems too. Finally it says about some projects which are executed with SCC. This paper helped in identifying the disadvantages of using SCC.
- In 1990, T.H. Cooke wrote a book "Concrete Pumping and Spraying: A practical guide". This book is related to pumping operations of concrete. A nomograph is suggested by this book which is used for determining the working power required for conventional concrete and SCC so that costing can be done. It explains the graph and tells the method of usage.
- In 2014, CPWD published Delhi Analysis if Rates, Vol. 1 and 2 which gives the rates of labor, material and machinery. It also gives the costing of different works and explains the method by which these rates are determined. In this study some of the costing has been done with the rates taken from these two volumes with necessary cost index so as to make them according to the latest rates.
- In 1992, Bureau of Indian Standards published Indian Standard on Concrete Vibrators – General Requirements which talks about vibrators and their method of usage in detail. It tells about the performance requirements as well. It also defines materials to be used in construction of vibrators. The significance of this standard for this study is that size (diameter) of vibrator is taken from here for calculation purposes in determining the percentage of reinforcement above which SCC is used.
- In 2009, Bureau of Indian Standards published Indian Standard on Concrete Mix Proportioning- Guidelines which tell about the mix design procedure to be adopted for designing various conventional concrete mixes. Significance to this study is that M40 conventional concrete has been designed by following the methodology set by this standard.
- In 2003, Hajime Okamura et al published a paper "Self Compacting Concrete" which talks about the development of SCC, mechanism by which SCC achieves self-compact ability, current status of SCC and applications of SCC in Japan. This paper has helped in understanding of difference in quantity of constituent materials in conventional concrete and SCC. It provided a background about the origin of SCC and its development.
- In 2015, Matha Prasad Adari et al published a paper "An experimental development of M40 grade self-compacted concrete and comparison in behavior with M40 conventional concrete" which suggested on how SCC is made and suggested some of the properties of SCC. They did experiment to determine the required

quantities of materials so that SCC of M40 grade can be prepared. Testing of the sample was done as per different tests specified so to check that the prepared sample meets the all the criteria to be called as self-compacting concrete. After that conventional M40 grade concrete sample is prepared and properties of both samples were compared. They concluded the strength of SCC is higher than conventional concrete. This study took the mix design of M40 SCC for the purpose of cost comparison.

4. ADVANTAGES OF SELF COMPACTING CONCRETE

- Faster construction can be achieved with the use of SCC as the workability of this concrete is high so transportation can be done easily. Pumping operations will require less energy as it possesses flow able properties. Further due to its flowing nature speed of construction will be increased. Rapid rate of concrete placement is possible decreasing the placing time.
- Reduction in site manpower is achieved in various stages like faster pumping requires less manpower hours, reduction of vibration needs negligible manpower, smooth surface obtained from SCC needs less labor for finishing purposes, if SCC is placed properly then there are negligible bug-holes and patches on surface thus reducing the manpower demand.
- The construction process becomes more productive which is evident by the fact that the truck has to wait for less time for unloading of SCC and can go early thus improving the productivity. Also the service life of vibration equipment and formwork will increase. Due to elimination of vibration to consolidate the mixture, the forms used in the precast operations will receive less wear and tear, decreasing the regular maintenance costs and costs of investing in new forms. SCC also shows high early strength allowing early removal of formwork thus increasing productivity.
- Improved durability (Ramsburg et al., 2003) because the surface obtained by using SCC is devoid of bug-holes or openings thus preventing the entry of water into the surface making it durable when compared to reinforced cement concrete.

5. DISADVANTAGES OF SELF-COMPACTING CONCRETE

- Requirement of more precise measurement and monitoring of the constituent materials.
- Requires more trial batches at laboratory and ready-mixed concrete plants.
- Lack of globally accepted test standards and mix designs
- More stringent requirements on the selection of materials.
- High fluidity and lack of care while placing SCC can lead to segregation.
- Wrong dose of admixtures and sand moisture content can change the properties of SCC to a large extent as SCC is a sensitive mixture.
- Difficult to determine the concrete produced in batching plants is SCC or not (Azamirad H. et al., 2005).
- Difficult to carry out self-compacting tests as it is needed to be done for the whole mix prepared (Azamirad H. et al., 2005).
- SCC to be handled carefully during transportation as well as on site.
- Problems related to the hardened SCC (e.g. low surface quality, reduced fire resistance due to spalling, increased cracking due to early shrinkage and increased drying shrinkage) can occur if the climatic conditions are adverse.
- Increased pressure on formwork leading to formation of leach.
- Lack of knowledge on SCC and unclear responsibility of the ready-mix producer versus the contractor.

6. PROCESS OF SELECTION OF SELF COMPACTING CONCRETE

The selection of SCC over RCC should be done in the following cases:

1. When congested reinforcement is present (compaction by manual or by mechanical vibrator is difficult in this situation) in a member then to ensure that concrete reaches in every corner and fills the formwork completely without voids and honeycombs, self-compacting concrete may be used.
2. Underwater concreting can be difficult if reinforced cement concrete is used as it will require compaction which will be difficult to perform. This problem can be addressed with the use of self-compacting concrete.
3. The surface finish produced by self-compacting concrete is good and patching is not necessary. This property becomes critical in selection of self-compacting concrete when pre-cast architectural panels are made. If SCC is proportioned right then bug-holes, honeycombs and other surface imperfections can be reduced on the finished surface obtained.
4. Areas where noise is undesirable like schools, hospitals etc. then SCC can be preferred since there is no requirement of vibration so no noise pollution is created. Concreting being done at night in residential areas will also require noise reduction. Exposure of workers and use of hearing protection can be reduced thereby reducing the insurance and safety costs.
5. Sloping or curved surfaces like domes where it is difficult for labor to reach to do compaction by vibration then SCC can be preferred as it will get compacted by its own weight ex. Rotary dome at Central Secretariat Metro station shown in figure 2.
6. Thinner concrete sections which due to workability issues couldn’t be accepted if using RCC are possible with SCC.
7. Greater freedom in design is possible as thin sections like filigree elements can be incorporated with the help of SCC. Slim and compacted moulds can be designed thus giving freedom in design both architecturally and structurally.

SCC poured at Rotary Dome at central secretariat station – Delhi Metro Project

Fig 2: SCC poured at Rotary Dome at central secretariat station: DMRC Courtesy: Shetty M.S., 2005

7. CRITERIA FOR SELECTION OF SELF COMPACTING CONCRETE

One of the criteria for selection of SCC is congested reinforcement present in structural members. The quantity of reinforcement in terms of percentage can be worked out that will lead to use of SCC. The method adopted for the derivation of quantity of reinforcement in terms of percentage above which SCC has to be adopted for slabs is that the clear spacing between reinforcement is taken equal to diameter of vibrator. Nominal spacing which is c/c distance between bars is computed and then the no. of bars in 1 m length of slab is determined. Area of tension reinforcement in 1 m length of slab is calculated and then percentage of reinforcement is determined by dividing the area of tension reinforcement by cross-sectional area of slab.

SLABS

Spacing that we can provide between the reinforcement bars will depend on the size of vibrator (Sizes of vibrator needle are taken from IS 2505: 1992) we are using. Let us take the diameter of needle vibrator as 75 mm. So it means clear spacing allowed is 75 mm.

Let us take diameter of bars as 10 mm. So c/c spacing of bars will be
= 75 + 10/2 + 10/2 = 85 mm

So no. of bars in 1 m = 1000/85 = 11.76 bars
Area of 1- 10 mm bar = $A = \pi d^2/4$ = 3.14 x 10^2/4 = 78.5 mm^2
Area of bars provided in 1 m = Area of 1 bar x No. of bars provided
= 78.5 x 11.76 = 923.16 mm^2

Let us assume the depth of slab be 125 mm. So the cross-sectional area of slab in 1 m = 125 x 1000 = 125,000 mm^2.
Percentage of tension reinforcement in 1 m of slab = (Area of bars/ Cross-sectional area of slab) x 100 = (923.16/125,000) x 100 = **0.738 % or 0.74 %**

It means that whenever the percentage of tension steel is greater than **0.74 %** using 10 mm diameter bars and thickness of slab is 125 mm then use SCC.

Relationship between percentages of reinforcement above which SCC is required, diameter of vibrating needle, diameter of reinforcement bar and thickness of slab can be worked out from above.

Let D be the diameter of vibrating needle and d be the diameter of reinforcement bar. T be the thickness of the slab considered.

Here D, d and T are in mm.

Percentage of reinforcement above which SCC is required =
$\frac{\text{Area of 1 bar x No.of bars in 1m length of slab}}{\text{Cross sectional area of slab in 1m length}}$ x 100
Area of 1 bar = $\frac{\pi d^2}{4}$ mm^2
No. of bars in 1 m length of slab = $\frac{1000}{D + d/2 + d/2} = \frac{1000}{D + d}$

Cross-sectional area of slab in 1 m length = Thickness of slab x length = T x 1000 mm^2

Substituting all values in the above equation we get the following:
$= \frac{\frac{\pi d^2}{4} X \frac{1000}{D+d}}{T X 1000}$ x 100

Simplifying the equation and putting the value of π as 3.14, we get the following eq. for

Percentage of tension reinforcement in slab above which SCC is required =
$= \frac{78.54\, d^2}{T\,(D+d)}$
Size of needle vibrator needed in terms of diameter (D) =
$= \frac{78.54\, d^2}{T\,(\%age\ of\ reinforcement)} - d$

Table 1 shows the percentage of tension reinforcement above which SCC is to be used for a given diameter of bar and diameter of vibrating needle. The thickness of slab considered is 125 mm.

Diameter of reinforcement bar(mm) / Diameter of vibrating needle(mm)	8	10	12	16
25	1.22 %	1.79 %	2.44 %	3.92 %
35	0.93 %	1.4 %	1.92 %	3.15 %
40	0.84 %	1.26 %	1.74 %	2.87 %
50	0.69 %	1.05 %	1.46 %	2.44 %
60	0.59 %	0.9 %	1.26 %	2.12 %
75	0.48 %	0.74 %	1.04 %	1.77 %
90	0.41 %	0.63 %	0.89 %	1.52 %

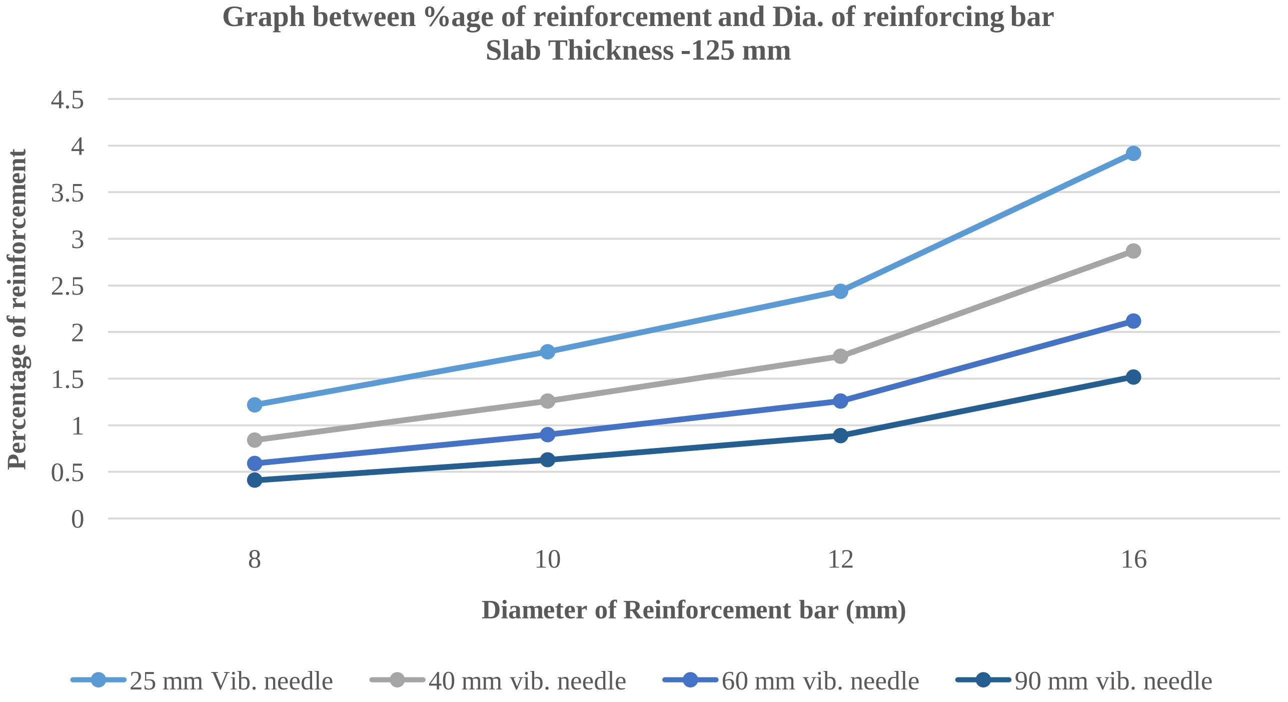


Table 2 shows the percentage of tension reinforcement above which SCC is to be used for a given thickness of slab and diameter of vibrating needle. The diameter of bar considered is 10 mm.

Thickness of slab (mm) / Diameter of vibrating needle(mm)	110	125	150	175	200
25	2.04 %	1.8 %	1.5 %	1.28 %	1.12 %
35	1.59 %	1.4 %	1.16 %	1 %	0.87 %
40	1.43 %	1.26 %	1.05 %	0.9 %	0.79 %
50	1.19 %	1.05 %	0.87 %	0.75 %	0.65 %
60	1.02 %	0.9 %	0.75 %	0.64 %	0.56 %
75	0.84 %	0.74 %	0.62 %	0.53 %	0.46 %
90	0.71 %	0.63 %	0.52 %	0.45 %	0.39 %

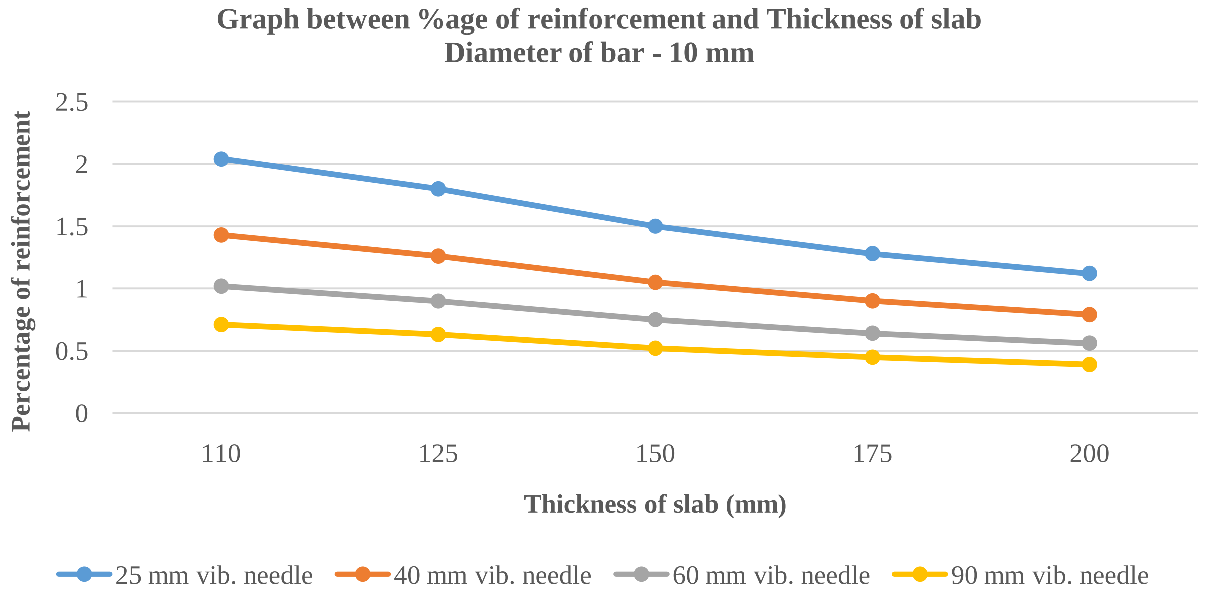


Table 3 shows the size of vibrator needle required for a given thickness of slab and diameter of reinforcement bar. The percentage of tension steel above which SCC is to be used is 2%.

Diameter of reinforcement bar (mm)	**8**	**10**	**12**	**16**
Thickness of slab (mm)				
110	No vib.	25	35	75
125	No vib.	No vib.	25	60
150	No vib.	No vib.	25	50
175	No vib.	No vib.	No vib.	40
200	No vib.	No vib.	No vib.	25

BEAMS

The methodology which can be adopted to determine the percentage of reinforcement in beams above which SCC has to be used is firstly determine the clear cover that needs to be left according to the exposure conditions as per IS 456:2000, then provide the clear spacing between bars according to the size of the vibrator. Place the bars such that the criteria for both the clear cover and clear spacing is met. Place the same diameter bar in the compression zone in the corner for calculating the area of reinforcement. Finally determine the percentage of steel above which SCC has to be used by dividing the area of reinforcement by cross-sectional area of steel.

Assumptions

- Dimension of beam is 230 x450 mm.
- Two bars of same diameter as that in tension zone are considered in compression zone of the beam. They will be taken in determining the cross-sectional area of reinforcement in the beam.
- Clear cover is taken as 25 mm as per IS 456:2000.
  Let us take the diameter of needle vibrator as 60 mm. So it means clear spacing allowed is 60 mm.

Let us take diameter of bars as 20 mm. So c/c spacing of bars will be
= 60 + 20/2 + 20/2 = 80 mm

The cross section of beam considered is 230 x 450 mm.

No. of bars allowed in tension zone of the beam = 230/80 = 2.875 = 3 bars

So 3- 20 mm bars at the bottom and 2 – 20 mm bars at the top resulting in 5 bars at the cross-section.

Area of 5- 20 mm bar $A = 5\ x\ \pi d^2/4$ = 5 x 3.14 x 20^2/4 = 1570 mm^2

Cross-sectional area of beam = 230 x 450 = 103,500 mm^2.

Percentage of reinforcement in beam = (Area of bars/ Cross-sectional area of beam) x 100 = (1570/103,500) x 100 = **1.52 %**

Table 4 shows the percentage of reinforcement above which SCC is to be used for a given diameter of bar and diameter of vibrating needle. Cross- section area of beam 230 x 450 mm

Diameter of reinforcement bar(mm) / **Diameter of vibrating needle(mm)**	**20**	**25**	**28**	**32**
25	1.82 %	2.84 %	2.97 %	3.88 %
35	1.52 %	2.37 %	2.97 %	3.88 %
40	1.52 %	2.37 %	2.97 %	3.88 %
50	1.52 %	2.37 %	2.38 %	3.11 %
60	1.52 %	1.9 %	2.38 %	3.11 %
75	1.21 %	1.9 %	2.38 %	3.11 %
90	1.21 %	1.9 %	2.38 %	3.11 %

8. IDENTIFICATION OF COSTS ASSOCIATED WITH SELF COMPACTING CONCRETE

Before carrying out analysis of each parameter which affect the costs of self-compacting concrete they need to be identified. Costs can be classified as follows:

- Costs that are in favor of SCC (Benefits)
  i. Tangible
- ✓ Faster pumping reduces pump hiring charges and also saves energy costs or running cost. Labor component is also reduced. This is also beneficial when concrete is to be placed at more heights.
- ✓ Reduction of use of vibrator in terms of running and maintenance costs. Hiring charges and labor charges will decrease. Also the life of vibrator will increase.
- ✓ Reduction of surface finishing costs and labor costs as SCC produces a surface which does not need any finishing.
- ✓ Truck turnaround time decreases which lead to reduction in cost of fuel and truck hiring charges along with reduction in operator charges.
- ✓ SCC flows on its own so less labor is required while placing of concrete thus reducing labor costs.
- ✓ Negligible bug-holes and patches obtained on the concrete surface reduces the maintenance costs and labor costs.
- ✓ Improved durability leading to less surface maintenance costs.
- ✓ Thinner concrete sections may be possible to construct which earlier might not be possible because of the workability requirements leading to less quantity of concrete hence less costs.

  ii. Intangible
- ✓ Noise reduction due to less truck turnaround time and minimal use of vibrator causes less medical expenses for people associated with the work.
- Costs that are not in favor of SCC (Costs)
  i. Tangible
- ✓ Material like super plasticizers and admixtures increases the cost of the mix.
- ✓ Skilled people are required for selection of materials, manufacturing (providing proper dosage of materials), testing, handling and placing which tends to raise the total cost.
- ✓ Costs involved in maintenance of formwork as high pressure are expected (Waarde, 2007).

9. QUANTIFICATION OF IDENTIFIED COSTS AND BENEFITS

All the costs and benefits described will need to be quantified so that benefit/cost ratio can be determined. The costs of materials, machinery and labor have been taken from Delhi Analysis of Rates-2014 and market rates. The cost index of 104 has been applied on the rates taken from DAR – 2014.

COSTS

- Cost of materials

The cost of materials for 1 m^3 of M40 grade of concrete for RCC and SCC are compared. Mix design of M40 grade RCC is done according to IS 10262: 2009 and mix design of M40 grade SCC has been taken from Matha Prasad Adari et al. (2015).

1 m^3 RCC of M40 grade

Material	**Weight (kg)**	**Volume(cu.m)**	**Rate (Rs)**	**Unit**	**Amount (Rs)**
Cement	542.86	-	6.3	kg	3420.02
Fine Agg.	410.97	0.15	1200	cu.m.	180
Coarse Agg.	1259.9	0.46	1175	cu.m.	540.5
Water	180	0.18	160	cu.m.	28.8
		Total =			**4169.32**

*Density of fine aggregates = 2660 kg/m^3
*Density of coarse aggregates = 2720 kg/m^3
*Density of water = 1000 kg/m^3

1 m^3 SCC M40 grade

Material	Weight (kg)	Volume(cu.m)	Rate (Rs)	Unit	Amount (Rs)
Cement	529.54	-	6.3	kg	3336.1
Micro silica	5.29	0.0025	30	cu.m.	158.7
Fine Agg.	917.13	0.35	1200	cu.m.	420
Coarse Agg.	717.18	0.27	1175	cu.m.	317.25
Water	181.84	0.18	160	cu.m.	28.8
Super-plasticizer	4.81	-	50	kg	240.5
			Total =		**4501.35**

Difference in price between SCC and RCC for 1 m^3 quantity = Rs 4501.35 – 4169.32 = Rs 332.03
SCC is **7.96 %** costlier when compared to RCC.

BENEFITS

- Faster pumping

Faster pumping reduces the pump hiring charges, running charges and labor charges. A nomograph is used to determine the size of pump and the pressure required to pump a given quantity of concrete (Cooke T.H., 1990). A nomograph links concrete out required per hour, pipeline through which concrete is pumped in mm, total length of pipeline which includes horizontal, vertical and bends in m, slump value in mm, pressure in bars required for pumping and working power required in KW to pump concrete. These parameters are divided into four quadrants of a graph. Nomograph is prepared for RCC and SCC for same grade of concrete by assuming parameters identical to both like quantity of concrete required per hour, pipeline diameter through which concrete in sent, length of pipeline and slump value. This is plotted on nomograph by joining different parameters with straight lines which gives the pressure required and working power for both types of concrete.

Let us take the following so as to determine the pressure and size of pump for both RCC and SCC by plotting on the nomograph as shown in figure 3.

Output required: 40 cu. m/hr

Pipeline diameter through which concrete is sent: 125 mm

Total length of pipeline including horizontal, vertical and bends: 145 m

	RCC M40 grade	SCC M40 grade
Slump Value	70 mm	500 mm

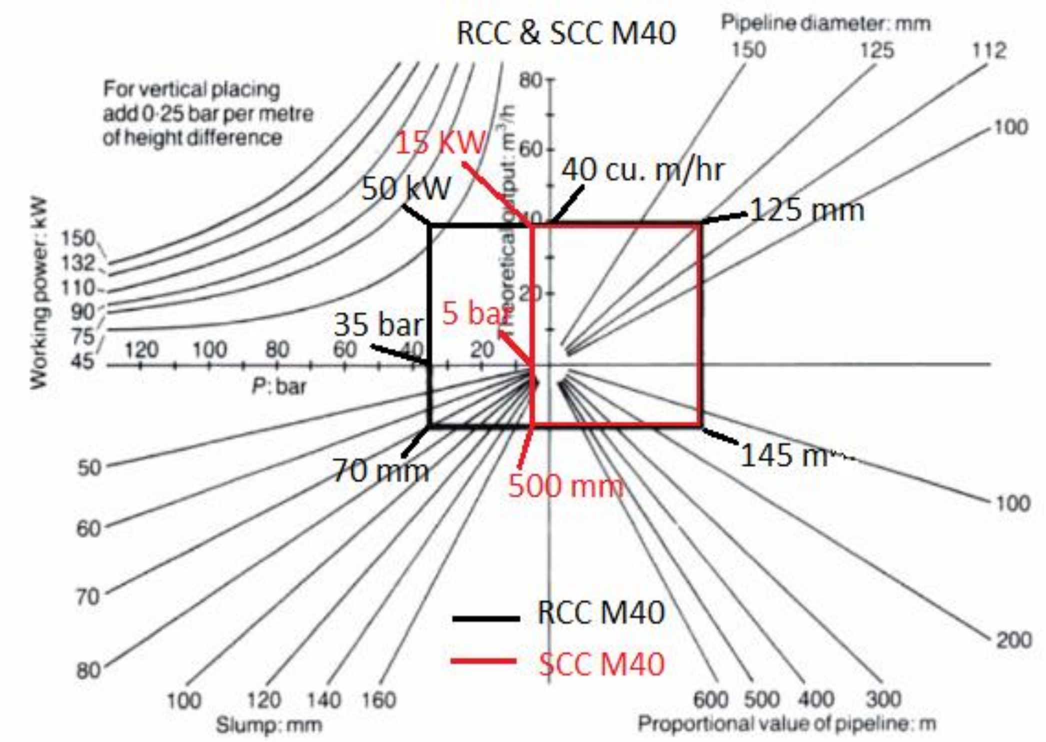


Fig 3: Nomograph for determining the size of concrete pump required for RCC and SCC M40 grade

From nomograph shown in figure 3 after plotting the requirements we get the following:

	RCC M40 grade	SCC M40 grade
Pressure (bars)	35 bar	5 bar
Working power of pump (kW)	50 KW	15 KW

Running charges
1 m^3 of concrete would be pumped in = 1/40 hr = 0.025 hr = 1.5 min
Energy consumed to pump RCC = Power req. x time = 50 x 0.025 = 1.25 KWh
Energy consumed to pump SCC = Power req x time = 15 x 0.025 = 0.375 KWh

Cost of electricity = Rs 6/KWh

Cost of pumping 1 m^3 RCC = 6 x 1.25 = Rs 7.5
Cost of pumping 1 m^3 SCC = 6 x 0.375 = Rs 2.25

Hiring charges
Hiring charges of pump = Rs 1,20,000/ Month
Hiring charge per day = 1,20,000/30 = Rs 4,000 / day
Taking that it is put to use for 8 hours
Hiring charge per hour = 4,000/8 = Rs 500/hr

If SCC would be have been pumped at 50 KW of power than the output concrete that would be obtained can be obtained by extrapolating on nomograph.

Output concrete will come as 133.33 cu m/hr for 50 KW of power. All other parameters remain the same as defined earlier.

1 m^3 of RCC takes 0.025 hr = 1.5 min
1 m^3 of SCC takes for same power = 1/133.33 = 0.0075 hr = 0.45 min

Hiring charge for RCC for 1 m^3 of concrete = 500 x 0.025 = Rs 12.5
Hiring charge for SCC for 1 m^3 of concrete = 500 x 0.0075 = Rs 3.75

Labor charges
Labor charges (6 beldar) for pumping operations which includes operating the pump, laying of pipes to the place of concreting.
Cost of 1 beldar = Rs 342.16/day
Cost of 6 beldar = Rs 2052.96/day = Rs 256.62/hr = Rs 4.28/min

For 1 m^3 of RCC labor charges are = Rs 4.28 x 1.5 = Rs 6.42
For 1 m^3 of SCC labor charges are = Rs 4.28 x 0.45 = Rs 1.93

Total charges associated with faster pumping
Total cost of pumping operations for 1 m^3 of RCC = Rs 7.5 + 12.5 + 6.42 = Rs 26.42
Total cost of pumping operations for 1 m^3 of SCC = Rs 2.25 + 3.75 + 1.93 = Rs 7.93

Difference in cost between pumping of SCC and RCC = Rs 26.42 – 7.93 = Rs 18.49

- Reduction of use of vibrator

SCC being able to flow on its own doesn't need vibrator for compaction. So there are saving in hiring, running and labor cost of vibrator when compared to RCC.

1 m^3 of RCC M40 grade
Hiring charges
Hiring charges of needle vibrator = Rs 500/day
1 m^3 of concrete requires 0.07 day of vibration as per Delhi Analysis of Rates-2014.
So, hiring charges for 1 m^3 of concrete = Rs 500 x 0.07 = Rs 35

Running charges
Running charges of vibrator = 0.5 Liter/hr
Cost of 1 liter diesel = Rs 53.93 / liter
Cost of fuel consumed by vibrator in 1 hour = Rs 53.93 x 0.5 = Rs 26.97/hr

1 m^3 of concrete requires 0.07 day or 0.07 x 8 = 0.56 hrs for vibration.
Running cost of vibrator for 1 m^3 of concrete = Rs 26.97 x 0.56 = Rs 15.10

Labor charges
Labor comprising of 1 beldar per vibrator is required for carrying out the compaction.
Cost of 1 beldar = Rs 342.16/day
Cost of labor (1 beldar) for vibration = Rs 342.16 x 0.07 = Rs 23.95

Total Charges associated with vibrator for 1 m^3 of RCC M40 grade = Rs 35 + 15.10 + 23.95 = Rs 74.05

1 m^3 of SCC M40 grade
Since SCC doesn't need vibration there will be no cost for SCC involving vibration and can be taken as 0.

Savings if SCC is adopted in terms of vibration = Rs 74.05 – 0 = Rs 74.05

- Reduced surface finishing costs

Cement plaster of about 12 mm thick can be done on structures to give them a uniform finish. RCC produces a surface which needs treatment as it contains bug-holes, patches etc. If proper treatment is not done then it may affect the durability of the structure. SCC producing a surface on which finishing is not required hence no finishing cost is considered for SCC.

1 m^3 of RCC M40 grade

If a beam of cross-section 300x 450 mm is considered then to accommodate 1 m^3 of concrete, length of beam required is:

$= \frac{1}{0.3 X 0.45} = 7.40$ m

Surface area on which plaster needs to be done = 7.40 x 0.3 = 2.22 m^2

Cost of cement plaster (1 cement: 6 fine sand) which includes material and labor cost is taken from Cl. 13.1.2 of Delhi Analysis of Rates-2014.
Cost for 1 m^2 of cement plaster = Rs 149.45
Cost for 2.22 m^2 of cement punning = Rs 149.45 x 2.22 = Rs 331.78

Applying cost index of 104 on 31/7/2015 issued by Central Public Works Department (CPWD).

The cost of 2.22 m^2 of cement punning becomes 1.04 x 331.78 = Rs 345.05

<u>1 m^3 of SCC M40 grade</u>
SCC produces good quality surface finish thus reducing the need of surface finish. For costing considerations no surface finishing costs are considered and hence taken as 0.

Savings in cost by using SCC in terms of surface finish = Rs 345.05 – 0 = Rs 345.05

- Truck turnaround time decreases which lead to reduction in cost

Since SCC has a flow able nature, supplying of SCC becomes fast which in turn increases the productivity by decreasing the truck turnaround time. Decrease in truck turnaround time means that there is a decrease in fuel and truck hiring charges. Also the truck operator charges will decrease.

Fuel consumption by transit mixer while pumping 5 L/hr
Cost of diesel = Rs 53.93/liter
So cost of 5 liter = Rs 53.93 x 5 = Rs 269.65
Cost of fuel consumed by transit mixer in 1 hour = Rs 269.65/hr
Cost of fuel consumed by transit mixer in 1 min = Rs 269.65/60/min = Rs 4.5/min

Hiring charges of transit mixer = Rs 1,20,000 / Month
Hiring charge per day = 1,20,000/30 = Rs 4,000 / day
Taking that it is put to use for 8 hours.
Hiring charge per hour = 4,000/8 = Rs 500/hr
Hiring charge per min = 500/60 = Rs 8.33/min

Driver charges for transit mixer = Rs 452.4/day
Mate charges for transit mixer = Rs 377.52/day
Total charges of labor = Rs 452.4 + 377.52 = Rs 829.92/day
Labor charges per hour = Rs 829.92/8 = Rs 103.74/hr
Labor charges per min = Rs 103.74/60 = Rs 1.73/min

Total charges associated with transit mixer = Rs 4.5 + 8.33 + 1.73 = Rs 14.56/min

<u>1 m^3 of RCC M40 grade</u>
From pump calculations 1 m^3 of RCC will be pumped in 1.5 min.
So, charges involved in pumping 1 m^3 of RCC = Rs 14.56 x 1.5 = Rs 21.84

<u>1 m^3 of SCC M40 grade</u>
From pump calculations 1 m^3 of SCC will be pumped in 0.45 min.
So, charges involved in pumping 1 m^3 of RCC = Rs 14.56 x 0.45 = Rs 6.552

Savings due to decrease in truck turnaround time = Rs 21.84 – 6.552 = Rs 15.288

- Labor Costs

Labor is involved in placing of concrete. SCC being more workable reduces the labor effort and time. Savings in time means faster work which increases the productivity and decreases the cost.

<u>1 m^3 of RCC M40 grade</u>
1 mason requires 0.029 day costing Rs 452.4 x 0.029 = Rs 13.12
1 beldar requires 0.166 day costing Rs 342.16 x 0.166 = Rs 56.80
Total = Rs 69.92
(The coefficients of labor are taken from CL. 5.48Y, DAR - 2014, CPWD)

<u>1 m^3 of SCC M40 grade</u>
1 mason requires 0.025 day costing Rs 452.4 x 0.025 = Rs 11.31
1 beldar requires 0.15 day costing Rs 342.16 x 0.15 = Rs 51.32
Total = Rs 62.63
(The coefficients of labor are taken from Cl. 5.48Z, DAR - 2014, CPWD)
Savings in labor cost if SCC is used = Rs 69.92 – 62.63 = Rs 6.99

10. RESULTS

Total cost of materials when using RCC = Rs 4169.32
Total cost of materials when using SCC = Rs 4501.35

Extra cost involved when using self-compacting concrete = Rs 332.03

Percentage increase in cost when using SCC = $\frac{4501.35-4169.32}{4169.32}\ x\ 100 = 7.96\ \%$

Sum of benefits when self-compacting concrete is used = Rs 18.49 + 74.05 + 345.05 + 15.29 + 6.99 = Rs 459.87

$$\textbf{Benefit/Cost ratio} = \frac{4169.32 + 459.87}{4501.35} = 1.03$$

11. CONCLUSION

The process and criteria for selection of SCC can be a part of guidelines in the making of the standards. Criteria for reinforcement in terms of percentage has been worked out which shows that above this value use of SCC is recommended. Benefit/cost ratio obtained by using self-compacting concrete comes around 1.03. This shows use of self-compacting concrete is beneficial when compared to conventional concrete. Some of the benefits like reduction in noise, improved durability, thinner concrete sections and faster construction if considered will make use of self-compacting concrete more beneficial. Effect of formwork pressure might have a negative impact on B/C ratio. At the same time B/C ratio is very sensitive a slight change in cost of materials or any other parameter might change the results. SCC should not only be judged by this ratio only, the other benefits it provides should be given due importance. SCC has an edge over conventional concrete when it comes to areas where using conventional concrete is difficult.

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