



GOVERNMENT OF MAHARASHTRA

WRD HANDBOOK CHAPTER NO. 3

SELF COMPACTING CONCRETE



MAHARASHTRA ENGINEERING RESEARCH INSTITUTE,
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WRD HANDBOOK CHAPTER NO. 03
SELF COMPACTED CONCRETE

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WRD HANDBOOK CHAPTER NO. 3

SELF COMPACTED CONCRETE

1. Introduction

1.1 General

With the tremendous development of construction of mega structures the world over, the demand for self compacting concrete (SCC) application is increasing. Many sites have the problems of congestion of reinforcement in principal structural members. The design issues are compounded due to the high risk of seismic zone, vulnerability to cyclonic storms and huge capacity addition of the plants to a very large scale. SCC has become the only choice in such difficult site environments. Ideally the development of concrete mix where placing and compaction has minimal dependence on the Standard of workmanship available on a particular site should improve the true quality of the concrete in the final structure, and hence its durability. This was an important driving force behind the development of self-compacting concrete (SCC).

Self-compacting concrete is considered as a breakthrough in concrete technology due to its improved performance and working environment. It has wide application from thin elements to bulk robust structures. SCC can be taken as greatest technical advancement and most revolutionary development in concrete technology over the years. SCC is a concrete of future, as it will be replacing normal concrete due to its distinct advantages.

Self-compacting concrete (SCC) also called as Self Consolidating Concrete or Rheodynamic concrete is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has at least engineering properties at par with and durability as traditional vibrated concrete. The principle behind Self Compacting Concrete (SCC) is that the settlement of aggregates is related to the viscosity of the fresh concrete.

SCC can be produced using the same ingredients as that of normal concrete. However, a closer tolerance is required to ensure strict control of workability characteristics. The proportioning of SCC mix is much more scientific than that of conventional concrete mixes. SCC mix requires high powder content, lesser quantity of coarse aggregate, high range superplasticizer and VMA (Viscosity Modifying Agent) to give stability and fluidity to concrete mix. The workability of SCC is equilibrium of fluidity, deformability, filling ability and resistance to segregation.

This equilibrium has to be maintained for a sufficient time period to allow for its transportation, placing and finishing. Combinations of tests are required to characterize the workability properties.

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but Self-Compacting Concrete was not developed until late 1980s in Japan.

In Europe it was probably first used in civil works for transportation networks in Sweden in the mid 1990s. The EC funded a multinational, industry lead project “SCC” 1997-2000 and since then SCC has found increasing use in all European countries and the use is increasing all over the world, and in India also. In India, the SCC has been used (about 5000 Cum.) in Kaiga Nuclear Power Project (Karnataka) and also in Kota Atomic Power project (Rajasthan). Some of the projects where SCC has been used are

- Delhi Metro Project – 10000 Cum.
- Tarapore Atomic Power Project – 6000 Cum.
- Gosikhurd Project – 5000 Cum.
- Purna Dam Project – 500 Cum.
- Lower Wardha Project – 2000 Cum.

The use of SCC is increasing day by day in India and many infrastructure projects are going in for SCC, the example being ‘The Signature Bridge’ on river Yamuna near New Delhi and the Bandra-Worli sea link project, Mumbai.

Self-Compacting Concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier de-molding and faster use of elements and structures.

The elimination of vibrating equipment improves the environment on and near construction sites where concrete is being placed, reducing the exposure of workers to noise and vibration.

The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and on-site civil engineering construction.

1.2 Definitions of SCC :

The Self compacting concrete has been defined by many and some of the definitions are as below

- i) EFNARC, May 2005, Guidelines for SCC defines it as “Concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction”.
- ii) Technical Bulletin TB-1501 defines SCC as “Self-Consolidating Concrete (SCC) also known as self-compacting concrete, a highly workable concrete that can flow through densely reinforced or complex structural elements under its own weight and adequately fill voids without segregation or excessive bleeding, and without the need for vibration.

- iii) Khayat K. H. defines SCC as: “A highly flowable, yet stable concrete is one that can spread readily into place and fill the formwork without any consolidation and undergoing any significant segregation”.
- iv) As per N.V.Nayak et.al: “A concrete that is capable of Self compacting (self consolidating), occupies all space in the form without any external efforts (in the form of mechanical vibration ,floating, poking etc.) is termed as self compacting concrete”.
- v) As per report # 1, SCC of CE241, Concrete technology (2004) : “SCC is in want of a standard definition, but may be nominally considered a concrete mix of exceptional deformability during casting, which still meets resistance to segregation and bleeding.”
- vi) Japan Concrete Institute defines SCC as “A concrete having self compatibility; self compactability of concrete is its ability related to the placeability, with which it can be uniformly filled and compacted in the every corner of formwork by its own weight without vibration during placing.”

1.3 Necessity To Choose SCC

SCC is considered as a preferred option due to its well known properties of flowability, passing ability and compatibility.

SCC is an excellent repair material for concrete encasement because of its ability to flow through narrow openings. Care shall be taken to avoid shrinkage of concrete by adding shrinkage compensating admixtures since bonding of new concrete with the old concrete is a requirement in repair works.

Congested reinforcements, secondary concreting of gate slots, complicated shapes of concrete elements necessitates the use of SCC (Photograph 1)



Photograph 1 - Situations necessitating use of SCC

1.4 Advantages of Self Compacting Concrete

- i) Self compacting concrete (SCC) is a concrete which is able to flow under its own weight, completely filling formwork & achieving full compaction, even in the congested places. The SCC mixes have these attributes because of their good deformability enabling them to maintain homogeneity at fresh state. It can be placed & compacted under its self weight with little or no vibration effort & which is at the same time is cohesive enough to be handled without segregation & bleeding.
- ii) Self compacting concrete offers a rapid rate of concrete placement with faster construction times & ease of flow around congested reinforcement. The fluidity & segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids & uniform concrete strength in situ, providing the potential for a superior level of finish & durability to the structure.
- iii) Use of fly ash in SCC is an eco friendly option and is useful in controlling the excess heat of hydration in concreting. It also improves to the qualities like homogeneity, permeability and durability of the concrete.
- iv) Use of flyash is mostly necessary to provide higher quantity of powdery material required in SSC. SCC has got a property of self compacting which removes one of the main reasons of discrepancy between the performance of laboratory concrete specimens and that of the concrete structures at site, namely the degree of compaction of the fresh concrete; as SCC mixture does not depend on the degree of compaction of the fresh concrete.
- v) SCC enables reduction in noise at site and so it ensures improved health and safety at site. The use of SCC reduces the exposure of the workers to sound intensities that are as low as one tenth of those produced when placing traditional vibrated concrete; introduction of SCC is truly a quiet revolution in concrete.
- vi) SCC requires reduced manpower over conventional concrete placing of SCC is much less strenuous activity than placing traditional vibrated concrete.
- vii) More innovative designs, more complex shapes, more thinner sections are possible with use of SCC.
- viii) SCC exhibit greater stability than traditional concrete.
- ix) Reduced internal bleeding when SCC is used is responsible for a denser and stronger ITZ with respect to that of CC. The positive role of SCC in decreasing microcracking and porosity of interfacial transition zone (ITZ) is also responsible for a more durable concrete.
- x) Large amount of fly ash or limestone filler in SCC favors formation of a less porous and, hence, a stronger transition zone due to a limited amount of microcracking in the vicinity of the ITZ.
- xi) The denser microstructure of the ITZ in SCC may contribute for a lower plastic settlement, higher bond between steel and concrete matrix, lower permeability to oxygen and lower chloride diffusion coefficient with respect to corresponding values for conventional concretes.

- xii) Higher tensile strength for SCC is due to improvement in the homogeneity and denser microstructure of the ITZ.
- xiii) SCC allows rapid pumping of concrete.
- xiv) SCC has uniform, even surface with less surface defects, voids honeycombs etc. by virtue of good filling ability.
- xv) SCC has improved aesthetics of final product with improved surface finish due to its good fluidity and deformability making SCC a competitive option vis-a-vis traditional concrete.
- xvi) When placing a new layer of SCC on old SCC, the bond between the old and new SCC is equal to or better than in the case of conventional vibrated concrete.
- xvii) A review of technical literature shows that SCC can flow (in formwork) horizontally a distance of 15-20m without segregation. A well designed SCC may have a free fall of as much as 8 m without segregation. However, from practical considerations height of free fall shall be restricted to 3 m and horizontal flow be as small as possible but restricted to 10 m.

1.5 Limitations of SCC

- i) Self compacting Concrete is a new technology and hence, requires well maintained and high degree of quality control & quality assurance methods. Production and placing of SCC need to be carried out by trained personnel only.
- ii) Absence of internal and external bleeding in SCC, however is one of the causes for their higher plastic shrinkage compared to traditional vibrated concrete. Hence, SCC should be cured as soon as practicable after placement to prevent surface shrinkage cracking.
- iii) The lower MSA (nominal maximum size of aggregate) and reduction in % of coarse aggregate in volume of SCC are responsible for lower modulus of elasticity compared to the conventional concrete. For this reason, the total shrinkage of SCC is also slightly higher.
- iv) SCC requires good and leak proof formwork due to presence of more fines and flowable concrete. Special attention is needed in design of the formwork for pressures based on the flowability, cohesiveness, rate and method of placing or pumping (from top/from bottom) etc.
- v) Before any SCC is produced at the plant and used at the job site, the mix must be properly proportioned and tested to assure compliance with the functional requirements and the project specifications. The ingredients and the equipment used in developing the mix and testing should be the same ingredients and equipment to be used in the final mix for the project.
- vi) Most common concrete mixers can be used for producing SCC. However, the mixing time may be longer than that for the conventional vibrated concrete.

- vii) SCC is more sensitive to the total water content in the mix. It is necessary to take into account the moisture/water content in the aggregates and the admixtures before adding the remaining water in the mix. The mixer must be clean and moist, and contains no free water.
- viii) The truck drivers (transit mixer) should be given oral and written instructions for handling SCC. He must check the concrete drum before filling with SCC to make sure that the drum is clean and moist, but with no free water. Extra care must be taken for long deliveries. The truck driver shall also be given training in regional languages about the effects of wrong handling, adding extra water etc. This training will help them to know the importance so that the instructions given to them can be implemented effectively.
- ix) The truck drivers should not be allowed to add water and/or admixtures during transit.
- x) SCC is more sensitive to temperature during the hardening process than the conventional vibrated concrete hence extra care shall be taken about the handling and keeping the concrete cool.
- xi) Because of high cementitious content, the control on temperature of concrete is highly important in extreme hot environment
- xii) SCC places more stringent requirements on the selection of materials in comparison with conventional concrete.
- xiii) SCC mix requires a large number of trial batches. In addition to the laboratory trial batches, field size trial batches should be used to simulate the typical production conditions.
- xiv) A change in the characteristics of a SCC mix could be a warning sign for quality control

2. Scope

This Chapter is an effort to represent a document addressed to those specifiers, designers, producers and users who wish to enhance their expertise and use of SCC. It will serve as a useful guide to the engineers and contractors working in Water resources department & Public works department.

The Guidelines in this chapter cover information that is common to SCC for the ready-mixed, site mixed concrete industry.

The Guidelines are drafted with an emphasis on ready-mixed, site mixed SCC where there are requirements in relation to the specification of the hardened state. In addition, the Guidelines cover specific and important requirements for user of SCC regarding the site preparation over traditional vibrated concrete.

The document describes the properties of SCC in its fresh and hardened state, and gives advice to user of ready-mixed, site mixed concrete, on how SCC should be specified in relation. Advice is given to the producer on constituent materials, their control and interaction.

Since there are number of different approaches to the design of SCC mixes, no specific method is recommended. However, approaches to mix design are given.

Advice is given to the contractor/user of ready-mixed, site mixed SCC on delivery and placing.

3. References

There is no Indian Standard (BIS) on SCC hence references are made to the Reports/Guidelines/Literature on the topic.

The references given in this chapter are as per Annexure A. All standards/reports/Guidelines are subject to revision, and the most recent editions of the standards indicated in Annex A shall be referred to.

4. Terminology

The European Guidelines (EFNARC) for SCC and the Technical Bulletin TB-1501 give terms and their definitions which are adopted with due modification as wherever felt necessary for the purposes of this Chapter.

- 4.1 **Admixture** - Material added during the mixing process of concrete in small quantities related to the mass of cementitious binder to modify the properties of fresh or hardened concrete.
- 4.2 **Aggregate blocking** - The condition in which coarse aggregate particles combine to form elements large enough to obstruct flow of the fresh concrete between reinforcing steel or other obstructions in the concrete formwork. This property is of increased importance in SCC because of the absence of vibration energy to dislodge these blockages.
- 4.3 **Air-migration** - The undesirable condition in which entrapped air in fresh SCC migrates to the top surface causing a bubbling or boiling appearance. This is an indication of unstable air and a low viscosity mortar. Air-popping is another term used for this occurrence.
- 4.4 **Binder** - Materials in SCC with particle sizes passing the 150 micron (No. 100) sieve. These include cement, supplementary cementitious materials and unreactive fillers.
- 4.5 **Bingham fluid** - A material that exhibits the behavior of having a yield stress. Thus a shear stress (y axis) versus shear rate curve will have y intercept, known as the yield stress, and a slope, known as the plastic viscosity. Concrete also tends to behave as a Bingham fluid, or near to it (pseudoplastic). For more information please refer 5.12.
- 4.6 **Bleed water** - The water that appears to rise to the surface of concrete subsequent to placement. ACI defines bleeding as “the autogenous flow of mixing water within, or its emergence from, newly placed concrete or mortar, caused by settlement of solid materials within the (concrete) mass.”
- 4.7 **Dynamic stability** - The characteristic of a fresh SCC mix that ensures uniform distribution of all solid particles and air voids as the SCC is transported and placed.
- 4.8 **Filling ability** - The ability of SCC to flow under its own weight (without vibration) into and fill completely all spaces within formwork containing obstacles such as reinforcement.
- 4.9 **Finishability** - The ease with which SCC can be finished to achieve the desired surface flatness and smoothness on that portion of an element that must be finished. Finishability does not refer to formed surface finish quality.
- 4.10 **Flowability** - The ease of flow of fresh concrete when unconfined by formwork and/reinforcement. A property of fresh SCC indicating the ease of flowing without manual or mechanical effort. This is a component of filling ability, but a concrete can have high flowability without high filling ability, if the passing ability is poor.
- 4.11 **Fluidity** – The ease of flow of fresh concrete.
- 4.12 **Paste** – The fraction of the concrete comprising powder (cement + SCM’s + unreactive powder), water and air, plus admixture, if applicable.

- 4.13 Passing ability** - The ability of SCC to flow through openings approaching the size of the mix's nominal maximum size aggregate, such as the space between steel reinforcing, without segregation or aggregate blocking.
- 4.14 Placeability** - The ability to place SCC in the time span required such that the material remains homogenous while exhibiting all the required SCC fresh concrete properties. A general term, encompassing elements of filling and passing ability, as well as time-dependent change.
- 4.15 Plastic viscosity** - The rheologist's term for measurement of a material's resistance to increase in its rate of flow with increasing application of force. In a plot of the force versus the flow rate, the higher the slope, the higher is the plastic viscosity. SCC mixes tend to have moderate to high plastic viscosity.
- 4.16 Pumpability** - The ability of an SCC mix to be pumped without significant degradation of its fresh SCC properties.
- 4.17 Robustness** - The capacity of concrete to retain its fresh properties when a small variation in the properties or quantities of the constituent materials occurs.
- 4.18 Rheology** - The science of the deformation and flow of materials. Certain of the critical properties of fresh SCC can best be understood through the principles of rheology. For more information please refer
- 4.19 Segregation resistance** - The ability of concrete to remain homogeneous in composition during mixing, transportation, handling, placement and finishing i.e. while in its fresh state.
- 4.20 Slump flow** - The mean diameter of the spread of fresh concrete using a conventional slump cone.
- 4.21 Slump flow test** - A test method using the standard Abram's slump cone (upright or inverted) on a flat surface to measure the unconfined flow and stability of SCC. The numerical value in mm of flow is determined as the average diameter of the circular deposit (patty) of SCC at the conclusion of the slump flow test.
- 4.22 Slump flow T500** - Measurement of the time it takes for the slump flow patty to reach a 500 mm (20 inch) diameter circle drawn on the slump flow plate, after starting to raise the slump cone. Most SCC will have a T500 of 2-5 seconds. The longer the time (at the same slump flow), generally the greater the passing ability.
- 4.23 Stability** - The ability of SCC to remain homogenous during mixing, transportation, handling, placement, finishing and curing.
- 4.24 Thixotropy** - The tendency of a material (e.g. SCC) to progressive loss of fluidity when allowed to rest undisturbed but to regain its fluidity when energy is applied.
- 4.25 Thixotropic behavior** - The property of a material that it exhibits a low viscosity while being mechanically agitated and for a while after, but stiffens after a period of rest. This is different from the normal Bingham plastic behavior of concrete, in which it appears to exhibit lower viscosity while moving than at rest, in that a change over time while at rest is required for a material to be thixotropic.

- 4.26 Viscosity** - The resistance to flow of a material (e.g. SCC) once flow has started. A rheological term defined as the magnitude of the change in the applied stress required for changing the unit flow velocity of a material. In other words, the slope of the stress-shear rate curve. In simpler terms viscosity is how “thick” a fluid behaves. Simple fluids like water or oil, which have no yield stress, appear to have the same “thickness” regardless of how fast they are moving, and are called “Newtonian.” concrete, which follows so called Bingham behavior, will have different apparent viscosities, with the lowest apparent viscosity at highest speed of shear.
- 4.27 Viscosity Modifying Admixture (VMA)** - Admixture added to fresh concrete to increase cohesion and segregation resistance. VMA increases the plastic viscosity and improves the stability of the mixture at a constant fluidity.
- 4.28 Water to cementitious ratio (w/cm)** - The ratio of the weight of free water to the weight of all cement and reactive powders such as slag, fly ash, silica fume, and metakaolin.
- 4.29 Workability** - That property of freshly mixed concrete or mortar that determines the ease, with which it can be mixed, placed, consolidated and finished. It is a complex combination of aspects of fluidity, cohesiveness, compactability, and stickiness, quantified in tests to determine filling ability, passing ability and stability.
- 4.30 Yield stress** - One of the rheological parameters of fresh concrete, fresh mortar and fresh paste. It is the minimum stress required to make the concrete flow. SCC requires a low yield stress. Inversely related to slump or slump flow.

5. Engineering properties

5.1 General

Self-compacting concrete and traditional vibrated concrete of similar compressive strength have comparable properties and hence SCC can be used in most applications where traditional vibrated concrete is used. However, SCC composition does differ from that of traditional concrete and the difference exists in the performance during fresh state; not much in terms of properties of hardened state.

In the design of concrete structures, engineers may refer to a number of structural properties of concrete which are not always part of the concrete specification. The most relevant are:

- Compressive strength
- Tensile strength
- Modulus of elasticity
- Creep
- Shrinkage
- Coefficient of thermal expansion
- Bond to reinforcement
- Shear force capacity in cold joints
- Fire resistance

Where the development of a specific concrete property is dependant on time, tests should be carried out taking into account the exposure conditions as per the relevant Indian Standard.

5.2 Compressive strength

Compressive strength is the most routinely and widely specified and tested engineering property and number of other concrete properties can be related and evaluated from compressive strength.

Self-compacting concrete with a similar water cement or cement binder ratio will usually have a slightly higher strength compared with traditional vibrated concrete, and this is due to an improved interface between the aggregate and hardened paste due to absence of vibrations. The strength development will be similar to traditionally vibrated concrete so maturity testing will be an effective way to control the strength development whether accelerated heating is used or not.

5.3 Tensile strength

For the SCC of specified strength, class and maturity, the tensile strength may be safely assumed to be the same as the one for a normal vibrated concrete as the volume of paste (cement + fines + water) which is more in SCC has no significant effect on tensile strength. In fact due to improvement in homogeneity and denser microstructure, the mechanical properties, and in particular, tensile strength of SCC may be higher than for conventional concrete. Also, due to a less porous microstructure, tensile strength of SCC should be higher than that of conventional concrete, Values available in literature seems to indicate higher split tensile strength for SCC with respect to conventional concrete.

5.4 Static modulus of elasticity

The modulus of elasticity (E -value, the ratio between stress and strain), is used in the elastic calculation of deflection, often the controlling parameter in slab design, and of pre or post tensioned elements.

As the bulk of the volume of concrete is aggregate, the type and amount of aggregate as well as its E -value have the most influence. Selecting an aggregate with a high E -value will increase the modulus of elasticity of concrete. However, increasing the paste volume could decrease the E -value. Because SCC often has a higher paste content and lower maximum size of coarse aggregate and reduced coarse aggregate volume than traditional vibrated concrete, the E -value of SCC may be somewhat lower thereby lowering the tendency to form cracks with respect to conventional concrete with the same time dependent deformations.

If SCC does have a slightly lower E modulus than traditional vibrated concrete, this will affect the relationship between the compressive strength and the camber due to prestressing or post-tensioning. For this reason, careful control should be exercised over the strength at the time when the prestressing and post-tensioning strands or wires are released.

5.5 Creep

Creep is defined as the gradual increase in deformation (strain) with time for a constant applied stress. It has both components, time dependent as well as stress dependant.

Creep takes place in the cement paste and it is influenced by its porosity which is directly related to its water to cementitious material ratio. During hydration, the porosity of the cement paste reduces and so for a given concrete, creep reduces as the strength increases. The type of cement is important if the age of loading is fixed. Cements that hydrate more rapidly will have higher strength at the age of loading, a lower stress/strength ratio and a lower creep. As the aggregates restrain the creep of the cement paste, the higher the volume of the aggregate and the higher the E -value of the aggregate, the lower the creep will be.

Due to the higher volume of cement paste, the creep coefficient for SCC may be expected to be higher than for normal concrete of equal strength, but such differences are small and covered by the safe assumptions in the tables and the formulae provided in the relevant codes.

However, for prestressed structural members the study conducted by Department of Civil and Environmental Engineering University of Wisconsin, USA states that "Creep and shrinkage strains, approximately twice that of a normal mix, do constitute a significant increase in the effects of creep and shrinkage which, in turn, would likely result in less than expected long term prestress in a girder after losses (if the higher loss was not accounted for in design) and undesirable girder behavior" & hence necessary precautions shall be taken when using SCC for prestressed structures.

5.6 Plastic Settlement

The beneficial effect in reducing internal bleeding is confirmed by the reduction of plastic settlement in SCC with respect to conventional concrete.

5.7 Shrinkage

5.7.1 Plastic Shrinkage

Absence of internal and external bleeding in SCC is one of the causes for its higher plastic shrinkage with respect to the conventional concrete. Researchers have found that for the same loss of water, plastic shrinkage of SCC is at least 2 times higher than that of conventional concrete. The lower water/fine material and the finer capillary for structure are responsible for a faster development of the negative pressure causing plastic shrinkage. Higher plastic shrinkage of SCC means that in order to gain beneficial effect on strength and durability due to improvement in properties, in real structures curing of fresh SCC surface shall be given great care. Early curing efforts and use of polymeric fibers results in good control over plastic shrinkage cracks. As SCC might shrink more than normal concrete because of presence of higher paste volume, use of synthetic fibers such as polypropylene/polyester will reduce shrinkage cracks being developed.

5.7.2 Drying Shrinkage

During hardening and in hardened concrete shrinkage is the sum of the autogenous and the drying shrinkage. Autogenous shrinkage occurs during setting and is caused by the internal consumption of water during hydration. The volume of the hydration products is less than the original volume of unhydrated cement and water and this reduction in volume causes tensile stresses and results in autogenous shrinkage.

Drying shrinkage is caused by the loss of water from the concrete to the atmosphere. Generally this loss of water is from the cement paste, but with a few types of aggregate the main loss of water is from the aggregate. Drying shrinkage is relatively slow and the stresses it induces are partially balanced by tension creep relief.

The aggregate restrains the shrinkage of the cement paste and so the higher the volume of the aggregate and the higher the E-value of the aggregate, the lower the drying shrinkage. A decrease in the maximum aggregate size which results in a higher paste volume increases the drying shrinkage.

Tests performed and shrinkage of different types of SCC and a reference concrete show that, in SCC:

- The deformation caused by shrinkage may be higher
- The value for the sum of the deformations due to shrinkage and creep are almost similar

Due to the restraint of the presence of reinforcement in a cross section the shrinkage strain will cause tension in concrete and compression in the reinforcement.

5.8 Coefficient of thermal expansion

The coefficient of thermal expansion of concrete is the change in linear dimension of a material per unit length (strain produced in concrete) after a unit change in temperature when the concrete is not restrained either internally (by reinforcing bars) or externally.

The coefficient of thermal expansion of concrete varies with its composition, age and moisture content it tends to increase with increasing cement content and decrease with age. As the bulk of concrete comprises aggregate, using an aggregate with a lower coefficient of thermal expansion will reduce the coefficient of thermal expansion of the resulting concrete. Reducing the coefficient of thermal expansion leads to a proportional reduction in the crack control reinforcement. Table 2 of *IS:14591* gives the values of coefficient of thermal expansion of concrete with various aggregates the values are between $0.58 \times 10^{-5}/^{\circ}\text{C}$ to $1.35 \times 10^{-5}/^{\circ}\text{C}$.

5.9 Bond to reinforcement, prestressing and wires

Reinforced concrete is based on an effective bond between concrete and the reinforcing bars. The concrete bond strength should be sufficient to prevent bond failure. The effectiveness of bond is affected by the position of the embedded bars and the quality of concrete as cast. An adequate concrete cover is necessary in order to properly transfer bond stresses between steel and concrete.

Poor bond often results from a failure of the concrete to fully encapsulate the bar during placing or bleed and segregation of the concrete before hardening which reduce the quality of contact on the bottom surface. SCC fluidity and cohesion minimize these negative effects, especially for top bars in deep sections. The bond strength between deformed bars and concrete matrix is higher in SCC than the conventional concrete. Higher bond strength in SCC is because of more stable paste capable of reducing the water film beneath the reinforcement, and consequently, to improve the mechanical properties.

Even if bond properties are generally enhanced when SCC is used, for a given compressive strength the formulae used in the relevant Codes should be used.

5.10 Fire resistance

Concrete is non-combustible and does not support the spread of flames. It produces no smoke, toxic gases or emissions when exposed to fire and does not contribute to the fire load. Concrete has a slow rate of heat transfer which makes it an effective fire shield for adjacent compartments and under typical fire conditions, concrete retains most of its strength.

The fire resistance of SCC is similar to normal concrete. In general a low permeability concrete may be more prone to spalling but the severity depends upon the aggregate type, concrete quality and moisture content. SCC can easily achieve the requirements for high strength, low permeability concrete and will perform in a similar way to any normal high strength concrete under fire conditions.

The use of polypropylene fibres in concrete has been shown to be effective in improving its resistance to spalling and bursting during fire. The mechanism is believed to be due to the fibres melting and being absorbed in the cement matrix. The fibre voids then provide expansion chambers and escape routes for steam, thus reducing the risk of spalling. Micro Polymeric (about 32 μm , Polypropylene) fibres have been successfully used with SCC.

5.11 Durability

The durability of a concrete structure is closely associated to the permeability of the surface layer, the one that should limit the ingress of substances that can initiate or propagate possible deleterious actions (CO_2 , chloride, sulphate, water, oxygen, alkalis, acids, etc.). In practice, durability depends on the material selection, concrete composition, as well as on the degree of supervision during placing, compaction, finishing and curing.

Honey-comb and lack of compaction of the surface layer, due to vibration difficulties in narrow spaces between the formwork and the re-bars or other inserts (e.g. post-tensioning ducts) has been recognized as a key factor of poor durability performance of reinforced concrete structures exposed to aggressive environments. Overcoming this was one of the main reasons for the original development of SCC in Japan.

Traditional vibrated concrete is subjected to compaction via vibration (or tamping), which is a discontinuous process. In the case of internal vibration, even when correctly executed, the volume of concrete within the area of influence of the vibrator does not receive the same compaction energy at all locations. This means, in the vibrated concrete there remains portions of over-vibrated and under-vibrated concrete.

Similarly, in the case of external vibration, the resulting compaction is essentially heterogeneous, depending on the distance to the vibration sources.

Therefore, result of the vibration is the concrete in structure with uneven compaction and with different permeabilities, which enhances the selective ingress of aggressive substances. Naturally, the consequences of incorrect vibration (honeycombing, segregation, bleeding, etc.) have a much stronger negative effect on permeability and, hence, on durability.

Self compacting concrete with the right properties will be free from those shortcomings and result in a material of consistently low and uniform permeability, offering less weak points for deleterious actions of the environment and, hence, better durability.

The greater durability of self compacting concrete satisfies the request for sustainability because it will be possible to minimize and delay the maintenance and repairs. So, it can be concluded that:

Extension of durability of SCC structures and elements is due to –

- i. the improved durability of SCC itself, as direct consequence of the better quality of the interfacial transition zone (itz) and of the lower tendency to crack in comparison with the conventional concrete.
- ii. A better quality of the concrete in the job-site, due to the reduced dependency on the procedures of casting and compaction.

5.12 Rheology of concrete

Rheology may be defined as the science of the deformation and flow of material and is concerned with relationships between stress, strain, rate of strain and time. The term rheology deals with materials whose flow properties are more complicated than those of ideal liquids which follow Newton's law of viscous flow viz. shear stress being proportional to the rate of shear strain are termed as Newtonian liquids. The flow behavior of fresh concrete does not conform to it. The ratio of shear stress to shear rate is not constant for concrete. The fact that concrete can stand in a pile (as in case of slump test) suggests that there is some minimum stress necessary for flow to occur. The minimum stress is called as yield stress and designated by symbol τ_0 . Thus for fresh concrete the flow equation is expressed by Bingham equation which can be written as

$$\tau = \tau_0 + \mu \dot{\gamma}$$

Where τ = yield value indicating cohesion of material.

μ = Plastic viscosity

$\dot{\gamma}$ = Rate of shear.

Thus, Bingham's equation gives relationship between shear stress of material expressed in terms of cohesion, plastic viscosity and rate at which the shear load is applied.

The Bingham's equation can be represented as given in figure 1

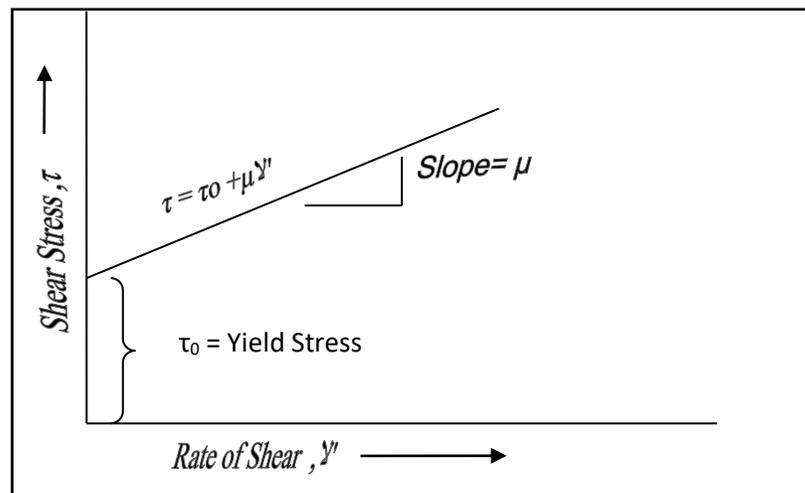


Figure 1 Bingham's model

The concrete normally follows the Bingham's equation under practical circumstances with certain limits i.e. yield stress is not well defined and the flow curves is not linear except over a limited range of shear rates.

Qualitative description of concrete rheology is shown in Figure 2

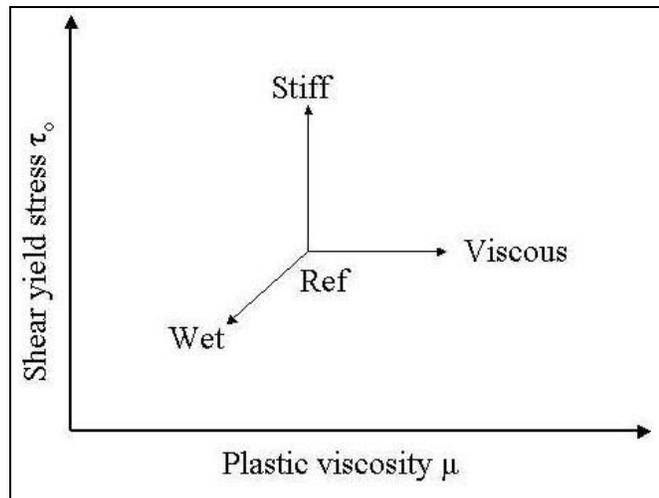


Figure 2 Qualitative description of concrete rheology

The rheology of fresh concrete like workability includes the parameters of stability, mobility and compactibility. These parameters encompass all the different attributes of fresh concrete which in turn determine the suitability of any concrete mix. The parameters can be represented as below (Figure 3)

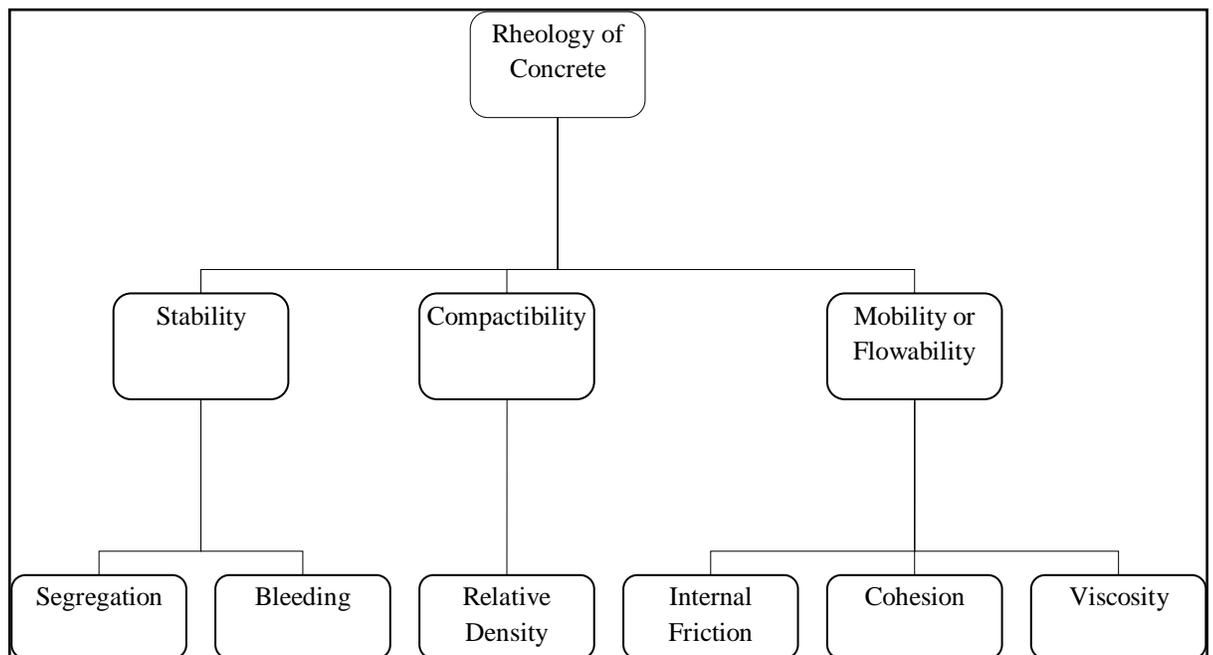


Figure 3 Parameters defining the rheology of fresh concrete.

Stability is defined as a condition in which the aggregate particles are held in homogenous dispersion in matrix of concrete. The segregation and bleeding are 2 attributes which measure the stability.

Mobility of fresh concrete is its ability to flow under momentum transfer i.e. under mechanical stress. The flow is restricted by cohesive, viscous and frictional forces. The cohesion force develops due to adhesion between the paste and aggregate particles; it provides shear strength to fresh concrete that resists segregation. The viscosity of the matrix contributes to the ease with which the aggregate particles can move and rearrange themselves within matrix. At low stresses no flow occurs and mix behaves as a solid of extremely high viscosity. As the stresses increase, the viscosity gradually decreases and the concrete behavior changes to that of a liquid. The internal friction occurs when a mixture is displaced and the aggregate particles translate and rotate. The resistance to deformation depends upon the shape and texture of the aggregate, the richness of mix, the w/c ratio and type of cement used.

Compactibility measures the ease with which fresh concrete is compacted. Compacting consists of expelling entrapped air and repositioning the aggregate particles in a dense mass without causing segregation.

Thus the knowledge of rheological properties of concrete is beneficial in selecting concrete mixtures that can be efficiently compacted in the forms.

The factors affecting rheological properties are:

- Mix proportions
- Consistency
- Hardening and stiffening
- Aggregate shape and grading
- Maximum aggregate size
- Admixtures

Concrete rheology and the effect of additives is as shown in figure below (Figure 4)

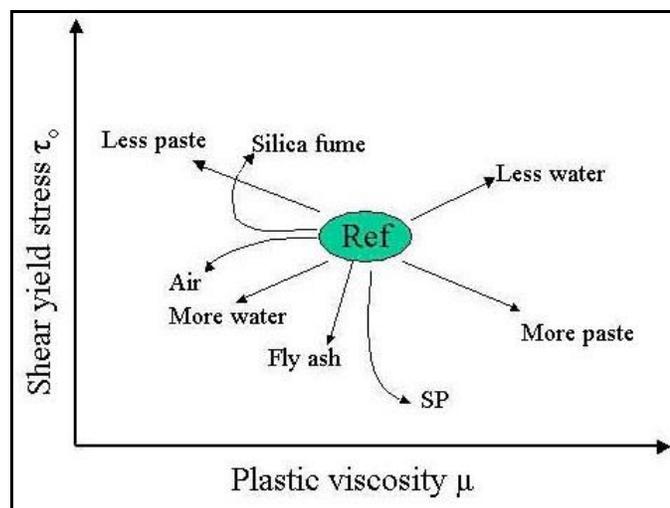


Figure 4 Effect of air, water and additives on rheological parameters

Hence, proper attention to the rheological properties of a mixture can effectively reduce construction and material costs.

6. Specifying SCC

6.1 General

SCC will normally be specified as a prescribed concrete or proprietary concrete. The proprietary concrete is the one wherein the producer assures the performance and need not declare the composition i.e. performance specification based concrete. The prescribed concrete is the one in which the user specifies the composition and the requirements.

6.1.1 Basic requirements

The specification for self compacting concrete shall contain:

- a) Requirement confirming to “The European Guidelines for SCC, May 2005, Annex A”
- b) Compressive strength
- c) Exposure class(s) and/or limiting values of composition, e.g. maximum w/c ratio, minimum cement content. (as per *IS 456: 2000*, & it’s Amendment no.3);
- d) Maximum nominal coarse aggregate size
- e) Class of exposure related to chloride ion penetration.
- f) Slump flow class or in special cases, a target value

The filling ability and stability of self-compacting concrete in the fresh state can be defined by the following four key characteristics. Each characteristic can be addressed by one or more test methods:

Table 1 Preferred Test Methods for Assessing Characteristics of SCC.

Characteristic	Preferred test method(s)
Flowability	Slump-flow test
Viscosity (assessed by rate of flow)	T ₅₀₀ Slump flow test or V-funnel test
Passing ability	L-box test
Segregation	Segregation resistance (sieve) test

The test methods excluding the sieve test are given in Annexure C (C.1 to C.5). Two important properties specific to SCC in its plastic state are its flowability and stability. SCC mixtures typically have a higher paste volume, less coarse aggregate, and higher sand-to-coarse aggregate ratio than typical concrete mixtures; mix is highly cohesive.

6.1.2 Additional requirements

In addition to the basic requirements (Sub-clause 6.1.1) the following additional requirements and provisions shall be:

- a) T₅₀₀ value for the Slump flow test or a V-funnel class (see 6.3 & Annex C);
- b) L-box class or, in special cases, a target value (see Annex C);
- c) Segregation resistance class or, in special cases, a target value
- d) Requirements for the temperature of the fresh concrete,
- e) Other technical requirements.

6.2 Requirements in the fresh state

Specific requirements for SCC in the fresh state depend on the type of application, and especially on:

- Confinement conditions related to the concrete element geometry, and the quantity, type and location of reinforcement its congestion, inserts, cover and recesses etc
- Placing equipment (e.g. pump, direct from truck-mixer, skip, tremie)
- Placing methods (e.g. number and position of delivery points)
- Finishing method.

The classifying system allows for an appropriate specification of SCC to cover these requirements, which are characterized as:

- Flowability Slump-flow
- Viscosity (measure of the speed of flow)
- Passing ability (flow without blocking)
- Segregation resistance

Details of the test methods for these characteristics can be found in Annexure -C

Information on selection of parameters and classes is given in Clause 6.3.

Self-compacting concrete requirements in the fresh state that are appropriate for a given application should be selected from one or more of these four key characteristics and then specified by class or target value .

Passing ability, viscosity and segregation resistance will affect in-situ properties of the hardened concrete. But these should only be specified if specifically needed.

- If there is little or no reinforcement, there may be no need to specify passing ability as a requirement may not be needed.
- Viscosity may be important where good surface finish is required or reinforcement is highly congested but may not be specified in most other cases.
- Segregation resistance becomes increasingly important with higher fluidity and lower viscosity SCC but if it needs to be specified. See Clause 6.3 for additional advice on specifying.

The required consistence retention time will depend on the transportation and placing time. This should be determined and specified and it is the responsibility of the producer to ensure that the SCC maintains its specified fresh properties during this period.

Self-compacting concrete should, if possible be placed in one continuous pour so delivery rates should be matched to placing rate and also be agreed with the producer in order to avoid placing stoppages due to lack of concrete or long delays in placing after the concrete reaches site.

6.3 Consistence classification – The EFNARC specifications for SCC gives the classification for SCC as under

6.3.1 Slump-flow

Slump-flow value describes the flowability of a fresh mix in unconfined conditions. It is a sensitive test that will normally be specified for all SCC, as the primary check that the fresh concrete consistence meets the specification. Visual observations during the test and/or measurement of the T_{500} time can give additional information on the segregation resistance and uniformity of each delivery.

The following are typical slump-flow classes for a range of applications:

- a) Slump flow-1 (*SF1*) 550 - 650 mm is appropriate for:
 - Unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. housing slabs)
 - Casting by a pump injection system (e.g. tunnel linings)
 - Sections those are small enough to prevent long horizontal flow (e.g. piles and some deep foundations). [Note: For piles slump flow 400 to 600 mm may be provided]
- b) Slump flow- 2 (*SF2*) 660 - 750 mm is suitable for many normal applications (e.g. walls, columns)
- c) Slump flow-3 (*SF3*) 760 – 850 mm is typically produced with a small maximum size of aggregates (less than 16 mm) and is used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. *SF3* will often give better surface finish than *SF 2* for normal vertical applications but segregation resistance is more difficult to control.

Target values higher than 850 mm may be specified in some special cases but great care should be taken regarding segregation and the maximum size of aggregate should normally be lower than 12 mm.

6.3.2 Viscosity

Viscosity can be assessed by the T_{500} time during the slump-flow test or assessed by the V-funnel flow time. The time value obtained does not measure the viscosity of SCC but is related to it by describing the rate of flow. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time. Viscosity (low or high) should be specified only in special cases such as those given below. It can be useful during mix development and it may be helpful to measure and record the T_{500} time while doing the slump-flow test as a way of confirming uniformity of the SCC from batch to batch.

- a) Viscosity *VS1* has good filling ability even with congested reinforcement. It is capable of self-leveling and generally has the best surface finish. However, it is more likely to suffer from bleeding and segregation.
- b) Viscosity *VS2* has no upper class limit but with increasing flow time it is more likely to exhibit thixotropic effects, which may be helpful in limiting the formwork pressure (see Clause 10.5) or improving segregation resistance. Negative effects may be experienced regarding surface finish (e.g. blow holes - see clause 12.2) and sensitivity to stoppages or delays between successive lifts.

6.3.3 Passing ability

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. In defining the passing ability, it is necessary to consider the geometry and density of the reinforcement, the flowability/filling ability and the maximum aggregate size.

The defining dimension is the smallest gap (confinement gap) through which SCC has to continuously flow to fill the formwork. This gap is usually but not always related to the reinforcement spacing. Unless the reinforcement is very congested, the space between reinforcement and formwork cover is not normally taken into account as SCC can surround the bars and does not need to continuously flow through these spaces.

Examples of passing ability specifications are given below:

1. Passing ability PA1 structures with a gap of 80 mm to 100 mm, (e.g. housing, vertical structures)
2. Passing ability PA2 structures with a gap of 60 mm to 80 mm, (e.g. civil engineering structures)
3. For thin slabs where the gap is greater than 80 mm and other structures where the gap is greater than 100 mm no specified passing ability is required.
4. For complex structures with a gap less than 60 mm, specific mock-up trials may be necessary.

6.3.4 Segregation resistance

Segregation resistance is fundamental for SCC in-situ homogeneity and quality. SCC can suffer from segregation during placing and also after placing but before stiffening. Segregation occurring after placing will be most detrimental in tall elements but even in thin slabs, it can lead to surface defects such as cracking or a weak surface.

In the absence of relevant experience, the following general guidance on segregation resistance classes is given in the following:

Segregation resistance becomes an important parameter with higher slump-flow classes and/or the lower viscosity class, or if placing conditions promotes segregation. If none of these apply, it is usually not necessary to specify a segregation resistance class.

- a) Segregation resistance 1 (*SR1*) is generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 meters and a confinement gap greater than 80 mm.
- b) Segregation resistance 2 (*SR2*) is preferred in vertical applications if the flow distance is more than 5 meters with a confinement gap greater than 80 mm in order to take care of segregation during flow.

SR2 may also be used for tall vertical applications with a confinement gap of less than 80 mm if the flow distance is less than 5 meters but if the flow is more than 5 meters a target SR value of less than 10% is recommended. *SR2* or a target value may be specified if the strength and quality of the top surface is particularly critical.

Table 2. Suggested specifications

Suggested class of SCC for various components						
Sr.no.	Component	Suggested specifications				Remarks
		SF Class	VS Class	PA Class	SR Class	
1	Secondary concrete such as for gate slots, brackets, inserts, anchoring etc.	<i>SF2</i>	<i>VS1</i>	<i>PA2</i>	<i>SR2</i>	
2	Conjestedly reinforced structural components / elements	<i>SF3</i>	<i>VS1</i>	<i>PA2</i>	<i>SR1</i>	
3	Structural elements with complex shapes	<i>SF3</i>	<i>VS1</i>	<i>PA2</i>	<i>SR1</i>	
4	Blockouts for M/C foundations	<i>SF1</i>	<i>VS2</i>	<i>PA1</i>	<i>SR</i>	
5	Emergency situations requiring quick concreting such as Packing river sluices ,outlets & similar	<i>SF1</i>	<i>VS2</i>	<i>PA1</i>	<i>SR2</i>	
6	Emergency repairs of urgent nature	<i>SF1or SF2</i>	<i>VS1 or VS</i>	<i>PA1 or PA2</i>	<i>SR1or SR2</i>	As per actual requirements based on size and shape of element and nature of repairs.
7	Concrete pavement works	<i>SF1</i>	<i>VS2</i>	<i>PA1</i>	<i>SR1</i>	
8	Tunnel lining	<i>SF1</i>	<i>VS1</i>	<i>PA1</i>	<i>SR2</i>	
9	Columns, beams, slabs in conventional structures	<i>SF1 or</i>	<i>VS2</i>	<i>PA1</i>	<i>SR1</i>	For slabs <i>SF1</i> and for other elements <i>SF2</i>
10	Prestressed girders and elements	<i>SF3</i>	<i>VS1</i>	<i>PA1</i>	<i>SR2</i>	

Note: - The above specifications are suggestive only & may be suitably modified as per the mix proportioning for the specific job requirement.

6.4 Acceptance criteria for SCC:

Typical acceptance criteria for SCC with a maximum aggregate size of 20 mm are as shown in table no.3.

Table 3. Acceptance criteria for Self Compacting Concrete.

Sr. No.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	slump flow by Abrams cone	mm	650	800
2	T500mm slump flow	Sec	2	5
3	J-ring	mm	0	10
4	V-funnel	Sec	6	12
5	Time increase, V-funnel at T 5minutes	Sec	0	+3
6	L-box	(h2/h1)	0.8	1.0
7	U-box	(h2-h1) mm	0	30
8	Fill box	%	90	100
9	GTM Screen stability test	%	0	15
10	Orimet	Sec	3	15

These requirements are to be fulfilled at the time of placing. Likely changes in workability during transport should be taken into account in production.

These typical requirements shown against each test method are based on current knowledge and practice. However future developments may lead to different requirements being adopted.

Special care should always be taken to ensure that no segregation of the mix is likely as, at present, there is not a simple and reliable test that gives information about segregation resistance of SCC in all practical situations.

7. Constituent materials

7.1 General

Mix proportions for SCC differ from those of ordinary concrete, in that the former has more powder content and less coarse aggregate. Moreover, SCC incorporates high range water reducers (HRWRA, superplasticizers) in larger amounts and frequently a viscosity modifying agent (VMA) in small doses. However, the constituent materials for SCC are the same as those used in traditional vibrated concrete conforming to IS 456:2000. In most cases the requirements for constituents are individually covered by relevant Indian standards. However, in order to be sure of uniform and consistent performance for SCC, additional care is needed in initial selection and also in the continual monitoring for uniformity of incoming batches.

The questions that dominate the selection of materials for SCC are: (i) limits on the amount of marginally unsuitable aggregates, that is, those deviating from ideal shapes and sizes, (ii) choice of HRWRA, (iii) choice of VMA, and (iv) interaction and compatibility between cement, HRWRA and VMA. These are discussed below

To achieve these requirements the control of the constituent materials needs to be increased and the tolerable variations restricted, so that daily production of SCC is within the conformity criteria without the need to test and/or adjust every batch.

7.2 Cement

Cements conforming to the concerned Indian Standard can be used for the production of SCC. The correct choice of cement type is normally dictated by the specific requirements of each application or what is currently being used by the producer rather than the specific requirements of SCC. However, there exists the problem of incompatibility between cement and HRWRA (high range water reducing admixture) particularly at low water contents. In concretes having low water content and high super plasticizer dosage (SNF based), gypsum (present in cement) may precipitate out causing a premature stiffening of the paste and consequent loss of slump. When lignosulphonates (which may have sugar in them) are used for retarding action to retain slump in hot weather conditions and VMAs are used the concrete may not set for nearly twenty hours. **Hence, before using any brand of cement it is advisable to verify its compatibility with the superplasticizer being used.**

As it is difficult for the field engineer to either verify the compatibility himself or get it tested every time. It is better to get a certificate / confirmation from admixture supplier about this aspect, as supplier would have done detailed compatibility study on each brand / grade of cement in the market. This certificate will also be useful for getting an estimate of optimum dosage.

7.3 Additions (/ Additives / Mineral admixtures)

Due to the fresh property requirements of SCC and higher powdery content, inert and pozzolanic/hydraulic additions are commonly used to improve and maintain the cohesion and segregation resistance. The addition will also regulate the cement content in order to reduce the heat of hydration and thermal shrinkage. These are also called as mineral admixtures.

The additions are classified according to their reactive capacity with water as shown in following Table 4.

Table 4. Additions in SCC

TYPE I	Inert or semi-inert	<ul style="list-style-type: none">• Mineral filler (limestone, dolomite etc)• Pigments
TYPE II	Pozzolanic	<ul style="list-style-type: none">• Fly ash conforming to IS3812Part I• Micro-silica or Silica fume conforming to IS15388• Metakaoline, rise husk ash
	Hydraulic	<ul style="list-style-type: none">• Ground granulated blast furnace slag conforming to IS12089

Self-compacting concrete is also selected for its high quality finish and good appearance but this may be compromised if the source of the addition does not have good colour consistency.

7.3.1 Mineral fillers

The particle size distribution, shape and water absorption of mineral fillers may affect the water demand /sensitivity and therefore suitability for use in the manufacture of SCC. Calcium carbonate based mineral fillers are widely used and can give excellent rheological properties and a good finish. The most advantageous fraction is that smaller than 0.075 mm (75 μm) and in general it is desirable for >70% to pass a 0.063mm sieve. (In many cases the concrete may be deficit of the particles of size 200 μm to 45 μm , and in such cases filler particles of the requires size can improve the performance of concrete.) Fillers specifically ground for this application offer the advantage of improved batch to batch consistency of particle size distribution, giving improved control over water demand and making them particularly suitable for SCC compared with other available materials. Coarse fraction (>45 μm) of flyash behaves more as a filler material rather as pozzolanic.

Mineral fillers may include use of lime stone powder/ granite powder passing through 125 micron sieve which increases paste volume.

7.3.2 Fly ash

Fly ash has been shown to be an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. In India, in particular fly-ash is amply available and can be a sustainable alternative. However, high levels of fly ash may produce a paste fraction which is so cohesive that it can be resistant to flow. Fraction of flyash below 45 μm are useful as pozzolanic, however, particles finer than 5 μm are highly useful. Fly ash must confirm to the relevant IS standard (IS: 3812 – 2007)

7.3.3 Micro silica /Silica fume

The high level of fineness and practically spherical shape of silica fume results in good cohesion and improved resistance to segregation. However, silica fume is also very effective in reducing or eliminating bleed and this can give rise to problems of rapid surface crusting. This can result in cold joints or surface defects if there are any breaks in concrete delivery and also to difficulty in finishing the top surface. Also, since silica fume has to be imported it is a costly alternative. The silica fume shall conform to *IS15388*. Typically, substantial part of micro silica should be below 1µm size, and silica fume should have particles below 0.1 µm.

7.3.4 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS) provides reactive fines with a low heat of hydration. GGBS is already present in some cement but is also available as an addition and may be added at the mixer. A high proportion of GGBS may affect stability of SCC resulting in reduced robustness with problems of consistence control while slower setting can also increase the risk of segregation. The GGBS shall conform to *IS12089*. Typically active hydraulic slag has particle size smaller than cement.

7.3.5 Other additions

Metakaolin, natural pozzolana, ground glass, air cooled slag and other fine fillers have also been used or considered as additions for SCC but their effects need to be carefully and individually evaluated before use for both short and long term effects on the concrete. Other type of slags (such as copper slag) can also qualify for use as additive, which have been investigated in details and tested. Other additions like metakaolin, etc. should conform to the relevant IS standards.

7.3.6 Blending of additives

Multiple blending (of additives) can give better particle packing (i.e. particle size distribution) and hence can result in better performance. However, with more blending materials, the techniques for arriving at optimum results will be more elaborate, which will be of worth for getting better performance. Performance is also improved, as the phase of reaction of different pozzolanic material being different, results in pore refinement.

7.3.7 Grading of material (particle size distribution): In general finer particles required are more compared to ordinary concrete. With adjustment of powdery content, enough cohesiveness is also imparted to concrete. Additive should be proportioned to result in continuously graded particle size distribution, to get optimum performance. For optimizing, the grading of powdery material with finer aggregate and coarse aggregate should merge in for better performance.

7.4 Aggregates

Aggregates constitute the bulk of a concrete mixture, and give dimensional stability to concrete. Among the various properties of aggregate, the important ones for SCC are the shape and gradation. Many researchers have been able to produce self-compacting concrete with locally available aggregate. It is observed from these studies that self-compactability is achievable at lower cement (or fines) content when rounded aggregates are used, as compared to angular aggregates. Although there have been several studies on the effect of coarse aggregate content on the flow behaviour of SCC, enough attention has not been paid to quantify the effect of the shape of the aggregate.

In the case of SCC, rounded aggregates would provide a better flowability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates. Moreover, the presence of flaky and elongated particles may give rise to blocking problems in confined areas and also increase the minimum yield stress

Another deficiency in aggregates is poor gradation. Use of fillers (either reactive or inert) has been suggested as a means of overcoming this problem. Coarse flyash (fraction $>45\mu\text{m}$) can help in improving the gradation of finer aggregates. A trial and error approach is used to fix the type and amount of filler. Alternatively, particle packing models could be used to reduce the number of experimental trials.

Normal-weight aggregates should conform to *IS383* and meet the durability requirements.

The moisture content, water absorption, grading and variations in fines content of all aggregates should be closely and continuously monitored and must be taken into account in order to produce SCC of constant quality. Using washed aggregates will normally give a more consistent product. Changing the source of supply is likely to make a significant change to the concrete properties and should be carefully and fully evaluated.

The shape and particle size distribution of the aggregate is very important and affects the packing and voids content. Some mix design methods use the voids content of the aggregate in predicting the volumes of paste and of mortar required. Single size aggregates and/or a gap in the grading between coarse and fine aggregates are used in some mix designs.

The reinforcement spacing is the main factor in determining the maximum aggregate size. Aggregate blocking must be avoided as SCC flows through the reinforcement and the L-box test is indicative of the passing ability of an SCC mix. The maximum aggregate size should generally be limited to 12 – 20 mm, although larger sizes are being used.

The particle size distribution and the shape of coarse aggregate directly influence the flow and passing ability of SCC and its paste demand. As already indicated above the more spherical the aggregate particles the less they are likely to cause blocking and the greater the flow because of reduced internal friction.

7.4.1 Fine Aggregate / Sand

The influence of fine aggregates on the fresh properties of the SCC is significantly greater than that of coarse aggregate. Particles size fractions of less than 0.075 mm should be included in the fines content of the paste and should also be taken into account in calculating the water powder ratio.

The high volume of paste in SCC mixes helps to reduce the internal friction between the sand particles but a good grain size distribution is still very important. Many SCC mix design methods use blended sands to match an optimised aggregate grading curve and this can also help to reduce the paste content. Some producers prefer gap-graded sand. The sand shall conform to *IS383*.

In view of reduced availability of river sand, use of manufactured sand and other alternative fine aggregate has become essential in some regions. In fact, river sand is simply not available in many areas. Although there are studies that have shown that quarry run could be used as a filler instead of limestone for SCC, there has not been sufficient documentation of the use of manufactured sand, either as fine aggregate or as a filler, in SCC. Partial replacement of sand by crushed fines has been found useful. Further research on this topic will be useful.

Option of using Crushed Stone Sand or Manufactured sand (M-sand) can be considered. In fact research studies have concluded that M-sand is more suited to SCC as it contains higher percentage of micro fines passing through 150 micron and 75 micron in comparison to natural river sand. Use of M-sand demands slightly more water and higher dosage of admixture. This can be established through laboratory trials.

However, it should be clearly understood that Quarry Dust is not manufactured sand.

7.5 Admixtures

SCC invariably incorporates chemical admixtures - in particular, a high range water reducing admixture (HRWRA) and sometimes, viscosity-modifying agent (VMA). The HRWRA helps in achieving excellent flow at low water contents and VMA reduces bleeding and improves the stability of the concrete mixture. An effective VMA can also bring down the powder requirement and still give the required stability. Moreover, SCC almost always includes a mineral admixture, to enhance the deformability and stability of concrete.

Superplasticizers or high range water reducing admixtures (HRWRA) conforming to *IS9103*. Viscosity modifying admixtures (VMA) may also be used to help reduce segregation and the sensitivity of the mix due to variations in other constituents, especially to moisture content. Other admixtures including air entraining, accelerating and retarding may be used in the same way as in traditional vibrated concrete but advice should be sought from the admixture manufacturer on use and the optimum time for addition and they should conform to *IS9103*.

Choice of admixture for optimum performance may be influenced by the physical and chemical properties of the binder/addition. Factors such as fineness, carbon content, alkalis and C_3A may have an effect. It is therefore recommended that compatibility is carefully checked if a change in supply of any of these constituents is to be made.

Admixtures will normally be very consistent from batch to batch but moving to another source or to another type from the same manufacturer is likely to have a significant effect on SCC performance and should be fully checked before any change is made.

Though all varieties of HRWRAs are mentioned, SNF based admixtures can be used because of lower price than PCE. But it is well known that PCE based admixtures have better performance than other varieties.

7.5.1 Superplasticizer/High range water reducing admixtures (HRWRA)

Superplasticizers are a water reducing admixture that causes a significant increase in flowability with little effect (slight decrease) on Viscosity. The role of superplasticizer on rheology of fresh concrete as shown in figure 5 below.

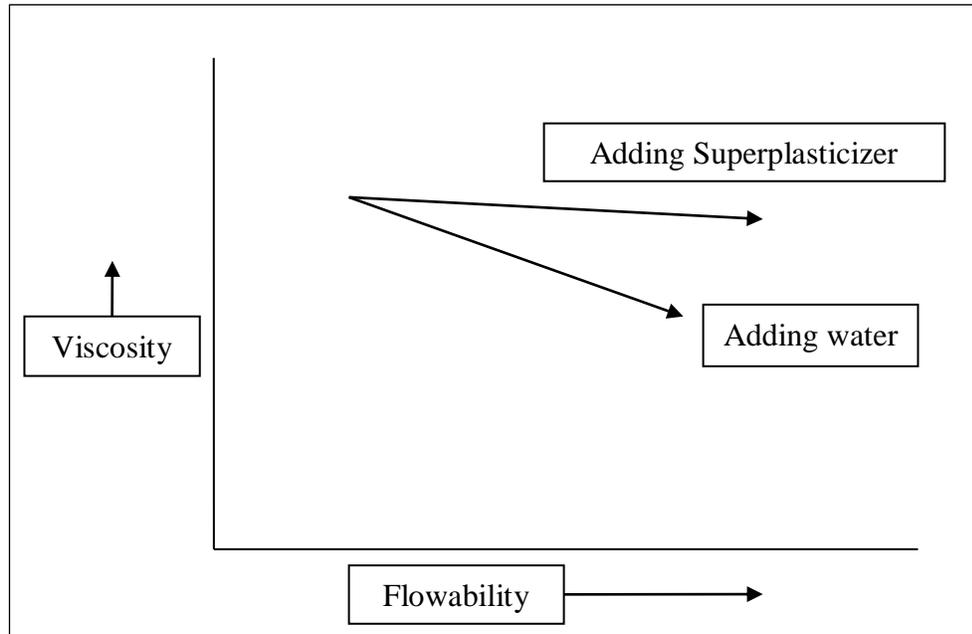


Figure 5 Effect of Superplasticizer

A number of studies have been conducted on the use of different types of HRWRAs with or without viscosity modifying agents in self-compacting concrete. These studies seem to indicate those that HRWRAs that work on the principle of ‘steric hindrance’ require a lower dosage compared to those based on ‘electrostatic repulsion’. Stated in other words, acrylic copolymers (AC) and polycarboxylate ethers (PCE) are effective at lower dosages compared to Sulfonated condensates of melamine (SMF) or naphthalene (SNF) formaldehyde. At present, SNF-based admixture is priced lower (in India) than that based on AC and PCE so SNF-based admixture seems to be preferable that based on PCE.

Most admixture manufacturers will have a range of superplasticizing admixtures tailored to specific user requirements and the effects of other mix constituents.

The admixture should bring about the required water reduction and fluidity but should also maintain its dispersing effect during the time required for transport and application. The required consistence retention will depend on the application.

7.5.2 Viscosity modifying admixtures

Admixtures that modify the cohesion of the SCC without significantly altering its fluidity are called viscosity modifying admixtures (VMA). These admixtures are used in SCC to minimize the effect of variations in moisture content, fines in the sands or its grain size distribution, making the SCC more robust and less sensitive to small variations in the proportions and condition of other constituents. However, they should not be regarded as a way of avoiding the need for a good mix design and careful selection of other SCC constituents.

Function of a Viscosity Modifying Admixture (VMA)

The key function of a VMA is to modify the rheological properties of the cement paste.

- The yield point describes the force needed to start the concrete moving. Yield point is related to the workability of the concrete and may be assessed by tests such as the slump value.
- Plastic Viscosity describes the resistance of a concrete to flow under external stress. Viscosity is caused by internal friction. The speed of flow of concrete is related to its plastic viscosity and may be assessed by the T500 time during a slump flow test or by the time to flow through a V Funnel.
- High viscosity, slow speed of flow; Low viscosity, fast speed of flow.

The balance between the yield point and the plastic viscosity is key to obtaining the appropriate concrete rheology. VMAs change the rheological properties of concrete by increasing the plastic viscosity but usually cause only a small increase in the yield point. Admixtures which decrease the yield point are called plasticizers and are often used in conjunction with a VMA to optimise the yield point.

So, VMAs are a family of admixtures designed for specific applications. They are used to:

- reduce segregation in highly flowable/self compacting concrete
- reduce washout in underwater concrete
- reduce friction and pressure in pumped concrete
- compensating for poor aggregate grading, especially a lack of fines in the sand
- reducing powder content in self compacting concrete
- reduce bleeding in concrete
- improve green strength in semi-dry concrete

Most VMAs are based on high molecular weight polymers with a high affinity to water. By interaction of the functional groups of the molecules with the water and the surfaces of the fines, VMAs build up a three dimensional structure in the liquid phase of the mix to increase the viscosity and/or yield point of the paste. The strength of the three dimensional structure affects the extent to which the yield point is increased.

This three dimensional structure/gel contributes to the control of the rheology of the mix, improving the uniform distribution and suspension of the aggregate particles and so reducing any tendency to bleeding, segregation and settlement.

Viscosity Modifying Admixtures make the concrete more tolerant to variations in the water content of the mix so that plastic viscosity is maintained and segregation prevented. The concrete has become more robust to small but normal changes in the moisture of the aggregate.

Viscosity Modifying Admixtures are not a substitute for poor quality constituents or mix design. Aggregates with a good grading curve should always be used for SCC and for high workability concrete as a lack of fines in aggregates will affect the rheology and may contribute to segregation and settlement. However, where suitable aggregates are not economically available, while using the available marginal aggregate the required rheology of the mix can often be achieved by utilizing a VMA to provide a more homogenous and cohesive concrete.

Potential benefits of a VMA in SCC may be summarised as follows:

- Less sensitive to variations in the moisture content of the aggregate
- The effects of small changes in the materials properties are minimised
- Lower powder content
- Reduces the level of production control
- Allows more fluid mixes to be used without the risk of segregation
- Improving placing rate
- Reduced risk of segregation and bleeding
- Reduced formwork pressure by thixotropic effect
- Better surface appearance

7.5.3 Air entraining admixtures

Air entraining admixtures may be used in the production of SCC to improve freeze-thaw durability. They are also used to improve the finishing of flat slabs and air entrainment is particularly useful in stabilising low powder content and/or lower strength SCC.

7.6 Fibers

Both metallic and polymeric fibers can be used in the production of SCC, but they may reduce flowability and passing ability. Trials are therefore needed to establish the optimum type, length and quantity of fibers, as well as the dose of superplasticizer, to give all the required properties to both the fresh and hardened concrete.

Polymer fibers can be used to improve the stability of SCC, as they help prevent settlement and cracking due to plastic shrinkage of the concrete.

Steel or long polymer structural fibers are used to modify the ductility/toughness of the hardened concrete. Their length and quantity is selected depending on the maximum size of aggregate and on structural requirements. If they are used as a substitute for normal reinforcement, the risk of blockage is no longer applicable but it should be emphasized that using SCC with fibers in structures with normal reinforcement significantly increases the risk of blockage. The use of fibers shall be done by referring to specialist literature. A separate PWD chapter on FRC is available and shall be referred.

7.7 Mixing water

Water used in SCC mixes shall be in accordance with the requirements of *IS456*. Where recycled water, recovered from processes in the concrete industry, is used the type/content and in particular, any variation in content of suspended particles should be taken into account as this may affect batch-to-batch uniformity of the mix.

8. Mix composition

8.1 General

A number of methods for proportioning SCC mix have been developed over the years with primary attention to produce satisfactory self-compacting properties. These methods vary in complexity and may require wide range of information on the effect of each ingredient on the mechanics of SCC mixes. They have inherent limitations also. In general, SCC mix proportioning methods consider volume as key parameter because of the importance and the need to fill over the voids between the aggregate particles by the paste.

Even though the different approaches for mix proportioning differ in some respects many of them are based on the concept of SCC being a particle suspension. The coarse aggregate is regarded as the solid phase suspended in the continuous phase- micro or fine mortar.

The general mix composition shall be chosen to satisfy all specified performance criteria for the SCC in both the fresh and hardened states. For ready-mixed concrete, these criteria will be part of specifications by the purchaser, and should meet the requirements set out in Chapter 6 of this document.

SCC is a concrete in which two normally incompatible properties of deformability and segregation resistance are both realized to achieve self compactability by such measures as to increase the powder content and/or use of VMA. For this reason, a wide variety of formulas and methods are possible for SCC satisfying self compactability requirements as well as performance requirements in hardened state such as durability.

8.2 Mix proportioning approaches

Different mix proportioning methods can be grouped in two categories based on their approaches.

- i) In first category, the basic steps are determination of quantity of coarse aggregate then deriving approximate quality of mortar compatible for SCC mix.
- ii) In second category, suitable mortar mix is first proportioned and then quantity of coarse aggregate is determined.

The mixes proportioned by both the above categories can be further subdivided into 3 types as below

- a) Powder type - the cement content is very high, mineral admixture content is very low or none the superplasticizer is high but no VMA is used.
- b) VMA type - almost equal quantity of cement and mineral admixture, high quantity of VMA is required for maintaining the homogeneity of the mix but superplasticizer requirement is less compared to first type.
- c) Mixed type (combined type) - Mineral admixture content in the mix is about one-third of the powder content and lower quantity of VMA is used.

Okumara and Ozawa (1995) of the University of Tokyo developed most probably the first method of SCC mix proportion in 1995, which is also known as general method. This method is based on first approach and a step by step method where in VMA is not used.

Bui et al (Nov.2002) introduced a new approach for proportioning of SCC that is based on second category approach and can produce both VMA & mixed type mixes. The approach is based on paste rheology method.

8.3 Mix proportioning principles

To achieve the required combination of properties in fresh SCC mixes:

- The fluidity and viscosity of the paste is adjusted and balanced by careful selection and proportioning of the cement and additions, by limiting the water/powder ratio and then by adding a superplasticizer and (optionally) a viscosity modifying admixture. Correctly controlling these components of SCC, their compatibility and interaction is the key to achieving good filling ability, passing ability and resistance to segregation.
- In order to control temperature rise and thermal shrinkage cracking as well as strength, the fine powder content may contain a significant proportion of type I or II additions to keep the cement content at an acceptable level.
- The paste is the vehicle for the transport of the aggregate; therefore the volume of the paste must be greater than the void volume in the aggregate so that all individual aggregate particles are fully coated and lubricated by a layer of paste. This increases fluidity and reduces aggregate friction.
- The coarse to fine aggregate ratio in the mix is reduced so that individual coarse aggregate particles are fully surrounded by a layer of mortar. This reduces aggregate interlock and bridging when the concrete passes through narrow openings or gaps between reinforcement and increases the passing ability of the SCC.

These mix design principles result in concrete that, compared to traditional vibrated concrete, normally contains:

- lower coarse aggregate content
- increased paste content
- low water/powder ratio
- increased superplasticizer
- Sometimes a viscosity modifying admixture.

8.4 Test methods

A wide range of test methods have been developed to measure and assess the fresh properties of SCC. Table 5 lists the most common tests grouped according to the property assessed. The various equipment for testing is as shown below (Photograph 2)

No single test is capable of assessing all of the key parameters, and a combination of tests is required to fully characterize an SCC mix. However, one of the well known methods Indian method of mix proportioning is published in the ICJ (Indian Concrete Journal) in 2004. It is titled "Mixture proportioning procedures for Self-Compacting Concrete" by Jagadish Vengala & RV Ranganath. The Indian Concrete Journal, 78(8), 13 - 21. Year - 2004. This paper explains the concept of trial mix with SP, Fly ash & water. Within a few trials, the field engineer will be able to arrive at an optimum mix design.

Table 5. Test properties and methods for evaluating SCC

Characteristic	Test method	Measured value
Flowability/filling ability	Slump-flow	total spread
Viscosity/ flowability	T500 V-funnel Orimet	flow time flow time flow time
Passing ability	L-box U-box J-ring	passing ratio height difference step height, total flow
Segregation resistance	Penetration sieve segregation settlement column	depth percent laitance segregation ratio



Photograph 2. Test equipments: V-funnel, U-tube, L-box

The Marsh cone is also being used to assess the flowability of the paste and the mortar components.

8.5 Basic mix proportioning

There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, precast and contracting companies have developed their own mix proportioning methods.

The various approaches are outlined in para 8.2 above.

A number of procedures for proportioning of mixes for SCC are there in vogue. These can be classified into four categories as below:

- i) Empirical methods
- ii) Rheology based methods
- iii) Particle packing models
- iv) Statistical methods

i) Empirical methods

A customary method for design of SCC is to follow the recommendations of Okamura and Ozawa. In the method, 50 percent of the solid volume is taken up by coarse aggregate, while 40 percent of the mortar volume is fine aggregate. Paste composition (i.e. water-to-powder ratio) is then determined using flow tests on mortar. Adjustments in coarse and fine aggregate contents are then made to achieve desired flow properties.

Modifications to the above approach have been proposed by Edamatsu et al. In the Edamatsu’s method, the limiting coarse aggregate volume ratio is kept at 0.5. The fine aggregate content, in this case, is then fixed using V-funnel test with standardised coarse aggregate (glass beads).

The guidelines recommended by EFNARC are also based on Okamura’s method. The difference is that instead of fixing the coarse aggregate limit at 0.5, a higher amount is permitted in the case of rounded aggregate (up to 0.6). The proportion of sand in the mortar is varied between 40 and 50 percent, and water-to-powder ratio and superplasticizer dosage are determined through mortar slump flow and V-funnel tests. A comparison of the three methods discussed in this section is presented in Table 6.

Table 6. Comparison of Empirical methods of mix proportioning of SCC

Proposed by	Maximum CA volume ratio	Maximum proportion of sand in mortar, percent	Paste composition (w/p ratio)	Remarks
Okamura and Ozawa	0.5	40 (empirical)	Mortar flow and V-funnel tests	Originally developed using moderate heat or belite rich cement
Edamatsu et al.	0.5	Determined by V-funnel test using standardised coarse aggregate	Mortar flow and V-funnel tests	Enables determination of stress transferability of mortar
EFNARC	0.5 – 0.6	40 – 50 percent (empirical)	Mortar flow and V-funnel tests	Allows more freedom in coarse aggregate content

ii) Rheology-based methods - Based on rheological methods of characterization of workability.

Conventional methods of measuring concrete workability such as the slump test provide a broad an indication of the amount of work required to compact the concrete mixture. With the advent of more fluid concretes (pumpable concrete, self-leveling concrete), it was necessary to measure the flow properties of concrete. The rheological methods of characterization of workability are described on the Rheology page.

iii) Particle packing models

The concept of particle packing is borrowed from the ceramic industry. Here, the principle is to minimize the void content of a dry granular mixture of all ingredients (including cement, fly ash and microsilica). This is done by the choice of appropriate sizes and gradation of aggregate.

There are two approaches in this method.

1) Discrete model

These refer to packing of systems containing two or more discrete size classes of particles. In this type of model, the coarsest particles form the base skeleton and its voids are filled by smaller particles and these in turn by finer particles and so on, in the order of decreasing particle size. The fundamental assumption of the discrete model is that each class of particles will pack to its maximum density in the volume available. The discrete models are further classified as binary, ternary and multimodal mixture models.

2) Continuous model

Continuous approach assumes that all sizes are present in the particle distribution system, that is, it can be described as a discrete approach having adjacent size classes ratios that approach 1:1 and no gaps exist between size classes.

iv) Statistical methods

Khayat et al. proposed a mixture design procedure based on statistical models using a factorial design of experiments. The advantage of such an approach is that one can evaluate the effects of critical factors using minimum number of experiments. Another advantage is that only an approximate idea of the variables that affect the response is required, and not the exact relationships.

In Khayat's study, five parameters - cementitious materials content (cm), water-to-cementitious materials ratio (w/cm), HRWRA concentrations, VMA concentration, and volume of coarse aggregate - at five different levels, were chosen. The response variables were the slump flow, relative flow resistance (analogous to torque measurement), and relative torque (viscosity). In addition, the V-funnel time, filling ability, and settlement were also measured. A total of 32 SCC mixtures were prepared to obtain the required relationships.

Further information on mix design and on methods of evaluating the properties of SCC can be found in the EFNARC Guidelines for SCC

These Guidelines are not intended to provide specific advice on mix design but Table 7 gives an indication of the typical range of constituents in SCC by weight and by volume. These proportions are in no way restrictive and many SCC mixes will fall outside this range for one or more constituents.

Table 7. Typical range of SCC mix composition

Constituent	Typical range by mass (kg/m³)	Typical range by volume (liters/ m³)
Powder	380 - 600	--
Paste	--	300 - 380
Water	150 - 210	150 - 210
Coarse aggregate	750 - 1000	270 - 360
Fine aggregate (sand)	Content balances the volume of the other constituents, typically 48 – 55% of total aggregate weight.	
Water/Powder ratio by volume	--	0.85 – 1.10

8.6 Mix proportioning methodology

Laboratory trials should be used to verify properties of the initial mix composition with respect to the specified characteristics and classes. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale in the concrete plant and if necessary at site to verify both the fresh and hardened properties.

The series of processes to determine the materials and their contents is referred to as proportioning and the mix proportioning for SCC is generally based on the methodology outlined below:

- evaluate the water demand and optimise the flow and stability of the paste
- determine the proportion of sand and the dose of admixture to give the required robustness
- test the sensitivity for small variations in quantities (the robustness)
- add an appropriate amount of coarse aggregate
- produce the fresh SCC in the laboratory mixer, perform the required tests
- test the properties of the SCC in the hardened state
- Produce trial mixes in the plant mixer.

The design process and sequence is graphically presented in figure 6 below:

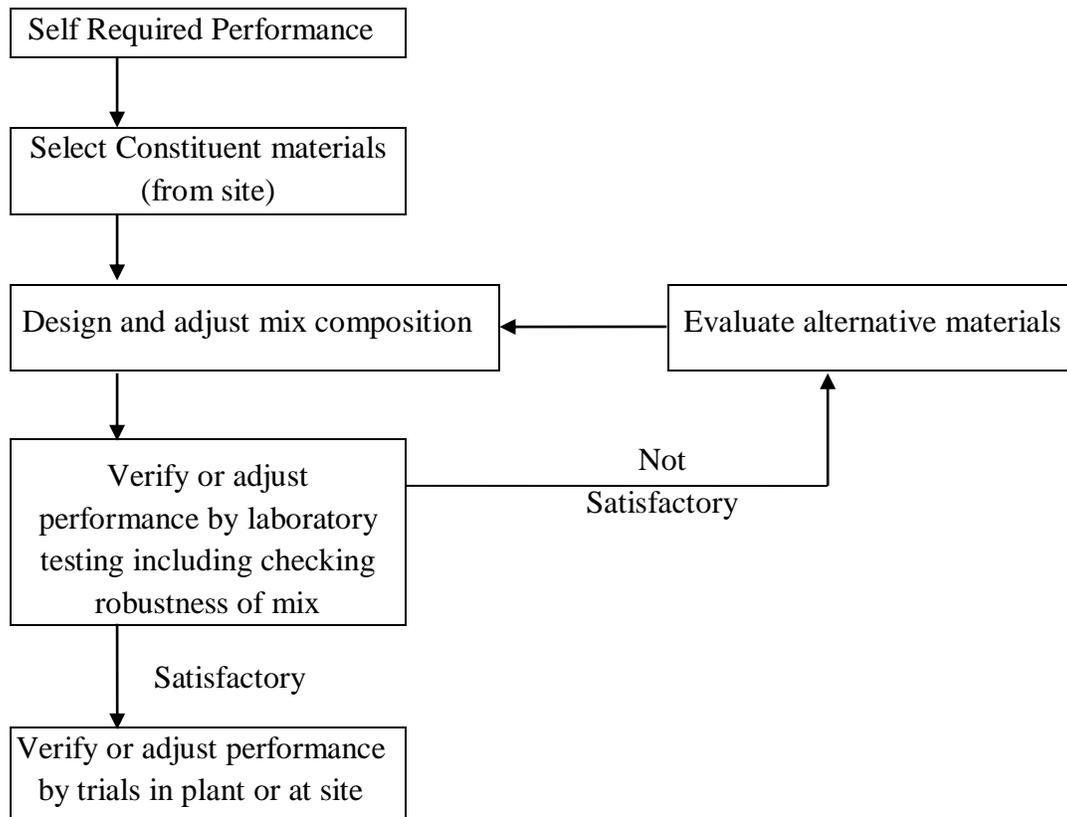


Figure 6 Flow Chart of Mix Proportioning

In the event that satisfactory performance is not obtained, consideration should be given to a fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate:

- adjust the cement to powder ratio and the water to powder ratio and test the flow and other properties of the paste
- try different types of addition (if available)
- adjust the proportions of the fine aggregate and the dosage of superplasticiser
- consider using a viscosity modifying agent to reduce sensitivity of the mix
- Adjust the proportion or grading of the coarse aggregate.

8.7 Robustness of SCC

Self-compacting concrete mix design aims to achieve an acceptable balance between the fresh state characteristics. Any variation in the uniformity of the constituents can upset this balance, resulting in a lack of filling/passing ability or to segregation. Most constituent variability can be equated to a change in water requirement, either due to changes in moisture content of the materials or changes in grading/specific surface both of which change the water demand of the mix.

Well designed SCC can give acceptable tolerance to daily fluctuations in these parameters, easing the pressure on testing/production control and reducing the possibility of problems on the job site. This tolerance is usually termed ‘robustness’ and is controlled by good practice in sourcing, storage and handling of basic constituents and by appropriate content of the fine powders and/or by use of a VMA.

A well designed and robust SCC can typically accept a 5 to 10 liter/m change in water content without falling outside the specified classes of performance when fresh. When designing an SCC mix, it can be helpful to test at plus and minus 5 and 10 liters of the target water content and measure the change in fresh state properties. This confirms the robustness of the mix or indicates that further adjustments to the design are needed.

8.8 Examples of SCC mixes

When designing an SCC mix, a suitable mix is selected among “Powder –type” by increasing the powder content, “VMA-type” using viscosity modifying admixture and “Combined-type” by increasing powder content and using viscosity agent in consideration of structural conditions, constructional conditions, available material, restrictions in concrete production plant etc. Examples of SCC mixes in some developed countries are given in the following tables to provide a feel for how SCC mixes differ from normal concrete mixes and from each other based on the specific needs of a project. In comparison to the conventional concrete, all three types work with an increased amount of superplasticizer.

Table 8 shows typical SCC mixes in Japan. Mix J1(Powder-type) is an example of SCC used in a LNG tank, Mix J2(VMA-type) is an example of SCC used for a massive caisson foundation of a bridge, and Mix J3 (Combined-type) is an example of SCC used in usual reinforced concrete structures. Table 9 shows some examples of SCC mixes in Europe while Tale 10 shows some examples of SCC mixes used in U.S. Table 11 shows the mix proportions used on 3 projects.

Table 8: Examples of SCC Mixes in Japan

Ingredients per m³	Mix J1 (Powder-type)	Mix J2 (VMA-type)	Mix J3 (Combined-type)
Water, kg	175	165	175
Portland cement type, kg	530	220	298
Fly Ash, kg	70	0	206
Ground Granulated Blast Furnace Slag, kg	0	220	0
Silica Fume ,kg	0	0	0
Fine Aggregate, kg	751	870	702
Coarse Aggregate, kg	789	825	871
*HRWRA, kg	9.0	4.4	10.6
**VMA,kg	0	4.1	0.0875
Slump Flow Test- Diam. Of spread, mm	625	600	660

Table 9. Examples of SCC Mixes in Europe

Ingredients per m³	Mix E1	Mix E2	Mix E3
Water, kg	190	192	200
Portland cement type,	280	330	310
Fly Ash, kg	0	0	190
Limestone Powder ,kg	245	0	0
Ground Granulated Blast Furnace Slag, kg	0	200	0
Funace Slag ,kg			
Silica Fume ,kg	0	0	0
Fine Aggregate, kg	865	870	700
Coarse Aggregate, kg	750	750	750
*HRWRA,kg	4.2	5.3	6.5
**VMA, kg	0	0	7.5
Slump Flow Test-Diam. Of spread, mm	600-750	600-750	600-750

Table 10: Examples of SCC Mixes in U.S.

Ingredients per m³	Mix U1	Mix U2	Mix U3
Water,kg	174	180	154
Portland cement type,	408	357	416
Fly Ash, kg	45	0	0
Ground Granulated Blast Furnace Slag, kg	0	119	0
Silica Fume kg	0	0	0
Fine Aggregate kg	1052	936	1015
Coarse Aggregate kg	616	684	892
*HRWRA, ml	1602	2500	2616
**VMA, ml	0	0	542
Slump Flow Test-Diam. Of spread, mm	710	660	610

Notes:

* HRWRA = High-range water reducing admixture.

** VMA = Viscosity-modifying admixture

*** Mix J1 uses low-heat type Portland cement.

Table 11. Sample Mix Proportioning of SCC for M30, M35 and M80

Sr. No.	Ingredient per m ³	Kg/m ³			Remarks
		M30	M35	M80	
1	Cement (OPC53 Gr.)	225	330	400	
2	Fly Ash	225	150	160	
3	Micro silica.	Nil	Nil	40	
4	Coarse Aggregate (CA) -20mm-10mm	354:708:355	455:764:309	284:711:427	
5	Fine Aggregate (FA)	288 River 684 crushed	917	970	Crushed sand
6	Water (W/B ratio)	165	163(0.34)	135 (0.225)	
7	PC Admixture As % of Binder by weight	0.8% Type G	0.8%	1.2	
8	VMA	0.60%	0.2%	0.2	
9	Ratio FA/CA	1.37	1.2	1.364	

9. Production for ready-mixed and site mixed SCC

9.1 General

Self-compacting concrete is less tolerant to changes in constituent characteristics and batching variances than conventional vibrated concrete. It is also more sensitive to fluctuations in the total water content than conventional vibrated concrete. Accordingly, it is important that all aspects of the production and placing operations and methods are carefully supervised.

The production of self-compacting concrete should be carried out in plants where the equipment, operation and materials are suitably controlled under a Quality Assurance scheme. It is recommended to verify about the accreditation for quality system of the producer and to ISO 9001 or equivalent.

It is important that that all personnel who will be involved in the production and delivery of SCC receive adequate training prior to production. This training may include observing trial batches being produced and tested. It should be emphasized that SCC can be successfully produced in a consistent and continuous way only at a properly equipped concrete mixing plant under a well established and reliable QC & QA system. Experience shows that SCC does not forgive any shortcuts.

Since SCC is very sensitive to variation in material properties, control on quality of incoming materials is a must at the batching plant. Before materials are unloaded at site/ batching plant, materials shall be checked and then accepted. This necessitates a stringent Quality Assurance plan.

Quality Council of India (QCI) has recently launched a scheme called Ready-mixed Concrete Production Control Scheme (RMPCPS). Batching plants producing SCC preferably should have a certificate under this scheme.

9.2 Storage and handling of constituent materials

Storage of constituent materials for SCC is in the same manner as that which should be followed for conventional vibrated concrete but because the mix is more sensitive to variations, additional importance and attention should be paid to the following points:

Aggregates: should be properly stored to avoid cross-contamination between different types and sizes and protected from weather to minimise the fluctuation of surface moisture content which is of great concern and movement of fines. Ground stock should be stored in purpose built partitioned bays, which will allow free drainage of excess moisture in the aggregates and rainwater.

There must be adequate storage capacity for aggregates as any significant disruption in the supply that causes a break in placing could cause serious complications. It is recommended that all material required stores in required quantities are filled in advance of a self-compacting pour.

Cements, additions and admixtures: There are no special requirements for the storage over that of conventional vibrated concrete. However for SCC there might be requirement of extra storage tanks and dispersing systems for VMAs. Manufacturer's recommendations for storage should always be followed. It is recommended that all material stores are filled in advance of a self-compacting pour to avoid the potential variations in performance following a fresh delivery. It is recommended to apply the best practices on the maintenance of stockpiles of materials, i.e. moisture content, free drainage, cleanliness and prevention of segregation.

9.3 Batching & Mixing equipment and trial mixes

SCC is much more sensitive to significant deviations of material quantities. Normal weighing tolerances regulated by standards are in general acceptable for production of SCC. Accuracy of weighing equipment may affect consistency of SCC and eventually on the cost to produce SCC, so more accurate equipment shall be used. Batching equipments should be regularly checked for accuracy.

Self-compacting concrete can be produced with any efficient concrete mixer including paddle mixers, free fall mixers and truck mixers but force action mixers are generally preferred. However, with SCC it is particularly important that the mixer is in a good mechanical condition and that it can ensure full and uniform mixing of the solid materials with sufficient shear action to disperse and activate the superplasticiser.

For production of SCC, the loading and mixing sequences are more important as it contain high amount of fine particles needed to be efficiently dispersed.

Experience has shown that the time necessary to achieve complete mixing of SCC may be longer than for normal concrete due to reduced frictional forces and to fully activate the superplasticiser. It is important that preliminary trials are carried out to ascertain the efficiency of individual mixers and the optimum sequence for addition of constituents. The volume of concrete for preliminary full-scale trials should not be less than half the capacity of the mixer and thereafter for better consistency the volume of SCC mix should be near to the maximum mixer capacity as possible. Mixer shall be clean but not dry.

Prior to commencing supply it is recommended that plant trials be conducted to ensure that in full scale production, the mix still conforms to the specification requirements for both fresh and hardened properties.

9.4 Plant mixing procedures

SCC normally requires a more efficient mixing e.g. longer mixing time, to make sure that all constituents have been mixed thoroughly. The high paste content and fluidity of SCC can make it more difficult to achieve a uniform mix than concrete of lower consistence. The main difficulty is the formation of unmixed "balls" of constituents and once these have formed they are not easily broken down. "Balling" is more likely to occur in free-fall mixers (particularly truck mixers) than forced action mixers (e.g. pan mixers). This problem can be avoided by first batching the concrete to a lower consistence than a self-compacting level until it is uniformly mixed. Addition of further water and superplasticiser will increase the workability (consistence) to the required level while avoiding "balling".

Time of addition of admixture during the batching is important as it can alter the effectiveness. When using VMA a late addition to the mix is preferred. A standard procedure should be adopted following plant trials and this procedure then strictly followed in order to reduce the potential for between-batch variances.

Admixtures should not be added directly to dry constituent materials but dispensed together with or in the mixing water. Different admixtures should not be blended together prior to dispensing unless specifically approved by the admixture manufacturer. This also applies to the potential for mixing of different admixtures in the dispenser or dosage lines. If air entraining admixtures are being used, they are best added before the superplasticiser and while the concrete is at a low consistency.

Due to the powerful effect of modern Superplasticizer, it is important that dispensers are calibrated regularly and where manual addition of admixtures takes place, measurement of the dosage is by a calibrated container or accurate dispensing equipment. Where more than one dosage addition is required to complete a batch there should be a means of counting the individual amounts added.

During production, there may be a number of factors that individually or collectively contribute to variations in the uniformity. The main factors are changes in the free moisture of the aggregate, aggregate particle size distribution and variations in batching sequence. Changes in properties may also be observed when new batches of other constituents are introduced. Because it is normally not possible to immediately identify the specific cause, it is recommended that adjustments to the workability (consistence) should be achieved by adjusting the level of superplasticiser.

There are a number of ways to load the mixer and the following illustrations have been included to explain the procedure to be get good concrete.

9.4.1 Free-fall plant (gravity type)/ Tilting drum and truck mounted mixers

First, approximately two thirds of the mixing water is added to the mixer. This is followed by the aggregates and cement. When a uniform mix is obtained, the remaining mixing water and the superplasticiser are added. Where VMA is used, this should be added after the superplasticiser and just prior to final water addition.

Truck mixers are likely to require additional mixing time for SCC as they are less efficient than plant mixers. Splitting the load into two or more batches can improve mixing efficiency. The condition of the truck mixer drum and mixing blades are particularly important for SCC and should be regularly inspected. The rotational speed of the drum during the mixing cycle should comply with the manufacturer's recommendations (usually 14 rpm).

9.4.2 Forced action mixers (Force type)

Aggregate is generally added to the mixer first, together with the cement. This is immediately followed by the main mixing water and superplasticiser. Where used, the VMA is added with the final water. The high shear produced by a forced action mixer improves the fluidity.

Due to the wide variation in mixers available, the exact methodology for loading the mixer should be determined by trials before commencing production. However, it shall be kept in mind that force types of mixers are normally regarded more efficient in mixing SCC than gravity mixers.

9.5 Production Control

9.5.1 Constituents

Self-compacting concrete is more sensitive than conventional vibrated concrete to variation in the physical properties of its constituents and especially to changes in aggregate moisture content, grading and shape, so more frequent test checks are necessary.

It is recommended that the aggregates are evaluated each day prior to commencing batching. Visual checks should be carried out on each delivery of aggregate; any noticeable change should be evaluated prior to accepting or rejecting the delivery. The moisture content of aggregates should be continuously monitored and the mix adjusted to account for any variation.

When new batches of cement (type or from different cement plant) or admixtures are delivered, additional performance tests may be necessary to monitor any significant changes or interactions between constituents. Total water in the mix should be closely controlled, which would include free water on surface of aggregate, mixing water and water in admixtures and VMA etc.

9.5.2 Production

The production and supply of SCC shall be subject to normal production control under the responsibility of the producer, and in the case of ready-mixed concrete, this shall be in accordance with contractual arrangements between purchaser and producer and the requirements of relevant IS.

The type of application will determine the specified characteristics and classes that the purchaser has given the producer. The production control must ensure that these are carefully complied with during production and any drift outside of the specified parameters should be immediately communicated to the batching plant operator and technical manager/engineer.

In the absence of previous experience with a particular mix design, additional resources may be needed for supervision of all aspects of initial production and testing of SCC.

In order to ensure consistent self-compacting properties, it is recommended that the producer tests every load for slump-flow until consistent results are obtained. Subsequently, every delivered batch should be visually checked before transportation to site or point of placing, and routine testing carried out to the frequency specified. Particular care is needed following each delivery of constituent materials, especially aggregates. For example, adjustment to the water content may be needed to compensate for variation in moisture of the aggregates.

9.6 Transportation and delivery

SCC can be delivered either by truck mixer or truck agitator for long haul. One of the main advantages of SCC is the increase in speed of placing. However, it is essential that the production capacity of the plant, journey time and placing capability at site are all balanced to ensure that site personnel can place the concrete without a break in supply and within the consistence retention time. Production stops can result in thixotropic gelling of concrete that has already been placed and this may affect the filling ability on restarting and / or result in lift lines on the vertical surface. Great care should be taken if SCC is to be delivered by tip trucks due to risk of static segregation and hence shall be avoided.

9.7 Site acceptance

In the case of ready-mixed concrete, it is important that there is an agreed and documented standardised procedure for receiving and accepting the SCC at site. The producer and specifiers should agree the procedure at the start of a contract. This should include visual inspection of every batch of the concrete and any specific tests and compliance parameters.

The producer is required to test concrete at the minimum frequency given in the specifications for consistence, strength and other properties. This is called “conformity testing”. Testing frequency shall not be less than that specified for normal concrete. Workability (consistence) should be checked for every batch load.

If additional testing is required such as testing every load for consistence until the required uniformity of supply is achieved, this can be made part of the contract of supply.

The specifiers can organize additional testing that in this is case it is called “identity testing”. The criteria for accepting/rejecting SCC are given in para 6.4.

The documented procedure should include details of responsibility for testing as well as a procedure for action to be taken in the event of non-compliance.

- The specifiers shall ensure that all site identity testing is carried out by competent, trained personnel in an environment that is vibration-free and protected against the weather. Equipment shall be with well maintained and calibrated and the test area should have a solid, level area for performing the tests.
- Concrete shall be remixed in the truck mixer for a least one minute (high speed) before a representative sample is taken.
- Sampling shall be carried out in accordance with relevant IS. The first SCC from a truck mixer may not be representative.
- When making SCC samples for compressive strength and other testing, the mould shall be filled in a single layer without compaction.

The recommended test for characterizing SCC on site is slump-flow. This gives a good indication of the uniformity of concrete supply. Slump-flow is a measure of the total fluidity and therefore filling ability of the concrete. A visual assessment for any indication of mortar/paste separation at the circumference of the flow and any aggregate separation in the central area also gives some indication of segregation resistance (Photograph 3.)

There should be continuous observation of the placed concrete to monitor effective filling and any indications of blocking, segregation or settlement.



Photograph 3. Slump-flow test

10. Site requirements and preparation

10.1 General

Prior to delivery of the concrete, the contractor/user must ensure that appropriate site preparations have been made. These should include:

- that the site can place the concrete at the agreed delivery rates.
- that acceptance procedures for the SCC are agreed and documented.
- that site personnel are trained in the specific requirements for placing SCC.
- that formwork is leakage free and properly prepared to receive SCC.

10.2 Site control

A pre- documented quality control procedure shall be followed on the job site for acceptance of self-compacting concrete.

It is recommended that every batch of SCC delivered should be tested for slump-flow until uniformity of supply is confirmed. Visual assessment by a competent person is then normally sufficient unless a batch is considered to be marginal. As the producer is required to undertake conformity testing, additional identity testing on site is generally unnecessary and should be restricted to critical situations or where variations are large.

10.3 Mix adjustment

In general, modification of SCC on site is undesirable as the producer should be capable of supplying the specified mix with the required properties for the job and shall be avoided. However if special circumstances exist or if some experimentation is expected/planned in order to optimise the mix for specific formwork configurations and surface finish, it may be prudent to establish a further documented procedure for minor adjustment of the concrete, under strict supervision at site.

The adjustment should be controlled and evaluated by the concrete technologist of the producer and under his responsibility. All modifications shall be recorded.

- Additions of admixtures such as for set control can be made on site before placing, provided the effect has been fully evaluated.
- Concretes that are found to have a slump-flow outside the conformity criteria should only be adjusted provided the procedure is agreed and documented.

10.4 Supervision and skills & training

It is essential that the site personnel used to place self-compacting concrete have been trained/instructed in the specific requirements for placing this type of concrete. Site personnel should be made aware of the advice given in various clauses of this chapter and particularly on the following items:

- rate of placing
- the effect of a break/stoppage during placing
- actions to be taken if a break/stoppage occurs
- observation for blockages, segregation or air release
- requirements for placing by pump, skip or chute, including positioning to induce flow
- finishing top surfaces and curing.

10.5 Formwork pressure

Using SCC opens us a possibility of enhanced casting rates, as there are no longer any limitation due to the compaction work by the site staff. A possible negative side effect of speeding up the casting rate is the potentially high form pressures that might occur. The risk of high form pressures shall be considered at planning stage. Absolute figures of formwork pressures cannot be given but is closely related to local conditions i.e. mix design etc.

Formwork pressure depends on the flowability and cohesion of the SCC, rate of pumping and vertical rise and the method of placing (from the top/from the bottom). Formwork design, including support and fixing systems, should assume that the full hydrostatic concrete pressure (of liquid of equivalent density) is applied to the formwork. If the SCC is being pumped from the bottom then locally, pressure can be above hydrostatic close to the pump entry point, especially on restart if there is an interruption in pumping. The form pressures shall be monitored during casting in order to reuse the integrity of formwork. Monitoring form pressure is especially important for high walls, columns or other high structures.

10.6 Formwork design

SCC can be placed in unusual or complex shapes which can be produced in formwork design that would normally not be possible with vibrated concrete. The absence of vibration can allow some novel formwork detailing such as that achieved by magnetically attached shape formers to metal formwork.

SCC should be considered as a liquid and design of formwork should be done by calculating according to a hydrostatic pressure, unless preliminary measurements are available which clearly show lower formwork pressure for intended SCC type and casting procedures and rate of placing.

The high flowability of SCC can result in flotation of any buoyant formwork units, stop ends or detailing that is not securely fixed. Particular attention should be given to fixing and sealing the formwork to the base where uplift could be a problem. Leakage at joints can occur and reduce an otherwise high quality of finish of SCC.

Because full hydrostatic concrete pressure should be assumed when using SCC, particular attention should be paid to both the outer supports and the tie rod system and spacing to ensure that the formwork will not deform/bulge during placing.

10.7 Formwork preparation

SCC normally produces a very high quality finish giving a mirror copy of the formwork. This gives opportunity for enhanced design but if care is not taken, SCC shows up any deficiencies in the formwork material, finish or the release agent and this will detract from the final appearance. Movement at joints or bending of the formwork under pressure from the concrete may also be more noticeable with SCC. Good formwork preparation is necessary and applies to all types of concrete but is more essential if the surface finish of SCC is to be maintained (Photograph 4).



Photograph 4 Formwork erected for SCC

Formwork release agents

Self-compacting concrete places explicit demands on type and application rate of mould release agents because of its ability to achieve a very high quality of surface finish. Much formwork used for SCC will be steel or resin surfaced plywood. These are either non-absorbent or have very low absorbency. Excess release agent at the form face and concrete interface can result in staining, retention of air bubbles which manifests themselves as bug holes and other imperfections.

Vegetable, mineral or water based mould release agents shall be applied extremely thinly, almost to the point that they are just wiped on with a cloth. It is also imperative that the mould release agents have not been diluted or adulterated in any way.

Self-compacting concrete will normally allow entrapped air to escape between the concrete and the formwork. Consequently, the release agent must also be of a type which will allow air to migrate in a controlled manner and escape from the concrete.

Certain release agents, when used in combination with impermeable formwork, are too viscous to allow air to escape effectively and this can result in air voids adhering to the surface of the formwork, resulting in bug holes/blowholes in the concrete. Without pre-evaluation, release agents should only be used with permeable or semi-permeable formwork in order to ensure a reliable surface finish.

The type of formwork can dictate the pre-treatment, the type of release agent and the way it is used.

10.8 Formwork for pumping bottom up

SCC allows novel methods of placing concrete including pumping bottom up (Photograph no.5). In this case the pump is connected via a special connector piece with slide valves into the formwork. The formwork design must be calculated to resist at least the full hydrostatic concrete pressure.



Photograph 5 Formwork erected for pumping SCC bottom up

If possible, the pumping point should be in the middle of the wall, thus minimizing the horizontal length of flow. The horizontal spacing of the pumping points will depend on the reinforcement and the flow capacity of the SCC and has to be agreed with the concrete supplier.

The vertical spacing of the pumping points depends on the maximum pressure that the formwork can take and has to be clarified with the formwork supplier.

After pumping from the bottom, the valve is closed and locked. At this time, protruding concrete can be pushed flush with the inner surface of the formwork via a special spindle. Alternatively, protruding concrete must be removed and the surface made good after removing the formwork.

11. Placing and finishing on site

11.1 General

The process of casting/placing SCC can be mechanized to a great extent; due to which increased productivity, lower cost and improved working environment is achieved. A minimum of manual interaction in the process is however necessary.

Self-compacting concrete is designed to have a very high flow combined with cohesion characteristics that ensure that the aggregate is uniformly suspended and does not segregate. The use of vibrators will affect this balance and will usually lead to significant segregation. For this reason, vibrating equipment should not be used with self-compacting concrete except in the special circumstances described in Clause 11.6. Particular attention should be given to possible external sources of vibration from, for instance, nearby equipment.

SCC is a liquid suspension following the rules of fluid mechanics while conventional vibrated concrete is a granular mass requiring vibration to be compacted. During placing, the concrete should be regularly visually checked to ensure that coarse aggregate is remaining at or very near the surface and that there is no indication of segregation. The concrete should form a regular advancing front at a shallow angle and be observed to flow round and fully enclose reinforcing bars without forming void pockets. There should not be excessive release of large air bubbles that would suggest air is being entrapped by the placing process. Foam on the upper surface is likely to indicate segregation. Check formwork for signs of leakage.

After completion of the first section of a job the quality of the hardened concrete should be checked and evaluated by both the producer and the specifier. Look for top surface laitance, a non-uniform surface colour, specific areas where air is being trapped and any other unwanted effects that are visible.

High quality surface finishes are a feature of SCC but to obtain a surface without blowhole, blemishes or discolouring, requires more than just concrete of good mix design and quality. No guidance currently exists on how to reliably and consistently obtain excellent surface finishes using SCC. However, the formwork face must be faultless and the execution of the casting work and finishing treatment must be of the highest quality. Concrete placers as well as site managers/foremen must understand and take into account the importance of each separate element of the execution, and must carry it out effectively.

It is essential that the personnel used to place self-compacting concrete have been trained/instructed in the specific requirements for placing this type of concrete.

11.2 Discharging

Discharge should not take place before control checks have been done. Self compacting concrete can be placed by direct discharge from truck mixers via a chute (Photograph 6). Alternatively it can be first discharged into a skip (with tremie pipe) or to a pump (Photograph 7).

A receiving hopper/holding vessel with agitator may be used if necessary if the SCC is to be held on site before placing. Vertical formwork can be cast by droppings from above using pumps or crane skips. Experience from dropping heights of 8 m exists but 1-3 m is well suited. Flat and shallow formwork such as slab and decks are more often filled from above.



Photograph 6. Photos showing SCC discharging through truck via chute



Photograph 7. Photos showing Placing of SCC by skip

11.3 Casting and Placing procedure and rate

Prior to placing SCC, it should be confirmed that reinforcement and formwork are arranged as planned and the formwork is free of water or debris.

The release of the concrete into the formwork must be in relation to the density of reinforcement, the concrete's flow characteristics and to the potential for entrapment of air.

A reasonable length of flow helps any excess air to escape. However a flow length of more than about 10 meters may create a greater risk of dynamic segregation or void formation.

A fast vertical casting rate may not allow air the time to rise to the surface and escape, causing an increased number of air voids to be trapped in the concrete and blowholes on the surface.

The casting process should be continuous and without interruption as this helps to maintain flow and reduces surface marks and colour variation.

The layer thickness should be kept as thin as possible in order to prevent larger air bubbles to get trapped in the concrete or at the form surface. It is also beneficial to let the concrete flow horizontally for some distance (depending on the mix, form geometry, denseness of reinforcement etc.) on the other hand the concrete has to be prevented to flow a very long distance in the form as this may lead to separation at the front. This is the very reason why the concrete should be released at fixed distances along the formwork. These points of release should be at a maximum distance from each other of about 5-8 m depending on the geometry of the form and density of reinforcement and other obstacles.

Some SCC, especially those with a slow rate of flow (high *T*500 or V-funnel time), can show a tendency to thixotropic gelling, causing stiffening when at rest, but regaining flowability if sufficient further shearing/stirring energy is applied. Thixotropic gelling can be avoided by keeping the concrete agitated on route to the site and prior to placing. Placing should be without interruptions and the filling locations of the form should be located to keep the casting front moving at all times. Once placing is finished, thixotropic gelling can be an advantage as leakage at joints and formwork pressure are both reduced soon after movement stops. It is important to plan the placing/casting sequence. Layers of fresh SCC should be given sometime for the release of air through the surface while on the other hand following layers should not come too late, which might make an integration of the layer difficult.

Self-compacting concrete is more cohesive and usually less prone to segregation than normal concrete but free fall of concrete during placing may still cause some segregation and increase the content of entrapped air so it should be avoided if possible. If unavoidable, free fall height should be limited and tests should be carried out to determine the effect.

When casting extensive horizontal areas where part of the total area must be completed before casting successive areas, permanent stop ends are required and metal lathing has been successfully used with SCC for this application.

11.4 Placing by pump

Pumping is the most common and suitable method of placing SCC due to high amount of fines and consequently the method from which most experience has been gathered. The usually high viscosity of SCC may require a slower pumping rate, in order to avoid high pressure built up in the piping system. High pressure may cause aggregate separation and pump stops.

If the pump has not been primed with a cement mortar the first part of the load (100 – 150 litres) should be run through the pump and recycled back into the truck. This lubricates the pump lines, while the residual coarse aggregate is remixed into the bulk of the SCC.

Self-compacting concrete is well suited to pumping through a valve from the bottom of the formwork provided it has good segregation resistance. This method gives a smooth and clean concrete surface and has proved to be very successful when casting walls in buildings, with system formwork and also in tunnel linings and columns. It has also been used for strengthening existing concrete or for placing new concrete within existing structures.

Pumping from the bottom of the formwork through a valve normally gives the best surface finish for any vertical element. It takes less air into concrete and allows faster casting rates than pumping from the top. The hopper and pump line must be kept completely full of concrete to ensure that air is not introduced at the bottom. It must also be remembered that restarting after a stop can lead to an increase in pressure on formwork.

After pumping from the bottom, the valve is closed and locked. Protruding concrete can be removed after removing of the formwork but special equipment is also available to get a smooth concrete surface without further actions after formwork removal.

When pumping from the top, and when surface finish needs to be optimised, SCC should be placed with a submerged hose in order to minimise the possibility of entrapped air. Casting should start at the lowest part of the form, and at a place where the pumping hose can be located as close as possible to the bottom of the form. As soon as sufficient depth has built up, the hose should then be submerged into the concrete. The end of the pump hose should, if possible, be maintained below the concrete surface at all times, including when changing its location so that air is never allowed into the hose. An alternative way of feeding the formwork with concrete is the use of openings or vents in the formwork. This is specially valuable at closed air inclined formworks. The openings should be large enough to allow the pump hose to pass inside the form in an inclined position and when the concrete level has reached the opening the pump hose is pulled out and moved to the next opening above. The lower openings are thereafter closed and concreting continued. The horizontal distances of 4-6m between the openings and corresponding 2-3 m vertically, have been proven successful.

The pumping should be controlled to produce a continuous and even rate of rise of the concrete in the formwork, with as few breaks in delivery as possible.

11.5 Placing by concrete chute or skip

Although casting of SCC by a pump is recommended both concrete chute and skip have been successfully used. When discharging with a chute, the outlet from the chute should be directed towards the farthest end of the casting and withdrawn as casting proceeds.

When casting SCC from a crane and skip the following points should be considered:

- The skip method is normally only useful for relatively small units or short walls due to the casting capacity (typically 12–20 m³/hour), but depends on the size of the concrete skip and the maneuverability of the crane.
- The skip has to be ‘tight’ to prevent loss of mortar or paste during transport
- The skip should not be subject to vibration or excessive shaking to avoid segregation of the concrete
- A prolonged stagnation of the mix in the skip can cause thixotropic stiffening so that it will not run from the skip spontaneously and smoothly when opened for discharge.

- Slow delivery rate can cause a prolonged period of stagnation in the form resulting in surface crusting or thixotropic stiffening and this can lead to visible horizontal mark between lifts.
- When casting high or thin walls the casting should take place through a tremie pipe or stocking (collapsing hose) from the skip. The use of a stocking rather than a rigid hose helps to keep the stocking full and prevents air being drawn into the concrete, this is especially important if the surface finish needs to be optimised. If a rigid tremie pipe is used, the end should be kept below the concrete surface at all times and extra care is needed to ensure that air is not drawn into the concrete.

11.6 Vibration

Vibration of SCC should generally be avoided as it is likely to result in significant settlement of the coarse aggregate. If the desired compaction is not being achieved, the concrete should first be checked for conformity to the specification. But there are some occasions when carefully controlled and light vibration may be needed:

- In some structures the formwork shape may cause air to be trapped at certain locations. This can normally be removed by localised tapping from outside or simple rodding in the affected area.
- Slabs, especially those cast from SCC in the lower slump-flow class may require light tamping or a very gently vibrating screed bar to give a level finish, free of protruding coarse aggregate.
- Following a break in placing if the live surface has crusted or stiffened to the extent that a cold joint or surface blemish could form.

11.7 Finishing slabs

Slabs will generally require a lower slump-flow class than SCC for walls and columns. This consistence, combined with the lack of bleed and tendency to thixotropic stiffening can make the concrete feel sticky and difficult to finish. Initial finishing needs to be carried out as soon as possible after the correct level has been reached, before thixotropic stiffening starts and before any surface drying (crusting) has occurred.

Vibrating floats and light vibrating screeds have proved to be effective in the screeding of SCC provided the slab is not inclined but manual equipment should be used if there is any risk of aggregate segregation. Steel floats function better than those of wood or polyurethane cell foam.

If the surface of the slab slopes more than 2-3 % care is required in the use of even light vibrating screed equipment as this can cause a sideways slipping or other unwanted movement of the fresh SCC.

Leveling of slabs is best carried out with the aid of light shimmying with a skip float (see Photograph 8). This ‘wakens’ the surface concrete and gives sufficient compacting work, without causing unwanted aggregate segregation. Correct consistence and execution of the concrete work will give a level and smooth surface without unduly enriching the matrix in the surface. Use of air entraining admixture has been shown to give good finishing properties in some cases.



Photograph 8. Leveling SCC with a skip float

After-treatment such as floating, the use of steel trowel finishing may be carried out.

11.8 Curing

Curing is important for all concrete but especially so for the top-surface of elements made with SCC. These can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. As there is very little or no bleeding the concrete will be more sensitive to plastic shrinkage cracking. The tendency of plastic shrinkage increases with the increase in the volumes of fines. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimise the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation.

12. Appearance and surface finish

12.1 General

SCC generally leads to a very nice concrete and hence, high quality surface finishes are a feature of SCC but careful attention to mix design and job site workmanship is required if this is to be achieved, as SCC is more sensitive with regard to surface finishing due to the way it is cast; the nature of formwork; the type and thickness of applied release agent; temperature of the formwork and weather conditions.



Photograph 9. Photos showing finished surface of SCC

The appearance of an element cast with SCC mainly depends on:

- the type of cement and addition used
- the mix composition of the SCC
- the material and the quality of the mould and formwork and release agent extremely smooth finishes can be obtained by means of steel and plywood formworks.
- the placing procedure.

The appearance is usually better than for conventional vibrated concrete:

- the colour is generally more uniform
- it is easier to avoid defects due to leakage spots at the location of mould joints and around strand or wires exit points
- the edges may be sharp if the mould is well designed and maintained
- blowholes are always present, but may be limited in number and size
- air voids under horizontal parts of the mould can be limited in size and number, when the mould is filled properly.

The following list of defects can be found in all types of concrete but with care, SCC can give an improved finish compared to traditional concrete:

- blowholes /bugholes
- honeycombing
- vertical sand stripes and other colour variations
- plastic or drying shrinkage cracking.

12.2 Blowholes or Bugholes

Air is introduced into concrete not only during the mixing process but also during the transportation and casting. The extent to which air is either stabilized within SCC or is lost during placing depends on the cohesion of the mix.

One of the primary defects affecting the surface aesthetics of concrete is bugholes. They are also called as blowholes, pinholes, surface voids are small, regular or irregular cavities (usually not exceeding 15mm). Bugholes result from the migration of entrapped air (and to a lesser extent water) to the fresh concrete-form interface. These surface defects manifest themselves mostly in vertically formed surfaces. During consolidation, the densification and subsequent volume shrinkage of the fresh concrete forces entrapped air voids out of the cementitious matrix.

The air bubbles, however, seek the nearest route to reach pressure equilibrium. When in a vertical form, the closest distance for the air bubbles' migration is to the interior form surface. If these bubbles are not directed vertically to the free surface of the setting concrete, after form removal, bugholes will be present. Bugholes are found more frequently in the upper portion of the concrete structure



Photograph 10. Photos showing the bugholes on concrete surface.

Causes: - Perhaps the most influential cause of bugholes is improper vibration, but obviously this is not the reason in SCC. Another factor that promotes bugholes formation is the form material itself. When impermeable forms (Steel) are used.

Mix design can also be considered a contributor to bugholes formation. A sticky or stiff mixture that does not respond to consolidation can be directly linked to increased surface void formation.

Cure :-

- (1) Proper consolidation.
- (2) Permeable Forms
- (3) Proper Mix design.

In addition to the factors detailed above, blowholes can also be due to the surface quality of the formwork and the type and/or quantity of release agent used. Advice should be sought from both the release agent supplier and the concrete producer. The blowholes are also formed due to the retarding effect of superplasticizer added or low casting temperature.

Air will be released more easily if the rate of rise of the concrete in the formwork is limited and also if it has to move sideways in the mould for several metres.

During compaction, with hand held pokers or fixed vibrators, entrapped air in the concrete or in the border zone between the form and concrete, can relatively easily be “pushed” upwards and out by the induced vibrations. For SCC, entrapped air has to be forced out by the moving concrete inside the formwork, with some help of gravitational forces. For this, SCC should always be given the possibility to flow for at least a certain distance. Casting all along the element should be avoided. Some entrapped air near the formwork may escape if the formwork is permeable enough. Tight formwork materials therefore often results in more porosity and blowholes compared to permeable formwork materials. Badly cleaned or heavily worn surfaces have a tendency to induce more surface porosity compared to new smooth surfaces. This is probably due to the fact that small air bubbles stick easier to dirty, rugged or bad cleaned surfaces. A thin coating of form release agent seems to be favourable in comparison to a thick layer since air bubbles apparently sticks harder to a thick layer of release agent. The choice of form release agents have shown to be more critical in regard to the appearance of the finished structure, compared to vibrated concrete. The amount of pores is partly also reflected by the casting rate. A high casting rate, with thick concrete layers, usually results in more blowholes compared to thinner layers and a lower casting rate.

Pumping from the bottom of the formwork generally produces better surface finish. If this is not possible the casting hose should be kept below the concrete surface at all times. If the concrete is allowed to free fall, this may increase the number of larger entrapped air voids both on the surface and within the body of the concrete.

12.3 Honeycombing

Honeycombing may be due to leakage in the formwork but is more usually caused by poor passing ability resulting in aggregate bridging and voids behind reinforcement.

SCC with poor passing ability is usually due to:

- slump-flow class too low
- viscosity too high
- maximum aggregate size too large
- Insufficient paste or too much coarse aggregate.

If honeycombing occurs and is not due to formwork leakage, the concrete should be checked against the specification. If conformity to the specification is confirmed, consideration should be given to revising the specification.

The use of plastic sealing strips or moisture curing gunned silicon rubber provides effective means of sealing joints in formwork. Adhesive sealing tape is usually placed on panel joint with very good results.

12.4 Colour consistency and surface aberrations

Vertical stripes at the SCC surface are rare and usually caused by bleed water. Any bleed water tends to accumulate at the vertical mould surface and flow upwards leaving visible stripes on the hardened concrete surface due to washout and or floatation of the mould oil.

There are several reasons why bleeding may occur:

- high water to powder ratio
- viscosity too low
- low temperature
- retarded set.

Other reasons for colour variations are:

- Uneven drying of surface (for example caused by new or dry timber moulds or plastic sheet that touch part of the concrete during the curing period)
- Over application or poor choice of release agent
- Differences in material source between batches of concrete.

To avoid colour differences, the amount of SCC needed for one panel should be accurately estimated as some colour variations can be expected with different batches.

12.5 Minimising surface cracking

SCC is designed to be stable and resistant to segregation but, like traditional vibrated concrete, it may suffer from plastic settlement cracking above reinforcing bars if aggregate settlement does occur. Some SCC mix designs, especially those where a very high quality finish is required, can be very close to the aggregate segregation point so extra control may be required. The use of a VMA, together with appropriate powder content may help to make the concrete more robust and decrease the risk of plastic settlement and cracking.

Plastic settlement cracks may be wide but normally they are not very deep so the surface can often be repaired by trowelling before the concrete sets.

Because SCC has little or no bleed it can lose surface water, resulting in drying shrinkage cracks if curing is not started at an early age.

ANNEXURE A
LIST OF REFERRED STANDARDS /REPORTS /GUIDELINES /LITERATURE

A- Reports; Guidelines; Standards.	
Sr. No.	Description
1)	The European Guidelines for Self Compacting Concrete(EFNARC) – Specifications, Production & use (May 2005)
2)	European Research Project –Measurements of properties of fresh self-compacting concrete- Acronym: TESTING SCC- Final Report (Sept. 2005)
3)	EFNARC- Guidelines for Viscosity Modifying Admixture for Concrete (Sept. 2005)
4)	Final report of RILEM Technical Committee 188-CSC: Casting of Self Compacting Concrete-RILEM Report 35 (2006)
5)	Concrete Technical Bulletin T B - 1 5 0 0 - An Introduction to Self-Consolidating Concrete (SCC)
6)	Concrete Technical Bulletin T B - 1 5 0 1 – Definition of Terms relating to Self-Consolidating Concrete (SCC)
7)	CE241: Concrete Technology – Report #1 : Self-consolidating concrete (March,2004)
8)	Self-compacting concrete – Chapter#18 in Handbook on Advanced Concrete Technology, edited by N.V. Nayak & A.K.Jain., Narosa Publishing House, New Delhi.
9)	Advanced Concrete Technology (Testing & Quality) edited by John Newman & Ban Seng Choo, ELSEVIER , Butterworth-Heinemann, London
10)	IS14591:1999- Temperature control of mass concrete for dams - Guidelines
B- Papers; Publications	
1)	Application of Self Compacting Concrete in Japan, Europe and the United States by Quchi,Nakamura,Osterberg,Hallberg,andLwin.
2)	Some trends in the use of concrete : Indian Scenario by Praveen Kumar and S.K. Kaushik (December 2003-The Indian Concrete Journal)
3)	- Self Compacting Concrete- Pressure on formwork and ability to deaerate by Tilo Proske,Carl-Alexander Graubner.Darmstadtconcrete 17(2002)
4)	Workability of Self Compacting Concrete by Chiara F.Ferraris,Lynn Brower, Celik Ozyildirim, Joseph Daczko USA (Natal Institute of Standards and Technology)
5)	Self- Compacting Concrete: What is new ? by M Collepari

6)	Engineering of Self Compacting Concrete by Subrato Chowdhury,& Sandeep Kadam Ultratech Cement Limited ,Mumbai
7)	Fresh Properties of Self -Compacting Concrete(SCC) by TimoWustolz from Otto-Graf- Journal Vol.14,2003
8)	Self Compacting Concrete : The Role of the particle size distribution by H.J.H. Brouwers and H.J. Radix
9)	Self Compacting Concrete: a quiet revolution by P J M Bartos*, University of Paisley, UK.
10)	Self -Compacting Concrete- procedure for Mix Design by Pratibha Aggarwal,Rafat Siddique,Yogesh Aggarwal,Surinder m Gupta.from Leonarda Electronic Journal of Practices and Technologies Issue 12, January-June 2008 Pg 15-24
11)	Application of Self Compacting Concrete in Japan, Europe and the United States by Masahiro Quchi,Sada-aki Nakamura, Thomas Osterberg,Sven-Erik Hallberg,and Myint Lwin.
12)	Recommendation for Self Compacting Concrete by JSCE(Japan Society of Civil Engineers) -Standard Specifications

ANNEXURE B
COMMITTEE COMPOSITION

(Ref: Final Order by Director General, MERI, Nashik vide no. MTD/META/Concrete handbook /Committee/13/2013 Dt.3/01/2013)

Sr.No.	Name	Organization
1	Shri.V.B.Pandhare.	Chairman Committee and Chief Engineer, DTRS, META, Nashik
2	Shri B.M Sukre	Chief Engineer & Administrator, Command Area Development Authority, Aurangabad (Special Invitee – Individual Capacity)
3	Shri R.D. Patankar	Superintending Engineer & Joint Director, MERI, Nashik and Committee member.
4	Shri R.V Shrigiriwar	Superintending Engineer, (Masonry Dam) ,CDO, Nashik and Member committee.
5	Shri K.M. Shah	Superintending Engineer, Quality Control Circle, Pune and Committee member.
6	Shri V. D. Nemade	Superintending Engineer, Quality Control Circle, Aurangabad and Committee member.
7	Shri R.M. Chouhan	Superintending Engineer, Quality Control Circle, Nagpur and Committee member.
8	Shri S.D.Kulkarni	Scientific Research Officer, Material Testing Division, MERI, Nashik and Member secretary committee.
9	Shri K.C. Tayade	Executive Engineer and Principal, Regional Training Centre, Nagpur and Committee member.(Individual capacity)
10	Shri R.G. Mundada	Executive Engineer, Quality control Division , Nanded and Committee member.(Individual capacity)

ANNEXURE C TEST METHODS FOR SCC

Introduction

It is important to appreciate that none of the test methods for SCC has yet been standardized, and the tests described are not yet perfected or definitive. So far no single test has achieved universal approval and most of them have their limitations. Similarly, no single method of test have been found which characterizes all the relevant workability aspects so each mix design shall be tested by more than one test method for different workability parameters. They are mainly ad-hoc methods, which have been devised specifically for SCC.

The different test methods are attempts to characterise the different properties of SCC. The following table 12 lists the test methods of SCC.

Table 12: List of test methods for workability properties of SCC

Sr. No.	Method	Property
1	Slump-flow by Abrams cone	Filling ability
2	T500mm slump flow	Filling ability
3	J-ring	Passing ability
4	V-funnel	Filling ability
5	V-funnel at T5minutes	Segregation resistance
6	L-box	Passing ability
7	U-box	Passing ability
8	Fill box	Passing ability
9	Sieve stability test	Segregation resistance
10	Orimet	Filling ability

In considering these tests, there are a number of points which should be taken into account:

- one principal difficulty in devising such tests is that they have to assess **three** distinct, though related, properties of fresh SCC – its filling ability (flowability), its passing ability (free from blocking at reinforcement), and its resistance to segregation (stability). No single test so far devised can measure all three properties.
- there is no clear relation between test results and performance on site;
- there is little precise data, therefore no clear guidance on compliance limits;
- duplicate tests are advised;
- the test methods and values are stated for maximum aggregate size of up to 20 mm; different test values and/or different equipment dimensions may be appropriate for other aggregate sizes;

- different test values may be appropriate for concrete being placed in vertical and horizontal elements;
- similarly, different test values may be appropriate for different reinforcement densities;
- in performing the tests, concrete should be sampled in accordance with relevant IS. It is wise to remix the concrete first with a scoop, unless the procedure indicates otherwise.

Table 13. The summary of general assessment of the test methods

Test method	Advantages	Disadvantages
1) Slump flow test & 2) T_{500} time Lab: Yes Site: Yes	<ul style="list-style-type: none"> • Easy and familiar • Good indication of filling ability • Very good correlation with rheology (S with yield stress; T_{500} with p.viscosity) • Sensitive to water content • Can be done with 1 operator only • Suitable for compliance testing • Good indication of flowing ability • Visual assessment possible for severe segregation 	<ul style="list-style-type: none"> • Needs stiff and flat base plate • Very sensitive to moisture condition of the base plate • Only tells part of story about filling ability • T_{500} not easy to measure for very fluid mixes • Usually needs 2 operators • Operator sensitive • Cannot detect moderate segregation
3) V-funnel test Lab: Yes Site: ?	<ul style="list-style-type: none"> • Reasonably good correlation with plastic viscosity • Indication of filling ability • Widely used, particularly in Japan • Possible to detect severe blocking 	<ul style="list-style-type: none"> • Physically difficult to perform • Unknown practical limits for results • Usually needs 2 operators • Visual assessment impossible
4) L-box test Lab: Yes Site: No	<ul style="list-style-type: none"> • Familiar and widely used • Good indication of passing ability • Can use any materials to construct • Good correlation with slump flow • Single measurement (h2) possible 	<ul style="list-style-type: none"> • Values may be irrelevant at highslump flow • Difficult to use on site and to clean • Essential that it be level • Relatively long time to prepare and test

5) U- tube test Lab: Yes Site: ?	<ul style="list-style-type: none"> • Reasonably good correlation with plastic viscosity • Indication of filling ability • Possible to detect severe blocking 	<ul style="list-style-type: none"> • Physically difficult to perform • Unknown practical limits for results • Usually needs 2 operators • Visual assessment impossible
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The other tests which are not dealt here are i) Orimet ii) J-Ring iii) Segregation resistance sieve stability test iv) Penetration test v) Fill box

C.1 & C.2 Test 1- Slump flow & Test 2: T₅₀₀time

Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of test

This is a simple, rapid test procedure, though two people are needed if the T₅₀₀ or T₇₅₀mm time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

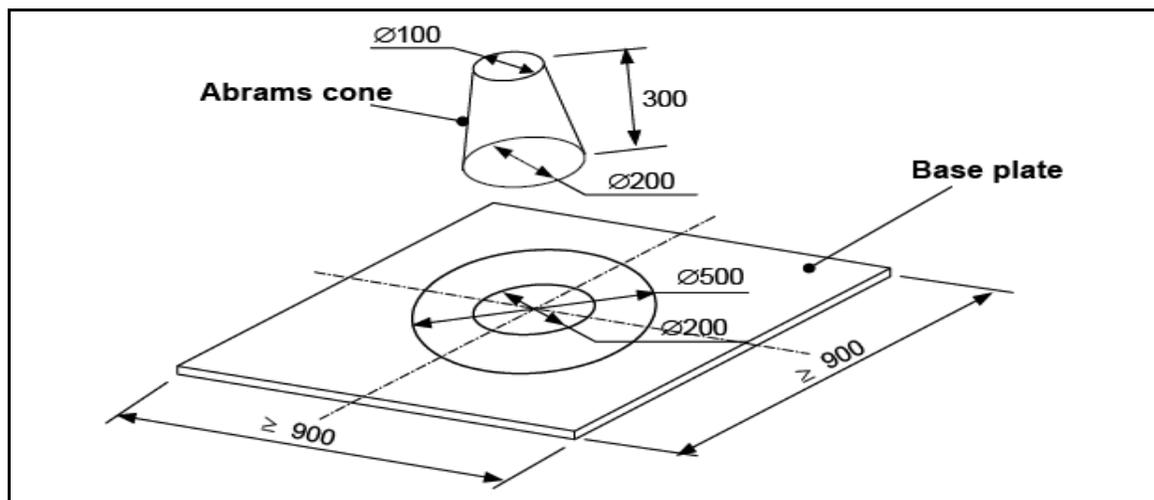


Figure no.7 Base plate and Abram's cone for slump testing

Equipment

The apparatus is shown in figure.

- Mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm.
- Base plate of a stiff non absorbing material, at least 900mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- Trowel
- Scoop
- Ruler
- Stopwatch (optional)

Procedure

About 6 liter of concrete is needed to perform the test, sampled normally. Moisten the base plate and inside of slump cone, Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel. Remove any surplus concrete from around the base of the cone. Raise the cone vertically and allow the concrete to flow out freely. Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm (50cm) spread circle. (This is the T_{500} time). Measure the final diameter of the concrete in two perpendicular directions. Calculate the average of the two measured diameters. (This is the slump flow in mm). Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of *at least* 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50 mm, as with the related flow table test, might be appropriate.

The T_{500} time is a secondary indication of flow. A lower time indicates greater flowability. The Brite Eu Ram research suggested that a time of 3-7 seconds is acceptable for civil engineering applications and 2-5 seconds for housing applications.

In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

C.3 Test 3: V- funnel test

Introduction

The test was developed in Japan and used by Ozawa et al. The equipment consists of a V-shaped funnel, shown in Fig.8. An alternative type of V-funnel, the O funnel, with a circular section is also used in Japan.

The described V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 liter of concrete and the time taken for it to flow through the apparatus measured.

After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Assessment of test

Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction.

While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear.

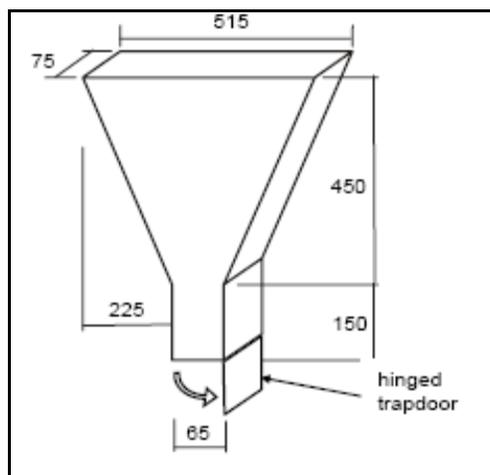


Figure 8 V- funnel

Equipment

- V-funnel
- bucket (±12 liter)
- trowel
- scoop
- stopwatch

Procedure flow time

About 12 liter of concrete is needed to perform the test, sampled normally. Set the V-funnel on firm ground. Moisten the inside surfaces of the funnel. Keep the trap door open to allow any surplus water to drain. Close the trap door and place a bucket underneath. Fill the apparatus completely with concrete without compacting or tamping; simply strike off the concrete level with the top with the trowel. Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time**). This is taken to be when light is seen from above through the funnel. The whole test has to be performed within 5 minutes.

Procedure flow time at T 5 minutes

Do not clean or moisten the inside surfaces of the funnel again. Close the trap door and refill the V-funnel immediately after measuring the flow time. Place a bucket underneath. Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel. Open the trap door 5 minutes after the second fill of the funnel and allow the concrete to flow out under gravity. Simultaneously start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time at T 5 minutes**). This is taken to be when light is seen from above through the funnel.

Interpretation of result

This test measures the ease of flow of the concrete; shorter flow times indicate greater flowability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow and prolonged flow times may give some indication of the susceptibility of the mix to blocking.

C.4 Test 4: L- box

Introduction

This test, based on a Japanese design for underwater concrete, has been described by Petersson. The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus is shown in figure.

The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, then the gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H_2/H_1 in the diagram). It indicates the

slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted.

The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T20 and T40 times and are an indication for the filling ability.

The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

Assessment of test

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section. Unfortunately there is no agreement on materials, dimensions, or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork.

Two operators are required if times are measured, and a degree of operator error is inevitable.

Equipment

- L box of a stiff non absorbing material see figure .
- trowel
- scoop
- stopwatch

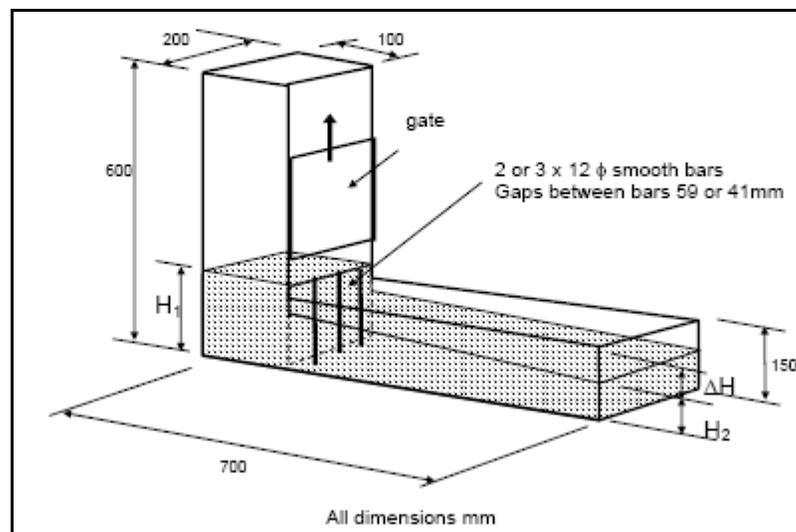


Figure 9 General assembly of L-box

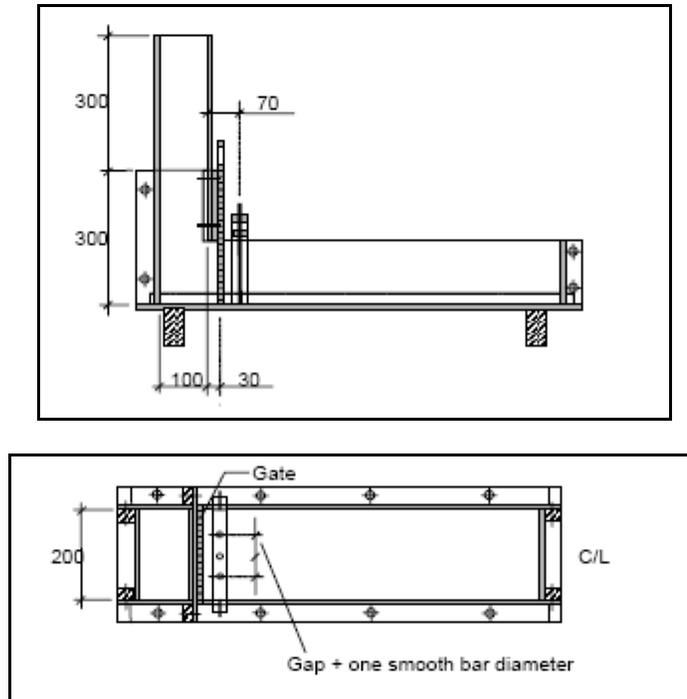


Figure 10 Dimensions and typical design of L-box

Procedure

About 14 liter of concrete is needed to perform the test, sampled normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the vertical section of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks. When the concrete stops flowing, the distances “H1” and “H2” are measured. Calculate $H2/H1$, **the blocking ratio**. The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so $H2/H1 = 1$. Therefore the nearer this test value, the ‘blocking ratio’, is to unity, the better the flow of the concrete. The EU research team suggested a minimum acceptable value of 0.8. T20 and T40 times can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

Test 5: U- Tube

Introduction

The test was developed by the Technology Research Centre of the Taisei Corporation in Japan. Sometimes the apparatus is called a “box-shaped” test. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Figure 11.

An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacings of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 liter of concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in both sections is measured.

Note: An alternative design of box to this, but built on the same principle is recommended by the Japan Society of Civil Engineers.

Assessment of test

This is a simple test to conduct, but the equipment may be difficult to construct. It provides a good direct assessment of filling ability. This is literally what the concrete has to do modified by an unmeasured requirement for passing ability. The 35mm gap between the sections of reinforcement may be considered too close. The question remains open of what filling height *less than* 30 cm. is still acceptable.

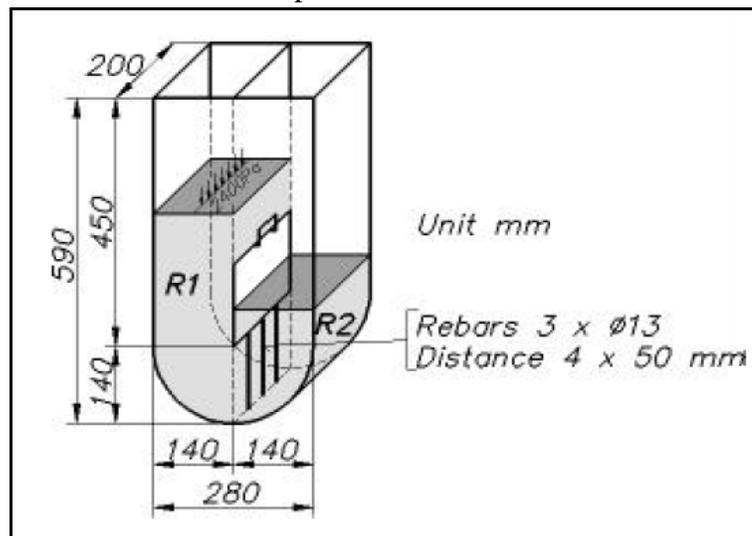


Figure 11 U-tube

Equipment

- U box of a stiff non absorbing material see figure .
- trowel
- scoop
- stopwatch

Procedure

About 20 liter of concrete is needed to perform the test, sampled normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the one compartment of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the other compartment. After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (R1). Measure also the height in the other compartment (R2). Calculate $R1 - R2$, **the filling height**. The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so $R1 - R2 = 0$. Therefore the nearer this test value, the 'filling height', is to zero, the better the flow and passing ability of the concrete.

ANNEXURE D
SAMPLE RATE ANALYSIS FOR SCC

- 1) Basic rate as per current C.S.R. for the item as per the component/element where SCC to be used (As per PWD or WRD CSR¹) ----- B
 - 2) Add lead & lift as admissible ----- L
 - 3) Add for special materials required for SCC per cum.
 - i) Fly Ash (Quantity required as per mix design * market rate²) = M1
 - ii) Micro silica (Quantity required as per mix design * market rate²) = M2
 - iii) Super plasticizer/Hyperplasticizer (Quantity required as per mix design * market rate²) = M3
 - iv) VMA (Quantity required as per mix design * market rate²) = M4

(Total M1+M2+M3+M4)- -----SM
 - 4) Add for special centering & formwork
(To be calculated as per requirement of job (-) conventional centering included in the basic CSR rate) ----- CF
 - 5) Add for machinery charges & special T & P required for testing as L.S. or % charges to be decided based on the nature and quantum of work ----- T
- Grand total GT = B+L+SM+CF+T**
- 6) Add 10% overhead charges on total (5) i.e. GT ----- O
 - 7) Add for statutory levies/Taxes/Insurance/Labour welfare tax etc.
As applicable on total (5) i.e. GT ----- SL
- Total Rate per cum. of SCC = GT + O+ SL**

- Notes :-**
- 1) The basic rate can be taken from PWD/WRD current schedule of rate based on the component/element where the SCC is to be used.
 - 2) The market rate of various special materials shall be ascertained at the time of execution of SCC and will vary with the Type and company brand/ make of the material.

ANNEXURE –E
CASE STUDIES OF SELF COMPACTING CONCRETE
Case study no.1 Gosikhurd Project, Bhandara, Maharashtra

- 1) Name of project: - Gosikhurd project.
- 2) Component where SCC is used: - Spillway gate & Emergency gate slots.
- 3) Total quantity of concrete for the spillway: - 9.0 lakh cum. (Approx).
- 4) Total quantity of SCC executed: 2000 cum.(Approx.)
- 5) Details of SCC executed (like location, dimension, no. of lifts, height of each lift etc.) :
 33 Nos. Spillway & emergency gate slots of total length 2896m ; & size width 1.05to 1.67m & depth 0.3 to 0.9m; lifts of 6m-9m.
- 6) Mix proportion:-
 - i) No. of trials : 12
 - ii) Prepared by :- QCC.& Apple chemie, Nagpur
 - iii) Vetted by :- MERI, Nasik
 - iv) Approved by : S.E.,G.P.C Nagpur
- 7) Mix proportion details :-

Grade of Concrete	MSA	Cement (Kg)	Fly ash %	Water in Lit.	Sand (Kg)
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
M30	20	425	35(230kg/m ³)	195	645

Metal			Admixture kg/m³		Remarks
40 mm (Kg)	20 mm (Kg)	10 mm (Kg)	Hyperplasticizer	VMA	
<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>
-Nil-	415	410	3.28	0.66	

- 8) Details about material :-
 - Cement: Make, grade, brand, (W-M-Y) – OPC43 grade,
 - Fly Ash-Khaparkheda, Specific gravity 2.2.
 - Sand: Zone II sand, F.M. 2.99; Sp.gravity-2.63; water absorption 0.94%.
 - Coarse aggregate: Basalt, Specific gravity 2.77; water absorption 0.35%; Impact value-15%; Crushing value-17.10%.

- 9) Details of tests taken by construction and quality control together.
- i) Slump (flow test) : Values 550- 720 mm.
 - ii) L box: 0.73 - 0.93.
 - iii) V funnel: 7sec.- 12 sec.
 - iv) Number of cube tested:- 102 sets
 - v) Average strength reported :- 418 kg/cm²
- 10) Formwork/Shuttering used :- Steel Shuttering
- 11) Difficulties encountered (if any) :- Water tightness was ensured by using tailored made steel plates and using rubber foam and thermocol sheets wherever required in joints.

ANNEXURE –E (contd. ...)

CASE STUDIES OF SELF COMPACTING CONCRETE

Case Study No.2 Lower Wardha Project, Wardha, Maharashtra

- 1) Name of project:- Lower Wardha project ,Wardha.
- 2) Component where SCC is used:- Radial gate slots & stop log slots.
- 3) Total quantity of concrete for the component (spillway):- 102157 cum.
- 4) Total quantity of SCC executed: 1957 cum.
- 5) Details of SCC executed (like location, dimension, no. of lifts, height of each lift etc.) :
31Nos. Spillway gate slots & stop log gate slots total length 1782 m.& size 1.2x0.75m;
lifts 3m - 6m.
- 6) Mix proportion:-
 - i) No. of trials :12
 - ii) Prepared by : QCC., Nagpur
 - iii) Vetted by : MERI, Nasik
 - iv) Approved by : S.E. N.I.C. Nagpur Letter No.TS1/869/ dt.26/12/2009
- 7) Mix proportion details :-

Grade of Concrete	MSA	Cement (Kg)	Fly ash %	Water in Lit.	Sand (Kg)
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
M30	20	416	35(224kg/m ³)	192	685.15

Metal			Admixture kg/m³		Remarks
40 mm (Kg)	20 mm (Kg)	10 mm (Kg)	Hyperplasticizer	VMA	
<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>
-Nil-	422.89	421.43	5.12	1.28	

- 8) Details about material :-

Cement: Make, grade, brand,(W-M-Y) Birla gold OPC 43 Grade.
Sand: Specific Gravity- 2.64, F.M.- 3.16, silt content- 2%
Coarse aggregate: Specific Gravity- 2.85, Flakiness index- 22.6%.
- 9) Details of tests taken by construction and quality control together.
 - i) Slump (flow test) : 90Tests (flow test) Values between 680-760 mm
 - ii) L box: - 5 Tests, Values between 0.87 to 0.91.

- iii) V funnel: - 35 Tests, Values between 9 to 11 seconds.
- iv) Number of cube tested: - 43 Nos.
- v) Average strength reported: - Compressive strength range 329 to 373 kg/cm².
- 10) Formwork/Shuttering used: - Steel Shuttering
- 11) Difficulties encountered (if any) :- Additional thermocol sheets used for water tightness.

ANNEXURE –E (contd. ...)

CASE STUDIES OF SELF COMPACTING CONCRETE

Case study no.3 Mumbai Mono Rail Project, Mumbai, Maharashtra

- 1) Name of project: - Mumbai Mono rail project.
- 2) Component where SCC is used: - Piers & stitch concrete for beams.
- 3) Total quantity of concrete for the component: - Pier-21249 cum & Beams-4028.07cum..
- 4) Total quantity of SCC executed: - M45 & M60 - 25277.07 cum.
- 5) Details of SCC executed (like location, dimension, no. of lifts, height of each lift etc): -
In Piers Total 10 m Height. Stitch concrete for beams 0.60 m width.
- 6) Mix proportion : -
 - i) Prepared by: - N.A.
 - ii) Vetted by: - N.A.
 - iii) Approved by: - N.A.
- 7) Mix proportion details:-

Grade of Concrete	MSA (mm)	Cement (Kg)	Fly ash (kg)	Water in Lit.	Sand (Kg)
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
M45SCC	12.5	390	145	216.2	953
M60SCC	12.5	450	170	217.1	884

Metal			Admixture kg/m3		Remarks (W/C ratio)
40 mm (Kg)	12.5 mm (Kg)	10 mm (Kg)	Hyperplasticizer	VMA	
<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>
---	802	--	SWC-cryso fluid-optima K620 4.28kg+supaplast SRC-1.07kg	--	0.33
---	774	--	SWC-cryso fluid optima K620-7.44kg+cryso plast V90- 2.24kg.	--	0.29

- 8) Details about material :-

- Cement: - Make, grade, brand,(W-M-Y) --.N.A.
Sand: - F.M. , Specific Gravity, silt content --N.A.
Coarse aggregate: - Sp. gravity, water absorption -- N.A.
- 9) Details of tests taken by construction and quality control together: - N.A.
- i) Slump (flow test) : Values between 740-800 mm for both grades.
 - ii) L box: - N.A.
 - iii) V funnel: - N.A
 - iv) Number of cube tested: - M45-631 nos. & M60-371nos.
 - v) Average strength reported: - Compressive strength range for M45- 533.4 kg/cm² & for M60- 694.3kg/cm².
- 10) Formwork/Shuttering used: - Steel Shuttering
- 11) Difficulties encountered (if any): - N.A.

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