White Paper

Guide To Implementing And Producing Self-Consolidating Concrete

GUIDE TO IMPLEMENTING & PRODUCING SCC

Introduction

Self-Consolidating Concrete (SCC) is a highly flowable, yet stable concrete that can flow readily into place and fill formwork with little to no vibration and without significant segregation. This type of concrete can be ideal for use in precast concrete given the many advantages, but, as with conventional concrete, SCC mixes should be carefully designed to achieve the required performance characteristics, properly placed and cured. Implementing SCC can be a challenge; however, with proper training, guidance and attention to quality control, producers can take advantage of its many benefits. This guide was developed to assist precast producers through the process of implementing and producing SCC in their operations.

What is SCC?

SCC was developed in Japan in the late 1980s due to a void of skilled concrete laborers. The goal was to create a new type of concrete that required no vibration or additional energy to place and consolidate. Lack of an adequate work force, highly congested reinforcement, and formwork that was difficult to work around were some of the complications that led to the introduction of SCC.

To be classified as an SCC, three primary components must exist:

1. **Flowability** - The ability to flow into and completely fill all intended spaces in a form, under its own weight and without external energy.
2. **Passing Ability** - The ability to flow through reinforcement and openings without the development of aggregate blockage.
3. **Stability** - The ability for SCC to remain a uniform, homogeneous mix during all phases of transportation and placement.

SCC is known for having several advantages. Some of these include:

- Reduced labor and energy to place and consolidate
- Reduced noise from consolidation
- Reduced maintenance of vibrators and forms
- Improved finish with fewer voids
- Decreased re-work on finished product
- Improved safety by eliminating personnel standing on forms to vibrate
- Decreased energy to pour densely reinforced members

Implementing

The process of implementing SCC into your operation can be broken into the following components.

1. Determine if any changes are needed to materials, forms or equipment in order to produce quality SCC. Implementation of these changes, if any, must be made before proceeding.
2. Develop the required SCC mixtures. The development process will include both laboratory trail batches and trial batches through the plant. “Robustness” testing must be a part of the mix development process to determine the failure point of the mix (segregation or blocking occurs).

3. Develop a Quality Control plan that includes training for the plant employees. Training should include batching, delivering, placing, finishing, testing and troubleshooting of the SCC.
4. Once production starts, continuous evaluation of the mix performance is necessary to fine tune both the mix and production process.

Products to be Manufactured

Determine the slump flow, passing ability and stability requirements for the product type to be cast using SCC. Flat slabs with minimal reinforcing will generally require a less flowable mix than thin wall vertical wall panels with congestive reinforcing and/or intricate formwork. Likewise, SCC transported in a ready-mix truck with agitation will not require the segregation resistance of a concrete transportation vehicle without agitation transported over rough terrain. Your admixture supplier or other qualified person will help with these determinations.

Raw Material Selection

Coarse Aggregate

Coarse aggregate for use in SCC typically conforms to ASTM C33; however, aggregates that do not meet the grading requirements of C33 can be used to produce a better combined grading. Most producers use a ¾-inch nominal maximum size or less coarse aggregate. The type of product manufactured, thickness of the unit, minimum required concrete cover over reinforcement, economic considerations and other factors ultimately must determine the size limitations and selection of the coarse aggregate chosen for a given mix. Coarse aggregate that contains non-deleterious material retained on a No. 200 sieve and pan may be advantageous to an SCC mix.

Lightweight Coarse Aggregate

Lightweight aggregates for use in SCC typically conform to ASTM C330. The pore structure and absorption rates of these materials make SCC with lightweight coarse aggregate particularly challenging. Follow manufactures recommendations for minimum absorbed moisture percentages and unit weight capabilities.

Fine Aggregate

Fine aggregate for use in SCC typically conforms to ASTM C33. Grading may deviate to achieve a more ideal grading curve when blending with other aggregates to develop a robust SCC design. As a quality control tool, the fineness modulus (FM) of the fine aggregate can be tracked and a maximum variation of+/- 0.20 can be used as a control target to aid in consistent mix performance. As data is collected comparing the mix performance to FM, this range can be adjusted. Particular attention should be given to the percent retained on each sieve as FM alone isn't sufficient to assure consistency. Aggregates with a higher percentage retained on a No. 200 sieve and the pan (as long as the material is not deleterious) may be advantageous.

Aggregate Blending

There are many programs available that will allow the mixologist to input the grading of available coarse and fine aggregate sources. This allows graphic viewing of, at any proportional ratio and volume of CA to FA, the percentage of total particles on each sieve size as it is blended in a mix. Such a blending program will help determine the optimum blend of aggregates.

An SCC mixture that incorporates multiple fine aggregate sources can significantly alter the stability, segregation resistance and consolidating ability of a desired mix. Using fine aggregate sources because they cost less per ton may not be the most economical solution for SCC in the long run. A more expensive fine aggregate source may allow the producer to reduce the cementitious content of the mix while maintaining the desired performance characteristics. In some instances, communication with your aggregate suppliers may assist them in providing your plant with "custom graded" aggregate to attain better performance of your SCC mixes. This same logic applies to conventional concrete as well, and overall could prove to be beneficial to all concrete mixes utilized at a production facility.

As there are an infinite number of aggregate blends, particle size distributions and profiles, the only logical method to attain an SCC mix capable of performing as required is to carry out trial batching, preferably with the assistance of an experienced professional with a detailed knowledge of SCC.

Cement

Cement must meet ASTM C150, C595 or C1157. Be aware that some state and agency DOTs may also require AASHTO M35 as acceptance criteria. Inspect and record Mill Certifications for fineness (Blaine) and the percentage passing the 315 sieve when running mix qualifications. If Blaine or the minus 315 changes significantly during production, there could be a change in concrete stability and other performance characteristics. Changes in paste volume and particle size will alter SCC mix characteristics. A change from one type of cement to another, or a source change, should prompt a re-qualification of a particular mix design.

ASTM C595 and C1157 hydraulic cements are alternatives to C150 portland cements and are performance-based specifications. These cements may be desirable due to the multiple particle sizes and configurations of the material, which can aid in mix stability and robustness.

Supplementary Cementitious Materials (SCMs)

SCMs generally meet ASTM C618 (Fly ash, Natural Pozzolans and Metakaolin), C989 (Slag), C 1866 (Ground Glass Pozzolan) or C1240 (Silica Fume). Benefits of using these include:

- Reduced permeability
- Improved rheology
- Improved robustness
- Increased compressive and flexural strength
- Lower heat of hydration
- Sulfate resistance
- ASR resistance
- Reduced efflorescence

Fly Ash

There are generally two types of fly ash. Class F fly ash has a low calcium content and usually has pozzolanic properties but is not cementitious. This means it possesses little or no strength in the presence of water but reacts with cement to enhance cementitious properties. Class C fly ash has a higher concentration of calcium and is cementitious as well as pozzolanic in nature. Both of these fly ashes are spherical in shape. Care must be taken when incorporating fly ash into concrete as changes in set time and early strength gain may be experienced.

Whenever possible, choose sources with lower carbon content. High-carbon fly ashes have been known to cause air content fluctuations and carbon bleeding to the surface after placement. Due to their spherical nature and the fact that they have a different particle size than other SCMs and cements, the use of fly ash often lowers the water demand of concrete and may improve the rheology of the mix. Typical cement replacements range from 15% to 30%, but higher percentages have been used successfully.

Slag Cement

Slag cements are divided into different grades. Grade 80 slag has the lowest reactivity, while grade 100 and grade 120 have higher reactivity levels. Grade 120 slag is favored by most users due to its higher reactivity. Water demand of grade 120 slag is approximately equal to that of cement. Typical cement replacements range from 15% to 50%, but special applications have demanded percentages as high as 75%. The use of slag typically reduces early age strength while increasing later age strength.

Silica Fume

Silica fume, also known as micro silica, is highly reactive with cement. This characteristic, along with its extremely small particle size, densifies and creates significant strength gains over straight cement mixes. Because of the extreme surface area of this material, small replacements will significantly improve the stability of an SCC mixture. Water demand of silica fume is higher than cement alone and can greatly affect the amount of HRWR (High Range Water Reducers) required for the mixture to flow. As a result, the economics of this material may influence its use. Typical usage range is 3% to 8% cement replacement.

Metakaolin

Metakaolin, a calcined kaolin clay, is often used instead of silica fume. Metakaolin is much finer that fly ash or slag but not as fine as silica fume. Properties such as reduced permeability are similar to those with silica fume. Metakaolin has a few advantages over silica fume in that it is a lighter (typically buff) color, has less impact on water demand and is not densified so mixing is easier. Metakaolin also will contribute significantly to mix stability.

Inert Material

Nominally inert materials have little or no pozzolanic or cementitious qualities. Pulverized limestone, finely divided quartz, dolomite, marble, granite and other materials are commonly used as filler for SCC. These components are generally quite economical because they are mostly based on waste materials.

Depending on size, inert material may be an attractive addition to SCC mixtures because of the low cost of the fines that they may contribute to the mix. As they are also a different particle size and configuration from other materials, they can assist in the stability and robust character of SCC. These are generally not a replacement of cement in relation to required strength but can replace a portion of the cement if it is being used for mix stability.

Addition rates vary significantly, so trial batching is essential for successful use of these products. Research must be done to ensure that no deleterious effects to the long-term durability of the concrete result from the use of the particular filler proposed.

There are many other types of pozzolans and cementitious materials available in use around the world with much success. This White Paper does not discuss all of them.

Water

Water, whether potable (drinkable) or non-potable, must be free of injurious contaminants such as oils, acids, salts, chlorides or other compounds that may be harmful to concrete. Wash water used in manufacturing SCC must meet the requirements of ASTM C1602.

Chemical Admixtures

Admixtures for use in concrete are used to enhance and/or obtain certain properties of fresh and hardened SCC. HRWR are essential to SCC in that they provide the plasticizing effects, allowing the concrete to flow while maintaining stability.

Air Entraining Admixtures

Air entraining admixtures must meet ASTM C260 specifications. Air entrainers are used to entrain microscopic air bubbles throughout the matrix of the concrete. Entrained air improves freeze-thaw durability and scaling resistance. It is especially advantageous to SCC by improving workability and flowability and also reduces segregation and bleeding.

It is generally added to the mix at the beginning of the mixing cycle, added to the mix water or dosed onto the sand prior to discharging into the mixer. Many variables affect the amount of air entraining admixture required to achieve a given air content. Aggregate amounts and grading, cement amounts and chemical makeup, pozzolan amounts and chemical makeup (particularly fly ash), and other raw material fluctuations all play a part in the air content achieved. Due to the viscosity of the paste fraction and other factors, SCC is particularly vulnerable to small changes in the amounts and character of the raw materials. A change in the viscosity of the SCC mixture will cause a change in the air content and the stability of the air.

High Range Water Reducers

Water reducers play an integral part in the success of SCC. Polycarboxylate high range water reducers are necessary to produce SCC. Their technology allows very high water reduction (up to 45%) with good overall mix characteristics. HRWRs must meet the requirements of ASTM C494 Type F or G. These materials are generally quite potent, with many using high solids and low dosages. This requires accurate metering and controlled adjustments to assure consistent SCC. Overdosing indicators may include air bubbles escaping to the surface of static SCC, paste bleed and segregation. Dosage rates vary greatly from source to source, so consult your admixture supplier for specific dosages for each mix and for mix timing and material sequencing.

Accelerators

Accelerating admixtures must meet the requirements of ASTM C 494, Type C or E. Set accelerators affect the concrete performance differently depending on their chemical composition. Some set accelerators shorten the time to achieve initial and final set while also increasing the early strength of the concrete, whereas some accelerators speed up early strength gain but have minimal impact on the initial and final set. Dosage rates vary from different suppliers, so consult your supplier for product details and mix timing. Dosages rates for accelerators also will vary due to ambient conditions, curing practices and the various cementitious materials used in the mix. The use of calcium chloride accelerators are not recommended as the additional chlorides promote the corrosion of reinforcing and may promote drying shrinkage. The 28-day strengths of concrete incorporating accelerating admixtures may be slightly lower than mixes without them. SCC mixtures should take these factors into consideration during trial batching and production. The water content of set accelerators should be included in the total water content of the mix.

Retarders

Retarders for use in concrete must meet the requirements of ASTM C494 for Type B or D. These products slow the setting time of concrete to reach initial and final set. This allows the plant to deliver the concrete to its final destination with the desired fresh properties, helps to homogenize multiple batch placements in the same member (preventing cold joints), and alters the natural stiffening long enough to complete the desired surface finish.

Dosage rates vary with supplier and product. Care should be taken to avoid overdosing, which may delay the stripping of the molds and time to serviceability to be extended past their intended target.

Controlled retardation may increase early and late strength gain by allowing the water to hydrate the cement more completely. Mix trials and historical data will help determine the optimum dosages for the ambient conditions.

Consult your admixture supplier for mix timing and proper material sequencing.

Corrosion Inhibitors

Corrosion inhibiting admixtures generally work by forming a film around steel reinforcing, which delays the chloride ions from reaching and attacking it. Dosage rates vary but generally range from 2 Gal/cu. yd to 5 Gal/cu. Yd. Many of these products, particularly ones based on calcium nitrite, can accelerate the setting time of concrete and cause rapid loss of workability.

More water reduction may be noted when polycarboxylate based HRWR's are utilized with higher dosages of corrosion inhibitors; mix trials should be performed to confirm this. The water content from corrosion inhibiting admixtures should be included in the total water content of the mix.

Viscosity modifying admixtures (VMA)

These materials are designed to alter the paste viscosity and/or bind the water into the concrete matrix of SCC. Mixes with less than desirable paste and/or mortar volumes at the flow required for a particular application and those incorporating poorly graded aggregates may benefit by the addition of a VMA. The addition of a VMA will typically help to stabilize the air content of the mix.

Overdosing of VMAs can lead to lower slump flows, increased T-20 times, incomplete consolidation, voids, honeycombing, sticky finishing, and poor aesthetics. Consult your admixture supplier for application data, mix introduction and dosage rates.

Dampproofing admixtures

These materials reduce the ingress of moisture, chlorides and other injurious materials thus improving the durability of concrete members. Because of their pore blocking nature, they have been used successfully to minimize efflorescence also. Consult your admixture supplier for dosage rates.

There are many other types of admixtures available for numerous applications. Pumping aids, fungicides, shrinkage reducers, ASR mitigation and others are available for specific projects. This guide does not discuss all of them.

Equipment

Forms may need to be altered due to the low viscosity of the paste with SCC. Larger gaps at joints will cause the paste to leak out. This loss of paste will result in honeycombing. Bugholes are a concern on formed surfaces. These small air voids are formed as the concrete is placed and are trapped on the formed surface. Cleanliness of forms, form material type, placing methods, mix proportions, mix viscosity, type of form release and amount of form release used are all factors in the number of bugholes that form. Also of particular concern is the static and dynamic outward pressure that SCC could exert on formwork. To maintain dimensional tolerances, additional bracing may be necessary, especially on wooden or other semi-flexible materials.

Generally, a mixer that can produce homogenized, high-quality conventional slump concrete will adequately produce SCC. As discussed elsewhere in this guideline, optimal sequencing of raw materials is required for highest efficiency and consistent mixing. Incorrect raw material sequencing may also create unmixed cement balls that do not disintegrate prior to discharging from the mixer, causing multiple problems.

Transporting equipment must have tight dispensing gates. Gates with gaps or weak closing apparatus may allow the mortar or paste to leak. Gates need to be rigid enough to prevent a breach of their integrity, both from a safety factor and efficiency standpoint. If a vehicle is used to transport the concrete from the mixer to the point of placement, several factors should be considered. Is there rough terrain to be traversed during this time? If so, the mix qualification should have reflected a simulation of this phase in the process, along with post-transport testing to ensure stability and adequate plastic properties at point of placement. Another way to handle this situation would be to use a transport vehicle that agitates the concrete during delivery to the form, such as a ready-mix truck.

Vibration and finishing equipment - If the mix qualification phase included the vibration of forms, the intensity and duration may need to be changed from conventional concrete to prevent over vibrating. In most cases, SCC does not require vibration. However, in some cases some vibration is required to ensure consolidation or produce a particular finish. If vibration is used it will require considerably less than conventional concrete. As with any concrete mixture, over vibration will cause the concrete to segregate. Over vibration can also cause a loss of entrained air from the in-place concrete.

Finishing SCC may require a timing adjustment for floating and troweling. Slump loss and early set may change from conventional concrete, which may also alter finish timing. Surface screeding and vibratory screeding may also require a change in timing, vibration duration, and intensity. It is possible that the normal process of using a vibrating screed may be eliminated as a step in the process with SCC. As in the case of conventional concrete, casting SCC outside during warm weather and in windy conditions can be a challenge as the surface may dry out quickly before the concrete reaches initial set.. This could result in a crusting of the surface, make finishing very difficult, and possibly result in plastic-shrinkage cracking from the loss of moisture on the top. An evaporation retardant will assist in minimizing these effects. Incorporating a microfiber into the mix will also reduce the likelihood of plastic-shrinkage cracking.

QA/QC Program

As part of standard quality control practice outlined in the NPCA Quality Control Manual, the plant's quality control program will need to include:

- Request and review all relevant mill test reports, evaluation reports and technical information (QCM 2.1).
- Establish mix designs and set parameters for slump flow, air contents and density (unit weight) (QCM 5.3).
- Establish minimum frequency of calibration of scales, meters and probes (QCM 5.1)
- Establish minimum testing frequency of aggregates including gradation and moisture content (QCM 5.2)
- Establish minimum testing frequency of fresh and hardened concrete (QCM 5.3)

In particular, standard procedures need to be discussed, reviewed and implemented to cover issues related to the following:

- Standard procedures to be followed with respect to evaluation and fate of inadequate concrete.
- What adjustments to inadequate mixes should be permitted?
- When should a mix be discarded?
- Who will make these decisions?
- Are post cast inspections required? (to check for paste leakage, make spot checks for dimensional integrity and static segregation of mix, evaluate air and water bleeding from mix)

Mix Trials

Mix trials should be performed with available sources of raw materials to determine which SCC mixture provides optimal performance. There is a balance between economy, performance and availability of materials, consistency from equipment, and other factors relating to the overall performance of the product cast that should be evaluated. Each mix should be proportioned to ensure it can maintain the required performance using actual plant equipment during day-to-day operations. If it cannot, then alterations are needed to the mix, plant equipment or both.

The assistance of a professional, qualified mixologist that can be trusted to provide the best possible SCC mix given the parameters available is most helpful.

ACI 237 is a resource that can be used when proportioning mixtures with guidance on paste and mortar content as well as powder contents for a given slump flow. Shrinkage testing may be required when implementing SCC. SCC mixtures may have higher paste and mortar contents resulting in an increase in drying shrinkage.

When final mixtures are developed in the lab, production mixes should be made in the same mixer that will be utilized during normal production. This will determine actual mix character exhibited under daily use.

EVALUATION

Cost/Benefit

Producing any product efficiently requires the manufacturer to reduce or eliminate steps within the operation which do not add value to the product. Eliminating operational waste as a result of inefficiencies, defects, rework, etc. is possible by implementing SCC in your plant. One of the most costly resources within an organization is labor. Process efficiency is just as important for a precaster, as it is for a large automobile manufacturer.

The first step in evaluating the economics of the precast operation is to analyze the direct and indirect costs within manufacturing. The two major sources of cost are materials and labor. Other indirect costs also can be considered but are more difficult to calculate. Some of the sources of material costs are the cost of cement, aggregates, admixtures, etc. The total amount of time spent within the process is the source of labor costs.

Perform a time study in the plant to determine the amount of time spent placing, consolidating, floating and patching the product. Record the time minutes per yard produced.

A trial production run with SCC will give you an indication of the savings possible, but until SCC is fully implemented and the process refined over time the full savings will not be known.

Some or all of the following financial impacts may be expected when comparing SCC to conventional concrete:

- Increase in consumption of cement and SCMs
- Increase in consumption of admixtures
- Decrease in labor due to speed of placement
- Decrease in labor due to reduction or elimination of vibrating and finishing

There are other costs which result from using a conventional concrete which are reduced and/or eliminated when switching to SCC. The cost of consolidation equipment is one of the major elements. Since little to no vibration is required with SCC, any expense used to purchase or maintain the vibration equipment will be retained as a savings. Also, the energy source used for consolidating will provide additional savings. The cost of air or electricity used to operate vibrating equipment is sometimes overlooked as a direct cost to producing concrete. Since the concrete is self-consolidating, overfilling a form is less likely to occur. This saves waste and may contribute to improving form cleanliness, as well as preventing harsh treatment, denting of forms after demolding product to remove buildup. There also will be less likelihood of employee injuries from climbing on formwork to vibrate concrete, and possible hearing loss from extreme noise.

Ultimately, the expected result of a cost comparison between SCC and conventional concrete would be that the net total cost per cubic yard would favor SCC.

Mix Qualification

In order to qualify an SCC mixture, the parameters by which it will be measured against must be known and understood. Below is an explanation of approved ASTM test methods. It is important that the testing criteria evaluate the three primary characteristics necessary to have a quality SCC mixture. These are flowability, passing ability and stability. Evaluation of these three key characteristics is necessary to ensure that the mix will perform consistently to produce a quality product.

Below is a chart of testing methods specifically for testing fresh SCC and the corresponding characteristics that each method is designed to evaluate. Several methods evaluate more than one distinctive attribute of SCC. These tests should be performed during the mix proportioning and mix qualifying process along with the testing normally run during day-to-day production. In addition, hardened analysis specific to individual project requirements must be performed.

SCC Fresh Concrete Test Methods

Test Method	Characteristic(s) Evaluated
Slump flow (ASTM C1611)	Flowability
VSI (ASTM 1611)	Mix Stability
J-Ring (ASTM 1621)	Passing Ability
Segregation (ASTM 1712)	Mix Stability (static)
Column Segregation Test (ASTM C1610)	Mix Stability (static)

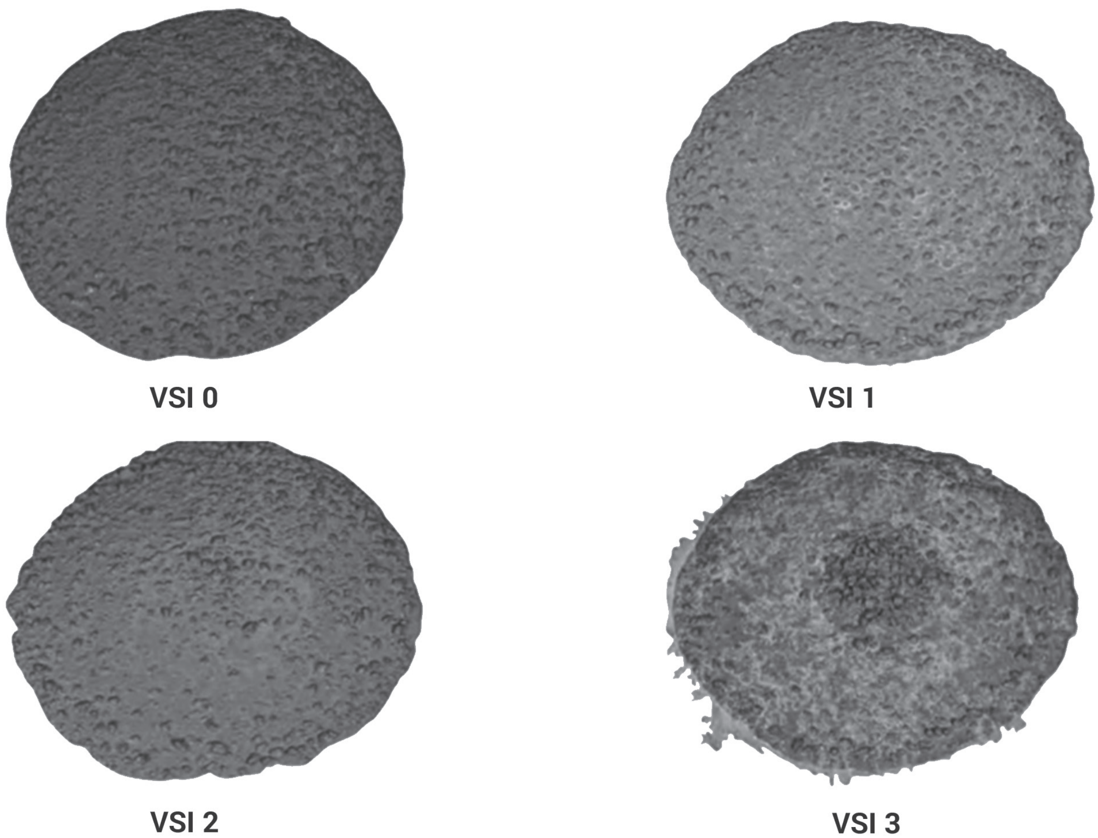
There are numerous test methods to evaluate the performance characteristics of SCC. The ones shown are some of the most common used in the U.S. A list of AASHTO standards related to SCC are found at the end of this document.

Slump Flow And Visual Stability Index (VSI)

ASTM C1611 - The slump flow of SCC is performed by measuring the spread of the displaced concrete from an Abrams cone onto a level, non-absorptive base. The larger the circle of concrete, the more flowable the concrete is. It is a relative indicator of a mix's filling ability.
Note: Test results may vary from a minimum of 20 inches to as high as 30 inches. For a specific mix typical parameters are a target slump flow ±2 inches.

Figure 1 – Slump Flow Test

VSI is a visual determination of the relative stability based on the appearance of the displaced sample from the slump flow test. For this test to have validity, the inspector must have experience in the visual characteristics of quality SCC and unstable SCC of the same or similar design. The inspector, in time, should be able to preliminarily evaluate the mix stability after placement. Some attributes of quality SCC after initial placement are coarse aggregate at or very near the top surface, stable paste with no air percolation and water bleed, and absence of foaming at form edges. Acceptability for SCC generally requires a VSI of 2 or less.



Courtesy BASF Construction Chemicals

Figure 2 – Visual Stability Index (VSI)

Column Segregation Test

ASTM C1610 - The purpose of this test is to evaluate the segregation resistance of SCC at rest (static segregation resistance). It involves the placing of concrete in a vertical cylindrical mold that is split into three lengths. After the mold is filled and allowed to sit for 15 minutes, the top portion is washed on a No. 4 sieve to isolate the material retained on a No. 4 sieve and the weight is recorded. The middle section of the mold is discarded, and the SCC from the lower section is washed on a No. 4 sieve and the material retained on the No. 4 sieve is then weighed. The relationship between the top and bottom weight of the material retained on the No. 4 sieve indicates the static stability of the mix. The sample used to perform this test should be collected according to ASTM C192/192M.
A passing result for this test method is typically 12% or less but specifications vary.

Static Segregation Tests

ASTM C1712, Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test – This test is a quick and easy assessment of the segregation resistance of an SCC mixture. When combined with the VSI, this test method gives the experienced practitioner an indication of the segregation resistance of the mix. It is best to correlate the results of this test with the column segregation test to allow this test to be used more frequently.

J-Ring

ASTM 1621 - A sample of freshly mixed concrete is placed in a mold, either in the upright or inverted position, that is concentric with the J-Ring. The concrete is placed in one lift without tamping or vibration. The mold is raised, and the concrete is allowed to spread through the J-Ring. The difference between the slump flow and J-Ring flow is an indicator of the passing ability of the concrete. A difference of less than 2 inches between the two tests is generally an acceptable outcome.

Figure 3 – J-Ring Test

Fabricating Specimens with Self-Consolidating Concrete

- ASTM C1758 – This standard practice covers the procedures for fabricating specimens in the field or lab with SCC. In order to meet the standard a minimum slump flow of 20 inches is required. If the slump flow is less than 20 inches then the procedures in the individual ASTM standards applies.

ASTM Standards affected are:

- C31 Standard Practice for making and Curing Concrete Test Specimens in the Field
- C138 Standard Test Method for Density (Unit Weight), Yield and Air Content (Gravimetric) of Concrete
- C173 Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
- C192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

Once the fresh testing results for an SCC mixture have been shown to be acceptable, the next step is to determine whether day-to-day standard raw material, equipment changes, and moisture fluctuations will prevent the mix from performing as required or if it requires adjustments.

Water Sensitivity (Robustness Testing)

Batch the SCC mixture and measure slump flow, VSI, unit weight and air content. Then add water at progressing amounts, typically 2 gallons/cy and perform the plastic test after each water addition until the mix becomes unstable and VSI reaches a result outside allowable parameters. This information will give an indication of impact variations in water content will have upon the mix. If the mix robustness is low, unstable after the first water addition, the procedures should be put in place to ensure that the plant operates within the limits required or adjustments to the mix are required to improve robustness,

Mock-Ups

A scaled-down or full-size mock-up test unit should be cast to simulate the product to be manufactured. The sample must mirror the intricacy of the formwork, expected reinforcing, height and finish requirements expected in production. This includes both the form finish and surface finishes required for the project(s). Hydrostatic pressures when utilizing SCC may be higher than with conventional mixes. Mock-ups also serve to determine what, if any, additional bracing, whalers, etc., may be warranted to maintain dimensional tolerances and prevent blowouts. There are many ways mock-ups can assist in the capabilities of a proposed mix. Simulated forms with Plexiglas walls can offer a visual “real time” view of the consolidation and aesthetic attributes. They may also help determine the placement point(s) to achieve the best finish, preventing the trapping of air and honeycombing tendencies.

Production equipment batch trials

Actual production loads will assist in the optimization of the mix by determining the best sequencing of the admixtures and other raw materials for a particular batch plant.

Variables such as the computer timing adjustments, mixer type and cleanliness, materials charging point to mixer, and mix time, all play a part in the overall consistency and performance of SCC. The wrong or inadequate sequence can lead to decreased admixture efficiency, unmixed cement or concrete balling, lower compressive strengths and other poor hardened performance. After a final mix has been proportioned, tested and approved for production, close monitoring of the mix should continue through production fresh SCC testing. Changes in temperature, seasonal fluctuations in raw materials and other factors which are not practical to simulate during mix qualification phase, may require adjustments of SCC mixtures. The assistance of a professional experienced in SCC along with trained plant personnel is essential.

Form Release

There are numerous brands and formulations of form releases available today. SCC is more flowable than conventional concrete and has different rheology, so there may be different result when using SCC with the form release that was used with conventional concrete. Mock-up testing using different types of form release will be a tool for evaluating several characteristics of the SCC/form release combination. Bugholes, staining capacity and ease of demolding are variables that should be assessed for their performance.

Care should also be taken to understand local and regional VOC (Volatile Organic Compounds) compliance laws.

Fresh concrete testing for daily production of SCC should include the following:

- Slump Flow and VSI (ASTM 1611)
- Static Segregation Resistance (ASTM C1712)

- Temperature (ASTM C1064)
- Air Content (ASTM C231, C173)
- Unit Wt./Yield (ASTM C138)
- Compression Specimens (ASTM C31)

Hardened testing may include the following. Project specific or agency requirements will drive the number and type of hardened tests to be performed.

- Freeze-Thaw resistance (ASTM C666)
- Chloride Permeability (ASTM C1202)
- Shrinkage (ASTM C157)
- Compressive Strength (ASTM C39)
- Air-Void Analysis of Hardened Concrete (ASTM C457)

IMPLEMENTATION

Training

Any precaster implementing SCC must start with a plantwide training program outlining the role of each individual in the successful batching, testing, transporting, placing and finishing of SCC. Each department must understand the changes required and responsibilities they have in the development and utilization of this technology.

Management

As the driver of the change to SCC, they must be aware of the processes, adjustments and issues that may arise during the early phase of implementation. Management must be cognizant of the raw material source changes and cost differentials that may be required. Probable adjustments in workforce staffing and man hours will need to be managed in order for any savings to be realized. Perhaps a complete overhaul of the post-cast handling may have to be addressed. If patching is no longer a standard practice with SCC, staging areas and secondary handling may be eliminated. These changes can have huge implications on the bottom-line profitability, but only if they are recognized and acted upon.

Quality Control

This department must know how to correctly test, evaluate and adjust SCC. In early implementation, weekly meetings may be necessary to help educate and evaluate the progress of the workforce. Testing frequencies and final product inspections may need to be increased, at least until everyone is trained and the SCC is consistent and stable. Certification specifically for technicians that can demonstrate proficiency in performing the required tests for SCC is available through the American Concrete Institute (ACI).

Production

This group will see, touch and be around the concrete more than any other. Therefore, it is important that they be able to evaluate SCC in the mixer. Learning to visually recognize unstable SCC is key to consistently producing quality SCC. Communication with the placing crew and quality control is imperative and allows adjustments to be made quickly. Standard operating procedures should be in place. If slump flows are lower than required, is vibration an option? If so, how long? If the slump flow is over allowable limits, what is to be done with the concrete? As with conventional concrete, delays in placement have a profound impact on SCC. If SCC loses slump flow due to delays, then plastic testing is required to determine the actual slump flow and air contents. Once these results are obtained the decision to place or not to place can be made along with the amount of vibration required if any.

One of the most important aspects of SCC is that it can be more sensitive to material changes and process changes than conventional concrete. It is important to implement into a production facility that has an established and is committed to a quality program. If possible, try to make sure that SCC is implemented into the process and overseen by someone who has prior SCC experience. If you do not have an experienced staff member, talk with your admixture supplier and solicit all the support that you can from them. It is crucial that an experienced batch plant operator is in place or is in line to be trained from the beginning stages of introducing SCC into production. This operator needs to be kept in place and in total control of the batching operation.

The next consideration to implement SCC in production is to make sure that your aggregate suppliers are consistent with their sieve analysis. Provide your aggregate suppliers with control ranges for each sieve size that are narrower than the ASTM C33 ranges. Make sure the aggregate supplier understands the changes you are making and is aware of the impact of the aggregates on the performance of the SCC. Make sure that your bins are maintained to ensure that there is no chance of cross contamination. Your aggregates are a crucial component of your ability to produce consistent, quality SCC.

The mechanical ability of your concrete mixer needs to be reviewed prior to running test batches. As with the production of conventional concrete, your mixer should be mechanically able to mix concrete uniformly. All adjustments to blades and scrapers need to be made and a maintenance program set up to check them periodically and adjust accordingly. It is important to run a series of test batches prior to full implementation to SCC. To ensure that your test batches can be duplicated, make sure that test batches are as large as your standard batch is going to be. One thing to keep in mind during the planning process is the need for more frequent concrete testing and checks during the initiation of SCC into production.

At first, testing consistency of SCC will be needed more frequently than what is needed for standard concrete. Testing requires that you test the consistency of the mix every batch until the desired consistency is met. As time prevails and your operator and inspectors become more experienced, visual assessments may be made, but testing according to ASTM is required. The changes in aggregate moisture need to be monitored closely, and an experienced operator needs to be in place to know what adjustments are needed, if any.

Another important planning step in SCC is the transportation methods of the concrete from the mixer and the capabilities of the mixer. It is important that production can complete the pouring of a product without waiting on concrete supply. The transfer process from your mixer to your concrete bucket is also crucial.

Training of production personnel is needed as SCC is implemented. Make sure that production personnel are there from the beginning during the test batch process.

Production personnel need to understand how SCC flows and recognize, identify and report mix problems such as segregation or flow problems through reinforcement. As sensitive as SCC can be, a good communication system between your production personnel and your mixer operator is important.

Sales, Engineering and Support Staff

Since SCC enhances the natural properties of concrete, the sales, engineering and support staff should also be trained in the benefits of SCC. Customers may not be familiar with SCC and everyone should be trained to answer questions about the product.

Trouble Shooting

Once you have selected your materials, determined mixture proportions and performed qualification testing proving that the SCC mixture meets the criteria that have been established there are going to be problems that occur as there are with traditional concrete mixtures. To properly address problems with SCC (or conventional concrete for that matter), the producer must be able to address the root of the problems within the production and placement processes. There are five categories that SCC producers can look to in order to establish the cause for problems with their mix: material changes, batching operations, moisture control, QA procedures, transporting and placing operations. The following is a guide to the identification, and elimination, of potential problems with SCC.

Material Changes

In the event that the fresh and hardened properties of a SCC mix have suddenly changed to produce an undesired result, it is recommended that the producer perform a document review to ensure that none of the raw materials selected during qualification process have changed. For plants that operate with multiple aggregate suppliers, and consequently multiple aggregate stockpiles, make sure that the stockpiles are clearly marked to avoid the mixing of different aggregate suppliers.

Further, it is imperative that there is constant communication between plant management and those individuals responsible for maintaining the aggregate stockpiles and bins, so everyone is involved in ensuring the quality of the finished product. In addition, when suspicions of problems with SCC arise, the aggregates should immediately be tested for compliance with your aggregate control specifications. The cement supply should also be checked. The type of cement purchased (type I, II, etc.) will affect the mix performance. Also, a change in the source for the cement, the fineness and the chemical properties can affect the quality and consistency of the SCC.

Batching Operations

The sensitive nature of SCC makes it susceptible to inconsistencies in the batching and mixing operations. Aggregate scales, cement scales, moisture probes, admixture dispensers ååand water dispensers must be calibrated and monitored to ensure accuracy of mix proportions, just as with conventional concrete. Should any component in the process become nonfunctioning the performance properties of the SCC will be altered. Changes in discharge settings or sequence can alter the entrained air content, reduce slump flow or contribute to segregation potential of the concrete.

Prescribed mixing times must be adhered to. High range water reducers must mix for the appropriate length of time to ensure proper dispersion throughout the SCC matrix. Insufficient mixing will result in a reduction of slump flow and inconsistent flows within the same batch, restricting the ability of the SCC to flow and to consolidate.

Moisture Control

Most of the difficulties associated with the production of SCC stem from moisture fluctuations throughout the course of daily production. Following guidelines set forth by the NPCA can greatly reduce the possibilities for poorly produced SCC. Automated adjustments for moisture through the use of moisture probes, while not required, are strongly recommended. In the absence of these systems, regular testing of aggregate moistures is required. Testing for slump flow and VSI can alert batch plant operators to fluctuations in moisture.

Excess moisture in SCC will decrease the stability of the mix. Expect to see the "champagne effect" or "percolation" as it is sometimes referred to, wherein air bubbles can be seen rising to the surface of the mix.

The "champagne effect" is the first indicator of mix instability and the producer should take immediate action to determine the cause(s) of the problem. If these subtle indicators are ignored, the net effect will be a mix that is likely to segregate and lead to rejected products. Severe indicators of mix instability are foaming, bleeding, and severe segregation. The producer must be continually aware of the physical behavior of the SCC mix and be trained in the potential causes and remedies to the problem. Ultimately, the mix may need to be re-proportioned and the producer may consider consulting with admixture representatives regarding admixture dosage rates.

Pouring Operations

It is essential in the mix proportioning and qualification phase of SCC to consider what type of members will be poured with the mix so that it best fits pouring operations. Intricate formwork with heavy reinforcement will require a less viscous mix to ensure complete coverage and consolidation of the concrete in the form. Placement should occur in timely fashion so that the effects of the HRWR are not diminished prior to placement, or retarding admixtures and/or a longer workability time HRWR should be used. Pouring forms too fast can lead to bugholes by entrapping air on the finished surface of the forms. Pouring too slowly may decrease the ability of SCC to fully consolidate (especially for more viscous mixes) if not enough head pressure is generated. In addition, SCC (as with conventional concrete) should not be dropped from significant heights as it may cause segregation. Testing during the mix qualification phase should include the average placement time of a given form to evaluate performance. Further, SCC is often referred to as concrete that does not require vibration. For more intricate formwork, or formwork containing heavy reinforcement or blockouts, the producer may find that light vibration or tapping of the forms will allow for the concrete to be fully consolidated. This can eliminate problems of bugholes, honeycombing, voids, and incomplete filling of formwork.

The key to addressing, understanding, and resolving issues discussed herein, can all be reconciled with adequate training of employees. A producer of SCC must be committed to ensure that all their employees, throughout all facets of production and quality, understand the benefits of SCC, and how to produce a consistent and quality product.

The following tables have been developed as a quick reference. Table 5 describes some potential problems associated with the placement of SCC and various components of the piece. Table 6 includes some potential problems and remedies. Table 7 lists potential adjustments to the mix proportions to correct certain problems.

Table 5 – Potential Problems

Element Characteristic	Potential Problems
Reinforcement Level	• Inhibition of flow • Blocking of coarse aggregate causing separation of aggregate and paste • Honeycombing
Element Shape Intricacy	• Inhibition of flow • Incomplete filling of form leaving voids
Element Depth	• Required free fall causing segregation • Increased potential for aggregate segregation/ settlement
Importance of Surface Finish	• Bugholes / voids on the surface • Sand streaking • Discoloration
Element Length	• Flow distance causing paste to separate from the aggregate
Wall Thickness	• Entrapment of voids on wall surface • Blocking of aggregate
Coarse Aggregate Content	• Blocking • Insufficient filling of forms • Poor surface finish
Placement Technique	• Entrapped air voids • Pump pressure causing segregation • Delays between deliveries causing lift lines • Casting from multiple locations causing lines

Table 6 – Potential Problems and Remedies

Problem	Remedy
Bugholes/Voids on Formed Surface	• Adjust slump flow • Adjust placement technique • Adjust placement speed • Decrease viscosity • Adjust aggregate proportions • Tap or vibrate lightly during casting (architectural/intricate forms)
Honeycombing	• Adjust aggregate proportions • Adjust slump flow • Change aggregate size • Increase viscosity
Incomplete Filling of Form	• Adjust slump flow • Adjust aggregate proportions • Decrease viscosity • Adjust placement technique
Sandstreaking	• Increase viscosity • Decrease flow • Adjust mix proportions to improve stability
Lift Lines	• Evaluate for thixotropy (increase water) • Adjust placement technique • Decrease viscosity • Adjust workability time by adding retarding admixture
Aggregate Blocking	• Adjust aggregate proportions • Modify mix proportions • Increase viscosity • Change aggregate size
Excessive Bleeding	• Decrease flow • Modify mix proportions • Decrease water or HRWR • Increase viscosity • Verify aggregate gradation

Table 7 Material Adjustments

	Powder Content	Water Content	C.A. Top size	S/A Ratio	VMA Dosage	HRWR Dosage
Fluidity						
Too Low		↑			↓	↑
Too High		↓			↑	↓
Viscosity						
Too Low	↑	↓			↑	
Too High		↑			↓	
Blocking	↑	↓	↓	↑	↑	
Stability Rating						
Too Low	↑				↑	
Too High	↓	↑		↓	↓	
Aggregate Pile			↓	↑		
Mortar Halo	↑	↓			↑	↓

References

AASHTO DESIGNATION	DESCRIPTION
T 345	Standard Test Method for Passing Ability for Self-Consolidating Concrete
T 347	Standard Method of Test for Slump Flow of Self-Consolidating Concrete (SCC)
T 349	Standard Method of Test for Filling Capacity of Self-Consolidating Concrete using the Caisson Test
T 351	Standard Method of Test for Visual Stability Index (VSI) of Self-Consolidating Concrete (SCC)
T 352	Standard Method of Test for Determining Formwork Pressure of Fresh Self-Consolidating Concrete Using Pressure Transducers
R 81	Standard Specification for Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders

ACI DESIGNATION	DESCRIPTION
PRC 237-07	Self-Consolidating Concrete (Reapproved)
PRC 212.3-16	Report on Chemical Admixtures for Concrete

ASTM DESIGNATION	DESCRIPTION
C31	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33	Standard Specification for Concrete Aggregates
C39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C138	Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C150	Standard Specification for Portland Cement
C157	Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
C173	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C192	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C231	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C260	Standard Specification for Air-Entraining Admixtures for Concrete
C330	Standard Specification for Lightweight Aggregates for Structural Concrete
C457	Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
C494	Standard Specification for Chemical Admixtures for Concrete
C595	Standard Specification for Blended Hydraulic Cements
C618	Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C666	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (Withdrawn 2024)
C989	Standard Specification for Slag Cement for Use in Concrete and Mortars
C1064	Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C1157	Standard Performance Specification for Hydraulic Cement
C1202	Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
C1240	Standard Specification for Silica Fume Used in Cementitious Mixtures
C1602	Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
C1610	Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique
C1611	Standard Test Method for Slump Flow of Self-Consolidating Concrete
C1621	Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring
C1712	Standard Test Method for Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test
C1758	Standard Practice for Fabricating Test Specimens with Self-Consolidating Concrete
C1866	Standard Specification for Ground-Glass Pozzolan for Use in Concrete