NPCA WHITE PAPER

GUIDE TO IMPLEMENTING SELF-CONSOLIDATING CONCRETE

National Precast Concrete Association
NPW WHITE PAPER

GUIDE TO IMPLEMENTING SCC - 2011

Introduction
Self-Consolidating Concrete (SCC) is a highly flowable, yet stable concrete that can spread readily into place, fill formwork with little to no consolidation and without undergoing significant separation. This type of concrete can be ideal for use in precast 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 investigating and implementing 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 compact. 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

SCC is believed by many to be the future of the concrete industry. With the passing of each year, it becomes more affordable and easier to use, while the number of facilities manufacturing with SCC continues to grow.
INVESTIGATION
The process of investigating and implementing SCC into your operation can be broken into three components.

1. Examine your current materials and equipment. Determine what changes may need to be made or equipment purchased in order to produce quality SCC.
2. Begin a trial batch and training process. A company should allow enough time for experimentation and factor in a learning curve.
3. Perform a cost/benefit analysis for your plant and products to determine the overall impact of switching.

Products to be Manufactured
Considerations should be made to 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 robust and flowable mix than thin wall vertical wall panels with congestive reinforcing and/or intricate formwork. Likewise, SCC transported in a ready-mixed truck with agitation will not require the segregation resistance of a concrete transportation vehicle without agitation transported over rough terrain. The assistance of your admixture supplier or other qualified person will help with these determinations.

Raw Material Selection

Coarse Aggregate
Coarse aggregate for use in SCC should conform to ASTM C33. SCC has successfully been manufactured using aggregate from 1 ½” nominal size to ½” nominal size, and even smaller in special circumstances. 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 containing material, which is retained on a 200 sieve and pan (providing it is not water soluble or deleterious) may be advantageous to an SCC mix. As with conventional-slump concrete, moisture contents must meet or exceed saturated surface dry (SSD) conditions.

Lightweight Coarse Aggregate
Lightweight aggregates for use in SCC must meet ASTM C330. These materials require a close monitoring of air content. The pore structure and absorption rates of these materials make SCC with lightweight course aggregate particularly challenging. Follow manufactures recommendations for minimum absorbed moisture percentages and unit weight capabilities.

Fine Aggregate
Fine aggregate for use in SCC should conform to ASTM C33 with the exception ofgradation requirements. Grading may deviate to achieve a more ideal grading curve when blending with other aggregates to develop a robust SCC design. Variations in the fineness modulus (FM) should not deviate from the qualification design by more than +/-0.20.
Concrete requires enough paste fraction in its matrix to maintain stable entrained air contents. Paste contents also assist in suspending the aggregate and water in the concrete. SCC may require a higher paste fraction in order to produce a more viscous, non-segregating mix. Aggregates with a higher percentage retained on a 200 sieve and the pan (as long as the material is not water soluble or deleterious) may be advantageous. Aggregate particles that are smaller than 0.005 inches are considered part of the powder content of a mix.

There are many programs available that will allow the mixologist to input the grading of a prospective coarse and fine aggregate source (or sources). This allows graphic viewing, 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 can help the preparer determine the optimum blend of available aggregates.

SCC incorporating multiple fine aggregate sources, or single sources that are not local, can significantly alter the stability, segregation resistance and compacting ability of a desired mix. Merely using local fine aggregate sources because they cost less per ton may not be the most economical solution for SCC in the long run. This is a common mistake when developing SCC. Minimum paste contents with contributions from fine aggregate often will be more economical than higher priced additional cementitious materials. 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. Be aware that some state and agency DOTs require AASHTO M35 as acceptance criteria also. Inspect and record Mill Certifications for fineness (Blaine) when running mix qualifications. If Blaine changes significantly during production there could be a change in concrete stability and character. Overall paste volume and particle size may alter SCC mix characteristics. A switch from one type of cement to another, or a source change, should prompt a re-qualification of a particular mix design.

Blended cements must meet the requirements of ASTM C595. These cements are in many instances desirable due to the multiple particle sizes and configurations of the material, which can aid in mix stability and robustness.

**Supplementary Cementitious Materials (SCMs)**
Pozzolans generally meet ASTM C618 (Fly ash), C989 (Slag), or C1240 (Silica Fume). These additions may be added for numerous reasons. They may lower the cost per cubic yard. Other enhancements may include higher performing hardened properties
such as reduced permeability, more desirable entrained air bubble matrix, increased strength, lower heat of hydration, sulfate resistance, etc. Efflorescence and ASR mitigation may be minimized with the use of pozzolanic materials.

As pozzolans are of different particle sizes and configurations than cement alone, the stability and segregation resistance may also be enhanced.

**Fly Ash**
There are generally two types of fly ash. Class F ash has 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 ash has a higher concentration of calcium and is cementitious as well as pozzolanic in nature. Both of these ashes are spherical in configuration. Care must be taken when incorporating ashes into concrete, as changes in set time and early strength gain may be experienced. Whenever possible, choose sources with lower carbon content. High-carbon 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 exhibit a different particle size than other pozzolans and cements, the use of fly ash often lower the water demand of concrete and provide a higher viscous, more robust character. Typical cement replacements range from 15% to 30%, but higher percentages have been used successfully.

**Ground Granulated Blast Furnace Slag**
Blast furnace slags 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 20% to 40%, but special applications have demanded percentages as high as 75%.

**Silica Fume**
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 can exhibit characteristics somewhat like viscosity modifying admixtures (VMAs) in that it can contribute significant paste and stability to an SCC mix. Water demand of silica fume is higher than cement alone, and the economics of this material may influence its use. Typical usage range is 3% to 8% cement replacement.

**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 mixes 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, but an addition to the mix or a substitution for a portion of fine aggregate.

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, such as Metakaolin, 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 harmful to concrete. Wash water used in manufacturing SCC must meet the chemical limits of ASTM C94.

**Chemical Admixtures**
Admixtures for use in concrete are used to enhance and/or obtain certain properties of fresh and hardened SCC. HRWR (High Range Water Reducers) are essential to SCC in that they provide the plasticizing effects, allowing the concrete to flow to self-consolidation

**Air Entraining Admixtures**
Air entraining admixtures must meet ASTM 260 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 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.

**High Range Water Reducers**
Water reducers play an integral part in the success of SCC. Polycarboxylate high range water reducers are highly recommended for use in SCC. Their technology allows very high water reduction (up to 45%) with good overall mix characteristics. HRWR’s must meet ASTM C494 Type F specifications. 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 a mix exhibiting air bubbles escaping to the surface of static SCC, and segregation.
Dosage rates vary greatly from source to source, so consult your supplier for specifics on the application for each mix. Consult source for mix timing and proper sequence.

**Accelerators**
Accelerating admixtures must meet ASTM C 494, TYPE C specifications. There are two different types of accelerators that alter the early strength characteristics of concrete in two distinct ways. Set accelerators shorten the 0 to 500psi set time (ASTM C403), whereas strength accelerators speed up very early strength gain (4 to 8hrs) but do little to alter the initial set characteristics. Dosage rates vary from different suppliers, so consult your supplier for product details and mix timing. The use of Calcium Chloride accelerators are not recommended as the additional chlorides promote the degradation 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 mix designs should take these factors into consideration during trial batching and production.

**Retarders**
Retarders for use in concrete must meet the criteria spelled out in ASTM C494 Type B specs. These products slow the setting time of concrete to the 500psi threshold (ASTM C403). 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 at seasonal environments. Consult your supplier for mix timing and proper sequence.

**Corrosion Inhibitors**
Corrosion resistant admixtures generally work by forming a film around steel reinforcing, which prevents 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 spread.

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. Also, note the water from corrosion inhibitors should always be considered as part of the mix water as contributing to the overall w/c.

**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 a strategic dose of VMA. Some VMA’s can help stabilize the air content at specific doses.
Overdosing of VMA’s can lead to lowered slump flows, incomplete self-compaction, voids, honeycombing, harsh or sticky finishing character, and poor aesthetics. Consult your admixture supplier for application data, mix introduction, and dosage rates.

**Dampproofing admixtures**

These materials prevent the ingress of moisture, chlorides and other injurious materials from attacking the durability of concrete members. Due to their pore blocking nature, they have been used successfully to minimize efflorescence also. Consult source for dosage rates.

There are many other types of admixtures available for numerous applications. Pumping aids, fungicides, shrinkage reducers, ASR mitigates, and others are available for specific projects. These guidelines cannot discuss all of them in this format.

**Equipment**

Forms may need to be altered due to the low viscosity of the paste with SCC. Larger gaps at joints could bleed paste out. This loss of paste will be displaced by either the other raw materials in the mix, causing honeycombing, or may leave air pockets. In certain cases, small air bubbles may enter the filled formwork and work their way up the form’s wall, appearing what some would incorrectly interpret as poorly consolidated, bughole. Also of particular concern is the static and dynamic outward pressure that SCC could exert on formwork. In order 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 of like caliber. As discussed elsewhere in this guideline, sequencing of raw materials may require a timing change for highest efficiency of speed and 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 a breach of the paste. 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 this trek, 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. SCC requires in most cases, no vibration. However, even lower flow mixes that needs some energy to self-compact, will require considerably less than conventional concrete. If over vibration occurs, the outcome will be just as dangerous as a poorly designed, segregated mix. The coarse aggregate will
sink, leaving only paste at the surface, and could cause depletion of the entrained air in the matrix of the concrete. Water may also bleed to the surface.

Finishing SCC may require a timing adjustment to when floats and trowels are used. Small entrapped air bubbles may surface for a short time, delaying finishability. 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 yet the concrete’s paste will remain plastic. This could result in a crusting of the surface and make finishing very difficult, and possibly create surface cracking from the loss of moisture on the top. A finishing aid/evaporation retardant will assist in minimizing these effects.

**QA/QC Program**
As part of standard quality control practice as 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.
- Establish mix designs and set parameters for slump flow and air contents
- Establish minimum frequency of calibration of scales and meters and probes
- Establish minimum testing frequency of aggregates including gradation and moisture content
- Establish minimum testing frequency of fresh and hardened concrete

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 multiple sources of raw materials to determine which constituent suppliers best support the final product objective. 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 design should be formulated to ensure it can maintain the required performance using actual plant equipment during day-to-day fluctuations. 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 providing the best possible SCC mix given the parameters available is most helpful. Formulation development should follow the guidelines in ACI 211. Coarse aggregate volumes may need to be altered from these specifications due to the higher paste and mortar requirements of many SCC mixes. Hardened shrinkage testing may be required when mixes utilize more than 50% fine aggregate to total aggregate by volume. Trial batching in the lab when in the development stages may be attractive to minimize concrete waste and preserve time savings.

When final mix(s) 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. Consumers do not wish to pay for operational waste as a result of inefficiencies, defects, rework, etc. One of the most costly resources within an organization is labor. Process efficiency is just as important for a small 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 can also 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. To illustrate the cost analysis, we will use some fictitious costs for materials and labor. The actual costs in any operation can then be substituted in the formulas to create a realistic cost analysis for a plant. The Tables below are for illustrative purposes only.
Table 1 – Material Costs for a Conventional Concrete

<table>
<thead>
<tr>
<th>Material (Standard Mix)</th>
<th>Extended Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>$27.6</td>
</tr>
<tr>
<td>SCM (Fly Ash, Slag, etc.)</td>
<td>$2.70</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>$9.00</td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>$6.50</td>
</tr>
<tr>
<td>Air Entrainment</td>
<td>$0.22</td>
</tr>
<tr>
<td>Water-reducing Admixture</td>
<td>$4.69</td>
</tr>
<tr>
<td>Total Cost per Yard</td>
<td>$50.71</td>
</tr>
</tbody>
</table>

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. Then, using a matrix similar to the one shown below, calculate the labor cost per yard of concrete. The labor rate is an average of the hourly rate (including overtime) and cost of benefits.

Table 2 – Approximate Labor Costs per Yd³ of Conventional Concrete

<table>
<thead>
<tr>
<th>Labor (Standard Mix)</th>
<th>Time / Yard (min.)</th>
<th>No. of Workers</th>
<th>Rate ($/hour)</th>
<th>Extended Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement</td>
<td>5</td>
<td>5</td>
<td>$15</td>
<td>$6.25</td>
</tr>
<tr>
<td>Vibrating</td>
<td>3</td>
<td>4</td>
<td>$15</td>
<td>$3.00</td>
</tr>
<tr>
<td>Floating</td>
<td>2</td>
<td>2</td>
<td>$15</td>
<td>$1.00</td>
</tr>
<tr>
<td>Patching</td>
<td>10</td>
<td>1</td>
<td>$15</td>
<td>$2.50</td>
</tr>
<tr>
<td>Total Cost per Yard</td>
<td></td>
<td></td>
<td></td>
<td>$12.75</td>
</tr>
</tbody>
</table>

The total cost of a conventional concrete in this example is $63.46 per cubic yard.

Once you have established the costs associated with pouring conventional concrete, use the same cost matrix to determine the cost of the SCC mix. A trial production run with SCC is necessary to obtain actual time study data. An alternate could be to use the time estimates from another precast plant.

Table 3 - Material Costs for a SCC

<table>
<thead>
<tr>
<th>Material (SCC Mix)</th>
<th>Cost/unit</th>
<th>Quantity</th>
<th>Extended Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>$32.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Cement (Fly Ash, Slag, etc.)</td>
<td>$3.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>$7.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>$7.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Entrainment</td>
<td>$0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCC Admixture</td>
<td>$5.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost per Yard</td>
<td>$56.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4 - Approximate Labor Costs per Yd³ of SCC

<table>
<thead>
<tr>
<th>Labor (SCC Mix)</th>
<th>Time / Yard (min.)</th>
<th>No. of Workers</th>
<th>Rate ($/hour)</th>
<th>Extended Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement</td>
<td>3</td>
<td>2</td>
<td>$15</td>
<td>$1.50</td>
</tr>
<tr>
<td>Vibrating</td>
<td>0</td>
<td>0</td>
<td>$15</td>
<td>$0.00</td>
</tr>
<tr>
<td>Floating</td>
<td>1</td>
<td>2</td>
<td>$15</td>
<td>$.50</td>
</tr>
<tr>
<td>Total Cost per Yard</td>
<td></td>
<td></td>
<td></td>
<td>$2.00</td>
</tr>
</tbody>
</table>

The total cost of self-consolidating concrete in this example is $58.29 per cubic yard, a hypothetical savings of $5.17 per yard.

Obviously the costs and savings realized in this example are based on estimations. The actual savings will vary. A savings of over $5.00 per yard is a substantial sum for a plant which produces 50, 75, or 100 yards of concrete per day. It can also benefit a plant that only produces a few yards per day. But it is not the only financial savings obtained by using SCC.

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. Little to no vibration is required with SCC. So 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-leveling, 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 placed concrete, and possible hearing loss from extreme noise.

Mix Qualification

In order to qualify a mix for a specific product or products, the parameters by which it will be measured against must be known and understood. Below is an explanation of testing criteria, some of which are approved ASTM specifications some that are in the process of approval by ASTM and others that are used by the industry but have not yet been recognized by pertinent national organizations. It is important that the testing criteria evaluate the three primary characteristics necessary to have SCC. These are flowability, passing ability and stability. Without evaluation of these, the mix cannot perform adequately or consistently to produce quality product.

Below is a chart of testing methods specifically pertinent to 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 mix formulation and mix qualifying 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

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Characteristic(s) Evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump flow (ASTM C1611)</td>
<td>Flowability</td>
</tr>
<tr>
<td>VSI (ASTM 1611)</td>
<td>Mix Stability</td>
</tr>
<tr>
<td>J-Ring (ASTM 1621)</td>
<td>Blockage Resistance</td>
</tr>
<tr>
<td>Static Segregation (ASTM 1712)</td>
<td>Mix Stability (static)</td>
</tr>
<tr>
<td>L-Box</td>
<td>Flowability/Blockage Resistance</td>
</tr>
<tr>
<td>Column Segregation Test</td>
<td>Mix Stability (static)</td>
</tr>
</tbody>
</table>

Appendix A contains the ASTM methods shown above and explained below. Test methods are not nationally approved yet but used as a tool by the industry is also explained in detail in the appendix. 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.

#### Slumpflow And Visual Stability Indicator (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 in. to as high as 30 in. For a specific mix typical parameters are a target slump flow +/-2 in.*

VSI is a visual determination of the relative stability based on the appearance of the displaced sample from the slump flow test. In order for this test to have validity, the inspector must have experience in the visual characteristics of sound 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 sound SCC after initial placement are coarse aggregate at or very near the top surface, stable paste with no air percolation and water bleed, absence of foaming at form edges, etc. Acceptability for SCC generally requires a result below VSI of 2.

#### L-Box

This test involves the use of a monolithic vertical and horizontal section with a movable gate of predetermined dimensions. The vertical portion is filled with SCC. The gate is opened, and the flow rate and slope of the concrete is measured. This is an indication of flowability. Reinforcing bars of varying size and spacing can be added in front of the gate to evaluate the blockage Resistance also. Multiple operator bias is expected with this method.

#### Static Segregations Tests

ASTM C1712 – Rapid Assessment of Static Segregation Resistance of SCC using Penetration Test – This test is a quick and easy assessment of the likelihood that segregation of a self consolidating concrete will occur.
Column Segregation Test
The grounds for this test are to evaluate the segregation resistance of SCC at rest (static segregation resistance). It involves the placing of concrete in a vertical tube that is split into three lengths. After a predetermined time, the top portion is sieved to isolate the coarser particles and their weight is recorded. The middle portion is discarded, and the lower portion’s coarser particles are then weighed. The relationship between the top and bottom coarse material indicates the static stability of the mix. The concrete used to perform this test should be collected from a mass of concrete placed in formwork. Concrete collected from the bottom of a bucket or from a wheelbarrow may skew results and not be indicative of actual stability.

Acceptable result if difference between top and bottom aggregate are not more than 12%.

J-Ring
ASTM 1621 - J-Ring procedure consists of a slump flow test performed with an open steel circular ring with tines around the Abrams cone. The tines project through the sample once the cone has been lifted. The tines simulate reinforcing and the level of restriction by the larger particles prevents the spread of the sample. This method is usually performed in conjunction with the slump flow test.

A difference of less than 2” between the two tests is generally an acceptable outcome.

In addition to these tests, current fresh concrete test methods must be modified to consider the characteristics of SCC. These specification changes are in discussion on a national level, but for our purposes they will need to be altered whenever evaluating SCC.

Test Methods Affected:

1. ASTM C31 Standard Practice for Making and Curing Concrete Test Specimens in the Field.
   Alteration - Fill cylinder molds in single lift with no rodding and tap lightly

2. ASTM C 138 Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.
   Alteration - Fill container in single lift with no rodding and tap lightly

3. ASTM C 173 Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.
   Alteration - Fill base in single lift with no rodding and tap lightly

4. ASTM C 192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.
   Alteration – Fill cylinder molds in single lift with no rodding and tap lightly

5. ASTM C 231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.
   Alteration – Fill base in single lift with no rodding and tap lightly
Once the fresh testing results for a design have been shown to be favorable, then 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 alterations.

**Water Sensitivity**
Batch a mixture at the design water to cement ratio and determine slump flow and VSI. Then add water at progressing amounts, and continue to perform the slump flow and VSI ratings until the mix becomes unstable and VSI reaches a result outside allowable parameters. This information will determine if the variations that rank the mix at the maximum allowable limits are within the fluctuations that plant equipment and raw materials notice in day-to-day plant conditions. If not then either the mix should be altered, or the equipment adjusted, or both.

*NOTE:* It is important to note that SCC mixes are generally more sensitive to water fluctuations. The use of automated moisture control is strongly recommended.

**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, mix time, etc. all play a part in the overall consistency and performance of SCC. The wrong or inadequate timing sequence can lead to decreased admixture efficiency, unmixed cement or concrete balling, lower compressive strengths and other poor hardened performance. They may also affect the fresh properties. After a final mix has been formulated, 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 slight retooling of SCC mixes. The assistance of a professional along with trained plant personnel is essential.

**Form oils selection**
There are numerous brands and formulations of bond breaking oils available today. The paste of SCC is more flowable than conventional concrete, so there may be enhanced interaction between the paste and the oil. Mock-up testing using different types may
provide a forum for evaluating several characteristics of oils. 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 (ASTM 1611)
- VSI (ASTM 1611)
- Temperature (ASTM 1064)
- Air Content (ASTM C231, C173 -amended)
- Unit Wt./Yield (ASTM C138 - amended)
- Compression Specimens (ASTM C31 - amended)

Hardened testing may include the following specifications. 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)
- Hardened Air analysis

**IMPLEMENTATION**

**Training**
A plant wide meeting outlining the initiative should be foremost for a successful transition to the implementation of SCC. Each department must understand the action points and responsibilities they have in the development, manufacture, 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 enforcement. 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.

**QA**
This department must know how to correctly test and spot poor results. They should have the ability to quickly note and adjust when seeing visual problems of fresh and hardened 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 educated and the SCC concrete is consistent and stable.

**Production**

This group will see, touch, and be around the concrete more than any other. It is important therefore, that they be able to spot poor concrete from the mixer, unstable characteristics both pre and post placement, and finishing issues so they can alert QA for evaluation and adjustment. Foremen should stay in tune with the man hour changes inherent when utilizing SCC so that he/she can divert idle hands or struggling staff to enhance efficiency. They should understand their SCC designs in case they encounter slump flows under or over their prescribed limits. If lower, is vibration an option? If so, how long? If 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 slump concrete stiffens up moderately prior to placement, vibration time and intensity can be increased to compensate. If plant staff are used to not vibrating, older SCC that has lost flow may not fully compact on its own, causing defective product.

**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. The improved efficiency may lead to the ability to reduce pricing to win a bid. The improved density may impact the design and structural characteristics of the finished product. The accounting department may question the impact that SCC has on direct materials costs. They can also be a resource for gathering data used to perform the cost/benefit analysis.

**Production**

One of the most important aspects of SCC is that it can be more sensitive than conventional concrete. It is important to implement into a production facility that has an established or is planning to establish and commit to a good 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. They must fall within the guidelines of ASTM C33. Make sure that your bins are maintained to ensure that there is no chance of cross contamination. Your aggregates are a crucial variable in the quality of the mix design and the flow ability of 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.

**Trouble Shooting**
The producer has selected their materials, determined proportions, and performed qualifications proving that the mix design meets the criteria that have been established for production of SCC with the specific application for the mix predetermined. This section seeks to address problems that are typically associated with the production of SCC in the producer’s day to day operations. To properly address inconsistencies with SCC (or conventional concrete for that matter) the producer must be able to address the root of the troubles 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, and pouring operations. The following is a guide to the identification, and elimination, of potential problems with self-consolidating concrete.

**Material Changes**
In the event that the fresh and hardened properties of a SCC mix have suddenly changed to produce an inconsistent 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 ASTM C33. The cement supply should also be checked when the consistency of the SCC is a problem. The type of cement purchased (type I, II, etc) can affect the mix design. Also, a change in the source for the cement (plant or silo), 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, and 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. Short batching will result in a reduction of slump flow and inconsistent flows within the same batch, restricting the ability of the self consolidating concrete to fully compact.

This will lead to a reduction of strength and an increase in porosity.

**Moisture Control**
Most of the difficulties associated with self consolidating concrete 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 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 settlement of the coarse aggregate. Severe indicators of mix instability are foaming, bleeding, and segregation. The producer must be continually aware of the physical behavior of the SCC mix and be educated in the potential causes and remedies to the situation. Ultimately, the mix may need to be re-designed and the producer may consider consulting with admixture representatives regarding admixture dosage rates.

**Pouring Operations**
It is essential in the design 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 compaction of the structure. 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 compact (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 mix 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 compacted. 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 alterations in mix design to certain problems.
## Table 5 – Potential Problems

<table>
<thead>
<tr>
<th>Element Characteristic/ Placement Technique</th>
<th>Potential Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement Level</td>
<td>• Inhibition of flow&lt;br&gt;• Blocking of coarse aggregate causing separation of aggregate and paste&lt;br&gt;• Honeycombing</td>
</tr>
<tr>
<td>Element Shape Intricacy</td>
<td>• Inhibition of flow&lt;br&gt;• Incomplete filling of form leaving voids</td>
</tr>
<tr>
<td>Element Depth</td>
<td>• Required free fall causing segregation&lt;br&gt;• Increased potential for aggregate segregation/settlement</td>
</tr>
<tr>
<td>Importance of Surface Finish</td>
<td>• Bugholes / voids on the surface&lt;br&gt;• Sand streaking&lt;br&gt;• Discoloration</td>
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<tr>
<td>Element length</td>
<td>• Flow distance causing paste to separate from the aggregate</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>• Entrapment of voids on wall surface&lt;br&gt;• Blocking of aggregate</td>
</tr>
<tr>
<td>Coarse Aggregate Content</td>
<td>• Blocking&lt;br&gt;• Insufficient filling of forms&lt;br&gt;• Poor surface finish</td>
</tr>
<tr>
<td>Placement Technique</td>
<td>• Entrapped air voids&lt;br&gt;• Pump pressure causing segregation&lt;br&gt;• Delays between deliveries causing lift lines&lt;br&gt;• Casting from multiple locations causing lines</td>
</tr>
<tr>
<td>Problem</td>
<td>Remedy</td>
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<tr>
<td>-------------------------------</td>
<td>------------------------------------------------------------------------</td>
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</tbody>
</table>
| Bigholes/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 agg 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 techniques  
• Decrease viscosity  
• Adjust workability time by adding retarding admix  
• Increase flow |
| Aggregate Blocking            | • Adjust aggregate proportions  
• Modify mix proportions  
• Increase viscosity  
• Change agg size |
| Excessive Bleeding            | • Decrease flow  
• Modify mix proportions  
• Decrease water or HRWR  
• Increase viscosity  
• Verify aggregate gradation |
Table 7 – Potential Mix Design Adjustments

<table>
<thead>
<tr>
<th></th>
<th>Powder Content</th>
<th>Water Content</th>
<th>C.A. Topsize</th>
<th>S/A Ratio</th>
<th>VMA Dosage</th>
<th>HRWR Dosage</th>
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</thead>
<tbody>
<tr>
<td><strong>Fluidity</strong></td>
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<td><strong>Viscosity</strong></td>
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<td>Too Low</td>
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<tr>
<td><strong>Blocking</strong></td>
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<td><strong>Stability Rating</strong></td>
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<td>Too Low</td>
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<tr>
<td>Aggregate Pile</td>
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<tr>
<td>Mortar Halo</td>
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