Self-Consolidating Concrete:
A Synthesis of Research Findings and Best Practices

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16. Abstract

The Connecticut Department of Transportation (ConnDOT) currently permits the use of self-consolidating concrete (SCC) technology on a limited basis for precast drainage structures, barriers and retaining walls. These include but are not limited to catch basins, manholes, culverts, retaining walls, and barrier curbs. At this time, ConnDOT does not permit the use of SCC for prestressed concrete applications, such as for bulb-tee girders, box beams and deck slabs; and does not permit its use for cast-in-place applications.

This study was conducted in order to help facilitate the specification of SCC technology by the ConnDOT. This included visiting precast plants that produce concrete products for ConnDOT and observing their practices, conducting a literature review on SCC, and summarizing a Research Advisory Committee survey conducted by the Missouri Department of Transportation appropriate to ConnDOT specifications. Based upon the findings of the study, it is recommended herein that ConnDOT's SCC specification continue to be limited to precast concrete applications not involving any prestressed elements. Once ConnDOT implements a more rigorous SCC specification and acceptance process involving the use of more workability tests, ConnDOT should consider pilot projects for precast/prestressed bridge elements and cast-in-place concrete construction.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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INTRODUCTION

The American Concrete Institute (ACI) defines self-consolidating concrete (SCC) as "…highly flowable, nonsegregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation." *(1)*

SCC is a relatively new material. It was first developed at the University of Tokyo in 1986 and the first publication on SCC was published in 1989. These early researchers indicated that enhanced qualities of SCC include safety, reduced labor and construction time, and ultimately improved product quality *(2)*.

This synthesis of practice study was initiated in the Fall of 2007 in order to determine whether the best SCC construction and quality assurance practices are being specified by the Connecticut Department of Transportation (ConnDOT). The objectives were to: survey and document practices in other states, document ConnDOT contractor/plant practices, and combine research findings on SCC into one report to help facilitate its specification and usage.

LITERATURE REVIEW

In 2007, ACI Committee 237 reported on SCC as an emerging technology, and in doing so, it began encouraging its development and appropriate usage *(1)*. While SCC is still an emerging technology in the United States, it has been used in Japan since the late 1980s and has already gained wide acceptance there, as well as in Europe *(1,3)*.

There are many advantages of using SCC in lieu of conventional concrete. ACI 237R lists numerous benefits, which will not be entirely duplicated or detailed in this review. These include reduced labor and equipment, accelerated construction, facilitated filling of heavily reinforced and complex sections, reduced noise (via eliminated vibration), increased designer flexibility for detailing reinforcing bar placement, and smoother surfaces with reduced honeycombing *(1)*.

There are aspects of SCC that should be noted that may present barriers to its widespread use. Perhaps the most prevalent is the lack of experience and familiarity of the contractors. Many of the problems that have been encountered using SCC, such as maintaining “flowability,” have also been encountered with conventional concrete (loss of slump or stiffening of the concrete), but contractors have had years of experience in dealing with these. The problem that is probably most unique to SCC versus conventional concrete is that of its tendency to segregate, but that can be minimized with experience and training. Finally, SCC mixes may also tend to have more shrinkage related issues due to higher cementitious material contents.

Case Studies

Ozyildririm and Davis investigated bulb-T beams cast with SCC in Virginia and published on the subject in the Transportation Research Record: Journal of the Transportation Research Board *(2,4)*. These papers were of particular interest to ConnDOT researchers because precasters working on ConnDOT projects have been using SCC for a few years, and will likely want to use it for precast/prestressed girders in the near future.

As part of a research project, two prototype 45-inch deep, 60-ft long test beams were cast with SCC and tested to failure at Federal Highway Administration’s (FHWA’s) Turner-Fairbank Highway Research Center. In summary, Ozyildririm and Davis *(4)* indicated "the test beams behaved at least as well as would be expected for normally consolidated concrete beams." In view of that, it was decided to proceed with plans to cast actual bulb-T beams using SCC.

The bulb-T beams were used on a 49-span Route 33 bridge over the Pamunkey River in Virignia. Eight 74-ft long, 45-inch bulb-T beams for one of the spans were cast with SCC. Approximately 14 yd^3 of SCC was required per beam. The beams were outfitted with vibrating wire gauges, Whittemore gauges, and themocouples. Strains and temperatures were monitored. Shrinkage, creep properties, transfer lengths, beam deflections and strand slip have been and/or will be determined.

Ozyildririm and Davis *(4)* concluded "SCC members can be designed by using the same methods, assumptions, and limiting values as used for normally consolidated concrete." They indicated that they were able to attain necessary slump flow without segregation, while achieving sufficient strength and satisfactory permeability. However, they warned that "SCC is sensitive to water content." They reported instances of low slump flow, which resulted in the loss of self-consolidation, and in these instances, mechanical vibration was necessary. They also warned that high slump flows may cause SCC to segregate. Finally, minimal slip between the stands and concrete was measured *(4)*, so the bond between them appeared to be satisfactory.

ACI 237R provides several case studies where SCC was used successfully in North America. For example, one was for a precast Double-Tee application. The case study was for Double-Tees at a parking garage for the Harrisburg International Airport. Fresh concrete properties included: air content of 5.5%, slump flow of 22±2 inches, and unit weight of 148 lb/ft^3. A compressive strength of 4000 psi was achieved in 13 hours, and the 28-day compressive strength was greater than 7200 psi. The case study also included mixture proportions and admixtures used *(1)*.

The Washington State Department of Transportation (WSDOT) and Colorado Department of Transportation (CDOT) both received Federal Highway Administration (FHWA) funding under the Innovative Bridge Research and Construction (IBRC) program to study the use of SCC on actual bridge applications *(5,6)*.

WSDOT used SCC for precast, prestressed girders on the shorter 80-foot span of the Tieton River Bridge, which was completed in 2009. Five 74-inch deep, wide flange girders spaced at 6 ft-9 inches on center were used. The compressive strength requirements were 4500 psi at release of the prestressing strands and 5700 psi at 28 days. They indicated that they increased concentrations of cementitious materials in each batch, including 150 pounds of Class C Fly Ash per cubic yard, and decreased the coarse aggregate content *(5)*.

Compressive strengths for the SCC girders were comparable to the girders cast with conventional concrete, the placement went smoothly, and the finishing work was reduced significantly by the flowability characteristics of the mix. WSDOT officials indicated that the added cost of materials was more than offset by savings in labor due to SCC's flowability *(5)*.

CDOT used SCC for a bridge replacement project on Interstate 25 in Trinidad, CO for cast-in-place retaining walls, abutments, and piers. In 2010, Kiousis and Whitcomb *(6)* documented CDOT's experience in using SCC for these applications.

They concluded that overall the use of SCC in this project was reasonably successful; however, they did note numerous aesthetic problems that owed to the all-around lack of SCC construction experience. The aesthetic problems were patched and/or repaired, and the structural integrity was deemed acceptable. Nevertheless, they warned *(6)*, "an inexperienced contractor can easily make mistakes that may result in unstable concrete that segregates easily, loses its flowability in an untimely manner, and results in unexpected amounts of entrained air."

Workability Test Methods for Mix Design and Quality Assurance

Numerous test methods for assessing the workability characteristics of self-consolidating concrete (SCC) were recently identified in a National Cooperative Highway Research Program (NCHRP) report *(3)* titled "Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements." The workability characteristics of SCC identified included: filling ability, passing ability, filling capacity, and segregation resistance.

According to ACI 237R *(1)*, "The filling ability (unconfined flowabilty) describes the ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight." Filling ability is measured with the slump flow and the T_{50} (ASTM C 1611) test method *(3)*. The test is performed using an inverted slump cone conforming to ASTM C 143 *(7)*. The cone is filled with SCC without any tamping or vibrations, and then lifted allowing the contents to spread. Two diameters of the spread concrete mass are then measured orthogonal to one another and averaged to determine the slump flow *(8)*. T_{50} refers to the time for which it takes the concrete mass to spread 20 inches, which provides a quantitative measure of the flow rate.

The slump flow test is appropriate for both mix design and quality control (QC) purposes *(3)*. Kyayat and Mitchell *(3)* recommended slump flow and T_{50} target values of 23.5 - 29 inches (600-735 mm) and 1.5 - 6 seconds, respectively.

ACI 237R *(1)* refers to the passing ability (confined flowability) as "…the ease with which concrete can pass among various obstacles and narrow spacing in the formwork without blockage." The passing ability is measured with the J-Ring flow (ASTM C 1621) and L-box test methods *(3)*. The procedure for determining the J-Ring flow is identical to that for determining the slump flow, except that a J-Ring is placed concentrically around the slump cone prior to raising it. Once the cone is raised, the concrete must pass through 16-5/8-inch round bars spaced evenly around the J-Ring at 2.36 inches on center. The difference between the slump flow distance (slump spread) and J-Ring flow distance (J-Ring spread) represents the passing ability of the concrete *(9)*.

The L-box test is performed with an L-shaped box with a horizontal and vertical section. A moveable gate and vertical lengths of reinforcing steel are located between the sections. The test is performed by filling the vertical section with SCC and then opening the gate to allow the concrete to flow into the horizontal section. Once the flow has stopped, the height of SCC is measured at the end of the horizontal section and in the vertical section. The height of concrete in the horizontal section (h_2) is divided by the height in the vertical section (h_1). Results are presented in terms of the L-box blocking ratio (h_2/h_1) *(10)*.

J-Ring and L-box tests are also appropriate for both mix design and QC purposes *(3)*. NCHRP Report 628 recommended target values for the J-Ring and L-box tests are

21.5–26 inches and 0.5–1.0, respectively. Passing ability (slump flow – J-Ring flow) target values range from 0–3 inches *(3)*.

ACI 237R *(1)* states "SCC can exhibit high filling capacity if it can achieve the levels of both filling ability and passing ability required to readily fill a predetermined section under the sole action of gravity." The filling capacity is measured with the caisson test *(3)*. An AASHTO designation was not yet assigned when NCHRP Report 628 was published. The name of the proposed AASHTO test is "Recommended Standard Method of Test for Filling Capacity of Self-Consolidating Concrete Using the Caisson Test." *(3)* This test is performed with a 500 x 300 x 150 mm caisson that has 35-16-mm diameter round copper bars fixed horizontally at various heights. SCC is added through a tremie pipe and allowed to flow between the 16-mm bars through to the other side of the caisson. The filling capacity is calculated by measuring the height of concrete at various locations across the width of the caisson *(3)*.

The caisson test is most appropriate for mix design purposes, and recommended target values range from 70% to 100% *(3)*.

Segregation resistance is measured with ASTM Test Method C 1610, "Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique." *(3)* A cylindrical mold is used to perform this test, whereby it is filled with SCC and then separated into three sections. The top and bottom sections are washed on a 4.75-mm sieve in order to determine the mass of coarse aggregate contained in each. The percent of static segregation (S) is calculated from these masses *(11)*.

The column segregation test is most appropriate for mix design purposes. Kyayat and Mitchell recommended target S values of 15% or less.

Another measure of segregation resistance is the visual stability index (VSI). This is visually observed by examining the concrete mass spread during the slump flow test in accordance with ASTM C 1611 *(3)*. The observed concrete mass is compared to reference values which include criteria to assess the stability of the SCC. A VSI value of 0 indicates the concrete is highly stable, a value of 1 indicates it is stable, a value of 2 indicates it is unstable, and a value of 3 indicates it is highly unstable *(8)*.

The VSI is appropriate for both mix design and QC purposes, and recommended target values are 0-1 (0 for deep elements) *(3)*.

The surface settlement test provides another measure of segregation resistance/static stability. An AASHTO designation was not yet assigned when NCHRP Report 628 was published. The name of the proposed AASHTO method is "Recommended Standard Method of Test for Surface Settlement Test to Evaluate Static Stability of Concrete." *(3)* A cylindrical mold is filled with SCC without rodding or vibration, and then a dial gauge or other measuring instrument is used to measure how much the concrete settles over time until reaching a steady state level. The settlement is calculated by measuring the distance between the initial and final height of concrete within the cylinder. The rate of settlement is calculated by measuring how much the concrete settles between 10 and 15 minutes of filling, which provides yet another indication of segregation resistance *(3)*.

The surface settlement test was recommended for mix design purposes. Recommended target values were a function of the maximum size aggregate (MSA): for 3/8 and ½-inch MSA, they were less than or equal to 0.27% per hour; for ¾-inch MSA, they were less than or equal to 0.12% per hour.

A guide for selecting mixture proportions for SCC is provided in ACI 237R *(1)*. It emphasizes that project specifications be reviewed before beginning the process in order to meet target parameters through minimal design iterations. A step-by-step mixture proportioning procedure is included, and a table with examples of successful SCC mixture proportions is provided.

Khayat and Mitchell *(3)* performed a parametric investigation of the materials selection and mix design of SCC. They sought to determine the material constituents, mixture proportions, and fluidity levels to achieve desired SCC properties, specifically for precast, prestressed concrete bridge elements.

They recommended a water to cementitious ratio (*w/cm*) range between 0.34 and 0.40, sand to total aggregate volumes between 0.46 and 0.50, coarse aggregate with ½-inch maximum size aggregate, and Type III cement with 20% Class F fly ash *(3)*.

They compared the Type III cement and 20% Class F fly ash mix to a similar mix with Type III cement and 30% slag. The SCC mix with the Type III cement and 20% Class F fly ash had superior passing ability relative to that for the Type III mix with 30% slag. Accordingly, they selected the Type III cement with 20% Class F fly ash for their experimental evaluation.

CONNDOT PRACTICES

At this time, ConnDOT uses SCC on a limited basis for precast catch basins, manholes, culverts, retaining walls, and barrier curbs. SCC is not being used for prestressed concrete applications, such as for bulb-tee girders, box beams and deck slabs; and, it is not being used for cast-in-place applications.

In 2008, Research staff visited five different precast plants to document SCC practices for ConnDOT products. ConnDOT does not currently have specifications for using SCC, other than what is already required for conventional concrete; however, slump flow tests were witnessed being performed at each plant. No other SCC workability tests, such as the J-Ring test for measuring passing ability, were performed.

Precast concrete mix designs were largely left intact, except for increased quantities of high-range water-reducing admixtures (HRWRA). The mix designs used at the precast plants had slightly higher *w/cm* than what was recommended in NCHRP Report 628 *(3)*. Khayat and Mitchell *(3)* recommended a *w/cm* range of between 0.34 to 0.40 in order to "…obtain the targeted stability, mechanical properties, visco-elastic properties, and durability." Granted, their recommendations were for precast, prestressed bridge element applications, while the mix designs used for ConnDOT applications were for drainage structures, barriers, and other non-prestressed elements. Nevertheless, *w/cm* between 0.41 and 0.43 were observed at some of the plants visited.

One of the plants visited used a Type III cement with 20% fly ash, at a rate of 750 lbs per cubic yard, for their SCC mix. Khayat and Mitchell *(3)* indicated that SCC made with these constituents "...can exhibit better slump flow retention, higher passing ability, and higher filling capacity than SCC made neat with Type I/II cement alone."

This mix design also included the use of a viscosity modifying admixture (VMA), which Khayat and Mitchell *(3)* found to enhance stability and provide homogeneous in-situ properties for SCC made with relatively high *w/cm*. In this instance, the *w/cm* was 0.43, which was relatively high compared to the 0.34 to 0.40 *w/cm* recommended above. The use of VMA in this case may have been beneficial, as they concluded, "use of thickening-type VMA is required for SCC made with moderate and relatively high *w/cm* and low binder content to enhance stability and obtain homogeneous in-situ properties."

There were some differences between how precast plant QC inspectors performed field tests with SCC. Some plants filled air meter measuring bowls in just one layer, screeded off the top without rodding or tapping the sides, and then attached the cover assembly. Other plants filled the measuring bowl in two layers, tapped the sides after filling each layer, screeded off the top, and then attached the cover assembly. The same thing was observed for cylinder molds, where some plants filled them in two layers as compared to a single layer, tapping the sides a couple of times after filling each layer. These differences are probably not very consequential, but uniformity in test methods is desirable.

Instead of performing slump tests, QC inspectors performed slump flow tests in accordance with ASTM C 1611 *(8)*. Target slump flow values varied slightly between plants: 22-28 inches, 21-24 inches, and 22-27 inches. Researchers witnessed a slump flow test performed at each plant visited, and measurements observed ranged between 22½ and 24 inches.

Some bleeding is evident in Figure 1 below, where a sample was collected by dumping SCC into a wheelbarrow from a bucket. This is the same way in which concrete was poured into the forms of catch basin tops that were poured from the same batch and same bucket. This bleeding occurred as a result of the hydraulic pressure caused by dropping the sample from the bucket (pressure head), but the SCC was remixed inside the forms with minimal manipulation with a shovel in order to achieve better uniformity.

FIGURE 1 - Fresh sample of concrete in wheelbarrow and concrete temperature being measured with probe. Note: visible evidence of bleeding.

FIGURE 2 - Measuring bowl for determining air content by the Pressure Method filled, struck off, and prepared to have cover assembly attached.

(a) (b)

(c) (d)

FIGURE 3 - Slump cone (a) inverted and filled, (b) struck off, (c) lifted, and (d) spread measured across two perpendicular axes through the center of material. (ASTM C1611)


05.06.2008

FIGURE 4 - Spread being measured from ASTM C1611. Slight bleeding observed as a sheen on the concrete mass, and segregation is evident in center of mass. VSI value between 1 (stable) and 2 (unstable).


05.06.2008

FIGURE 5 - Catch basin top being poured from large bucket.

FIGURE 6 - Slight remixing and manipulation of SCC with a shovel for catch basin top.

It should be noted that while ConnDOT does not currently specify SCC for prestress applications, ConnDOT has been using conventional concrete with slumps of up to 8 inches for past twenty years or so. These higher-slump concretes have been specified in special provisions.

Higher-slump concretes have been used successfully for ConnDOT's prestressed New England bulb-tee girders, prestressed voided deck slabs, and prestressed box beams. These higher-slump concretes require some internal vibration, but the amount of vibration is greatly reduced by the increased flowability of the mixes. Skilled concrete laborers know to back off on the vibration for more flowable mixes, and increase vibration for stiffer mixes. These concretes do not tend to segregate or bleed.

OTHER STATE HIGHWAY AGENCY PRACTICES

The scope of work for this project originally included performing a state highway agency (SHA) survey to see what was being done nationally with SCC, but before this was done, a Research Advisory Committee (RAC) survey was received by ConnDOT. The RAC survey was performed by the Missouri Department of Transportation (MoDOT) in 2008.

It was determined that the RAC survey addressed the needs of this study, and it was decided that another survey on the subject would only produce a duplication of efforts with little or no additional benefit. The following discussion presents results of the RAC survey. This author gratefully acknowledges MoDOT for their cooperation in making these survey results available for this report. It is anticipated that MoDOT will publish these results in the near future.

The survey results indicated that twenty two (22) SHAs plus British Columbia out of 25 respondents were already using or considering using SCC in 2008. At least sixteen SHAs were using SCC for precast applications, and three (3) states responded that they allowed SCC for prestress concrete applications. Six SHAs indicated that they already had used SCC for cast-in-place applications.

Three of the SHAs described a certain learning curve associated with using SCC. The Colorado Department of Transportation (CDOT) stated that "the main problems associated with SCC are related with lack of experience and familiarity of the contractors." The Iowa Department of Transportation (Iowa DOT) described "learning curve issues such as making sure that forms are properly sealed." Finally, the West Virginia Department of Transportation (WV DOT) noted: "it seems that there is a learning curve that these fabricators go through with regards to their mix and the use of SCC."

CDOT identified issues associated with maintaining "flowability" of SCC with temperature. They responded that "SCC drops its flowability very quickly in temperatures above 75 or 80 degrees." This resulted in scenarios in which trucks arrived with SCC at 25 inches of slump flow, but by the time the truck was empty, the slump flow was only 18 inches or less. Not surprisingly, the Florida Department of Transportation (FDOT) experienced similar issues with their heat, as they indicated the SCC "did not stay fluid as long as it was supposed to."

The New York State Department of Transportation (NYSDOT) emphasized that "the key in any application is maintaining a constant head during placing." They experienced problems with substructure pours when this was not done. Of course, changes in flowability can only exacerbate difficulties in maintaining a constant head.

Pennsylvania Department of Transportation (PennDOT) noted issues with negative draft conditions, such as the top of the bottom flange of girders, which required cosmetic repairs. However, it should be noted that these types of negative draft areas have historically been problematic in Connecticut and elsewhere, as ConnDOT precast inspectors have also witnessed these types of cosmetic issues with conventional concrete.

A number of states identified problems with segregation. The Texas Department of Transportation (TxDOT) witnessed segregation and bleeding, while the Wisconsin Department of Transportation (WisDOT) noted “fabricators have had trouble with maintaining adequate batch to batch consistency during large girder pours.” WisDOT continued, “A slightly wet batch comes along and the aggregate totally separates from the paste during the pouring process.” The Maine Department of Transportation (MaineDOT) indicated “a few of the plants have had difficulty controlling the spread and segregation of the mix.”

Some SHAs experienced issues with moisture in the aggregates. The British Columbia Ministry of Transportation required strict QC on the moisture content and aggregate gradation in order to meet specifications, and the New Hampshire Department of Transportation (NHDOT) recommended that batch plants measure moisture more often than for conventional concrete.

Several SHAs that responded to the survey indicated that their SCC design parameters were not different than their conventional concrete parameters. This included ConnDOT. FDOT and PennDOT also responded that requirements are the same for SCC and conventional concrete. CDOT stated, “our prestressed fabricators have used SCC in their precast products, but do not use any different design parameters as far as we know.”

SUMMARY

SCC usage continues to expand in North America. Many SHAs already permit their precast concrete producers to use SCC for their products, some have permitted its use in prestressed applications, and a few have already permitted its use for cast-in-place concrete construction.

Certainly, contractors have had problems with SCC, but many of these problems are due to a lack of experience and familiarity. There is a learning curve to deal with, but nothing that can’t be overcome.

ConnDOT Division of Materials Testing (DMT) personnel are commended for recognizing changes in the concrete industry. With the advent of high-range water-reducing admixtures, concrete producers have been able to attain required design parameters with SCC. As such, during the past ten years or so precast concrete producers have used SCC for concrete products with success. Moreover, precast concrete plants have been successfully making concrete products with slumps of up to 8 inches for ConnDOT for about twenty years now.

Research staff visited five different precast plants during this study. They witnessed plant QC inspectors perform tests for concrete temperature, air content by the pressure method, and witnessed them making concrete test specimens. QC inspectors also performed slump flow tests in accordance with ASTM C 1611; however, no further workability tests were performed. Finally, research staff reviewed a few of the SCC mix designs.

RECOMMENDATIONS

NCHRP Report 628 “Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements” was recently published in 2009, following the initiation of this ConnDOT study. This provides ConnDOT with a well-designed research reference that was prepared through a coordinated program of cooperative Research. NCHRP guidelines for “the selection of constituent materials, proportioning of concrete mixtures, testing methods, fresh and hardened concrete properties, production and QC issues, and other aspects of SCC” should ideally be followed for further SCC implementation; however, at a minimum the following are recommended:

- ConnDOT should require a more rigorous SCC mix design and acceptance process. The process should incorporate the use of workability tests on trial batches prepared by precast plants as part of their QC plan. Each mix design should be required to meet specified test results for filling ability, passing ability, filling capacity, static stability, and air volume. NCHRP Report 628 provides target values for these tests, which are tabulated in Appendix A. Perhaps these target values should be specified initially until proven that other values are more appropriate.
- In addition to the slump flow tests, at a minimum, ConnDOT should require precast plant inspectors to perform the following tests for QC purposes:

  - VSI (which is simply an observation of the mass of concrete from the slump flow test).
  - T_{50} (can be performed simultaneously with slump flow using a second operator *(4)*)
  - J-Ring flow (ASTM 1621).

It is recommended, that at this time, ConnDOT's SCC specification continue to be limited to precast concrete applications not involving any prestressed elements. Once the above recommendations are implemented for these precast applications, ConnDOT should begin to move forward with specifying SCC for prestressed applications, and for cast-in-place concrete construction.

Once ConnDOT personnel are comfortable with these additional requirements, pilot projects for precast/prestressed bridge elements should be performed. Likewise, pilot projects for SCC cast-in-place construction should be selected, which will present a number of new challenges, such as transport time and extreme weather conditions, especially hot weather that will cause a rapid loss of self-consolidation properties.

REFERENCES

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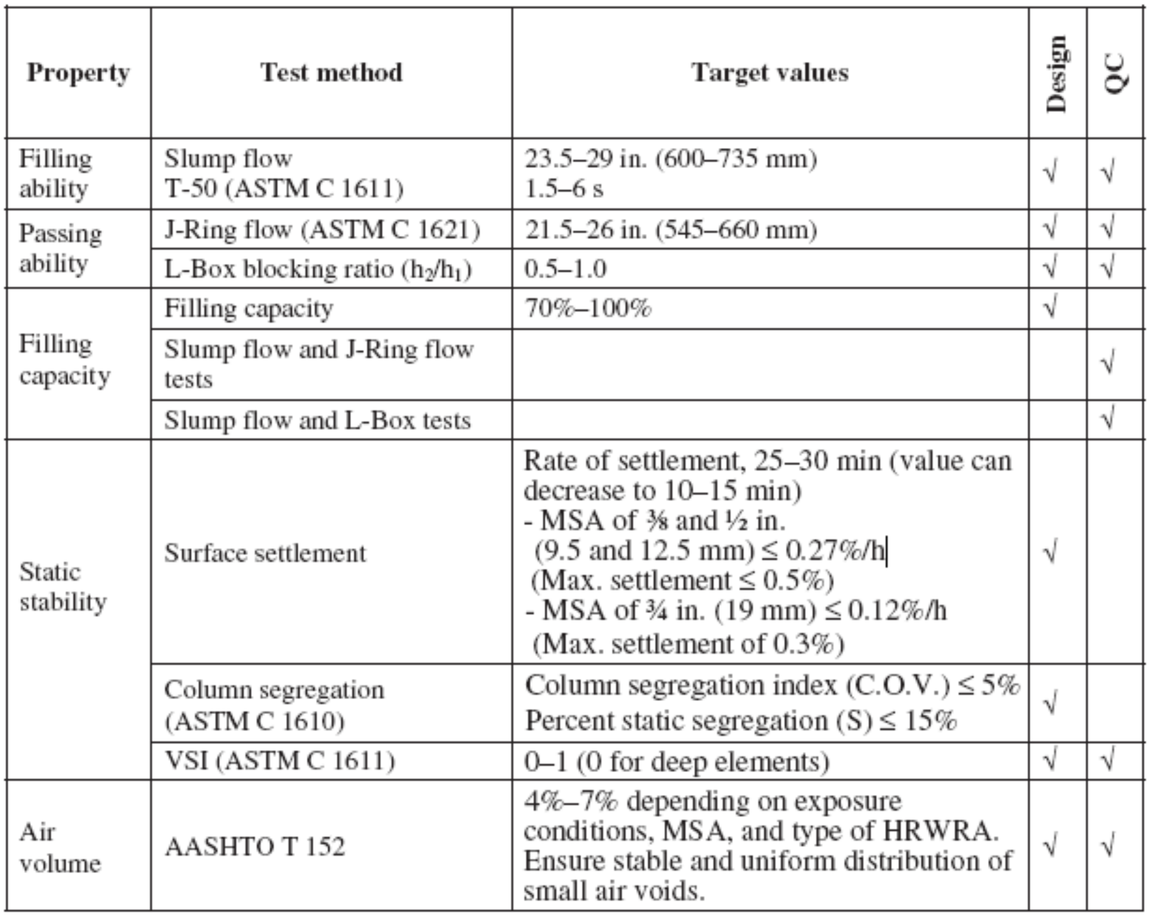
7. ASTM C 143/C 143M, *Standard Test Method for Slump of Hydraulic Cement Concrete*.
8. ASTM C 1611/C 1611M-05, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*.
9. ASTM C 1621/C 1621M-06, *Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring*.
10. ACI 237R-07, Emerging Technology Series, *Self-Consolidating Concrete*, Reported by ACI Committee 237.
11. ASTM C 1610/C 1610M-06a, *Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique*.

APPENDIX A

TABLE A-1 Target Values for Workability Tests from NCHRP Report 628



Property	Test method	Target values	Design	QC
Filling ability	Slump flow T-50 (ASTM C 1611)	23.5–29 in. (600–735 mm) 1.5–6 s	√	√
Passing ability	J-Ring flow (ASTM C 1621)	21.5–26 in. (545–660 mm)	√	√
	L-Box blocking ratio (h_2/h_1)	0.5–1.0	√	√
Filling capacity	Filling capacity	70%–100%	√	
	Slump flow and J-Ring flow tests			√
	Slump flow and L-Box tests			√
Static stability	Surface settlement	Rate of settlement, 25–30 min (value can decrease to 10–15 min) - MSA of ⅜ and ½ in. (9.5 and 12.5 mm) ≤ 0.27%/h (Max. settlement ≤ 0.5%) - MSA of ¾ in. (19 mm) ≤ 0.12%/h (Max. settlement of 0.3%)	√	
	Column segregation (ASTM C 1610)	Column segregation index (C.O.V.) ≤ 5% Percent static segregation (S) ≤ 15%	√	
	VSI (ASTM C 1611)	0–1 (0 for deep elements)	√	√
Air volume	AASHTO T 152	4%–7% depending on exposure conditions, MSA, and type of HRWRA. Ensure stable and uniform distribution of small air voids.	√	√