Development of a Guide for Cast-in-Place Applications of Self-Consolidating Concrete

Nebraska Department of Roads (NDOR)

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1. Introduction

1.1. Definition of SCC

According to the American Concrete Institute (ACI) Committee 237, Self-Consolidating Concrete (SCC) is defined as "a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation". Another definition is given by the European Guidelines of SCC " SCC is a concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction".

Based on these definitions, it is concluded that the three basic properties of SCC are:

a. Filling ability: The ability of SCC to flow and fill completely all spaces within the formwork under its own weight.

b. Passing ability: The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation and/or blocking.

c. Segregation resistance (stability): The ability of SCC to remain homogeneous in composition during the transport and placing.

Although the placement of concrete without vibration has been there for a long time as in underwater concrete, mass concrete, and shaft concrete, these applications generally result in a low strength concrete that has consistency problems. SCC, on the other hand, is a high-performance concrete that has higher density, consistency, strength, durability and finishing quality than conventional concrete. SCC also achieves full compaction without any vibration even in areas of complex formwork and congested reinforcement. These advantages result in significant reduction in construction time, noise pollution, and substantial savings in labor cost especially in placing, curing, and finishing tasks. In

addition, the flowability and cohesiveness of the SCC allows pumping concrete at above average rates, for longer distances, and from higher elevations without segregation problems.

1.2. History of SCC

SCC was first developed by researchers at the University of Tokyo, Japan, in the late 1980's. Since the early 1990's, SCC has been increasingly produced and applied to several bridge and tunnel construction projects in Japan. Examples are the construction of the anchorages of the Akashi-Kaikyo bridge (i.e. the longest suspension bridge in the world), and the construction of the heavily reinforced piers of the Ritto bridge.

In Europe, SCC has been applied to a large number of infrastructure projects since the mid 1990's, such as the Sodra Lanken project, the largest infrastructure project in Sweden. This project included the construction of four lane freeway, junction bridges, retaining walls, and tunnels. In 1996, several European countries formed the first consortium on developing SCC for practical applications, which resulted in a large project titled "Rational Production and Improved Working Environment through using Self-compacting Concrete."

In the United States, SCC has been gaining much interest since the late 1990's especially in the precast concrete industry due to the significant reduction of the noise level in plants, shortened production cycle, and improved product quality. The 1st North America Conference on the Design and Use of SCC was held in Illinois in 2002 to examine all the aspects of this emerging technology. In 2004, the National Cooperative Highway Research Program (NCHRP) has funded a research project (NCHRP 18-12) titled "Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements". This project aims to develop guidelines for using SCC in precast, prestressed concrete bridges and recommend relevant changes to AASHTO LRFD bridge design and construction specifications.

Nebraska is considered a national leader in the application of SCC to precast prestressed concrete bridges. Over the last ten years, NDOR has supported the

development and application of precast prestressed girders (NU girders) and full-depth deck panels (NU deck), shown in Figure 1, using SCC. Concrete manufacturers in Omaha and Lincoln have gained extensive experience in working with SCC to efficiently produce high quality and innovative products that are nationally pronounced. However, this experience is limited to precast concrete that are developed in a controlled environment (i.e. in plant) and using a limited number of mix designs. The cast-in-place application of SCC is more sophisticated due to the exceptional sensitivity of SCC to factors such as, water/cement ratio, placing temperature, delivery time, and admixtures content (SCC sometimes called hypersensitive concrete); and its special in-site quality control / quality assurance procedures.

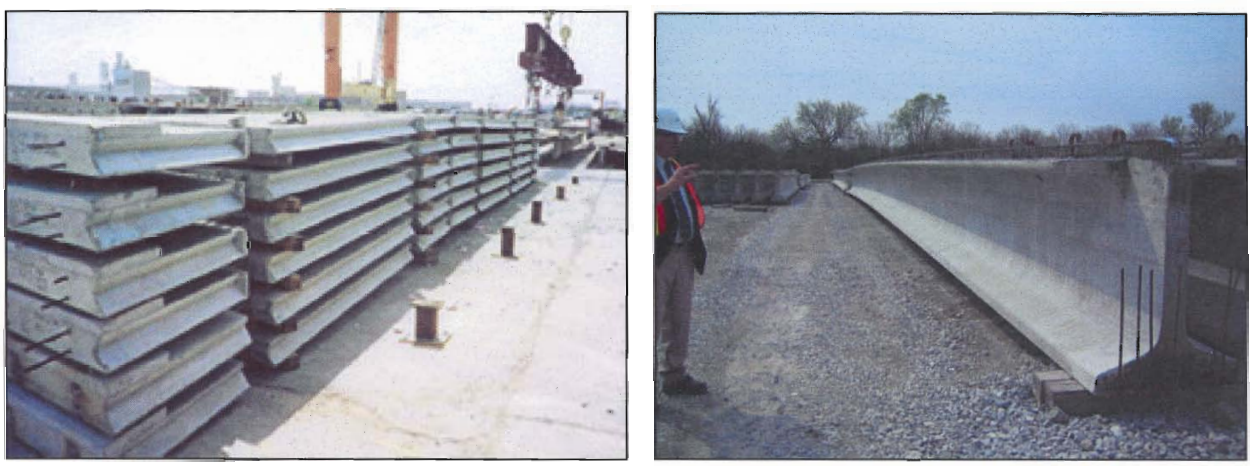

Figure 1. Precast NU deck and NU girder manufactured in Nebraska using SCC

1.3. Problem Statement

Several challenging questions arise when the fresh SCC is delivered to the site for cast-in-place applications. Examples of these questions are:

1. What are the tests need to be carried out to verify the quality of fresh SCC in site before casting? And what are the acceptable ranges of test results?
2. What is the acceptable range of delivery time for SCC? And what actions should be taken if this range is violated?

3. What is the acceptable range of placing temperature for SCC? And what actions should be taken is this range is violated?
4. What is the maximum distance for pumping SCC and the maximum casting elevation that maintains the basic SCC properties?

1.4. Research Objectives

The main objective of the proposed research project was to develop a practical guide for the cast-in-place application of SCC in Nebraska. This guide will provide NDOR engineers and contractors with a better understanding of the behavior of fresh SCC when used on site for cast-in-place applications. The research project will focus on the applications that are most needed for special NDOR projects, such as threaded rod bridge deck connections. The specific objectives of this research project were:

1. Design a SCC mix that satisfies the special requirements of NDOR in terms of material type, water-cement ratio, air content, and 28-day compressive strength.
2. Develop practical procedures for testing fresh SCC on site to determine its key properties. These procedures have to be economically and technically feasible when performed at various site conditions. Also, these procedures have to provide the quality control engineer with immediate results that can be easily interpreted to assist in making accept/reject/treat decisions in a timely fashion.
3. Investigate the impact of the delivery time on the properties of fresh SCC. This investigation will determine whether SCC can be used given the distance from the construction site to the ready-mix plant. The possible actions that can be taken if the delivery truck is delayed or concrete placing is deferred will be determined.
4. Investigate the impact of the temperature on the properties of fresh SCC. This investigation will also determine the range of temperature that is acceptable for the given application. Also, the actions that should be taken when the temperature is outside the acceptable range will be recommended.
5. Investigate the impact of pumping the SCC for long distances and pouring it from significant heights on the segregation resistance of the mix.

2. Testing Methods of SCC

Several test methods have been developed to evaluate the three basic properties of SCC. Table 1 categorizes these methods according to the measured property and presents those methods adopted in this project in bold.

Table 1. Test methods for SCC

Property	Testing Method
Filling ability (flow ability)	**Slump-flow by Abrams cone** **T_{50cm} slump flow** **V-funnel** Oriment test **L-box** U-box
Passing ability	**J-ring** **L-box** U-box Fill-box
Segregation resistance (static stability)	Column method technique **V-funnel at $T_{5minutes}$** GTM screen stability test **Visual Stability Index**

Currently, there are only three ASTM standards that specify methods for testing the properties of fresh SCC:

- ASTM C1611/C1611M-05 "Standard Test Method for Slump Flow of Self-Consolidating Concrete"
- ASTM C1621/C1621M-06 "Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring"
- ASTM C1610/C1610M-06 "Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Method Technique"

There is also an ASTM standard for the admixtures used in producing flowing concrete, ASTM C1017/C1017M-03 "Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete". In addition, almost all the ASTM standard test methods for fresh and hardened conventional concrete are applicable to SCC with the exception of the slump test and compaction requirements during specimen preparation for

compressive strength testing (no rodding is needed). The following subsections present all the test methods adopted in this project for fresh and hardened SCC in more details.

2.1. Slump-Flow Test

The purpose of slump-flow test is to determine the flowability and segregation resistance of fresh SCC. The testing equipment consists of the standard slump cone (i.e. Abram's cone) and the flow table shown in Figure 2. A 20 in (50 cm) diameter circle is marked on the flow table and the cone is placed in its center either the normal orientation or inverted (i.e. small opening down). After the cone is filled with concrete, it is raised in 3±1 seconds to a height of 9±3 in allowing the fluid concrete to flow freely on the table. The following parameters are measured:

- Time after which concrete spread circle diameter reaches 20 in (50 cm) (T_{50cm})
- Final spread of the flowing concrete (average of the largest diameter and the diameter in the perpendicular direction)
- Visual Stability Index (VSI)

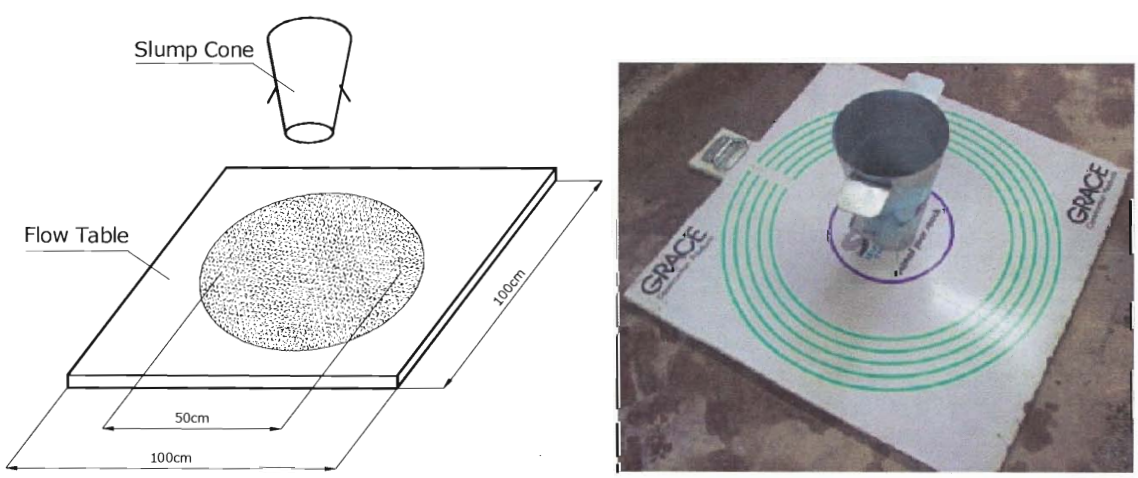

Figure 2. Slump Flow Test Apparatus

Depending on the slump flow, concrete has a higher or more limited capability to fill up formwork under its own weight. There is no generally accepted rule which defines clearly the flow ability requirements. However, according to the literature, an acceptable

total spread of SCC is between 22 and 30 in (560 and 760 mm). The time corresponding to the spread of 20 in (500 mm) should be between 2 and 5 seconds. Lower time indicates a better flowability of SCC. Visual stability index obtained from this test is discussed in the following subsection.

2.2. Visual Stability Index

The purpose of the visual stability index (VSI) test is to determine segregation resistance or/and static stability of fresh self-consolidating concrete. Fresh concrete is rated based on visual inspection of the slump flow patty immediately after it stops flowing. The appearance of the patty is then compared to pictures and descriptions of the surface bleed, mortar halo, and aggregate distribution. The VSI ranks the stability of the SCC on a scale between 0 and 3, as described in details in Table 2 and shown in Figures 3 to 6.

Table 2. Visual Stability Index

Visual Stability Index	Description of quality of SCC
0	High-quality SCC with no indication of segregation or separation. Very good aggregate distribution and materials carried to the outer edge of the slump flow.
1	High-quality SCC, mix is starting to exhibit a mortar halo and possibly some bleed water/separation. This is an acceptable SCC mixture. Good aggregate distribution, although a little more mortar is present at the outer edges of the slump flow.
2	Mix is exhibiting more mix separation, a more pronounced mortar halo, and uneven distribution of aggregate. Qualified QC personnel should evaluate this mix further before acceptance or rejections. Retest from another sample. Evaluate the application as to whether this mix should be used. VSI of #2 indicates marginal or borderline quality. A corrective action should be taken on batches that follow to correct this situation.
3	SCC mix showing all the signs of segregation, separation, bleeding, and instability. Reject this mix. A corrective action should be taken immediately on a following batch.

Figure 3. Visual Stability Index = 0 (Acceptable)

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FINAL REPORT

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16. Abstract

The State of Nebraska is one of the national leaders in the application of self-consolidating concrete (SCC) in the precast industry. The main advantages of SCC over conventional concrete are: its ability to fill complex formwork with hard to reach corners, ability to pass through rebar congested areas, and resistance to segregation with no need for mechanical vibration. There is a great need in Nebraska for using SCC in special cast-in-place applications, such as threaded rod bridge deck connections. However, the on-site application of SCC has special requirements that differ from those of precast applications and need to be satisfied to ensure the concrete quality.

The objective of this research project is to develop a practical guide for cast-in-place applications of the self-consolidating concrete. The major focus of this guide is to identify SCC mix design, mixing procedures, field testing methods, and troubleshooting steps. The SCC mix is developed using local materials (cement and class F fly ash (1PF), 47B sand and gravel, and ½" limestone) and admixtures currently available in the Nebraska market. Several trial mixes are developed and tested at the University of Nebraska Laboratories to establish the proper mixing procedures and acceptance criteria for testing fresh and hardened SCC properties. Two full-scale field tests are performed to evaluate the impact of the delivery time, concrete temperature, and pouring method on the basic SCC properties. A guide that summarizes the outcomes of the research project is prepared to be used by concrete contractors and quality assurance personals.

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ABSTRACT

The State of Nebraska is one of the national leaders in the application of self-consolidating concrete (SCC) in the precast industry. The main advantages of SCC over conventional concrete are: its ability to fill complex formwork with hard to reach corners, ability to pass through rebar congested areas, and resistance to segregation with no need for mechanical vibration. There is a great need in Nebraska for using SCC in special cast-in-place applications, such as threaded rod bridge deck connections, etc. However, the on-site application of SCC has special requirements that differ from those of precast applications and need to be satisfied to ensure the concrete quality.

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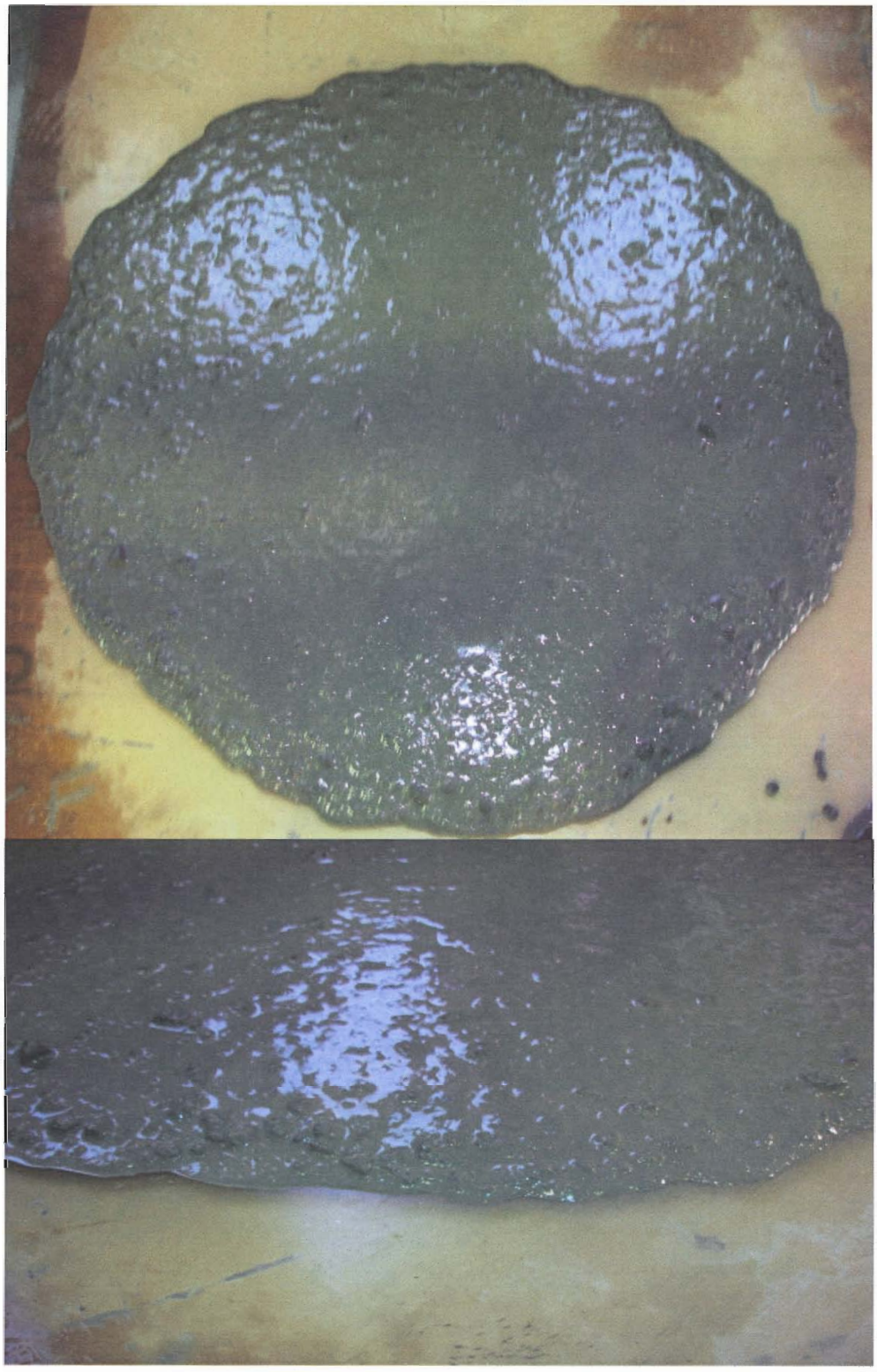


Figure 4. Visual Stability Index = 1 (Acceptable)

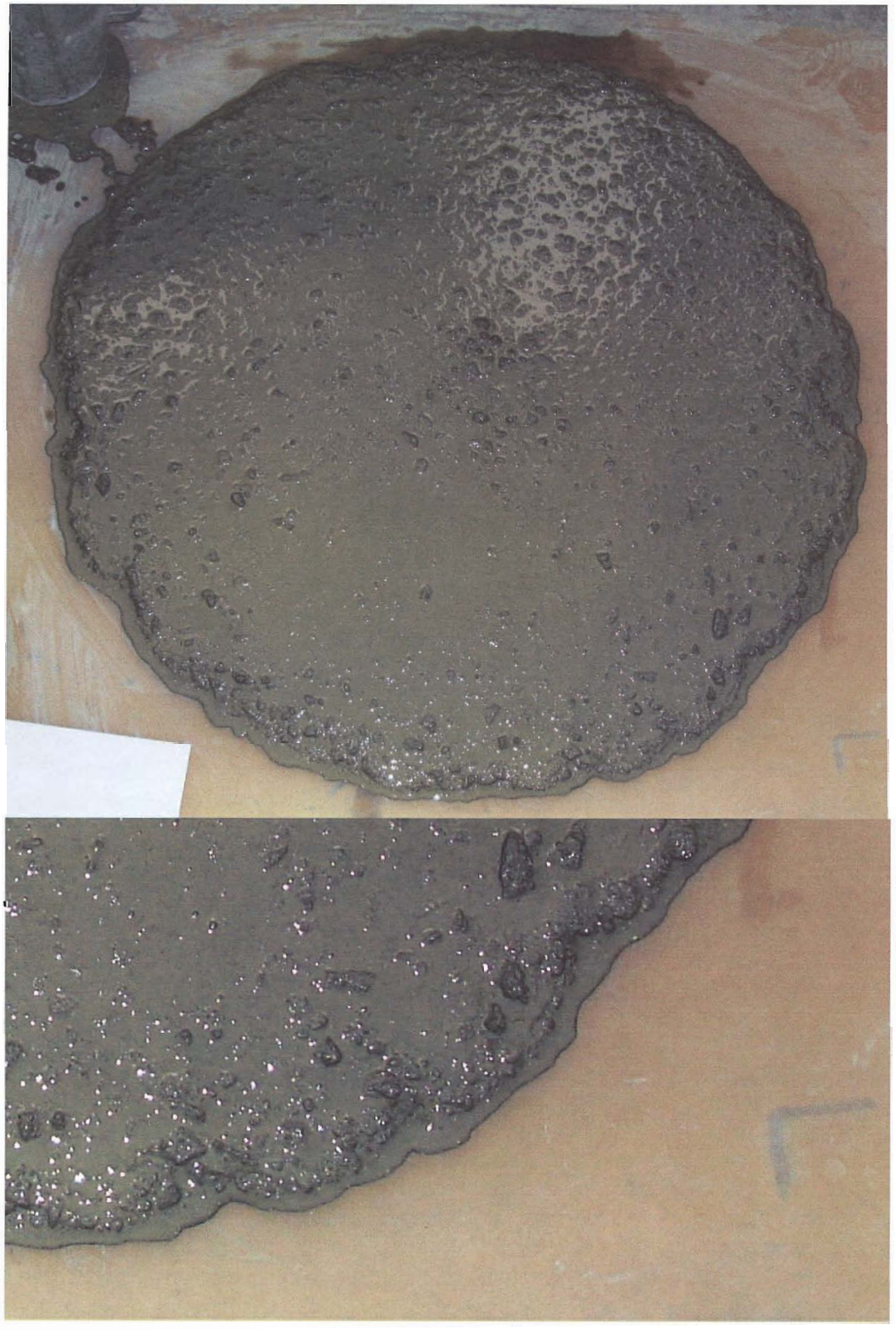


Figure 5. Visual Stability Index = 2 (Not Acceptable)

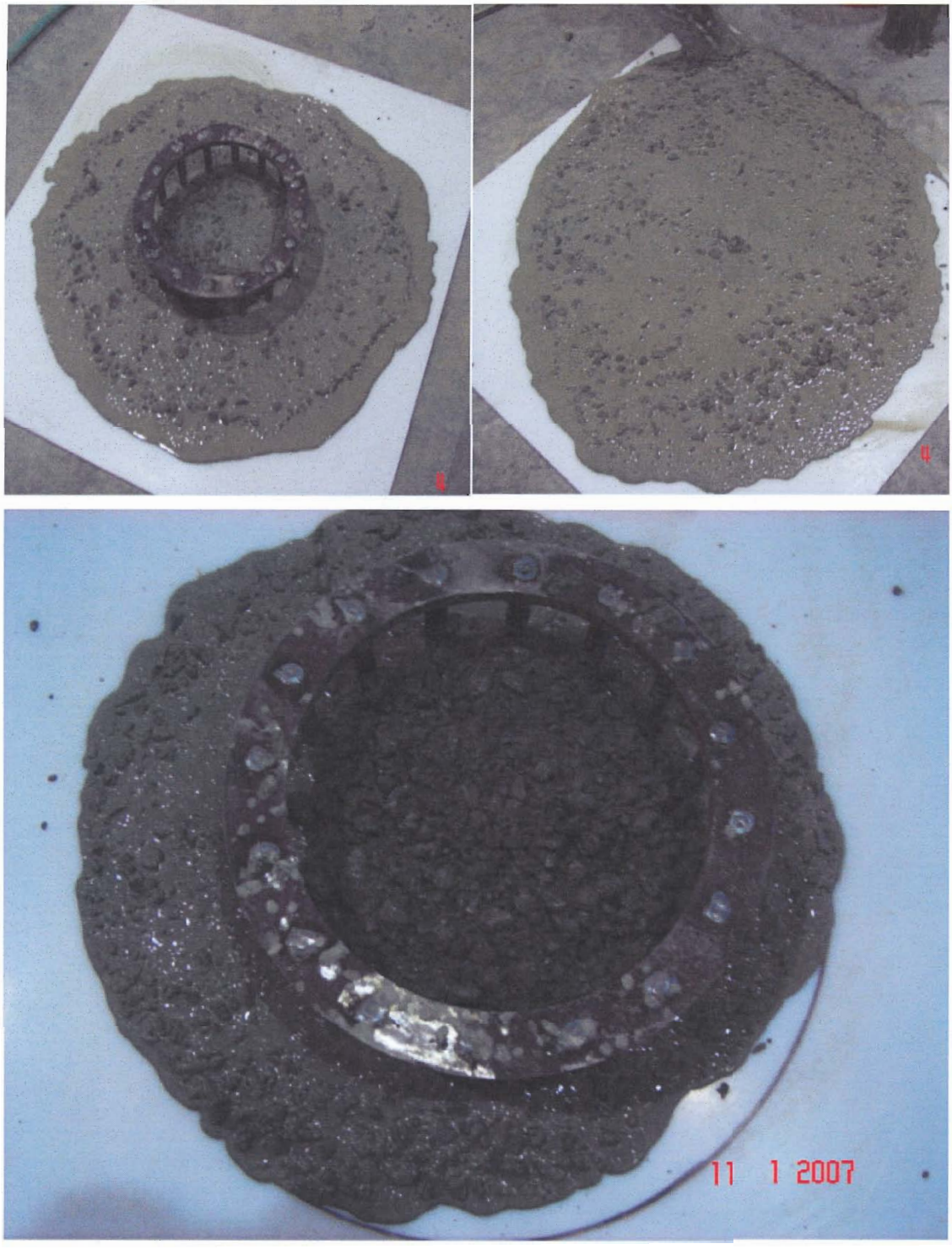
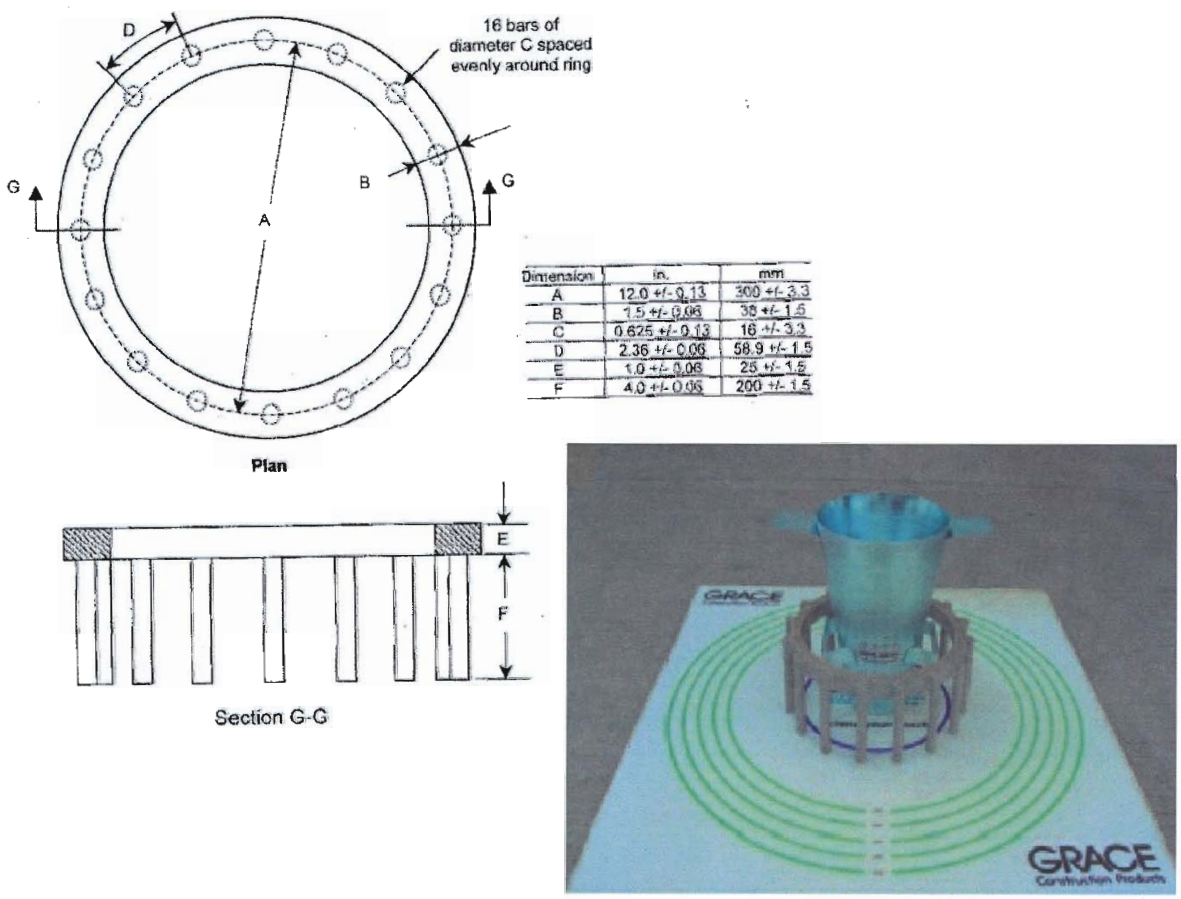


Figure 6. Visual Stability Index = 3 (Not Acceptable)

2.3. J-ring Test

The purpose of the J-ring test is to determine the passing ability of fresh SCC. Also, the flowability and stability of SCC can be determined using this test. This test is limited to concrete with the maximum aggregate size of 1 in (25 mm). The equipment includes an open steel ring welded to the supporting reinforcing bars. According to the ASTM C1621M-06, the diameter of the ring is 12 in (300 mm), the height is 4 in (100 mm), the thickness is 1 in (25 mm), and the bars are 16 #5 as shown in Figure 7. The same flow table and slump cone of the slump flow test are used in this test. The SCC flows through the reinforcing bars of the J-ring and onto the flow table. The average spread of the slump flow patty is measured to provide the J-ring flow. Two tests, slump flow and J-ring, should be completed within 6 minutes. Differences in the spread of concrete on the flow table indicate level of passing ability of SCC as shown in Table 3. In general, it is assumed that differences less than 1 in (25 mm) represent good passing ability of SCC.



Dimension	in.	mm
A	12.0 +/- 0.13	300 +/- 3.3
B	1.5 +/- 0.06	38 +/- 1.5
C	0.625 +/- 0.13	16 +/- 3.3
D	2.36 +/- 0.06	58.9 +/- 1.5
E	1.0 +/- 0.06	25 +/- 1.5
F	4.0 +/- 0.06	200 +/- 1.5

Figure 7. J-ring Test Apparatus

Table 3. J-ring Test – ASTM requirements for SCC

Passing ability	Difference in Flows	Blocking Assessments
Good	0 – 1 in.	No visible blocking
Medium	1 – 2 in.	Minimal or moderate blocking
Poor	Above 2 in.	Noticeable to extreme blocking

2.4. L-box Test

The purpose of the L-box test is to determine passing and filling ability of SCC. This test is limited to concrete with maximum aggregate sizes of 1 in (25 mm). The equipment includes L-shaped box that is shown in Figure 8. This test is similar to the J-ring test as it assesses the passing ability of concrete through a rebar cage. The L-box consists of vertical and horizontal parts of rectangular sections 6 x 8 in. (150 x 200 mm) which are separated by a movable gate. The vertical leg of the L-box is filled with concrete (gate is closed) and after 1 minute the sliding gate is opened so concrete can flow out into the horizontal leg of the L-box. Concrete passes through a layer of reinforcing bars at the location of the gate. Three measurements are taken during this test:

- Time at which concrete reaches half of the length of the horizontal leg of the L-box (T_{20})
- Time at which concrete reached the end of the horizontal leg of the L-box (T_{40})
- At the end of flow, when concrete stops, the depth of concrete at gate (H_1) and the depth of concrete at the front wall of L-box (H_2)

Acceptable value of the so-called blocking ratio, H_2/H_1, is between 0.80 – 0.85. Perfect SCC has a blocking ratio equal to 1. In addition, both blocking and stability can be detected visually. If concrete builds up behind the bars, it is either having passing problem or segregated.

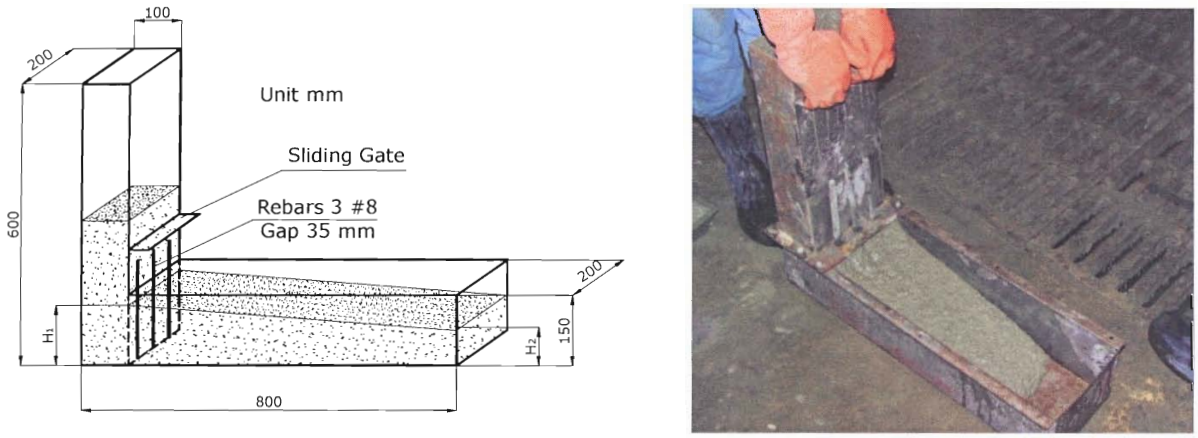


Figure 8. L-box Test Apparatus

2.5. V-funnel test

The purpose of V-funnel test is to determine passing ability and segregation resistance of fresh SCC. The equipment is shown in Figure 9. The V-funnel is filled with SCC (around 3.5 gallons or 12 liters) and it stabilizes for around 1 minute. Then, the gate at the bottom of the funnel is opened, time measurement starts, and concrete flows out through the gate. The time concrete flows out is recorded (flow-time). If during this flow any blocking leading to stoppage of flow or temporary stops occurs, this should be noted. The procedure can be repeated (filling the funnel and flow concrete) with the same SCC mix, to check the segregation resistance. V-funnel at 5 minutes is another version of the same test. Apparatus is filled with concrete and left for 5 minutes to settle. Segregation at the top of concrete funnel is visually inspected.

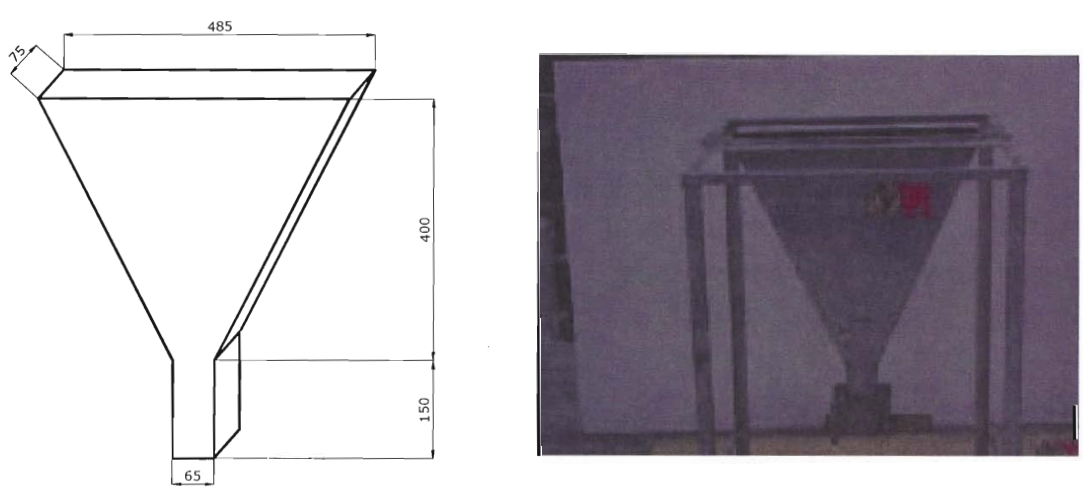


Figure 9. V-funnel Apparatus

This test measures the ease of flow of SCC through small sections. Shorter flow time indicates better flowability and passing ability of SCC. A flow time of 6 to 12 seconds is considered appropriate. After 5 minutes of settling concrete in the funnel, the segregation of concrete will be indicated by a less continuous flow, stops of flow and blockings, which leads to an increase in flow time.

2.6. Air Content in Fresh SCC – Pressure Method

The air content in fresh concrete affects its workability, cohesiveness, and segregation resistance. It also affects the properties of the hardened concrete such as compressive strength and resistance to freezing and thawing. There are several methods to measure air content in fresh concrete: Pressure Method - ASTM C231, Volumetric Method - ASTM C173, Gravimetric Method - ASTM C138. In this study the Pressure Method was used. In this method, the air content of freshly mixed concrete is determined from observation of the change in volume of concrete with the change in pressure. The test determines the air content excluding any air that may exist in voids within aggregate particles. Therefore, this method is applicable only for concretes made with relatively dense aggregate particles. Additionally, the aggregate correction factor considering density and inside air must be determined. The test device, Pressure Air Meter Type B, is shown in Figure 10. The air meter is made of corrosion resistant aluminum alloy with a heavy duty pump and built in pressure gauge. The base has a volume of 0.25 cubic feet (7000 cubic cm) and can also be used for unit weight measurements.

Figure 10. Pressure Air Content Meter, Type B

The determination of air content in freshly mixed concrete consists of two separate measurements to determine: (1) aggregate correction factor, and (2) nominal air content in freshly mixed concrete. Based on the results of these measurements, the air content in concrete is obtained as follows:

$$A_s = A_1 - G$$

Where A is the air content of the sample in percentage, A_1 is the nominal air content in percentage, and G is the aggregate correction factor in percentage. Both the nominal air content and aggregate correction factor are determined from the scale on the apparatus. The measured air content represents the free and not closed-in voids air, which has direct influence on workability properties of freshly mixed concrete.

2.7. Air Content in Hardened SCC – Modified Point Count Method

According to ASTM C 457, the microscopical determinations of the air content in hardened concrete can be performed using two procedures: (1) linear traverse, and (2) modified point-count. Based on the data collected using any of these procedures, the following parameters are calculated.

- **Void frequency (symbolized in ASTM C 457 by n):** It is the number of voids per unit length of traverse. The void frequency is required in the calculation of the average chord in the modified point-count method.
- **Average chord length (symbolized in ASTM C 457 by l):** It is the length of the sum of the chords of the air voids divided by the number of voids encountered in the traverse.
- **Specific surface (symbolized in ASTM C 457 by α):** It is the surface area of the average void divided by the volume of the average void. It is calculated from the average chord. The higher values (higher void surface area per void internal volume) indicate smaller voids. Small voids (with a shorter average chord) are desirable because they disperse throughout the concrete with small unprotected volumes of paste in between. If the same air-void content was present in larger voids, the unprotected volumes of paste would be much larger.

- **Spacing factor (ASTM C 457):** It is calculated from the specific surface, the percentage of air voids, and the percentage of paste that must be protected. It is expressed as a decimal value of the measurement unit. The spacing factor is a theoretical measure of the average distance water or expansive force must travel before it contacts an air void (i.e., half the average distance between air voids).

The major parameters of the air-void system are interdependent. Most concrete require only that the air-void content be within particular limits. Recently, the trend toward performance-related specifications has introduced the requirement that the spacing factor be below a particular limit or the specific surface be above a particular limit. Although one-sided limits on the spacing factor or specific surface do not preclude air-void contents that are too high, compressive strength requirements serve as a limit on excessive air.

2.8. Compressive Strength Test

Compressive strength of SCC is determined using the standard test method in accordance to the ASTM Standard Specifications C 39. In this project, SCC is molded in cylinders of dimensions of 8 x 4 inches (depth x diameter) prepared and cured in accordance with ASTM Specifications C 192 with the exception of compaction requirements (no rodding). The test is performed by applying a compressive axial load to a specimen (along the side surface of the cylinder) at a rate within the prescribed range until failure as shown in Figure 11. The compressive strength is then calculated by dividing the maximum applied load at failure, by cross-section area of the specimen.

Figure 11. Compressive Strength Test

3. SCC Mix Design

Due to the required properties of SCC in its fresh state, the SCC mix has to be designed differently from conventional concrete. These properties can be achieved by using high powder content, Viscosity Modifying Agents (VMA), or combination of both. In addition, SCC mixes usually require the use of smaller aggregate size and higher dosage of superplasticizers than conventional concrete mixes. Powder type SCC is very popular in Europe because of the availability of blended cement with desired powder contents. In this type, viscosity is improved by using high percentage of fillers such as fly ash, glass filler, limestone powder, silica fume and quartzite filler. In North America, the VMA type of SCC is most popular due to the unavailability of preblended cement. Table 4 lists the recommended dosage of SCC ingredients.

Table 4. Recommended Dosage of Ingredients for the SCC

Components	Recommendations
Cement	21.8 – 28.1 lb/ft^3
Powder, cement, mineral fillers, finest fraction of aggregates < No. 100	24.9 – 37.4 lb/ft^3
Sand fractions No.100 to No.4	> 40 % of volume of cement mortar > 50 % of volume of cement paste
Coarse aggregate > No. 4, max 3/4 in	28 – 35 % of volume of concrete
Water	4.0 – 5.7 lb/ft^3
Mineral fillers, fly ash, granulated slag, quartz powder or calcareous powder and micro-silica	30 – 40 % mass of cement, even up to 60 %
Superplasticizers	According to producer recommendations, usually in a range of 0.2 – 3.0 % mass of cement
Water-cement ratio	0.2 - 0.6 with special recommendation < 0.45
Water- powder ratio	Volumetric ratio 0.8 – 1.1

3.1. Examples of SCC Mix Designs

Below are tables that show examples of SCC mix designs used in Japan, Europe, and North America.

Table 5. Examples of SCC Mixes in Japan

Ingredients	Mix J1 (Powder type)	Mix J2 (VMA Type)	Mix J3 (Combination Type)
Coarse Aggregate	1327	1388	1469
Fine Aggregate, lb	1263	1463	1181
Cement, lb	891	370	502
Fly Ash, lb	118	0	346
Silica Fume, lb	0	0	0
Ground Granulated Blast Furnace Slag, lb	0	484	0
Water, lb	294	278	294
HRWR, lb	15.29	7.65	17.6
VMA, lb	0	6.88	0.15
Slump Flow test Spread, in	24.6	23.6	23.6

Mix proportions are for 1 yd^3 of concrete

Table 6. Examples of SCC Mixes in Europe

Ingredients	Mix E1 (Powder type)	Mix E2 (VMA Type)	Mix E3 (Combination Type)
Coarse Aggregate	1261	1261	1261
Fine Aggregate, lb	1455	1463	1177
Cement, lb	471	555	521
Fly Ash, lb	0	0	320
Limestone Powder, lb	412	0	0
Silica Fume, lb			
Ground Granulated Blast Furnace Slag, lb	0	226	0
Water, lb	320	323	336
HRWR, lb	7.03	9.94	10.93
VMA, lb	0	0	12.46
Slump Flow test Spread, in	23.6 - 29.5	23.6 - 29.5	23.6 - 29.5

Mix proportions are for 1 yd^3 of concrete

Table 7. Examples of SCC Mixes in the United States

Ingredients	Mix U1 (Powder type)	Mix U2 (VMA Type)	Mix U3 (Combination Type)
Coarse Aggregate	1038	1153	1504
Fine Aggregate, lb	1773	1578	1711
Cement, lb	688	602	701
Fly Ash, lb	76	0	0
Silica Fume, lb	0	0	0
Slag, lb	0	201	0
Water, lb	293	303	260
HRWR, ml	1602	2500	2616
VMA, lb	0	0	542
Slump Flow Spread, in	28	26	24

Mix proportions are for 1 yd^3 of concrete

3.2. NDOR Requirements for SCC Mix Design

The scope of this study is to develop SCC for special applications in bridge construction in Nebraska. Therefore, the SCC mix is designed based on the following requirements specified by NDOR:

1. 28-day compressive strength not less than 6 ksi
2. Entrained air content 4-6 %
3. Water/powder ratio equal to 0.37
4. Use of local aggregates (47B sand and gravel for fine aggregate, and limestone for coarse aggregate)
5. Nominal aggregate size ½ in (minimum bar spacing and clear concrete cover ¾ in.)
6. Cement type 1PF that has approximately 25% of fly ash type F pre-blended with cement type I/II (Fly ash type C cannot be used).

3.3. Laboratory Tests

3.3.1. Aggregate Gradation

Figures 12 and 13 show the gradation tables and curves for the samples of fine and coarse aggregates obtained from ready mix producers. These samples were used by the research team in Omaha and Lincoln to develop SCC mixes for laboratory testing.

Table 8. Coarse Aggregate (Limestone ½ in nominal size) Gradation

Sieve No.	Sieve Size (mm)	Weight Retained (lb)	Percentage Retained	Cumulative % Retained	Cumulative % Passing
3/4"	19	0.00	0.0%	0.0%	100.0%
1/2"	12.5	4.08	25.5%	25.5%	74.5%
3/8"	9.5	4.21	26.3%	51.8%	48.2%
#4	4.75	6.17	38.6%	90.4%	9.6%
#8	2.36	0.94	5.9%	96.3%	3.7%
#16	1.18	0.10	0.6%	96.9%	3.1%
#30	0.6	0.05	0.3%	97.2%	2.8%
#50	0.3	0.03	0.2%	97.4%	2.6%
#100	0.15	0.02	0.1%	97.5%	2.5%
Pan		0.4	2.5%	100.0%	0.0%
Total		16.00			

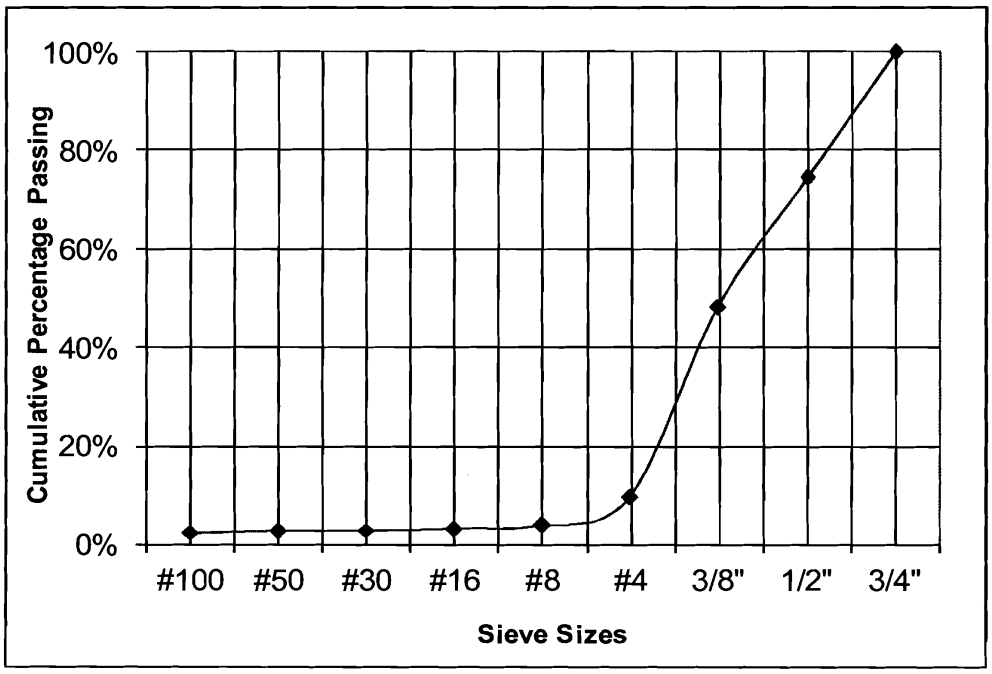


Figure 12. Coarse Aggregate (Limestone ½ in nominal size) Gradation

Table 9. Fine Aggregate (47B Sand and Gravel) Gradation

Sieve No.	Sieve Size (mm)	Weight Retained (lb)	Percentage Retained	Cumulative % Retained	Cumulative % Passing
3/4"	19	0.00	0.0%	0.0%	100.0%
1/2"	12.5	0.05	0.6%	0.6%	99.4%
3/8"	9.5	0.10	1.3%	1.9%	98.1%
#4	4.75	0.85	10.6%	12.5%	87.5%
#8	2.36	1.63	20.4%	32.9%	67.1%
#16	1.18	1.60	20.0%	52.9%	47.1%
#30	0.6	1.45	18.1%	71.0%	29.0%
#50	0.3	1.60	20.0%	91.0%	9.0%
#100	0.15	0.66	8.3%	99.3%	0.8%
Pan		0.06	0.8%	100.0%	0.0%
Total		8.00	FM	3.62	

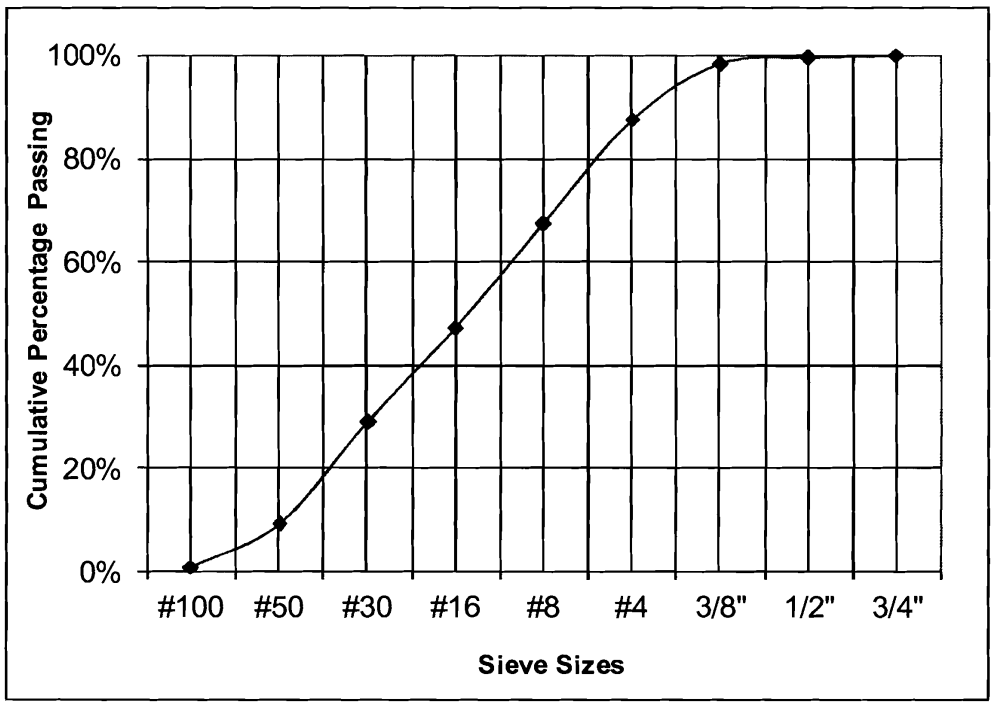


Figure 13. Fine Aggregate (47B Sand and Gravel) Gradation

3.3.2. Mortar Tests

Mortar tests were performed to evaluate the impact of different types of high range water reducer (HRWR) and viscosity modifying agents (VMA) on the flowability of the

mix at different times. Slump flow tests were performed using the mortar cone shown in Figure 14. The cone height is 2.9 in and upper and lower diameters are 1.6 in and 3.5 in respectively. The cone is used on a flow table that is 10 in diameter (ASTM C230).

Figure 14. Mortar Slump Flow Test Apparatus

Two HRWR admixtures commonly used in Nebraska were evaluated in terms of the initial flowability and slump flow retention. The two admixtures are Glenium 3030 and Glenium 3400 that are products of BASF Corporation. The composition of the mortar was kept constant at all times with water-cement ratio equals to 0.37 and sand content equals to 58% by volume of mortar. Figures 15 and 16 demonstrate slump flow retention curves for different quantities of Glenium 3030 and Glenium 3400. The quantities of admixtures are given as a percentage of the cementious material by weight. These figures indicate that the higher the dosage of HRWR, the higher the flowability and the longer the flow retention time. Comparing figures 15 and 16 indicates that Glenium 3400 has a stronger effect on the initial flowability than Glenium 3030. This means it requires a smaller dosage of Glenium 3400 than Glenium 3030 to achieve the same flowability.

Viscosity modifying agents (VMA) are used to improve stability of the mix, and reduce bleeding and segregation. The impact of the VMA Rheomac 362 on slump flow is shown in Figure 17. This figure indicates that even small amounts of VMA significantly reduce the flowability and shorten the flow retention time. However, the addition of VMA substantially improves segregation resistance and stability of the SCC.

Higher dosages of HRWR may be needed when VMA is used to maintain the proper flowability and its retention time.

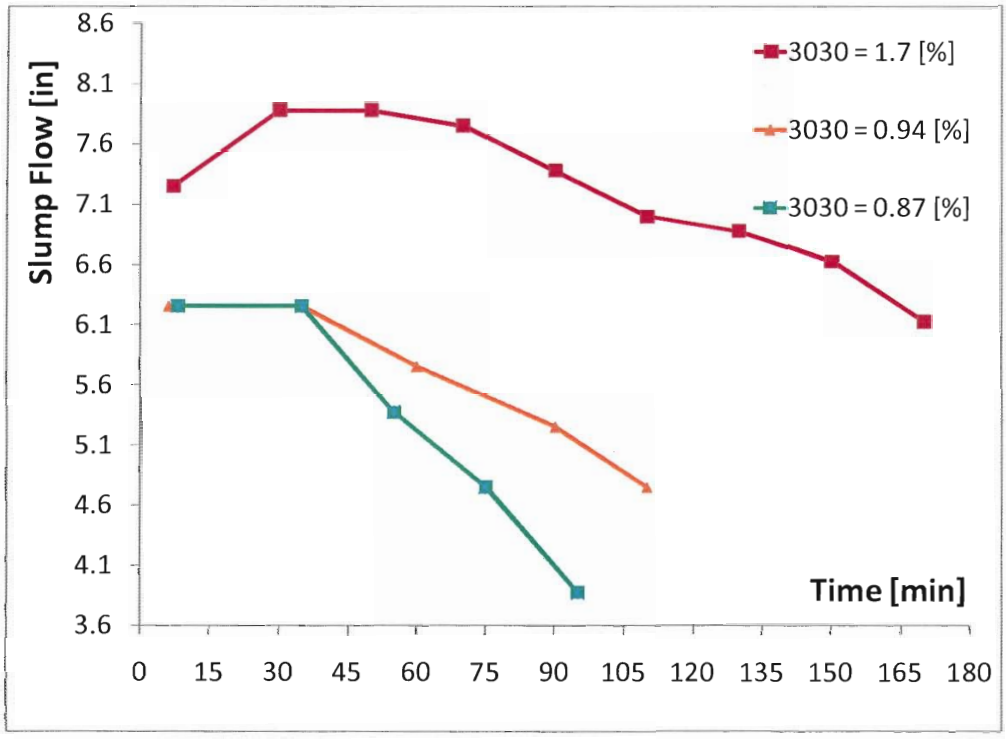


Figure 15. Slump Flow Retention Curves for Different Dosages of Glenium 3030

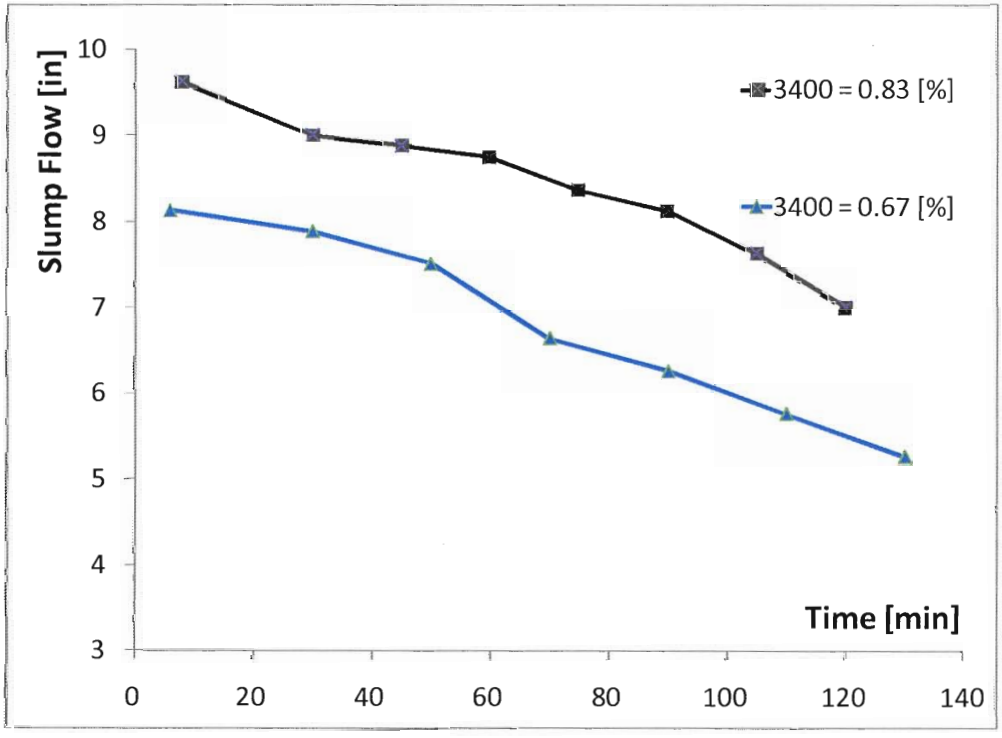


Figure 16. Slump Flow Retention Curves for Different Dosages of Glenium 3400

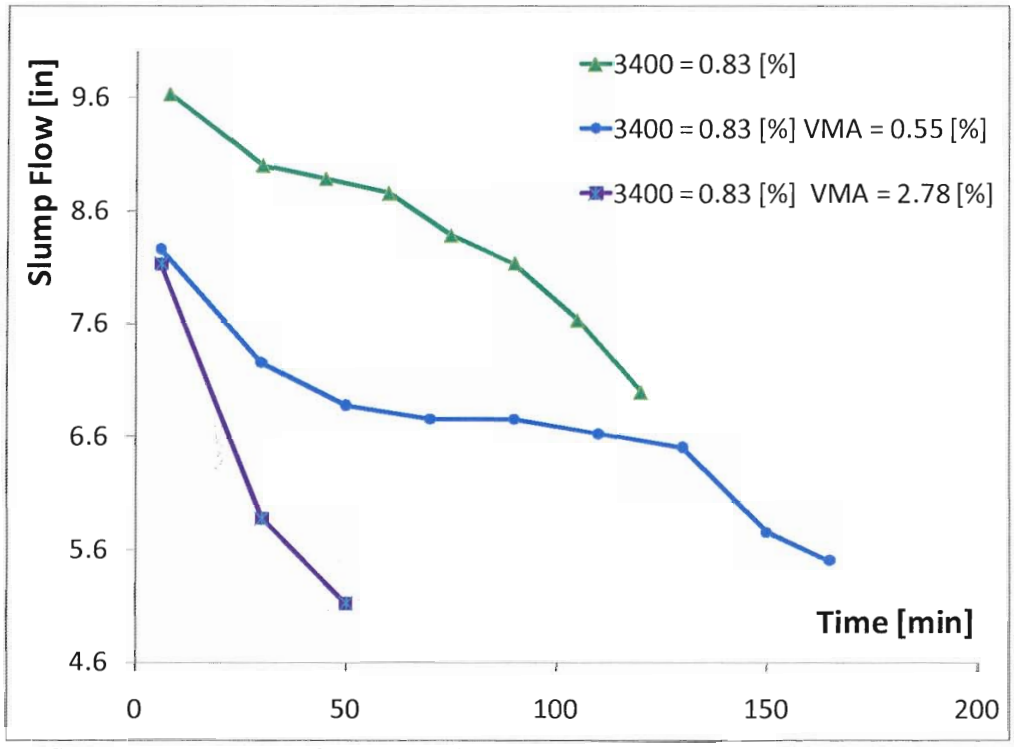


Figure 17. Slump Flow Retention Curves for Different Dosages of Rheomac VMA 362 for Mortar with HRWR Glenium 3400.

3.3.3. SCC Tests

Several SCC mixes were developed and tested at the UNL Structural Laboratory in Lincoln and Omaha campuses. The objective of this investigation is to determine the dosage of HRWR, Retarder, AEA, and VMA that result in a SCC mix with adequate flowability, passing ability, and segregation resistance for at least 90 mins from the time of adding the water to the mix. In addition, the mix is required to satisfy the NDOR requirements listed in section 3.2 in terms of air content and compressive strength. In order to evaluate the impact of these admixtures on the key properties of fresh SCC, the proportions of other components were kept constant as follows:

- 1PF Cement = 810 lb/cy
- 47B Sand and Gravel = 2088 lb/cy
- ½" Limestone, nominal size = 702 lb/cy
- Water/Powder ratio = 0.37

Also, mixing procedures and testing methods were kept constant throughout the investigation to provide a fair comparison and consistent results. Figure 18 shows the mixing procedures followed in mixing 0.0556 cu yd of SCC using a 0.111 cu yd drum mixer. It was also decided that the Slump Flow test with the Visual Stability Index and J-ring test are adequate for evaluating the SCC properties. This is because the information obtained from other tests, such as V-funnel and L-box tests, was found to be redundant and always matching the results of Slump Flow, VSI, and J-ring tests. In addition, V-funnel and L-box tests are not user friendly for daily applications in construction sites.

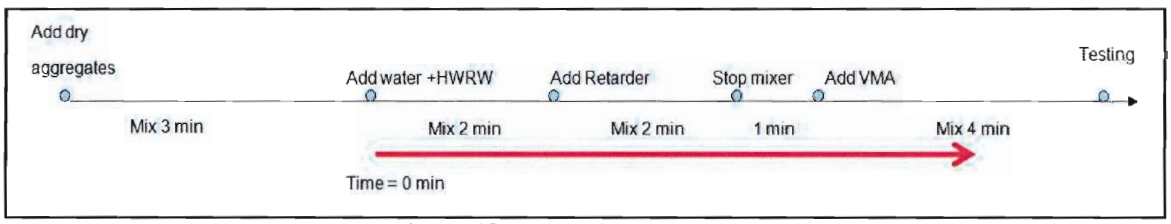


Figure 18. Mixing Procedures.

The first group of mixes were developed using the HRWR Glenium 3400 and VMA Rheomac 362 without any retarders or air entrainment admixtures. The goal was to determine the right dosage of HRWR and VMA that results in a flowable non-segregated mix. Figure 19 shows the slump flow of a mix that has 6.3 lb/cy of Glenium 3400 and 2.7 lb.cy of Rheomac 362. The average spread of this mix after 15 mins was 25 in and T_{50} was 2.5 sec. However, the mix lost its flowability after 30 min as shown in Figure 20.

Figure 19. Slump Flow of SCC after 15 mins

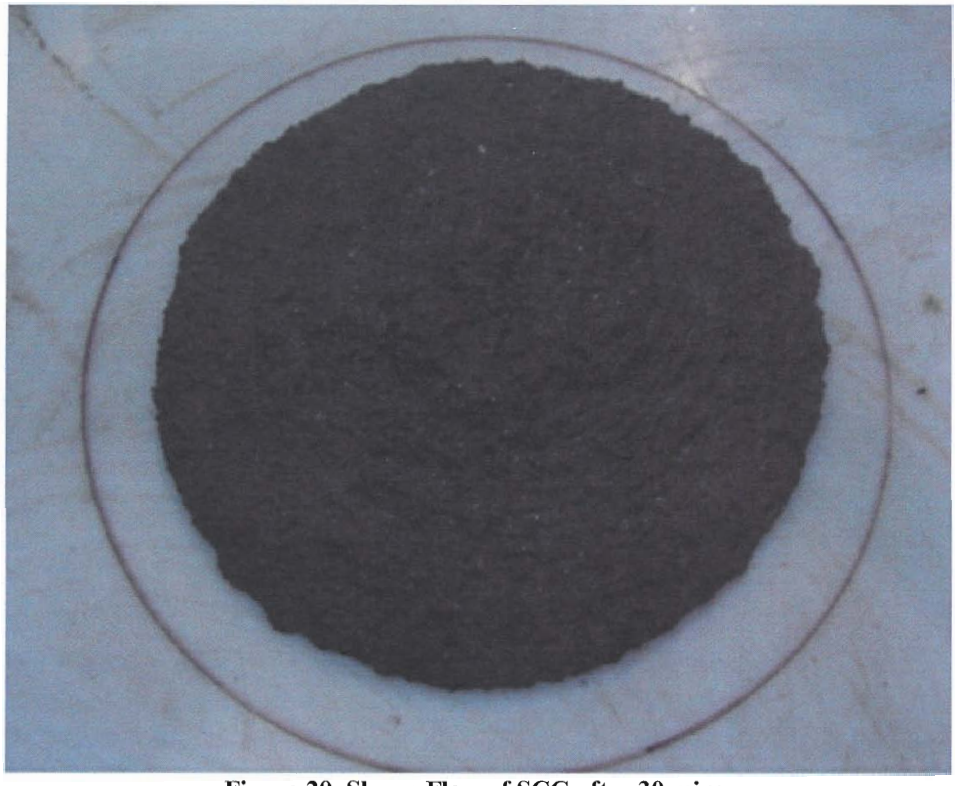


Figure 20. Slump Flow of SCC after 30 mins

More mixes were tried with different amounts of HRWR and VMA, but none of them had adequate flowability for more than 45 mins. Therefore, it was decided to add retarders to the mix to improve its flowability over a longer duration. Figure 21 shows slump flow retention curves for different dosages of the retarder Pozzolith 300R and constant dosage of HRWR and VMA. This figure indicates a significant increase in the flowability retention with the addition of retarder (5.9 lb/cy). The figure also indicates that excessive amount of retarder (11.7 lb/cy) does not improve the flowability retention for more than 75 mins. This means the addition of retarder can improve the flowability retention up to a certain time, then, another dosage of HRWR has to be added to maintain the flowability for a longer period.

Figures 22 (a) and (b) show the effect of another retarder (Delvo Stabilizer) on the flowability retention. The retarder was added to different quantities of HRWR and VMA and demonstrated the same effect as it works partially as a water reducer, and as a retarder that delays the setting time up to a certain limit.

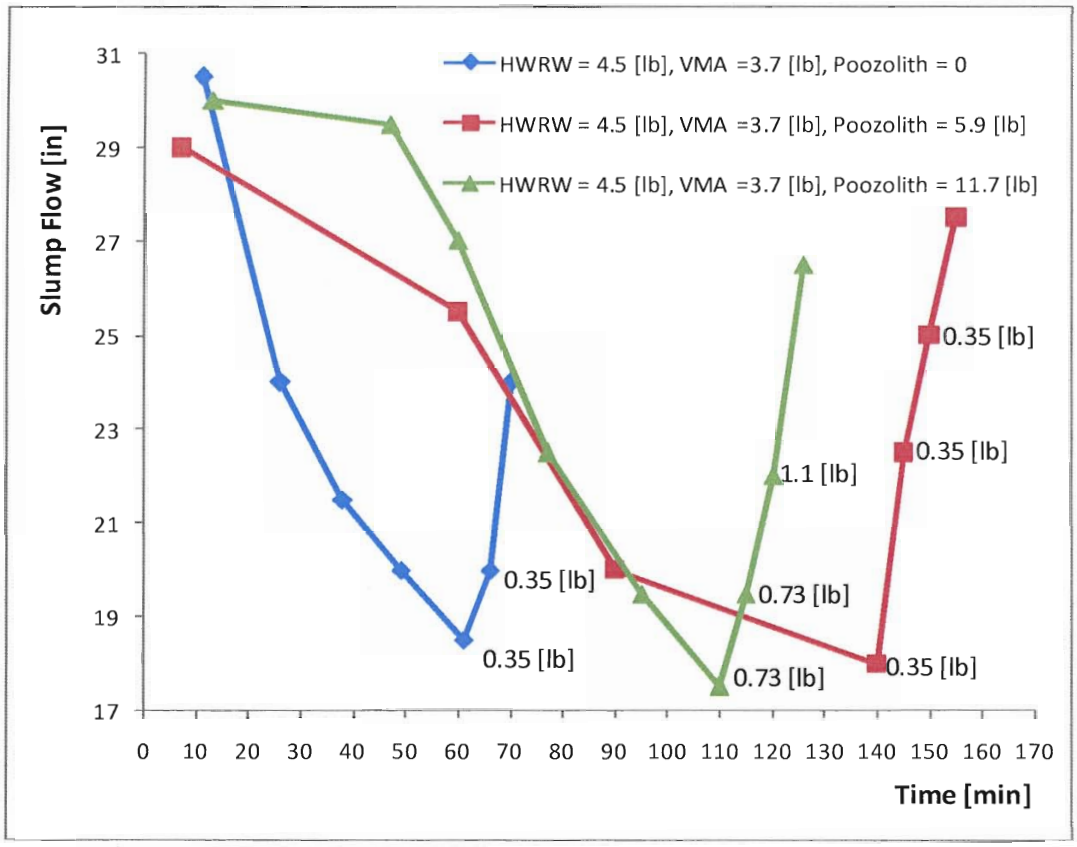
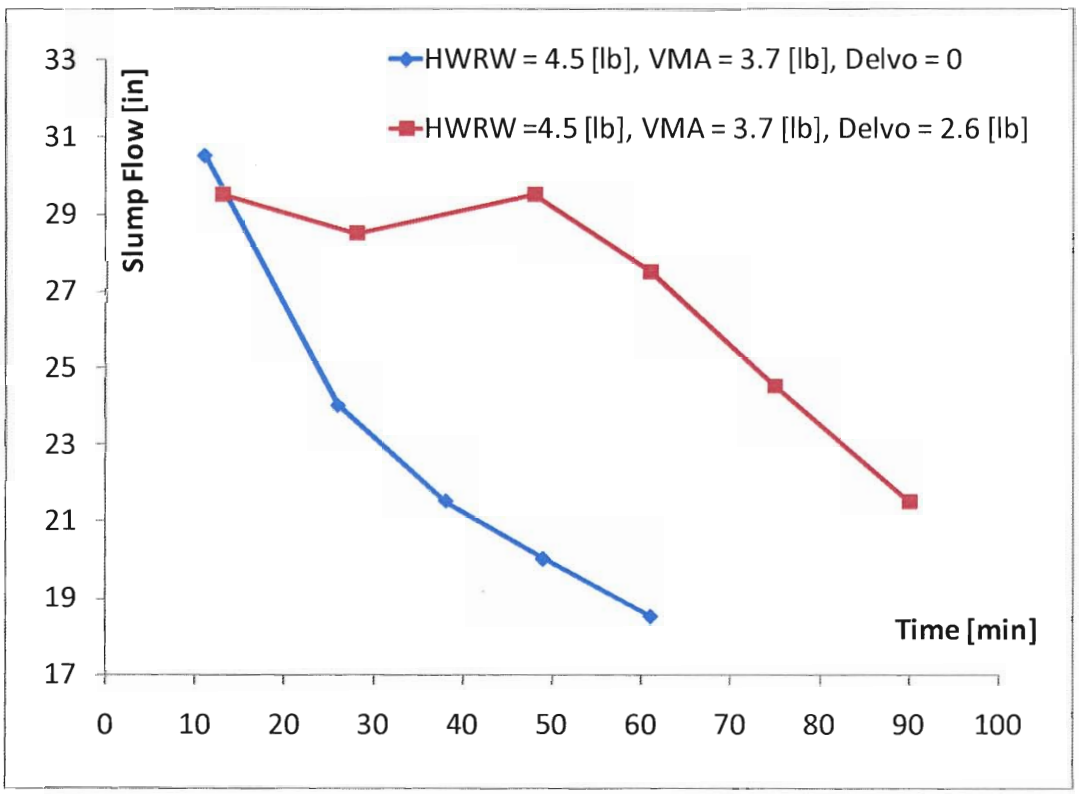
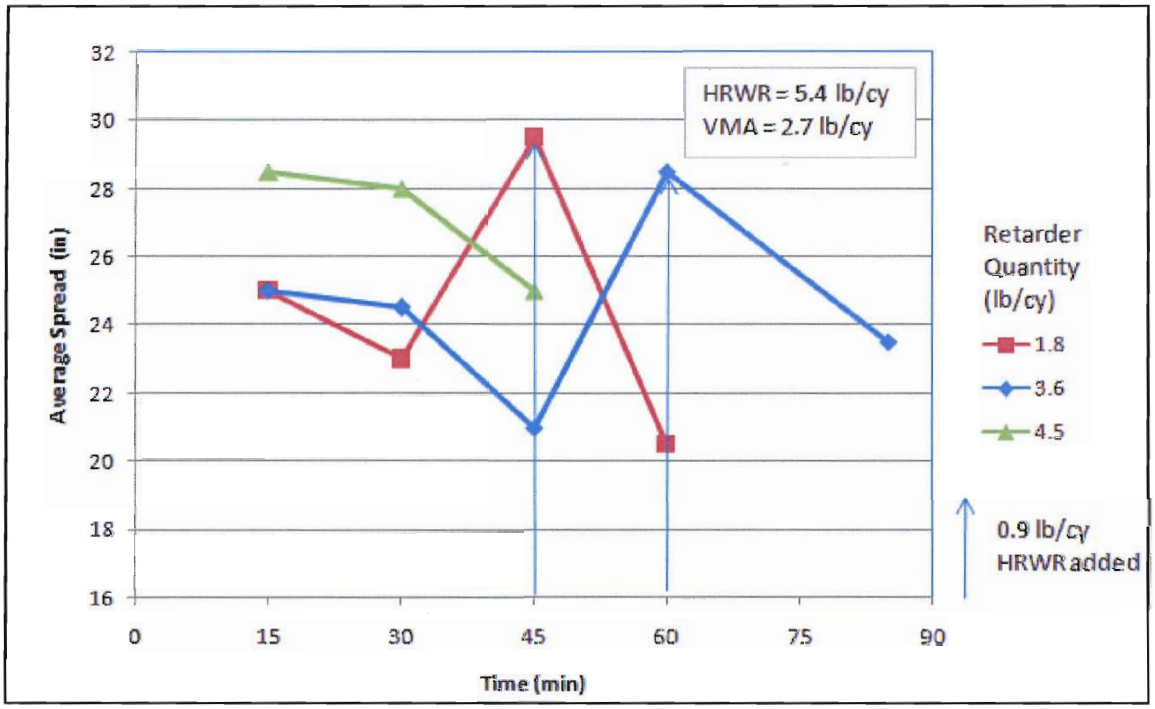


Figure 21. Effect of the Retarder Pozzolith 300R on the SCC Flowability



(a)



(b)

Figure 22. Effect of the Retarder Delvo Stabilizer on the SCC Flowability

On the other hand, adding retarders has an adverse effect on the early strength of the hardened concrete. Figure 23 shows the SCC strength development with time for different amounts of retarder. It clearly demonstrates that Pozzolith 300R significantly delay the setting, and therefore, reduce the early strength.

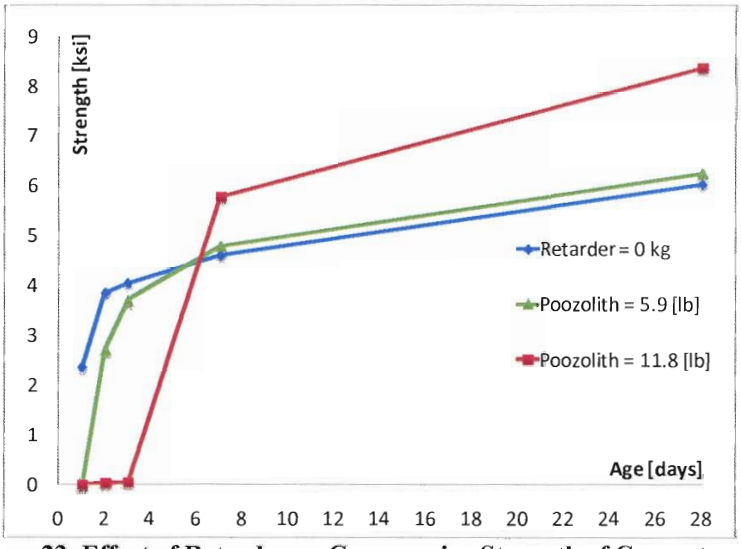


Figure 23. Effect of Retarder on Compressive Strength of Concrete

In order to determine the amount of air entrainment admixture (AEA) that satisfies NDOR requirement (i.e. air content 4%-6%), three mixes were made with different amounts of AEA (Pav-Air 90). The Pressure method (ASTM 231) was used to determine the air content in the fresh concrete for each mix. Figure 24 shows the three samples of hardened concrete that correspond to each mix and the cores extracted from each sample. The Modified Point-Count Method (ASTM C457) was used to determine the percentage of entrained air, percentage of entrapped air, and space factor for different AEA dosages.

Figure 24. SCC Samples Used for Air Content Measurements

Figure 25 shows the results of the Pressure Method and Modified Point-Count Method performed on three SCC samples with different AEA dosages. This figure indicates a significant increase in both entrained and entrapped air content with the addition of AEA. It also shows a relatively good agreement between the results of the Pressure Method and Modified Point-Count Method. Therefore, the Pressure Method, due to its simplicity, is recommended for the on-site measurement of the air content.

Table 10. Air Content in Hardened Concrete

Measured Parameter	Air Entrainment Admixture Content		
	0.0 lb/cy	0.2 lb/cy	0.4 lb/cy
Air Entrained %	0.654	5.77	12.292
Air Entraped %	0.353	0.687	2.068
Total Air %	1.007	6.457	14.36
Pressure Method Readings	N/A	8%	16%
Spacing Factor	0.2	0.03	0.01

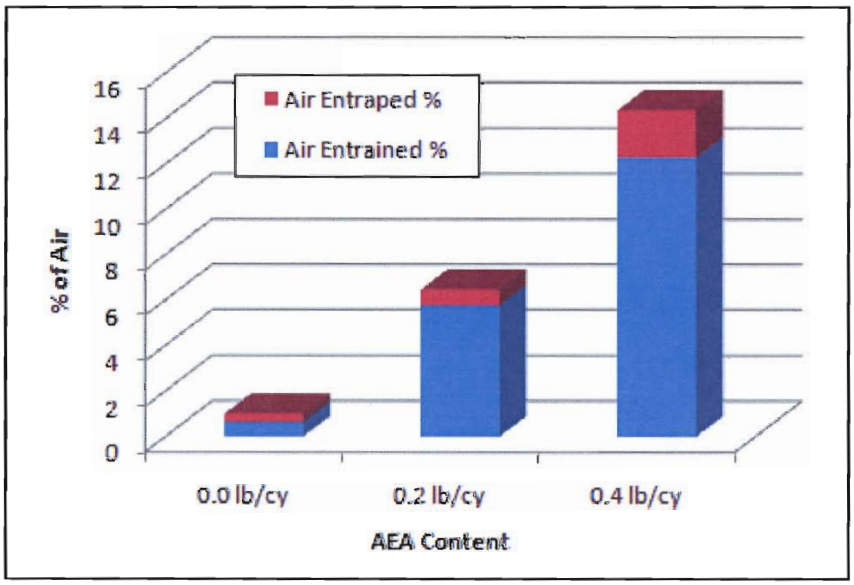


Figure 25. Effect of AEA Admixture on the Air Content in Hardened Concrete

The adverse effect of adding AEA on the compressive strength was evaluated using three cylinders taken from each mix. Figure 26 shows the 7-day compressive strength of these cylinders. This figure indicates a significant decrease in the compressive strength with the addition of AEA. Based on the results of air content and compressive strength testing, it was decided to limit the dosage of AEA to 0.1 lb/cy.

In order to ensure that the 28-day compressive strength of the proposed mix satisfies NDOR requirements (i.e. at least 6000 psi), several cylinders were taken from the mix that contains 0.1 lb/cy of AEA. The results of breaking three cylinders after 1, 3, 7, and 14 days are plotted in Figure 27. This figure shows that the required strength was achieved after 14 days only.

Table 11. Effect of AEA Admixture on the 7-Day Compressive Strength

Sample No.	Air Entrainment Admixture Content		
	0.0 lb/cy	0.2 lb/cy	0.4 lb/cy
1	7,447	5,448	2,116
2	7,803	5,682	2,289
3	7,982	5,700	2,075

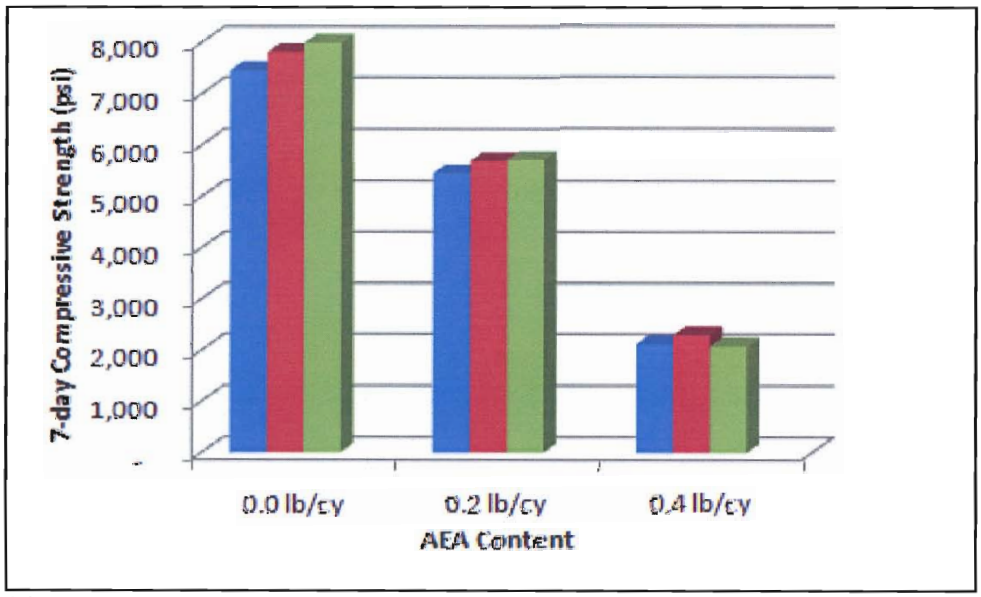


Figure 26. Effect of AEA Admixture on the 7-Day Compressive Strength (Different colors represent different samples).

Table 12. Compressive Strength of the Proposed Mix

Age (Days)	Sample 1	Sample 2	Sample 3	Average Strength (psi)
1	3,622	3,751	3,681	3,685
3	4,681	4,394	4,557	4,544
7	5,209	5,154	5,712	5,358
14	6,606	6,977	7,075	6,886

Based on the outcome of laboratory tests, the SCC mix shown in Table 13 is proposed as a base mix for cast-in-place applications in bridge construction. This mix satisfies all the NDOR requirements listed in section 3.2. Another mix with a different HRWR is also proposed in Table 14 as an alternative mix. The material cost per cubic yard of concrete

is estimated at $65 based on the unit price of individual components shown in Tables 13 and 14. It should be noted that these mixes may need an additional dosage of HRWR (0.6 lb/cy of Glenium 3400 or 0.8 lb/cy of Glenium 3030) after one hour if the required flowability is not achieved.

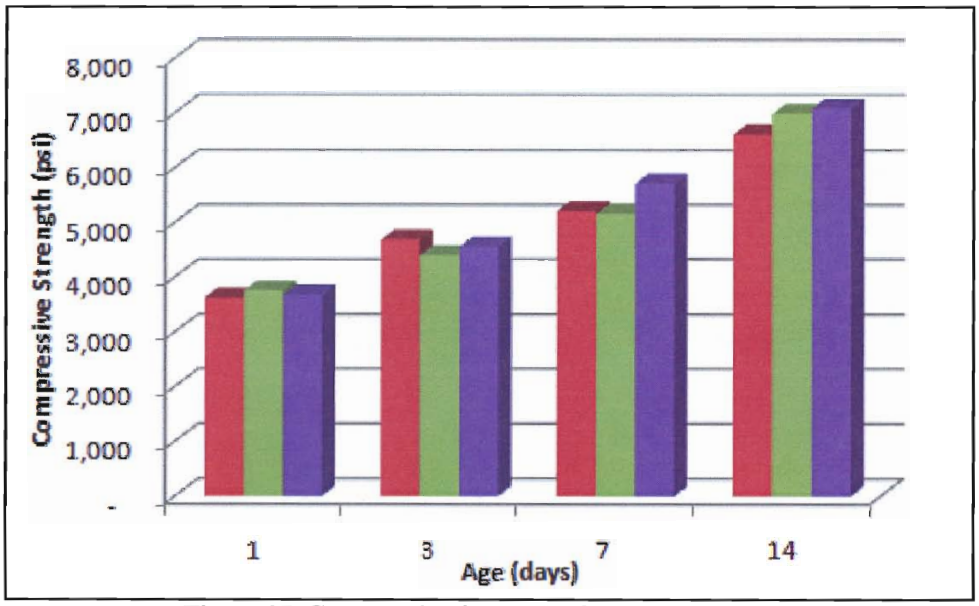


Figure 27. Compressive Strength of the Proposed Mix

Table 13. Proposed SSC Mix and Material Cost (Base Mix)

Material Description	Weight (lb/yd^3)	Admix (oz/cwt)	Cost / Ton or Gallon	Cost / yd^3
1PF Cement	810.0		$ 90.0	$ 36.45
47B Sand	2088.0		$ 6.0	$ 6.26
1/2" Limestone	702.0		$ 10.0	$ 3.51
Total Water	297.0		$ -	$ -
HRWR Glenium 3400NV	4.5	8.9	$ 16.0	$ 8.62
Retarder DELVO	3.6	7.1	$ 11.0	$ 4.74
AEA Pav Air 90	0.1	0.2	$ 3.0	$ 0.04
VMA Rheomac 362	2.7	5.3	$ 10.0	$ 3.23
TOTAL				$ 62.85

Table 14. Proposed SSC Mix and Material Cost (Alternative Mix)

Material Description	Weight (lb/yd^3)	Admix (oz/cwt)	Cost / Ton or Gallon	Cost / yd^3
1PF Cement	810		$ 90.0	$ 36.45
47B Sand	2088		$ 6.0	$ 6.26
1/2" Limestone	702		$ 10.0	$ 3.51
Total Water	297		$ -	$ -
HRWR Glenium 3030	6.0	11.9	$ 14.0	$ 10.05
Retarder DELVO	3.6	7.1	$ 11.0	$ 4.74
AEA Pav Air 90	0.1	0.2	$ 3.0	$ 0.04
VMA Rheomac 362	2.7	5.3	$ 10.0	$ 3.23
TOTAL				$ 64.29

4. Full Scale Tests

On-site applications of SCC require the consideration of several issues, such as the delivery time, temperature, height, and pumping. For special applications of SCC in bridge construction, NDOR specified the following conditions:

- Delivery time of concrete up to 90 minutes.
- Concrete temperature up to 90° F during pouring.
- Drop height of at least 5 ft.
- Pumping distance of at least 300 ft.

To ensure that the developed SCC mix has acceptable performance under these conditions, two full-scale tests were performed as described in details in the following subsections.

4.1. Delivery Time and Drop Height Test

The main objective of this test was to investigate the impact of the delivery time on the key properties of SCC, namely: filling ability, passing ability, and resistance to segregation. Also, the impact of pouring height on the stability and consistency of the SCC mix was investigated. In this test, the alternative mix proposed in the previous section was chosen based on the availability of the HRWR to the ready mix supplier. It should be noted that SCC used in this test was delivered to the site without the VMA and with only 2/3 of the required HRWR. VMA and the remaining amount of HRWR were added upon the truck arrival on-site, which was 35 min after water was first added to the dry mix (i.e. time = 0).

The fresh SCC was poured in four wooden forms for 4 ft wide, 4 ft high, and 7 ¼ in thick walls; and one insulated concrete form (ICF) for 4 ft wide, 8 ft high, and 6 in thick wall. The wooden form walls were reinforced as shown in Figure 28 with a minimum clearance of ¾ in between bars to evaluate the filling ability and passing ability of the developed mix. The non-reinforced ICF wall was used to evaluate the resistance to segregation of the developed mix when the concrete is dropped from 9 ft height.

The four wooden forms were filled at 15-minute time intervals starting at time equal 45 minutes. Before each pour, the Slump Flow test and J-ring test were performed according to the ASTM standards C1611M-05 and C1621M-06, respectively. Figure 30 shows the results of these two tests for the four pours. It should be noted that 0.8 lb/cy of the HRWR was added after the second pour due to the loss in the SCC flowability. Also, VSI, T_{50} , and concrete temperature were recorded for all pours as shown in Table 15.

Figure 28. Reinforcement Scheme.

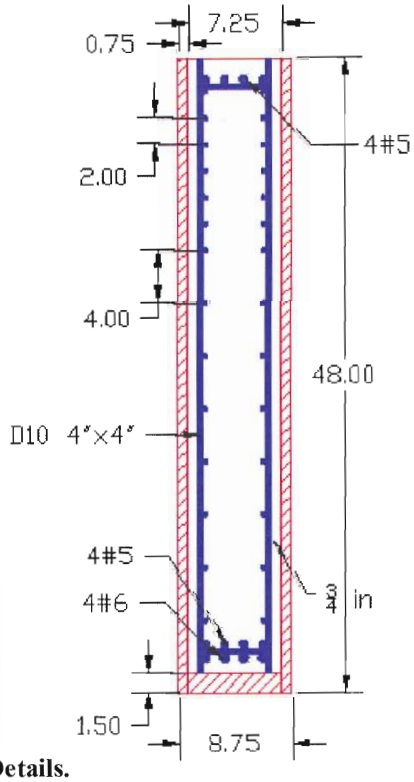


Figure 29. Reinforcing Details.

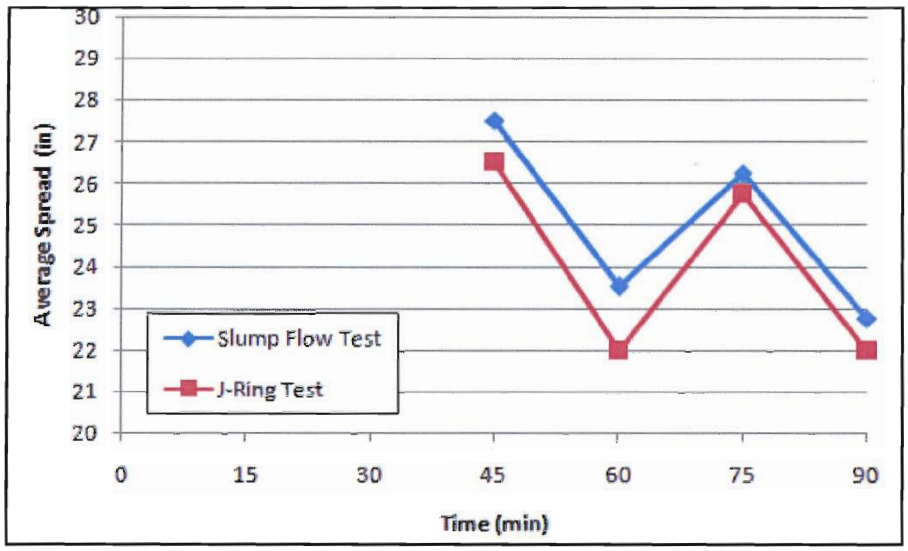


Figure 30. SCC Slump Flow and J-Ring Test Results

After 115 minutes of mixing and the addition of another dosage of HRWR, the ICF wall shown in Figure 31 was poured. The ICF wall was poured in two lifts by dropping the concrete from a 9 ft elevation. Although the ICF could not withstand the lateral pressure of the SCC that caused failure to two form ties, a substantial amount of concrete remained inside the form and was used later for coring.

Table 15. Summary of Test Results

Time (min)	45	60	75	90
Wall Form	#1	#2	#3	#4
T_{50} (sec)	2	2	2	1
Slump D_{long} (in)	28	24	27	23
Slump D_{short} (in)	27	23	25.5	22.5
Average Slump Flow (in)	27.5	23.5	26.25	22.75
Visual Stability Index (VSI)	0	0	0	0
J-Ring D_{long} (in)	27	22	26.5	22
J-Ring D_{short} (in)	26	22	25	22
Average J-Ring Flow (in)	26.5	22	25.75	22
Difference (in)	1.0	1.5	0.5	0.8
Temperature (F)	85	86	87	89
Comments		0.8 lb/cy Glenium 3030 was added		

Figure 31. ICF Wall

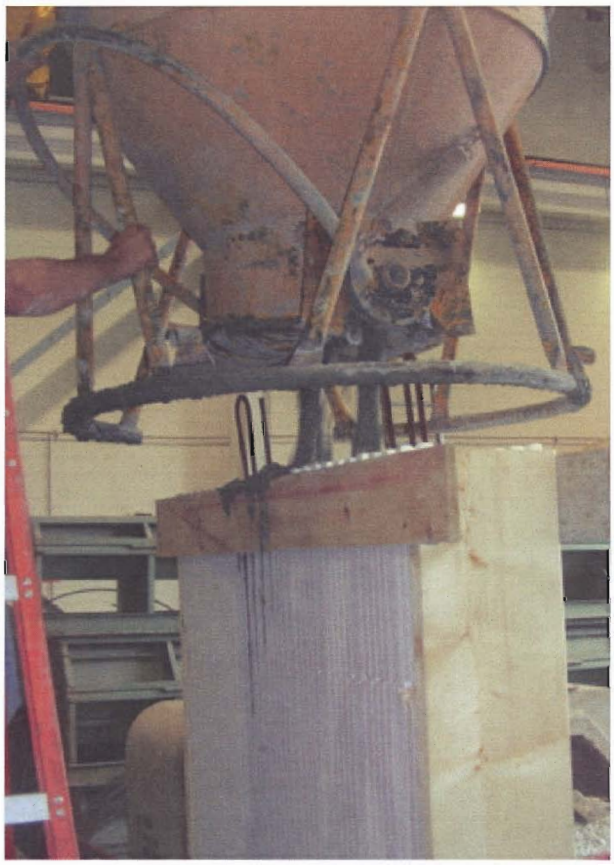


Figure 32. Pouring 8 ft ICF Wall Using SCC

Concrete cores were taken after 24 hours to evaluate the air content in the hardened concrete using the Modified Point-Count Method (ASTM C457) and to visually examine the consistency of the concrete. Figure 33 shows the two cores extracted from the top and bottom of each of the reinforced wall as well as the two cores extracted from the bottom of the ICF wall. The uniform distribution of coarse aggregate (i.e. limestone) in all the cores indicates the stability of the SCC mix and its resistance to segregation even when dropped from 9 ft elevation.

Figure 33. Cores extracted from the top and bottom of the reinforced wall

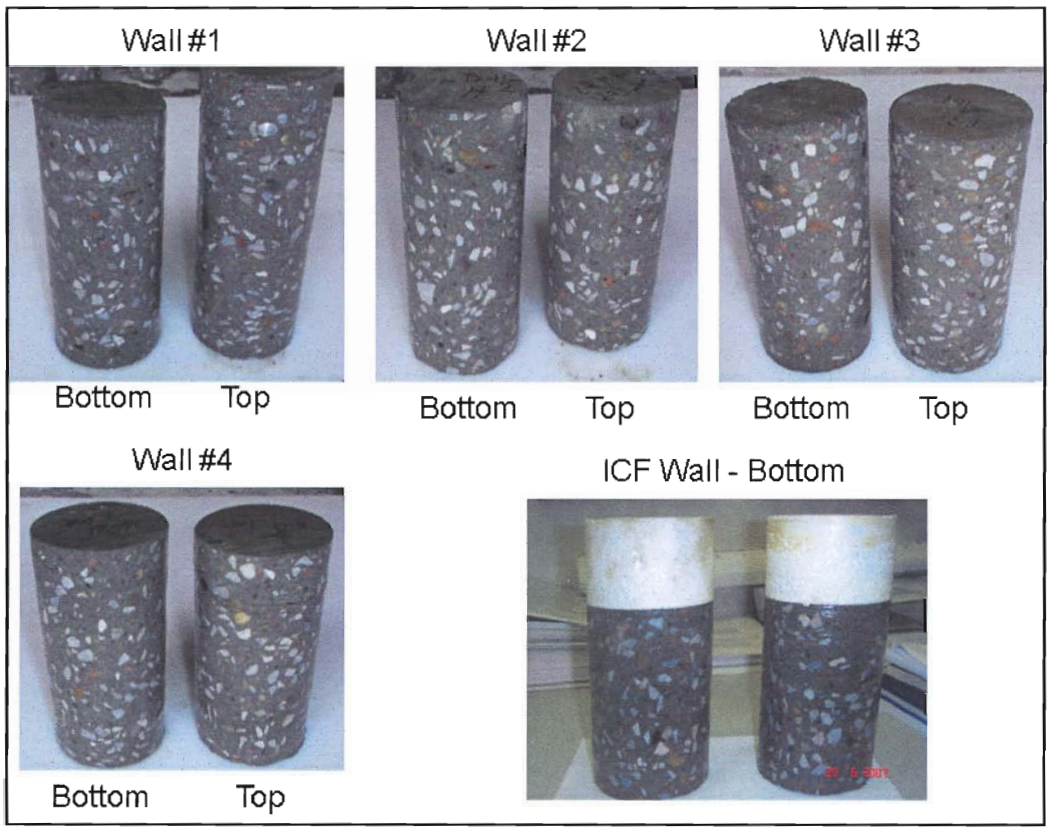


Figure 34. Cores Taken From the Top and the Bottom of Each Wall.

Figure 35 shows the results of air content test performed using the Modified Point-Count Method for each pour. These results indicate that the amount of air is approximately 5% in the first three pours and more than 6% in the fourth pour. This increase is mainly due to the increase in the trapped air and not the entrained air. These values of entrained air are considered acceptable according to the NDOR criteria.

Table 16. Air Content in Hardened SCC.

Measured Parameter	Pour Time			
	45	60	75	90
Air Entrained %	4.38	3.87	4.07	4.03
Air Entraped %	0.79	1.42	1.04	2.24
Total Air %	5.17	5.29	5.11	6.27
Spacing Factor	0.008	0.009	0.008	0.009

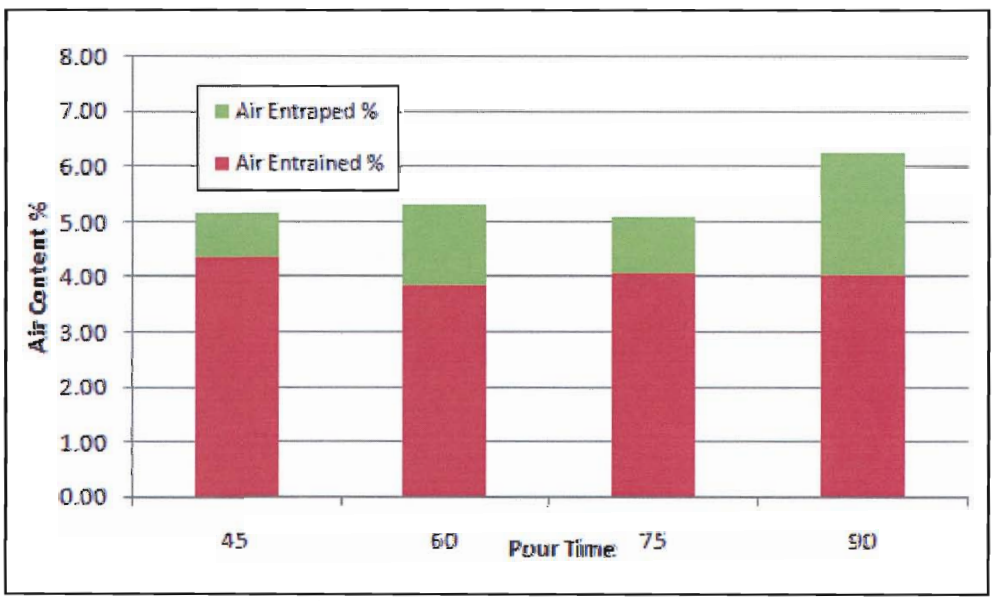


Figure 35. Air Content in Hardened SCC.

Three 4x8 cylinders were taken from each pour and tested for compressive strength after 28 days. Figure 36 shows the testing results and the average compressive strength for each pour. This average is always greater than 6 ksi, which is the NDOR minimum acceptable strength. Figure 36 also indicates that there is no significant change in the compressive strength due to the delivery time or the addition of HRWR.

Table 17. The 28-Day Compressive Strength of the SCC Cylinders

Pour Time	Sample 1	Sample 2	Sample 3	Average Strength (psi)
45	7,043	6,919	7,040	7,001
60	7,265	7,082	7,316	7,221
75	7,284	7,287	7,616	7,396
90	7,246	7,401	7,437	7,361

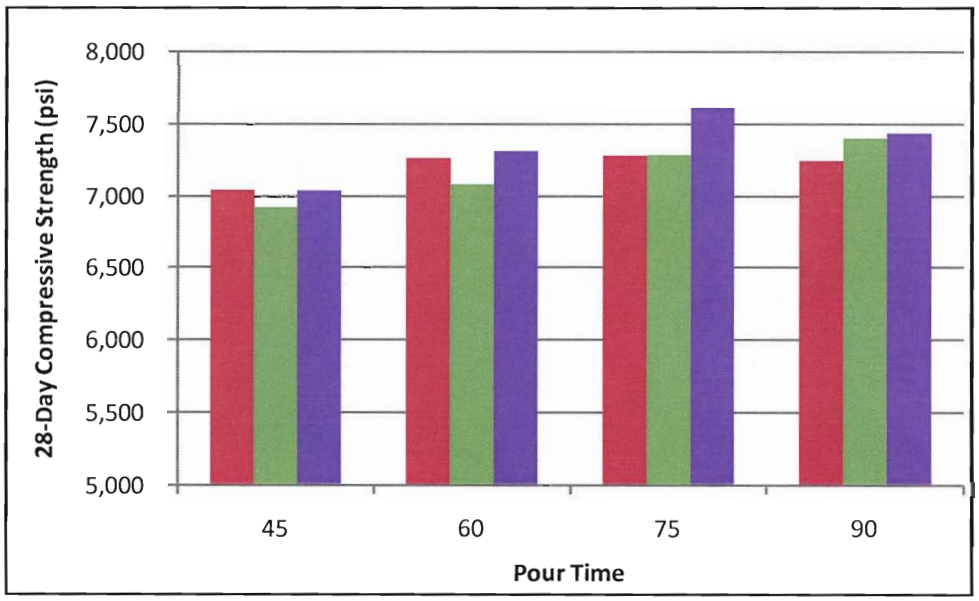


Figure 36. The 28-Day Compressive Strength of the SCC Cylinders

4.2. Pumpability and Pouring Temperature Test

This test was performed to evaluate whether the developed SCC mix maintains its properties throughout the pumping process. It was decided to pump SCC in an extremely hot weather (i.e. temperature is approximately 100°F) to investigate the effect of elevated temperatures on the properties of fresh SCC. Pumping was carried out with the pump shown in the Figure 37 for the distance of 340 ft, which is considered as the maximum practical distance used for on-site bridge applications in Nebraska.

In this test, the alternative mix proposed in the previous section was chosen based on the availability of the HRWR to the ready mix supplier. It should be noted that SCC used in this test was delivered to the site without the VMA and with only 2/3 of the required HRWR.

VMA and the remaining amount of HRWR were added upon the arrival of the truck mixer to the site, which was 9 min after water was first added to the dry mix (i.e. time = 0). The temperature of the fresh SCC at that time was 85°F and the average slump flow was 26 in. After adding the VMA and agitating the mix for 5 minutes, slump flow decreased to 22 in and air content measured with the pressure method was found to be 2%. The remaining amount of HRWR was added, and mix was agitated for another 6 minutes. Because the mix became too flowable, which might lead to segregation, it was decided to keep mixing for approximately 13 minutes to improve the stability of the mix. Slump flow was then found to be 30 in and the air content was found to be 2.5%. An additional dosage of 0.5 lb of AEA was used and the concrete was pumped. The temperature of the mix was 94°F and the temperature of the hose surface was 120°F.

The pumped SCC was poured in two concrete barriers as shown in Figure 30. Slump flow test performed after pumping indicated a spread of 28 in and VSI of 0 as shown in Figure 39. At that time, the concrete temperature was found to be 98°F, and the air content measured using the Pressure Method was found to be 4%. These results indicate that there is no significant loss in either the flowability or the air content of the SCC due to pumping (up to 340 ft) or elevated temperatures (up to 98°F)

Table 18. Summary of Test Results

Time [min]		9	11	16	19	25	38	41	58
Slump Flow [in]		26	-	22	-	-	30	Start Pumping	28
T_{50}		2	-	3	-	-	1		1
Air Content Press. Meth.		-	-	2%	-	-	2.50%		4%
Hardened Air	Entraped	-	-	-	-	-	1.79%		2.61%
	Entrained	-	-	-	-	-	1.04%		2.74%
Temperature [°F]		85	-	88	-	-	94		98
Remarks		Before addition of VMA and remaining	Addition of VMA		Addition of remaining HRWR	Mix too liquid. Segregation.	**Sampels A taken.** 0.5 lb of AEA admixture added		**Sampels B taken.**

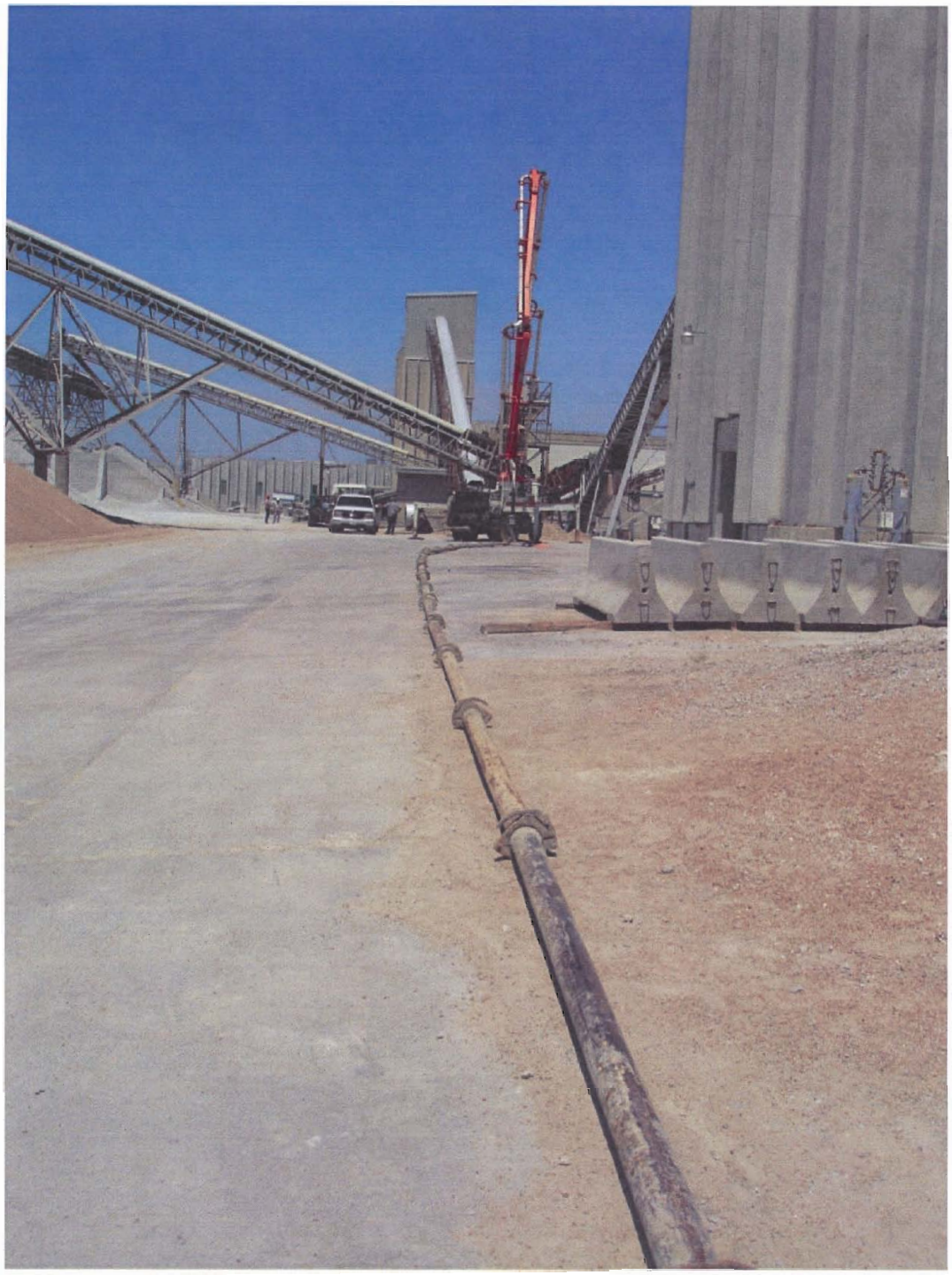


Figure 37. Equipment Used for Pumpability Test

Figure 38. Pouring Concrete Barrier Using the Pumped SCC

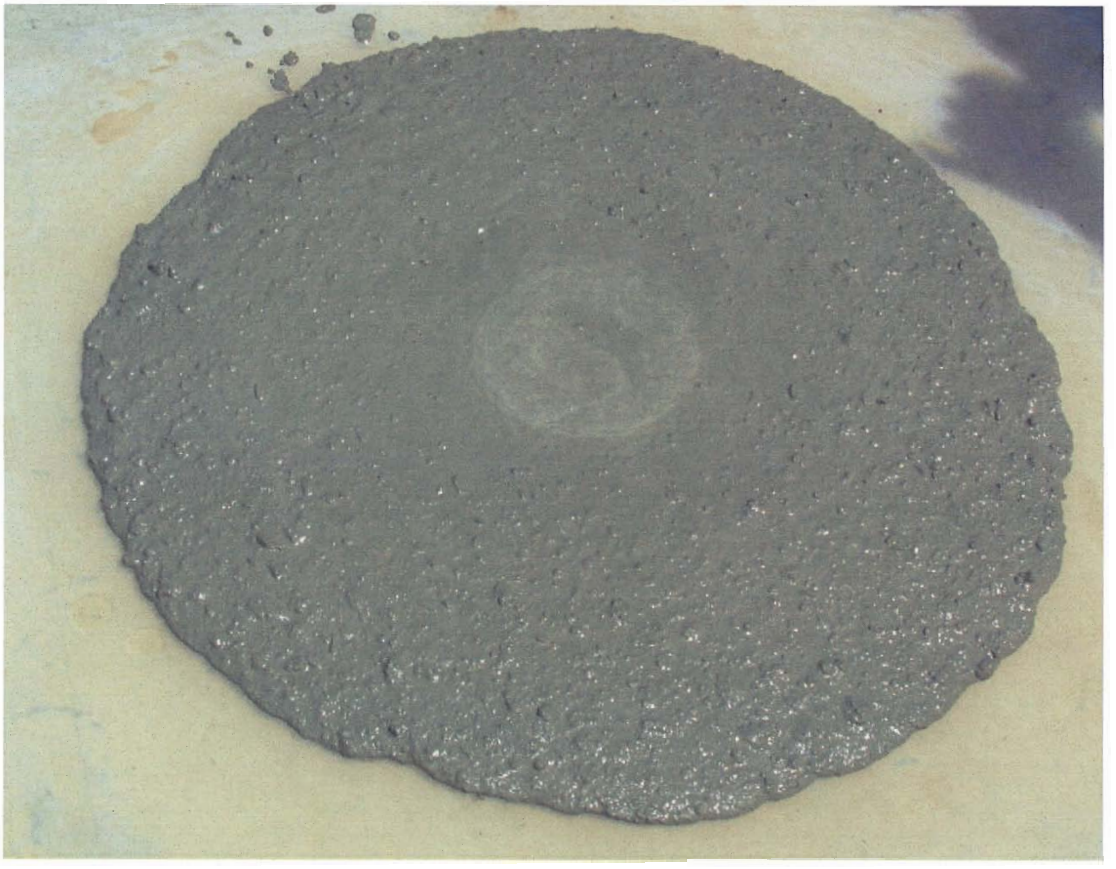


Figure 39. Slump Flow Test – After Pumping

5. Summary and Conclusions

The objective of this research project was to develop a practical guide for cast-in-place applications of the self-consolidating concrete. The major focus of this guide was to identify SCC mix design, mixing procedures, field testing methods, and the impact of on-site conditions on the performance of the mix. Several laboratory and full-scale investigations were performed to achieve this objective. The outcome of these investigations can be summarized as follows:

1. A SCC mix was developed using local materials (1PF cement and fly ash, 47B sand and gravel, ½" limestone) as specified by NDOR.. This mix also satisfies NDOR requirements in terms of 28-day compressive 6 ksi strength and air content (4-6%).
2. The Slump Flow Test, Visual Stability Index, and J-ring Test provided adequate information on the basic properties of SCC (i.e. flowability, passing ability, and segregation resistance). These tests can be used on-site to evaluate the properties of cast-in-place SCC immediately before pouring.
3. SCC mixing procedures are different from those of conventional concrete due to the use of different admixtures such as, HRWR, VMA, Retarder, and AEA. No extra water is allowed to be added to the mix after the initial mixing. However, additional dosage of HRWR (depending on the type) can be used to retain the flowability for longer periods (i.e. more than 90 mins).
4. The developed SCC mix maintained its properties under the following conditions:
    a. Delivery time up to 115 mins (Additional dosages of HRWR were used)
    b. Pouring height up to 9 ft
    c. Temperature up to 98°F
    d. Pumping distance up to 340 ft.
5. A general SCC Guide for special cast-in-place applications was developed to be used by ready mix producers and contractors in mixing, testing, and pouring SCC.

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APPENDIX

Nebraska DOR Guide

for

Special Applications of

Cast-in-Place Self-Consolidating Concrete (SCC)

Nebraska DOR Guide

for

Special Applications of Cast-in-Place Self-Consolidating Concrete (SCC)

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1. Scope

This Guide specifies the procedures for using special cast-in-place applications of self-consolidating concrete (SCC). These procedures are based on the experience gained from laboratory and full-scale tests.

SCC must have an adequate flowing ability, segregation resistance during and after placing of concrete, and filling ability through dense reinforcement and around other obstacles such as recesses and embedded items.

2. *Material Property Requirements*

The SCC mix design satisfies the following requirements specified by the Nebraska Department of Roads (NDOR):

Base Cement Type[1]	Portland Cement (Min. lb/cy)	Pre-Blended Class F Fly Ash (Min. lb/cy)[1]	Total Cementitious Materials (Min. lb/cy)	Proportion of Fine Agg. To Total Agg. (% by wt.)[2]	Type of Coarse Agg.	Air Content (% Min.)[3]	Water/ Cementitious Ratio (Max.)	28-Day Required Strength (Min. psi)
1PF	607	203	810	75 +/- 3	Limestone	6.0	0.37	6000

(1) Mixes with Type 1PF and Class F fly ash designation are pre-blended or interground with Class F fly ash by the cement mill producer at a rate of 25%±2%. No additional Class F fly ash will be added at the batch plant. Type 1PF cement shall meet all requirements of ASTM C 595

(2) Aggregates shall meet Section 1033 of the Standard Specifications except for the gradation of the aggregate.

(3) As determined by ASTM C 173, "Air Content of Freshly Mixed Concrete by the Volumetric Method"

Material requirements

- Maximum nominal aggregate size is 3/4 inch (this provides a minimum clear cover of 3/4 inch).
- Mix must retain SCC properties for up to 90 minutes based on ASTM C 1611 Slump Flow Test, Visual Stability Index (found in Appendix of ASTM 1611), and ASTM 1621 J-Ring method.
- Achieve pumpability up to 250 ft. without causing segregation based on Visual Stability Index described in the appendix of ASTM 1611.

3. Materials

According to the NDOR recommendation, 1PF cement (Type I/II cement pre-blended with 25% +/- 2% of Class F fly ash) is required for use with locally available aggregates. Examples of gradation curves used during the experimental in field trial are shown in Tables 1 and 2.

Table 1. Course Aggregate Gradation

Percent Passing		
Sieve Size	Target Value	Tolerance
1½ inch	100	None
1 inch	100	None
¾ inch	100	None
½ inch	75	± 5
3/8 inch	30	± 15
# 4	6	± 6
#10	---	---
#20	2*	± 2
#200	1.5	± 1.5

* The precent passing may be increased to 3±3 provided no more than 1.5% is passing the #200 sieve when washed.

Table 2. Fine Aggregate Gradation

Percent Passing		
Sieve Size	Target Value	Tolerance
1 inch	100	None
3/8 inch	---	---
# 4	87	± 10
#10	60	± 10
#20	28	± 12
#200	1.5	± 1.5

4. SCC Mix Design

The recommended mix design is given in Table 3:

Table 3. SCC Mix Design (per cubic yard)

Item	Weight $\frac{lb}{cy}$	Admixtures
I PF Cement	810	
Course Aggregate (Limestone)	702	
Fine Aggregate (Sand and Gravel)	2088	
Water	297	
Pav Air 90	0.2	3.2
*Type B Retarder	3.6	57.6
** Type F High Range Water Reducer (HRWR)	6	96
***Viscosity Modifying Admixture	2.7	43.2

Note: All admixtures will be determined by the ready mix plant and will meet NDOR specifications. Below is the list of products which were used during the research that was conducted in order to develop this user guide:

* Delvo Stabilizer

** Glenium 3030

*** Rheomac VMA 362

It is recommended that concrete be mixed with 2/3 of the required amount of HRWR at the plant. The VMA and the remaining 1/3 of HRWR should be added on site just before casting.

5. Forms and Molds

All common materials can be used for form surfaces. With regard to surface pores, wood is found to perform better than plywood, and plywood is better than steel.

When using a mold release agent on the surfaces, let the surfaces dry completely, as any release agent left on the mold will cause pores to develop. A vegetable-oil-based release agent will perform better than oil-based petroleum products. When using formwork with smooth surfaces, the best surface quality is obtained without using any mold release agent, especially when a new plywood or wood form is used. When the form's skin is colder than the SCC, more pores will develop on the surface.

During winter conditions, when temperatures are less than +40 °F (5 °C), it may be necessary to use thermal insulation (outside the formwork) to maintain the temperature and normal setting time of concrete, as SCC is more sensitive than traditional vibrated concrete to low temperatures during the hardening process.

When placing concrete for a wall, a better surface can be obtained by using a tube connected to the bottom of the formwork rather than casting from above. Also, keeping the opening of the hose from the concrete pump under the surface of the fresh concrete can result in a better surface on the hardened concrete.

Because of the additional pressure that SCC places on formwork, as compared to traditional concrete, the formwork must be designed to account for hydrostatic pressure. The forms must be rigid enough to maintain the weight of the flowable concrete and withstand all lateral pressure. The form joints shall also be sealed to prevent any leakage that could occur with SCC.

6. Transportation

SCC must be transported to the construction site by agitating mixer trucks. On site, SCC can be delivered using a concrete pump, or chute.

SCC can segregate if it is not agitated properly during transport and waiting time. Mixer trucks must be checked to ensure they are suitable for this purpose prior to use. The truck driver must check the concrete drum before filling it with SCC to make sure that the drum is clean and moist but without free water. During transport to the site and the waiting time, the drum must rotate at low speed (not less than 1 rotation per minute). However, just before delivery at the construction site, the drum must be rotated at full speed (10-20 rotations per minute) for at least 3 minutes prior to placement. Extra care is required for long deliveries.

Before the SCC is poured on site, it must be checked using the Visual Stability Index and Slump flow test (see ASTM 1611) to verify the material's workability and make sure that there is no sign of segregation.

7. Placement

Before starting to use SCC on site, the personnel must be informed of its special requirements. After gaining some experience with SCC, it is recommended that the results be discussed and evaluated.

The flowchart for suggested placement of SCC which was utilized in the research field trial conducted to develop this user guide is shown in Figure 3. The tests that are required by NDOR to verify that delivered SCC retains the necessary material properties upon delivery are the Slump Flow test (ASTM 1611), Visual Stability Index test (ASTM 1611Appendix), and the J-Ring (ASTM 1621). If the consistency is acceptable according to NDOR specifications and there is no sign of segregation, the concrete can be placed.

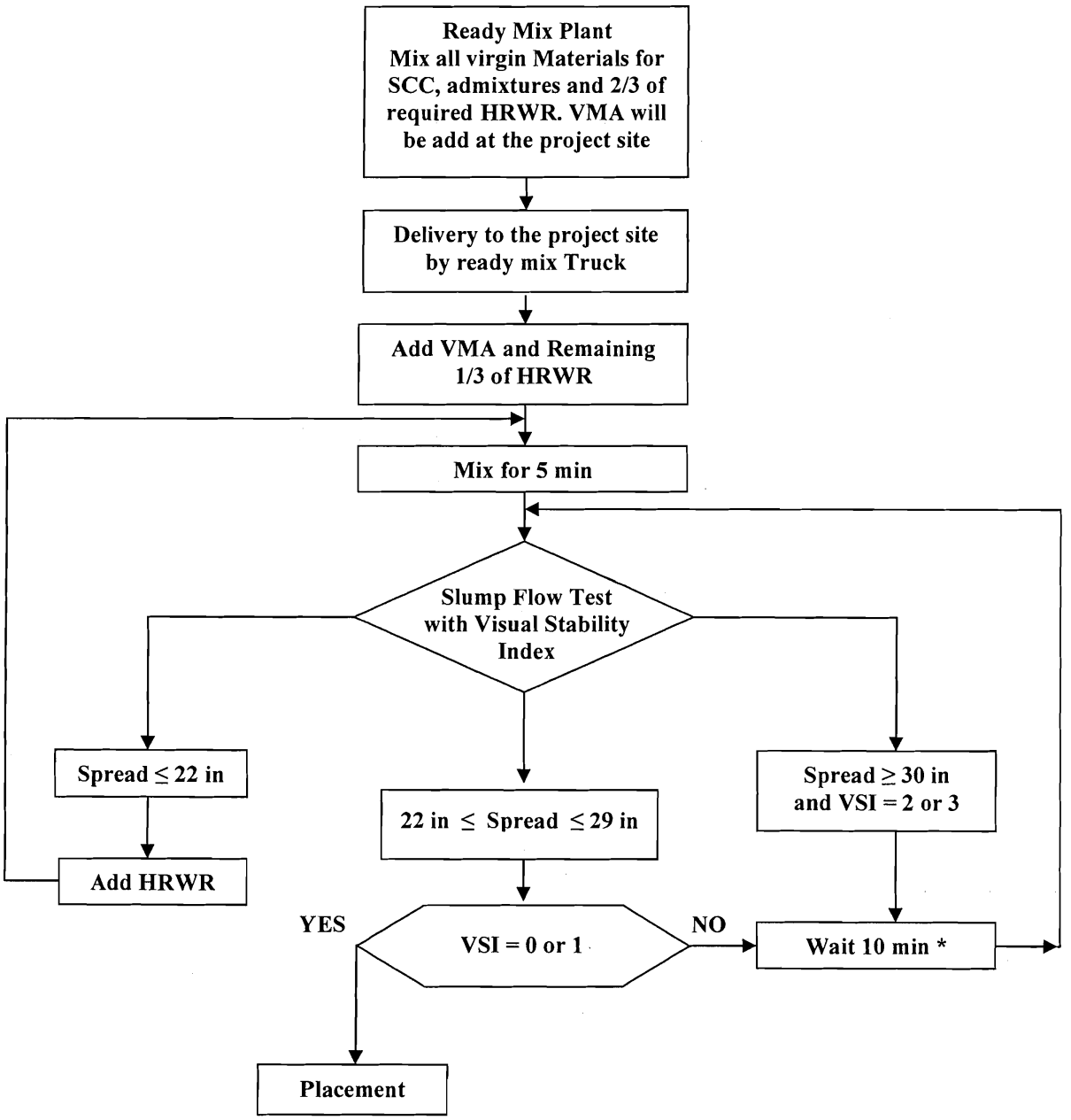
SCC can be delivered by pump, skip, or chute. Infield research trials proved that SCC can be successfully pumped the required 250 ft which was evaluated during the investigation.

If there is an unintended interruption during casting and the concrete mix starts to harden, it may be necessary to "wake up" the placed concrete before resuming the casting operation. This can be accomplished by striking a stick or a board into the concrete several times.

It is difficult to obtain a sloped surface grater that 2% using SCC. If possible traditional concrete should be considered when these slopes are specified.
Reducing the SCC slump flow may help to achieve slopes greater than 2% using SCC, however this is an issue that must be taken into account when developing the mix design.

When there are different levels within the area to be cast, problems may arise. One solution is to erect a form with a floating surface panel for the part including the raised area. Then, the lower part is cast and left for some time until it has started to stiffen; and after that, it is possible to finish placing the concrete. Another way to handle this problem is, if possible, to use traditional vibrated concrete for the slopes or raised areas.

Large amounts of admixtures are necessary when casting in cooler weather, concrete will experience a longer initial set time. The opposite will be true for normal ambient temperatures due to the amount of fines in the SCC mix design. Once the admixtures begin to wear off, traditional vibrating might be necessary.



* If VSI is 2 or 3 after 20 min, the concrete mix can be unacceptable for structural applications.

Figure 3. Suggested Procedure for Placing on Site.

8. Quality Control

Ready Mix plant shall be pre-approved by NDOR before any SCC is produced for a state project, by any ready mix plant. In addition to normal testing, the following tests are useful during the development, production and quality control for the use of SCC.

- Slump flow ASTM 1611
- T-50 ASTM 1611
- J-Ring ASTM 1621
- Visual Stability Index Appendix of ASTM 1611
- Air Content, Pressure Method ASTM 173

For a given mix, it is recommended that upper limits are set on the Slump Flow test and the T50. The Slump Flow test and the T50 are still the best methods to determine the filling ability for fresh concrete properties at least on the construction site, but they are not sufficient by themselves to determine if the concrete is segregation resistant.

The slump flow test shall be used for comparison with the target value from the mix design but can also be used by experienced personnel to indicate the quality of the concrete with respect to segregation, separation, etc.