

New Hampshire  
**DOT**  
Research Record



Investigation of the Performance of Self-Consolidating Concrete in Drilled Shafts



Final Report

Prepared by the New Hampshire Department of Transportation in cooperation with the U.S.  
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<p>This report summarizes the New Hampshire Department of Transportation's (NHDOT) investigation of the performance of self-consolidating concrete (SCC) when used in drilled shaft applications. SCC and conventional concrete (CC) piles were evaluated side-by-side for infilling properties, air content, and segregation. The investigation was undertaken because the method of construction on this highway project exposed several feet of the shafts after they were poured affording a unique opportunity to observe the infilling properties of the two mixes. The NHDOT concluded that for the mixes used, there was no significant difference in performance.</p>				
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# **Investigation of the Performance of Self-Consolidating Concrete in Drilled Shafts**

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**January 2011**

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## ABSTRACT

This report summarizes the New Hampshire Department of Transportation's (NHDOT) investigation of the performance of self-consolidating concrete (SCC) when used in drilled shaft applications. SCC and conventional concrete (CC) piles were evaluated side-by-side for infilling properties, air content, and segregation. The investigation was undertaken because the method of construction on this highway project exposed several feet of the shafts after they were poured affording a unique opportunity to observe the infilling properties of the two mixes. The NHDOT concluded that for the mixes used, there was no significant difference in performance.

## INTRODUCTION

The use of SCC in subsurface foundations is becoming more common in the U. S. The most obvious benefit of using SCC is that it infills around reinforcement easily, making it easier to work with and eliminating the need to vibrate the freshly placed concrete.

The New Hampshire Department of Transportation (NHDOT) recognizes the potential benefits of SCC and decided to evaluate for itself the use of SCC in drilled shafts on one of its projects. The original objective of this experimentation was to evaluate the performance and field practicality of using SCC in submerged conditions. The shafts, in the end, did not have much water in them so the project evolved into an evaluation of the performance and field practicality of using SCC in drilled shafts.

## APPROACH

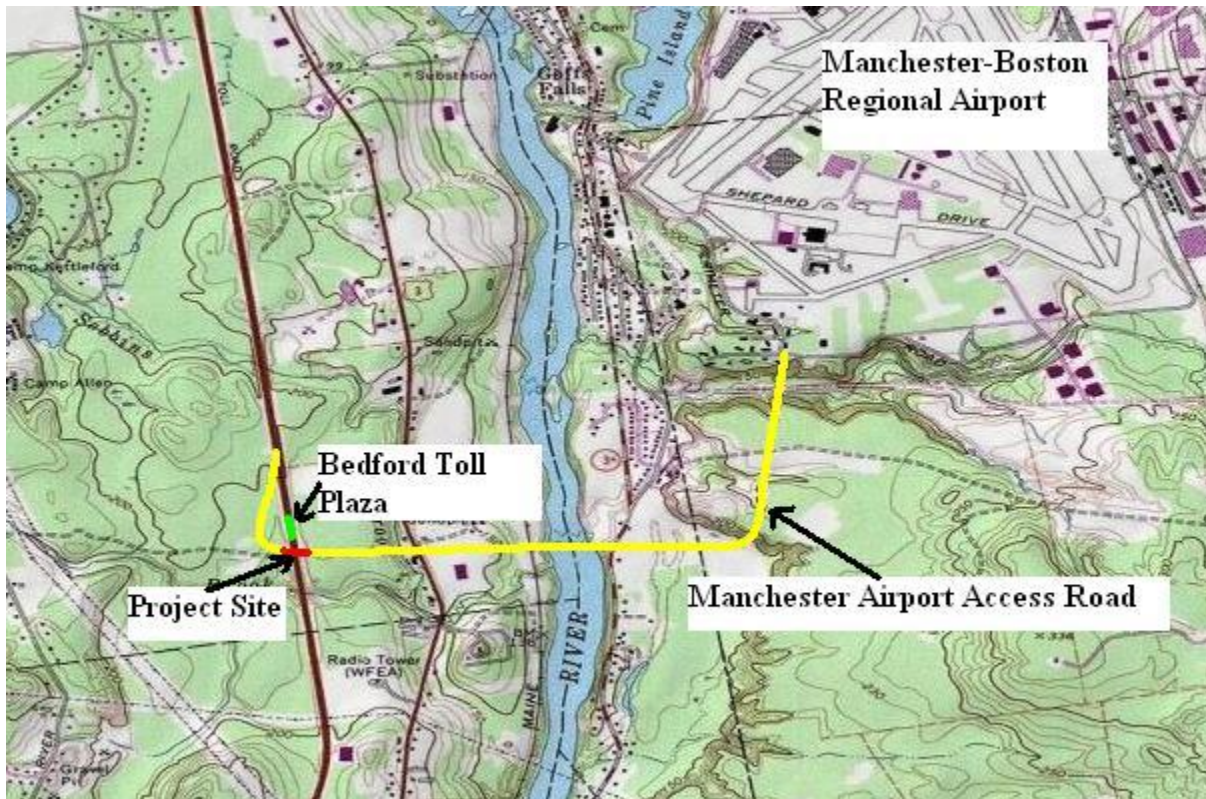


Figure 1: Site Location

The project chosen was a bridge carrying the F. E. Everett Turnpike over the newly constructed Airport Access Road in Bedford, NH. The girders for the bridge rest on a wall made of interlocking concrete piles called a secant pile wall (See Figures 2 and 3). The bridge girder seat system is poured on top of the wall to form the abutment. Because the abutments would be partially excavated to place the Airport Access Road underneath the Turnpike, there would be a rare opportunity to observe how well the concrete had infilled around the reinforcement cages in the primary secant piles.

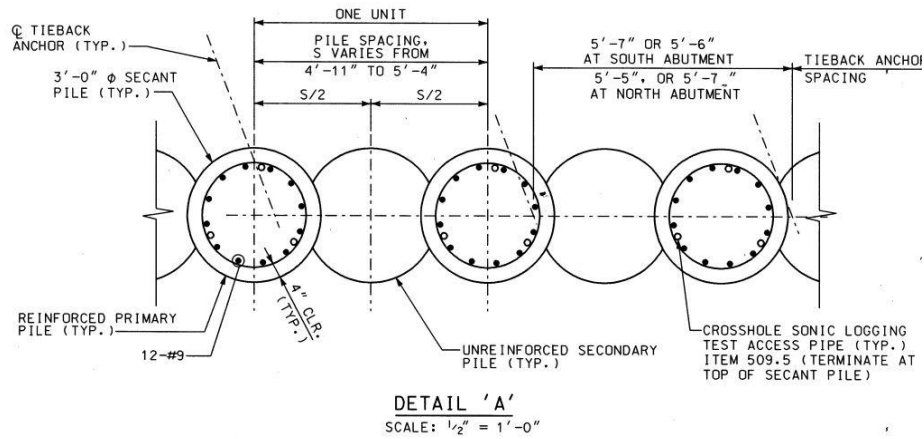


Figure 2: Plan view of secant pile wall showing primary and secondary pile interlock

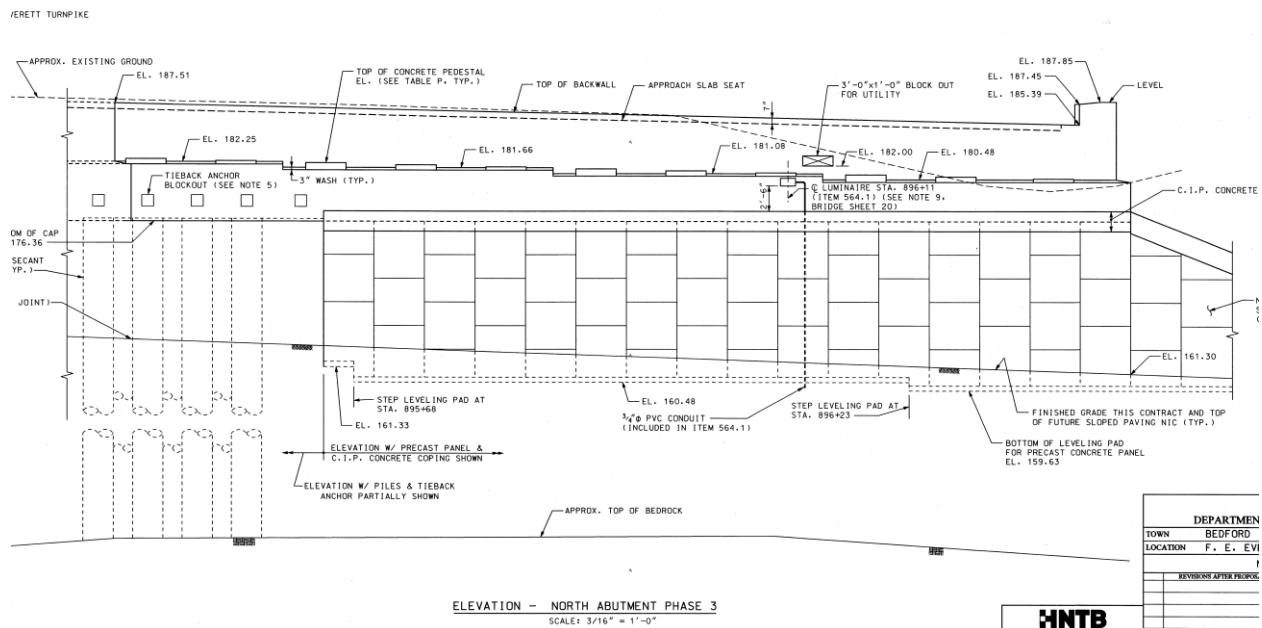


Figure 3: Elevation view of abutment showing secant pile wall construction and architectural wall facing to hide the secant piles

The secant wall that forms the abutment was constructed by drilling a series of shafts 3 feet in diameter at 2.5 feet center-to-center spacing. These shafts, called secondary shafts, did not receive reinforcement and were filled with concrete and allowed to cure. After curing, primary shafts 3 feet in diameter were drilled in between the secondary piles. The primary shafts overlap the secondary shafts and this arrangement causes the piles to interlock forming a wall. The interlock is illustrated in Figure 4. Reinforcement cages were put into the primary shafts and then concrete was placed. The bridge was constructed in three phases, and the piles evaluated by this project were constructed at the northern abutment during the third phase of the project. Three primary piles were constructed using SCC and the remaining primary piles were constructed using CC with a very high slump (9 to 11 inches). All of the secondary piles were constructed using CC with high slump.



*Figure 4: Interlocking pile template showing the outline of the secant wall.*

## **INSTALLATION**

The piles used as tests for this project are the westernmost 5 primary piles poured at the northern abutment during Phase 3 of the construction sequence. The secondary piles were constructed and then the primary shafts were drilled. The primary shafts for the first three piles were drilled on September 16<sup>th</sup> and 17<sup>th</sup>. They were from 35 to 40 feet deep. As the shafts were drilled, temporary steel casing was used to maintain their integrity. The bottom section of casing had a driving shoe but was otherwise identical to the top sections. The casings were 3 feet in diameter. The rebar cages for the shafts were prefabricated and placed into the shafts by crane. The rebar cages included sonic crosshole logging tubes for post-installation testing.

On September 18, 2009, the first three primary secant piles were poured using SCC. The SCC mix was a 4000 psi mix with an aggregate size of 3/8" and a water cement ratio of .38. The water-reducing admixture used was Glenium 7500 and the unit weight was approximately 145 pcf. The mix design report is available in Appendix 1. Four concrete trucks were used to fill the three shafts. Testing was done on the first two trucks. Admixtures and water were added into the drums of the trucks after they arrived at the site, and additional mixing occurred until the RediMix Companies representative was satisfied. The SCC from the first truck spread 22 inches and had an air content of 5.5%. Fifteen gallons of water were added to the second truck and about 178 ounces of Glenium admixture. The SCC from the second truck spread to a "tight" 20 inches and had an air content of about 4.3%.

The concrete was placed using a pump truck and the tremie method of placement. The pump tube was inserted all the way down to the bottom of the shaft and the concrete was pumped up from there. The original plan was for the shafts to be full of water, but after the crews cleaned out the shafts, the shafts did not refill with water. The concrete was placed starting with the westernmost shaft and proceeding east. The piles were designated according to position as N3PX standing for north abutment, construction phase 3, primary pile X.



Figure 5: Measuring the spread of SCC



Figure 6: Rebar cages before installation



Figure 7: Pumping SCC into Shaft



Figure 8: Removing a section of casing

### **Western SCC Shaft (N3P1)**

Shaft N3P1 had 2 feet of water in it. The concrete pump tube was inserted down to the bottom of the shaft and then raised a few inches. The concrete was pumped from this position until the shaft was approaching half full. The pump tube started bouncing vigorously when the concrete began to flow. When the shaft began approaching half full, the pump tube was removed and then the casing was lifted so that the first section could be extracted. The pump tube was then reinserted into the concrete and more concrete was pumped in until the concrete was within 6 or 7 feet of the surface. At this point a small bilge pump was lowered and the water trapped on top of the concrete was suctioned off. After the water was suctioned off, the second section of casing was removed before pumping began again. The shaft was filled to slightly overfull and then the third and final section of casing was removed. The top of the concrete in the shaft was leveled with the concrete in the adjacent secondary piles by removing the excess concrete with a shovel. This shaft received all of the concrete from the first truck and some from the second truck.

### **Middle SCC Shaft (N3P3)**

Shaft N3P3 had 6 inches to a foot of water in it. The placement was done identically to Shaft N3P1. The little foam ball that was used to plug the concrete pump truck tube during its insertion into the shaft is believed to be in this shaft somewhere. The remainder of the second truck and part of the third truck were used to fill this shaft.

### **Eastern SCC Shaft (N3P5)**

Shaft N3P5 was virtually dry. Placement was done identically to the first two shafts except that there was no need to suction water off the top of the concrete. The remainder of the third truck and all of a fourth truck were used to fill this shaft.

### **CC Shafts N3P7 and N3P9**

The remaining primary piles were placed using CC designed for a high slump. Piles N3P7 and N3P9 were chosen for comparison with the SCC piles. They were poured on September 18<sup>th</sup> 2009 as well. The mix design for the CC was for 4000 psi with 3/8" aggregate. The water cement ratio was .443 and the unit weight was approximately 129 pcf. The air content measured at placement was 5.2% for the CC. The CC was placed by dropping the concrete directly into the drilled shaft. The mix design is attached in Appendix 1.

## **EVALUATION**

Cylinders were made from each mix. The 28-day strength of the SCC cylinders was approximately 6300 psi and the unit weight was on target at about 146 pcf. The 28-day strength of the CC cylinders was 5000 psi and the unit weight was approximately 137 pcf. The strengths were more than the 4000 psi required.

The secant piles themselves were evaluated for soundness and voids both non-destructively and destructively. The non-destructive evaluation was performed by sonic crosshole logging and by

visual examination of the exposed portions of the piles. The destructive evaluation consisted of taking cores from the center of each of the five piles.

Tom Cleary of the NHDOT's Geotechnical Section performed the sonic crosshole logging. Sonic crosshole logging is prepared for by installing tubes at predetermined locations within the shaft. After the concrete has been poured and cured, a signal generator and a receiver are lowered into different tubes and the time that it takes for the receiver to get the signal is recorded. This is done throughout the shaft using different combinations of tubes so that an estimate of the soundness of the concrete in the pile can be formed.



*Figure 9: Sonic crosshole logging tubes*

The five shafts were cored on October 7-9, 2009. Audley Construction built a gravel platform in front of primary drilled shafts N3P1 through N3P9 and the NHDOT drill crew was able to get a truck-mounted drill rig up onto this platform and in position to core the shafts. The shafts were cored with a 2-inch diamond bit in sections approximately 4.8 feet in length. The cores were taken from the top to within 6 inches of the bottom of each shaft. The bottoms of the shafts were not penetrated so that the core holes would be easier to patch with grout. The drilling process went smoothly and the drill crew noted that the concrete was harder to core as they neared the bottoms of the shafts.



*Figure 10: Coring secant piles*

The cores were taken back to the lab for inspection. The cores were looked at for evidence of channelization, segregation, and any other abnormalities. One thing that was immediately obvious was that the cores from all five piles contained numerous voids bigger than 1 mm in diameter. This is indicative of entrapped air rather than the evenly distributed voids of 1 mm or less in diameter formed by entrained air. Figures 11 through 16 shows, from visual comparison of the cores, that the SCC shafts appeared to have larger and more air voids near the top of the pile than the cores from the CC shafts. The cores from the SCC also appeared to have slightly more voids in the mid-section of the pile than the CC cores. Near the bottom of the pile the situation was reversed and the CC cores appeared to have more voids than the SCC cores. “Appeared” is not quantitative so one SCC core and one CC core were selected for further study.



*Figure 11: N3P3 SCC 1 to 3 ft depth (more voids)*



*Figure 13: N3P3 SCC 26-27 (less voids)*



*Figure 12: N3P3 SCC 17-18 ft depth (several voids)*



*Figure 14: N3P7 CC 1 to 4 ft depth (less and smaller voids)*



Figure 15: N3P7 CC 17-18 ft depth (several voids)



Figure 16: N3P7 CC 26-27 ft depth (more voids)

The effort to quantify and qualify the air content in the hardened concrete was undertaken by students from the University of New Hampshire under the direction of Professor David Gress. The students analyzed the cores from two of the piles according to ASTM C 457 *Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*. The full report prepared by the students is attached to this report as Appendix 2. The cores were from N3P1, which was a SCC pile, and N3P9, which was a CC pile. The students used Procedure B, the Modified Point Count method. The cores were divided into 6-inch lengths and then sections at similar depths from each core were analyzed. All of the sections in each core were not analyzed due to the intense effort and labor required. In general terms, the air content of both cores was not uniform throughout the pile length and did not vary linearly with depth.

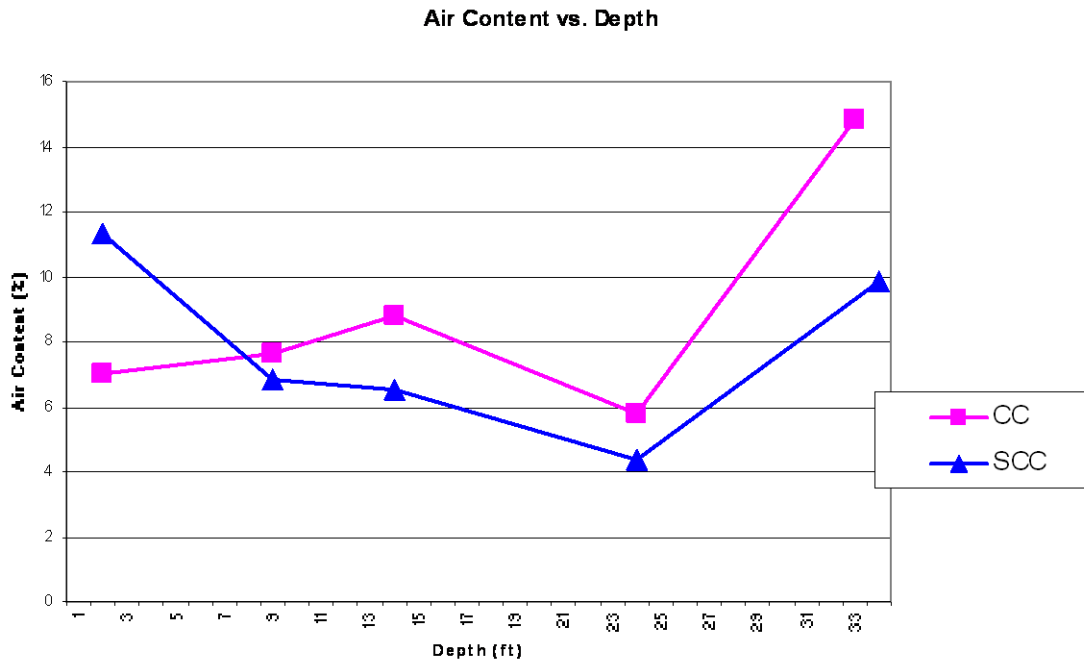


Figure 17: Air Content vs. Depth



The air content of the cores from the two piles is shown graphically in Figure 17. In SCC pile N3P1, air content was at its maximum value of 11.33% at the top of the pile, at its minimum of 4.4% at 22.5 feet and then rose to 9.82% at the bottom of the pile. The air content for CC pile N3P9 was at 7.0 % at the top of the pile, at its minimum at 5.8% at 22.5 feet, and then at its maximum of 14.86% at the bottom of the core. Figures 18-20 show core sections that were prepared and analyzed by the UNH students. The differences in air void content can be seen in the photos.



*Figure 18: Sections from the 1-foot depth of the piles (SCC on left, CC on right) this was the section of the SCC pile with the highest air content.*



*Figure 19: Sections from the 23-foot depth of the piles (SCC on left, CC on right). This was the section with the lowest air content for both piles.*



Figure 20: Sections from the 28-foot depth (SCC on left, CC on Right.). This was the section with the highest air content for the CC pile.

The UNH students also calculated the spacing factor of the voids as part of the evaluation. The spacing factor is a measure of the maximum distance in the cement paste from the perimeter of an air void. The spacing factors in the core samples evaluated ranged from 0.02 in up to 0.06 in. A maximum spacing factor of .008 is the general target for good freeze thaw durability. In this case, the concrete is not directly exposed to the elements and freeze thaw durability was not a major consideration. One might think that the highest spacing factor would correspond to the area with the lowest air content. This was not the case as seen graphically in Figure 20, probably because of the random nature of entrapped air.

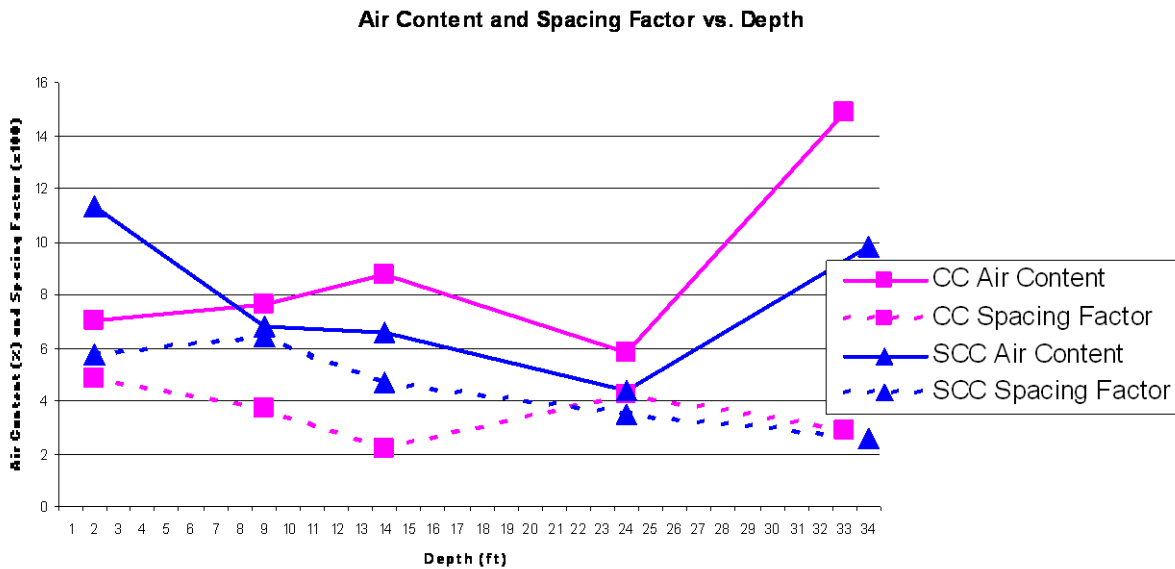


Figure 21: Air content and spacing factor vs. depth

In the spring of 2010, the secant pile wall was partially excavated for construction of the underpass allowing for inspection of the secant piles. In general visual appearance, there was not an easily discernible difference between the appearance or texture of the SCC piles and the CC piles. Both types of concrete filled in completely around the reinforcement cages for the visible lengths of the piles. If one did not know the identity of the piles, it would have been impossible to visually tell which piles used which type of concrete.



*Figure 22: Primary piles are marked in pink paint*



*Figure 23: Architectural wall that conceals secant pile wall*



*Figure 24: Primary SCC piles N3P1, N3P3, and N3P5*

**SCC Pile N3P1** was encased for most of its length in a hard layer of material that appeared to be a mixture of soil and cementitious material from the concrete. This hard layer was about two inches thick and changed in color from tan to the same color as the concrete as one chipped through it towards the concrete. The other SCC piles did not exhibit this. The only difference between this pile and the other two SCC piles was the presence of 2 feet of water over the concrete in this pile when the concrete was placed. An ice pick and a masonry hammer were used to chisel down to the surface of the concrete in the pile. The material had the consistency of hardened clay and considerable effort was needed to chip through it. The material appeared to be in addition to the concrete, meaning that from what the observer could tell, it did not infringe into the three-foot diameter of the pile. In Figure 25 below, the color differences can be seen. The tan outer layer has been chipped through to the grey inner layer. In Figure 26, two areas of exposed hardened concrete are pointed out. The picture shows how the grayish material needs to be scraped or chipped away to expose the concrete. The fingers are pointing directly at the exposed concrete (very light grey to white colored); most of the rest of the picture shows the grey colored hardened material. The concrete that was exposed was hard and sound as evidenced by striking it with the masonry hammer. No reinforcement or evidence of blockage caused by reinforcement was visible.



*Figure 25: N3P1 chipped down to concrete*



*Figure 26: Fingers pointing to slits of exposed light grey concrete on N3P1, darker gray material around concrete is part of the hard layer that formed around the pile*

**SCC Piles N3P3 and N3P5** were not encased in a layer of hard material like N3P1. The material adhering to these piles was easily scraped away and the surface of the concrete did not reveal any “bug holes”. The surfaces of the piles were defined enough to show the vertical striations left by the casing when the shafts were drilled. N3P3 had between 6 inches to a foot of water in the shaft when it was placed, and N3P5 had a dry shaft when it was placed. This might account for the lack of a hard layer such as was at N3P1. The concrete in both N3P3 and N3P5 was hard and sound when struck with a masonry hammer. No reinforcement or evidence of blockages caused by reinforcement was visible.



*Figure 27: N3P3*



*Figure 29: N3P5*



*Figure 28: Close up of N3P3*



*Figure 30: Close up of N3P5*

**CC Piles N3P7 and N3P9** looked very similar to SCC Piles N3P3 and N3P5. Any material adhering to these piles was easily scraped away and the surface did not reveal any “bug holes”. The concrete in these piles was also hard and sound when struck with a masonry hammer. No reinforcement or evidence of blockages caused by reinforcement was visible.



Figure 31: Primary CC piles N3P7 and N3P9



Figure 32: N3P7



Figure 34: N3P9



Figure 33: Close up of hammer marks on N3P7



Figure 35: Casing impression marks in N3P9

When inspecting the secant wall, horizontal cracks were noticed in several of the secondary piles. The cracks varied in width from hairline to big enough to stick a dime into. There was no reinforcing steel placed in secondary piles, so the cracks are probably the result of shrinkage. The primary piles that were evaluated in this report did not exhibit such cracking.



*Figure 36: Horizontal crack in secondary pile*

## **CONCLUSIONS AND RECOMMENDATIONS**

This comparative evaluation of CC and SCC on an NHDOT project showed that both types of concrete performed equally. There was no evidence of voids related to blockage caused by reinforcement leading to the conclusion that both types of concrete infilled around the reinforcing without problems. One of the commonly cited advantages of SCC is its ability to flow for long distances without segregating into aggregate and paste. Both the SCC and the CC in this project did not display any evidence of segregation. It would be interesting to compare these two specific mixes in a situation where horizontal flow of the concrete during placement occur and observe if the SCC would outperform the CC. Sonic crosshole logging of the SCC and the CC piles did not indicate the presence of any anomalies inside the piles that would cause concern. Visual inspection and sonic crosshole logging of the rest of the primary piles that formed the secant wall but were not included in this evaluation did not reveal any problems either.

For the economic comparison, for this particular project, the SCC cost approximately \$10/cy more than CC. This was for a small quantity of SCC and a larger quantity would probably cost less per cubic yard. For this particular application, the additional cost of the SCC did not result in any apparent benefits versus CC.

The air content tests did not reveal any conclusive differences between the CC and the SCC mixes. The SCC cores appeared to have larger air voids near the tops of the piles and this may in part be due to the tremie method of installation. The tube had to be reinserted every time a section of the casing was pulled out and air must have been introduced during this process since the foam ball was not used to plug the tube every time it was reinserted. The only difference visible in the piles was the presence of the hard outer layer that surrounded N3P1. The concrete in the pile itself was hard and sound and there is no explanation for the hard layer or reason to believe that it indicates a problem with the concrete. It is reasonable to believe that SCC will work as well as CC in NH subsurface conditions.



## REFERENCES

“ASTM C 457 Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.” *ASTM International Volume 04.2*

Hall, Ben, Eric Picard, Sean Tarbox. “Evaluation of Cores from Piles in Secant Wall.” University of New Hampshire, May 19, 2010.

**APPENDIX 1  
CONCRETE MIXES**

# Self Consolidating Concrete Mix

09/07/2009 19:42

6035249806

NHDOT BELMONT

PAGE 03

## Mix Design Report

Redimix Companies, Inc.  
P.O. Box 480  
Winnisquam, NH 03289

see MIX III Mix Report  
SCC 930029-Self Consolidating Concrete 40658684 [0]  
Strength Compressive: 4000 psi  
03/10/2009

Customer : R.S. Audley, Inc.	Contractor : R. S. Audley, Inc.
Project : Bedford-Manchester-Londonderry 11512C	

Compressive Strength : 4000 psi at 28 Days	Source of Concrete : Redimix Companies, Inc.-Manchester
Aggregate size : 3/8" - 9.5 mm	Construction type : NH DOT, Class AA-3/8"
Air : 5.0 to 9.0 %	Placement : Direct/ Pump
Water/Cement ratio : 0.380	Unit Weight : 144.56 pcf
Slump : 0.00 to 0.00 in	Design Date : 01/15/2009

Constituents :	Quantity	Density	Volume
CQ TYPE II (Ciment Quebec)	592 lb	3.150	3.01
Flyash (Headwaters Resources)	66 lb	2.360	0.45
Water	30.0 ga	1.000	4.01
3/8" Stone (Litchfield S&G)	1500 lb	2.700	8.90
F.A. (Quinn Materials)	1500 lb	2.670	9.00
Air - MB AE 90 (BASF Admixtures)	5.00 floz (US)/yd <sup>3</sup>	1.020	0.01
WR - Glenium 7500 (BASF Admixtures)	52.64 floz (US)/yd <sup>3</sup>	1.000	0.05
	6.0 %		1.62
<b>Total :</b>	<b>3912</b>		<b>27.06</b>

**Remarks :**  
Admixtures to be adjusted as necessary to maintain consistency.  
Slump is not applicable.  
Additional Glenium 7500 may need to be added on-site.

Reported by Rick Lalumiere	Approval by : _____
Date : 03/10/2009	Date : //

03/10/2009

# Conventional Concrete Mix

09/07/2009 19:42 6035249806

NHDOT BELMONT

PAGE 04

## Mix Design Report

Manchester Redimix Concrete  
89 Calef Road

Manchester, NH 03103

seeMIX III Mix Report  
MCLASSAA-8 930002-NHDOT AA, 3/8"  
Strength Compressive: 4000 psi  
10/12/2007

Customer :	McKinney Drilling Company
Project :	Bedford-Manchester-Londonderry 11512-C

Compressive Strength :	4000 psi at 28 Days	Contractor :	McKinney Drilling Company
Aggregate size :	3/8" -- 9.5 mm	Source of Concrete :	Manchester Redimix Concrete
Air :	5.0 to 9.0 %	Construction type :	Drilled Shafts/Piles
Water/Cement ratio :	0.443	Placement :	Direct/Pump
Slump :	3.00 to 5.00 in	Unit Weight :	129.20
Slump after SP:	0.00 0.00 in		

Constituents :	Quantity	Density	Volume
Cement Ciment Quebec Type II	461 lb	3.150	2.35
Mineral Additive SLAG - NewCam (Lafarge North America)	197 lb	2.291	1.38
Water Water	35.0 ga	1.000	4.68
Coarse Aggregate 3/8" - Litchfield 3/8" (Litchfield S&G)	1420 lb	2.630	8.65
Fine Aggregate Quinn Materials, Fine	1400 lb	2.840	8.50
Admixture MB AE 90	6.00 floz (US)	1.010	0.01
Admixture Polyheed 1020	13.16 floz	1.070	0.01
Admixture SuperP - Rheobuild 1000 (BASF Admixtures)	0.00 floz (US)	1.200	
Air	6.0 %		1.63
<b>Total :</b>	<b>3514</b>		<b>27.20</b>

Remarks :  
Admixtures to be adjusted as necessary to maintain consistency.

Reported by Rick Lalumiere	Approval by : _____
Date : 10/12/2007	Date : //

**APPENDIX 2**  
**UNIVERSITY OF NEW HAMPSHIRE STUDENT REPORT**  
**(CIE 722 Report)**

CIE 722 UNH

# Evaluation of Cores from Piles in Secant Wall

Testing For Air Content Using ASTM 457

**Ben Hall, Eric Picard, Sean Tarbox**  
**5/19/2010**

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## Introduction

The project to evaluate and compare the cores from the secant wall was acquired in early March of 2010. The project group received four boxes of cores from the New Hampshire DOT, which contained two separate cores of two types of concrete both used in piles in a secant wall on a bridge project. Of the four boxes, two were filled with a core from a pile poured using conventional concrete while the other two boxes were filled with a core using self consolidating concrete (SCC). The goal of the project was to determine the air content of the hardened concrete cores and report the data back to the New Hampshire DOT.

The process for completing this process was planned out thoroughly before the project began. Before removing any concrete from the core boxes it was determined that we would use the ASTM 457, which is the standard test method for microscopic determination of parameters of the air void system in hardened concrete. This test method also has two sub methods of analysis that can be used; the linear transverse method or the modified point count method. For this project the modified point count method was used.

After determining the test method used the core samples were split into their respective concrete types and we established a naming convention for each. Once the cores were labeled, all samples could be correctly identified outside of its place inside of the core box, the samples were prepared for testing. This included cutting the samples from a small circular core to a flat rectangular testable surface. Next the samples had to have their surfaces finished in preparation for the microscope work. Finally the samples could be tested using the test method outlined in ASTM 457.



## Naming Convention

The naming convention of the cores was put in place to differentiate between the two different mixes of concrete and to specify the depth of individual core sections. The naming process began with identifying each mix. The SCC mix was labeled with an 'S' and the conventional concrete mix was labeled with a 'C'. At this point the ASTM 457 standard had to be consulted to determine how long the cores needed to be to satisfy the number of points needed for the modified point count method. Since both mixes had about a 3/8" aggregate size the samples needed about 1125 points each. From this it was determined that we needed at least a minimum length of 6" to get enough points.

The cores were then marked at 6" sections and labeled from the top down. The top 6" sample of the core was labeled with a 1 and the next 6" sample was labeled a 2. This process was repeated until the bottom of the core was reached for each mix. An arrow was also drawn on each sample to show which direction was towards the bottom of the core, this was done so that during the entire process the orientation of the sample was not placed incorrectly. While dividing the cores up into 6" long sections if a section was split into two pieces due to a break in the core each piece was given a digit after a decimal point to differentiate between the pieces in that section. For example; if inside of the conventional concrete core sample S-6 had a break in it the piece closest to the top of the core was labeled S-6.1 and any proceeding pieces were labeled S-6.2 and so forth.

## Cutting

Cutting the concrete samples was done in two stages after being labeled. The goal of the cutting was to reduce the cylindrical sample to a flat rectangular sample that could be seen easily under a microscope. The two stages involved two different types of wet saws that made different cuts to the samples. This was done to ensure that a flat even surface was attained on the samples.

The first wet saw we used was to cut the long cores from the box into the 6" samples needed for testing. This larger saw, shown in Figure 1, was used for this task because it had a large clear area in which to place the long cores and would make the cut fast and clean. After using the large saw to cut the long cores the samples were brought to a smaller wet saw for two final cuts.

This smaller wet saw was used to transform the circular core into a rectangular shape shown in Figure 2. Figure 3 shows how the last two cuts were taken to achieve this sample. Two cuts were taken close to each side such that a rectangular testable sample was created by the two cuts. Cutting the cores in this fashion provided the testing environment with a level sample that makes it easier to keep in focus during microscope testing.

Figure 1: Large Wet Saw



Figure 2: Final Sample



Figure 3: Final Cuts



## Polishing

After cutting the concrete samples the final step of preparation before testing is polishing. The goal of polishing the samples is to provide a very smooth and even surface of which to view the sample with a microscope. An uneven testing surface will result in questionable data and will also prolong the test as the microscope must be re-focused with every change in elevation.

The polishing process is comprised of a type of wheel, similar to a potter's wheel, on which grit is applied. The surface on which the testing is required is placed face down on the wheel. The grit acts like sandpaper on the wheel and removes small layers of the face of the sample. This polishing process brings the surface of the concrete from a powdery rough finish to a smooth finish that will actually reflect light.

This is done by using several applications of grits, each with a different degree of fineness. The first grit applied is the roughest of the grits and is mainly used to reduce any large scratches left from cutting. This grit is applied for the most amount of time because it is most important. The first grit determines how well the finished polished sample comes out. The longer the sample is subject to this grit the smoother and more level the final sample will be.

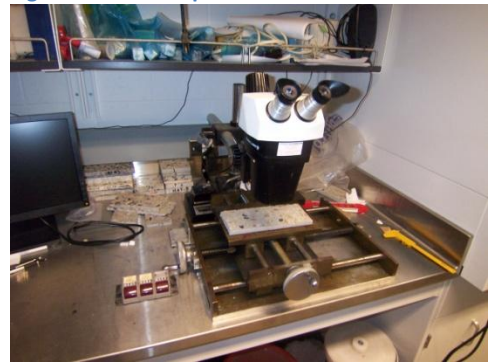
After removing all large scratches and any large abrasions of the face of the sample a finer grit is added to the sample. This improves on the smooth surface applied to the sample by the rough grit. A finer grit is then added to the wheel every so often to bring the sample to a glossy smooth finish. The surface of the sample is verified to be polished well enough by holding the sample up towards a light on the ceiling. Tilting the concrete slightly one can see the light from the ceiling lights reflected off of the freshly polished concrete surface, meaning it is good enough for testing.

## Testing

For the ASTM 457 testing each cut and polished sample had to be looked at in order to determine the air content within that sample. This was done using a microscope, shown in Figure 4, that would allow the tester to see in inner-makings of the sample at a magnified level. Each sample had to be checked for amount of paste, aggregate, and air voids that made up that particular section of concrete. This was done to determine the air percentage in the sample of the concrete.

Before the inspection process begins the plate in which the sample sits on under the micro scope must be leveled. This is done to keep the sample in focus through the entire inspection. The sample is also squared on the plate using markings painted onto the plate. This is done to ensure that while inspecting the sample the test is moving along a straight line across the sample.

Figure 4: Microscope



Starting in the upper left hand corner the tester then rotates the handle by one complete turn to move the sample  $1/10''$  to the right. After moving  $1/10''$  across the sample the tester determines if the crosshair of the microscope is located on paste, air, or aggregate. A counter device is incremented by one for the material the crosshair landed on. This is repeated again and again until the other side of the sample has been reached. Once the other end of the sample is reached the tester then places his/her numbers in a spread sheet. Inside of the spreadsheet the numbers are verified to add up to 60, as there are 60 tenths of an inch in a 6'' sample.

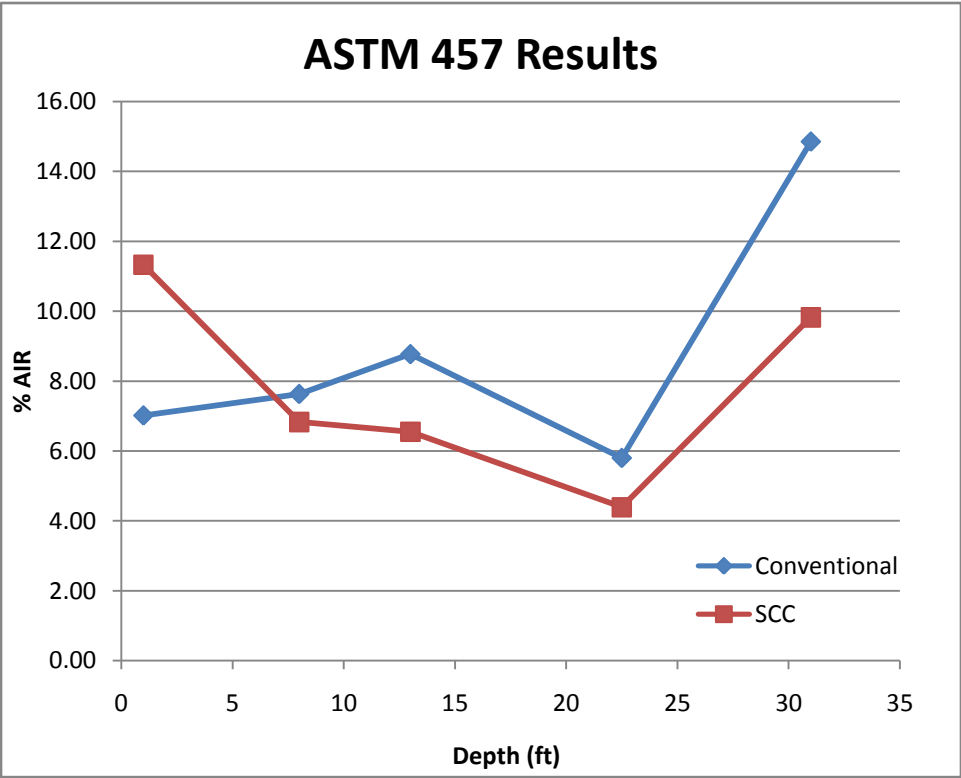
The next step is to turn the handle back and counting the number of air voids the cross hairs intersect during this pass on the sample. Once the tester reaches back to the start point the number of

air voids is recorded and the sample is then moved up 1/10" by another handle on the lower end of the plate on which the sample is sitting on. This process is repeated until the tester has reached the bottom of the sample and ended on the lower right hand corner of the sample. Once this has been completed there is sufficient information inside of the spreadsheet for it to perform all of the calculations needed by ASTM 457. Tables from this spreadsheet can be seen for all of the tests inside of the Appendix.

# Results

After completing the ASTM 457 test on 5 samples for each concrete there is a clear similarity between both samples. There were also several oddities found in the two samples of concrete after testing. The data from the tests are shown in Figure 5. The graph shows the different air percentage found in each sample throughout the entire depth of each core.

Figure 5: Test Data



The most notable find from this testing is that the air content of both samples is not predictable and doesn't vary linearly with depth.

## Conclusion

It appears that the topmost section of the SCC sample had an air content higher than any other portion of the core at 11.33%. Then the air content of the SCC varies between 4.39% and 6.83% from around 8.0' to 22.5' below the top. Then again the air content increases steadily until it maxes out at 9.82% at the bottom 31.0' below the top. The conventional concrete varied from 5.80% to 8.77% air from the top to about 22.5' down. Similar to the SCC sample the air content then rises to 14.86% at the bottom of the core.

The sudden rise in air content could be attributed to standing water in the forms of the piers. It was noted that for the initial 10' or so of the pour that water was present on the surface and could of attributed water void cavities. Water voids also appear near the surface of any surface that was compacted for finishing. This would explain the high air content near the surface of the SCC sample. Taking this into consideration if both samples are compared to each other from 8.0' to 22.5' the air content of SCC is 1-2% less than that of conventional concrete, but follows a similar pattern as seen in figure 5.

It should also be noted that many of the air voids in the sample appeared to be entrapped air instead of entrained air. The average void size appeared larger than 1mm suggesting they were the result of entrapped air. These large air voids can be seen in figure 2.

## Appendix

Lab Technician:	Ben Hall	Date	4/28/2010
Concrete type:	Conventional	Sample:	C-2
		Approx. Depth (ft):	1

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
31	6	23	60		11
31	4	25	60		14
37	3	20	60		17
35	2	23	60		18
37	5	18	60		14
36	7	17	60		12
35	6	19	60		10
36	2	22	60		9
36	0	24	60		8
38	2	20	60		11
43	4	13	60		13
36	5	19	60		12
37	6	17	60		17
36	5	19	60		12
37	6	17	60		19
38	5	17	60		11
37	3	20	60		13
35	6	19	60		15
35	3	22	60		9
$S_p$	$S_a$		$S_t$		$N$
686	80	374	1140		245

Distance Between Stops	$I$	0.1 in
Total Transverse Length	$T_t$	114 in
Air Content	$A$	7.017544 %
Void Frequency	$n$	2.149123
Paste Content	$p$	60.17544 %
Paste-Air Ratio	$p/A$	8.575
Average Chord Length	$l$	0.032653 in
Specific Surface	$\alpha$	122.5
Spacing Factor	$L$	0.048315



Lab Technician:	Sean Tarbox	Date	5/11/2010
Concrete type:	Conventional	Sample:	C-16
		Approx. Depth (ft):	8

Modified Point Count Method					
	Stop on		Count		Voids Intersected
	Paste	Air			
29	3	28	60		11
30	5	25	60		23
27	7	26	60		20
25	5	30	60		11
33	3	24	60		19
29	7	24	60		15
27	6	27	60		18
29	3	28	60		10
33	4	23	60		15
29	4	27	60		15
32	2	26	60		15
34	6	20	60		19
27	3	30	60		18
24	4	32	60		18
25	7	28	60		13
34	4	22	60		14
34	4	22	60		18
31	8	21	60		18
33	2	25	60		13
$S_p$	$S_a$		$S_t$		$N$
565	87	488	1140		303

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114	in
Air Content	$A$	7.631579	%
Void Frequency	$n$	2.657895	
Paste Content	$p$	49.5614	%
Paste-Air Ratio	$p/A$	6.494253	
Average Chord Length	$l$	0.028713	in
Specific Surface	$\alpha$	139.3103	
Spacing Factor	$L$	0.037464	

Lab Technician:	Ben Hall		Date	4/28/2010
Concrete type:	Conventional	Sample:	C-26	Approx. Depth (ft): 13

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
27	9	24	60		21
30	5	25	60		28
30	3	27	60		29
31	4	25	60		31
31	5	24	60		29
27	3	30	60		33
27	4	29	60		28
32	3	25	60		29
26	6	28	60		22
30	6	24	60		29
26	10	24	60		36
31	8	21	60		43
28	5	27	60		23
29	5	26	60		30
30	6	24	60		30
32	6	22	60		27
30	3	27	60		24
26	6	28	60		26
35	3	22	60		25
$S_p$	$S_a$		$S_t$		$N$
558	100	482	1140		543

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114	in
Air Content	$A$	8.77193	%
Void Frequency	$n$	4.763158	
Paste Content	$p$	48.94737	%
Paste-Air Ratio	$p/A$	5.58	
Average Chord Length	$l$	0.018416	in
Specific Surface	$\alpha$	217.2	
Spacing Factor	$L$	0.022423	

Lab Technician:	Sean Tarbox	Date	5/12/2010
Concrete type:	Conventional	Sample:	C-45
		Approx. Depth (ft):	23

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
29	2	30	61		11
25	3	32	60		14
31	4	26	61		11
29	2	29	60		18
25	4	31	60		19
34	4	22	60		16
30	7	24	61		10
34	2	25	61		12
30	4	25	59		11
28	4	29	61		16
35	2	25	62		14
33	3	26	62		11
37	4	20	61		17
35	2	25	62		6
33	5	23	61		9
31	7	23	61		12
33	1	28	62		10
32	4	24	60		9
31	3	26	60		11
$S_p$	$S_a$		$S_t$		$N$
595	67	493	1155		237

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	115.5	in
Air Content	$A$	5.800866	%
Void Frequency	$n$	2.051948	
Paste Content	$p$	51.51515	%
Paste-Air Ratio	$p/A$	8.880597	
Average Chord Length	$l$	0.02827	in
Specific Surface	$\alpha$	141.4925	
Spacing Factor	$L$	0.042493	

Lab Technician:	Eric Picard		Date	4/23/2010
Concrete type:	Conventional	Sample:	C-63	Approx. Depth (ft): 31.5

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
22	12	25	59		25
24	8	27	59		32
21	11	27	59		30
31	8	20	59		26
25	10	24	59		28
28	11	20	59		23
25	6	28	59		28
30	6	23	59		19
38	5	16	59		15
27	7	25	59		21
30	7	22	59		26
34	6	19	59		24
23	11	25	59		20
30	12	17	59		18
29	9	21	59		21
27	7	25	59		30
26	13	20	59		22
			0		0
			0		0
$S_p$	$S_a$		$S_t$		$N$
470	149	384	1003		408

Distance Between Stops	$I$	0.1 in
Total Transverse Length	$T_t$	100.3 in
Air Content	$A$	14.85543 %
Void Frequency	$n$	4.067797
Paste Content	$p$	46.85942 %
Paste-Air Ratio	$p/A$	3.154362
Average Chord Length	$l$	0.03652 in
Specific Surface	$\alpha$	109.5302
Spacing Factor	$L$	0.028799



Lab Technician:	Eric Picard		Date	5/3/2010
Concrete type:	Self Consolidating	Sample:	S-2	Approx. Depth (ft): 1

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
36	10	13	59		21
37	6	16	59		19
36	4	19	59		16
37	8	14	59		19
45	4	10	59		21
39	7	13	59		17
40	6	13	59		15
40	8	11	59		16
41	9	9	59		16
43	5	11	59		12
45	7	7	59		10
40	7	12	59		11
39	6	14	59		13
37	10	12	59		16
42	9	8	59		18
43	4	12	59		8
43	3	13	59		9
38	5	16	59		10
40	9	10	59		14
$S_p$	$S_a$		$S_t$		$N$
761	127	233	1121		281

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	112.1	in
Air Content	$A$	11.32917	%
Void Frequency	$n$	2.50669	
Paste Content	$p$	67.88582	%
Paste-Air Ratio	$p/A$	5.992126	
Average Chord Length	$l$	0.045196	in
Specific Surface	$\alpha$	88.50394	
Spacing Factor	$L$	0.056848	

Lab Technician: Sean Tarbox		Date 5/11/2010
Concrete type: Self Consolidating	Sample: S-15	Approx. Depth (ft): 7.5

Modified Point Count Method					
Stop on	Aggregate		Count		Voids Intersected
	Paste	Air			
34	2	24	60		11
35	3	22	60		11
33	4	23	60		11
31	9	20	60		16
24	5	31	60		6
27	3	30	60		6
29	3	28	60		6
33	2	25	60		5
30	4	26	60		6
30	2	28	60		6
30	5	25	60		9
32	5	23	60		11
37	5	18	60		9
32	5	23	60		11
27	3	30	60		8
27	6	28	61		10
32	5	23	60		10
30	3	28	61		11
27	4	29	60		7
$S_p$	$S_a$		$S_t$		$N$
580	78	484	1142		170

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114.2	in
Air Content	$A$	6.830123	%
Void Frequency	$n$	1.488616	
Paste Content	$p$	50.78809	%
Paste-Air Ratio	$p/A$	7.435897	
Average Chord Length	$l$	0.045882	in
Specific Surface	$\alpha$	87.17949	
Spacing Factor	$L$	0.06366	

Lab Technician:	Sean Tarbox		Date	5/12/2010
Concrete type:	Self Consolidating	Sample:	S-25	Approx. Depth (ft): 12.5

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
31	1	28	60		3
29	1	28	58		6
31	2	28	61		8
33	1	26	60		10
34	4	23	61		14
19	4	36	59		13
39	2	20	61		13
31	5	25	61		12
34	7	19	60		19
31	1	29	61		11
27	3	31	61		18
30	6	24	60		14
30	3	27	60		11
32	7	21	60		15
31	6	22	59		11
28	5	28	61		11
32	7	22	61		14
28	5	27	60		11
27	5	29	61		8
$S_p$	$S_a$		$S_t$		$N$
577	75	493	1145		222

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114.5	in
Air Content	$A$	6.550218	%
Void Frequency	$n$	1.938865	
Paste Content	$p$	50.39301	%
Paste-Air Ratio	$p/A$	7.693333	
Average Chord Length	$l$	0.033784	in
Specific Surface	$\alpha$	118.4	
Spacing Factor	$L$	0.047601	



Lab Technician: Sean Tarbox		Date 4/26/2010
Concrete type: SCC	Sample: S-45	Approx. Depth (ft): 22.5

Modified Point Count Method					
Stop on	Aggregate		Count		Voids Intersected
	Paste	Air			
30	3	27	60		9
30	1	29	60		20
18	6	36	60		10
36	5	19	60		9
29	1	30	60		14
26	5	29	60		17
33	4	23	60		14
32	3	25	60		15
28	3	29	60		9
28	2	30	60		14
29	3	28	60		12
32	3	25	60		6
33	1	26	60		19
29	0	31	60		8
32	3	25	60		17
28	1	31	60		10
34	2	24	60		14
30	2	28	60		14
28	2	28	58		7
$S_p$	$S_a$		$S_t$		$N$
565	50	523	1138		238

Distance Between Stops	$I$	0.1 in
Total Transverse Length	$T_t$	113.8 in
Air Content	$A$	4.3936731 %
Void Frequency	$n$	2.0913884
Paste Content	$p$	49.648506 %
Paste-Air Ratio	$p/A$	11.3
Average Chord Length	$l$	0.0210084 in
Specific Surface	$\alpha$	190.4
Spacing Factor	$L$	0.0351632

Lab Technician: Sean Tarbox		Date 4/26/2010
Concrete type: SCC	Sample: S-56	Approx. Depth (ft): 28

Modified Point Count Method					
Stop on		Aggregate	Count		Voids Intersected
Paste	Air				
26	6	28	60		15
31	4	25	60		24
31	4	25	60		25
28	5	27	60		17
30	6	24	60		15
29	4	27	60		20
30	6	24	60		21
23	8	29	60		21
28	6	26	60		19
33	5	22	60		22
31	5	24	60		13
24	5	31	60		24
29	6	25	60		19
31	6	23	60		22
26	5	29	60		13
25	8	27	60		16
26	4	30	60		19
32	6	22	60		21
26	7	27	60		16
$S_p$	$S_a$		$S_t$		$N$
539	106	495	1140		362

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114	in
Air Content	$A$	9.2982456	%
Void Frequency	$n$	3.1754386	
Paste Content	$p$	47.280702	%
Paste-Air Ratio	$p/A$	5.0849057	
Average Chord Length	$l$	0.0292818	in
Specific Surface	$\alpha$	136.60377	
Spacing Factor	$L$	0.0341699	

Lab Technician: Ben Hall		Date 4/28/2010
Concrete type: Self-Consolidating	Sample: S-65	Approx. Depth (ft): 32.5

Modified Point Count Method					
Paste	Stop on		Count		Voids Intersected
	Air	Aggregate			
25	7	28	60		39
20	9	31	60		25
23	6	31	60		32
27	8	25	60		31
25	5	30	60		22
23	8	29	60		20
28	6	26	60		21
26	7	27	60		20
22	7	31	60		32
23	5	32	60		23
33	2	25	60		26
27	7	26	60		20
28	8	24	60		21
28	5	27	60		18
29	4	27	60		16
30	5	25	60		20
30	4	26	60		28
30	3	27	60		25
28	6	26	60		35
$S_p$	$S_a$		$S_t$		$N$
505	112	523	1140		474

Distance Between Stops	$I$	0.1	in
Total Transverse Length	$T_t$	114	in
Air Content	$A$	9.824561	%
Void Frequency	$n$	4.157895	
Paste Content	$p$	44.29825	%
Paste-Air Ratio	$p/A$	4.508929	
Average Chord Length	$l$	0.023629	in
Specific Surface	$\alpha$	169.2857	
Spacing Factor	$L$	0.026096	