

**USE OF SELF-CONSOLIDATING CONCRETE FOR
BRIDGE DRILLED SHAFT CONSTRUCTION**



FINAL PROJECT REPORT

by

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Prepared in cooperation with the:

State of Hawaii
Department of Transportation
Harbors Division
and
U.S. Department of Transportation
Federal Highway Administration



**UNIVERSITY OF HAWAII
COLLEGE OF ENGINEERING**

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

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16. Abstract This report is based on research performed at the University of Hawaii on the use of Self-Consolidating Concrete for construction of drilled shafts for the North Kahana Bridge Replacement project on Oahu, Hawaii. Drilled shaft construction has long been susceptible to poor concrete consolidation due to inaccessibility and heavy reinforcement cages preventing movement of concrete from interior to exterior of the drilled shaft. Because the shaft concrete is never exposed for visual inspection, these defects sometimes go undetected. Cross-hole sonic logging of drilled shafts is often used to ensure that the interior concrete is sound, but cannot be used to inspect the cover concrete outside the reinforcement cage. Self-consolidating concrete (SCC) has gained popularity for use in drilled shafts because of its ability to pass through congested reinforcement and fully fill the drilled shaft without the need for mechanical consolidation. In an attempt to utilize SCC for drilled shaft construction in Hawaii, the Hawaii Department of Transportation (HDOT) applied for and received funding from the Federal Highway Administration (FHWA) to experiment with SCC during construction of the drilled shafts on the North Kahana Bridge Replacement project on Oahu. The Civil and Environmental Engineering Department (CEE) of the University of Hawaii at Manoa (UHM) was commissioned to perform this study. This report represents the final report on this project. The research project was performed in a number of stages, each resulting in a research report documenting that phase of the work. The abstracts and major conclusions from these reports are included here, along with references to the full research reports available online. In addition, interim reports to HDOT are included that show the progression of decision-making during the project.					
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Executive Summary

This report is based on research performed at the University of Hawaii on the use of Self-Consolidating Concrete for construction of drilled shafts for the North Kahana Bridge Replacement project on Oahu, Hawaii.

Drilled shaft construction has long been susceptible to poor concrete consolidation due to inaccessibility and heavy reinforcement cages preventing movement of concrete from interior to exterior of the drilled shaft. Because the shaft concrete is never exposed for visual inspection, these defects sometimes go undetected. Cross-hole sonic logging of drilled shafts is often used to ensure that the interior concrete is sound, but cannot be used to inspect the cover concrete outside the reinforcement cage.

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This final report is organized as follows:

Development of Self-Consolidating Concrete for Drilled Shaft Applications in Hawaii by Renee Ishisaka and Ian N. Robertson, August 2007.

This report details the development of SCC mixtures and draft specifications for use of SCC in drilled shaft construction. The research on which this report is based was performed prior to construction of the trial shafts at the North Kahana Bridge project. Only the abstract, conclusions and draft specifications (See Appendix A) from this report are included herein, and the reader is referred to the original report (available online) for further details of this study. (Pages 1-4)

Download at: <http://cee.hawaii.edu/reports/UHM-CEE-07-05.pdf>

Trial Placement of Ameron mixture 4539 SCC - UH Manoa, Wednesday, January 13, 2010 by Ian N. Robertson and Gaur P. Johnson.

This report was submitted to HDOT to provide details of the trial placement of an Ameron SCC mixture proposed for use in the SCC shafts at the North Kahana Bridge project. The report is included in its entirety. (Pages 5-16)

Placement of SCC and CC in load test shafts at N. Kahana Bridge - Preliminary Thermal Data by Ian N. Robertson and Gaur P. Johnson.

This report was submitted to HDOT to document thermal measurements taken during construction of the SCC and CC trial shafts and load test shafts at the North Kahana Bridge project. The report is included in its entirety. (Pages 17-28)

Preliminary Report on N. Kahana Bridge SCC Trial Shafts - N. Kahana SCC and CC Shaft Comparison by Ian Robertson and Gaur Johnson, July 1, 2010.

This report was submitted to HDOT to assist in the decision making process as to whether SCC should be used in the production shafts for the North Kahana Bridge project. Based on visual observations from the cores recovered from the SCC and CC trial and load test shafts, and on preliminary results from the cross-hole analysis and load tests performed on the shafts, it was recommended that SCC not be used for the production shafts. The report is included in its entirety. (Pages 29-32)

Quantifying Segregation in Self-Consolidating Concrete through Image Analysis by Daniel Johnson, Gaur Johnson and Ian N. Robertson, May 2010.

This research report documents the development of an image analysis approach to quantifying segregation in hardened SCC concrete. The approach was used to assess segregation of SCC cylinders made from SCC used in the North Kahana Bridge project trial shafts. Only the abstract and conclusions from this report are included herein, and the reader is referred to the original report (available online) for further details of this study. (Pages 33-34)

Download at: <http://cee.hawaii.edu/reports/UHM-CEE-10-04.pdf>

Determining In-Place Material Properties of Concrete in Drilled Shafts by Jennifer A. Abayon, Gaur P. Johnson and Ian N. Robertson, May 2011.

This research report documents an extensive analysis of the static and dynamic properties of the concrete cores recovered from the SCC and CC trial shafts placed at the North Kahana Bridge Project. Only the abstract and conclusions from this report are included herein, and the reader is referred to the original report (available online) for further details of this study. (Pages 35-36)

Download at: <http://cee.hawaii.edu/reports/UHM-CEE-11-07.pdf>

Appendix A: Draft SCC Specifications (Pages 37-50)

Provides the draft SCC specifications developed for use during construction of the trial shafts at the North Kahana Bridge project.

Appendix B: Hawaiian Connections Article (Pages 51-53)

Provides a copy of an article on the trial placement of SCC at UH Manoa in the Local Technical Assistance Program newsletter, Hawaiian Connections, Vol. 12, No. 1, Spring 2010

Acknowledgements

This report draws from research work performed by a number of graduate research students at UH Manoa, including Renee Ishisaka, Daniel Johnson, Jennifer Abayon and Tevita Akau'ola. Their contribution to this effort is greatly appreciated. A number of undergraduate students have also assisted during the course of this project, as recognized in the individual research reports referenced herein. Their assistance is also acknowledged.

Dr. Gaur Johnson is thanked for his considerable effort in directing and supervising many of the students working on this project, and with his assistance during field instrumentation of the drilled shafts at the North Kahana Bridge.

This research was funded by an Innovative Bridge Research and Construction (IBRC) grant from the Federal Highway Administration, through the Research Branch of the Hawaii Department of Transportation. This funding is gratefully acknowledged.

The contents of this report reflect the view of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Hawaii, Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Development of Self-Consolidating Concrete for Drilled Shaft

Applications in Hawaii

By

Renee Ishisaka and Ian N. Robertson

UHM Research Report – UHM/CEE/07-05 – August 2007

Available for Download at: <http://cee.hawaii.edu/reports/UHM-CEE-07-05.pdf>

Abstract

Self Consolidating Concrete (SCC) is a high flow concrete that provides various advantages over traditional concrete. It can flow between dense reinforcing steel under its own weight, reducing or even eliminating the need for mechanical consolidation. It can also reduce finishing time and produce a higher quality end result. SCC was developed during the late 1980's in Japan and has since become quite common in Japanese and European construction. Over the past few years, there has been increased interest in this product in the United States, especially for precast construction. Research has been done in several states, however, many recommend using rounded aggregate, such as river gravel, to improve flow. The aggregate that is readily available in Hawai'i is made from crushed basalt and is very angular. This may cause problems in getting the mix to flow properly without segregation.

In traditional drilled shaft construction, reinforcing cages are often very dense and the larger aggregate tend to interfere with the concrete flow through the reinforcing steel and into the outer areas of the shaft. Debris from shaft walls can also interfere with the concrete's ability to fill properly. These obstructions often result in large voids, inadequate coverage of reinforcing steel and even exposed reinforcing steel. It is also difficult to uniformly vibrate the concrete in these shafts and over-vibration can lead to segregation of the concrete. Using SCC in drilled shaft construction would minimize these problems since the fluidity of the mix should carry larger aggregates through dense reinforcing steel and completely surround the reinforcing steel to protect it from corrosion. This in turn will provide more uniform coverage as well as prevent the reinforcing steel from being exposed to the ground.

The objective of this project is to explore the viability of using SCC for drilled shaft construction in Hawai'i. The scope of this report covers the first phase of a larger project. It addresses drafting specifications, working with and gaining an understanding of the material, and evaluating the feasibility of using SCC for local projects, particularly drilled shaft construction. The draft specifications are included as Appendix A.

Preliminary specifications were drafted based on literature review of research that has already been conducted by other institutions and the needs of drilled shaft construction. The locally available aggregates are significantly different from those used in “traditional” SCC and could affect the quality of the SCC produced. The angularity and high aspect ratio of the local aggregates may increase the aggregate interlocking and inhibit flow. Testing was performed to understand the effects of the aggregates and commonly used admixtures on the concrete behavior and to develop viable mix designs. Research from various institutions indicates that the mixing method can significantly affect the characteristics of SCC. Consequently, a standard mixing procedure was developed and used to help reduce the number of variables present during the trials. As trial mixes were made with the local materials, a set of mix design guidelines were developed and the specifications were refined as the behavior of the material was experienced firsthand. SCC mix trials were conducted using aggregates from both of Honolulu’s main quarries, Halawa and Kapa’a. A sample mix was also batched at a local ready mix plant to observe any differences caused by producing a large volume in a plant setting.

[Please refer to the full report available online for the body of the report]

Conclusions

- The use of SCC for drilled shaft pile construction in Hawai‘i is promising.
- The effect of the angularity of the aggregates can be overcome by proper mix proportioning, the appropriate use of admixtures, and retempering with HRWR on site.
- The physical properties of the aggregate appear to influence the mix behavior. This became evident when attempting to use the same mix design with aggregates from the two different quarries (Kapa’a and Halawa).
- The fresh properties of SCC are very sensitive to overall water content, as well as aggregate water content.
- Mixes with a water cement ratio less than 0.5 typically exhibit retention of the desired flow characteristics for less than 30 minutes. On site re-dosing with HRWR (retempering) immediately before placement seems to be the best option for obtaining the desired flow rates at the time of placement.
- High range water reducers (HRWR) are important to obtain the desired flow characteristics but cause segregation and excessive bubbling in high quantities.
- HRWR should not be used in doses higher than 20 oz./cwt.
- Viscosity modifying admixtures reinforce the stability of the mix, it cannot “create” it.
- Retarding admixtures such as Delvo or Daratard HC are ineffective at prolonging the time frame for desirable flow characteristics. They also seem to produce less stable mixes and should be avoided unless time between mixing and placement will exceed 90 minutes.
- Using nine sacks of cement per cubic yard versus eight sacks per cubic yard produced a more workable mix.

- A water cement ratio of 0.45 appears to be the most promising for both quarries.
- The idea of the modified segregation column is promising as a more manageable alternative to the segregation column, however, more testing needs to be done with varying aggregate sizes and segregation levels to produce a reliable correlation.
- For retempering with HRWR on site, enough HRWR should be added at the batching plant to produce a roughly self leveling mix and HRWR should be added on site in approximately 1.5 oz/cwt increments on site until the desired flow characteristics are obtained.
- Retempering does not appear to adversely affect the performance of SCC. In some instances, it seemed to produce a more desirable product.
- The slump flow and J-Ring are the tests best suited for field qualification because of their portability and ease of execution.
- The traditional segregation column is not practical. Segregation columns in general are not suitable for field qualification because they cannot provide immediate results.

Recommendations

- More testing should be done with respect to retempering. It is recommended that more mix trials be conducted to determine the maximum amounts of HRWR that are tolerated by each mix initially and after each retempering.
- Further testing to incorporate retarding admixtures, such as Delvo, while maintaining a stable mix should be done to determine the viability of SCC when faced with extended transport/placement times.
- The modified segregation column is a much more manageable alternative to the traditional segregation column. It is recommended that further testing be done to determine if it is accurate. This testing should include multiple tests with both the segregation column and modified segregation column to provide a better basis of variability. These tests should also be done on mixes with varying amounts of visual segregation.



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Trial Placement of Ameron mixture 4539 SCC

UH Manoa, Wednesday, January 13, 2010

Ian N. Robertson, Ph.D., S.E. and Gaur P. Johnson, Ph.D., S.E.

Summary

This document briefly presents the results of the trial placement of SCC provided by Ameron for the North Kahana Bridge SCC drilled shafts. As required in the project specs, Ameron provided a truck with 4 cu yds of the SCC mixture planned for use in the SCC trial shaft and SCC load test shaft at the bridge project. The mixture delivered to UH was the 4-hour retarded version of 4539SCC (see Appendix for mixture design). The evaluation at UH Manoa was performed to verify that the SCC would meet the project specifications and provide adequate flow and filling properties for the field drilled shafts.

Evaluation Procedure

The evaluation was performed using slump flow, J-ring, T-50 and segregation tests at 30 minute intervals after concrete batching. In addition, three 1 cu yd forms with rebar similar to that planned for the drilled shafts (Figure 1), were placed at 1, 2 and 3 hours after concrete batching. Finally, slump tests were performed at 4 and 5 hours after concrete batching. Figure 2 shows a typical set of slump flow and J-ring tests, while Figure 3 shows placement of SCC in one of the 1 cu yd forms. Figure 4 shows the flow and filling potential as the SCC passes through and around the reinforcement cage.



Figure 1: Trial placement 1 cuyd form with reinforcing cage matching drilled shaft reinforcement



Figure 2: Typical slump flow and J-ring tests



Figure 3: Placement of SCC by pump hose at bottom of form behind reinforcing cage



Figure 4: Good flow and filling characteristics around bundled vertical bars

Evaluation Results

Figure 5 shows the slump flow measurements taken every 30 minutes after batching. The first 5 readings were within the 23 ± 3 " specified range. During this time, two forms were filled at 1 and 2 hours after batching. The concrete showed excellent flow and filling potential for both forms, even though the second was placed when the slump flow matched the lower limit of 20". Prior to placement of the third form, the slump flow measured 19.5", just below the 20" lower limit. Water was added to the remaining concrete in the truck (approximately 1.5 cuyd) at 1.33 gal/cuyd. The design mix allows for up to 2 gal/cuyd additional water to increase slump flow at the site. This water addition increased the slump flow to 23" as shown in Figure 5. The third form was then filled, with flow and filling characteristics identical to the first two forms.

J-ring tests were performed along with the slump flow tests at 30 minute intervals. The difference between the slump flow without the J-ring, and that with the J-ring represents the ability of the mix to pass through a reinforcing cage. Figure 6 shows that this J-ring difference tended to exceed the 2" maximum currently in the project specs. However, the concrete was able to flow through and around the drilled shaft reinforcing cage without apparent segregation and with complete filling. It was therefore concluded that the 2" spec may be more stringent than necessary for this mixture. It is proposed that this spec be revised to 3" for the field placement of SCC at the N. Kahana bridge project. After the addition of water at the 3 hour mark, this 3" limit was exceeded by 0.5" as seen in Figure 6. This did not appear to adversely affect the filling ability during placement of the Form 3.

Throughout all slump flow tests, the Visual Stability Index, VSI, was consistently very good (0 or 0.5 compared with a maximum limit of 1.5) (Figure 7). This agreed with the observation that there was minimal segregation or bleeding during placement of the three forms.

The T-50 times, which represent the speed with which the SCC concrete reaches a 50cm diameter circle during the slump flow test, were consistently below the recommended lower limit (Figure 8). This is an indication that the SCC mixture does not have as much fine material as may typically be expected. However, there was no apparent detrimental consequence of this low T-50 time for this application, so it is recommended that this spec limit be ignored during field placement of the SCC trial shafts.

During this trial placement, we experimented with a modified version of a European standard for segregation resistance. This test involves allowing the SCC to settle in a bucket for 15 minutes. A portion of this concrete is then poured from the bucket onto a #5 sieve and allowed to sit for 2 minutes. The amount passing the #5 sieve is then compared with the total concrete poured onto the sieve to determine the amount of paste segregation. During the trial evaluation, this ratio, known as the segregation resistance, was consistently below the recommended maximum limit of 0.20 (Figure 9).

Concrete temperature was measured in two locations within the second 1cuyd form. One thermistor was placed at 1" from the top of the concrete, while the other was placed in the center of the 1 cuyd form (ie. 18 inches from the edge in all directions). Another thermistor was placed in the center of a 6"x12" concrete cylinder stored in a plastic mold adjacent to the 1 cuyd form. This cylinder was cast at the same time as the 1 cuyd form. Finally the ambient temperature was recorded at the datalogger. Figure 10 shows the temperature variation at these four locations in degrees Celsius, while Figure 11 shows the results in degrees Fahrenheit. Form 2 was placed at

11:30AM on January 13, 2010. The temperatures were recorded every 5 minutes for the next 31 hours, followed by hourly readings for the next 5 days.

The ambient temperature showed diurnal variations between approximately 22 and 25°C (72 and 77°F). The temperature at the center of the 6"x12" cylinder climbed to 32°C (90°F) at 7.5 hours after placement and then declined to match the ambient temperature after about 4 days. The temperature measured at 1" from the surface of the 1 cuyd concrete pour initially followed the same trend as the concrete cylinder, but with lower temperatures because it is closer to the concrete surface. However, as the interior temperature of the 1 cuyd concrete increased to a peak of 65°C (149°F) at 27 hours after placement (2:30PM on January 14), the edge temperature elevated to a peak of 34°C (93°F). The maximum gradient between interior and exterior concrete was 33°C (59°F) occurring 22 hours after the pour at 9:30AM on January 14.

Future Tests

Two concrete cylinders (6"x12") were made at 30 minute interval after concrete batching. Some of these cylinders will be tested in compression at 28 days age to determine elastic modulus and compressive strength of the concrete. Others will be used to investigate segregation using a digital scanning technique developed as part of this project. The results of this segregation evaluation will be compared with the wet concrete segregation tests performed during concrete placement.

Once the three 1 cuyd forms have reached 28 days age, the forms will be stripped and a number of 4" diameter cores will be removed from the top and bottom of each cube. These cores will be analyzed using the same digital scanning technique to determine the extent of segregation between top and bottom of the concrete pour. The results of this segregation evaluation will be compared with the wet mix segregation results and the concrete cylinder segregation evaluation.

Four 6"x12" concrete cylinders with embedded vibrating wire strain gages were poured at the same time as Form 2. Two of these cylinders will be loaded into a creep frame seven days after concrete placement, while the other two will serve as reference shrinkage cylinders. The creep and shrinkage specimens will be stored at 50% relative humidity and 21°C (70°F) in the basement of the Structures Laboratory at UH, and monitored for at least three months.

Conclusion

Based on the initial evaluation performed at UH and described in this report, Ameron mixture 4539SCC with 4-hour retarder is approved for placement in the trial SCC shafts at the N. Kahana Bridge project. Ameron also has developed a 6-hour retarded version of the same mixture by increasing the Pozzoloth 100XR. Although this 6-hour mixture was not evaluated at UH, we have no reason to believe that it will not satisfy the project specifications. If the 6-hour mixture is used during the SCC trial shaft placement, and problems are observed during field testing, it is recommended that the 4-hour mixture be used in the subsequent SCC loadtest shaft.

A more detailed evaluation of this concrete mixture will be possible after the 28 day strength and segregation tests are completed. Creep and shrinkage results will also be evaluated once they are available.

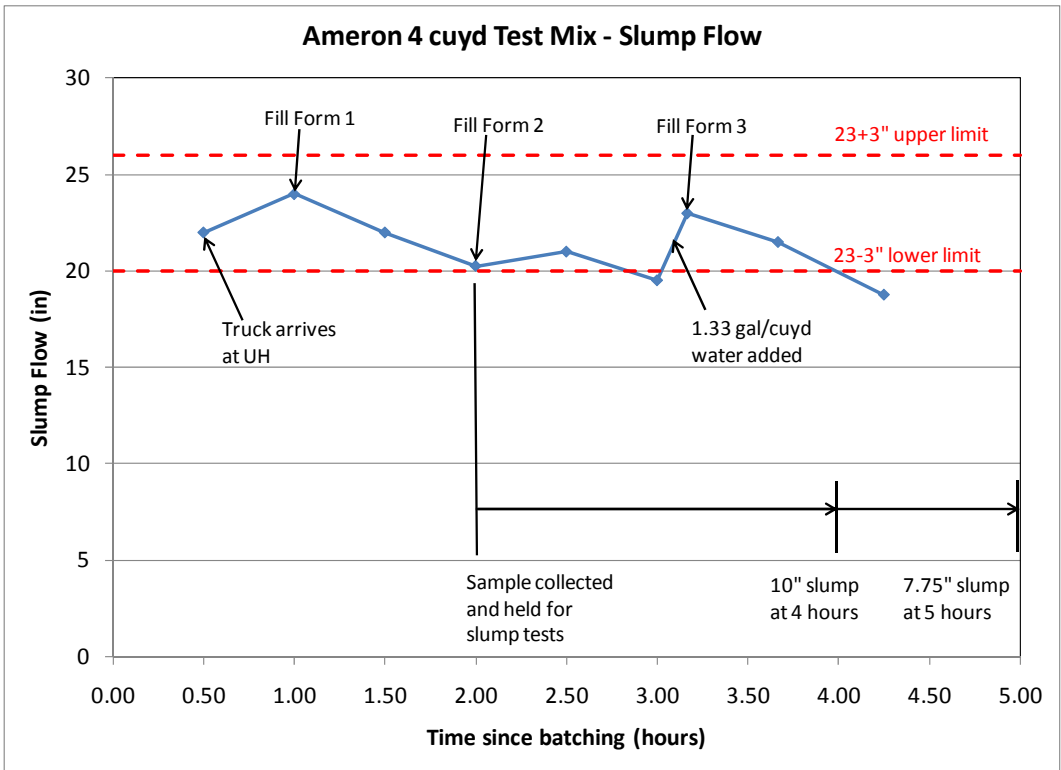


Figure 5: Slump flow results

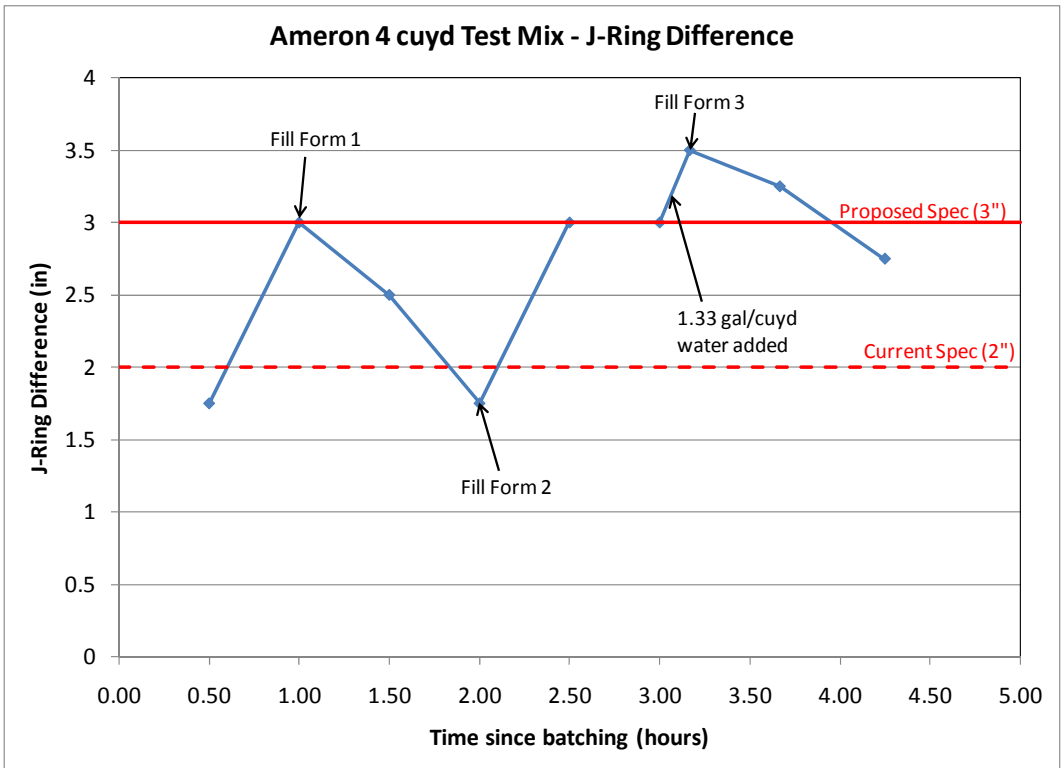


Figure 6: J-Ring difference

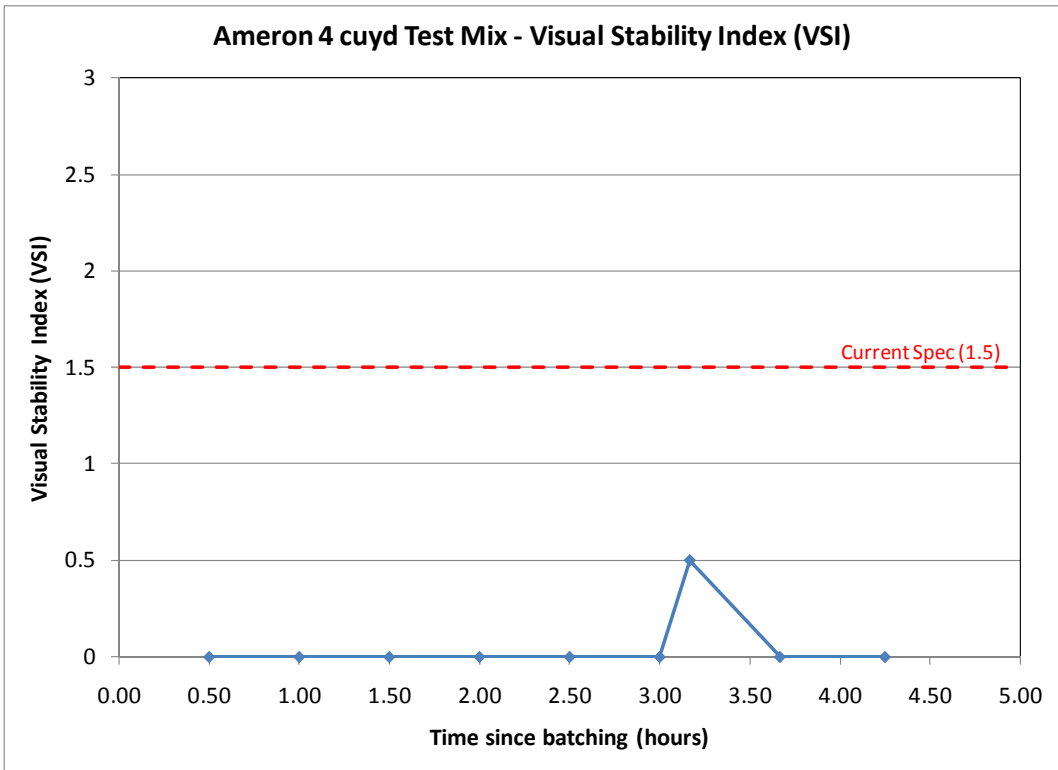


Figure 7: Visual stability index (VSI)

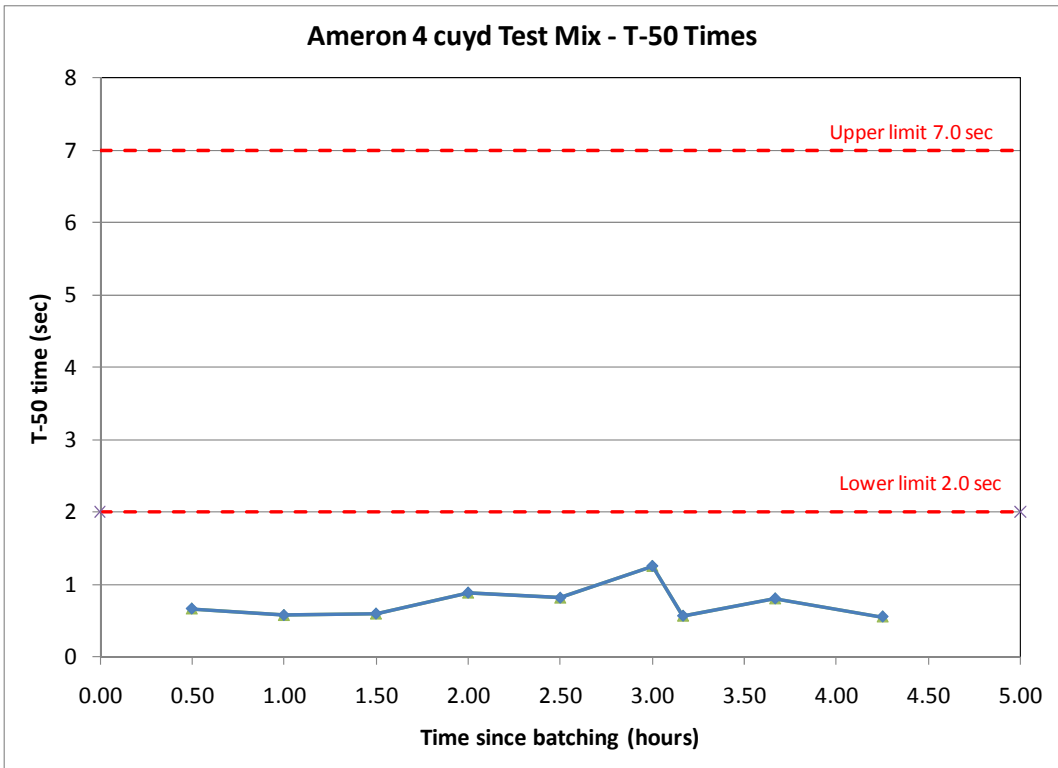


Figure 8: T-50 time

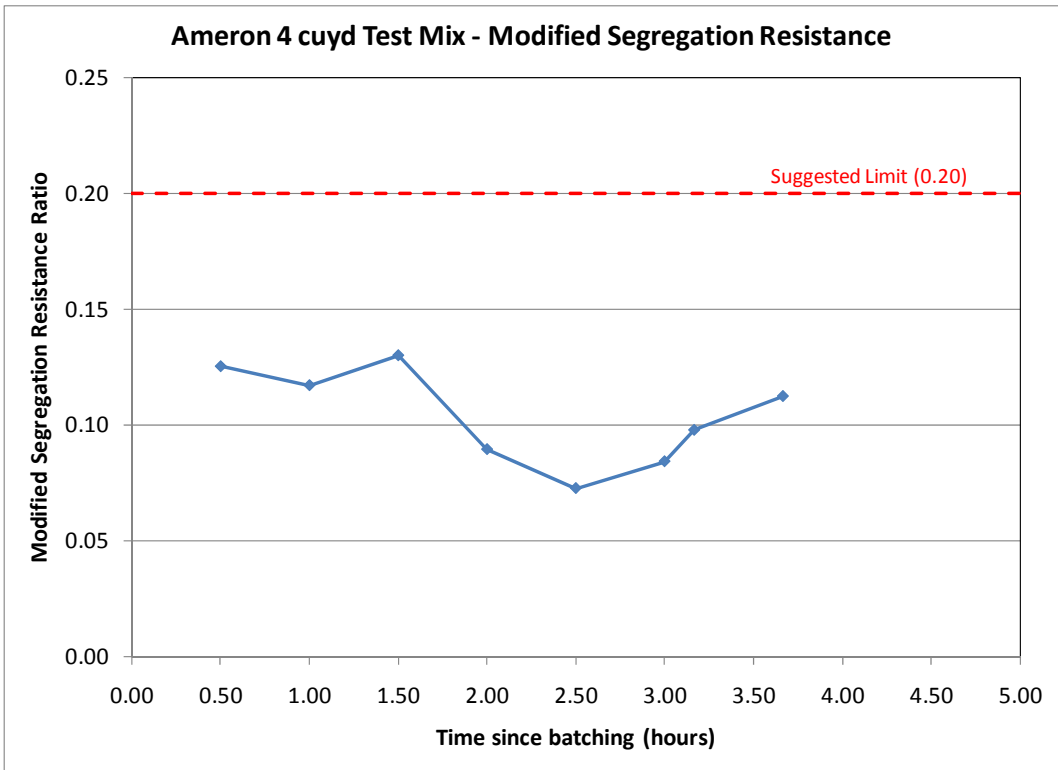


Figure 9: Modified Segregation Resistance Ratio

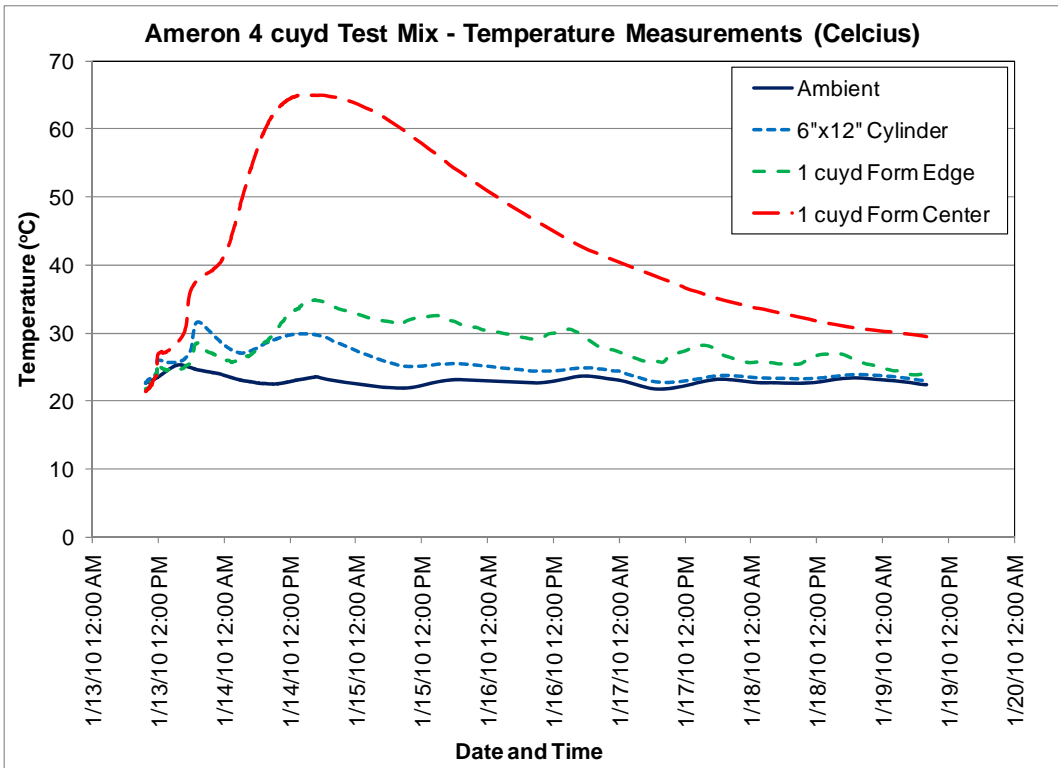


Figure 10: Temperature measurements (Celcius)

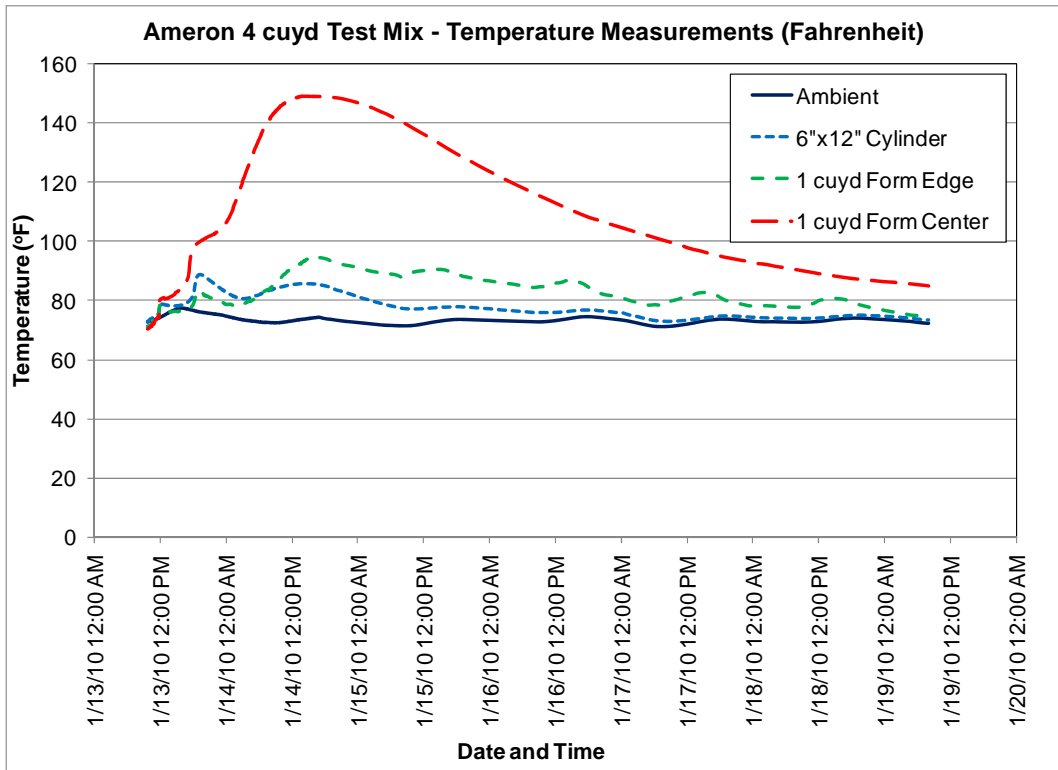


Figure 11: Temperature measurements (Fahrenheit)

APPENDIX

**AMERON CONCRETE MIX SUBMITTAL
MIX NUMBER 4539SCC**



Concrete Mix Submittal

Effective Date: 1/6/2010

Submittal Number: 7283

To: UNIVERSITY OF HAWAII, MANOA

Project: REPLACEMENT OF NORTH KAHANA STREAM BRIDGE

Gentlemen: The following mixes are certified to comply with the guidelines of ACI 211.1 "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete and ASTM C-94 "Standard Specification for Ready Mixed Concrete with option A, B, or C as indicated: **Option C.**

The mixes may be modified to maintain yield, slump, setting time and strength. Prior to unloading, a maximum of two (2) gallons of water per cubic yard, may be added provided that the specification limits for slump, w/c and time are not exceeded.

Remarks With extra Retarder up to four (4) hours.

Material	Coarse Agg	Fine Agg	Fine Agg	Cement	Admix	Admix	Admix	Admix
Type	Basalt	Coral	Basalt	I / II	A	B	F	Rheomac VM
Source	Kapaa	Maui	Kapaa	Hawaiian	M Builders	M Builders	M Builders	Master Bldrs.
Spec	ASTM C-33	ASTM C-33	ASTM C-33	ASTM C-150	ASTM C-494	ASTM C-494		

Weights in Lbs Per Cubic Yard (SSD)

		Mix: 4500 PSI 3/8" SELF CONSOLIDATING					
Item code	Abs	Sp.G.	4539SCC				
Slump			25" - 27" Spread				
3/8" Chip (#8)	3.5	2.70	1200				
Dune Sand	2.0	2.65	305				
Conc Sand	4.5	2.65	1272				
Cement		3.15	799 (8.5 sk)				
Water		1.00	358 (43 gal)				
Pozz 220N			3 oz/cwt				
Pozz 100XR			3 - 6 oz/cwt				
Glenium NS			8 - 10 oz/cwt				
VMA			4 oz/cwt				
Air			2 %				

Respectfully submitted,

Rudy S. Botardo
Rudy S. Botardo
Technical Service



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Placement of SCC and CC in load test shafts at N. Kahana Bridge

Preliminary Thermal Data

Ian N. Robertson, Ph.D., S.E. and Gaur P. Johnson, Ph.D., S.E.

This preliminary report provides a comparison of temperature measurements for the Self-Consolidating Concrete, SCC Load Test Shaft and the Conventional Concrete, CC (AKA: Tremie mix) Load Test Shaft at the N. Kahana Bridge project.

SCC Load Test Shaft:

Placement was performed on January 28, 2010, from 9:55AM to 2:27PM, with a final 5 cuyd placement at 4:08PM. Data from the thermal sensors were recorded continuously from 6:00PM on January 28 till 10:30AM on February 6, 2010. Figure 12 to Figure 16 show samples of the raw temperature measurements at various depths in the SCC load test shaft. Sensors A and E are located on the reinforcing cage at either side of the shaft. Sensor C is located at the center of the shaft, while sensors B and D are located at quarter points across the section. Sensors AX and EX are located on the outside of the cage at selected locations. Sensors that failed or provided unreliable readings have been ignored.

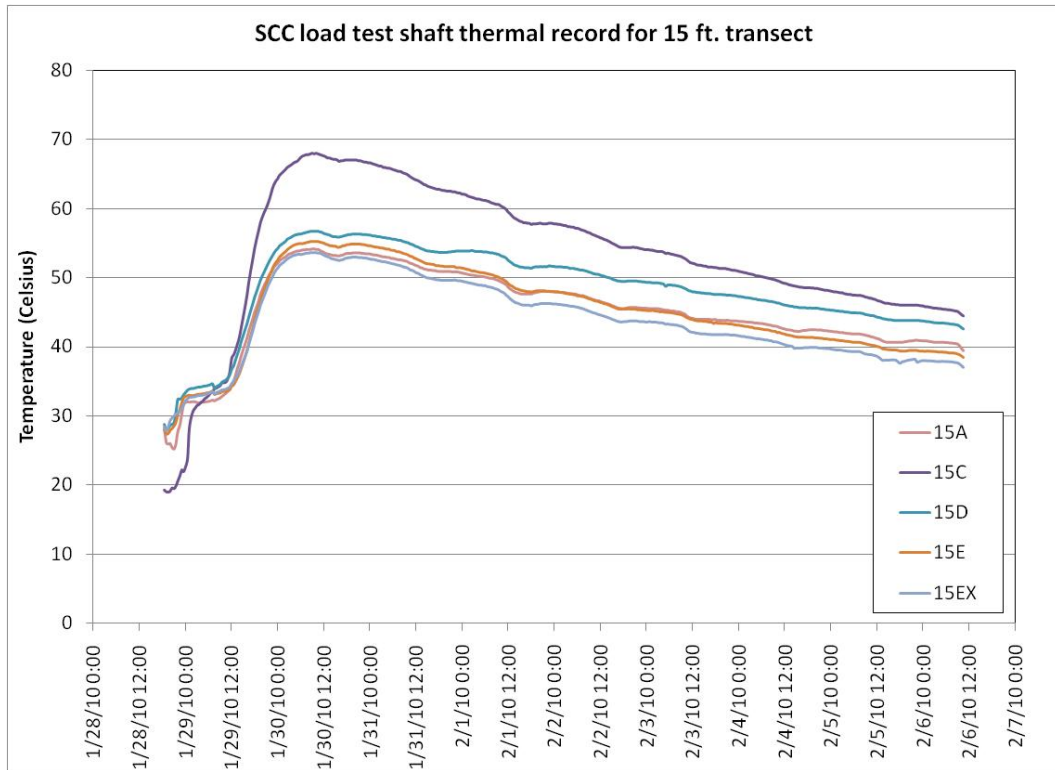


Figure 12: SCC Load Test shaft thermal measurements at 15 ft. depth.

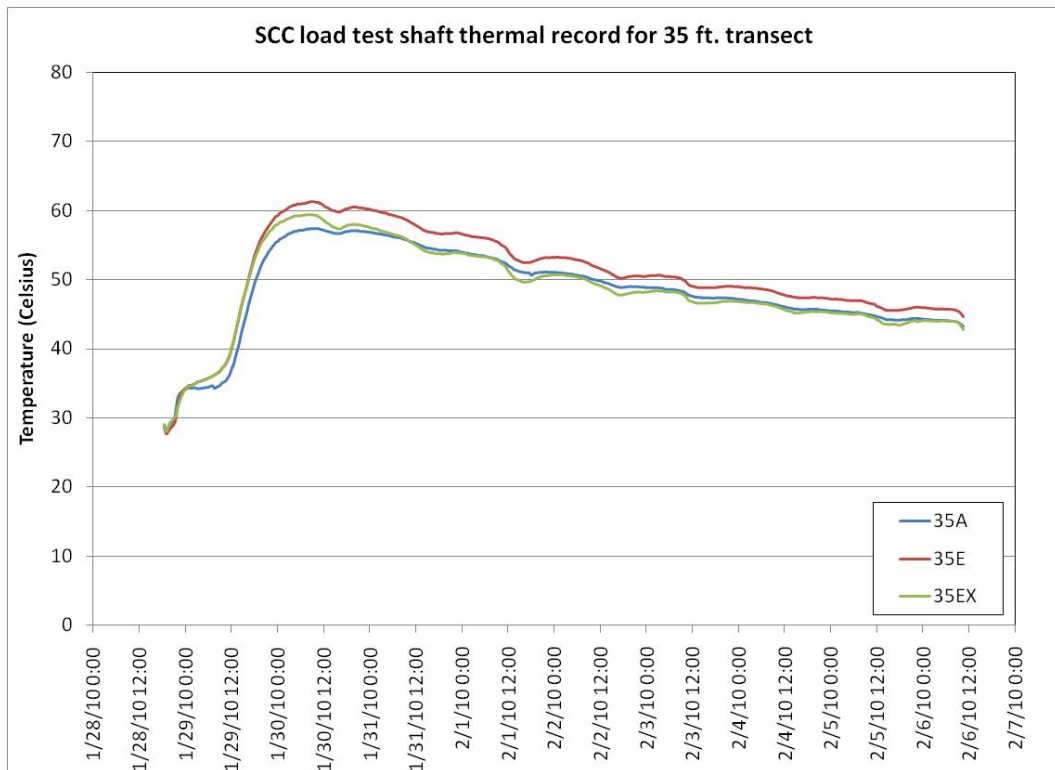


Figure 13: SCC Load Test shaft thermal measurements at 35 ft. depth.

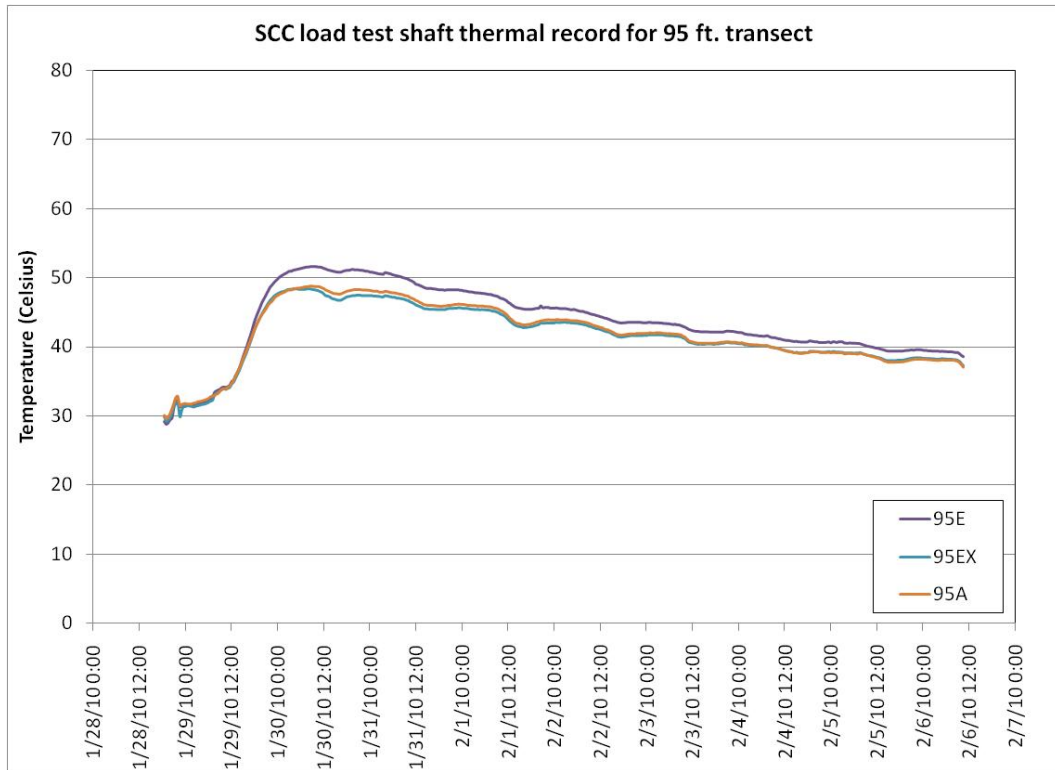


Figure 14: SCC Load Test shaft thermal measurements at 95 ft. depth.

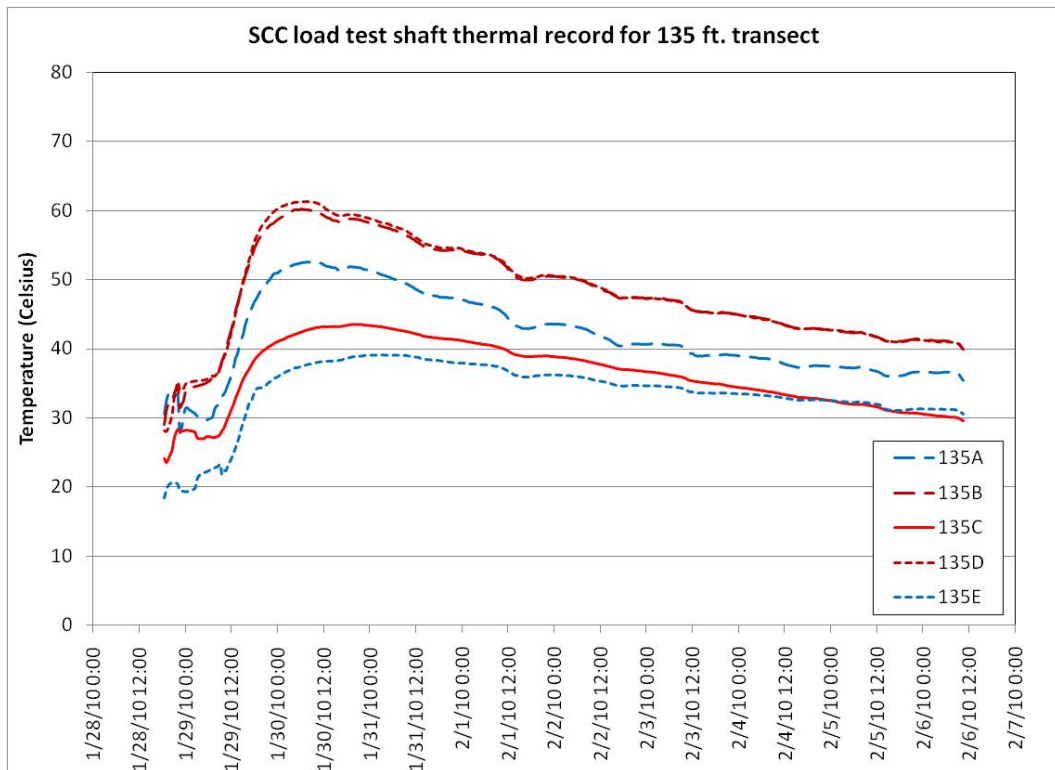


Figure 15: SCC Load Test shaft thermal measurements at 135 ft. depth.

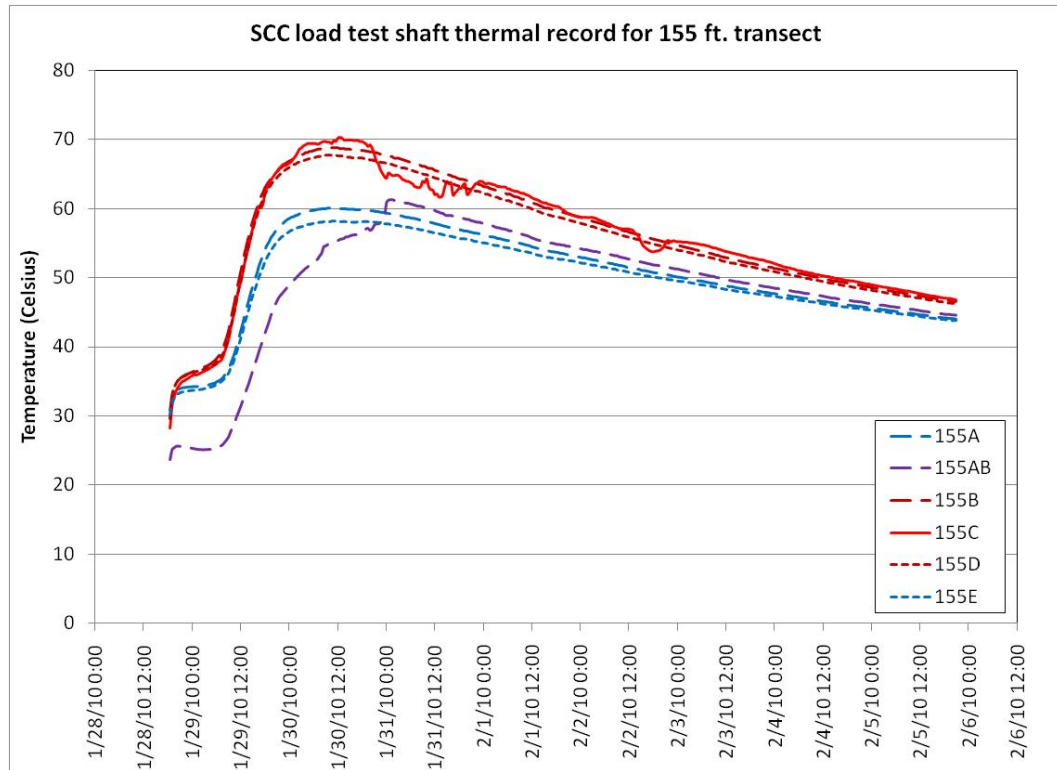


Figure 16: SCC Load Test shaft thermal measurements at 155 ft. depth.

Conventional Concrete (Tremie) Load Test Shaft:

Placement was performed on February 3, 2010, from 8:55AM to 1:39PM. Data from the thermal sensors were recorded from 4:00PM on February 3 till 3:30PM on February 9, 2010. Unfortunately, failure of the datalogger occurred at 7:00AM on February 4. This failure was only detected during data downloading on February 6. The datalogger was then replaced and data recording started again at 11:30AM on February 6. This meant that the peak temperatures for the Tremie Load Test shaft were not recorded.

Figure 17 to Figure 21 show samples of the raw temperature measurements at various depths in the tremie load test shaft. Sensors A and E are located on the reinforcing cage at either side of the shaft. Sensor C is located at the center of the shaft, while sensors B and D are located at quarter points across the section. Sensors AX and EX are located on the outside of the cage at selected locations. Sensors that failed or provided unreliable readings have been ignored.

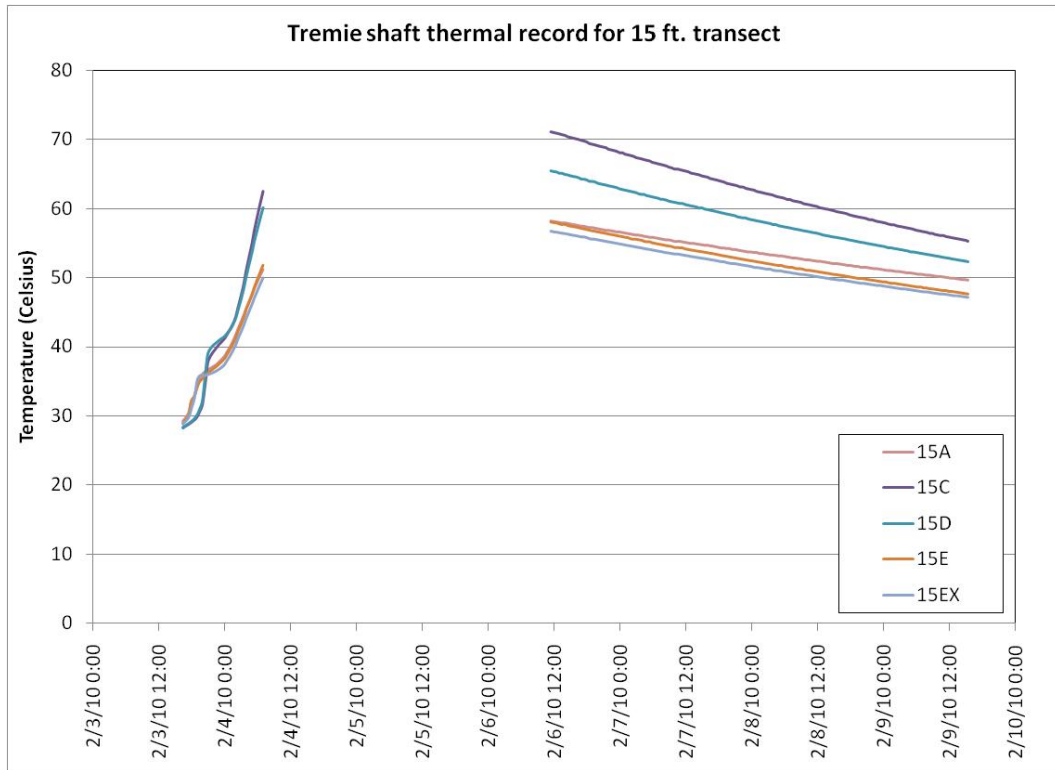


Figure 17: Tremie Load Test shaft thermal measurements at 15 ft. depth.

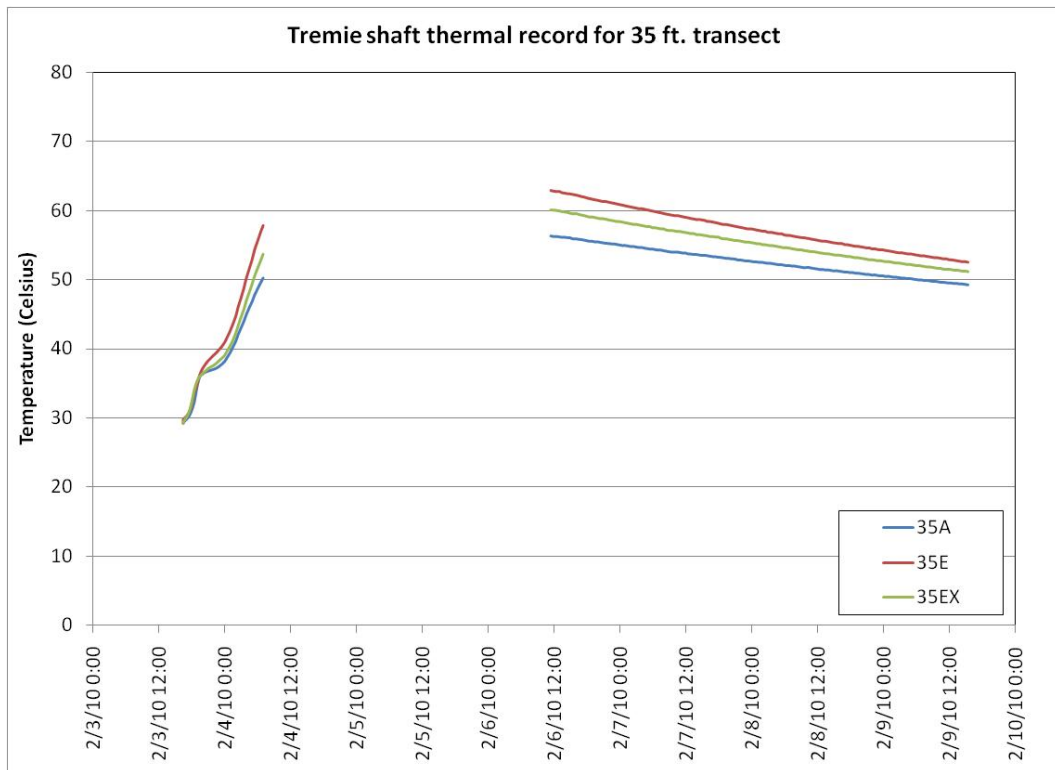


Figure 18: Tremie Load Test shaft thermal measurements at 35 ft. depth.

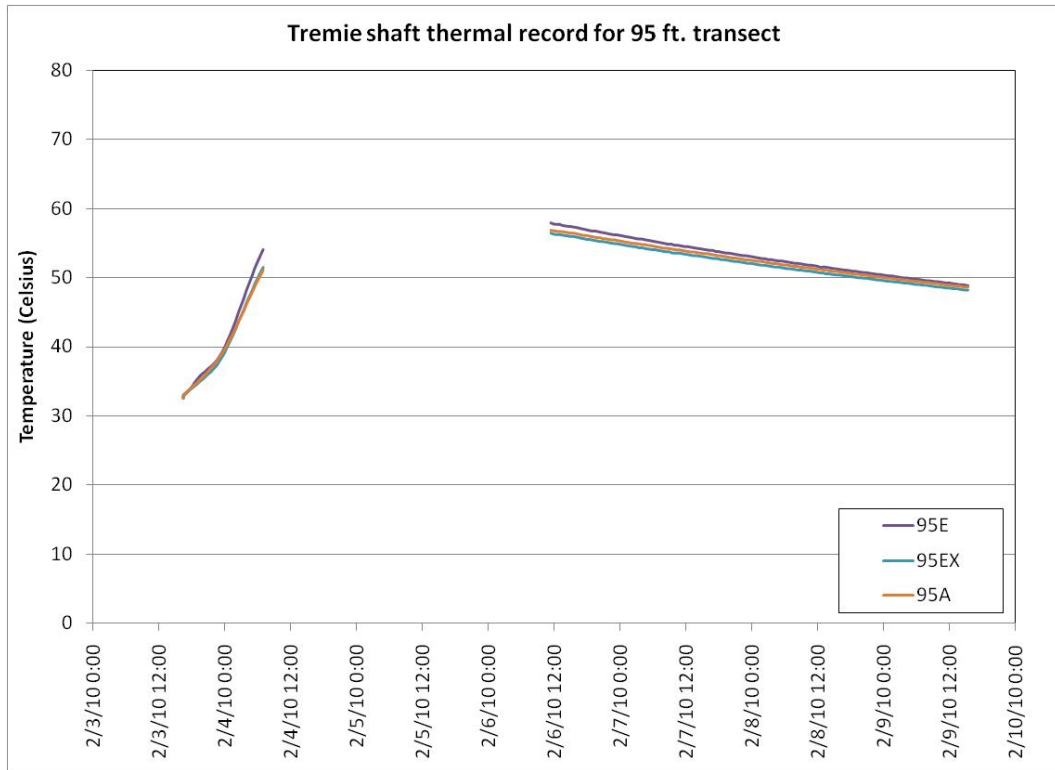


Figure 19: Tremie Load Test shaft thermal measurements at 95 ft. depth.

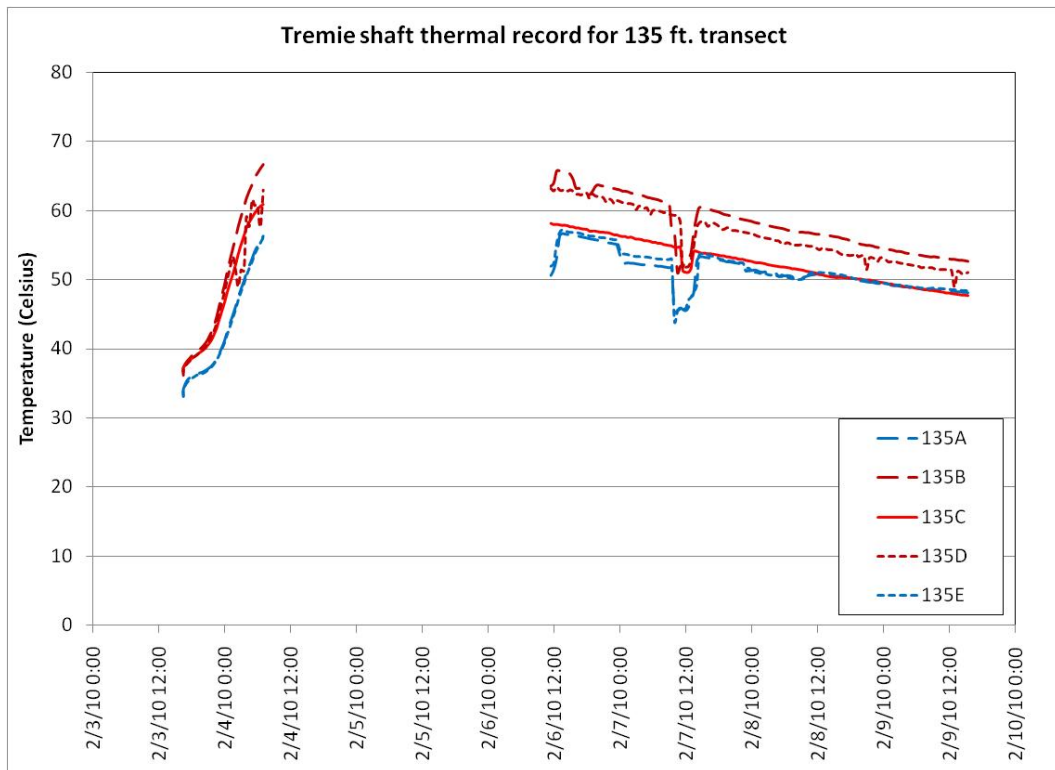


Figure 20: Tremie Load Test shaft thermal measurements at 135 ft. depth.

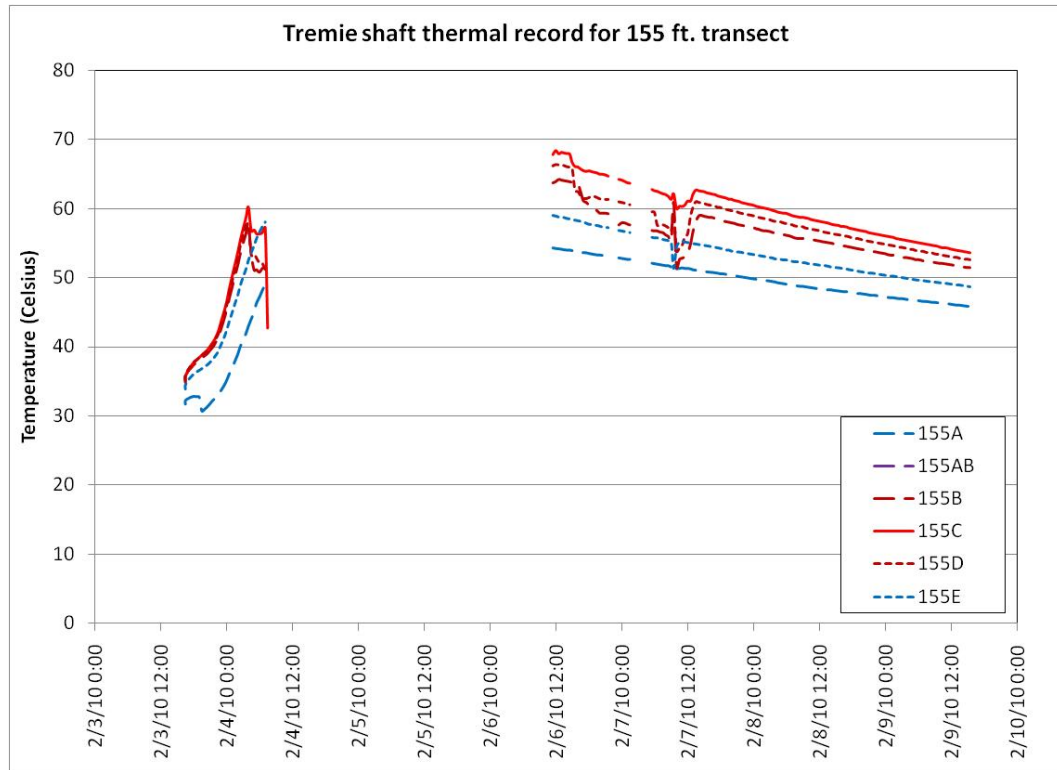


Figure 21: Tremie Load Test shaft thermal measurements at 155 ft. depth.

Comparison between SCC and Tremie Load Test Shafts:

Because of datalogger failure, the peak temperatures were not capture for the Tremie shaft. Recording of temperatures was restored 3 days and 2.5 hours after the start of the Tremie shaft placement. In order to compare the temperatures in the SCC and Tremie shafts, the following plots show a comparison at 3 days and 2.5 hours after concrete placement for each shaft. These are NOT the maximum temperatures in the concrete, but give an indication of how the SCC and Tremie concrete temperatures compare.

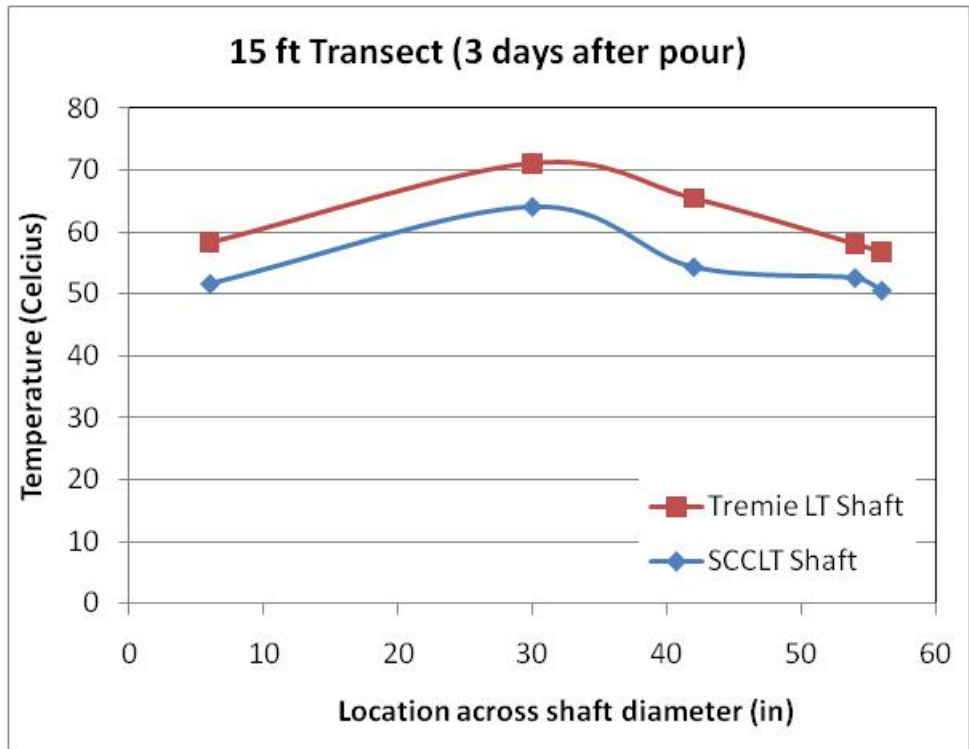


Figure 22: Comparison of day 3 thermal transects at 15 ft depth.

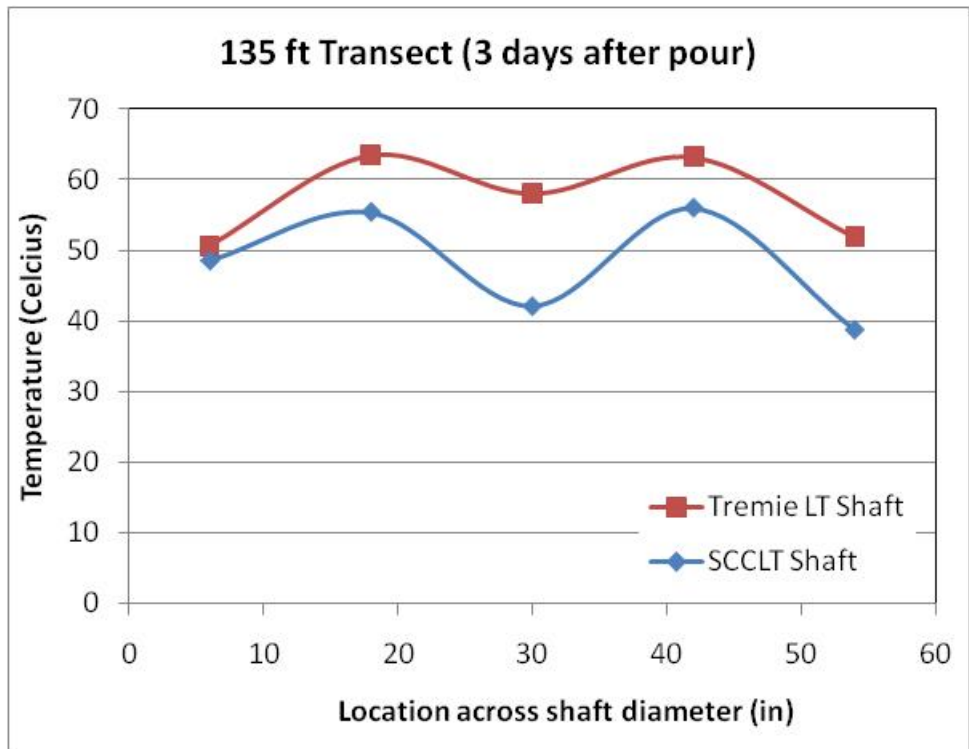


Figure 23: Comparison of day 3 thermal transects at 135 ft depth.

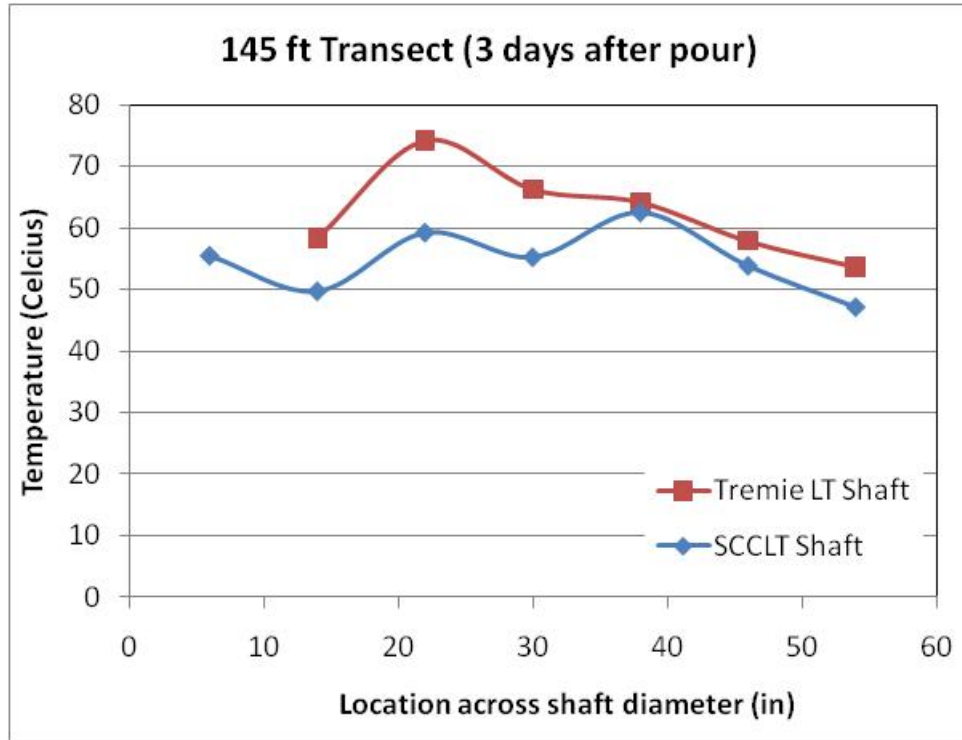


Figure 24: Comparison of day 3 thermal transects at 145 ft depth.

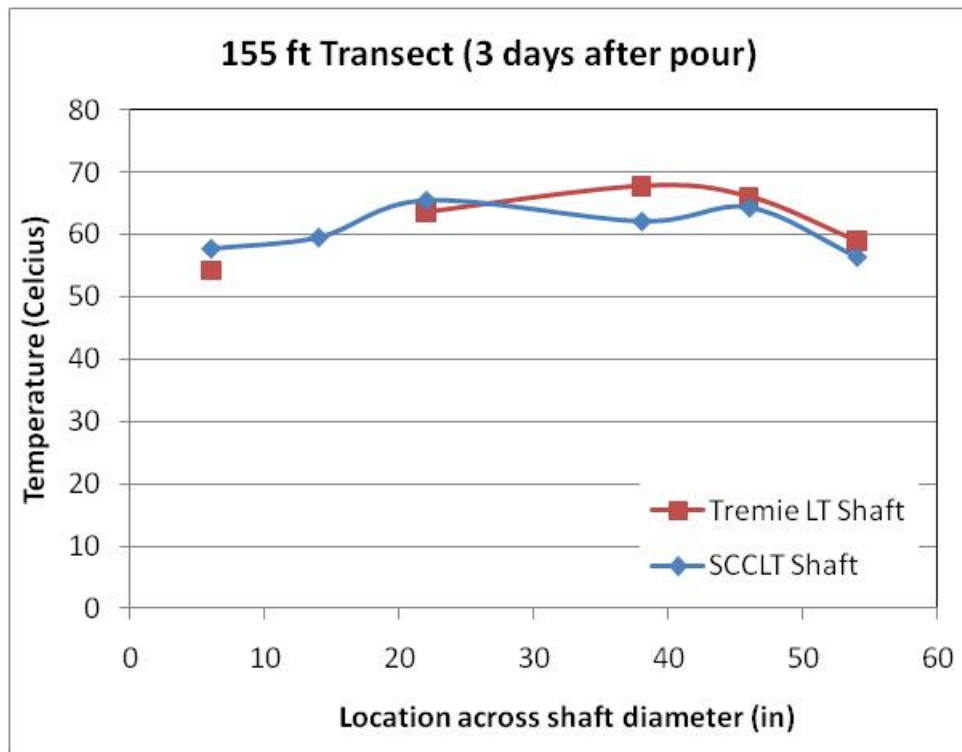


Figure 25: Comparison of day 3 thermal transects at 155 ft depth.

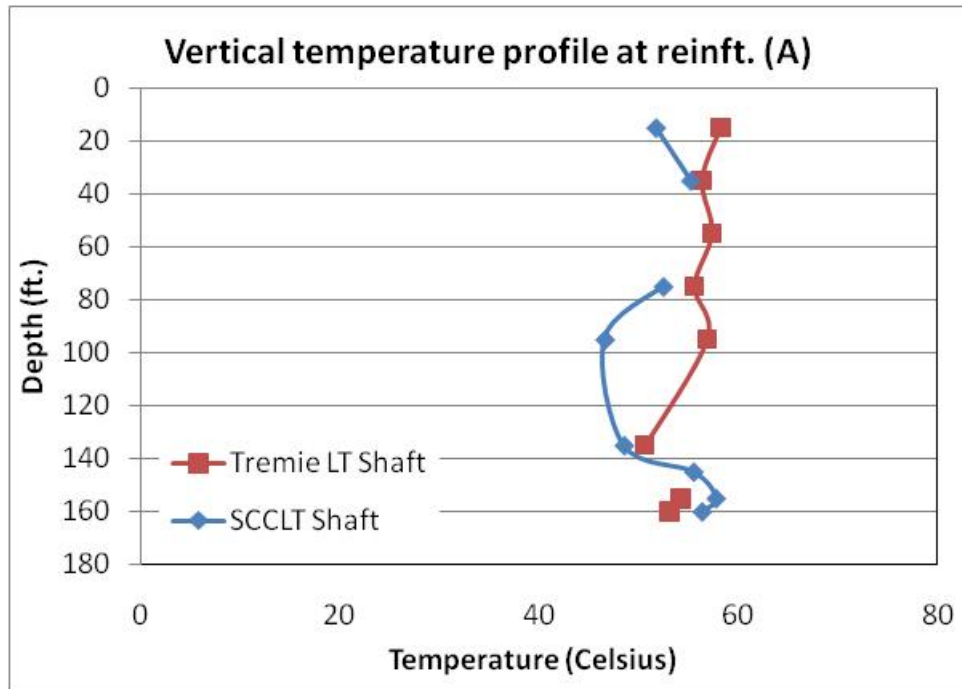


Figure 26: Comparison of day 3 vertical thermal gradient at reinforcement cage side 'A'.

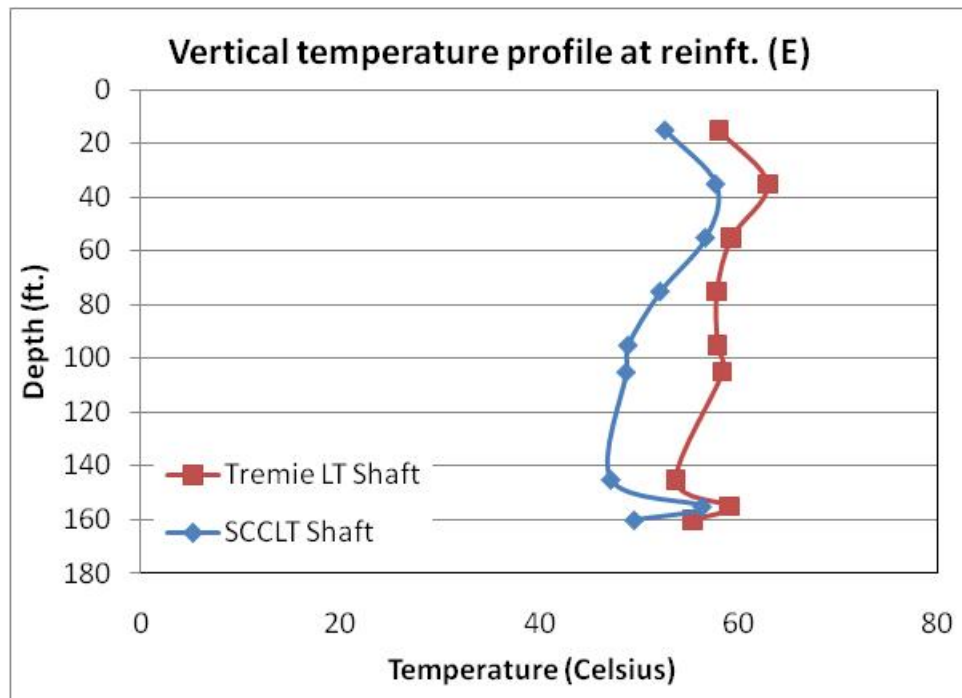


Figure 27: Comparison of day 3 vertical thermal gradient at reinforcement cage side 'E'.

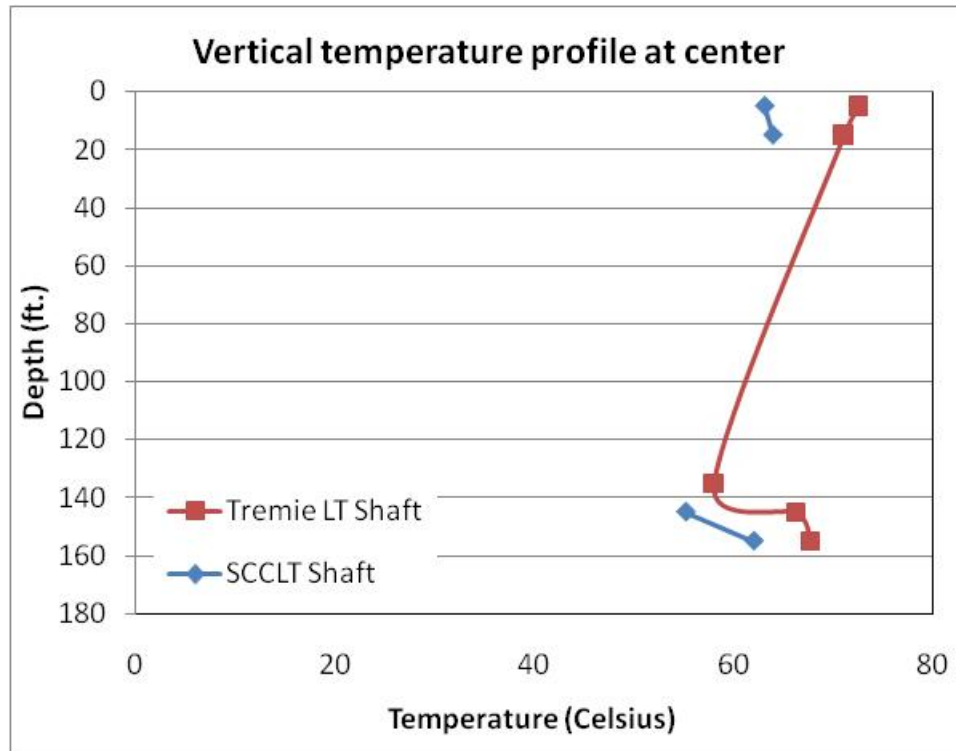


Figure 28: Comparison of day 3 vertical thermal gradient at center of shaft.

Preliminary Observations:

- The maximum temperature measured in the SCC load test shaft was 70°C recorded at the center of the shaft at 155 feet depth. A similar temperature of 68°C was recorded at the center of the shaft at 15 feet depth.
- Comparison of the SCC and Tremie shaft thermal measurements shows that the temperature of the Tremie shaft concrete was generally higher than the SCC concrete.
- Due to failure of the datalogger, the maximum temperature in the Tremie load test shaft was not recorded. However, based on the available information, and comparison with the SCC shaft temperatures, it is estimated that the maximum temperature in the Tremie shaft was on the order of 75 to 78°C.

Preliminary Report on N. Kahana Bridge SCC Trial Shafts

N. Kahana SCC and CC Shaft Comparison

Ian Robertson and Gaur Johnson

Dept. of Civil and Environmental Engineering, UH Manoa

July 1, 2010

Our analysis of the performance of Self-Consolidating Concrete (SCC) and Conventional Concrete (CC) (also referred to as Tremie mix) in the trial and load test shafts at the North Kahana Bridge site is on-going. In the interests of providing feedback for use in selecting the concrete mixture to be used for the production shafts, the following observations may be useful.

Batching and Delivery to site

During the first placement of SCC in the Trial Shaft the concrete delivered to site was consistently at the lower limit of specified slump flow of $23'' \pm 3''$. On a number of occasions, additional mixing water had to be added at the site to achieve the minimum 20'' slump flow. During the second placement of SCC in the Load Test Shaft, the concrete supplier performed slump flow tests at the batch plant prior to dispatching each truck. The concrete arrived at site consistently close to the top of the specified slump flow range. On a number of occasions, trucks had to be held for up to 45 minutes for the slump flow to drop to the maximum 26'' limit before being placed in the shaft. At this limit, segregation of the mix in the wheel barrow was apparent although it did not appear to translate to a segregation problem in the shaft itself.

Neither of these situations was ideal; however, with this experience, we believe the concrete supplier would be able to deliver a more consistent slump flow near the middle of the specified range if the concrete were to be used in the future. However, the course aggregate is currently stored in the open at the batch plant so rain will significantly affect the slump flow and stability of this mix.

The placement of CC in the Load Test Shaft proceeded without problem. The concrete supplier is clearly familiar with this mix and was able to supply concrete with slump consistently within the specified limits. Only occasionally was water added on site to increase the slump.

Placement

During placement of the concrete, both SCC and CC had sufficient flow characteristics to permit unimpeded pump and tremie placement. The drilling contractor had no concerns about working with either concrete mix.

Temperature

Measurements of temperature were made in all three shafts for a week after placement. Unfortunately failure of the datalogger on the CC shaft meant the peak temperatures were not recorded. However, the thermal measurements showed that both concrete mixtures had similar elevated curing temperatures, with the CC slightly higher than the SCC concrete. The difference may be partly attributed to the ambient temperature on the day of placement.

Concrete Strength and Modulus tests

Compression strength and modulus tests performed on standard 6x12" cylinders show similar results for both SCC and CC mixtures.

CSL Tests

We have not yet received the Cross-hole Sonic Logging results, but apparently they indicate potential cavities in the SCC drilled shafts. Once we receive these results, we will compare them with the core logs described below.

Load Tests

Load tests were performed on the SCC and CC Load Test shafts. The load test reports indicate similar behavior for both shafts, but indicate an unexplained low apparent modulus for the SCC concrete directly adjacent to the load cell.

Drilled Core Analysis

Two full depth cores were recovered from each of the trial and test shafts. The trial shaft core was full length (160') while the load test cores were terminated at the load cell (120' each). Both cores were recovered from the interior of each shaft. It was not possible to core the concrete outside the reinforcing cage to verify concrete flow through the cage.

Visual inspection of the cores indicates poor concrete quality at a number of locations in the SCC shafts. Most notably, near the top of the SCC Load Test shaft (top 19'), there was significant washout and loss of core in one of the two cores. This may be the result of premature removal of the top casing unit while the contractor waited for delivery of the final concrete truck. However, small cavities and possible bleed channels were observed at various depths in the SCC cores.

No such defects were noted in the CC cores. However, areas of the CC cores indicated an absence of coarse aggregate, indicating potential segregation. These will be investigated further through image analysis.

Conclusion

Based on the observations made during the test shaft construction at the N. Kahana Bridge site, the self-consolidating concrete used for this project is not considered suitable for the production shafts.

Further Research

We plan to continue our research on this SCC mixture to try to develop a mix that will provide improved performance. This will involve:

糞 Detailed investigation of the cores recovered from the N. Kahana test shafts. The SCC and CC cores will be analyzed in detail for variations in paste content along the height of each core. The effects of high temperature curing will be investigated by performing compression tests on core samples along with similar size cores from cylinders made during the concrete placement.

糞 Replacement of cement with alternate fine materials including fly ash, crusher dust, crushed recycled glass, etc. will be investigated to develop a mix with lower heat of hydration, lower water content, reduced bleeding potential, and improved segregation resistance.

Quantifying Segregation in Self-Consolidating Concrete through Image

Analysis

By

Daniel Johnson, Gaur Johnson and Ian N. Robertson

UHM Research Report – UHM/CEE/10-04 – May 2010

Available for Download at: <http://cee.hawaii.edu/reports/UHM-CEE-10-04.pdf>

Abstract

Self-consolidating concrete is ideal for use in drilled shaft construction because it does not require mechanical vibration. Performance of SCC must be closely monitored, so that its ability to resist segregation is acceptable. Segregation is the separation and settling of coarse aggregate in a sample of fresh SCC, which can lead to inconsistencies in concrete performance.

A method was developed which attempted to identify segregation in a hardened concrete sample by analyzing cross-section images at differing heights of standard-sized SCC cylinders. This method determined measured gradations and concrete paste percentage of cross-sections near the top and bottom of these samples, and identified segregation as differences between these values over the height of a sample. This method correctly identified aggregate particles and created comparable gradations. It was determined that, when segregation exists, it primarily affects the top and bottom 1” of a sample, leaving the rest of the sample decently distributed.

[Please refer to the full report available online for the body of the report]

Conclusions and Recommendations

Based on the test results outlined in this report, analytical and procedural conclusions were made about identifying segregation in hardened samples of SCC using image analysis. The process of scanning and analyzing cross-sections of hardened concrete samples using *ImageJ* correctly identified aggregate particles. Results most closely represented the observed mix with unpolished cross-sections.

An observed gradation was found and compared at different cross-section heights along a sample of SCC using this image analysis method. The area-based aggregate particle model consistently produced gradations closer to the measured gradation than other attempted particle models. This gradation was between the measured mix gradation for coarse aggregate only and a combination of coarse and fine aggregate. The observed gradations of top and bottom cross-section scans were compared, where shifts in gradation from top to bottom indicated segregation may have occurred.

Identified particle areas were summed in order to determine identified paste content for each SCC cylinder cross-section. This paste area was compared, top to bottom, of each cylinder, and was compared with results from the sieve segregation test. The differences in paste percentage from a single cylinder produced mixed results identifying potential segregation. The paste-area (PA) ratio strongly correlated with results from the sieve segregation test for the 09/25/2009 test mix, where cross-sections were cut 1/2" from either end of the smaller 4x8" cylinders. No trends were observed when attempting this relation with 4x8" cylinders during the 12/11/2009 test mix, or cross-sections cut 1" from either end of standard 6x12" cylinders used for all other samples.

Cross-sections 1" from either end on an SCC cylinder produced no identified trends in determining whether segregation has occurred, where cross-sections 1/2" from either end produced a trend that identified segregation in line with the sieve segregation test. Vertical section scans of the remaining 10" of previously tested cylinders from the 02/24/2010 test mix showed evenly distributed aggregate particles and no identifiable segregation. This was consistent over a sample of cylinders which were distributed across the spectrum of segregation values from the sieve segregation test. This indicated that when segregation occurred, it primarily affected the top and bottom 1" of the sample in a regular SCC mix.

SCC must be closely monitored for segregation, as even slight changes in mix proportions can strongly affect slump flow. Future testing of this image analysis method is recommended, and could include attempting to capture SCC samples of differing resistances to segregation using other methods than adjusting the water dosage. SCC mixes with larger maximum aggregate sizes (3/4") are more prone to segregation, and might be better at getting a wide range of segregation values in an attempt to find a trend with standard fresh concrete tests.

Determining In-Place Material Properties of Concrete in Drilled Shafts

By

Jennifer A. Abayon, Gaur P. Johnson and Ian N. Robertson

UHM Research Report – UHM/CEE/11-07 – May 2011

Available for Download at: <http://cee.hawaii.edu/reports/UHM-CEE-11-07.pdf>

Abstract

Elastic modulus and compressive strength are the most valued material properties of concrete in structural engineering. These properties are commonly measured because of their significance in design, quality control and quality assurance. The purpose of this research is to evaluate the material properties of hardened concrete in drilled shaft foundation for the replacement of the North Kahana Stream Bridge. Generally, molded test specimens are indicative of the actual properties of concrete in structures. However, for the purpose of investigating the use of self-consolidating concrete with locally available aggregates in drilled shafts, correlations between molded specimens and cores from test drilled shafts were examined to determine the in-place material properties of concrete. The results of this research are intended to assist in the study of SCC use in Hawaii, in comparison with conventional concrete.

A series of tests and analyses were performed to calculate the dynamic and static moduli of elasticity and compressive strength of concrete in one conventional concrete drilled shaft and two SCC drilled shafts. Based on the results, it was determined that the SCC drilled shafts have higher and more preferable material properties of hardened concrete than the drilled shaft constructed with conventional concrete. There was also less inconsistency observed in the SCC data to which less irregularity in concrete performance could be attributed. It was concluded that the SCC and conventional concrete mixture designs were both recommendable for use in the North Kahana Stream Bridge drilled shaft construction.

[Please refer to the full report available online for the body of the report]

Conclusions and Recommendations

For the replacement of the North Kahana Bridge, three test drilled shafts were constructed to evaluate the suggested concrete mixture designs to be used for the drilled shafts supporting the bridge. A series of tests were performed on several molded test cylinders and cores obtained from the shafts to determine the dynamic and static moduli of elasticity and the compressive strength of the concrete. Using the results from the test cylinders, correction factors were produced to convert the test shaft core results to estimated in-place material properties of the concrete in the drilled shafts. Equations were also developed to estimate the compressive strength of concrete at any particular location in the test shafts.

The three test shafts were found to have satisfactory material properties, with an overall average dynamic modulus of 4325 ksi, static modulus of 3564 ksi, and compressive strength of 6849 psi. The concrete in the test shafts was determined to be high strength concrete. However, ACI committee 363, which proposes an elastic modulus equation for high strength concrete, greatly overestimates the static modulus in the test shafts. Newton and Pham (2001) give a better approximation of the static modulus with the equation derived from concrete made with Hawaiian aggregates, which are comparable to the materials used in this research.

It was found that the SCC shafts have higher and more desirable properties over the LTC shaft. Also, there was less discrepancy between the results from the SCC shafts compared to the conventional concrete shaft. This suggested better homogeneity along the depth of the SCC shafts, meaning no significant segregation occurred, and possible concrete placement problems for the LTC shaft. It was also found that the compressive strength and static modulus of elasticity increased with the depth of the shafts. Based on the results of this research, it was concluded that the SCC mixture design had better hardened concrete material properties than the conventional concrete mixture.

For similar testing in the future, it is recommended to use the standard size specimens as suggested by the standard test methods for more reliable results. It is also preferable to have equal quantities of specimens when making comparisons between different mix designs or drilled shafts.

Appendix A: Draft SCC Specifications

STATE OF HAWAI'I
DEPARTMENT OF TRANSPORTATION
EXPERIMENTAL DRILLED SHAFT CASTING PROGRAM

1.0 DESCRIPTION

These Special Provisions are for the experimental shaft casting program for the proposed North Kahana Stream Bridge Replacement project on Oahu, Hawai'i. The information obtained during this experimental shaft casting program may be incorporated into the load test program and production shafts of the project. The experimental castings will include both normal conventional concrete and self consolidating concrete (SCC). Experimental drilled shaft castings should be: installed by an approved Drilled Shaft Sub-Contractor who will provide services for the experimental research portion of the project.

Prior to any construction at the experimental drilled shaft casting sites, a preconstruction conference will be scheduled with representatives of the Contractor, Subcontractors, Engineer and University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536) to discuss all aspects of the experimental drilled shaft casting program.

2.0 SCOPE

The work under these Special Provisions consists of the Contractor furnishing the supervision, labor, material, equipment and related services necessary to install the experimental shaft castings in the presence of the Engineer as indicated on the project plans, attached drawings, and specified herein.

For this project, the objectives of the experimental casting program are:

1. Demonstrate the use of SCC in an actual field setting;
2. Obtain experience with the use of SCC for drilled shaft construction;

The objective is as follows:

Construct experimental castings of drilled shafts using both SCC and conventional concrete, with these castings to be observed during construction; examined to inspect the characteristics of the as-built concrete shafts; and subsequently monitored for six (6) months by the University of Hawai'i research team personnel.

All installation of experimental drilled shaft castings will be conducted under the direction of the Engineer with accommodations made by the Contractor.

For the purposes of these provisions, experimental castings will consist of two (2), full depth, fully reinforced, 5 ft diameter drilled shafts (one with SCC and one with conventional concrete). The shafts will be located as shown in the plans or an approved alternate site.

3.0 CONTRACTORS RESPONSIBILITIES

The Contractor shall furnish all supervision, labor, material, equipment and related services necessary to install and monitor the experimental shaft castings in the presence of the Engineer.

The Contractor shall protect the experimental shaft castings from damage during the duration of the experimental program.

3.1 Surveying: The contractor shall be responsible for locating the experimental drilled shaft castings in the field and ensuring that no conflicts exist between the experimental shaft castings and the existing or proposed structures, utilities or other construction.

The Contractor shall provide a Professional Land Surveyor registered in the State of Hawai'i and provide as-built plans of the experimental shaft casting locations as well as any temporary structures associated with the experimental test project or as directed by the Engineer.

3.2 Site Preparation: The Contractor shall perform all site preparation as required to access, construct, monitor and perform the experimental casting program. It shall be the Contractor's responsibility to identify and protect all facilities (e.g., underground utilities), which could be impacted by the construction and performance of the experimental casting program. Within wetlands and waterways, the Contractor shall substitute all potentially hazardous fluids with biodegradable alternatives, where necessary. On land, the Contractor shall remove all potentially hazardous fluids prior to demobilization from the site.

The Contractor shall provide and maintain safe access to the experimental shaft casting test area for the purpose of data collection throughout the experimental program. The contractor shall coordinate with the University of Hawai'i research team personnel and / or their Sub-Contractors to provide access to recover concrete cores from the full depth of the drilled shaft castings.

3.3 Existing soil conditions: The subsurface conditions encountered at the site are presented in the contract drawings and contract proposal.

4.0 EXPERIMENTAL DRILLED SHAFT CASTINGS

The work under this section shall govern the construction of two (2) experimental drilled shaft casting. Experimental drilled shaft castings shall be composed of a reinforced concrete section, cast-in-place against in situ soil. Experimental drilled shaft castings shall be straight shaft type, and shall be vertical. Construction shall be in accordance with the details and dimensions shown in the Plans, and the requirements of these Special Provisions and the Project Specifications.

Work on load test shafts will not commence until the experimental drilled shaft casting(s) have been tested and evaluated. Upon direction from HDOT, the Contractor shall proceed with construction of the load test shafts. This direction shall be forthcoming 30 days from date the casting shafts are tested and evaluated.

5.0 REFERENCES: The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

ACI 211.3 – Standard Practice for Selecting Proportions for No-Slump Concrete.

ACI 304 – Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete.

ACI 318 – Building Code Requirements for Reinforced Concrete.

ASTM C 31 – Making and Curing Concrete Test Specimens in the Field.

ASTM C 33 – Concrete Aggregates.

ASTM C 39 – Compressive Strength of Cylindrical Concrete Specimens.

ASTM C 42 – Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.

ASTM C 94 – Ready-Mixed Concrete

ASTM C 143 – Slump of Portland Cement

ASTM C 150 – Standard Specification for Portland Cement

ASTM C 171 – Sheet Materials for Curing Concrete

ASTM C 260 – Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C 494 – Standard Specification for Chemical Admixtures for Concrete

ASTM C 1611 – Standard Test Method for Slump Flow of Self-Consolidating Concrete

ASTM C 1621 – Standard Test Method for Passing Ability of Self-Consolidating Concrete

ASTM D 448 – Standard Classification for Sizes of Aggregate for Road and Bridge Construction

6.0 MATERIALS

A. Portland Cement shall conform to the requirements of ASTM C150, Type I, for all concrete work.

B. Concrete Aggregates:

1. Fine Aggregates shall be calcareous or basalt sands, or a combination thereof. They shall meet the grading requirements of ASTM C33 unless the concrete producer can provide past data that shows that a proposed non-conforming gradation will produce concrete with the required strength and suitable workability.

The maximum acceptable fine to total aggregate ratio is 50% by volume.

2. Coarse Aggregates shall be crushed close-grained, blue lava rock meeting the grading requirements of sizes 57 or 67 (ASTM D448) or both. The maximum size of aggregate shall not be larger than 3/4 inch.

C. Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials or other substances that may be deleterious to concrete or reinforcement. Non-potable water shall not be used.

D. Admixtures, if used, shall conform to ASTM C494 or ASTM C260 and shall be mixed in proper amount in accordance with directions of manufacturer. Water reducers may only be added at the batching plant unless it is a concrete mix design requirement to maintain the slump flow characteristics specified for placement and has been approved per Paragraph 6.2.

6.1 TESTS

A. Slump Flow: Standard slump flow tests as described in ASTM C1611 will be made periodically during the placement of concrete by the Engineer or Inspector to ensure that the slump flow spread for which the concrete has been designed is met. At least one slump flow test shall be performed for every 50 cubic yards of concrete placed. Any concrete batch tested and showing slump flow spread not within the approved range at the time of placement shall be rejected. Any concrete placed prior to slump flow testing shall be the sole responsibility of the Contractor and shall be rejected should the subsequent slump flow test of the batch in question indicate that the slump flow spread is outside the acceptable range. All rejected concrete shall be promptly removed and properly replaced. All costs resulting therefrom shall be borne by the Contractor.

B. J-Ring: Standard J-Ring tests with deformed bars, as described in ASTM C1621, will be made periodically during the placement of concrete by the Engineer or Inspector to ensure that the passing rate for which the concrete has been designed is met. At least one J-Ring test shall be performed for every 50 cubic yards of concrete placed. Any concrete batch tested and showing a blocking of 2 inches or greater shall be rejected. Batches exhibiting blocking greater than 1 inch and less than 2 inches may be rejected at the discretion of the Engineer or Inspector. Any concrete placed prior to J-Ring testing shall be the sole responsibility of the Contractor and shall be rejected should the subsequent J-Ring test of the batch in question indicate that the blocking exceeds the maximum acceptable limit. All rejected concrete shall be promptly removed and properly replaced. All costs resulting therefrom shall be borne by the Contractor.

C. Visual Stability Index: The Visual Stability Index (VSI) should be determined by the Engineer or Inspector according to ASTM C1611 Appendix X1 every time a slump flow test is conducted. Concrete with a VSI greater than 1.5 shall be rejected.

D. Compressive Strength: During the progress of the work compressive strength tests of concrete shall be made in accordance with ASTM C39. Standard 6-inch x 12-inch cylinders shall be taken from each major pour by the Engineer or Inspector at the rate of 3 cylinders for each 100 cubic yards. Notwithstanding this established rate, however, the Engineer, University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536), or Inspector shall take concrete cylinders in whatever quantity he/she deems fit and/or necessary from any concrete pour.

1. The Engineer or Inspector will make and identify all test cylinders. The Contractor shall provide the equipment, such as a shovel and a wheelbarrow for the Engineer or Inspector to make and move the cylinders, and shall also provide the labor and equipment to deliver the cylinders to the testing laboratory as directed by the Engineer or Inspector.

2. Cost of testing will be borne by the Client.

3. The standard age for testing the cylinders shall be 28 days. However, 7-day tests may be made for indication of final 28-day strengths.

4. All cylinders shall be made and cured in accordance with ASTM C31 with the exception that test cylinders shall be made in one lift with no rodding or vibration.

5. In all cases where the strength of any group of cylinders falls below the minimum compressive strength specified, the Engineer shall have the right to require that test specimens be cut from the structure. Specimens shall be selected by the Engineer from the location in the structure represented by the test specimen or specimens which failed. Specimens shall be secured, prepared, and tested in accordance with ASTM C42 within a period of 60 days after placing the concrete. The testing shall be performed by a laboratory approved by the Engineer. Concrete in the area represented by the core tests will be considered structurally adequate if the average strength of 3 cores is no less than 85% of the specified 28-day strength, and the strength of any individual core is no less than 75% of the 28-days strength specified. Should laboratory analysis indicate, however, that the proper concrete mix has not been used by the Contractor, all such concrete placed using the improper mix shall be subject to rejection. The cost of cutting specimens from the structure, patching the resulting holes, and making the analysis, including laboratory and consultation costs, shall be borne by the Contractor.

The holes from which the cored samples are taken shall be packed solid with no-slump concrete proportioned in accordance with the ACI 211.3 "Standard Practice for Selecting Proportions of No-Slump Concrete". The patching concrete shall have an "extremely dry" consistency and the same design strength as the specified concrete.

6. If the strength of the specimens cut from the structure falls below the requirements stipulated above, the Engineer shall have the right to require any and all

defective concrete to be replaced, and all costs resulting therefrom shall be borne by the Contractor.

6.2 DESIGN OF SELF-CONSOLIDATING CONCRETE MIXTURES

The SCC mix design for experimental drilled shaft castings concrete shall be provided by the Engineer. The conventional concrete mix design for experimental drilled shaft castings and production drill shaft concrete shall be provided by the Contractor, approved by the Engineer, and except as modified herein, shall meet the requirements of the Project Specifications.

A. Ingredients for concrete shall be Portland cement, fine and coarse aggregates and water.

B. Minimum 28-Day Strength: Concrete shall have a minimum 28-day specified compressive strength ($f'c$) of 4000 psi.

C. Segregation: Concrete shall be designed so that the concrete materials will not segregate nor cause excessive bleeding. The Visual Stability Index (VSI) of the concrete, at the time of placement, shall be 1.5 or less.

D. Slump flow spread shall be 21 ± 3 inches at the time of placement.

E. Slump flow spread with the deformed bar J-Ring shall be within 2 inches of the slump flow spread without the J-Ring.

F. Concrete shall have a T_{20} (T_{50}) time of 4.5 ± 2.5 seconds and shall be recorded for each slump flow test.

G. Concrete shall be designed to achieve an L-Box test value of $H2/H1 = 0.65$ to 0.8 .

H. Slump for the concrete shall be a minimum of 6 inches after 4 hours from initial mixing.

I. The Contractor shall submit for approval by the Engineer the mixes to be used at least 14 days before the actual concrete placing operations. The submittal shall include any retempering procedures conforming with Paragraph 6.3D. A production batch of the submitted mix design shall be delivered to the University of Hawai'i (10 days before actual concrete placement) for the purpose of evaluating the performance specifications by the Engineer and the University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536).

J. The Contractor shall use only approved mixes.

K. For budgeting purposes, the following two SCC mix design proportions should be used as a starting point:

Halawa Quarry Mixture Constituents	Value
------------------------------------	-------

Type I/II Cement (Hawaiian Cement)	846 pcy
Water	380.7 pcy
Class F Fly ash (---)	0 pcy
Halawa 3F (3/4" max) (SSD)	1066 pcy
Halawa Chips (3/8" max) (SSD)	284 pcy
Halawa #4 Basalt Sand (SSD)	738 pcy
Maui Dune Sand (SSD)	198 pcy
Nanakuli Lagoon Sand (SSD)	415 pcy
Entrained air	2%
MB - Delvo Stabilizer .	5 oz/cwt
MB - Glenium 3030 NS	8 to 15 oz/cwt
MB - Rheomac VMA 358	3 to 6 oz/cwt
Kapaa Quarry Mixture Constituents	Value
Type I/II Cement (Hawaiian Cement)	846 pcy
Water	380.7 pcy
Class F Fly ash (---)	0 pcy
Kapaa (3/4" max) (SSD)	1110 pcy
Kapaa (3/8" max) (SSD)	240 pcy
Kapaa Basalt Sand (SSD)	1047 pcy
Maui Dune Sand (SSD)	153 pcy
Nanakuli Lagoon Sand (SSD)	150 pcy
Entrained air	2%
MB - Delvo Stabilizer .	5 oz/cwt
MB - Glenium 3030 NS	8 to 12 oz/cwt
MB - Rheomac VMA 358	3 to 9 oz/cwt

6.3 MIXING CONCRETE

A. All concrete throughout shall be either job or plant mixed in an approved power operated mixer that will ensure uniformity and homogeneity of the concrete produced. The Contractor shall provide a sufficient number of mixers to continuously carry on the work.

B. Mixing at Jobsite shall be performed in accordance with ACI 304 and as follows:

1. Concrete shall be thoroughly mixed in a batch mixer of an approved type and size which will ensure a uniform distribution of materials throughout the mass. The machine shall have a control device to prevent materials from being discharged until they have been mixed for the specified minimum time.

2. The entire contents of the drum shall be discharged before materials of the succeeding batch are placed therein. No mixer shall be used which has a rated capacity of less than a 1-sack batch and no mixer shall be charged in excess of its rated capacity.

3. The first batch of materials placed in the mixer after the machine has been cleaned shall contain a sufficient excess of cement, sand and water to coat the inside of the drum without reducing the required mortar content of the mix. Upon cessation of mixing, the mixer shall be thoroughly cleaned.

C. Ready Mixed and Mixed-In-Transit Concrete shall be mixed to conform to the provisions of ASTM C94 and as follows:

1. The plant shall have sufficient capacity and transportation equipment to deliver concrete at the rate desired. The interval between batches for a pour shall not exceed 30 minutes.

2. The time elapsed between the introduction of the mixing water to the cement and aggregates, and the placing of concrete in its final position shall not exceed 90 minutes.

3. In hot weather (more than 90 degrees Fahrenheit ambient temperature) or other conditions contributing to quick stiffening of the concrete, the elapsed time in 2, shall not exceed 60 minutes, if no retarding admixture is used. If an ASTM C494 Type B or D admixture is added to the concrete, the maximum elapsed time in 2 shall remain at 90 minutes.

D. Concrete shall be mixed only in such quantity as is required for immediate use.

No retempering will be permitted, unless such procedure is specified and tested according to the approved concrete mix design, Paragraph 6.2 I. Concrete that has started to harden shall be discarded and promptly removed from the jobsite.

E. Admixtures conforming to Paragraph 6.0 may be used in the concrete as recommended by the supplier and approved by the Engineer. Retempering with admixtures shall only occur as detailed in the concrete mix design approved by the Engineer in Paragraph 6.2 I.

7.0 CONSTRUCTION

The Contractor shall supply all materials required to install the experimental drilled shaft castings as required. This Special Provision supplements the requirements of Section 712 of the Specifications.

7.1 Construction Sequence Plan: The Contractor shall develop a detailed construction sequence plan and submit the same for review and approval by the Engineer two (2) weeks prior to beginning construction of the experimental drilled shaft castings. The construction sequence plan shall provide detailed information as outlined in Section 712 of the Specifications and include the following:

1. Details on how the experimental castings will be installed, protected and remain accessible to the University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536) for the duration of the experimental shaft casting and testing program.
2. Other information shown in the plans or requested by the Engineer.

The Engineer will review the experimental drilled shaft casting construction sequence plan for conformance with these Special Provisions and the Project Plans and Specifications. Within seven (7) days after receipt of the construction documents, the Engineer will notify the Contractor of any additional information necessary to satisfy the Project Plans, these Special Provisions, and the Project Specifications. Any part of the construction sequence plan that is unsatisfactory will be rejected and the Contractor shall submit changes agreed upon for reevaluation. The Engineer will notify the Contractor within seven (7) days after receipt of proposed changes.

During the construction of experimental drilled shaft castings, the Contractor may elect to make minor modifications to his procedures for constructing the remaining foundations. This is permissible provided the Engineer is informed in writing of any desired changes in technique and equipment, and such changes are approved by the Engineer.

7.2 Experimental Drilled Shaft Casting Construction: The Contractor shall supply all materials required to install the experimental drilled shaft castings as required. This Special Provision supplements the requirements of Section 712 of the specifications.

Fabrication of the reinforcing steel cage shall be performed prior to concrete placement to allow installation of instrumentation by the Engineer and / or University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536). The Contractor shall coordinate the access required for instrumentation installation. Instrumentation pertaining to the experimental portion will be provided and installed by the Engineer and / or the University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536) with the exception of the following:

Inclinometer casings,

Transparent acrylic casing (capped at each end), two (2) each drilled shaft full depth of drilled shafts,

Cross-Hole Sonic Logging set-ups for integrity testing,

Other incidentals necessary to secure and maintain safe items (i), (ii), and (iii) during reinforcing cage installation.

The Contractor shall coordinate the number and placement of these items with the Engineer and the University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536).

The Contractor will be delayed up to a maximum of 4 hours per shaft during the placement of concrete within the experimental drilled shaft castings. Delays will be outlined by the Engineer prior to concrete placement.

7.3 Experimental Drilled Shaft Casting Installation: The contractor shall construct the experimental drilled shaft casting using the approved shaft installation techniques until the experimental casting has been completed. The techniques used to construct the experimental drilled shaft castings will be used for load test and production drilled shafts at the option of the Engineer and HDOT.

7.4 PLACING SELF-CONSOLIDATING CONCRETE IN DRILLED SHAFTS

A. No concrete shall be placed in the absence of the Engineer and University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536) or Inspector who shall be given one day advance notice of starting time of each concrete pour.

Place no concrete until reinforcing, embeds, instrumentation, and all other items to be installed prior to concrete placement, have been inspected and approved by the Engineer and University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536) or Inspector. Concrete placed without such notice and approval shall be rejected.

B. Preparation

1. Excavations must be cleared of all loose debris prior to concrete placement.
2. Before depositing the concrete, the reinforcing steel cage and any necessary concrete spacer blocks or other approved spacers to ensure the concentric placement of the cage shall be in place.

D. Depositing

1. Concrete shall be placed as soon as possible after excavation has been completed.
2. Drilled shafts shall not remain open for more than eight (8) hours.
3. Concrete shall be placed continuously. Cold joints are not allowed.
4. Concrete is to be placed by tremie to prevent segregation and splashing.

8.0 SCHEDULING AND RESTRICTIONS

Prior to the elapse of at least-sixteen (16) hours after a drilled shaft has achieved its initial concrete set (as determined by the Engineer), no adjacent shaft shall be drilled, no adjacent piles shall be driven, and no equipment wheel loads or "excessive" vibrations shall be allowed to occur at any point within a 25 ft radius of the drilled shaft.

In the event that the Contractor fails to satisfactorily perform the procedures described within, the Engineer may shut down the construction operations and/or reject the experimental drilled shaft casting. All the work, construction, and testing on the experimental drilled shaft castings, shall be performed during the daylight hours. All testing procedures will be performed by University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536).

Upon completion experimental drilled shaft cutting, coring and testing activities, the remaining portions of the experimental drilled shaft castings shall be completed per the direction of the Plans and / or the Engineer. Payment for removing the experimental drilled shaft castings shall be included in this pay item.

9.0 METHOD OF MEASUREMENT

9.1 Experimental Drilled Shaft Castings: Experimental drilled shaft casting construction will be paid for at the unit price bid per each for the type and diameter and at the locations indicated on the Plans, complete in place as specified. Final payment shall be made when all experimental drilled shaft castings have been accepted by the Engineer and University of Hawai'i research team personnel (Contact: Ian Robertson 808-956-6536). This payment shall be full compensation for labor, material and equipment for:

- (i) All excavations including disposal of excavated materials and slurry;
- (ii) Temporary casing, shoring and/or dewatering;
- (iii) Removing obstructions;
- (iv) Cleaning and pumping;
- (v) Reinforcing steel in the shaft;
- (vi) Conventional concrete in the shaft, SCC concrete in shaft, and slurry;
- (vii) Inclinator casing;
- (viii) Transparent acrylic casing (capped at each end), two (2) each full depth of drilled shafts;
- (ix) Surveying of experimental shaft casts locations as described in Paragraph 3.1.
- (x) Site preparation as described in Paragraph 3.2.
- (xi) Cross-Hole Sonic Logging set-ups for experimental shaft castings;

(xii) Other incidentals necessary to complete the experimental drilled shaft castings as shown in the Plans.

10.0 BASIS OF PAYMENT

Payment will be made under:

Item No.	Pay Item	Pay Unit
8990309	EXPERIMENTAL DRILLED SHAFT CASTING	EA

Appendix B: Hawaiian Connections Article

Copied from Hawaiian Connections, Vol. 12, No. 1, Spring 2010

Trial Placement of Self-Consolidating Concrete

By Ian N. Robertson and Gaur P. Johnson, University of Hawai'i

As part of a research project at the University of Hawai'i at Manoa, funded by HDOT, a new type of concrete is being evaluated for use in drilled shaft construction in Hawai'i. Self-Consolidating Concrete (SCC) is a highly fluid concrete designed to flow through and around dense reinforcing steel without the need for mechanical vibration. Because of the improved filling characteristics, surface finish and reduced labor costs during placement, SCC has gained popularity in Europe, Japan and increasingly in Mainland USA. Apart from a limited number of small placements, SCC has not been used on a large scale in Hawai'i. This research project is investigating the potential use of SCC for the drilled shafts supporting the new North Kahana bridge under construction on Kamehameha highway.

A trial placement of the SCC mixture planned for use in the trial shaft and load test shaft at the bridge project was conducted at UH. The mixture was the 4-hour retarded version of Ameron mix 4539SCC. The evaluation was performed to verify that the SCC would meet the project specifications and provide adequate flow and filling properties for the field drilled shafts.

The evaluation was based on slump flow, J-ring, T-50 and segregation tests at 30 minute intervals after concrete batching. In addition, three 1 cu yd forms with rebar similar to that planned for the drilled shafts (Figure 1), were placed at 1, 2 and 3 hours after concrete batching. Finally, slump tests were performed at 4 and 5 hours after concrete batching.

Trial Placement of Self-Consolidating Concrete (continued from page 6)



Figure 1: Trial Placement 1 cuyd Form with Reinforcing Cage Matching Drilled Shaft Reinforcement

Figure 2 shows the slump flow measurements taken every 30 minutes after batching. The first 5 readings were within the 23+3" specified range. During this time, two forms were filled at 1 and 2 hours after batching. The concrete showed excellent flow and filling potential for both forms, even though the second was placed when the slump flow matched the lower limit of 20". Prior to placement of the third form, the slump flow measured 19.5", just below the 20" lower limit. Water was added to the remaining concrete in the truck (approximately 1.5 cuyd) at 1.33 gal/cuyd. The design mix allows for up to 2 gal/cuyd additional water to increase slump flow at the site. This water addition increased the slump flow to 23". The third form was then filled, with flow and filling characteristics identical to the first two forms.

J-ring tests were performed along with the slump flow tests at 30 minute intervals. The difference between the slump flow without the J-ring, and that with the J-ring represents the ability of the mix to pass through a reinforcing cage. Figure 3 shows that this J-ring difference tended to exceed the 2" maximum currently in the project specs. However, the concrete was able to flow through and around the drilled shaft reinforcing cage without apparent segregation and with complete filling. It was therefore concluded that the 2" spec may be more stringent than necessary for this mixture. It is proposed that this spec be revised to 3" for the field placement of SCC at the N. Kahana bridge project. After the addition of water at the 3 hour mark, this 3" limit was exceeded by 0.5" as seen

in Figure 3. This did not appear to adversely affect the filling ability during placement of the third form.

Concrete temperature was measured in two locations within the second 1cuyd form. One thermistor was placed at 1" from the top of the concrete, while the other was placed in the center of the 1 cuyd form (ie. 18 inches from the edge in all directions). Another thermistor was placed in the center of a 6"x12" concrete cylinder stored in a plastic mold adjacent to the 1 cuyd form. This cylinder was cast at the same time as the 1 cuyd form. Finally the ambient temperature was recorded at the datalogger. Form 2 was placed at 11:30AM on January 13, 2010 and the temperatures were recorded every 5 minutes for the next 31 hours, followed by hourly readings for the next 5 days.

The ambient temperature showed diurnal variations between approximately 72 and 77°F. The temperature at the center of the 6"x12" cylinder climbed to 90°F at 7.5 hours after placement and then declined to match the ambient temperature after about 4 days. The temperature measured at 1" from the surface of the 1 cuyd concrete pour initially followed the same trend as the concrete cylinder, but with lower temperatures because it is closer to the concrete surface. However, as the interior temperature of the 1 cuyd concrete increased to a peak of 149°F at 27 hours after

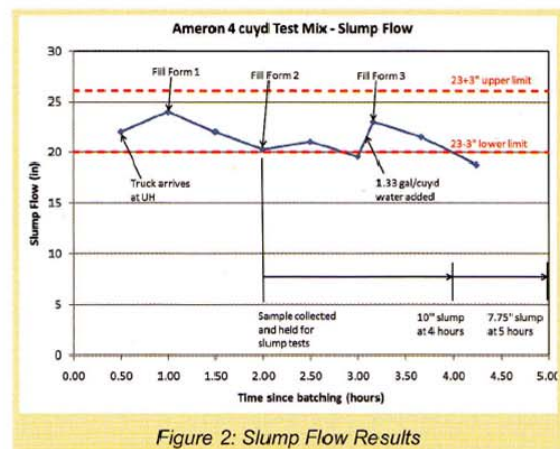


Figure 2: Slump Flow Results

(Continued on Page 9)

Trial Placement of Self-Consolidating Concrete (continued from page 7)

placement, the edge temperature elevated to a peak of 93°F. The maximum gradient between interior and exterior concrete was 59°F occurring 22 hours after the pour.

Based on the initial evaluation, Ameron mixture 4539SCC with 4-hour retarder was approved for placement in the trial SCC shafts at the N. Kahana Bridge project. The two trial SCC shafts were placed successfully using this mixture, along with a traditional tremie mix shaft. Evaluation of these field placements will be used to decide about the concrete characteristics for construction of the bridge drilled shafts.

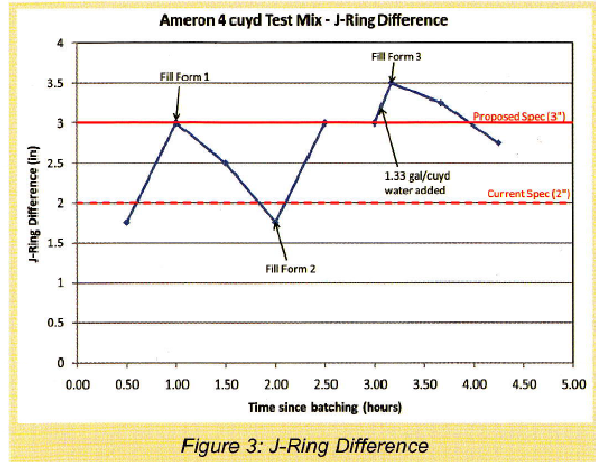


Figure 3: J-Ring Difference