EVALUATION OF SELF-CONSOLIDATING CONCRETE STABILITY TEST METHODS DURING THE PRODUCTION OF PRECAST, PRESTRESSED BRIDGE GIRDERS

Samuel D. Keske, Department of Civil Engineering, Auburn University, Auburn, AL
Dr. Anton K. Schindler, Department of Civil Engineering, Auburn University, Auburn, AL
Dr. Robert W. Barnes, Department of Civil Engineering, Auburn University, Auburn, AL

ABSTRACT

Prior to statewide implementation of self-consolidating concrete (SCC) in precast bridge member construction, the Alabama Department of Transportation required the development of a quality assurance testing protocol for the assessment of stability. Five stability test methods were selected for study: the Visual Stability Index (VSI), the Column Segregation Test, the Rapid Penetration Test, the Sieve Stability Test, and the Surface Settlement Test.

These fresh test methods were evaluated during the full-scale implementation of SCC to produce seven 100 ft BT-54 and seven 134 ft BT-72 precast, prestressed bridge girders. Also, companion girders were produced with conventional-slump concrete, and the construction operations and surface finish associated with each concrete type were compared. An earlier laboratory study resulted in a proposed stability testing protocol that requires the combined use of the VSI and sieve stability test. The effectiveness of this protocol was studied, as was the repeatability of the fresh test results in relation to laboratory testing results.

The proposed stability testing protocol facilitated effective assessment of the degree of SCC stability during production, and the field test results correlated well with laboratory results. All SCC girders were more rapidly cast, required less labor, and exhibited similar or better surface finish than the companion conventional-slump concrete girders.

Keywords: Quality Assurance, Segregation, Surface Finish

INTRODUCTION

Self-consolidating concrete (SCC) is a highly fluid, nonsegregating concrete that can spread through reinforcement and completely fill formwork without the use of mechanical consolidation1. Because of its fluid nature, it can fill heavily congested or irregularly shaped members more easily than conventional-slump concrete while also providing an improved quality and surface finish. Its use also eliminates the need for vibratory consolidation efforts and decreases wear and tear on forms and equipment. Because of these attributes, one of the most advantageous implementations of SCC is in the production of precast, prestressed bridge girders, where reinforcement congestion and member shape make filling and consolidation of conventional-slump concrete difficult.

Accompanying the advantages of SCC are several potential disadvantages. SCC is given its fluid nature by changing the mixture proportions and adding chemical admixtures, and the effects of these mixture changes and chemical additions on the mixture's fresh and hardened properties are not always clear. Because adjustments to the mixture and chemical admixtures may have unexpected effects, it is of vital importance to producers to quantifiably monitor the properties of the concrete affected by these adjustments. However, despite the importance of monitoring the fresh properties of SCC, standardization of the material's unique testing requirements is ongoing.

Of particular concern is the testing of fresh stability of SCC, as segregation (primarily settlement of constituents and migration of bleed water) can detrimentally affect the performance of the hardened product. Accurately assessing stability by testing the fresh concrete has proven difficult: few tests are currently available to measure it. The most widely used of these tests in the U.S. is the Visual Stability Index (VSI). This test involves visually assigning a discreet segregation index value ranging from 0 to 3 based on the appearance of the tested sample, with 0 showing no signs of segregation and 3 showing clear segregation2. The VSI is a rapid and simple test, but, because it is visually assessed, it is subjective. Its subjectivity may limit its value to quality assurance (QA) testing, and it may prove difficult to determine mixture acceptance or rejection based on its result.

Recently, more test methods have been proposed that potentially offer a more quantitative and less subjective assessment of SCC stability than the VSI, and several researchers3, 4, 5 have studied these test methods and proposed methodologies for their use in testing fresh stability. After studying the technician-friendliness of several fresh stability test methods and the relevance of their results to in-situ hardened uniformity, Keske4 proposed a testing protocol that involves the combined use of the VSI and the less subjective, but more time-consuming, sieve stability test. That protocol was evaluated during this research, as were several other promising stability test methods identified by Keske4, including the column segregation test6, rapid penetration test7, and surface settlement test5.

RESEARCH OBJECTIVES

Prior to statewide implementation of SCC in precast, prestressed bridge member production, the Alabama Department of Transportation (ALDOT) required the development of a quality assurance protocol for the assessment of SCC stability. The authors assessed several promising stability tests and proposed a stability testing protocol during previous research4. The research described in this paper was conducted to

- Evaluate the repeatability of results, ease of use, and plant acceptance of the proposed fresh stability testing protocol during full-scale implementation of SCC in the production of precast, prestressed bulb-tee girders,

- Evaluate the correlations between fresh stability tests that had been determined previously during laboratory testing at Auburn University.

EXPERIMENTAL PROGRAM

OVERVIEW OF FULL-SCALE PROJECT

Auburn University researchers have worked with ALDOT in recent years to study the implementation of SCC in precast, prestressed bridge element construction. Previously completed research projects included formulation of the mixture proportions and properties8, study of the material's hardened behavior9, [10], and assessment of test methods that could be used to test the material's fresh stability4. The ultimate goal of the research was to produce the state's first SCC precast, prestressed bridge—a task that began in the fall of 2010.

The bridge selected for study has four spans—two outer spans each consisting of seven 100 ft BT-54 bulb-tees, and two inner spans each consisting of seven 134 ft BT-72 bulb-tees. One span of BT-54s and one span of BT-72s were made with SCC while the companion spans were constructed with conventional-slump concrete girders. This allowed for a direct comparison of the construction operations and fresh and hardened properties associated with each type of concrete. Construction of the bridge over Hillabee Creek in Alexander City, AL, took place in the summer of 2011 and is shown in Fig. **1**.

The twenty-eight girders were produced at Hanson Precast of Pelham, AL during the months of September and October of 2010. The plant employed a central rotational mixer, and concrete was delivered to the prestressing bed in 3 yd^3 loads. Three BT-54 bulb-tees were cast in each of four days (two days of conventional-slump placements and two days of SCC placements), and the seventh conventional-slump and seventh SCC girders were cast on the same bed during a fifth production day. Following the completion of BT-54 production, two BT-72 bulb-tees were cast in each of six days (three days of conventional-slump placements and three days of SCC placements). Similar to the production of the BT-54s, the seventh conventional-slump and SCC girders were cast on the same bed during a seventh production day.

Fig. 1 Construction of precast, prestressed bridge over Hillabee Creek in Alexander City, AL

To facilitate direct comparison of the hardened properties of each concrete, the conventional-slump concrete mixtures and SCC mixtures employed had the same target prestress release strength and target 28-day strength. Different targets were set for BT-54s and BT-72s as follows:

- Conventional-slump concrete and SCC placed in BT-54 bulb-tees had a target release strength of 5200 psi and a target 28-day strength of 6000 psi, and

- Conventional-slump concrete and SCC placed in BT-72 bulb-tees had a target release strength of 5800 psi and a target 28-day strength of 8000 psi.

The slump of the conventional-slump concrete was not to exceed 9 in., and the required slump flow of the SCC was 27 ± 2 in. QA acceptance of the SCC was determined using the VSI, and only batches exhibiting a VSI less than 2 were accepted. Other fresh stability test methods were conducted by the researchers, but the results of those tests were not used to determine batch acceptance.

FRESH STABILITY TEST METHODS

A total of five fresh stability test methods were evaluated during full-scale production: the VSI, sieve stability, column segregation, rapid penetration, and surface settlement tests. After evaluating these five tests in a laboratory environment, the researchers[4] determined that the VSI and sieve stability test were the best suited tests for use in routine quality assurance testing, while the surface settlement test was best suited for assessing segregation risk (or a lack of stability) during prequalification testing. Nonetheless, all five tests offered potential advantages, so they were all chosen for further study during the plant-production phase of the research.

The sieve stability test, shown in Fig. **2**, involves placing a sample of SCC in a container to rest for 15 minutes, after which the sample is poured from a height of 20 in. onto a No. 4 (or 5 mm) sieve. As seen in Fig. **2** and recommended by the test's creator[3], a pouring apparatus was used during this testing to ensure that the SCC would be poured from a consistent height. After being poured onto the sieve, the sample is allowed to settle for 2 minutes before the sieve and pan are separated to determine the amount of laitance that passed through the sieve. The amount of laitance is expressed as a percentage of the weight of the sample that was poured onto the sieve and pan, with higher percentages indicating decreased stability. Several researchers[3, 4, 8] have found the test to correlate well with measures of in-situ uniformity during laboratory testing, and it is frequently recommended[3, 4] for QA testing.

Fig. 2 Sieve stability test apparatus

The proposed fresh stability testing protocol that was evaluated during this research requires the simultaneous initiation of the VSI and the sieve stability test. The VSI is subjective and potentially inadequate in mixtures that do not show bleeding segregation[1, 5], but it is very fast and was found to correlate equally well with measures of in-situ hardened uniformity as more quantitative tests[4]. As a result of earlier research at Auburn University, Keske[4] recommended employing the VSI first for quality assurance testing, with any VSI value less than 2 ensuring that the SCC will exhibit acceptable uniformity. Because the VSI is subjective and correlated well with the sieve stability test during laboratory testing, the sieve stability test result should be obtained to determine acceptance or rejection in borderline cases in which the VSI exceeds 1. This protocol would remove potential technician variation from the determination of stability acceptance or rejection. The sieve stability test could be discontinued if the tested concrete is clearly stable (showing a VSI of 1 or less).

Several researchers[4, 5] have found the surface settlement test to also correlate well to measures of in-situ uniformity during laboratory testing, and they have recommended it for prequalification testing of SCC mixtures to be used in precast, prestressed applications. The test, shown in Fig. **3**, involves measuring the settlement of a thin acrylic plate into the top of a column of concrete as the concrete hardens. Because it is time-consuming (requiring up to several hours for the concrete to harden), sensitive (settlement is measured to ±0.0004 in.), and would not be used during in-field quality assurance testing, the surface settlement test was conducted during this research in a secure laboratory on the plant premises only to assess the stability of the mixtures and further study the relationship between its result and those of the other fresh stability tests.

Fig. 3 Surface settlement test apparatus with clear acrylic plate

Other promising fresh stability test methods that were identified during previous research and that were conducted during the full-scale production process included the column segregation test[6] and rapid penetration test[7], both of which have been standardized for use in the assessment of SCC stability. Several researchers[4, 8, 12] have found the column segregation test to be too slow and laborious to implement during quality assurance testing because of the difficulty of separating and wet-sieving the SCC from the sections of the column segregation apparatus. This process is shown in Fig. 4. Meanwhile, others[5, 13] recommend it for quality assurance testing.

Several researchers[4, 8] have found the rapid penetration test to correlate poorly with other fresh stability tests, and Keske4 found it to correlate poorly with measures of in-situ uniformity. However, it is a rapid and quantitative test that only requires the measurement of a probe's penetration into a sample of SCC, as shown in Fig. 4. For this reason, several researchers[3, 12] have recommended it for QA testing of SCC stability.

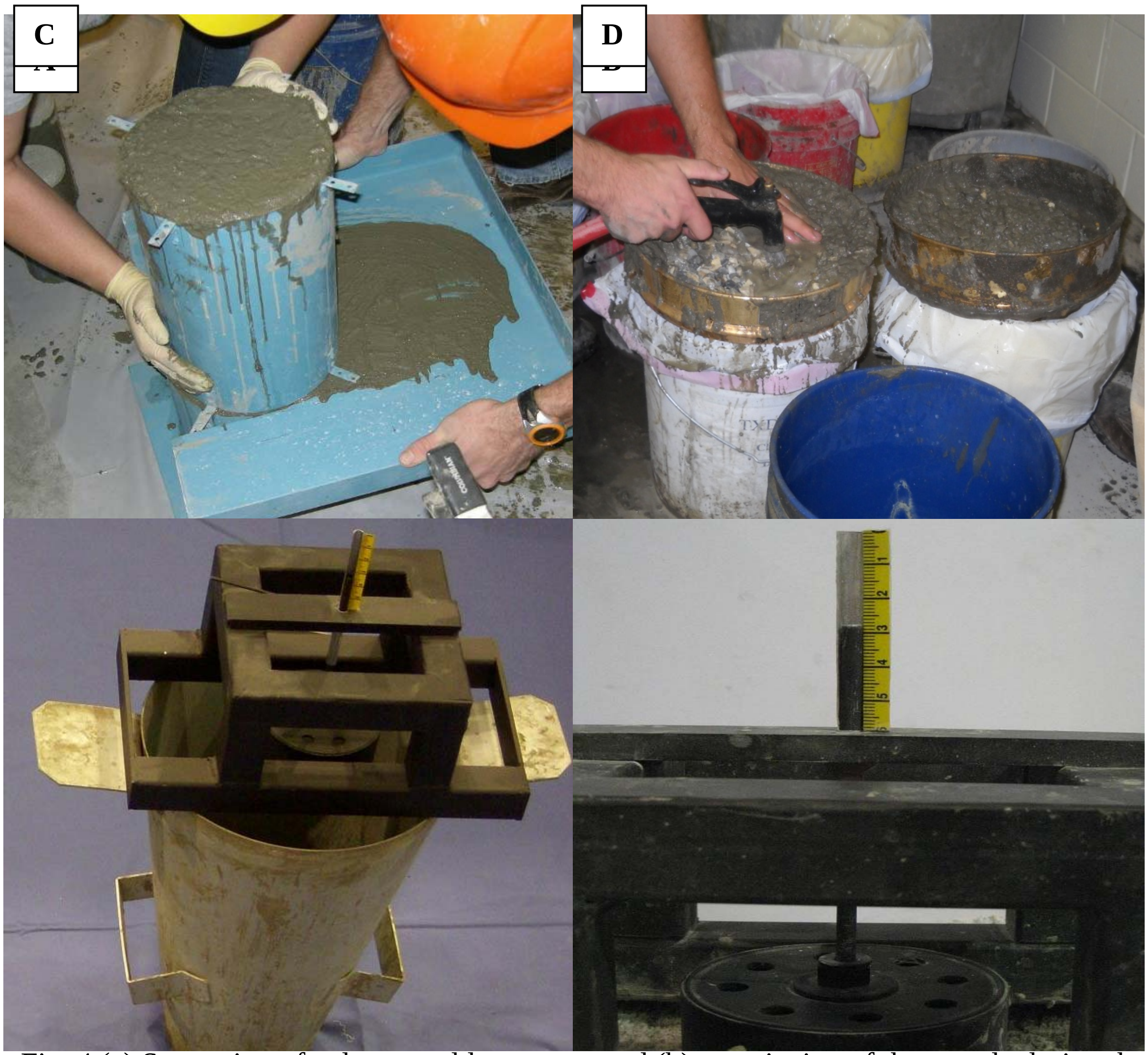

Fig. 4 (a) Separation of column mold segments and (b) wet-sieving of the sample during the column segregation test; (c) inverted slump cone and rapid penetration test apparatus, and (d) reading of 28 mm penetration depth during the rapid penetration test

TESTING PROCEDURE

The specifications established specifically for this construction project required that ALDOT and plant personnel be trained concerning SCC-specific testing prior to full-scale production in the plant. Shown in Fig. **5**, Auburn University personnel conducted this training in August 2010 in order to

- Train ALDOT and plant technicians to correctly assess the slump flow and VSI of SCC so that they could be responsible for QA testing during full-scale production,

- Familiarize all technicians with the VSI testing procedure and provide them with a pocket guide to testing in order to limit subjectivity and technician variation during full-scale production, and

- Inform all technicians of required test method procedural modifications that are necessary for SCC, such as air content testing and fabrication of strength-testing specimens.

Fig. 5 Slump flow and VSI training of ALDOT and Hanson Precast personnel

While ALDOT personnel were responsible for QA testing and plant personnel were responsible for quality control (QC) testing, the Auburn University researchers were also present to observe all testing and to conduct their own testing to achieve the research objectives described above. While the ALDOT technicians were only required to test the

VSI to determine batch acceptance or rejection, the Auburn University researchers independently conducted the VSI and the sieve stability test at least twice per SCC production day in order to assess the stability testing protocol proposed by Keske4. Because it could be conducted very quickly, the rapid penetration test was also conducted at least twice per SCC production day.

The column segregation test and surface settlement test, which are more time-consuming and labor-intensive, were conducted once per day to coincide with the first cycle of testing of the other three stability test methods. All testing by ALDOT technicians, plant personnel, and Auburn University researchers was conducted on a patio outside of the plant's materials testing laboratory located along the path between the mixer and the prestressing bed. The only exception was that the surface settlement test was conducted inside the laboratory and away from any other testing in order to limit interference that could affect its results. A pair of each of the five stability tests was conducted simultaneously during each testing cycle, and the results obtained from two apparatuses were averaged before analysis.

The first cycle of testing was conducted on a sample taken from the first 3 yd^3 batch dispensed, and that batch was also tested by ALDOT and plant personnel for QC and QA purposes. A second cycle of research testing was always conducted approximately halfway through the day's production to coincide with the second cycle of QC and QA testing. Whenever they were able to conduct all stability testing quickly enough to accommodate a third cycle of testing, the researchers were also allowed to stop a third truck for testing at any point during the day's placement.

RESULTS AND DISCUSSION

SCC testing was conducted a total of nineteen times over seven production days, and conventional-slump concrete placements were observed over an additional seven production days. Two of the days of conventional-slump concrete and SCC production coincided, as one conventional-slump and one SCC girder were cast on the same prestressing bed during each of those days. Production of SCC and conventional-slump concrete alternated over each of the other ten production days.

Each SCC placement required fewer than half as many laborers as each conventional-slump concrete placement. All production activities were conducted more rapidly during SCC placements until top-surface scratch roughening and covering of the girders for steam curing. Since a delay was required before roughening the top surface of the SCC girders to ensure that the concrete would set sufficiently to hold the desired texture, total production times were only marginally quicker during SCC placements.

Despite the absence of consolidation efforts during SCC placements, the SCC girders regularly exhibited an equal to much better surface finish than companion conventional-slump concrete girders. Examples of the surface finish achieved with each concrete type are shown in **Error! Not a valid bookmark self-reference.**. In that figure, it is apparent that bug holes were both deeper and more prevalent in conventional-slump concrete, while the primary undesirable surface features in the SCC girders were shallow bleed channels and surface bubbles that occurred in the bottom bulb where bleed water and air bubbles were trapped against the upper surface of the bottom bulb formwork.

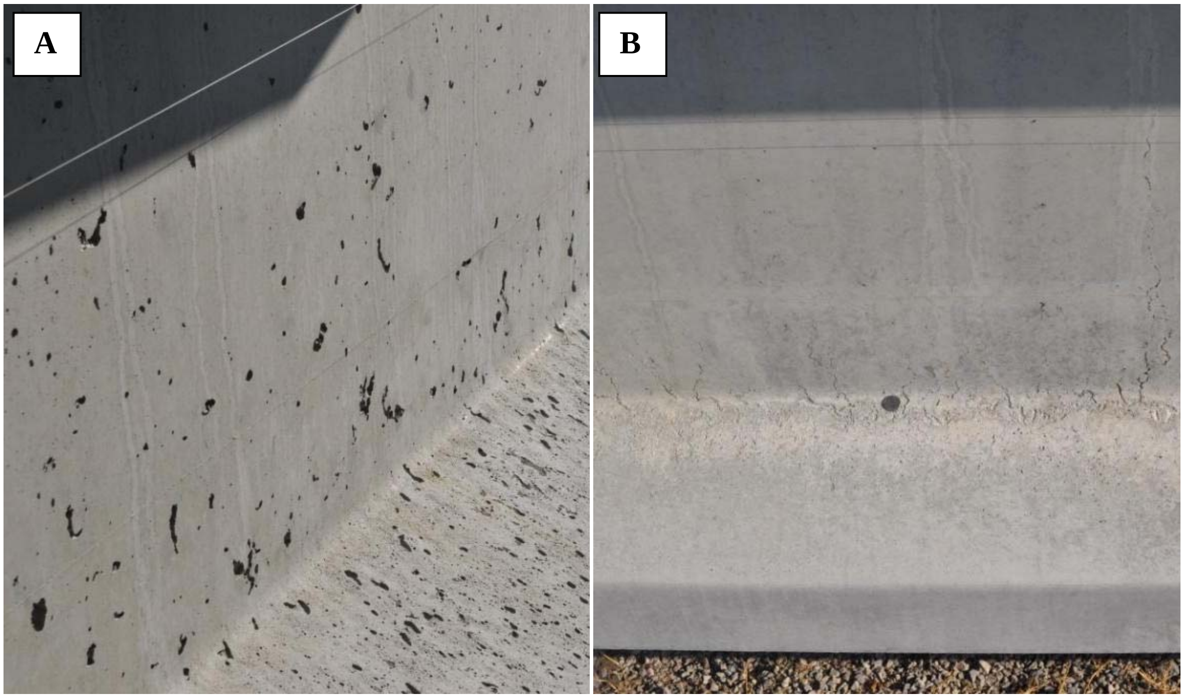

Fig. 6 Surface finishes of BT-72 bulb-tees cast with (a) conventional-slump concrete and (b) SCC (with quarter dollar to show scale)

According to the precast producer, the improved surface finish of the SCC girders was the single largest advantage gained through use of the material, and the producer was confident that continued adjustments to the SCC mixture would eventually result in a surface finish that would require no additional rubbing or patching prior to shipment. The producer was also confident that obviating these resurfacing measures would provide a cost savings that would exceed any savings realized from removal of the consolidation efforts currently required for conventional-slump concrete. The producer went on to state that the company would prefer to use SCC for all precast, prestressed placements.

FRESH TEST RESULTS

The ranges of fresh stability test results shown in Table 1 were obtained during the seven SCC production days. These ranges of test results indicate that the SCC exhibited satisfactory stability according to most cited recommendations. In two samples, the surface settlement result exceeded the limit recommended by Keske. However, only one of those two samples showed a borderline VSI result of 1.5, and neither sample exhibited an unacceptably high sieve stability result. Also, the two questionable results were obtained during the first two SCC production days, so it can be concluded that the SCC regularly showed acceptable stability and the producer quickly learned to improve the level of stability through QC testing.

Table 1 Ranges of fresh stability test results obtained during full-scale SCC production

Test Method	Range of Results	Acceptability of Results
VSI	0–1.5 *visual stability index*	Acceptable[4,14] Unacceptable[5]
Sieve Stability	0–10.4 % *sieved fraction*	Acceptable[3, 4, 14]
Surface Settlement	0.067–0.265 %/hr *rate of settlement*	Acceptable[5] Unacceptable[4]
Column Segregation	1.3–7.9 % *segregation index*	Acceptable[5, 8]
Rapid Penetration	2–13 mm *penetration depth*	Acceptable[7, 12]

In general, the ALDOT personnel and plant personnel found that the VSI was acceptably easy to conduct. However, the Auburn University researchers observed that the technicians occasionally had difficulty reaching a consensus agreement regarding the VSI value for a sample. Most frequently, the disagreement was over whether to assign a VSI of 1 or 1.5, both of which would have been acceptable based on the project specifications. The plant personnel also always agreed to reject any batches that exhibited a VSI of 2 or greater, but the researchers were able to see that the proposed testing protocol would have been beneficial to limit the subjectivity and uncertainty of those situations.

After observing the Auburn University researchers during their operation of the sieve stability test, the technicians for ALDOT and the plant agreed that the test would be fairly easy to conduct for QA and QC purposes. Their main concern was that, after waiting for the 15 minutes required of the sieve stability test, the tested load of SCC could have begun to set. They also observed that such a concern may shift the focus of the VSI determination to the assignment of a 1 (which would allow the sieve stability test to be discontinued) or a 1.5 (which would require waiting for the sieve stability test). The researchers are confident that, based on previously determined correlations to in-situ uniformity[4], such a shift would ensure that any placed SCC would exhibit acceptable stability.

COMPARISON OF FIELD AND LABORATORY RESULTS

Evaluation of the correlations previously established by the researchers[4] was a primary objective of this research. To reach this objective, the surface settlement, column segregation, and rapid penetration tests were conducted in order to compare their results to each other and to the VSI and sieve stability test. Several notable relationships from previous Auburn University research[4] were of interest during this testing:

- Strong linear correlations were previously observed between the sieve stability test and each of the VSI and column segregation tests (linear regression r^2-values of 0.77 and 0.54, respectively),

- A strong nonlinear correlation was previously observed between the rate of settlement and maximum settlement results determined during the surface settlement test (r^2 of 0.47), and

- No strong correlation was previously observed between the rapid penetration test and any other fresh stability test (no r^2 exceeding 0.40).

The field and laboratory data collected from the VSI and sieve stability test are compared in Fig. 7. Over the ranges of concrete tested, the relationship between the VSI and sieve stability test determined during field testing was almost identical to the relationship found during laboratory testing. This confirms that the VSI is well correlated to the more quantitative sieve stability test4 and strengthens the previous recommendation4 that the two tests be used in conjunction to determine QA acceptance or rejection. Because the VSI is much faster but is potentially subjective, the sieve stability test would provide a quantitative result in borderline VSI situations to allow objective determination of batch acceptance or rejection.

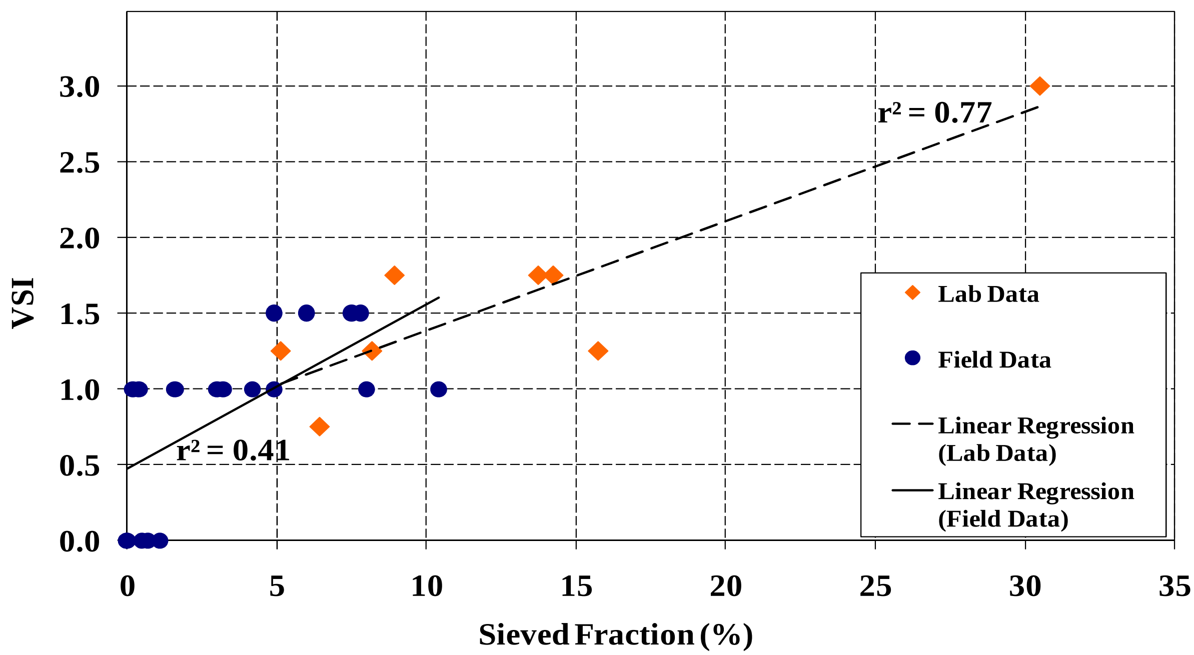

Fig. 7 Comparison of field and laboratory data from the sieve stability test and VSI

The field and laboratory data collected from the column segregation and sieve stability tests are compared in Fig. 8. Like the relationship between the VSI and sieve stability test, the relationship between the column segregation test and the sieve stability test determined during field testing was almost identical to the relationship found during earlier laboratory testing. This confirms other researchers'4, 8 observation that the sieve stability test is well correlated to the more time-consuming and laborious column segregation test and strengthens the previous recommendation4 that the sieve stability test should always be used in place of the column segregation test to determine QA acceptance or rejection.

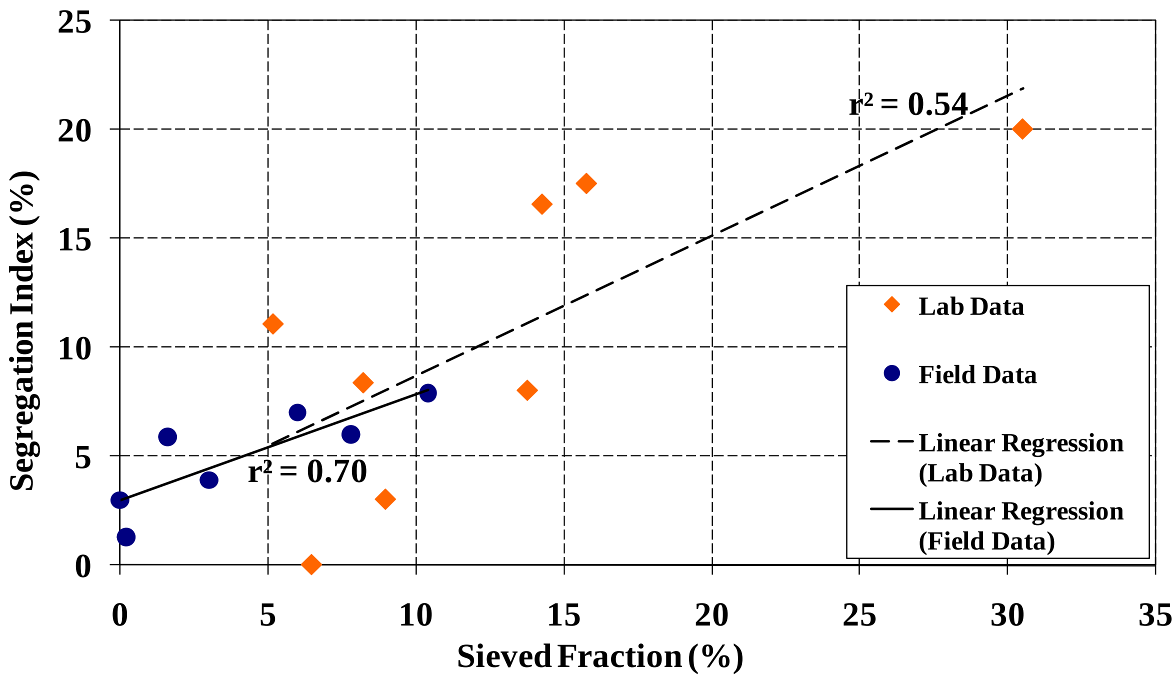

Fig. 8 Comparison of field and laboratory data from the sieve stability test and the column segregation test

A comparison of the field and laboratory results of the surface settlement test is shown in Fig. 9. As can be seen in that figure, the nonlinear correlation determined during field testing was similar to the relationship determined during laboratory testing, and it exhibited a slightly higher r^2-value (0.52 versus 0.47). Furthermore, the field data exhibit a similar nonlinear relationship to that found by Hwang, Khayat, and Bonneau[15]. The repeated observation that the more rapidly calculable rate of settlement correlates well with the very time-consuming measurement of the ultimate settlement during this test confirms the recommendation by Keske4 that only the rate of settlement determined between 10 and 15 minutes need be determined while conducting the test.

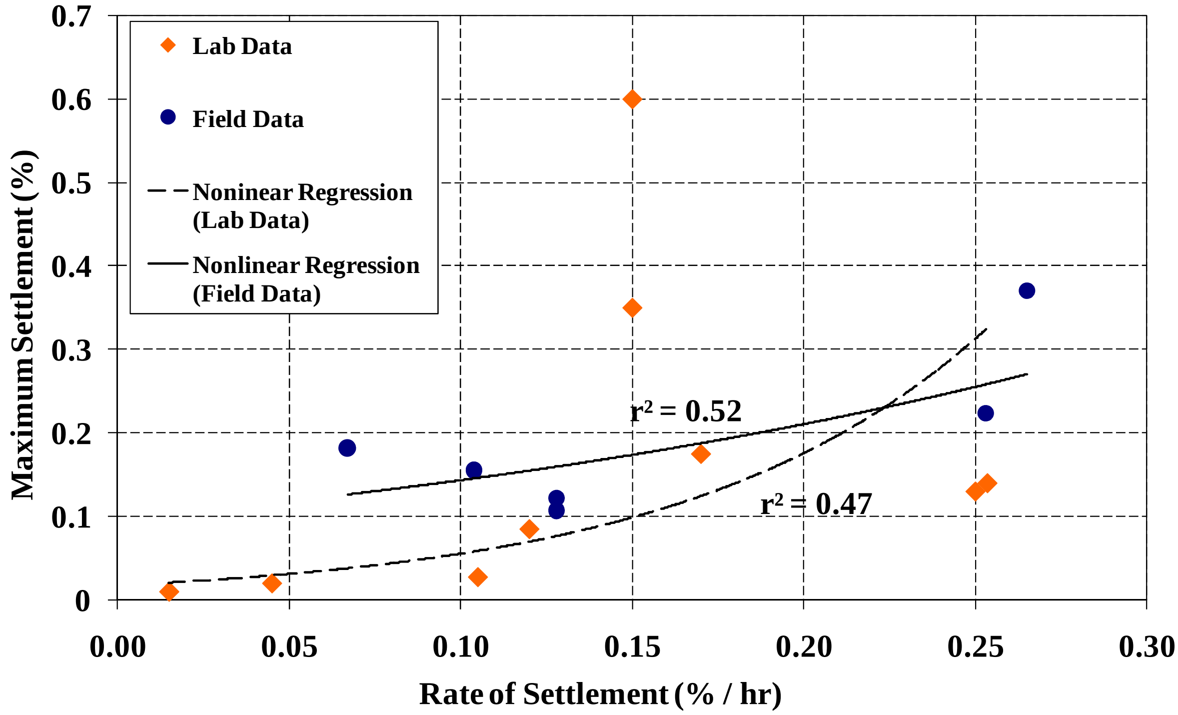

Fig. 9 Comparison of field and laboratory data from the surface settlement test

Lastly, the absence of strong correlation between the rapid penetration test and any other fresh stability test that had been observed by several researchers[4, 8] was again observed during this research. While the test is both rapid and quantitative, the current variation of the test requires further research before being used to assess the stability of SCC. The test's poor performance may be due to excessive scatter in its results or because the mechanism that is observed (penetration of a probe into a sample of SCC) is poorly related to other measures of stability.

FUTURE WORK

Based on this study, future research should be focused on studying the abbreviation of the 15-minute testing time required for the sieve stability test. As previously mentioned, a primary concern in the integration of the sieve stability test into QA testing is that the prolonged testing time may detrimentally affect the ability of the producer to place any batch that must wait for its result. If an abbreviated test time (such as 5 or 10 minutes) could still provide repeatable results that correlate well with the 15-minute results, the time savings would be highly valuable to precast, prestressed concrete producers.

Future research should also be focused on determining the repeatability of the surface settlement test over a wider range of SCC mixtures. While the data collected in the field were similar to the data collected in an earlier laboratory investigation, the correlation between the rate of settlement and maximum settlement determined during the test was slightly different. Further research should confirm whether a single relationship is appropriate or if, as Khayat and Mitchell5 recommend, different mixture-specific relationships should be used.

Furthermore, the Auburn University researchers plan to continue training precast, prestressed plant personnel and ALDOT personnel on SCC-specific testing procedures. These procedures include guidance on the measurement of the slump flow, the VSI, the sieve stability test, and the surface settlement test. The ALDOT personnel and personnel of Hanson Precast found the training to be highly valuable, and they felt that such training greatly reduced the risk of subjectivity associated with the VSI.

CONCLUSIONS AND RECOMMENDATIONS

During production of the state of Alabama's first full-scale SCC precast, prestressed bridge girders, this study was conducted to further assess a stability testing protocol and other fresh stability test methods that had been previously studied in a laboratory setting at Auburn University. Several conclusions were reached as a result of this research:

1. The proposed stability testing protocol consisting of simultaneous initiation of the VSI test and sieve stability test, with reliance on the sieve stability result in borderline VSI situations, can effectively facilitate assessment of SCC stability during production. Such a combination can remove the subjectivity of the VSI from borderline decisions while allowing rapid assessment of clearly stable SCC.

2. A previously determined strong correlation between the VSI and sieve stability test was confirmed. The VSI is well correlated to more time-consuming but less subjective tests.

3. A previously determined strong correlation between the column segregation and sieve stability tests was confirmed. The sieve stability test should always be used in place of the column segregation test when determining SCC stability.

4. A previously determined strong correlation between the rate of settlement and maximum settlement determined during the surface settlement test was confirmed. Only the measurement of the rate of settlement determined between 10 and 15 minutes is necessary when conducting the test.

5. All SCC placements during this full-scale production exhibited acceptable stability and achieved equal or better surface finishes than conventional-slump concrete. The precast, prestressed producer was confident that the use of SCC would create appreciable cost savings relative to the use of conventional-slump concrete.

REFERENCES

1. ACI Committee 237*, Self-consolidating concrete (ACI 237R-07)*, 2007.
2. ASTM C 1611, *Standard test method for slump flow of self-consolidating concrete*, 2005.
3. EPG (Self-Compacting Concrete European Project Group), *The European guidelines for self-compacting concrete*, 2005.
4. Keske, S.D., *Assessment of Stability Test Methods for Self-Consolidating Concrete,* MS thesis Auburn University, 2011.
5. Khayat, K.H., and Mitchell, D., *National Cooperative Highway Research Program (NCHRP) Report 628: Self-consolidating concrete for precast, prestressed concrete bridge elements*, 2009.
6. ASTM C 1610, *Standard test method for static segregation of self-consolidating concrete using column technique*, 2006. *ASTM International*. West Conshohocken, PA.
7. ASTM C 1712, *Standard test method for rapid assessment of static segregation resistance of self-consolidating concrete using penetration test*, 2009.
8. Schindler, A., Barnes, R., Roberts, J.B., and Rodriguez, S., "Properties of Self-Consolidating Concrete for Prestressed Members," *ACI Materials Journal* V. 104, No. 1, January-February 2007, pp. 53-61.
9. Levy, K.R., Barnes, R., and Schindler, A., "Time-dependent Deformations of Pretensioned, Self-Consolidating Concrete," in *Proceedings of the Third International fib (International Federation for Structural Concrete) Congress and Exhibition in Washington, D.C., 29 May–2 June 2010: Think Globally, Build Locally*, Precast/Prestressed Concrete Institute, 2010.
10. Boehm, K.M., Barnes, R., and Schindler, A., *Performance of Self-Consolidating Concrete in Prestressed Girders: Report No. FHWA/ALDOT 930-602*, 2010.
11. Koehler, E.P., and Fowler D.W., "Comparison of workability test methods for self-consolidating concrete," *Journal of ASTM International* V. 7, No. 2, February 2010.
12. Bui, V.K., Attiogbe, E.K., Vojtko, D., Schaef, S., and See, H.T., "A rapid test for segregation resistance of self-consolidating concrete," in *2007 Concrete technology forum: Focus on high performance concrete*, National Ready Mixed Concrete Association, 2007.
13. Assaad, J., Khayat, K.H., and Daczko, J.A., "Evaluation of static stability of self-consolidating concrete," *ACI Materials Journal* V. 101, No. 3, May-June 2004, pp. 207-215.
14. PCI (Precast/Prestressed Concrete Institute), *Interim guidelines for the use of self-consolidating concrete in Precast/Prestressed Concrete Institute member plants*, 1st ed., 2004.
15. Hwang, S., Khayat, K.H., and Bonneau, O. "Performance-based specifications of self-consolidating concrete used in structural applications," *ACI Materials Journal* V. 103, No. 2, March-April 2006, pp. 121-129.