EVALUATION OF RESISTIVITY METERS FOR

CONCRETE QUALITY ASSURANCE,

PROJECT TR201414

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ABSTRACT

This research evaluated a series of MoDOT concrete mixtures to verify existing relationships between surface resistivity (SR), rapid chloride permeability (RCP), chloride ion diffusion, and the AASHTO penetrability classes. The research also performed a precision and bias evaluation to provide acceptable limits should SR be implemented for quality assurance and to refine language in the AASHTO test standard. In the precision and bias determination concrete was produced from three field sites and tested at both UMKC and MoDOT labs. Field mixtures included a paving mixture, a bridge deck mixture, and a structural mixture. Eleven other mix designs were produced in the lab and evaluated for RCP correlation and included paving, bridge deck, structural, and repair mixtures per Missouri Department of Transportation requirements. Additional testing included surface resistivity testing on sealed samples and an existing bridge deck. Results showed excellent correlation between SR and RCP which matched existing relationships provided by AASHTO and other state DOTs. The structural mixture containing 50% Class F fly ash had the best performance with “very low” chloride ion penetrability at 90 days. A ternary paving mixture with 20% Class C fly ash and 30% slag replacement for cement also demonstrated low permeability as well as high compressive strength with an average value of over 9,000 psi at 90 days. The two repair mixtures showed moderate to low penetrability readings and high early strength consistent with their desired purpose. Tests were also performed on a series of slab samples to evaluate SR as a tool for evaluating sealer application. The presence of silane and lithium silicate were able to be detected by the SR test. As value added to the laboratory research, field testing was attempted on a bridge deck with the goal of providing non-destructive insight to the steel condition in the field. Due to the condition of the bridge conclusions could not be drawn other than making recommendations for future bridge deck evaluations. The extensive amount of surface resistivity testing (>4500 tests) on 14 concrete mixtures at ages from 3 hours to 90 days using multiple labs, equipment, operators, and curing conditions has verified RCP relationships and allowed refinement of a testing procedure for a MoDOT standard in the Engineering Policy Guide. Surface resistivity presents an opportunity to improve MoDOT concrete mixtures and specifications to increase durability without adding significant additional testing costs.

The faculty listed below, appointed by the Dean of the School of Computing and Engineering, have examined a thesis titled “Evaluation of Resistivity Meters for Concrete Quality Assurance, Project TR201414," presented by Dirk P. Hudson, candidate for the Masters of Science degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

EXECUTIVE SUMMARY

Concrete permeability is the most important factor affecting the long-term durability of both plain and reinforced concrete structures. Current standard test methods to measure concrete permeability are destructive, time consuming, and expensive. The objective of this study was to develop or verify a test protocol to measure the surface resistivity (SR) of concrete. Ideally, the new test method would replace the rapid chloride permeability (RCP) test as a quality control tool for new construction and for potential evaluation of existing structures in Missouri. Researchers at the Louisiana Transportation Research Center (LTRC) have experimented with surface resistivity testing as an alternative to rapid chloride permeability testing, and the state of Louisiana has recently accepted surface resistivity testing to be used as a quality control tool. LTRC researchers predicted over $1,500,000 in savings per year by using surface resistivity in place of rapid chloride permeability testing (Rupnow and Icenogle, 2011; Rupnow and Icenogle, 2012).

The research team at University of Missouri – Kansas City started using surface resistivity measurements as an indicator of concrete permeability in 2009. After five years of observation of good correlation between the surface resistivity and concrete permeability, the team initiated this study to support implementation of surface resistivity as a quality control tool in the State of Missouri. Replacement of concrete permeability testing with a simpler and lower cost surface resistivity testing as a quality control tool is expected to improve the quality of concrete in Missouri leading to lower permeability concrete with improved service life, reduced distress, and reduced amount of maintenance and reconstruction.

Results from surface resistivity meters (AASHTO TP 95-11) and RCP testing (AASHTO T277) performed on MoDOT concrete mix designs were compared and tested for correlation. The project developed criteria for acceptance of concrete using a surface resistivity meter with values acceptable and appropriate for pavements, bridge decks, substructural elements, rapid set patches, and bridge deck sealers. Throughout the process of testing with surface resistivity meters, protocols were developed for using the meters as a quality control method for new and existing concrete. A short training course describing a uniform procedure for use of the surface resistivity meters was developed for MoDOT inspectors.

Additionally, the UMKC team incorporated field verification of the proposed standard on three construction projects as well as coordinating evaluation of an existing structure during the Fall of 2014. Based on the results determined from lab testing and field testing, remarks on MoDOT's current mix design requirements were made.

This report documents the phases of the project in a sequential manner, which follows:

- Chapter 2: Literature Review - A literature review of background information necessary for developing the idea and objective of the project.
- Chapter 3: Materials - The wide range of materials used in the concrete mixtures are explained in this chapter.

- Chapter 4: Mixture Designs - All of the mixture designs used throughout the project are addressed in this chapter.
- Chapter 5: Lab Mixing and Testing Methods - The standard protocols for mixing and testing the lab samples are presented in this chapter.
- Chapter 6: Field Testing Methods - Field test procedures required a more stringent test protocol to be made to ensure consistencies in testing which are discussed in this chapter.
- Chapter 7: Precision and Bias - The surface resistivity test method was checked for precision and bias in regards to the maximum amount of time allowed out of the curing environment and minimum amount of time required to be in a curing environment for concrete samples.
- Chapter 8: Lab Results and Discussion - The results from the lab portion of testing are posted in this chapter. Discussions and observations made on the lab samples are explained in detail.
- Chapter 9: Field Results and Discussion - The results from the field portion of testing are provided in this chapter. Discussions and observations made on the field samples are explained in detail along with numerous pictures documenting the activities on the bridge deck.
- Chapter 10: Sealer Testing and Results - The effect of sealers on the concrete surface was researched in detail to determine the impact of each approved sealer on resistivity testing within this chapter.

- Chapter 11: Conclusions and Future Research - A summary of results, conclusions drawn, and areas of future research are laid forth in this chapter.

CHAPTER 2

LITERATURE REVIEW

As Missouri Department of Transportation (MoDOT) and Federal Highway Administration (FHWA) move towards end result and performance-based specifications, concrete permeability testing, using the Rapid Chloride Permeability (RCP) test, has become more commonplace. Concrete permeability has been determined as the most important criteria for long-term durability. RCP test has been the most common method for testing the permeability of concrete in the past decade. RCP test is a highly effective method for evaluating and predicting concrete performance, however the equipment necessary to run the test is expensive and costs approximately $20,000. RCP testing also requires significant training for technical personnel and time consuming arduous sample preparation procedure prior to testing. While permeability has been an excellent measure of future concrete performance, the cost for equipment, manpower required to perform RCP testing, and the duration of the testing limits the use of RCP testing for quality assurance (QA) in all but the most important projects.

A second method of testing investigated in this study as an indicator of concrete permeability was ASTM C1556, *Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion* (ASTM C1556, 2013). ASTM C1556 involves unidirectional exposure of concrete specimens to a chloride solution for a minimum of 35 days. Following the exposure period, ground samples are collected from each sample at various depths from the exposure surface and their chloride content is determined through potentiometric titration. This difficult and time consuming process leads to determination of an apparent chloride diffusion coefficient as an indicator of concrete permeability. Surface resistivity testing has been shown to be the more desirable successor to the previous dated test methods.

Theory of Resistivity

Concrete and soils are comprised of solid particles, liquid, and water vapor-filled pore spaces. When an electrical charge is passed through these materials, the resistance of the solid and pore spaces are significantly higher than the electrolyte (liquid in pores). Samples with more interconnected fluid-filled spaces pass a higher charge and result in lower resistivity (Spragg et al., 2012). Resistivity testing is commonplace for soils to determine grounding capacity and corrosivity, with higher voltage resistivity systems able to provide subsurface layer mapping. Both bulk and surface resistivity testing have been used on concrete for a number of years but only after soil resistivity had been extensively researched (Morris et al., 1996; Spragg et al., 2012; Sengul and Gjorv, 2008).

DOTs are using surface resistivity testing for QA and acceptance of newly-placed concrete, verification of in-place properties, and evaluating corrosion potential (primarily on bridge decks). The Florida DOT first standardized surface resistivity testing in 2005 with FM5-578 *Florida Test Method for Concrete Resistivity as an Electrical Indicator of its Permeability*

(Kessler et al., 2008). The Florida DOT, contractors, and producers gained enough confidence that by 2007 surface resistivity replaced RCP test in Florida acceptance specifications.

Figure 1 shows a correction developed by the Florida DOT demonstrating the correlation of surface resistivity and RCP (Kessler et al., 2008). Both axes are in logarithmic scale. Mixtures shown in Figure 1 include concrete with water-to-cement ratios (w/cm) varying from 0.28 to 0.49, cementitious materials contents varying from 564 to 900 pounds per cubic yard (pcy) containing binary combinations of fly ash, slag, metakaolin, silica fume, and ultrafine fly ash. Mixtures also contained combinations of water reducing agents, air entrainment, and calcium nitrate accelerator. Even with the wide variety of project variables, the correlation between RCP and surface resistivity was apparent and consistent. As shown in the upper right hand corner of Figure 1, four inch by eight inch concrete cylinders were tested by placing a four-probe Wenner Array Surface Resistivity Meter on the eight inch face of the specimen (Kessler et al., 2008).

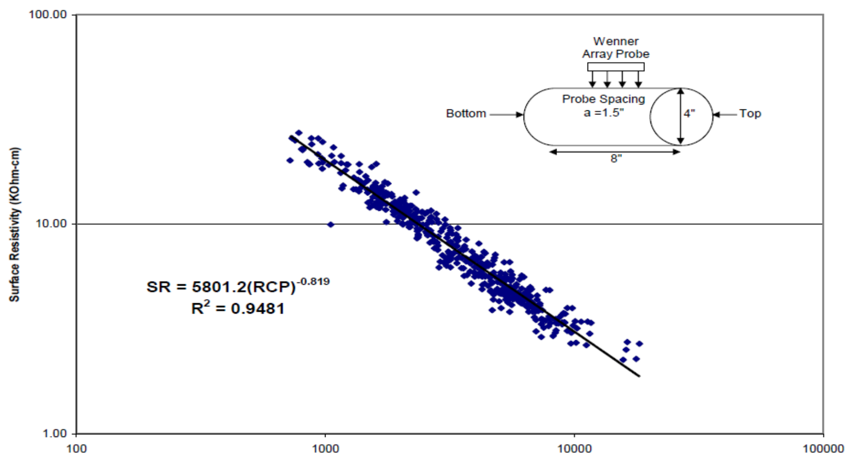


Figure 1. Correlation of surface resistivity with RCP charge passed (Kessler et al., 2008)

After Florida conducted the initial research on surface resistivity testing on concrete, the Louisiana DOT researched furthermore into the new testing area. The team in Louisiana continuously investigated into surface resistivity producing numerous reports in a short period of time. A draft AASHTO standard was configured based off of the additional research by Louisiana. The Florida DOT, Louisiana DOT, and the AASHTO standards all use the correlations shown in Table 1 for acceptance of surface resistivity related to RCP (Florida DOT, 2004; LA DOTD TR 233, 2011). Studies on surface resistivity of concrete have shown that sample geometry affects the resistivity measurements and correction factors were developed to convert measurements taken from flat surfaces. Surface resistivity using a Wenner array probe is a non-destructive test. Therefore cylinders cast for compressive strength testing can also be used for surface resistivity measurements. This process would save technicians time and money as well as limit the number of cylinders necessary for testing. Table 1 shows the numerical correlation of surface resistivity and RCP for the differing chloride ion permeability groupings and sample geometrics (Florida DOT, 2004). In Table 1, the term Semi-Infinite Slab (Real) indicates that the sample was flat, such as a bridge deck tested in the field, instead of a cylindrical sample that was tested in the laboratory.

Table 1. Correlation of surface resistivity with RCP for various sample geometries (Florida DOT, 2004)

ASTM C1202 / AASHTO T277		Surface Resistivity Test		
Chloride Ion Permeability	RCP Test Charged Passed (coulombs)	4 X 8 Cylinder (Kohm-cm) a=1.5 (Measured)	6 X 12 Cylinder (KOhm-cm) a=1.5 (Measured)	Semi-Infinite Slab (Real)
High	>4,000	< 12	< 9.5	< 6.7
Moderate	2,000-4,000	12 - 21	9.5 - 16.5	6.7 - 11.7
Low	1,000-2,000	21 - 37	16.5 – 29	11.7 - 20.6
Very Low	100-1,000	37 - 254	29 – 199	20.6 - 141.1
Negligible	<100	> 254	> 199	> 141.1

a = Wenner Probe spacing

Prior to implementation of surface resistivity testing as a quality control tool in Louisiana, a large study was performed to verify the applicability of this test to mixtures containing high amounts of supplementary cementitious materials (SCMs). High SCM mixtures are most commonly used in low heat of hydration designs such as in bridge abutments, columns, drill shafts, and other substructure elements. All of these structures contain significant amounts of steel and are subject to corrosion considerations. Figure 2 shows the correlation of RCP and surface resistivity results obtained in the Louisiana study incorporating high SCM mixtures. The observed correlation between surface resistivity and RCP was very consistent with the Florida observations and closely matched AASHTO penetrability classes for RCP evaluation as seen by the red squares shown in Figure 2 (Rupnow and Icenogle, 2012). It should be noted that because the axes in Figure 2 are not on a logarithmic scale, the correlation does not look linear as it was shown in Figure 1.

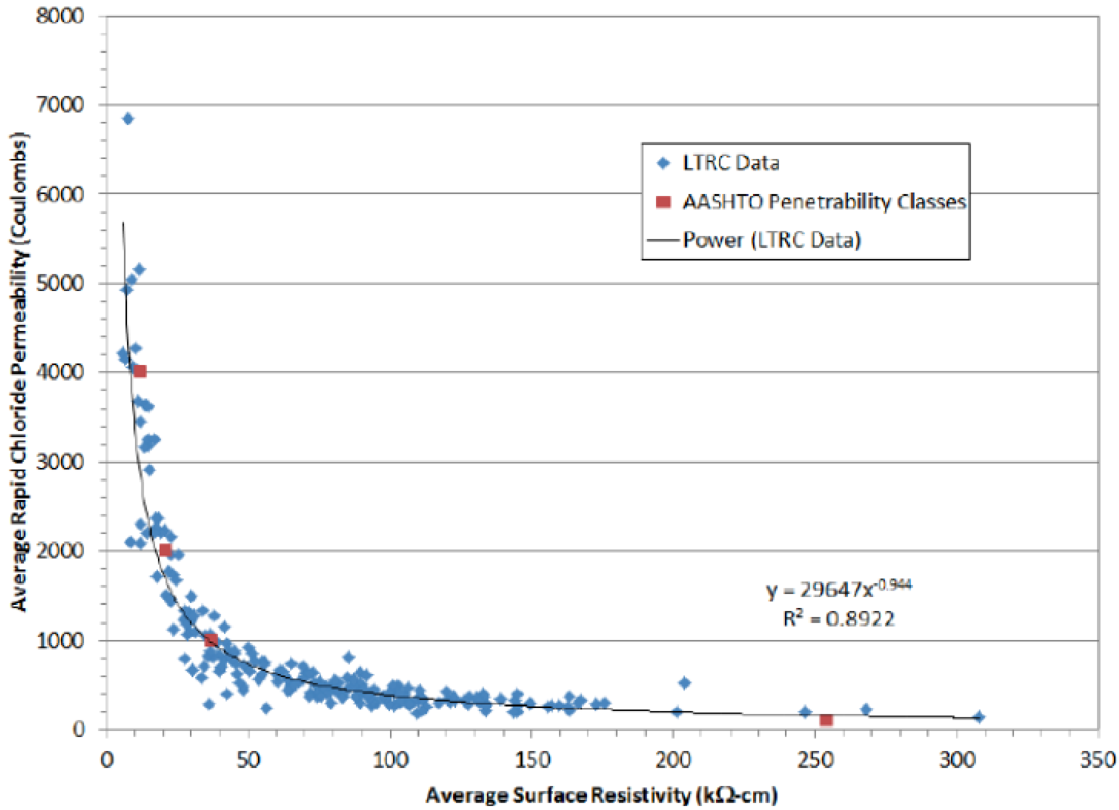


Figure 2. Relationship between RCP and surface resistivity for high SCM mixtures (Rupnow and Icenogle, 2012)

A logical progression of the comparison between RCP and surface resistivity was to evaluate the variability introduced by common mixture components. Various factors are known to affect resistivity measurements in concrete with the most significant factor being temperature and moisture content (Gowers and Millard, 1991). A complete ruggedness study was performed which evaluated the effects of aggregate type, aggregate size, calcium nitrate, lime water curing, segregation, air content, temperature, surface moisture, age, probe spacing, and number of data points collected (Rupnow and Icenogle, 2013). For a single mixture, sample age and aggregate type (gravel versus limestone) were the only significant factors for surface resistivity. Those factors were also significant for RCP. The correlation between RCP and surface resistivity obtained in this ruggedness study matched the relationship observed in the Louisiana DOT study that was shown in Figure 2 (Rupnow and Icenogle, 2013). Many of the previously mentioned studies report precision and bias of the sample data. Reported precision and bias statements in the literature for within lab repeatability and between lab reproducibility are within acceptable limits for the American Society for Testing and Materials (ASTM) standard (Paredes et al., 2012).

The Florida DOT has also pioneered the use of surface resistivity testing for evaluation of structural concrete. Study results from field concrete indicated that moisture level in the concrete was critical to consistent measurements (Liu et al., 2010). North Carolina and Utah DOTs have used bags of ice placed on bridge decks at selected locations before testing to minimize the temperature and moisture effects. A protocol where the pavement is wetted, covered with a saturated towel, and covered with 10 pounds (lbs) of ice for 2 hours has produced low variability (Ghosh et al., 2012; Cavalline et al., 2013). Routine resistivity testing of bridge decks and structural concrete could be an additional tool to assess the concrete for probability of corrosion deterioration. MoDOT has used RCP test results for acceptance of bridge deck sealers (Wenzlick, 2007). Since surface resistivity can be measured in the field, a potential use of this technology could be to verify the effectiveness and quality of application of approved sealants. Therefore in this study surface resistivity of concrete samples with different applied sealers were also evaluated.

Researchers at the Florida Department of Transportation investigated possibilities of using resistivity to test field samples. Results were promising and the development of a surface resistivity test in the near future was expected. The researchers cored out two-inch cylindrical samples from the bridge to test and used a Wenner array as shown in Figure 3 (Liu et al., 2010).

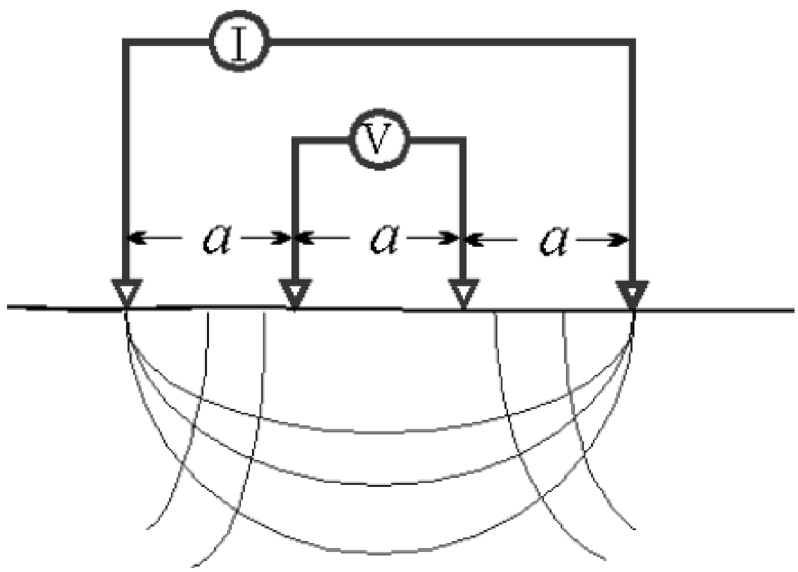


Figure 3. Diagram of Wenner method used for measuring concrete resistivity (Lui et al., 2010)

As shown in Figure 3, the Wenner array has four equi-spaced electrodes that send an electrical current throughout the test specimen in order to calculate the resistivity of the sample.

According to Liu, “Once in contact with the concrete, a trapezoidal potential is applied between the outer probes which generates a current (I) inversely proportional to the resistivity of the concrete.” The inner probes measure the potential difference (V). The apparent resistivity is calculated using Ohm’s law which is shown in Equation 1 (Liu et al., 2010).

$$\rho = \frac{2\pi a V}{I} \qquad \text{(Equation 1)}$$

To maintain a standardized procedure, the Louisiana Transportation Research Center (LTRC) developed a marking system for the concrete cylinders shown in Figure 4. Samples were marked at 0, 90, 180, and 270 degrees. The developed standard that was also accepted by AASHTO requires collection of 8 measurements, 2 at each mark, by rotating the sample. LTRC also published an instructional video on how to use the resistivity equipment in lab use (Rupnow and Icenogle, 2011).

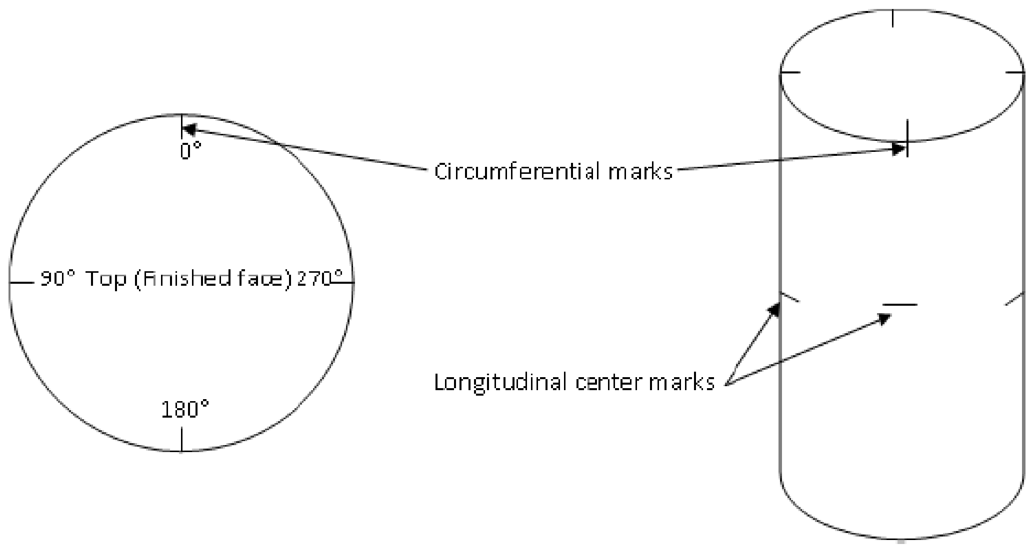


Figure 4. Cylinder markings (Rupnow and Icenogle, 2011)

Additional research on the theory of resistivity was performed by researchers at the Georgia Institute of Technology. The surface resistivity method was related to binder composition and microstructure of the concrete sample. The mixtures in the study demonstrated numerical backing as to why mixtures with higher porosities tend to have lower electrical resistivities (Nadelman and Kurtis, 2014). The relationship of the factors affecting surface resistivity has also been investigated by the LTRC researchers by using ruggedness testing. The testing showed that age and aggregate type are significant factors for surface resistivity (Rupnow and Icenogle, 2013). The theory of resistivity has been intensely researched since the correlation of RCP with surface resistivity was established for quality control testing purposes.

Temperature and moisture have been discovered as two variables that greatly affect surface resistivity readings. If the temperature of the testing environment or cylinder is much higher than room temperature, the surface resistivity reading will be much lower than expected. In terms of moisture, if the concrete cylinder is too dry, the resistivity reading will be higher than expected as well (Rupnow and Icenogle, 2013). MoDOT tested the effects of temperature on resistivity and found similar results as stated above. Higher temperatures (equal to or greater than 127 degrees Fahrenheit) reduced resistivity while lower temperature (equal to or less than 39 degrees Fahrenheit) increased resistivity.

Resistivity Meters

Surface resistivity meters are small, fast, and relatively inexpensive at approximately $3,000. The non-destructive, hand-held meters only require minimal training or expertise and have low variability throughout testing. Surface resistivity correlates well to bulk resistivity, chloride diffusivity, and most importantly RCP (Icenogle and Rupnow, 2012). Surface resistivity testing has proven successful in Louisiana, North Carolina, Florida, Pennsylvania, Utah, Minnesota, and other states for quality control of new concrete and evaluation of existing structures.

Original resistivity testing on concrete used a bulk arrangement adopted from soil testing equipment as shown in Figure 5 (Germann, 2010). A moist sponge was needed to provide sufficient electrical contact with the sample and must be accounted for in the final measurement. Surface resistivity uses a four pin array where the outer two pins create a current differential which is measured by the inner two pins (Figure 6). The pins are often spring-loaded and contain moisture reservoirs to ensure good electrical connection. Both methods correlate well for cylindrical samples, however only surface resistivity equipment has been determined to be appropriate for field use. AASHTO completed a standardized surface resistivity testing using data and recommendations from Purdue University, Florida DOT, and Louisiana DOT. Equipment for the *Standard Test Method for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration*, AASHTO TP 95-11, is a Wenner four pin array with 1.5 inch spacing. This study evaluated several surface and bulk resistivity tools for accuracy and for practicality of use.

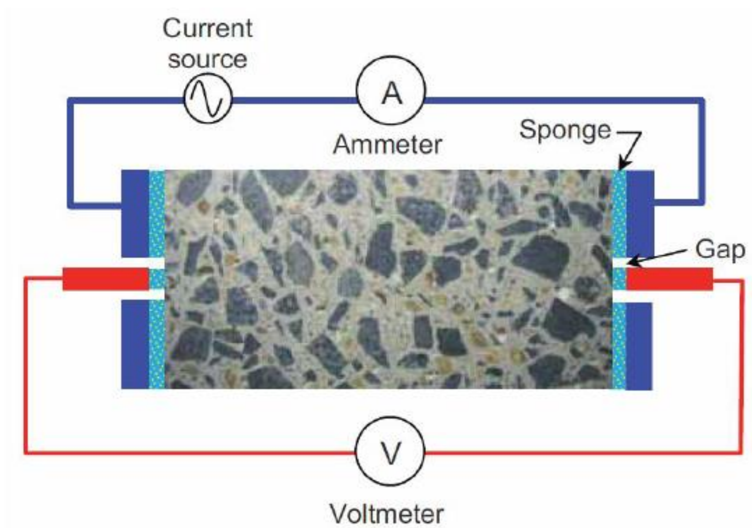


Figure 5. Bulk resistivity setup developed in theory from soil testing equipment (Germann, 2010)

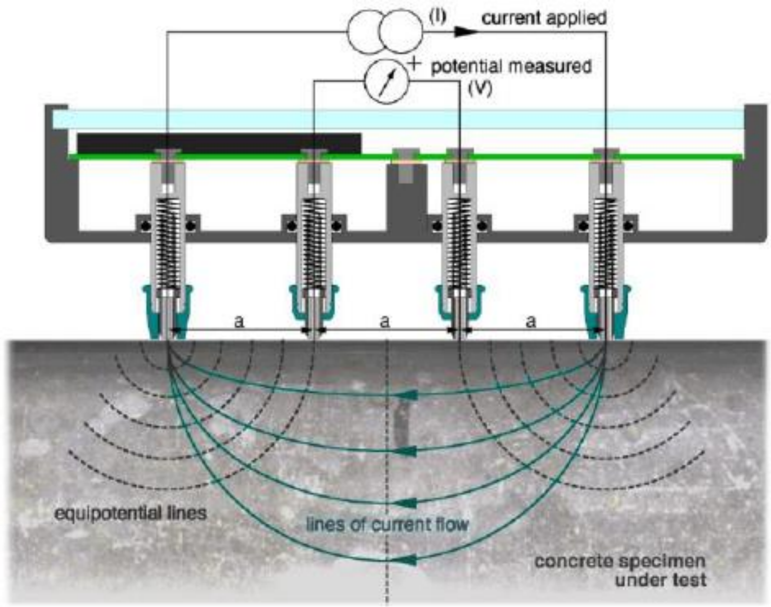


Figure 6. Surface resistivity setup with Wenner four pin array

(Rupnow and Icenogle, 2012)

Many of the initial resistivity studies were performed using the CNS Farnell Mark 2 model U95 unit where the display and the probe are separate. The Mark 2 resistivity meter has been discontinued and a majority of DOTs are now using a combined unit, the Proceq resipod (Figure 7). A statistical comparison between both equipment types determined no difference between data produced during round-robin testing (Paredes et al., 2012). The resipod is a handheld device with fixed probes and a rechargeable battery. The unit has a reverse LCD display suitable for use in full sunlight. Each resipod kit comes with a low and high resistivity calibration board for rapid verification of performance.

Figure 7. Proceq resipod surface resistivity meter (Proceq, 2015)

Soil resistivity meters are typically housed in small cases as shown in Figure 8 for the Miller 400D unit. Units are designed for field use and contain a rechargeable battery and connection ports for the probes. Soil resistivity meters are generally lower cost than units specifically designed for concrete, however custom probes are required for the correct 1.5 inch spacing.

Figure 8. Miller 400D soil resistivity meter (M.C. Miller, 2010)

The Giatec Surf (shown in Figure 9) was a new surface resistivity meter for evaluating concrete cylinders. The clamshell unit makes four simultaneous readings. Since the cost of the Surf has been considerably more expensive than either the resipod or Miller 400D and limited to only 4 inch by 8 inch cylinders, the Giatec Surf is predicted to not be practical for MoDOT purposes. However, the Giatec Surf was included in testing for statistical evaluation and comparison of precision between the different equipment types.

Figure 9. Giatec Surf surface resistivity meter (Giatec Scientific, 2015)

Prior to final selection of a resistivity meter for this study, a round robin test was performed at UMKC using these three discussed resistivity meters in surface and bulk resistivity modes. The control group concrete mixture was used to compare operator variability within each equipment type and testing mode along with variability across the equipment types. The final selection parameters used to recommend a surface resistivity meter to MoDOT included, but were not limited to, variability, ease of use, cost, applicability, and durability / ruggedness.

In a research study conducted by Icenogle and Rupnow of LTRC, seventeen surface resistivity meters (Proceq resipods) and seventeen operators tested samples prepared by the research team over two days. The testing conducted was in a round-robin format. Eight mixtures were tested with two replicates of each mixture being supplied. The results demonstrate low values of coefficient of variation (COV) which in turn led to a precision statement and conclusion to be drawn from the concrete surface resistivity testing. The final conclusion was “the results of two properly conducted tests in different laboratories on the same material should not differ by more than 11%” (Icenogle and Rupnow, 2012).

Rapid Chloride Permeability

Rapid chloride permeability (RCP) has been the standard test method for quality control for over a decade when testing for chloride ion penetration. The test has been standardized in ASTM C1202 and AASHTO T277 (ASTM C1202, 2013). Kessler requested to replace RCP with a new surface resistivity method due to the labor intensive and time consuming nature of RCP. The surface resistivity method proposed also would be non-destructive whereas RCP requires additional samples to be made. Figure 10 displays the RCP test procedure and the amount of days required for testing. Figure 11 displays the surface resistivity test procedure using an old Wenner four pin array meter (Kessler et al., 2008). The Proceq resipod is an updated and improved model from the meter shown in Figure 11. The figures visually display the steps necessary to run the three-day RCP testing compared to the one-hour surface resistivity testing.

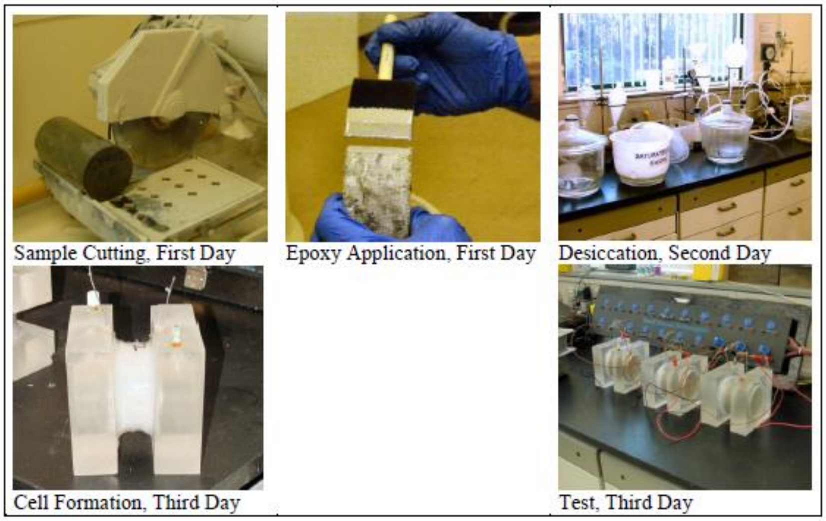


Figure 10. RCP test procedure (Kessler et al., 2008)

Figure 11. SR test procedure (Kessler et al., 2008)

In continuation of displaying the differences between the test methods, a cost analysis has been ran for the Louisiana Department of Transportation and Development (LA DOTD). The cost benefit analysis shown in Table 2 and a one year quality control cost analysis shown in Table 3 were developed by LTRC researchers when conducting a project comparing surface resistivity testing to RCP. As shown in the tables, the surface resistivity testing is demonstrated to save the DOT nearly 1.5 million dollars. The RCP equipment's upfront cost surpasses the resistivity meter but the major difference in price was found to be the amount of labor and work hours the test required (Rupnow and Icenogle, 2011). A similar cost analysis was performed for MoDOT as a part of this study.

Table 2. Input values for cost benefit analysis (Rupnow and Icenogle, 2011)

Equipment	Initial Cost ($)	Number of Testing Hours Required	Technician Hourly Wage or Cost per Test ($)
ASTM C 1202	$18,000.00	8.0	$500.00
Surface Resistivity	$2,800.00	0.33	$23.38

Table 3. Comparison of one year quality control costs for the SR and RCP (Rupnow and Icenogle, 2011)

Test Method	Number of Lots	Number of Testing Hours Required	Hourly Wage/Cost per Test ($)	Tech. Cost/Test Cost ($)	Total Cost ($)	Cost Per Sample ($)
ASTM C 1202	3000	–	$500	$1,500,000	$1,500,000.00	$500.00
Surface Resistivity	3000	990	$23.38	$23,146	$25,946.20	$8.65
				SAVINGS	**$1,474,053.80**	

CHAPTER 3

MATERIALS

Cementitious Materials

Cementitious materials are vital to developing the paste in the mixture which will lead to strength gain and increased durability when a proper amount of cementitious material is used. Ash Grove Type I/II Portland cement and supplementary cementitious materials (SCMs) were used in a majority of the mixes. The SCMs varied in replacement percentage and purpose intended for the numerous different mix designs.

The most common SCM used in this project was fly ash. Class C and Class F fly ashes were used. The Class C fly ash was obtained from the La Cygne Power Plant owned by Kansas City Power & Light (KCP&L). Class C ash was used for paving, bridge deck, and structural mix designs with replacement percentages between 15 and 20 percent of the total cementitious material amount. Class F fly ash was from Veolia's location in Kansas City, Missouri. Class F ash was used at 50 percent replacement for a structural mix due to the Class F ash's usefulness at increasing durability and reducing permeability of the concrete mixture.

Ground-granulated blast furnace slag (GGBFS) was used in a ternary, paving mix design at a replacement rate of 30 percent of the total cementitious materials. The grade 120 slag was paired with Class C ash to create a ternary mixture with the desired characteristics of increased durability and reduced permeability. The final cementitious material used was

Calcium Sulfoaluminate Cement (CSA) obtained from Buzzi Unicem. CSA is used for a repair mix design due to the fast setting properties of this material. CSA was used at a 50 percent replacement rate. A 100 percent CSA replacement trial batch was attempted but the mixture was setting too fast and nearly hardened in the mixer.

Aggregates

The coarse aggregate used throughout the duration of the project was Cedar Valley 1 inch limestone. The material specification provided for Cedar Valley one inch rock is shown in Table 4.

Table 4. Cedar Valley one inch coarse aggregate material specification

Sieve Analysis ASTM C136 & C117		
Seive Size	% Passing	Specificatio
6"		
5"		
4"		
3"		
2"		
1-1/2"	100	
1"	85	
3/4"	64	
1/2"	41	
3/8"	26	
#4	5	
#8	4	
#16	3	
#30	3	
#50	3	
#100	2	
#200	2.3	

Test	Standard	Results	Specificatio n ASTM C-
Plasticity Index	D4318		
Freeze Thaw	T103		
3/4 - 3/8	T103	**27.3**	1.0 Max
3/8 - #4	T103	**20.1**	2.0 Max
Chert %	C123	0.0	3.0
Organic Impurities	C40		
Clay Lumps and Friable %	C142	0.0	2.0
Shale % MODOT	TM-71	0.0	0.5 Max
Soundness-Mg % loss	C88	3.0	18 Max
Soundness-Na, % loss	C88	3.7	12 Max
Absorption	C128	0.20	
Specific Gravity-Bulk	C128	2.69	
Specific Gravity-SSD	C128	2.70	
Specific Gravity-Apparent	C128	2.71	
Bulk Density (Dry), pcf	C29	101.6	
Void Content (Dry), %	C29	39.1	
Resistivity(ohm-cm)	T288		
Sulfates	T290		
Chlorides	T260		
PH	T289		
LA Abrasion % Gradation	C131	24.6	50 Max

The fine aggregate used throughout the duration of the project was Kansas River sand. The material specification provided for Kansas River sand is shown in Table 5.

Table 5. Kansas River sand fine aggregate material specification

Sieve Analysis, ASTM C136 & C117			
Sieve Size or No.	Percent Passing	Specification ASTM C33	
		Min	Max
5"			
4"			
3.5"			
3"			
2.5"			
2"			
1.5"			
1"			
3/4"			
1/2"			
3/8"	100	100	
#4	99	95	100
#8	89	80	100
#16	74	50	85
#30	53	25	60
#50	18	5	30
#100	2	0	10
#200	1.0	0	3

Test methods are ASTM unless otherwise indicated			
Test	Standard	Result	ASTM C33
Fineness Modulus	C125	2.65	2.3 - 3.1
Total Lightweight Pieces, %	C123	0.04	
Coal & Lignite, %	C123	0.01	0.5 Max
Clay Lumps & Friable, %	C142	0.20	3 Max
Organic Impurities	C40	0	3 Max
Sand Equivalent Value	D2419	98	
Soundness Fine - Mg, % loss	C88	4	15 Max
Absorption (Fine), %	C128	0.4	
Specific Gravity Bulk Dry (Fine)	C128	2.61	
Specific Gravity Bulk SSD (Fine)	C128	2.62	
Specific Gravity Apparent (Fine)	C128	2.64	
Chloride Content, %	C1218	0.0027	
Maximum Between Sieves, %	C33	35	45 Max

A lightweight aggregate was also used in a bridge deck mix design for internal curing purposes in accordance with ASTM C1761 (ASTM C1761, 2013). The Bentz Equation (published in National Institute of Standards and Technology) was used to determine the amount of lightweight aggregate in the mixture (Bentz et al., 2005).

Admixtures

An air-entraining agent (AEA) was used in all of the mix designs. Typical dosage rates for AEA was 1.5 ounces per 100 pounds of cementitious material with the only exception being 3 ounces per 100 pounds of cementitious material for the repair mix using accelerator.

A high range water reducer (HRWR) was used in all of the mix designs. Dosage rates for HRWR ranged from 3 to 26.6 ounces per 100 pounds of cementitious material.

An accelerating admixture (Pozzolith NC 534) was used to accelerate the repair mixture. The mixture was proposed to act like 4x4 (4000 pounds per square inch in 4 hours) concrete. The dosage rate for the repair mix desiring early set time was 90 ounces per 100 pounds of cementitious material.

A retarding admixture (citric acid) was used to help slow down the CSA repair mixture enough to place the concrete in 4 inch by 8 inch cylinder molds before the initial set. The dosage rate for the citric acid was 0.40 percent of the cementitious material by weight. The citric acid (powder form) was batched out for each mixture, measured to the nearest tenth of a gram, and added to the water in the mixture. The water was stirred until the citric acid had been uniformly distributed. The water was added to the mixture in the same procedure as a normal mixture. The mixture designs utilizing the described materials are provided in the following chapter.

CHAPTER 4

MIXTURE DESIGNS

Five types of mixtures were placed and tested in this project based on requirements of the concrete. The four mixing proportion groups were paving, bridge deck, structural, and repair mixtures. In addition to concrete mixtures tested in the laboratory, samples were collected from three field applications and tested in the laboratory. These mixtures included a paving, bridge deck, and a structural mixture. All mixtures were designed and developed using the Missouri Department of Transportation (MoDOT) Standards and Specifications Section 501 Concrete. Table 6 displays a table from MoDOT Section 501 Concrete showing the design in terms of cementitious materials for differing mixture proportions. The second concrete classification column (Class B Concrete) and the fourth column (Class B-2 Concrete) were the specifications that were followed for a majority of the mixtures in this study. Class B Concrete was used for the paving mixtures in this project excluding the ternary mixture containing a total of 50% SCM replacement. Class B-2 Concrete was used for the bridge deck mixtures in this project. Another exclusion was the 50% Class F fly ash replacement used for a structural mix. The two mixtures not following the specifications listed were suggested mixture designs by Dr. John Kevern. The entirety of the MoDOT Section 501 Concrete's specifications are attached in Appendix A (MoDOT Section 501, 2014).

Table 6. MoDOT Section 501 cementitious materials requirements

(MoDOT Section 501, 2014)

Cement Requirements[a,b]							
Class of Sand	Class A-1 Concrete	Class B Concrete	Class B-1 Concrete	Class B-2 Concrete	Class MB-2 Concrete[g,h]	Pavement Concrete	Seal Concrete
A[c]	600	525	610	705	600	560	660
B[d]	640	565	640	735	620	560	695
C[e]	--	585	660	750	640	560	715
D[f]	--	620	695	790	660	560	735

[a]When used, Type IP, I(PM), IS or I(SM) cement shall be substituted on a pound for pound basis for Type I or Type II cement and adjustments in design mix proportions will be required to correct the volume yield of the mixture.

[b]The contractor may submit an optimized mix design which has a maximum 50 pounds per cubic yard reduction in cement from that shown in the tables. If the contractor chooses this option, the mixture will be subject to review, laboratory testing and approval by the engineer. All other requirements for the cement factor will apply.

[c]Class A sand will include all sand, except manufactured sand, weighing 109 pounds per cubic foot or more.

[d]Class B sand will include all chert, river and Crowley Ridge sand weighing from 106 to 108 pounds, inclusive, per cubic foot or glacial sand weighing 108 pounds or less per cubic foot.

[e]Class C sand will include all chert, river and Crowley Ridge sand weighing from 101 to 105 pounds, inclusive, per cubic foot.

[f]Class D sand will include all sand weighing 100 pounds or less per cubic foot and any manufactured sand that is produced by the process of grinding and pulverizing large particles of aggregate or which contains more than 50 percent of material produced by the reduction of coarser particles. Manufactured sand produced from limestone or dolomite shall not be used in Portland cement concrete for driving surfaces such as bridge decks, pavements and full depth shoulders.

[g]Modified B-2 (MB-2) concrete may be used in-place of Class B-2 Concrete.

[h]Modified B-2 (MB-2) concrete shall use at least one supplementary cementitious material in accordance with this specification. In no case shall MB-2 concrete use less than 15 percent fly ash or GGBFS when used as the individual supplementary cementitious material. In no case shall MB-2 concrete use less than 6 percent metakaolin when used as the individual supplementary cementitious material.

Paving Mixtures

Three paving mix designs were batched at the University of Missouri – Kansas City (UMKC) laboratory. All three mixtures contained 560 pounds per cubic yard (pcy) of cementitious materials. One mixture was a standard, 100% Type I/II Portland Cement mixture. A binary mix design was proportioned using 20% Class C fly ash. A ternary mix design was proportioned using 20% Class C fly ash and 30% slag. The water to cement (w/c) ratio of all of the paving mixtures was 0.40. Table 7 displays the mixture proportions of the three paving mixtures placed at the UMKC lab. The convention used in the mixture name was that the "P" stands for paving mixture. The number stands for the percent of cementitious material. The letter behind the number stands for the SCM implemented in the mixture. The letter "C" in the mixture title stands for cement, the letter "A" for Class C fly ash, and the letter "S" for slag throughout the entirety of this project.

The P:100C mix was batched for a second set of samples and cured within the concrete molds until the testing day. All of the mixtures cast in the study were wet cured in a lime bath except for this second set of cylinders batched from the P:100C mixture. The P:100C in Molds group was naturally cured in the molds and set on a shelf at room temperature conditions. The dry cured concrete was previously shown through literature review to have lower resistivity values when tested. The concrete mix left in molds was also tested to see how long the cylinder would have to be placed in a lime cure tank to not have significantly different results than the samples that were lime cured the entire time.

Table 7. Paving mix designs

Material	P:100C Amount (pcy)	P:80C-20A Amount (pcy)	P:50C-20A-30S Amount (pcy)
Cement	560	450	280
Class C Fly Ash	-	110	110
Slag	-	-	170
Cedar Valley CA	1815	1805	1800
River sand FA	1315	1305	1300
Water	225	225	225
AEA	1.5 oz/cwt	1.5 oz/cwt	1.5 cz/cwt
HRWR	6 oz/cwt	4 oz/cwt	4 oz/cwt

Bridge Deck Mixtures

Three bridge deck mix designs were mixed and placed at the UMKC laboratory as shown in Table 8. Bridge deck mixtures are identified with a “B2” designation to match the description of like mixtures in the MoDOT specification guide. Two of the mixtures had 705 pcy of cementitious materials (B2 and B2L) while the modified B2 mixture (MB2) had 600 pcy of cementitious materials. All three of the mixture proportions had 15 percent Class C fly ash replacement. The B2L mixture used lightweight aggregate to assist with internal curing of the concrete. The w/c of all of the bridge deck mixtures was 0.38. The letter “L” in the mixture title stands for lightweight aggregate and the “M” stands for modified B2 mixture (which was the mix design with over 100 less pcy of cementitious materials).

Table 8. Bridge deck mix designs

Material	B2:85C-15A Amount (pcy)	B2L:85C-15A Amount (pcy)	MB2:85C-15A Amount (pcy)
Cement	600	600	510
Class C Fly Ash	105	105	90
Cedar Valley CA	1665	1665	1780
Riversand FA	1205	1075	1290
Lightweight FA	-	135	-
Water	270	270	230
AEA	1.5 oz/cwt	1.5 oz/cwt	1.5 oz/cwt
HRWR	6 oz/cwt	4 oz/cwt	4 oz/cwt

Structural Mixtures

Two structural mix designs were mixed and placed at the UMKC laboratory as shown in Table 9. Structural mixtures are identified with an "S" designation. Both of the mixtures had 600 pcy of cementitious material. One structural mix incorporated 20 percent Class C fly ash while the other structural mix replaced Type I/II cement with 50 percent Class F fly ash. Class F fly ash has been shown to increase the durability and decrease the permeability of concrete when used at desired values. The w/c of the structural mixtures was 0.38. The letter "F" in the mixture title stands for Class F fly ash.

Table 9. Structural mix designs

Material	S:80C-20A Amount (pcy)	S:50C-50F Amount (pcy)
Cement	480	300
Class C Fly Ash	120	-
Class F Fly Ash	-	300
Cedar Valley CA	1775	1750
Riversand FA	1285	1265
Water	230	230
AEA	1.5 oz/cwt	1.5 oz/cwt
HRWR	3 oz/cwt	4 oz/cwt

Repair Mixtures

Two repair mix designs were mixed and placed at the UMKC laboratory as shown in Table 10 and the mixtures were identified with letters R1 and R2. Both of the mixtures had 660 pcy of cementitious material. One repair mix used 50 percent CSA replacement in order to get an early set time. The second repair mix relied on a large dosage of accelerator (NC 534) to provide the early set time. The w/c of the repair mixtures was 0.35. Several trial batches with trial and error were required before a medium size batch could be placed for the repair mixes due to the desired characteristics of slump, early strength, and early set time.

Table 10. Repair mix designs

Material	R1:50C-50CSA Amount (pcy)	R2:100C Amount (pcy)
CSA	330	-
Cement	330	660
Cedar Valley CA	1740	1755
Riversand FA	1260	1270
Water	230	230
AEA	1.5 oz/cwt	3 oz/cwt
HRWR	16 oz/cwt	26.6 oz/cwt
(Retarder) Citric Acid	0.4%	-
(Accelerator) NC 534	-	90 oz/cwt

Field Mixtures

As explained before, 4 inch by 8 inch cylindrical samples were collected from three MoDOT job sites for further testing and verification. On September 9th, 2014, a structural mixture being used for a bridge abutment was sampled at Interstate 70 and Manchester in Kansas City, MO. Eighteen, 4 by 8 inch cylinders were placed. The total cementitious materials used in the structural mix design were 611 pcy with 20% of the total cementitious materials being Class C fly ash. The w/c ratio of the structural mix design was 0.44.

On September 26th, 2014, a bridge deck mixture being used for a bridge reconstruction project was sampled at Route 41 and Lamine River near Boonville, MO. The total cementitious materials used in the bridge deck mix design were 600 pcy with 25% of the total cementitious materials being Class C fly ash. The w/c ratio of the structural mix design was 0.42. The bridge deck mixture used a mid-range water reducer (MRWR). The retarder used (Delvo) assisted in the concrete being workable for a longer period of time.

On October 1st, 2014, a paving mixture being used for a new highway project was sampled on Highway 364 near St. Charles, MO. The total cementitious materials used in the paving mix design were 544 pcy with 25% of the total cementitious materials being Class C fly ash. The w/c ratio of the structural mix design was 0.42. An intermediate aggregate (IA) source was used to assist in creating a very well-graded aggregate combination for the mix design. Table 11 displays the mixture proportions of the three concrete mix designs placed at the job sites.

Table 11. Field mix designs

Material	Structural Amount (pcy)	Bridge Deck Amount (pcy)	Paving Amount (pcy)
Cement	490	450	410
Class C Fly Ash	120	150	135
CA	1805	1830	1365
FA	1145	1145	1245
IA	-	-	500
Water	270	250	230
AEA	1.4 oz/cwt	6 oz/cwt	1.5 oz/cwt
HRWR	6 oz/cwt	-	4.5 oz/cwt
MRWR	-	18 oz/cwt	-
(Retarder) Delvo	-	15.65 oz/cwt	-

CHAPTER 5

LAB MIXING AND TEST METHODS

All concrete mixtures placed in the duration of this project were mixed in accordance with ASTM C192 (ASTM C192, 2013). The slump of the concrete mixtures was tested in accordance with ASTM C143 (ASTM C143, 2013). The density, unit weight, and yield of the concrete mixture was tested in accordance with ASTM C138 (ASTM C138, 2013). The air content of the freshly mixed concrete was measured using the pressure method and a Type-B meter in accordance with ASTM C231 (ASTM C231, 2013).

Standard mixing procedure steps were as follows:

1. Determine batch design based on 1 CY of concrete mix design.
2. Determine moisture content of aggregate.
3. Perform moisture and water balance for aggregate and water components.
4. Weigh and batch out all materials included in the design.
5. Mix the concrete in accordance with ASTM C192.
6. Test slump in accordance with ASTM C143.
7. Test density, unit weight, yield, and air content as soon as slump test has concluded. This was performed in accordance to ASTM C138 and ASTM C231.
8. Place and cap the remaining fresh concrete into 4 inch by 8 inch cylinders.

Resistivity Testing

A round robin of resistivity testing was conducted. Although bulk resistivity measurements were evaluated for select mixtures, this study focused on surface resistivity testing. Surface resistivity was tested using a Proceq resipod in accordance with AASHTO TP 95-11 (AASHTO TP 95-11, 2011) and LA DOTD TR 233-11 (LA DOTD TR 233-11, 2011). The Proceq resipod was shown in Figure 7. The Giatec Surf surface resistivity meter used similar processes to test the cylinder but provided a specimen holder and casing within the apparatus. The Giatec Surf was shown in Figure 9 and produced results that were not significantly different from the Proceq resipod resistivity readings (Appendix C).

A surface resistivity standard was developed as part of this project, titled *106.3.2.XX TM-XX, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration,* for use by MoDOT for a consistent surface resistivity testing practice. The standard is expected to be added to MoDOT Engineering Policy Guide Category 106.3.2 Materials Inspection Test Methods once accepted by MoDOT officials. The standard includes a surface resistivity test form to allow for consistent recording of surface resistivity values. Calculations and conclusions in regards to penetrability classes can be developed quickly from the form. An example form showing calculations/inputs and a blank form were included with the standard mentioned previously. The surface resistivity standard for MoDOT describing the procedure followed for every surface resistivity test in this project (along with the testing form) is provided in Appendix B.

Bulk resistivity measurements were also performed using the Proceq resipod with a custom-made set of cells. The cells were placed on the ends of the specimen and banana plugs were used to connect the cells to the resipod as shown earlier in Figure 5. The other end of the electrical cord had alligator clips that clamped onto the four probes of the Proceq resipod. The readings from bulk resistivity were consistent and directly correlated with the values found from surface resistivity. A factor correlating the two test methods was recorded throughout the testing of the concrete samples (approximately around 2.7 BR:SR). Bulk resistivity was tested at least once for all the paving mix design samples and the results are record in Appendix C.

The round robin testing also included the use of a Miller 400D soil resistivity meter which was shown in Figure 8. The readings from the soil resistivity meter were not consistent and did not correlate in a meaningful way to the concrete resistivity instruments. The soil resistivity meter could not properly read the concrete cylinders even though the soil resistivity method used by the soil meter was similar in theory.

Samples with 100% cement without any SCMs were used for round robin testing of the different instruments. The samples were tested using all resistivity methods for all ages of testing. Based on the results of this testing, the Proceq resipod instrument for surface resistivity measurement was determined to be the best device for determining the surface resistivity to be used in the remainder of this study.

Surface resistivity using the Proceq resipod was tested on the paving, bridge deck, and structural mix designs at ages of 7, 14, 28, 56, and 90 days. Surface resistivity was tested on the repair mix designs at 3 hours, 6 hours, 12 hours, 1 day, 7, 14, 28, 56, and 90 days. The field samples placed at the job site and were tested in the laboratory at ages of 7, 28, and 90 days by multiple testers. Tests were conducted using Proceq resipods to ensure consistency and no significant difference between operators or equipment. The MoDOT laboratory in Jefferson City, MO assisted with providing the additional technicians required for the equipment verification portion of the project. The sample size was three samples for every test age for every mix design. Eight resistivity readings were taken for every sample. The project totaled to over 4500 surface resistivity data points being taken. Table 12 shows the testing plan for the entirety of the project.

Table 12. MoDOT mixtures and testing for laboratory correlation study

Tests		RCP (AASHTO T277)	Surface Resistivity (AASHTO TP95-11)	Bulk Resistivity	Diffusion (ASTM D1556)	Compressive Strength (ASTM C39)
Test Age		7, 28, 90 days	7, 14, 28, 56, 90 days		90 days	7, 28, 90 days
Mixture Type	Mix Properties					
Paving	Cement only	Minimum of 3 samples, 4x8 in. cylinders				
	Binary					
	Ternary					
Bridge Deck	Standard					
	Lightweight					
	Ultra-low permeability					
Structural	Standard					
	Low heat of hydration					
Test Age		1 & 90 days	3, 6, 12, 24 hrs, 7, 14, 28, 56, 90 days		90 days	3, 6, 12, 24 hrs, 7, 14, 28, 56, 90 days
Mixture Type	Mix Properties					
Repair	CSA	Minimum of 3 samples 4x8 in. cylinders				
	Conventional high early strength					

Rapid Chloride Permeability Testing

Rapid chloride permeability was tested in accordance with ASTM C1202 (ASTM C1202, 2013). RCP was tested on the paving, bridge deck, and structural mix designs at ages of 7, 28, and 90 days. RCP was tested on the repair mix designs at 1 and 90 days. The field samples, placed at the job site but tested in the laboratory at ages of 7, 28, and 90 days. The RCP results correlated with the surface resistivity results similar to the Louisiana DOT's graph shown in Figure 2. The sample size was three samples for every test age for every mix design. The project totaled over 100 RCP tests being run with each test requiring multiple days to run. Costs of performing RCP tests and surface resistivity tests are shown in Table 26.

The RCP testing procedure involves saw cutting a 4 inch by 8 inch cylinder into a 2 inch puck. The puck was air-dried for at least one hour prior to being taped with packaging tape on the sides. The tape was tightly wrapped around the cylindrical sides of the concrete puck to ensure no leakage of solutions through the sides that could cause inaccuracies while testing. Concrete pucks were vacuum saturated as required by ASTM C1202. The puck was then placed in RCP test cells which apply a voltage between two solution reservoirs filled with sodium chloride and sodium hydroxide. Use of neoprene sleeves around the concrete puck on both sides of the standard RCP cells was found to work nicely to prevent leakage of any solution during testing. Sodium chloride and sodium hydroxide solutions were placed into the cells and the RCP equipment was plugged in and started. After six hours of testing, the total amount of charge passing through the samples was recorded in Coulombs.

Chloride Ion Diffusion Testing

Chloride ion diffusion was tested in accordance with ASTM C1556 (ASTM C1556, 2013). Chloride ion diffusion was tested on three of the paving mix designs: P:100C, P:80C-20A, and P:50C-20A-30S. After 90 days of curing, three samples for each mix design were taped and ponded in solution. Figure 12 shows the concrete specimen being taped around the edges to develop a seal and lip for the solution to pond in. Figure 13 shows caulk being applied to seal the gap between the tape and the side of the concrete. Figure 14 shows the final diffusion unit with a tightened hose clamp to prevent leaks.

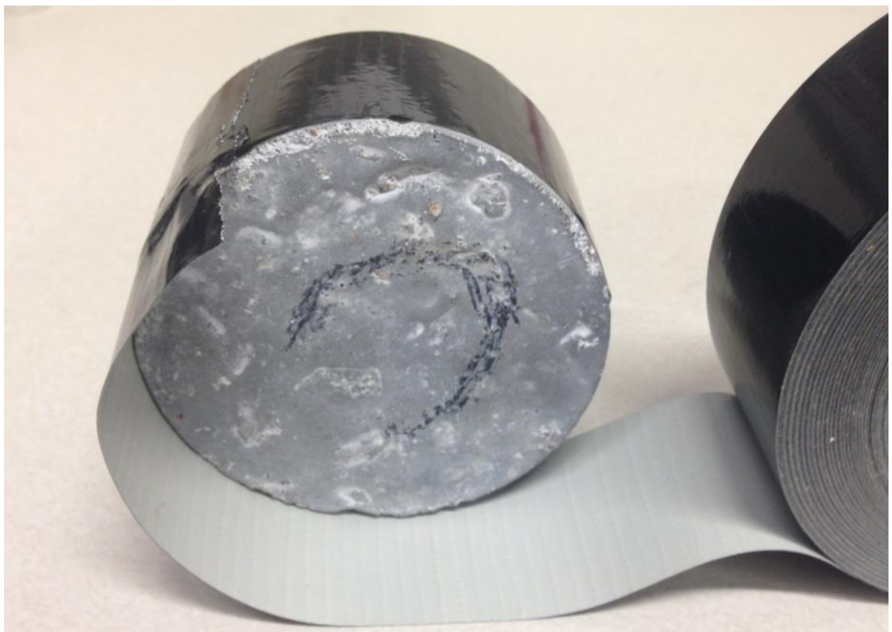


Figure 12. Chloride ion diffusion sample being taped

Figure 13. Caulking the joint between concrete and tape

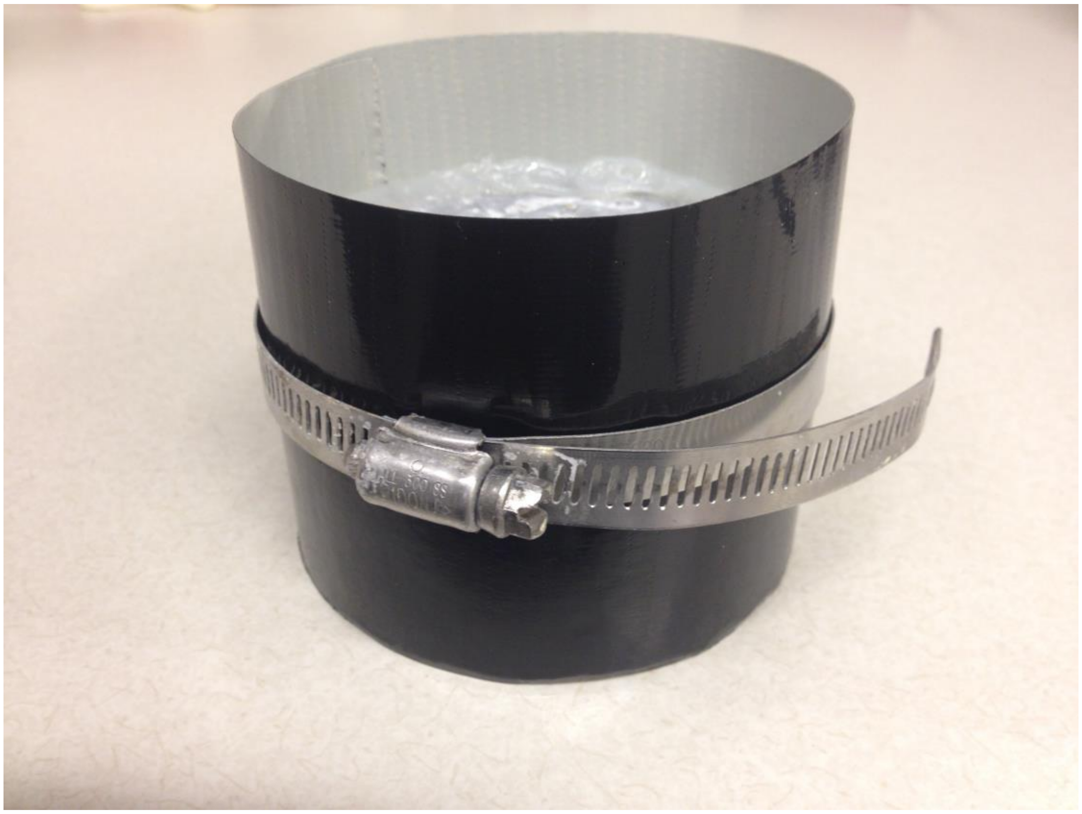


Figure 14. Final chloride ion diffusion product before ponding.

CHAPTER 6

FIELD TEST METHODS

The field test methods were performed on a bridge deck in Putnam Country, Missouri located on Highway 136. The bridge deck was in poor condition and scheduled to be replaced in the spring of 2015. Based on the literature review, a testing protocol was developed for conducting field tests.

The first step of the test method was to evaluate the current bridge condition utilizing the Pavement Condition Index (PCI) method described in ASTM D6433 (ASTM D6433, 2013). The *Joint Rigid Pavement Condition Survey Data Sheet for Sample Unit* was completed indicating distress types and the severity of the distresses. The purpose was to indicate significantly deteriorated sections and relatively good sections of bridge deck and test approximately ten locations on the bridge using the surface resistivity meter. In theory, a correlation should be developed between resistivity results and the findings of the PCI evaluation.

Once locations were selected for testing, water was liberally placed on the surface and a 10 pound ice bag was placed on the wet spot. The ice was left on the spot for two hours to make sure that the temperature had leveled off at a consistent value as indicated by previous studies. One spot was checked with an infrared temperature meter every fifteen minutes to determine the exact time when the ice bags were producing a constant reading on the bridge deck section.

After two hours, the ice bags were removed and the bridge deck surface was confirmed to be saturated. If not, water was added to the surface without any ponding occurring. The Proceq resipod meter was used for surface resistivity testing on the bridge deck. Resistivity was tested the section in a pattern shown in Figure 15 with four readings in the horizontal direction, four readings in the vertical direction, and four readings in a diagonal direction. The twelve readings were averaged together and then correlated back to the typical surface resistivity data for 4 inch by 8 inch cylinders.

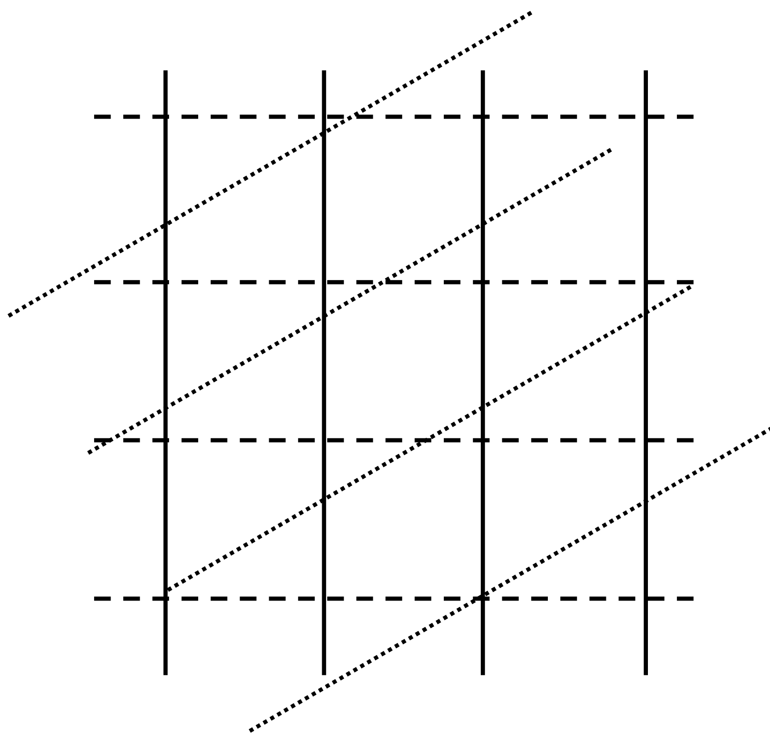


Figure 15. Direction diagram of surface resistivity readings for field testing

CHAPTER 7

PRECISION AND BIAS

To ensure precision throughout the surface resistivity testing, the amount of time allowable for the concrete sample to be out of the curing environment (a lime bath cure tank in this instance) was determined. The P:100C cylinders were tested at ages of 7, 14, 28, 56, and 90 days. At each age, the samples were taken out of the lime bath and placed on a countertop at standard lab conditions. The samples were tested at 0 seconds, 30 seconds, 1 minute, 2, 5, 10, 15, 20, and 30 minutes after removed. Three specimens were tested at each age and for each increment of time elapsed. Statistical analysis was run on MiniTab (a statistical analysis program) utilizing t-tests to determine if the set average (after being multiplied by 1.1 for the curing condition correction of being placed in a lime cure tank) was significantly different from the control (0 seconds) test group. Table 13 displays the average surface resistivity readings for the samples which underwent the precision and bias testing. The underlined values in the table represent statistical significance from the 0 second reading. The Giatec Surf resistivity meter was tested at 0 seconds as well to ensure that the Proceq and Giatec devices recorded readings were not significantly different. In all cases, the Proceq resipod and the Giatec Surf had results that were deemed not significantly different. Due to this, the Proceq resipod was selected to be the instrument for measuring surface resistivity for the remainder of the project.

Table 13. Allowable time outside of cure tank before SR testing

Amount of Time out of Lime Bath	Average Surface Resistivity in kOhm-cm Age of P:100C Mix				
	7 Day	14 Day	28 Day	56 Day	90 Day
0 sec	10.4	11.7	13.8	16.0	16.3
Giatec 0 sec	10.7	11.8	14.1	16.2	16.8
30 secs	10.4	11.8	14.0	16.1	16.3
1 min	10.6	11.9	14.0	16.1	16.3
2 min	10.7	12.1	14.1	16.2	16.5
5 min	10.8	12.2	14.3	16.2	16.7
10 min	<u>11.0</u>	<u>12.6</u>	14.5	16.4	16.9
15 min	<u>11.2</u>	<u>12.8</u>	<u>14.6</u>	<u>16.6</u>	<u>17.2</u>
20 min	<u>11.4</u>	<u>13.1</u>	<u>14.8</u>	<u>16.6</u>	<u>17.4</u>
30 min	<u>11.5</u>	<u>13.2</u>	<u>15.0</u>	<u>16.8</u>	<u>17.7</u>

***** Underlined values demonstrate the average was significantly different from 0 second value.

The data shown in Table 13 concluded that the concrete sample must be tested within five minutes of being taken from the cure tank to ensure that the data is not significantly different. This stipulation was followed throughout the entirety of the project by leaving the samples in the cure tank until right before that specific and singular concrete specimen was to be tested. From evaluating the results in Table 13, the amount of time out of the lime bath seems to be correlated with how dense the concrete is. The concrete would get denser over time allowing a longer amount of time before the results are statistically different. The best practice for surface resistivity testing is to remove only one cylinder at a time from curing. Figure 16 shows the results from Table 13 graphically. The left side of the vertical dotted line showed values that were not significantly different in value. The right side of the dotted line was figured to be significantly different data when compared to the initial surface resistivity reading.

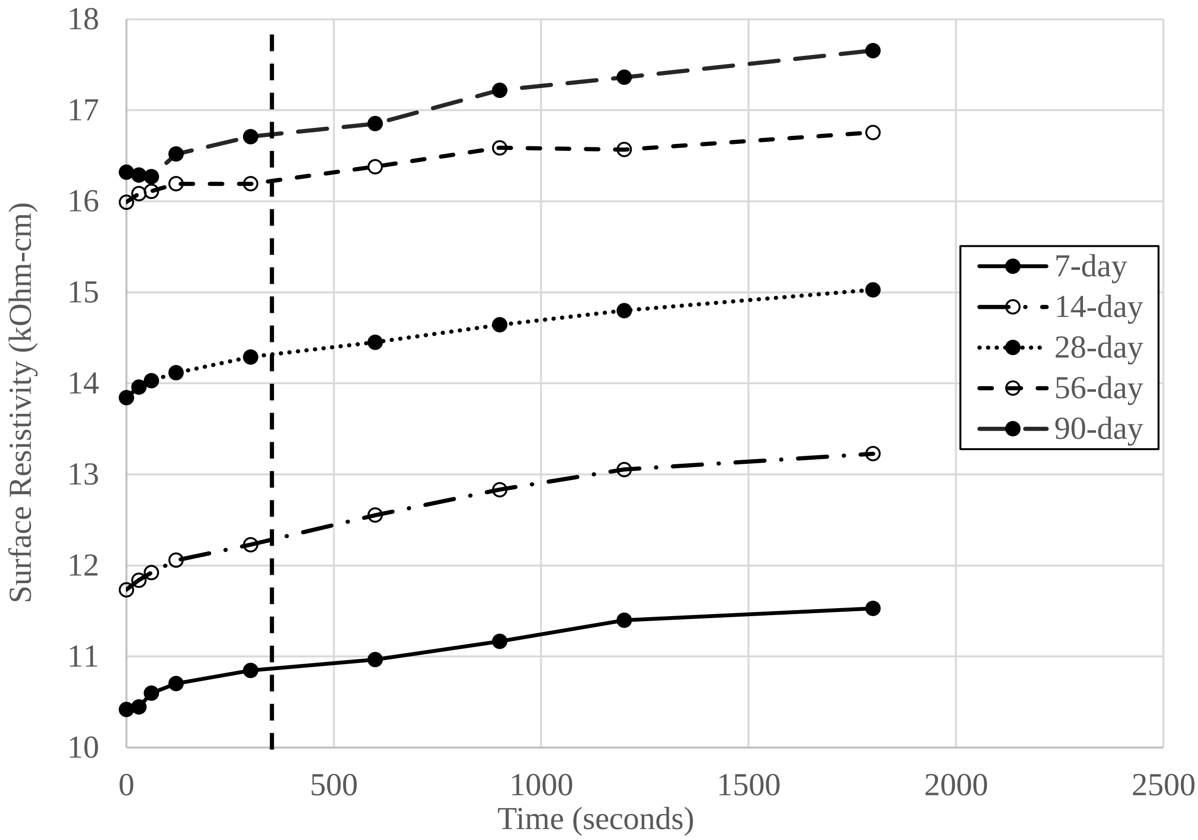


Figure 16. Time allowable out of cure tank before SR testing

Testing was conducted on the P:100C cured in molds to determine the amount of time the dry cylinders had to be placed in a cure tank before the values were not significantly different from the sample cured the entire duration (the 0 second sample from Table 13 at the same age). The sample was left in the molds until the test age. At the test age, the cylinder mold was stripped, tested at the dry state, and then put in the cure tank at increments of 15, 30, 45, and 60 minutes. The result from this precision testing in terms of minutes necessary in regards to proper cure tank time would be particularly helpful for cores taken in the field. The core would likely be dry and to get a reasonable correlation to RCP testing, the dry core would need to be placed in the cure tank for a given amount of time. Table 14 shows the set average for the testing (set average shown is after the 1.1 curing condition correction factor has been multiplied to the values). Figure 17 demonstrates shows the results from Table 14 graphically. The sample would need to be placed in the cure tank for thirty minutes (according to the data and statistical analysis), to be accurately tested in a laboratory setting. An assumption was made in this portion of the testing that the resistivity values were not statistically different between the P:100C mixtures with the two different methods of curing.

Table 14. Required minimum time in lime cure tank for concrete prior to SR testing

Amount of Time in Lime Bath	Average Surface Resistivity in kOhm-cm Age of P:100C in Molds Mix				
	7 Day	14 Day	28 Day	56 Day	90 Day
Dry (0 secs)	11.8	13.5	14.8	18.8	19.5
15 minutes	10.7	11.7	13.6	16.6	17.3
30 minutes	10.6	11.4	13.4	16.3	16.9
45 minutes	10.6	11.3	13.4	16.2	16.6
60 minutes	10.6	11.3	13.3	16.1	16.5

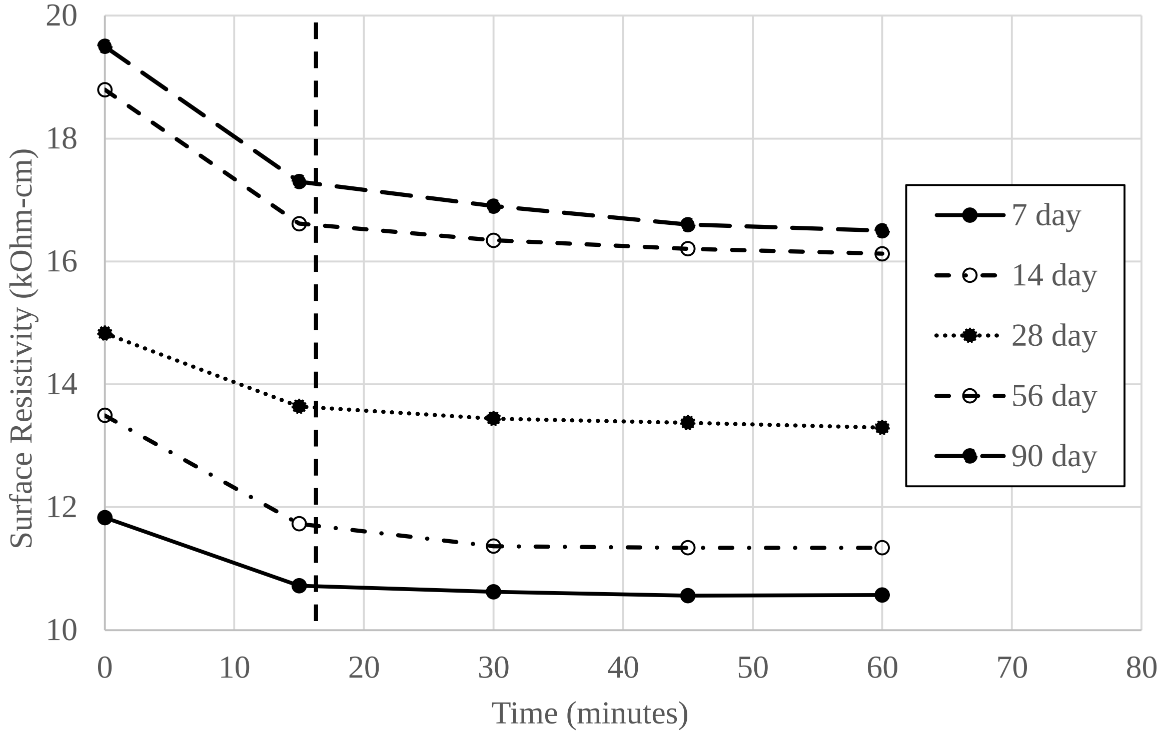


Figure 17. P:100C in molds – time in cure tank

The first set of field produced and lab tested cylinders were from a bridge project at the intersection of Manchester and I-70 in Kansas City, MO. The concrete mixture sampled was a structural mix being used for the bridge abutment. Thirty-six total samples were produced with eighteen going to UMKC and eighteen going to MoDOT. One variation noted during this pour was that UMKC's sample were transported back to the testing lab (less than twenty minutes away) within the first 24 hours of curing. This could have affected the cylinders negatively with initial and final set not occurring before transporting. Table 15 shows the average results for SR, RCP, and compressive strength.

Table 15. Average results for Manchester and I-70 structural mixture

Test	UMKC Laboratory S @ 7 days	UMKC Laboratory S @ 28 days	UMKC Laboratory S @ 90 days	MoDOT Laboratory S @ 7 days	MoDOT Laboratory S @ 28 days	MoDOT Laboratory S @ 90 days
SR (kOhm cm)	5.8	8.5	13.1	5.1	7.7	14.0
RCP (Coulombs)	7327	4694	2754	3463	4875	2630
f 'c (psi)	4039	4894	5856	3570	4730	5340

The 7 day RCP testing overheated for the MoDOT laboratory causing the test to shut off before the six hour test concluded. This brought forth another advantage for the resistivity meter regarding the meter's durability, consistency, and reliability while testing. The RCP test has to be carefully performed to prevent testing errors. Two cylinders taken to the MoDOT lab had defects as well. The two RCP pucks are shown in Figure 18. The first puck has a crack and the second puck has a piece of yellow tape inside of the cylinder. Surface resistivity testing was able to test the defective sample; RCP was not capable of testing the cracked or defective sample. These two pucks were from the same cylinder so MoDOT ended up testing two other pucks for RCP instead of the standard three pucks tested at the other ages.

Figure 18. Field produced concrete cylinders with defects

The second set of field produced and lab tested cylinders were produced from a bridge project at the Route 41 bridge over the Lamine River. The project location was approximately five miles west of Booneville, MO. The concrete mixture sampled was a bridge deck mix being used for that project. Thirty-six total samples were made with eighteen going to the UMKC lab and eighteen going to the MoDOT lab in Jefferson City. All samples were left over night for 24 hours of curing before transportation. The first 24 hours of curing was with moist burlap placed on top of the sealed cylinders. Table 16 shows the average results for SR, RCP, and compressive strength.

Table 16. Average results for Route 41 and Lamine River bridge deck mixture

Test	UMKC Laboratory			MoDOT Laboratory		
	B @ 7 days	B @ 28 days	B @ 90 days	B @ 7 days	B @ 28 days	B @ 90 days
SR (kOhm cm)	5.7	10.5	18.2	6.1	12.0	21.1
RCP (Coulombs)	5558	3152	2057	6799	3279	2163
f 'c (psi)	4799	5878	5833	4270	5440	5470

The final set of field produced and lab tested cylinders were produced from a new highway project (on Route 364) in St. Charles, MO. The concrete mixture sampled was a paving mix design. Thirty-six total samples were made with eighteen going to the UMKC lab and eighteen going to the MoDOT lab in Jefferson City. All samples were left over night for 24 hours of curing before transportation. The first 24 hours of curing was with moist burlap placed on top of the sealed cylinders. Table 17 shows the average results for SR, RCP, and compressive strength.

Table 17. Average results for Highway 364 paving mixture

Test	UMKC Laboratory			MoDOT Laboratory		
	P @ 7 days	P @ 28 days	P @ 90 days	P @ 7 days	P @ 28 days	P @ 90 days
SR (kOhm cm)	6.9	11.9	19.8	7	12.7	22.8
RCP (Coulombs)	4221	2936	1798	5155	2232	1132
f 'c (psi)	3840	5015	6439	3720	4500	5340

The field produced, lab tested samples for the Highway 364 paving concrete mix design that MoDOT placed and brought back to their lab had surface voids defect throughout. The UMKC samples were taken first from the concrete wheelbarrow and showed no defects. The MoDOT appeared to have been molded after the UMKC samples and contained significantly more honey-combing as shown in Figure 19.

Figure 19. Highway 364 paving concrete with surface voids

According to Rupnow and Icenogle's Precision and Bias article, "The within-laboratory variances in different laboratories are assumed the same for analysis with ASTM C802" (Rupnow and Icenogle, 2012). Similarly to that study, the data was ran on the UMKC laboratory to ensure that the laboratory averages and variances correspond and agree with the ASTM's specifications. While analyzing this study, all variances were considered. Table 18 displays the laboratory averages and variances (in parenthesis). The variances between all of the interchangeable variables, including operator, resistivity meter, laboratory testing, and the concrete mixture being tested, have been found and reported as low values noticeably below the guidelines for the test method. The table shows the averages of the data calculated and the vast majority of covariance's calculated are in Appendix C.

Table 18. Lab averages in kOhm-cm (lab variances for the sample set)

Operator	Resistivity Meter	Mixture and Age at Testing: Average SR Readings in kOhm-cm (Lab Variances)								
		S @ 7 days	S @ 28 days	S @ 90 days	B @ 7 days	B @ 28 days	B @ 90 days	P @ 7 days	P @ 28 days	P @ 90 days
1	A	5.7 (0.051)	8.5 (0.074)	13.1 (0.170)	5.7 (0.017)	10.5 (0.047)	18.2 (0.230)	7.0 (0.046)	11.9 (0.088)	19.7 (0.330)
	B	5.8 (0.046)	8.5 (0.071)	13.1 (0.196)	5.7 (0.023)	10.5 (0.071)	18.2 (0.343)	6.9 (0.046)	11.9 (0.108)	19.9 (0.341)
2	A	5.8 (0.051)	8.5 (0.085)	-	5.7 (0.027)	10.6 (0.089)	-	6.9 (0.041)	11.9 (0.113)	-
	B	5.8 (0.043)	8.5 (0.104)	-	5.7 (0.041)	10.6 (0.088)	-	7.0 (0.030)	12.0 (0.133)	-
3	A	5.6 (0.019)	-	-	-	-	-	-	-	-
	B	5.9 (0.107)	-	-	-	-	-	-	-	-

Due to the inconsistency in the 24 hour curing of the structural mixture at Manchester and I-70, and due to the honeycomb defect apparent on the paving mixture on Highway 364 for the MoDOT samples; the Route 41 bridge deck concrete mixture design was used for the rest of the precision and bias calculations.

Based off of the procedures developed and executed by Tyson Rupnow in Louisiana, precision and bias calculations were derived for the results found in this project (Rupnow and Icenogle, 2012). The single operator coefficient of variations (COV) of a single test result has been found to be 1.4%. The multi-operator COV of a single test result has been found to be 2.1%. Both of the values are acceptable according to the Rupnow and Icenogle study (Rupnow and Icenogle, 2012).

According to the previous study, the results of two properly conducted tests by the same operator on concrete samples from the same batch and of the same diameter should not differ by more than 5.5%. For this project, the results of two properly conducted tests by the same operator resulted in a COV of 1.6%. The results of two properly conducted tests on concrete samples from the same batch and of the same diameter being tested at different laboratories should not differ by more than 6.3% The multi-laboratory COV of a single test result has been found to be 4.3%.

All percentages for COV are acceptable for the surface resistivity meter in terms of different operators, different equipment, and different laboratories based on the Precision and Bias study conducted by Rupnow and Icenogle. The study will likely become the foundation of research for the AASHTO standard’s Precision and Bias section. The consistency of the Proceq resipod meter has been emphasized throughout the project and the statistical analysis in the precision and bias section support the claim. There should be little to no differences between the interchanging of the variables as long as the test is conducted properly and the operator has been properly trained on using the equipment.

CHAPTER 8

LAB RESULTS AND DISCUSSION

Surface Resistivity Testing

Table 19 shows the surface resistivity data for the nine mixtures batched in the UMKC laboratory, excluding the repair mixtures. The surface resistivity readings are the average of the three samples for each age and include the curing condition correction factor of 1.1. Previously shown in Table 1 are the permeability classes for surface resistivity values when testing a 4 inch by 8 inch cylinder. As shown in Table 19, the S:50C-50F and P:50C-20A-30S have the highest value for surface resistivity. The permeability classes for the mixture designs was Very Low and Low respectively. A majority of the other seven mixtures were in the High or Moderate ranges for permeability. Air content percentages are shown in the Appendix and no clear correlation between air content and resistivity was developed in this study.

Table 19. Surface resistivity for nine mixtures

	Surface Resistivity of the Mixture Designs in kOhm-cm								
Age	P: 100C	P:100C in Molds	P: 80C-20A	P: 50C-20A - 30S	B2:85C-15A	B2L:85C-15A	MB2:85C-15A	S:80C-20A	S:50C-50F
7	10.4	10.7	5.7	8.0	7.8	7.6	7.7	10.1	7.4
14	11.7	11.8	7.1	13.9	9.0	8.9	8.9	12.1	13.7
28	13.8	14.1	9.7	22.0	10.4	10.7	10.6	14.2	28.7
56	16.0	16.2	13.0	29.7	12.5	14.6	13.2	19.4	50.7
90	16.3	16.8	16.3	36.8	16.4	20.0	16.7	26.0	76.0

Two repair mixtures were tested for surface resistivity using the Proceq resipod. Table 20 shows the repair mixture results for surface resistivity. During hydration, the CSA generated more heat in the concrete within the first 24 hours. This extra heat caused the R1 surface resistivity readings to be higher than if tested at ambient temperature. The chemistry of CSA hydration (such as the conductivity of the reactants and products) could have also influenced the SR readings.

Table 20. Surface resistivity for repair mixtures

Age	Surface Resistivity of the Mixture Designs in kOhm-cm	
	R1:50C-50CSA	R2:100C
3 hour	29.1	1.1
6 hour	32.9	1.7
12 hour	32.9	3.1
1 day	29.0	5.5
7	17.9	8.7
14	16.7	9.9
28	17.3	11.4
56	32.2	14.4
90 days	37.2	16.3

Figure 20 shows a time versus SR results for all eleven mixtures batched in the UMKC laboratory. The structural design mix with 50% Class F fly ash replacement produced the highest surface resistivity readings. The only mixture to not follow the trend of gradually increasing in terms of surface resistivity over time was the R1:50C-50CSA mixture. The R1 mixture did not follow a similar trend to the other mixtures due to initial peak in resistivity while the CSA was hydrating.

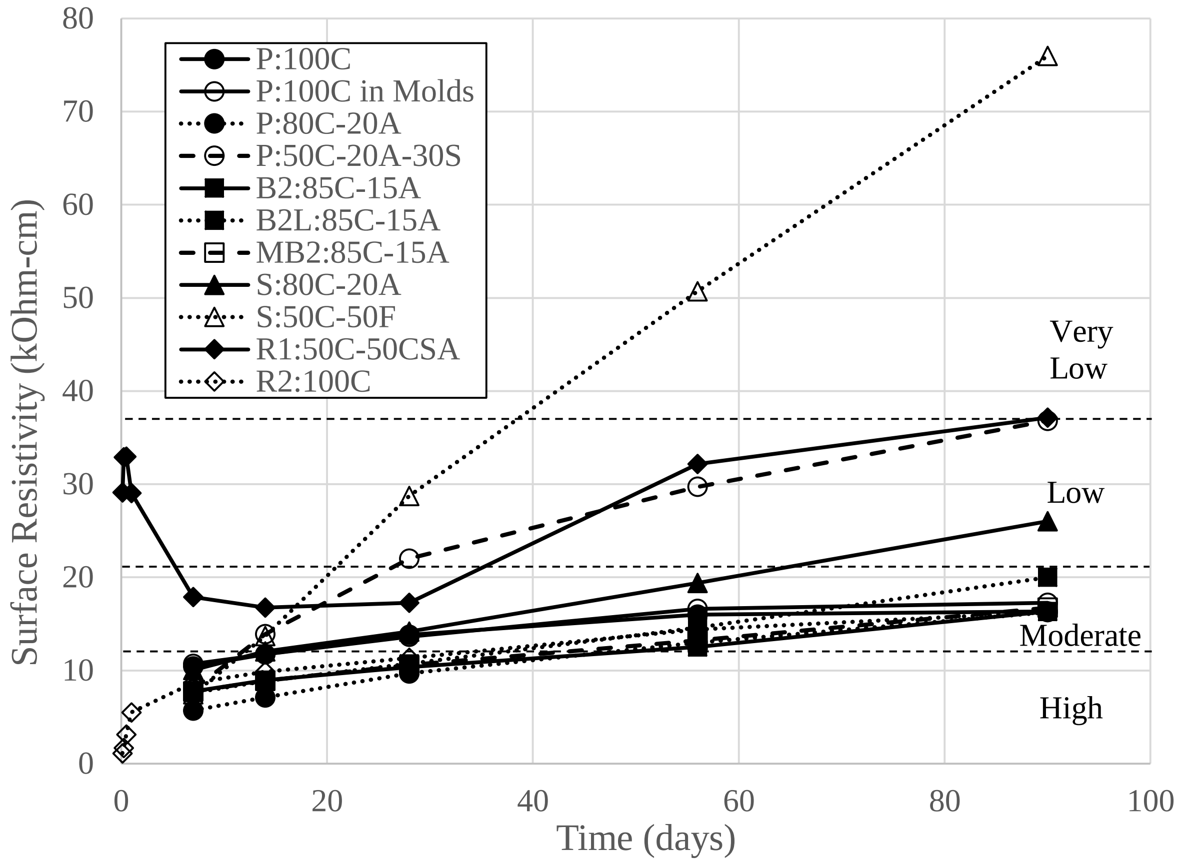


Figure 20. All concrete mixtures placed at UMKC laboratory tested for SR

Figure 21 shows the time versus SR graph for the paving mixtures. The only paving mix design that performed well in terms of surface resistivity was the ternary mixture that incorporated Class C fly ash and slag as supplementary cementitious materials. The ternary mix is recommended for any concrete application due to improved durability properties. The ternary mixture would have a statistically lower chloride ion penetrability when compared to all other paving mixture designs.

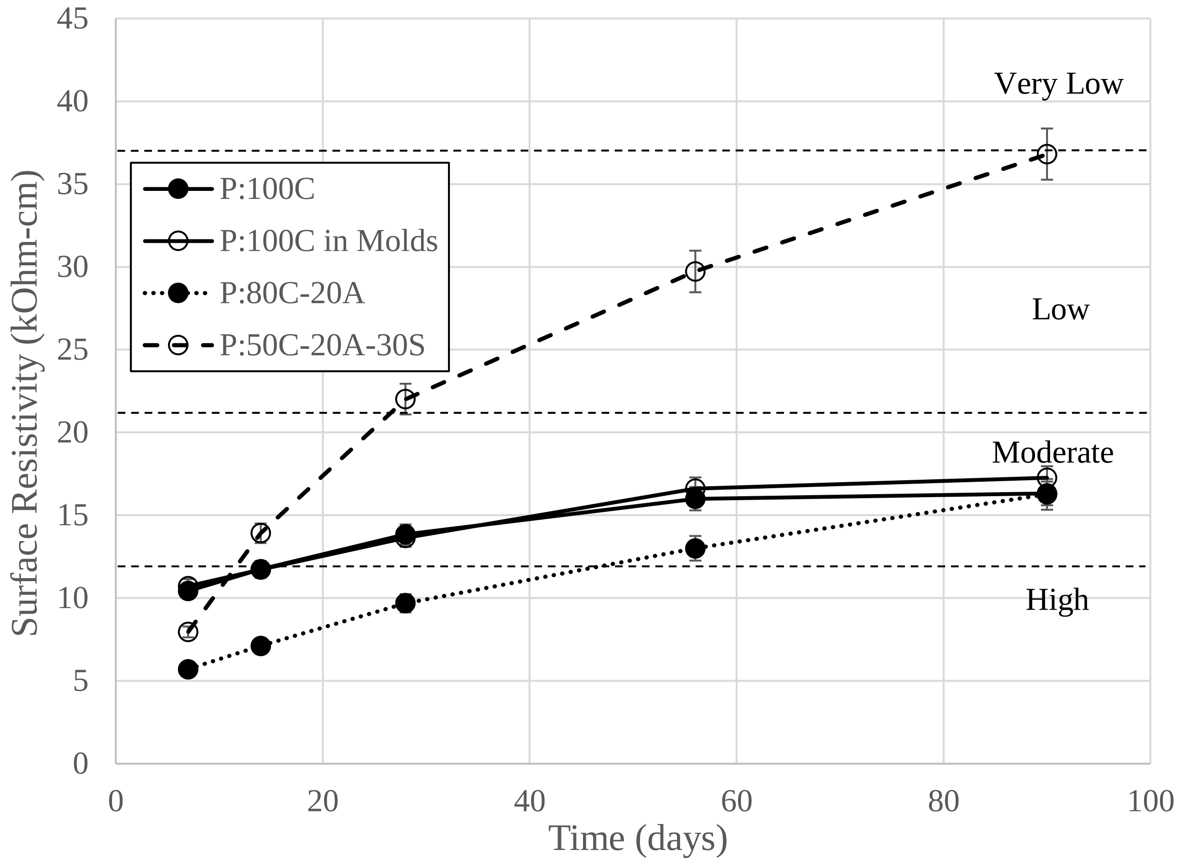


Figure 21. Paving mixture designs - SR results

Figure 22 shows the time versus SR graph for the bridge deck mixtures. None of the bridge deck mix designs batched based off of the specifications table in the MoDOT Section 501 performed particularly well in terms of surface resistivity. After correlating the results to RCP testing and penetrability clas0ses, the lowest permeability classifcation readings for the bridge deck designs were still classified as "Moderate" at 90 days. For concrete at 90 days, "Low" or "Very Low" permeability classifications are recommended for achieving long life concrete performance. The MB2 mix (705 lbs of cement) did approximately the same as the

B2 mix (600 lbs of cement) so the higher cement content is not helping the MoDOT bridge mixture. The lightweight aggregate mixtures showed some improvement likely due to the internal curing effect that aggregate provided to the concrete.

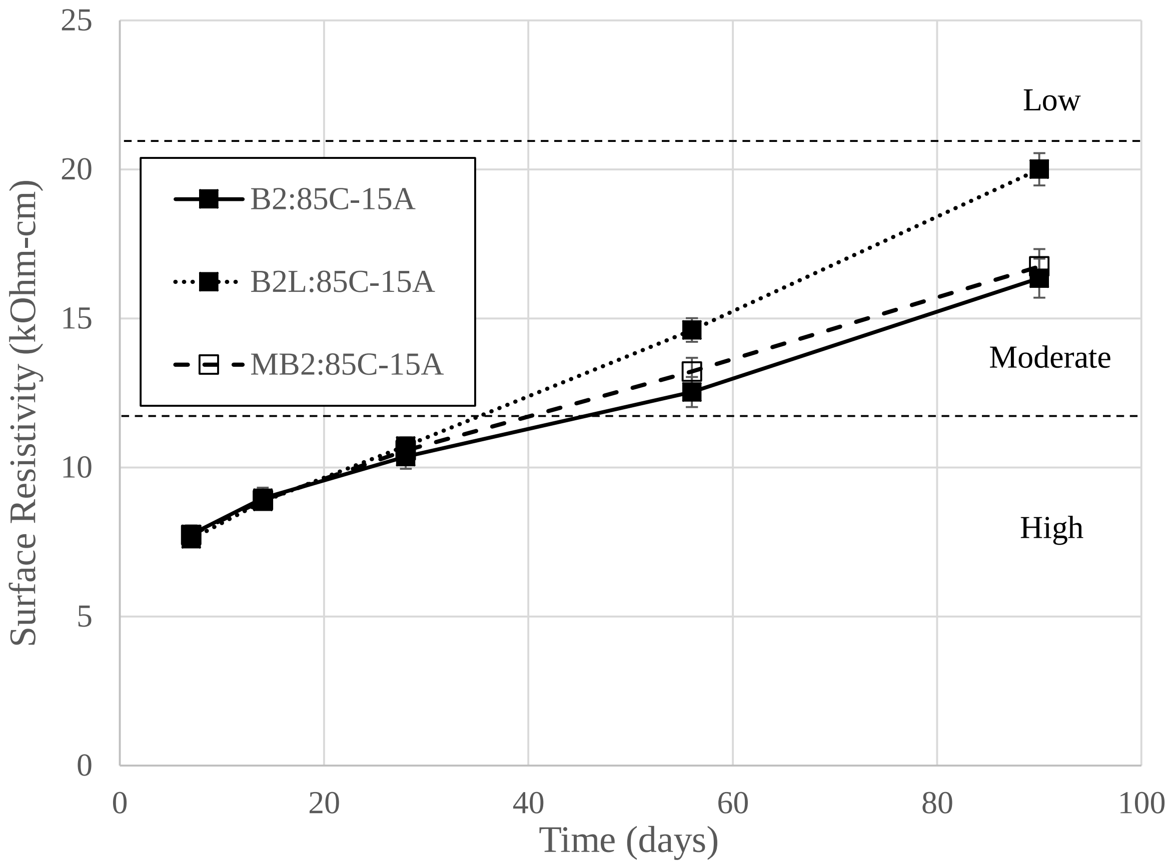


Figure 22. Bridge deck mixture designs - SR results

Figure 23 shows the time versus SR graph for the structural mixtures. As shown clearly in Figure 23, S:50C-50F showed to have the best results from the SR testing. The Class F fly ash decreased the permeability of the concrete substantially, leading to a permeability classification of "Very Low". The Class F fly ash mix would be a good candidate to incorporate more in the field specifically for the longevity of the concrete due to the pavements ability to resist penetration of water and chloride ions.

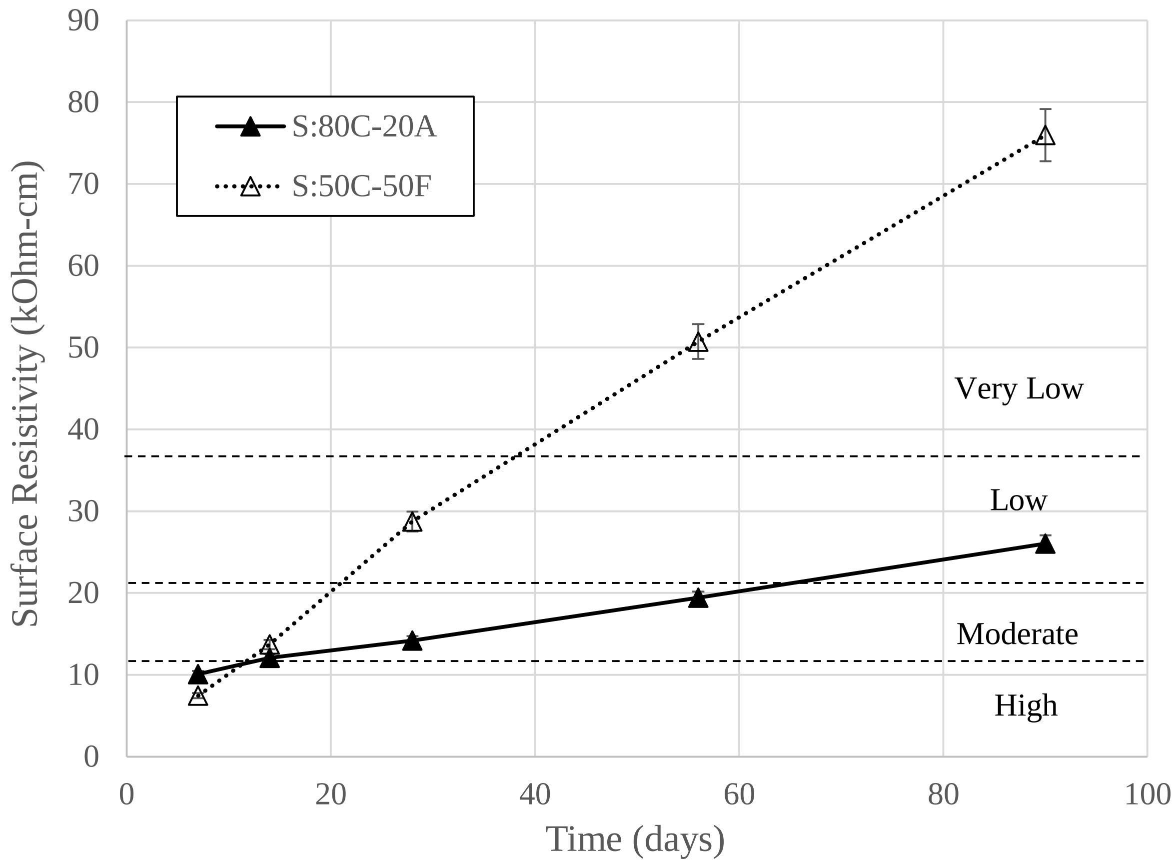


Figure 23. Structural mixture designs - SR results

Figure 24 shows the time versus SR graph for the repair mixtures. The R1 curve was the only non-regular trend in the data recorded. The CSA material caused the reaction to happen quickly and ettringite produced heat that caused the surface of the concrete to be raised in temperature. The R2 mixture had a similar curve to the other nine mixtures poured at the UMKC lab.

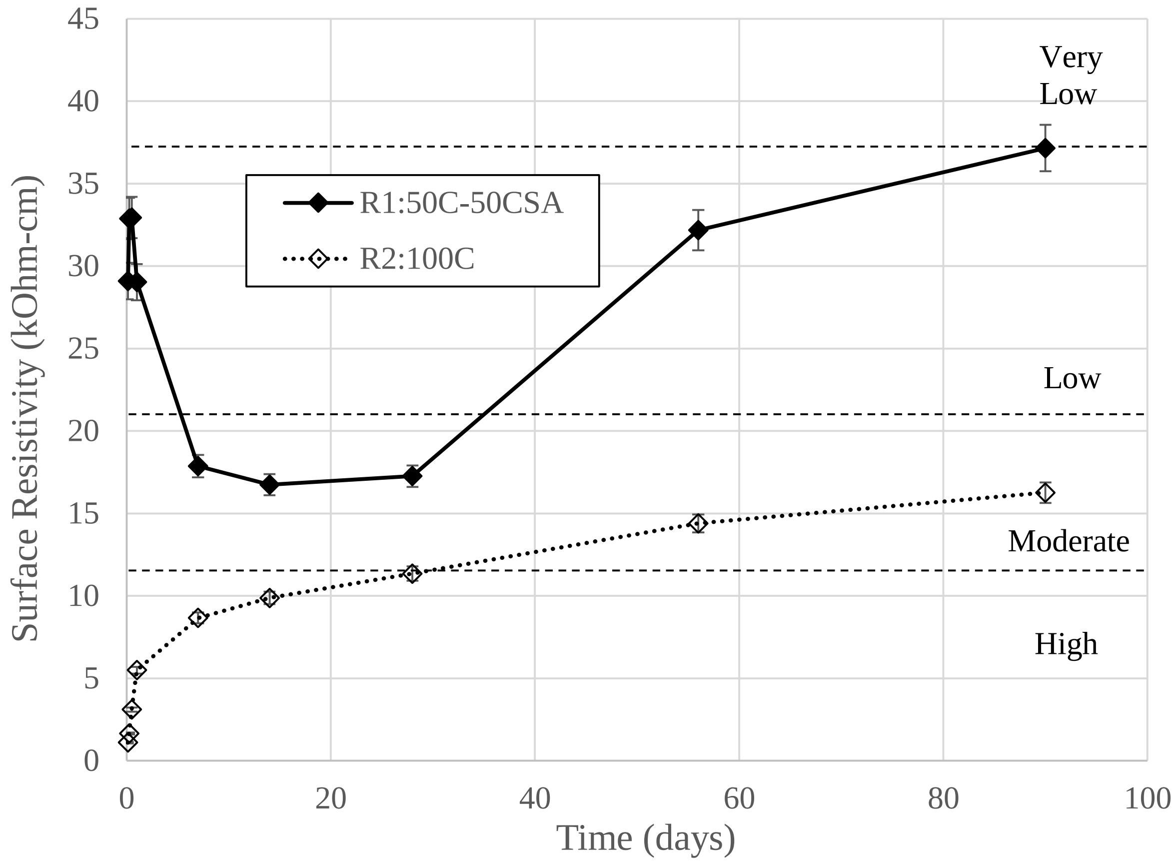


Figure 24. Repair mixture designs – SR results

Rapid Chloride Permeability

Rapid Chloride Permeability was tested at concrete ages of 7, 28, and 90 days for the standard nine mixtures (paving, bridge deck, and structural). RCP was tested at concrete ages of 1 and 90 days for the two repair mixtures. RCP was tested at concrete ages of 7, 28, and 90 days for the three field produced, lab tested mixtures. Average RCP data (three samples per test group) were plotted versus the corresponding age and mix design surface resistivity testing (the average of three samples, 24 SR readings, per test group). Figure 25 displays SR vs. RCP for this study. Figure 26 compares the values in Figure 25 to the research project by LTRC (Figure 3 in study).

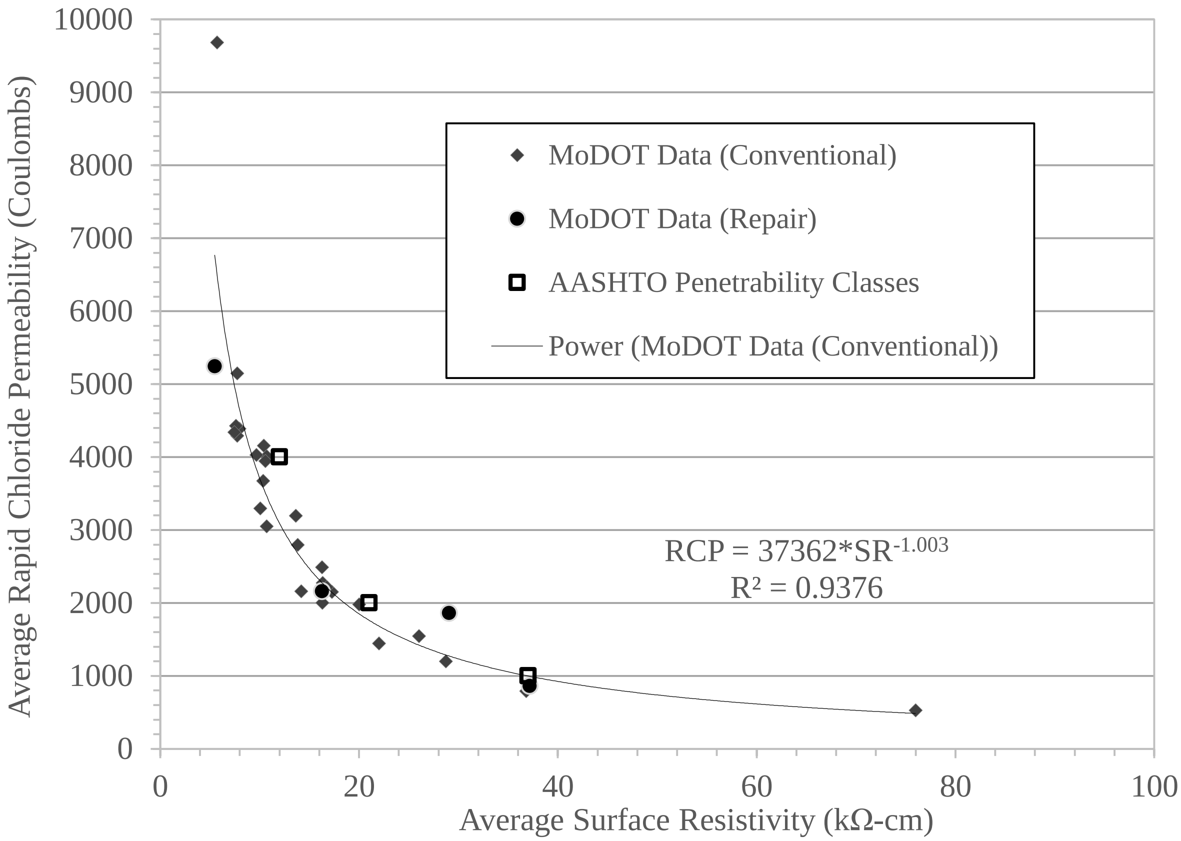


Figure 25. SR vs. RCP plot

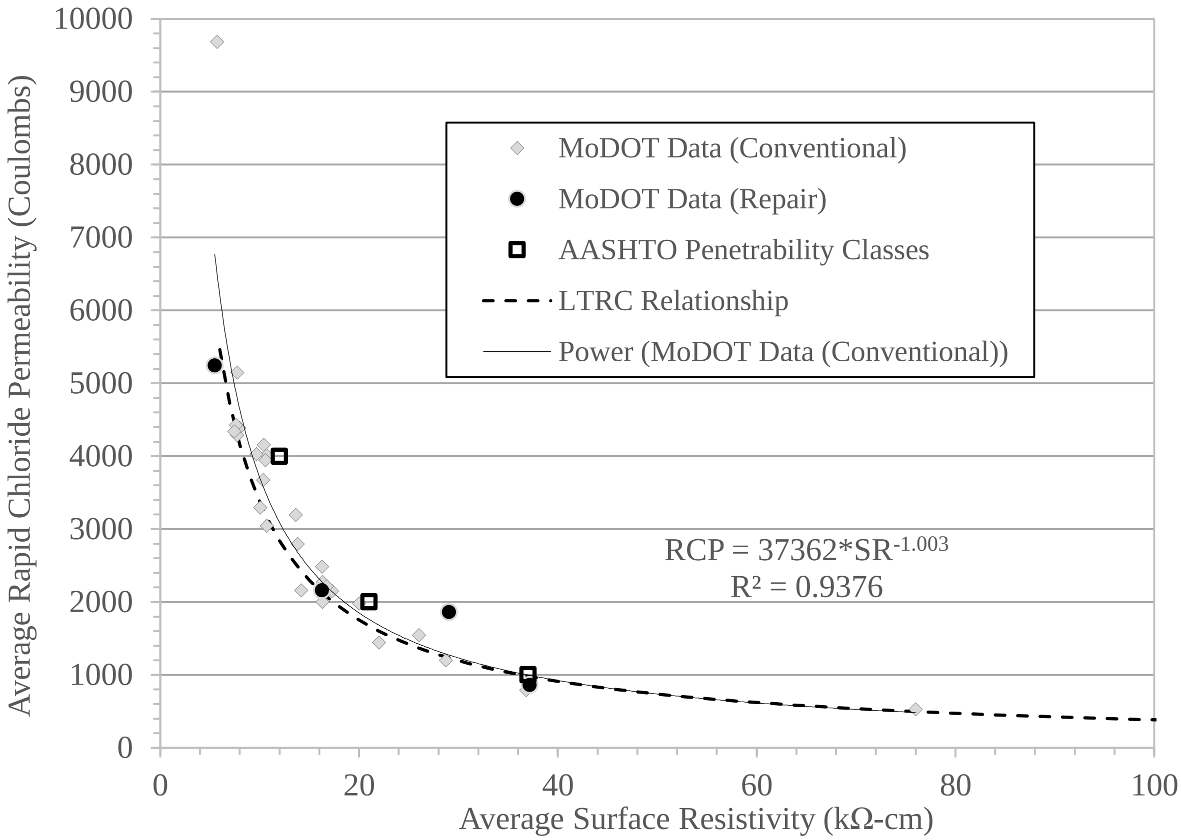


Figure 26. SR vs. RCP plot with LTRC data

Results from this project match the data previously shown from LTRC. Additionally, the values found within this study lie between the LTRC and the AASHTO permeability classes. This would conclude that accuracy and precision had been carried out throughout the entirety of the project as well as a consistent correlation between SR and RCP being approved and agreed upon throughout the nation. The equation provided is a quick check that may be performed after testing for SR to determine an approximate value for what should be expected from RCP testing. The fact that the research conducted in this project ended up splitting the gap between the LTRC and AASHTO data ensures the validity of the test procedures, test environment, and precautions taken throughout the entirety of the project.

Chloride Ion Diffusion

After at least 90 days of curing in a lime solution, concrete cylinders were cut and ponded with 165 grams NaCl (sodium chloride) per liter of solution. Three samples of each of the follow concrete mixtures were tested: P:100C, P:80C-20A, and P:50C-20A-30S. The concrete samples had NaCl solution ponded on the top surface of the sample for 56 days. The surface of the sample was grinded, titration made, and then the titrations were tested for chloride ion content. Table 21 displays the chloride ion contents of the samples in percentage as determined by titration. Plots are shown in Appendix D for chloride ion diffusion.

Table 21. Chloride ion content percentages

x (mm)	Chloride Ion Content (%)		
	P:100C	P:80C-20A	P:50C-20A-30S
2	0.947	1.761	0.758
3	0.702	1.214	0.546
4	0.540	0.980	0.364
5	0.449	0.772	0.245
7	0.331	0.490	0.099
9	0.247	0.312	0.083
11	0.168	0.187	-
13	0.119	0.128	-

As hypothesized after obtaining the results from our surface resistivity and rapid chloride permeability testing, the P:80C-20A mix had the highest chloride ion content, which correlates to higher chloride ion penetration. The P:50C-20A-30S group performed by far the most desirable once again out of the paving mix designs. Two of the ternary samples had no recordings successfully taken during the titration process. This could be due to not enough chloride ion penetrating the concrete (which is highly desirable), due to not enough time ponded with the NaCl solution, or due to the slag containing some sulfur within the supplementary cementitious material which can prohibit accurate readings from the titration machine. The P:100C group performed nearly in the middle of the two groups throughout.

The projected surface chloride concentration at the exposed surface (C_s) and apparent chloride diffusion coefficient (D) was derived using the data in Table 21. The projected surface chloride concentration at the exposed surface was measured in percent of mass. The apparent chloride diffusion coefficient was measured in meters squared per second. The results for the two variables are shown in Table 22.

Table 22. Chloride ion diffusion testing calculations

Summary	C_s (% mass)	D (m^2/s)
P:100C	0.878	7.96 E-12
P:80C-20A	1.742	3.89 E-12
P:50C-20A-30S	0.893	1.72 E-12

From surface resistivity, rapid chloride permeability, and chloride ion diffusion testing, the ternary mix design can be concluded as the best paving mixture tested in this project at resisting chloride ion penetration. The ternary mixture had a higher surface resistivity reading, a lower RCP test reading, and more desirable results from the chloride ion diffusion test than any of the other paving mixtures. The correlation has been developed and confirmed that the chloride ion diffusion testing is matching up in accordance with the results shown by the Proceq resipod surface resistivity meter and the RCP equipment.

Compressive Strength

Since surface resistivity is a non-destructive test, compressive strength testing can be performed on all the samples tested for resistivity. Compressive strength testing was performed to compare to previous specifications for concrete mixtures in terms of compressive strength. If performance based specifications are implemented for a final concrete product, durability testing (specifically surface resistivity) would be recommended as the primary testing measurable instead of strength testing. The compressive strength data is shown numerically in Table 23 and graphically in Figures 27 through Figure 30.

Table 23. Compressive strength data for the eleven mixtures placed at UMKC

Mixture Designation	Description	Average Compressive Strength in Pounds per Square Inch								
		3 hours	6 hours	12 hours	1 day	7 day	14 day	28 day	56 day	90 day
P:100C	Paving, cement only	-	-	-	-	4754	-	6951	-	7810
P:100C in Molds	Paving, cement only, no cure tank	-	-	-	-	5237	-	6206	-	7077
P:80C-20A	Paving, 20% C ash	-	-	-	-	3380	-	4828	-	5913
P:50C-20A-30S	Paving, ternary 50%	-	-	-	-	5131	-	7572	-	9237
B2:85C-15A	Bridge Deck, standard, 15% C ash	-	-	-	-	4611	-	5782	-	6618
B2L:85C-15A	Bridge Deck, lightweight	-	-	-	-	4429	-	5591	-	6695
MB2:85C-15A	Bridge Deck, low permeability	-	-	-	-	5501	-	6582	-	7755
S:80C-20A	Structural, standard, 20% C ash	-	-	-	-	5860	-	6842	-	8159
S:50C-50F	Structural, low heat, 50% F ash	-	-	-	-	3803	-	6132	-	7373
R1:50C-50CSA	Repair, 50% CSA	3459	4009	4403	4716	5445	5777	5708	8314	10432
R2:100C	Repair, 4x4 concrete	117	1391	4577	6376	9157	10104	11167	11687	12416

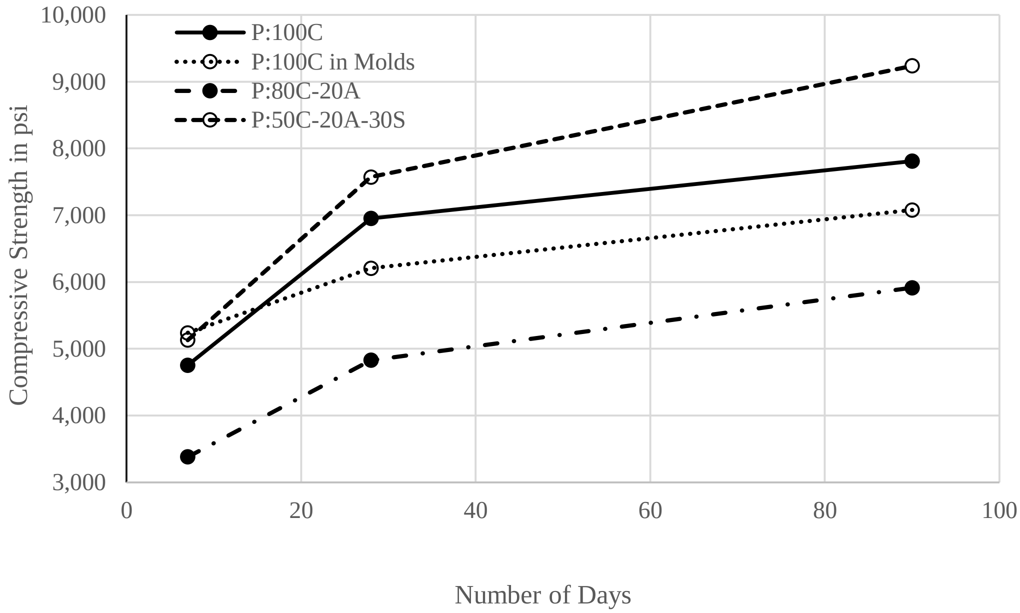


Figure 27. Compressive strength of paving mix designs

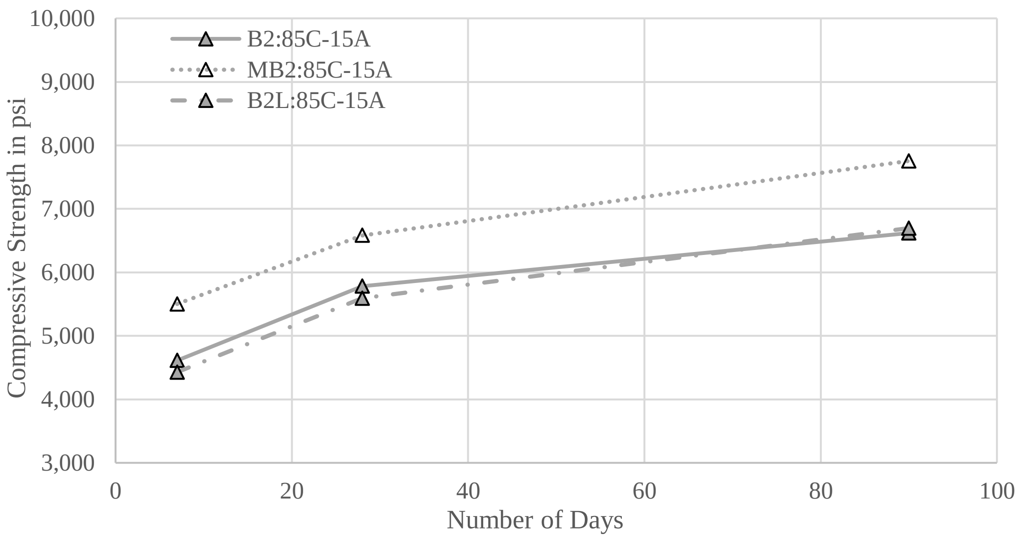


Figure 28. Compressive strength of bridge deck mix designs

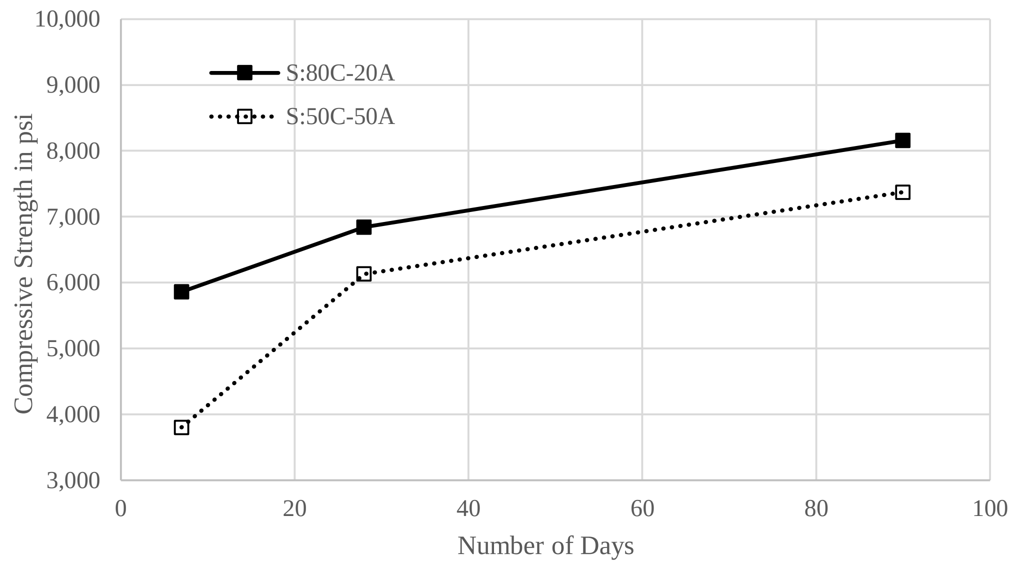


Figure 29. Compressive strength of structural mix designs

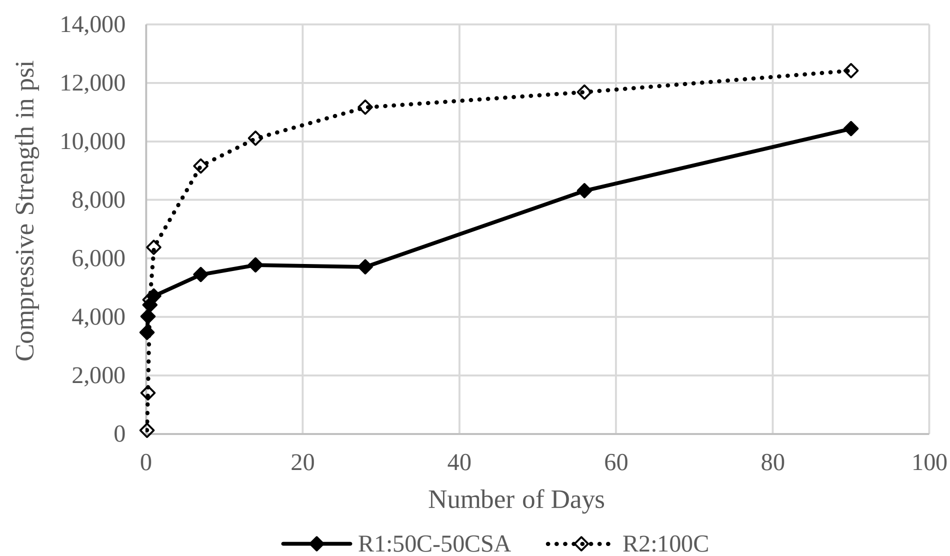


Figure 30. Compressive strength of repair mix designs.

CHAPTER 9

FIELD RESULTS AND DISCUSSION

The field testing was conducted on a bridge in Putnam Country, Missouri located on Highway 136. This was the third bridge the project team had visited in hopes of finding an ideal bridge for surface resistivity testing. MoDOT's team in Jefferson City, MO was assisting in locating a bridge to provide as a test section. The first two bridges suggested and site visited turned out to have recently been resurfaced with an asphalt overlay or sealed with an asphalt membrane. Both bridges were to be replaced within the year and adding asphalt material to a concrete bridge sometimes occurs before the reconstruction of the bridge. MoDOT officials in Jefferson City assisted with a last site visit to Putnam County on October 28th, 2014.

Upon arriving at the bridge, a worn-down asphalt emulsion was found on the concrete bridge. The bridge was still able to be tested but additional steps were to be added to the standard procedure to determine results. A PCI was performed on the bridge attempting to determine significantly deteriorated and relatively good sections of bridge deck. The ten locations were selected based off of the PCI's findings. The locations were tested using the surface resistivity meter. A majority of the PCI was based on popouts or worn-down spots of the asphalt emulsion where the concrete pavement could be clearly seen. Figure 31 shows the locations of concrete sections tested on the bridge in Putnam County.

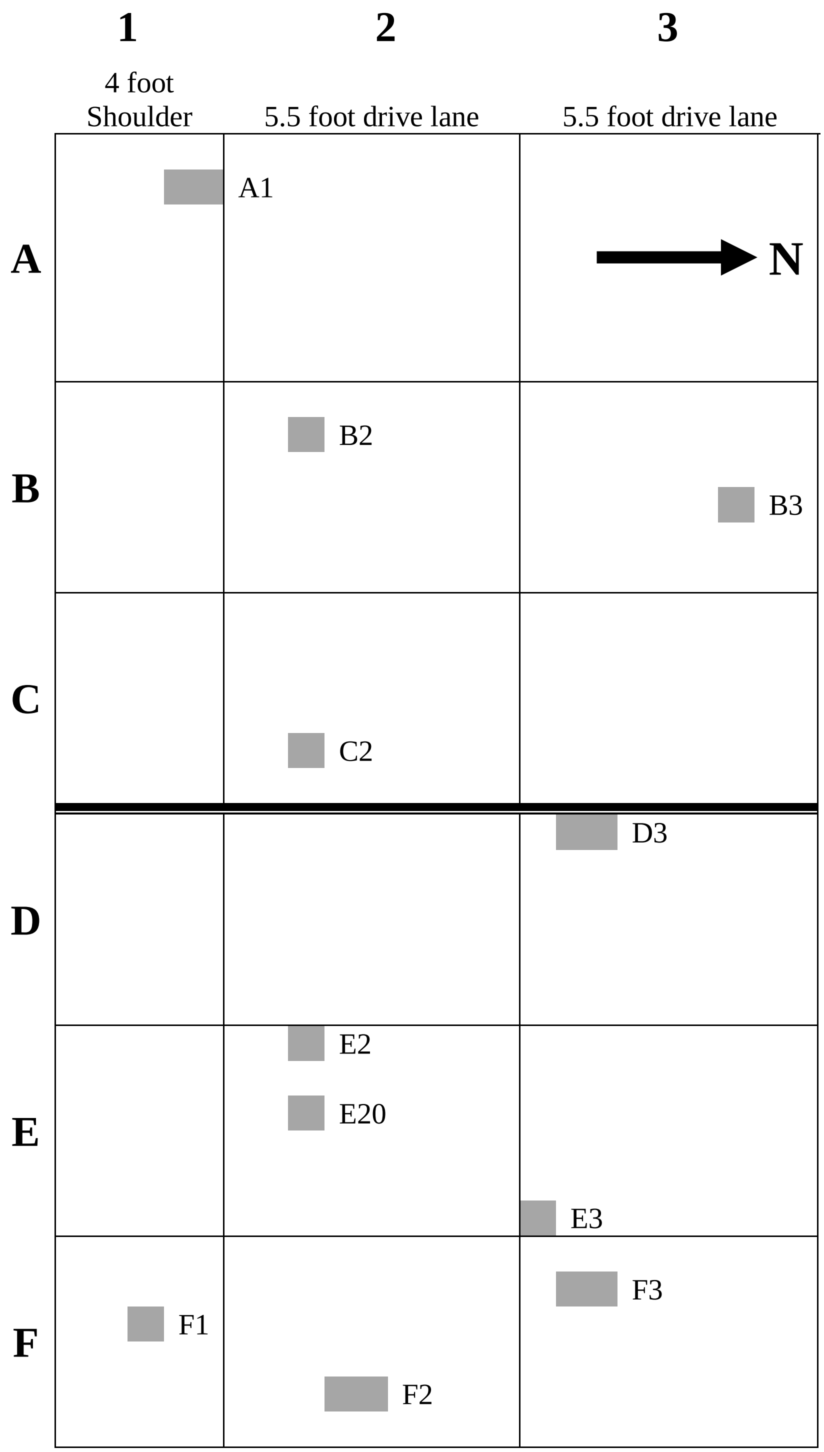


Figure 31. Locations of test sections on Putnam County Bridge

In Figure 31, the bold and double border line between section C and D indicates the location of an expansion joint in the bridge. The border lines between the other lettered section designations indicate there was a concrete joint located there on the bridge. The figure was not drawn to scale as the bridge was much longer than it was wide.

The bridge was on a low volume route in poor condition that crosses over Shoal Creek. Figure 32 shows a photograph of the bridge. Testing was conducted on the east bound lane only. Figure 33 displays the center of the bridge looking east. The bridge has noticeable amounts of asphalts and popouts spread throughout the bridge's entirety. Asphalt patches were placed in concrete distressed areas to improve drivability of the riding surface until the deck is replaced.

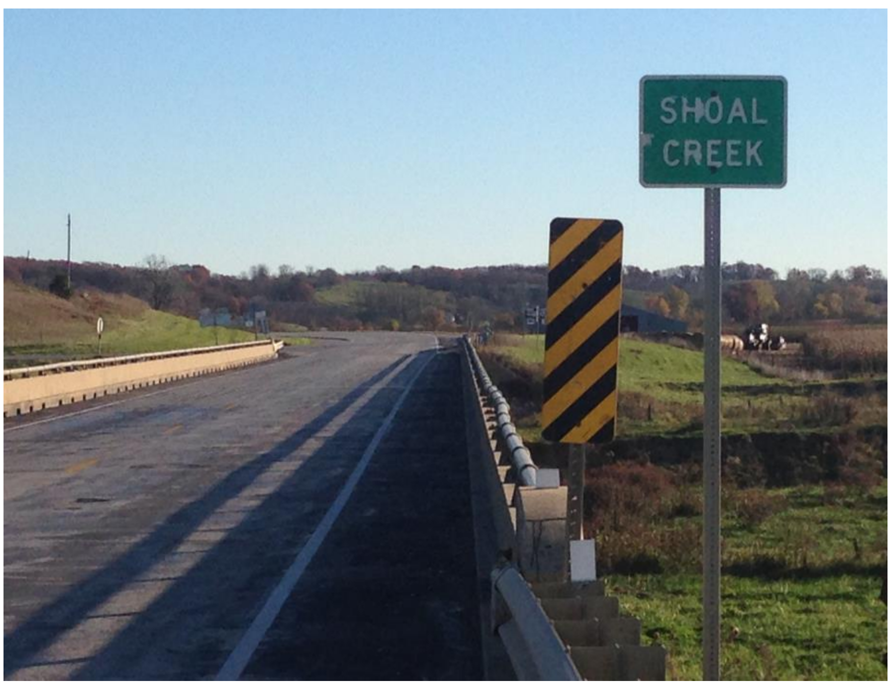


Figure 32. Shoulder view of bridge looking east

Figure 33. Center of bridge with asphalt looking east

The bridge showed severe distress to the rebar and underneath of the bridge. Figure 34 displays the side view of the visible distress and deterioration on the drainage openings in the barrier walls to allow runoff. Figure 35 displays a close up view of the deterioration and corrosion that occurred over time from the run off. Figure 36 shows a photograph illustrating the lack of thickness of the bridge deck. While on site, a farmer warned the driller of portions of the bridge being reportedly two inches thin on the easternmost side. The concrete pavement was as thin as three or four inches at sections. The driller notified the team that a core of four to eight inches as previously desired would not be possible any longer. Figure 37 displays the lack of spacing in the rebar grid. The rebar was spaced between three to six inches running north to south as determined by the figure. The driller noted that the rebar was closer than previously expected. Due to the close rebar spacing, the steel locating equipment experienced difficulty in locating the embedded rebar in the bridge deck.

Figure 34. Side view of deteriorating bridge

Figure 35. Numerous holes shown corroding throughout the span of the bridge

Figure 36. Close up on thickness of concrete bridge deck

Figure 37. Rebar spacing shown underneath the bridge in corroded section

Figure 38 displays a concrete popout that was filled with an asphalt patch that also popped out. The figure displays the severity of the bridge as well as confirming the rebar spacing shown in earlier figures. The spacing in the rebar grid placed in the bridge was much less than indicated in the plans (the exact spacing was unknown prior to testing but was expected to be sufficient to allow a 4 inch core to be taken). All of this information was taken into account before picking locations for the placement of ice bags.

Figure 38. Concrete popout revealing rebar

Figures 39 and 40 display the current pavement condition at the time of arrival. Figure 39 looks east revealing the amount of asphalt emulsion still overlaid on the concrete bridge. Figure 40 displays the patch of asphalt emulsion worn off of the concrete pavement where surface resistivity testing could be conducted.

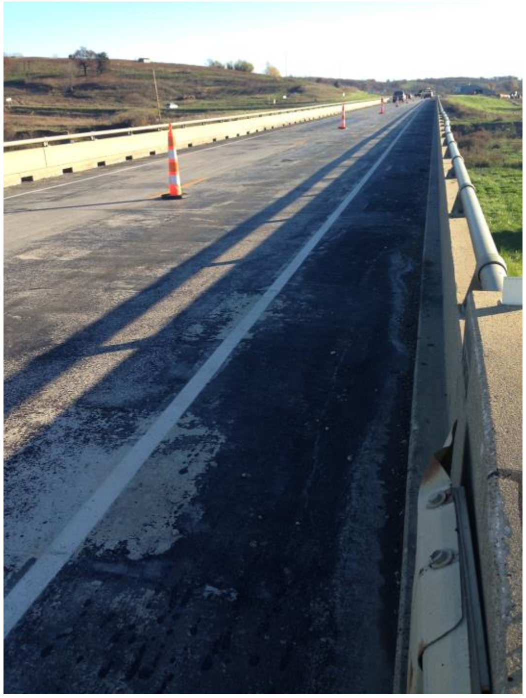


Figure 39. Bridge deck with asphalt emulsion facing east

Figure 40. Example of a worn off spot of asphalt emulsion showing concrete underneath

Figure 41 displays the expansion joint in bridge and two test locations. The selection of poor and good locations on the bridge had been chosen by this point in time and the ice bags laid upon the saturated bridge deck. The expansion joint was a point of interest in hopes of finding a correlation in resistivity between the two sides of the expansion joint.

Figure 41. Expansion joint and two test sections

Figure 42 displays the length of the bridge looking west with ice bags spread out to all eleven locations chosen. Water was sprayed onto the test section before the ice bag was placed. The ice bag was placed on the bridge section in order to normalize the temperature. This was standard practice specifically in hot weather to ensure that the heat was not affecting the resistivity readings. On the test day in late October, the weather was not concerning as the day was both chilly and windy. The ice bags were able to normalize to a temperature in the 30 to 40 degree range much sooner.

Figure 42. View of ice bags facing west on the bridge

Figures 43 through 46 display the additional step added to the procedure after initial testing on the bridge. The asphalt emulsion was proven to throw the resistivity readings off and contort the data. The solution developed was to grind off the first few layers of the asphalt emulsion and concrete. An angle grinder was used to quickly grind the asphalt away. Pure concrete was the after product to the grinding, at least to what was visible to the human eye.

Figure 43. Ground spot where asphalt emulsion was beforehand

Figure 44. Angle grinder shown in a previously ground spot of pavement

Figure 45. Water and ice bag placed back onto a ground spot of pavement

Figure 46. Ice bag replaced onto location for temperature to neutralize

After the temperature neutralized with the newly ground locations, the Proceq resipod was used to test for surface resistivity. The meter read inconsistent and spotty results throughout the project likely due to the asphalt emulsion product being applied beforehand to the bridge deck. If any type of asphalt was placed onto a bridge deck, testing for surface resistivity would not be suggested due to the nature of the meter's capabilities. Occasionally, the surface resistivity reading was as hypothesized such as the 23.7 kOhm-cm reading shown in Figure 47. The entirety of the field data from the bridge deck has been placed into Appendix E: Field Data.

Figure 47. Surface resistivity testing on the bridge deck

When the surface resistivity testing was finished, the driller lined up the equipment to core the bridge for further testing. A two inch RCP puck would have been desired so that the surface resistivity value could be accurately correlated with a known and standardized table regarding chloride ion penetrability classes. Figure 48 displays the steel locator being used to find the direction and placement of the steel reinforcement.

Figure 48. Steel locator being used by certified MoDOT technician

Figure 49 displays the drilling equipment in action attempting to core the concrete bridge deck. Unfortunately, the spacing between the steel reinforcement could never be found. Thirteen consecutive drillings ran into rebar and had to be backed out of the hole before the core reached a depth that was satisfactory for testing.

Figure 49. Drilling equipment attempting to core the concrete bridge deck

Figure 50 and Figure 51 display the attempts the driller performed in order to try to avoid the steel reinforcement and successfully take a core of the bridge deck. Utilizing the knowledge and experience of the driller, all possible locations of a core between the rebar spacing were attempted but none ended up being successful. With experienced workers, the bridge deck still could not be successfully cored due to the odd formation of the steel reinforcement in the bridge.

Figure 50. Five unsuccessful attempts at drilling a core of the bridge deck

Figure 51. Six more unsuccessful attempts at drilling a core of the bridge deck

In one test section that was attempted to be drilled, the driller decided to drill through the reinforcement to see what the issue with the rebar spacing was. From the core taken and popped out of the bridge deck, rebar was found entering the core from a diagonal angle. The steel exited the core in a diagonal angle as well. In Figure 52, the top of the picture would be east. The top left of the figure was where the rebar entered the core and then the rebar exited the core in the bottom left section of that hole. Not only was this bridge reinforced with rebar going horizontally and laterally through the deck; the bridge also had bars bending and hooking in the deck that could not be predicted or figured out in a consistent pattern. This led to further difficulties when trying to find a coring location where rebar was not present. In total, three test sections totaling to thirteen cores were attempted with each and every one hitting some form of steel that prohibited the core from being successfully taken. Data for the surface resistivity results are shown in Appendix E: Field Data.

Figures 52. Core popped out with diagonal entry and exit of steel reinforcement

CHAPTER 10

SEALER TESTING AND RESULTS

Testing on concrete with sealers placed on the surface had previously been researched to have mixed results with surface resistivity. The literature review concluded that not all surface resistivity meters or methods were able to penetrate the sealer and provide accurate readings. Twenty-four pans of concrete were placed using the B2:85C-15A mix design as standard for bridge decks in Missouri. The size of the sample in the pans was approximately 12 inches by 9.5 inches by 4.5 inches thick.

Sealer Materials

Four different sealers were used in the testing of the concrete samples. Silane, lithium silicate, acrylic, and soy bean oil were used as sealers for the concrete. Silane, the standard sealer for MoDOT, was predicted to substantially increase the resistivity reading values due to the sealer preventing water entry. With no water passing through the surface, the current of the resistivity meter cannot be effectively carried.

Lithium silicate was also used as a concrete sealer in the project. Lithium silicate has been used as a hardener and densifier in concrete. In theory, as the top layer of the concrete hardens/densifies from lithium silicate sealer, the pores becoming smaller and the permeability decreases. In correlation, the resistivity readings from the resistivity meter should increase.

Another sealer used in this portion of the project was an acrylic sealer. Acrylic sealers have become outdated in the state of Missouri and are generally not used anymore due to the sealer wearing off. An acrylic sealer was tested to see if surface resistivity testing concurred with MoDOT's decision and to see whether the meters could read through an already existing bridge deck with acrylic sealer on the pavement.

The final sealer used was soy bean oil and was used at only one application rate (100% coverage).

Test Method for Sealers

B2:85C-15A bridge deck concrete was mixed and then placed and tamped in the deicer pans. Three specimens were tested for each group: control group, 100% silane, 50% silane, 100% lithium silicate, 50% lithium silicate, 100% acrylic, 50% acrylic, and 100% bean oil totaling to 24 concrete samples. The step-by-step procedure for curing and testing the sealer samples are as follows:

1. Allow the concrete to air-dry until mass is normalized within 0.1% of the total mass for two weight readings at least 24 hours apart.
2. Place a wet wash cloth on the surface of the concrete sample for one hour.
3. Record temperature and the baseline surface resistivity readings on all twenty-four samples. The tests were conducted similarly to Figure 15 without testing in the diagonal direction.
4. Allow at least 48 additional hours for the concrete samples mass to normalize again through air-drying.

5. Apply sealers at an application rate of 1 gallon per 200 square feet of concrete surface for 100% coverage. For 50% coverage, apply 1 gallon per 400 square feet of concrete surface. The sealers were evenly applied from a spray bottle calculating the weight in grams needed on each sample determined by the specific gravity and specific weight of the sample. Figure 53 shows a sealer being applied to the concrete specimen from a spray bottle with the appropriate dosage. Figure 54 shows the final product of the spraying with the bottom sample being sprayed already and the top one remaining unsealed concrete.

Figure 53. Sealer being sprayed and applied to concrete.

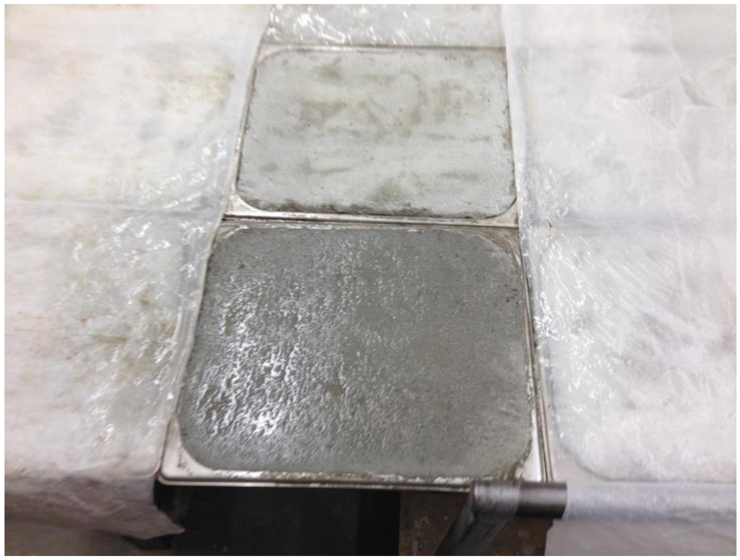


Figure 54. After product showing one sample sealed

1. Let the samples cure for at least seven days after the sealer was applied.
2. Repeat Steps 2 and 3 to determine the surface resistivity values with the sealers applied to the concrete.

Results for all Sealer Testing

The concrete samples were tested for surface resistivity at an age of 35 days. Table 24 displays the average values of all test groups. The average of the 19 concrete samples not cracked was 12.3 kOhm - cm. The values found from this flat surface and shape (the samples were not cylindrical) were approximately similar to the values calculated for the B2:85C-15A cylinders tested in the laboratory portion of the project. Five of the samples cracked while trying to remove the sample from the pan. The cracked concrete samples were still tested but the groups of the five samples with cracks are italicized in the table.

Table 24. Initial surface resistivity values for sealer samples

Sample Designation	Set Average
Control A	11.5
Silane 100% A	12.6
Silane 50% A	13.9
LiSi 100% A	11.3
LiSi 50% A	13.6
Acrylic 100% A	11.7
Acrylic 50% A	9.8
Bean Oil 100% A	10.1

In accordance with the procedure stated prior, the sealers were applied to the concrete samples and allowed to cure for seven days. The samples were then tested again for surface resistivity. The results for surface resistivity after the sealed concrete aged an additional seven days (49 days total age of concrete) are in Table 15.

Table 25. Final surface resistivity values for sealer samples

Sample Designation	Set Average
Control	14.1
Silane 100%	759.0
Silane 50%	784.2
LiSi 100%	34.4
LiSi 50%	27.6
Acrylic 100%A	3.7
Acrylic 50% A	35.9
Bean Oil 100% A	28.4

The silane noticeably and consistently greatly increased the surface resistivity readings. The lithium silicate samples doubled the control group values in regards to surface resistivity but not nearly as great as the silane sealer. For the data shown in the Appendix, “OF” on the table means that the surface resistivity meter overflowed when trying to take the reading. A value of 1250 kOhm - cm was used for the “OF” readings (as stated in the manual).The corrected average value was displayed in Table 25. The acrylic and bean oil samples did not perform consistent enough to draw conclusive discussions.

CHAPTER 11

CONCLUSIONS AND FUTURE RESEARCH

From this study, the following conclusions have been drawn:

- A good correlation was made and verified with previous research studies in terms of SR to RCP test results. SR and RCP testing correlate as researched prior to the start of this study and a Proceq resipod should be accepted as a potential way to measure and then correlate to determine if the quality of the concrete is acceptable. The correlation between surface resistivity and rapid chloride permeability testing was previously shown in Figure 25.
- Surface resistivity testing was much faster and lower cost than RCP to perform. The cost estimate for this project is shown in Table 26 and was based off of Table 2 and 3 by Rupnow and Icenogle.

Table 26. Cost estimate for SR and RCP in this project

Test Method	Number of Lots	Number of Testing Hours Required	Hourly Wage/Cost per Test ($)	Tech. Cost/Test Cost ($)	Total Cost ($)	Cost Per Sample ($)
ASTM C 1202	147	1,176	$500.00	$73,500	$73,500	$500.00
Surface Resistivity	654	216	$23.38	$5,046	$7,846	$11.99

- Precision and bias analysis determined that the sample must be tested within five minutes of taking the concrete specimen from the cure environment
- The use of Class F fly ash or slag in the ternary mixture proved to be beneficial to the penetrability and durability of the concrete sample.
- Most of the mixtures, including all of the bridge deck mixtures, had high penetrability at 28 days and only moderate penetrability at 90 days according to the SR and RCP results.
- Repair mixes showed promising results in terms of durability and strength. The CSA mix gave some discrepancies with early age readings possibly due to heat given off but the samples were able to be evaluated by the surface resistivity meter once the first week had passed.
- From the sealers testing, the use of silane sealer does not allow water through to the surface. The use of lithium silicate seemed to densify the surface of concrete as predicted from the results in this study. The Proceq resipod could be used to measure when sealers are present. A meter would definitely help provide the user with information of whether the silane was properly applied or not due to the extraordinarily high reading the meter would yield.
- SR is appropriate for mixture development and acceptance. However, field bridge testing needs further research. Asphalt emulsions and/or silane sealers prohibit accurate SR results.

- MoDOT mixtures had relatively poor performance in terms of average surface resistivity values (and permeability classification) when compared to the numerous Louisiana studies. The ternary mixture was a standard Iowa mix that out produced a majority of the MoDOT specified mixtures. The Class F fly ash mixture is rarely used by MoDOT but shown to be a good solution for future work. Additionally, the two repair mixes performed better than most of the other mixtures determined using the MoDOT specification guide.
- SR testing presents an opportunity to improve MoDOT concrete mixtures and specifications to increase durability without adding significant additional testing costs.
- Future research in regards to the project include developing new mixture designs for MoDOT emphasizing durability testing rather than compressive strength (end-result, performance based specifications), researching further into SR as a health monitoring tool for existing structures, and the use of a SR meter as a quality control test to check proper application of sealers.

APPENDIX A

MODOT SECTION 501 CONCRETE

SECTION 501

CONCRETE

501.1 Description. Concrete shall consist of a mixture of cement, fine aggregate, coarse aggregate and water, combined in the proportions specified for the various classes. Admixtures may be added as specifically required or permitted.

501.2 Material. All material shall be in accordance with Division 1000, Material Details, and specifically as follows:

Item	Section
Coarse Aggregate[a]	1005.2
Fine Aggregate[a]	1005.3
Ground Granulated Blast Furnace Slag	1017
Fly Ash	1018
Cement	1019
Concrete Admixture	1054
Concrete Tinting Material	1056
Water	1070

[a]Regardless of the gradation of the coarse and fine aggregate used in concrete for pavement or base, the aggregate shall meet the quality requirements of coarse and fine aggregate for concrete pavement.

501.2.1 Aggregate Acceptance. Quality control (QC) sampling and testing will be performed by the contractor and quality assurance (QA) sampling and testing will be performed by the engineer for aggregate in Portland cement concrete masonry in accordance with the following table at the last possible point of incorporation into the project. Aggregate samples may be taken either by sampling the flowing aggregate stream or upon approval by the engineer, from the stockpile.

Item	Property	QC Test Frequency	QA Test Frequency
Portland Cement Concrete Masonry	Gradation of Coarse Aggregate - AASHTO T 27 and T 11	One per 500 cubic yards per fraction per project.	One QC split per 2,500 cubic yards with a minimum of one per project. One independent QA per project.
	Gradation of Fine Aggregate - AASHTO T 27 and T 11		
	Deleterious Content - MoDOT Test Method TM 71		
	Absorption of Coarse Aggregate - AASHTO T 85		
	Thin or Elongated Pieces - ASTM D 4791 (+3/4 in., 5:1)	One per source per project.	One per source per year.

501.2.2 Retained Samples. The contractor shall retain the QC split sample for seven days until requested by the engineer for comparison testing. A comparison will be considered favorable when the QA results of a QC retained sample are within the applicable limits specified in Sec 403.18.2.

501.3 Mix Design. The proportions of cement, fine aggregate and coarse aggregate for concrete shall be approved by the engineer within the applicable limits of the specifications for the class of concrete specified in the contract. The contractor shall submit a mixture designed by absolute volume methods or an optimized mix design method such as Shilstone method or other recognized optimization method. Optimized will refer to aggregate gradations that produce lower water demands, as well as improved workability and finishing characteristics. The target and allowable gradation range of each fraction shall be included. The contractor may be required to submit representative samples of each ingredient to Construction and Materials for laboratory testing.

501.3.1 Required Information. The concrete mix design shall contain the following information:

(a) Source, type and specific gravity of Portland cement

(b) Source, type (class, grade, etc.) and specific gravity of supplementary materials, if used

(c) Source, name, type and amount of admixtures

(d) Source, type (formation, etc.), ledge number if applicable, and gradation of the aggregate

(e) Specific gravity and absorption of each fraction in accordance with AASHTO T 85 for coarse aggregate and AASHTO T 84 for fine aggregate, including raw data

(f) Unit Weight of each fraction in accordance with AASHTO T 19

(g) The percent of each aggregate component used for optimized concrete mixes

(h) The design air content and slump

(i) Batch weights of Portland Cement and supplemental cementitious materials

(j) Batch weights of coarse, intermediate and fine aggregates

(k) Batch weight of water

501.3.2 Paving Concrete. For PCCP mixes, the gradation requirements of Sec 1005 will not apply. For all fractions, 100 percent of each fraction shall pass the 2-inch sieve. When Grade F is required, 100 percent of each fraction shall pass the 3/4-inch sieve.

501.3.3 Optimized Masonry Concrete. For optimized PCCM mixes, the gradation requirements of Sec 1005.2 and Sec 1005.3 will not apply. For coarse aggregate, 100 percent of each fraction shall pass the one-inch sieve and no more that 2.5 percent shall pass the No. 200 sieve. This value may be increased to 3.0 percent passing, provided there is no more than 1.0 percent of the material passing the No. 200 sieve in the fine aggregate. For fine aggregate, no more than 2.0 percent shall pass the No. 200 sieve for natural sand, and no more than 4.0 percent shall pass the No. 200 sieve for manufactured sand.

501.3.4 Non-Optimized Masonry Concrete. When optimized aggregate gradations are not selected by the contractor, all provisions, including gradations requirements of Sec 1005 shall apply

501.3.5 Fine Aggregate Classes. Fine aggregates are grouped into four classes and a minimum cement factor has been established for each class.

501.3.6 Cement Factors. The minimum cement requirements in pounds per cubic yard of concrete for the various classes of sand shall be as follows:

Cement Requirements[a,b]							
Class of Sand	**Class A-1 Concrete**	**Class B Concrete**	**Class B-1 Concrete**	**Class B-2 Concrete**	**Class MB-2 Concrete[g,h]**	**Pavement Concrete**	**Seal Concrete**
A[c]	600	525	610	705	600	560	660
B[d]	640	565	640	735	620	560	695
C[e]	--	585	660	750	640	560	715
D[f]	--	620	695	790	660	560	735

[a]When used, Type IP, I(PM), IS or I(SM) cement shall be substituted on a pound for pound basis for Type I or Type II cement and adjustments in design mix proportions will be required to correct the volume yield of the mixture.

[b]The contractor may submit an optimized mix design which has a maximum 50 pounds per cubic yard reduction in cement from that shown in the tables. If the contractor chooses this option, the mixture will be subject to review, laboratory testing and approval by the engineer. All other requirements for the cement factor will apply.

[c]Class A sand will include all sand, except manufactured sand, weighing 109 pounds per cubic foot or more.

[d]Class B sand will include all chert, river and Crowley Ridge sand weighing from 106 to 108 pounds, inclusive, per cubic foot or glacial sand weighing 108 pounds or less per cubic foot.

[e]Class C sand will include all chert, river and Crowley Ridge sand weighing from 101 to 105 pounds, inclusive, per cubic foot.

[f]Class D sand will include all sand weighing 100 pounds or less per cubic foot and any manufactured sand that is produced by the process of grinding and pulverizing large particles of aggregate or which contains more than 50 percent of material produced by the reduction of coarser particles. Manufactured sand produced from limestone or dolomite shall not be used in Portland cement concrete for driving surfaces such as bridge decks, pavements and full depth shoulders.

[g]Modified B-2 (MB-2) concrete may be used in-place of Class B-2 Concrete.

[h]Modified B-2 (MB-2) concrete shall use at least one supplementary cementitious material in accordance with this specification. In no case shall MB-2 concrete use less than 15 percent fly ash or GGBFS when used as the individual supplementary cementitious material. In no case shall MB-2 concrete use less than 6 percent metakaolin when used as the individual supplementary cementitious material.

501.3.7 Unit Weight. The weight per cubic foot shall be the dry rodded weight per cubic foot of the aggregate, determined in accordance with AASHTO T 19.

501.3.8 Compressive Strength Requirements. Concrete classes shall meet the following compressive strength requirements in pounds per square inch:

Minimum Design Compressive Strength[1]						
Class A-1 Concrete	**Class B Concrete**	**Class B-1 Concrete**	**Class B-2 Concrete**	**Class MB-2 Concrete**	**Pavement Concrete**	**Seal Concrete**
6,000	3,000	4,000	4,000	4,000	4,000	3,000

[1]Minimum compressive strength required unless otherwise specified in the contract documents or approved by the engineer.

501.3.9 Absorptions. Coarse aggregate absorption tolerances shall be in accordance with Sec 502.11.3.3.

501.4 Sampling. Sampling of fresh concrete shall be in accordance with AASHTO T 141, except that for central or truck mixed concrete, the entire sample for slump and air tests and for molding compressive strength specimens may be taken at one time after approximately one cubic yard of concrete has been discharged, instead of at three or more regular intervals during the discharge of the entire batch. Acceptability of the concrete for slump and air content and, if applicable, for strength requirements, will be determined by tests on these samples.

501.5 Consistency. The slump of the concrete shall be within the limits for the respective classes of concrete. The concrete shall be uniform in consistency and shall contain the minimum quantity of water required to produce the designated slump. The slump of concrete mixes will be determined in accordance with AASHTO T 119. The quantity of mixing water in the concrete shall be considered the net quantity after proper allowance has been made for absorption by the aggregate. The slump and mixing water content of the concrete, when placed in the work, shall not exceed the following limits:

Slump and Maximum Water/Cementitious Materials Ratio			
Class of Concrete	Max. Slump, In.	Max. Pounds of Mixing Water Per Pound of Cementitious Materials	
		Air-Entrained	Non-Air-Entrained
A-1	3 1/2	0.46	0.51
B	4	0.51	0.55
B-1	4	0.44	0.53
B-2	3	0.40	----
MB-2	6	0.42	----
Pavement	----	0.50	0.53
Seal	8	----	0.53

501.6 Measurement of Material. The cement and aggregate for concrete shall be measured by weight. The weights of coarse and fine aggregates to be used will be calculated from the proportions approved by the engineer. Batches that do not contain the proper quantities of material shall be wasted at the contractor's expense.

501.6.1 Weighing Tolerances. The weighing and batching equipment shall be designed and maintained in such a condition that the material for each batch can be quickly and accurately weighed and shall be operated within a tolerance of plus or minus 0.5 percent for cement and plus or minus 1.0 percent for aggregate. The equipment used for delivery of material to the weigh hoppers shall not permit intermingling of material. Weighing hoppers shall discharge completely and there shall be no accumulation of tare material. Scales shall be accurate to within 0.4 percent of the net load applied. The change in load required to change the position of rest of the indicating element or elements of indicating scales an observable amount shall not be greater than 0.1 percent of the nominal scale capacity. If beam-type scales are used, a separate beam shall be provided for each type of material to be used and means shall be provided for adjustment of tare on a scale separate from those used for other material.

501.6.2 Water Meter Tolerances. Mixing water shall be measured by volume or by weight. If measured by weight, scales shall be in accordance with Sec 501.6.1. The device for the measurement shall be readily adjustable and under all operating conditions shall measure the required quantity within a tolerance of one quart or one percent, whichever is greater.

501.6.3 Calibration Frequency. Plant scales and water metering devices shall be calibrated and certified annually and after every plant move by an approved commercial scale service. Admixture metering devices shall be calibrated by a commercial scale company, the admixture company or the concrete plant company. Plant scales that have not been moved shall be verified six months after their calibration. A copy of the calibration and verification shall be provided to the engineer.

501.7 Mixing. The mixer shall produce concrete uniform in color, appearance and distribution of the material throughout the mixture. The cement, aggregate and no less than 60 percent of the water shall be mixed a minimum of one minute. The remaining water shall be added within 15 seconds after all other material for the batch is in the mixer. If mixers having multiple compartment drums are used, the time required to transfer material between compartments will be considered mixing time. The speed at which the drum rotates shall be as designated by the manufacturer. If such mixing does not result in uniform and smooth texture concrete, a sufficient number of additional revolutions at the same speed shall be performed until a thorough mixing of each batch of concrete is secured. The mixing time shall be measured from the time all cement, aggregate and 60 percent of the water are in the drum. The volume of concrete mixed in each batch shall not exceed the manufacturer's rated capacity. The mixer shall be equipped to automatically time the mixing of each batch of concrete. If the automatic timing device becomes inoperable, a manual timing device shall be provided to complete the day's operation.

501.8 Central and Truck Mixed Concrete. The following additional requirements will apply to central and truck mixed concrete.

501.8.1 Mixer Inspection. All central mixers, truck mixers and agitators shall be in accordance with of these specifications prior to use, and inspection of the equipment shall be made periodically during the work. Only equipment found acceptable in every respect and capable of producing uniform results will be permitted.

501.8.2 Uniformity Testing.
A uniformity test in accordance with ASTM C 94 Annex A1, shall be performed during the annual calibration at a central mix drum plant and at the beginning of production for a project at a mobile paving plant.

(a) A uniformity test shall be performed for the largest and smallest proposed batch size.

(b) The two samples shall be obtained within an elapsed time of no more than 15 minutes.

(c) The air content, slump and mix proportions of the concrete tested shall be in accordance with these specifications for that class of concrete or the uniformity tests shall be invalid.

(d) The use of a one-quarter cubic foot measure will be permitted in determination of weight per cubic foot.

(e) Cylinders may be cured in damp sand after the first 48 hours.

(f) The contractor may designate the mixing time for which uniformity tests are to be performed. The mixing time shall be a minimum of 60 seconds. The maximum mixing time shall not exceed the mixing time established by uniformity tests by more than 60 seconds for air-entrained concrete. The mixed concrete shall meet the uniformity requirements specified above before any concrete may be used for pavement or structures. The engineer may allow the use of the test concrete for appropriate incidental construction. Tests shall be performed by the contractor, in the presence of the engineer. No direct payment will be made for labor, equipment, material or testing. After operational procedures of batching and mixing are thus established, no changes in procedure will be permitted without re-establishing procedures by uniformity tests.

501.8.2.1 Measuring Mixing Time. Measurement of mixing time shall start at the time all the solid material is in the drum and shall end at the beginning of the next sequential operation.

501.8.2.2 Verification of Mixer. Mixer performance tests shall be repeated whenever the appearance of the concrete or the coarse aggregate content of samples selected in accordance with ASTM C 94, as modified above, indicates that adequate mixing is not being accomplished.

501.8.3 Truck Mixed Concrete. Truck mixed concrete shall be mixed at the proportioning plant and the mixer shall operate at agitating speed while in transit. Truck mixed concrete may be mixed at the point of delivery, provided the cement or cement and mixing water, are added at that point. Mixing of truck mixed concrete shall begin immediately after the introduction of the mixing water and cement to the aggregate or the introduction of the cement to the aggregate.

501.8.4 Truck Mixer Requirements. A truck mixer shall consist of a watertight revolving drum suitably mounted, fitted with adequate blades, and equipped with a device for determining the number of mixing revolutions. Truck mixers shall produce a thoroughly mixed and uniform mass of concrete and shall discharge the concrete without segregation. A truck agitator shall consist of a watertight revolving drum or a watertight container suitably mounted and fitted with adequate revolving blades. Truck agitators shall transport and discharge the concrete without segregation. Mixers and agitators shall be cleaned of accumulation of hardened concrete or mortar.

501.8.5 Rating Plate. Except as hereinafter permitted, each truck mixer shall have permanently attached to the truck a metal rating plate issued by and in accordance with the capacity requirements of the Truck Mixer Manufacturers Bureau (TMMB), as approved by NRMCA, on which is stated the maximum capacity in terms of volume of mixed concrete for the various uses to which the equipment is applicable. The truck shall also have attached a manufacturer's data plate that shall state the actual capacity as an agitator, and the maximum and minimum mixing and agitating speeds. If truck mixers are used for mixing or agitating, the volume of concrete in each batch shall not exceed the maximum capacity shown on the metal rating plate issued by the TMMB, as approved by NRMCA, except that if a lower capacity for agitating is shown on the manufacturer's data plate, that lower capacity shall govern. The minimum batch size for truck mixers shall be one cubic yard. The engineer may reduce the batch size or reject use of any truck mixer that does not produce concrete uniform in color, appearance and distribution of material throughout the mass. A quantity of concrete that results in axle and gross loads in excess of statutory limits will not be permitted.

501.8.6 Truck Mixing Requirements. Truck mixers and agitators shall be operated at the speed of rotation designated by the manufacturer of the equipment. Truck mixed concrete shall initially be mixed no less than 70 or more than 100 revolutions of the drum at mixing speed after all ingredients, including water, are in the mixer, except that when the batch volume does not exceed 57.5 percent of the gross volume of the drum or 91 percent of the rated maximum capacity, the number of revolutions required for mixing shall be no less than 50 or more than 100. When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed, agitation of the concrete shall continue during transportation at the speed designated by the manufacturer of the equipment as agitating speed. Water may be added to the mixture no more than two times after initial mixing is completed. Each time water is added, the drum shall be turned an additional 30 revolutions, or more if necessary, at mixing speed, until uniform mixing is accomplished. All water added will be included in determining the effective water in the mixture.

501.8.7 Water Adjustments at Job Site. Each increment of water added at the job site shall be measured within a tolerance of one percent of the total effective water required for the batch. Water used to wash the drum of the mixer shall not be used as mixing water.

501.8.8 Handling and Discharge Requirements. Central or truck mixed concrete shall be delivered to the site of the work and shall meet the following conditions:

(a) The handling and discharge of concrete shall not cause segregation or damage to the concrete and will allow placement with a minimum of handling. All handling and discharge shall occur prior to initial set of the concrete.

(b) Truck mixed concrete shall not exceed 300 revolutions after the beginning of mixing.

501.8.9 Non-Agitating Equipment. The discharge of concrete transported in non-agitating equipment shall not cause segregation or damage to the concrete and will allow placement with a minimum of handling. All handling and discharge shall occur prior to initial set of the concrete. Bodies of non-agitating hauling equipment shall be smooth, mortar-tight metal containers capable of discharging the concrete at a satisfactory, controlled rate without segregation.

501.8.10 Testing Facilities.
The contractor shall provide a Type 1 laboratory in accordance with Sec 601 at a paving plant for the engineer to inspect ingredients and processes used in the manufacture and delivery of the concrete. The contractor shall furnish the necessary equipment and personnel to assist the engineer in obtaining a representative QA sample. The ready mix producer shall notify the designated MoDOT representative every day that concrete is being supplied for a MoDOT project. A daily log of plant production shall be available for the engineer to review.

501.8.11 Delivery Tickets. The manufacturer of truck mixed concrete and of central mixed concrete for use in structures shall furnish to the engineer with each truck load of concrete before unloading at the site, a delivery ticket on which is shown information concerning the concrete as follows:

(a) Name of concrete plant.

(b) Serial number of the ticket.

(c) Truck number when a truck mixer is utilized.

(d) Name of contractor.

(e) Job Number, route and county designation.

(f) MoDOT mix identification number assigned to the mix.

(g) Specific class of concrete.

(h) Quantity of concrete in cubic yards.

(i) Date and time when batch was loaded or first mixing of cement and aggregate.

(j) Number of revolutions, when truck mixed.

501.8.12 Concrete Plant Documentation. The contractor shall complete the required concrete plant documentation once per working day at the central ready mix or paving plant. The documentation shall be made available to the engineer within 24 hours after concrete is batched.

501.9 Volumetric Batched and Continuous Mixed Concrete. Upon written request by the contractor, the engineer may approve the use of concrete proportioned by volume. If concrete is proportioned by volume, the other requirements of these specifications with the following modifications will apply.

501.9.1 Proportional Devices. Volume proportioning devices, such as counters, calibrated gate openings or flow meters, shall be available for controlling and determining the quantities of the ingredients discharged. In operation, the entire measuring and dispensing mechanism shall produce the specified proportions of each ingredient.

501.9.2 Controls. All indicating devices that affect the accuracy of proportioning and mixing of concrete shall be in full view of and near enough to be read by the operator while concrete is being produced. The operator shall have convenient access to all controls.

501.9.3 Calibration. The proportioning devices shall be calibrated by the contractor in the presence of and subject to approval from the engineer. Calibration of the cement and aggregate proportioning devices shall be accomplished by weighing each component. Calibration of the admixture and water proportioning devices shall be accomplished by weight or volume. Tolerances in proportioning the individual components will be as follows:

Item	Tolerance
Cement, Weight percent	0 to +4
Fine Aggregate, Weight percent	± 2
Coarse Aggregate, Weight) percent	± 2
Admixtures, Weight or Volume percent	± 3
Water, Weight or Volume Percent	± 1

501.9.4 Verification of Yield. Verification of the proportioning devices may be required at any time by the engineer. Verification shall be accomplished as follows. With the cement meter set on zero and all other controls set for the designated mix, the activated mixer shall discharge mixed material into a 1/4 cubic yard container measuring 36 x 36 x 9 inches. When the container is level-struck full, making provisions for settling the material into all corners, the cement meter shall show a discharge equal to the design proportion of cement for 1/4 cubic yard. A tolerance of ± 1/8 inch from the top of the container will be permitted. If the correct yield is not obtained, the proportioning devices shall be adjusted to obtain the design mix or the proportioning devices shall be recalibrated as directed by the engineer.

501.9.5 Water Control. The rate of water supplied shall be measured by a calibrated flow meter coordinated with the cement and aggregate feeding mechanism and with the mixer. The rate shall be adjustable in order to control slump at the desired level.

501.9.6 Liquid Admixture. Liquid admixtures shall be dispensed through a controlled flow meter. A positive means to observe the continuous flow of material shall be provided. If an admixture requires diluting, the admixture shall be diluted and thoroughly mixed prior to introducing the admixture into the dispenser. When admixtures are diluted, the ratio of dilution and the mixing shall be approved by and performed in the presence of the engineer.

501.9.7 Concrete Mixer. The concrete mixer shall be approved by the engineer and shall be an auger-type continuous mixer used in conjunction with volumetric proportioning. The mixer shall produce concrete, uniform in color and appearance, with homogeneous distribution of the material throughout the mixture. Mixing time necessary to produce uniform concrete shall be established by the contractor and shall comply with other requirements of these specifications. Only equipment found acceptable in every respect and capable of producing uniform results will be permitted.

501.9.7.1 Material Storage Capacity. The continuous mixer shall be capable of carrying sufficient unmixed dry bulk cement, fine aggregate, coarse aggregate, admixtures and water, in separate compartments to produce no less than 6 cubic yards of concrete at the job site. Each batching or mixing unit or both, shall carry in a prominent place a metal plate or plates on which are plainly marked the gross volume of the unit in terms of mixed concrete, discharge speed and the weight-calibrated constant of the machine in terms of a revolution counter or other output indicator.

501.9.7.2 Measurement of Cement. The continuous mixer shall be capable of positive measurement of cement being introduced into the mix. A recording meter visible to the operator and equipped with a ticket printout shall indicate the quantity.

501.9.7.3 Measurement of Water. The continuous mixer shall provide positive control of the flow of water and admixtures into the mixing chamber. Water flow shall be indicated by a flow meter and be readily adjustable to provide for minor variations in aggregate moisture. The mixer shall be capable of continuously circulating or mechanically agitating the admixtures.

501.9.7.4 Scalping Screen. The continuous mixer shall have a one-inch maximum size scalping screen over the fine aggregate bin to screen out mud balls, conglomerate lumps or any other contaminant material that could interrupt the flow of fine aggregate during proportioning.

501.9.7.5 Batching Operations. The continuous mixer shall be capable of being calibrated to automatically proportion and blend all components on a continuous or intermittent basis as required, and shall discharge mixed material through a conventional chute.

501.9.8 Handling Materials. Storage facilities for all material shall be designed to permit the engineer to make necessary inspections prior to the batching operations. The facilities shall also permit identification of approved material at all times, and shall be designed to avoid mixing with or contaminating by, unapproved material. Coarse and fine aggregate shall be furnished and handled so variations in the moisture content affecting the uniform consistency of the concrete will be avoided.

501.10 Air-Entrained Concrete. Air content for all classifications of concrete shall be determined in accordance with AASHTO T 152. Air-entrained concrete shall be used for the construction of the following items:

(a) All retaining walls and bridge units, except culvert-type structures and seal courses.

(b) Concrete median barriers.

(c) All piles (not required for cast-in-place concrete piles).

(d) Concrete pavements.

(e) Approach slabs and paved approaches.

(f) Concrete medians and median strips.

(g) Sidewalks, curb ramps and steps.

(h) Curbs, gutters, curb and gutter and surface drain basins and drains.

(i) Concrete pedestals for signs, signals and lighting.

501.10.1 Other Concrete. All other concrete, except seal concrete, may be air-entrained but only in accordance with the requirements of these specifications.

501.10.2 Required Air Content. If air-entrained concrete is used, the designated quantity of air by volume shall be a minimum of 5.0 percent. For concrete pavement, the specified air content will apply to the measurements taken behind the paver or to measurements taken in front of the paver minus the established air loss through the paver.

501.10.3 Incorporation Procedures. Air-entraining admixtures shall be added to the concrete during the mixing process. The admixture shall be of such volume and strength that the admixture can be accurately measured and dispensed in accordance with the manufacturer's recommendations. The dispenser shall consistently deliver the required quantity of admixture within a tolerance of ± 3 percent.

501.10.4 Redosing. When the measured air content is below the minimum specified value, the contractor will be allowed to re-dose the concrete in the field one time. The contractor shall submit a Re-dosing Plan to the engineer for approval. The Re-dosing Plan shall address the following:

(a) Field measurement of the air entrainment admixture

(b) Brand of air entrainment admixture being used

(c) Incorporation and mixing of the air entrainment admixture

(d) The use of additional water

501.10.4.1 Allowed. The Re-dosing Plan shall be approved prior to use.

501.10.4.2 Other Requirements. All other requirements of this specification shall still apply.

501.10.4.3 Unacceptable Results. Concrete with a measured air content below 4.0 percent is unacceptable.

501.11 Concrete Admixtures for Retarding Set. If specified in the contract, an approved retarding admixture shall be provided and incorporated into the concrete. If not specified in the contract, the use of an approved retarding admixture will be permitted upon written notification from the contractor. Any retarding admixture shall be added in accordance with Sec 501.10.3 by means of a dispenser conforming to the requirements of that section. No direct payment will be made for furnishing the retarding admixture or for incorporating the admixture into the mixture.

501.12 Water-Reducing Admixtures. Type A water-reducing admixtures may be used in any concrete. When Type A water-reducing admixture is added to pavement concrete for paving purposes, a reduction of cement up to 25 lbs per cubic yard will be permitted. The dosage rate of Type A water-reducing admixture shall be within the ranges recommended by the manufacturer and approved by the engineer. Any cementitious material substitution permitted by specification shall be based on the reduced cement content. Water-reducing admixtures shall be added in accordance with Sec 501.10.3 by means of a dispenser conforming to the requirements of that section. High range water-reducing admixtures may be used when specified or as approved by the engineer.

501.12.1 Modified B-2 Utilized. Modified B-2 concrete shall use a Type A or Type D water-reducer admixture.

501.12.2 Silica Fume and Metakoalin Utilized. Concrete utilizing silica fume or metakaolin shall use a water-reducer admixture that may be added by hand methods. The amount of water contained by the water-reducer admixture shall be included in the overall water content of the concrete.

501.12.3 Consistency Requirement. When a water-reducer admixture is used the maximum allowed slump may be increased to 6 inches for all concrete classes. The concrete shall be homogeneous with no aggregate segregation.

501.13 Accelerating Admixtures. The use of calcium chloride or other approved accelerating admixtures in concrete mixtures will not be permitted, except in concrete used for pavement repair in accordance with Sec 613.

501.14 Supplementary Cementitious Materials in Concrete. The contractor may use fly ash, GGBFS, silica fume or metakaolin in the production of concrete in accordance with these specifications. Ternary mixes will be allowed for all concrete classes. Ternary mixes are mixes that contain a combination of Portland cement and two supplementary cementitious materials. Supplementary cementitious materials may be used to replace a maximum of 40 percent of the Portland cement. The amount of each supplementary cementitious materials used in a ternary mix shall not exceed the limits specified herein.

501.14.1 Fly Ash. Approved Class C or Class F fly ash may be used to replace a maximum of 25 percent of the Portland cement on a pound for pound basis in all concrete.

501.14.2 Ground Granulated Blast Furnace Slag. Approved GGBFS may be used to replace a maximum of 30 percent of the Portland cement on a pound for pound basis in all concrete.

501.14.3 Silica Fume. Approved silica fume may be used to replace a percent of the Portland cement on a pound for pound basis. The following limits shall apply when silica fume is used:

Silica Fume Replacement Limits, %		
Class of Concrete	**Minimum**	**Maximum**
MB-2	6	8
A-1, B, B-1, B-2, PCCP, Seal	----	8

501.14.3.1 Silica Fume Requirements. Silica fume shall be approved prior to use and be in accordance with ASTM C 1240, except as noted herein. If dry compacted form, the admixture shall be 100 percent silica fume with no admixtures. Silica fume slurries may contain other approved admixtures, such as water reducers or retarders, if the admixtures are included by the manufacturer of the silica fume admixture.

501.14.3.2 Manufacturer Certification. The contractor shall furnish to the engineer a manufacturer's certification along with the brand name, batch identification, quantity represented, percent solids and the type, name and quantity of any admixtures, that are provided in the silica fume admixture.

501.14.3.3 Silica Fume Test Results. The manufacturer's certification shall contain results of recent tests conducted on samples of the silica fume material taken during production or transfer and indicating conformance with Tables 1 and 3 of ASTM C 1240 and this specification. The supplier shall further certify that the material being furnished is in accordance with this specification.

501.14.3.4 Silica Fume Approval. For approval prior to use, the supplier shall furnish the same information to: Construction and Materials, P.O. Box 270, Jefferson City, MO 65102, along with any requested samples for testing.

501.14.3.5 Silica Fume Slurry. Liquid silica fume admixture shall be protected from freezing at all times.

501.14.3.6 Admixture Compatibility. All admixtures used shall be compatible with the silica fume admixture and shall be recommended or approved in writing by the manufacturer of the silica fume admixture.

501.14.4 Metakaolin. Approved metakaolin may be used to replace a maximum of 15 percent of the Portland cement on a pound for pound basis in all concrete.

501.14.4.1 Metakaolin Requirement. Metakaolin shall be approved prior to use and be in accordance with AASHTO M321.

501.14.4.2 Manufacturer Certification. The contractor shall furnish to the engineer a manufacturer's certification along with the brand name, batch identification and quantity represented.

501.14.4.3 Metakaolin Test Results. The manufacturer's certification shall contain results of recent tests conducted on samples of the metakaolin taken during production or transfer and indicating conformance with AASHTO M321 and this specification. The supplier shall further certify that the material being furnished is in accordance with this specification.

501.14.4.4 Metakaolin Approval. For approval prior to use, the supplier shall furnish the same information to: Construction and Materials, P.O. Box 270, Jefferson City, MO 65102, along with any requested samples for testing.

501.14.5 Source Changes. Changes in class or source of fly ash, grade and source of GGBFS, brand and source of silica fume or brand and source of metakaolin used in concrete structures will be permitted only with written approval from the engineer. Only fly ash, GGBFS, silica fume or metakaolin resulting in concrete of the same color shall be used in any individual unit of the structure.

501.14.6 Mix Proportions. When fly ash, GGBFS, silica fume or metakaolin is used, an adjustment in design mix proportions will be required to correct the volume yield of mixture. Approval shall be obtained from the engineer prior to any change in mix design or proportions.

501.14.7 Mixing Water. Maximum mixing water shall be based on total cementitious material. The quantity of mixing water in the concrete shall be considered the net quantity after proper allowance has been made for absorption by the aggregate.

501.14.8 Measuring Fly Ash and Ground Granulated Blast Furnace Slag. Fly ash or GGBFS shall be measured in the same manner and with the same accuracy as cement. Fly ash or GGBFS may be weighed separately on the same scale as cement, provided the scale increments are such that the specified weighing accuracy can be maintained. If the fly ash or GGBFS is weighed together with the cement, the cement shall be weighed first and the accuracy shall apply to the combined weight.

501.14.9 Measuring Silica Fume and Metakaolin. Silica fume or metakolin shall be measured by weight or volume within a tolerance of plus or minus 2 percent.

501.14.10 Silica Fume and Metakaolin Batching Sequence. Silica fume or metakaolin shall be added at the plant at the same point in the batch sequence as recommended by the manufacturer of the material . The silica fume or metakaolin may be added by hand methods.

501.14.11 Calculating Silica Fume Solids. For silica fume solutions, the quantity of liquid silica fume admixture needed to furnish the required silica fume solids shall be calculated based on the weight per gallon and percent solids of the silica fume admixture being used.

501.14.12 Measuring Cementitious Materials. Fly ash, GGBFS, silica fume or metakaolin will be considered as cement when measuring mixing time.

501.15 Commercial Mixture. If specified in the contract that an approved commercial mixture of concrete may be used, the contractor shall notify the engineer in writing, setting out for approval the source and proportions of the mixture proposed to be furnished. The statement shall include the following:

(a) The types and sources of aggregate.

(b) Type and source of cement and other cementitious material.

(c) Scale weights of each aggregate proposed as pounds per cubic yard of concrete.

(d) Quantity of water proposed, as pounds or gallons per cubic yard of concrete.

(e) Quantity of cement proposed as pounds per cubic yard of concrete.

501.15.1 Minimum Cement Content. The concrete shall contain no less than 517 pounds of cement per cubic yard. The use of fly ash, GGBFS, silica fume or metakaolin shall be in accordance with Sec 501.14. The plant shall comply with other requirements of these specifications or be as approved by the engineer. The concrete will be subject to acceptance or rejection by visual inspection at the job site.

501.15.2 Certification. The supplier shall furnish certification with the first truck load of each day's production of concrete that the material and mix proportions used are in accordance with the approved mixture. Upon completion of the work, plant certification shall be furnished by the supplier for the total quantity delivered.

APPENDIX B

PROPOSED MODOT EPG SURFACE RESISTIVITY STANDARD

106.3.2.XX TM-XX, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration

This test method covers the determination of the electrical resistivity of concrete to provide a rapid indication of its resistance to penetration of chloride ions for quality assurance purposes. This test method is applicable to types of concrete where established correlations exist between this test procedure and other permeability measurement procedures (specifically rapid chloride permeability test method AASHTO T 277).

Referenced Documents: AASHTO R 39, Making and Curing Concrete Test Specimens in the Laboratory
AASHTO T 277, Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
AASHTO TP 95, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration
LA DOTD TR 233, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration

106.3.2.XX.1 Equipment

A. Surface Resistivity Apparatus – Apparatus with Wenner array probe capable of adjustment of the probe tip spacing to 1.5 inch (38.1 mm).

B. Specimen Holder – Non-conductive holding device to prevent movement while readings are being taken.

C. Marking Device or Chalk – To write on the surface of the concrete.

D. Towel – To bring the concrete sample to saturated-surface-dry (SSD) condition and remove excess moisture from the sample.

E. Shallow Pan – To hold a small amount of water to dip the tips of the resistivity apparatus into.

106.3.2.XX.2 Sample Preparation

A set is composed of a minimum of three (3) specimen samples. Sample preparation and selection depends on the purpose of the test. Standard testing includes 4 inch (100 mm) diameter cylinders.

Transport the cores or field cylinders to the laboratory. Cylinders cast in the laboratory shall be prepared following procedures in AASHTO R 39.

Immediately after sample removal from the mold, make four indelible marks on the top (finish face) circular face of the specimen marking the 0, 90, 180, and 270 degree points of the circumference. Mark and label the sample similarly to the sample shown in Figure 1.

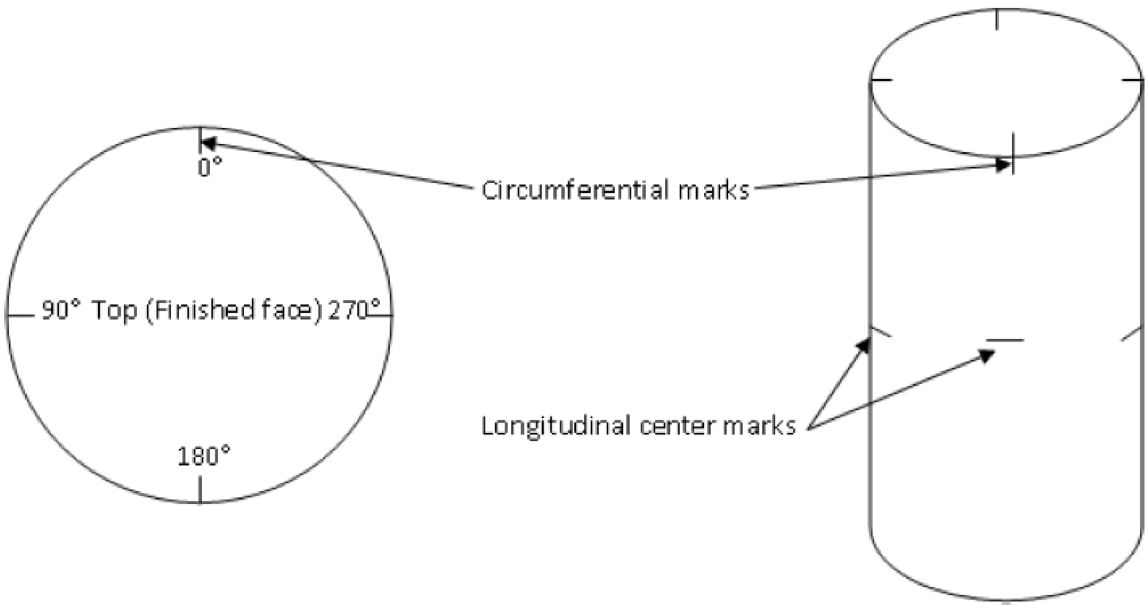


Figure 1. Specimen Marking

Condition and saturate the concrete cylinder in water by placing samples in a 100% humidity condition for at least 7 days prior to testing.

> **Note #1**: Placing cylinders in a lime cure tank or humidity room for 15 minutes before testing will produce statistically similar results.

106.3.2.XX.3 Procedure

1. Remove specimen from water or humidity room, blot off excess water with towel, and transfer specimen to specimen holder with the 0 degree mark on top.

   > **Note #2**: Concrete specimen must be tested within 5 minutes of removing from cure tank or humidity room. Strongly recommended to remove and test one cylinder at a time to ensure this.

2. Fill shallow pan with approximately ½ inch (12.7 mm) of water.

3. If using a Proceq resipod resistivity meter, lightly press down the meter and its probes into the shallow pan of water to fill the reservoirs with water. Press the resistivity meter onto the

12 kOhm-cm Proceq constant/control reading plate to ensure accuracy of the meter's readings.

4. Place surface resistivity apparatus on longitudinal side of specimen making sure longitudinal center mark is equidistant between the two inner probes. Firmly press the meter down against the specimen.

5. Take measurement of display unit when number becomes stable.

6. Rotate specimen 90˚ to 90 degree mark, and repeat steps 4 and 5 above.

7. Rotate specimen 90˚ to 180 degree mark, and repeat steps 4 and 5.

8. Rotate specimen 90˚ to 270 degree mark, and repeat steps 4 and 5.

9. Repeat last four readings at 0˚, 90˚, 180˚, and 270˚ marks. Record all eight readings in data table.

10. Repeat steps 1 through 9 for the other two or more specimens in the set.

Figure 2 demonstrates the surface resistivity apparatus (Proceq resipod) taking a reading on a 4 by 8 inch concrete specimen that is placed in a non-conductive specimen holder. The Proceq control reading plate is displayed below the specimen holder.

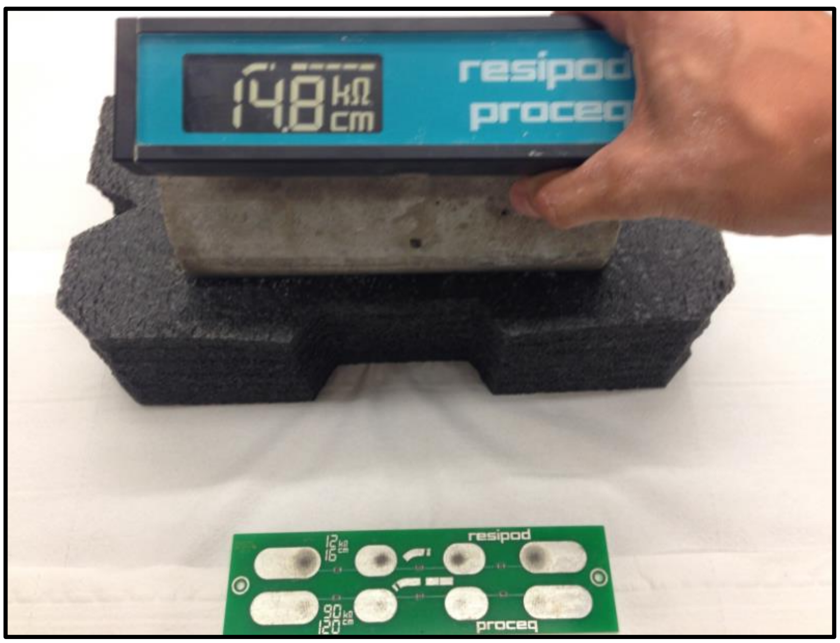


Figure 2. Surface Resistivity Testing

106.3.2.XX.4 Calculations

Record all readings in the table shown in Table 1. Calculate average resistivity for each specimen in the set. Calculate average resistivity of the entire set.

Table 1. Surface Resistivity Data Table

Surface Resistivity (SR) Readings (Kohm-cm)									
Sample	0°	90°	180°	270°	0°	90°	180°	270°	Average
A									
B									
C									
Set Average									
Curing Condition Correction (x 1.1 lime tank or 1.0 for moist room)									
Penetrability Based on Test									

If the specimens were cured in lime water tank, multiply set average by 1.1. If specimens were cured in moist room, multiply set average by 1.0.

Use Table 2 and the size of the specimens to evaluate the test results based on the resistivity. These values were developed from data on various types of concretes.

Table 2. Chloride Ion Penetrability Based

Chloride Ion Penetrability	Surface Resistivity Test	
	100-mm X 200-mm (4 in. X 8 in.) Cylinder (KOhm-cm) a=1.5	150-mm X 300-mm (6 in. X 12 in.) Cylinder (KOhm-cm) a=1.5
High	< 12.0	< 9.5
Moderate	12.0 – 21.0	9.5 - 16.5
Low	21.0 – 37.0	16.5 – 29.0
Very Low	37.0 – 254.0	29.0 – 199.0
Negligible	> 254.0	> 199.0

a = Wenner probe tip spacing

Date 8/6/2014

Missouri Department of Transportation

STRUCTURAL CONCRETE TESTS

(MoDOT EPG 106.3.2.XX and AASHTO TP 95)

Project No. TR201414

MoDOT Mix Desc. PAVING

Date Sampled 06-11-14

Date Received (Lab) 06-11-14

Purpose Code 3

1. Quality Control
2. Verification
3. Acceptance
4. Check
5. Resample
6. Source Appr.
7. Design
8. Indep. Assur
9. Preliminary Source Test

Admixture: Air Y (Y = Yes, N = No)

Remarks TERNARY MIX DESIGN USED ON HIGHWAY MADE IN LAB; 56 DAY TESTING

Item No. P: 50C-20A-30S

Cylinders Made By DPH

Acceptance Tests By DPH

Batch Number 001

Date Tested 08-06-14

Acceptance Tests

Slump, in. (AASHTO T 119) 3.75

Air Content, % (AASHTO T 152) 4.0

Sample No.	Laboratory No.	0	90	180	270	0	90	180	270	Specimen Avg
SR#1	56 DAY A	27.8	27.4	29.3	26.7	27.7	27.2	29.4	26.4	27.7
SR#2	56 DAY B	25.9	24.6	28.2	26.6	25.9	24.1	28.4	26.6	26.3
SR#3	56 DAY C	27.6	26.6	26.7	27.6	27.1	26.1	27.2	27.4	27.0

Samples Cured in Lime Water Y (Y = Yes, N = No)

Curing Condition Correction 1.1

Batch Avg 29.7

Penetrability Low

Batch Number

Date Tested

Acceptance Tests

Slump, in. (AASHTO T 119)

Air Content, % (AASHTO T 152)

Sample No.	Laboratory No.	0	90	180	270	0	90	180	270	Specimen Avg

Samples Cured in Lime Water (Y = Yes, N = No)

Note: If Yes, Curing Condition Correction = 1.1

Curing Condition Correction

Batch Avg

Penetrability

Penetrabilty Table

Penetrabilty	4 in. X 8 in. Cylinder (KOhm-cm)	6 in. X 12 in. Cylinder (KOhm-cm)
High	< 12	< 9.5
Moderate	12 - 21	9.5 - 16.5
Low	21 - 37	16.5 - 29
Very Low	37 - 254	29 - 199
Negligible	> 254	> 199

Tested By DPH

Checked By JTK

Remarks 2

Approved By District Lab Engineer

Date

Missouri Department of Transportation

STRUCTURAL CONCRETE TESTS

(MoDOT EPG 106.3.2.XX and AASHTO TP 95)

Project No. ____________ MoDOT Mix Desc. ____________

Date Sampled ____________ Date Received (Lab) ____________

Purpose Code ___

1. Quality Control
2. Verification
3. Acceptance
4. Check
5. Resample
6. Source Appr.
7. Design
8. Indep. Assur
9. Preliminary Source Test

Admixture: Air ___ Y = Yes N = No

Remarks ____________

Item No. ____________

Cylinders Made By ____________ Acceptance Tests By ____________

Batch Number ____________

Date Tested ____________

Acceptance Tests

Slump, in. (AASHTO T 119) ______ Air Content, % (AASHTO T 152) ______

Sample No.	Laboratory No.	0	90	180	270	0	90	180	270	Specimen Avg

Samples Cured in Lime Water ___ Y = Yes N = No

Curing Condition Correction ______

Batch Avg ______

Penetrability ______

Batch Number ____________

Date Tested ____________

Acceptance Tests

Slump, in. (AASHTO T 119) ______ Air Content, % (AASHTO T 152) ______

Sample No.	Laboratory No.	0	90	180	270	0	90	180	270	Specimen Avg

Samples Cured in Lime Water ___ Y = Yes N = No

Note: If Yes, Curing Condition Correction = 1.1

Curing Condition Correction ______

Batch Avg ______

Penetrability ______

Penetrabilty Table

Penetrabilty	4 in. X 8 in. Cylinder (KOhm-cm)	6 in. X 12 in. Cylinder (KOhm-cm)
High	< 12	< 9.5
Moderate	12 - 21	9.5 - 16.5
Low	21 - 37	16.5 - 29
Very Low	37 - 254	29 - 199
Negligible	> 254	> 199

Tested By ____________

Checked By ____________

Remarks 2 ____________

Approved By ____________

APPENDIX C

RESISTIVITY TESTING

Age (days)	Sample Designation	P:100C Mix Design - Surface Resistivity (SR) Readings (Kohm-cm) 0˚	90˚	180˚	270˚	0˚	90˚	180˚	270˚	Average	Std	COV(%)	Set Average	Curing Condition Correction	Chloride Ion Penetrability
7	A	10.1	9.4	9.4	9.9	10.0	9.4	9.8	9.7	9.7	0.285	2.9%	9.5	10.4	High
	B	9.3	8.3	8.9	9.7	9.2	8.5	8.9	9.5	9.0	0.481	5.3%			
	C	9.2	9.0	10.1	10.3	9.4	9.3	9.8	10.2	9.7	0.501	5.2%			
7 (Giatec)	A	9.9	9.3	10.4	10.1	9.9	9.3	10.4	10.1	9.9	0.430	4.3%	9.7	10.7	High
	B	8.9	9.6	9.1	9.6	8.9	9.6	9.1	9.5	9.3	0.318	3.4%			
	C	9.6	10.3	10.1	10.1	9.6	10.3	10.1	10.1	10.0	0.276	2.8%			
14	A	11.9	10.6	10.9	11.2	11.9	10.7	11.1	11.2	11.2	0.491	4.4%	10.7	11.7	High
	B	10.5	9.4	10.0	10.8	10.5	9.4	10.2	10.8	10.2	0.563	5.5%			
	C	10.1	10.0	10.6	11.5	10.2	10.5	10.6	11.4	10.6	0.564	5.3%			
14 (Giatec)	A	11.0	11.4	11.3	11.3	11.0	11.4	11.3	11.2	11.2	0.160	1.4%	10.8	11.8	High
	B	10.9	10.0	9.8	10.3	10.9	10.0	9.8	10.3	10.3	0.444	4.3%			
	C	10.9	11.5	10.0	10.7	10.9	11.5	10.0	10.7	10.8	0.573	5.3%			
28	A	14.0	12.7	12.9	12.7	13.9	12.7	13.0	12.7	13.1	0.552	4.2%	12.6	13.8	Moderate
	B	12.4	11.5	12.0	12.9	12.5	11.4	11.9	12.8	12.2	0.565	4.6%			
	C	12.6	11.7	12.5	13.3	12.6	11.8	12.5	13.0	12.5	0.540	4.3%			
28 (Giatec)	A	12.7	12.8	13.3	14.2	12.8	12.8	13.3	14.2	13.3	0.623	4.7%	12.8	14.1	Moderate
	B	11.9	12.2	12.1	12.6	12.0	12.2	12.1	12.6	12.2	0.259	2.1%			
	C	12.7	12.9	12.9	13.4	12.7	12.9	12.9	13.4	13.0	0.276	2.1%			
56	A	15.5	14.5	15.0	15.1	15.7	14.6	14.8	15.0	15.0	0.413	2.7%	14.5	16.0	Moderate
	B	14.5	13.1	13.9	14.9	14.4	13.1	13.8	14.8	14.1	0.707	5.0%			
	C	13.8	14.1	14.6	15.4	14.0	14.0	14.9	15.4	14.5	0.648	4.5%			
56 (Giatec)	A	15.3	15.6	15.3	14.8	15.3	15.6	15.3	14.8	15.3	0.307	2.0%	14.8	16.2	Moderate
	B	14.1	14.8	14.4	14.2	14.1	14.8	14.3	14.2	14.4	0.288	2.0%			
	C	14.4	14.8	14.6	14.8	14.4	14.8	14.6	14.9	14.7	0.192	1.3%			
90	A	15.6	14.9	15.4	15.1	16.0	15.1	15.3	14.9	15.3	0.376	2.5%	14.8	16.3	Moderate
	B	15.0	13.8	14.2	15.4	15.1	13.7	14.2	15.1	14.6	0.661	4.5%			
	C	14.1	13.9	14.9	15.8	14.5	13.8	14.8	15.5	14.7	0.731	5.0%			
90 (Giatec)	A	15.7	16.2	15.3	15.5	15.8	16.2	15.3	15.6	15.7	0.355	2.3%	15.3	16.8	Moderate
	B	15.4	15.5	14.5	14.8	15.4	15.6	14.5	14.8	15.1	0.460	3.1%			
	C	15.5	14.7	15.3	14.9	15.5	14.6	15.3	14.9	15.1	0.356	2.4%			

P: 100C in Molds (15 mins in bath)	**7**	A	9.8	9.9	10.1	10.1	10.2	10.4	10.5	10.6	10.2	0.283	2.8%	9.7	10.7	High
		B	8.7	8.8	9.2	9.3	9.3	9.4	10.0	10.2	9.4	0.521	5.6%			
		C	9.0	9.2	9.7	9.8	9.8	9.9	10.0	10.0	9.7	0.373	3.9%			
	14	A	10.2	10.2	10.3	10.3	10.7	10.7	10.8	10.9	10.5	0.290	2.8%	10.7	11.7	High
		B	10.8	10.9	11.0	11.1	11.5	11.6	11.9	11.9	11.3	0.444	3.9%			
		C	9.5	9.5	10.0	10.0	10.1	10.2	10.6	11.2	10.1	0.560	5.5%			
	28	A	12.2	12.5	12.5	12.8	12.8	13.1	13.8	14.3	13.0	0.713	5.5%	12.4	13.6	Moderate
		B	11.3	11.5	11.6	11.6	11.6	11.7	11.7	11.9	11.6	0.173	1.5%			
		C	12.1	12.1	12.6	12.6	12.7	12.8	12.8	13.0	12.6	0.327	2.6%			
	56	A	14.2	14.5	14.8	15.1	15.2	15.9	16.0	16.2	15.2	0.735	4.8%	15.1	16.6	Moderate
		B	15.1	15.2	15.3	15.5	15.6	16.0	16.2	16.2	15.6	0.444	2.8%			
		C	13.9	13.9	14.0	14.1	14.2	14.2	15.5	15.7	14.4	0.729	5.0%			
	90	A	15.1	15.1	15.9	15.7	15.1	15.1	16.1	15.8	15.5	0.429	2.8%	15.7	17.3	Moderate
		B	14.3	15.3	14.2	14.2	14.3	15.2	13.8	14.3	14.5	0.521	3.6%			
		C	16.7	18.9	17.1	15.9	16.7	18.7	16.8	16.3	17.1	1.088	6.3%			
P: 80C - 20A	**7**	A	5.4	5.9	4.6	5.7	5.5	5.8	4.6	5.8	5.4	0.528	9.7%	5.2	5.7	High
		B	4.6	5.2	5.3	5.4	4.5	5.2	5.3	5.3	5.1	0.346	6.8%			
		C	5.0	5.4	4.9	4.9	4.9	5.3	5.0	4.9	5.0	0.200	4.0%			
	14	A	6.6	7.2	5.8	7.0	6.7	7.4	5.8	7.1	6.7	0.612	9.1%	6.5	7.1	High
		B	5.7	6.7	6.5	6.6	5.9	6.5	6.7	6.6	6.4	0.382	6.0%			
		C	6.1	6.6	6.2	6.2	6.1	6.7	6.2	6.2	6.3	0.230	3.7%			
	28	A	9.3	9.8	8.0	9.3	9.4	9.9	8.0	9.4	9.1	0.737	8.1%	8.8	9.7	High
		B	7.8	9.0	8.9	8.9	8.1	9.1	9.0	8.9	8.7	0.482	5.5%			
		C	8.6	8.8	8.4	8.4	8.5	9.0	8.4	8.5	8.6	0.219	2.6%			
	56	A	12.3	12.7	11.0	12.4	12.8	13.1	10.9	12.4	12.2	0.814	6.7%	11.8	13.0	Moderate
		B	10.5	12.2	12.0	12.4	10.7	12.2	11.9	12.1	11.8	0.727	6.2%			
		C	11.4	11.7	11.8	11.5	11.2	11.7	11.4	11.4	11.5	0.203	1.8%			
	90	A	15.8	16.1	13.5	15.1	15.7	16.4	13.3	15.5	15.2	1.162	7.7%	14.8	16.3	Moderate
		B	13.3	15.5	15.2	15.2	13.3	15.2	15.1	15.2	14.8	0.902	6.1%			
		C	14.2	14.7	14.5	14.4	14.3	14.6	14.4	14.4	14.4	0.160	1.1%			

P: 50C - 20A - 30S	**7**	A	7.2	7.1	8.0	7.0	7.3	7.1	7.9	7.4	7.4	0.377	5.1%	7.2	8.0	High
		B	7.2	7.0	7.6	6.9	7.0	6.9	7.6	7.0	7.2	0.293	4.1%			
		C	7.4	6.6	7.6	7.2	7.5	6.6	7.5	7.0	7.2	0.403	5.6%			
	14	A	12.9	12.5	13.8	12.2	12.9	12.6	13.7	12.4	12.9	0.590	4.6%	12.7	13.9	Moderate
		B	12.4	11.9	13.2	12.3	12.2	12.0	13.3	12.2	12.4	0.526	4.2%			
		C	13.0	11.9	13.1	12.8	13.0	11.8	12.8	12.7	12.6	0.504	4.0%			
	28	A	21.0	20.2	21.3	19.6	20.8	20.0	22.0	19.5	20.6	0.875	4.3%	20.0	22.0	Low
		B	19.6	18.1	21.0	19.4	19.1	18.6	20.8	19.5	19.5	0.992	5.1%			
		C	20.3	19.4	20.3	20.3	20.3	18.8	20.0	20.3	20.0	0.566	2.8%			
	56	A	27.8	27.4	29.3	26.7	27.7	27.2	29.4	26.4	27.7	1.100	4.0%	27.0	29.7	Low
		B	25.9	24.6	28.2	26.6	25.9	24.1	28.4	26.6	26.3	1.523	5.8%			
		C	27.6	26.6	26.7	27.6	27.1	26.1	27.2	27.4	27.0	0.531	2.0%			
	90	A	34.9	34.5	35.5	32.8	34.3	34.7	34.6	33.0	34.3	0.928	2.7%	33.5	36.8	Low
		B	32.1	30.4	35.2	32.6	31.5	31.0	35.9	32.7	32.7	1.944	6.0%			
		C	34.1	32.7	32.6	34.5	33.6	32.7	32.5	34.7	33.4	0.914	2.7%			
B2:85C-15A	**7**	A	7.5	6.7	6.8	6.9	7.4	7.0	6.7	6.9	7.0	0.304	4.4%	7.0	7.8	High
		B	6.4	7.1	7.5	7.5	6.4	7.0	7.4	7.3	7.1	0.453	6.4%			
		C	7.3	7.0	7.2	7.0	7.4	6.6	7.1	7.0	7.1	0.243	3.4%			
	14	A	7.3	8.0	8.8	8.7	7.6	8.0	8.8	8.9	8.3	0.619	7.5%	8.2	9.0	High
		B	8.3	7.8	7.9	8.1	8.3	7.7	7.9	8.0	8.0	0.220	2.8%			
		C	8.5	8.0	8.2	8.1	8.5	8.0	8.2	8.0	8.2	0.210	2.6%			
	28	A	9.7	9.6	9.8	9.9	9.8	9.6	9.7	9.9	9.8	0.120	1.2%	9.4	10.4	High
		B	9.4	9.0	9.1	9.3	9.3	8.9	9.1	9.3	9.2	0.175	1.9%			
		C	9.6	9.1	9.2	9.4	9.5	9.1	9.2	9.7	9.4	0.233	2.5%			
	56	A	10.1	11.1	11.9	12.4	10.4	10.9	11.8	12.0	11.3	0.824	7.3%	11.4	12.5	Moderate
		B	11.8	11.6	11.0	11.5	12.1	11.3	11.1	11.2	11.5	0.374	3.3%			
		C	12.0	11.4	11.2	11.2	12.0	11.3	10.9	11.2	11.4	0.396	3.5%			
	90	A	13.7	14.7	16.0	15.6	13.5	14.4	15.6	15.9	14.9	0.991	6.6%	14.9	16.4	Moderate
		B	15.2	14.9	14.7	14.9	15.6	15.2	14.5	14.8	15.0	0.345	2.3%			
		C	15.2	13.9	14.3	15.1	15.6	14.7	14.2	14.6	14.7	0.571	3.9%			

B2L:85C-15A	**7**	A	7.3	7.1	7.2	7.2	7.3	7.1	7.0	7.3	7.2	0.113	1.6%			
		B	6.8	7.1	6.8	6.6	6.7	7.0	6.7	6.7	6.8	0.169	2.5%	6.9	7.6	High
		C	6.6	6.5	6.7	7.2	6.7	6.4	6.7	7.2	6.8	0.298	4.4%			
	14	A	8.6	8.2	8.1	8.3	8.6	8.2	8.2	8.2	8.3	0.193	2.3%			
		B	7.8	8.4	7.9	7.7	7.8	8.3	7.9	7.8	8.0	0.256	3.2%	8.1	8.9	High
		C	7.9	7.7	7.9	8.1	7.8	7.7	7.8	8.3	7.9	0.207	2.6%			
	28	A	10.3	10.0	10.1	10.0	10.5	10.0	10.0	10.2	10.1	0.185	1.8%			
		B	9.5	10.2	9.9	9.4	9.3	10.1	9.7	9.4	9.7	0.344	3.6%	9.7	10.7	High
		C	9.1	9.4	9.5	9.6	9.3	9.4	9.3	9.7	9.4	0.189	2.0%			
	56	A	14.7	13.6	13.9	13.8	14.2	13.7	13.7	13.8	13.9	0.362	2.6%			
		B	12.6	13.4	13.4	12.6	12.5	13.1	13.3	12.5	12.9	0.413	3.2%	13.3	14.6	Moderate
		C	12.8	13.0	12.9	13.4	12.9	12.8	12.9	13.3	13.0	0.227	1.7%			
	90	A	20.2	18.7	18.7	18.4	19.5	18.5	18.7	19.0	19.0	0.605	3.2%			
		B	17.1	18.5	18.1	17.3	16.8	18.4	17.8	17.1	17.6	0.650	3.7%	18.2	20.0	Moderate
		C	18.6	17.9	17.8	18.1	18.1	17.5	17.4	18.3	18.0	0.400	2.2%			
MB2:85C-15A	**7**	A	7.2	7.0	7.1	6.9	7.0	6.8	7.1	7.2	7.0	0.141	2.0%			
		B	7.4	7.9	7.5	7.2	7.2	8.2	7.6	7.3	7.5	0.354	4.7%	7.0	7.7	High
		C	7.2	6.2	6.2	6.8	6.9	6.1	6.2	6.6	6.5	0.410	6.3%			
	14	A	8.1	7.9	8.2	8.0	8.1	7.8	8.3	8.1	8.1	0.160	2.0%			
		B	8.5	9.2	8.6	8.4	8.6	9.0	8.7	8.3	8.7	0.302	3.5%	8.1	8.9	High
		C	7.8	7.2	7.3	7.8	8.0	7.4	7.1	7.8	7.6	0.338	4.5%			
	28	A	9.7	9.4	9.4	9.9	9.6	9.5	9.5	9.8	9.6	0.185	1.9%			
		B	9.9	10.7	10.0	9.6	9.8	10.8	9.9	9.8	10.1	0.441	4.4%	9.6	10.6	High
		C	9.1	9.1	8.9	9.5	9.2	9.0	9.0	9.6	9.2	0.249	2.7%			
	56	A	12.2	11.9	12.5	12.2	12.0	11.9	12.2	12.0	12.1	0.203	1.7%			
		B	12.3	13.7	12.7	12.3	12.4	13.6	12.9	12.0	12.7	0.625	4.9%	12.0	13.2	Moderate
		C	11.5	11.0	10.6	11.7	11.5	10.9	10.8	11.6	11.2	0.421	3.8%			
	90	A	15.4	14.8	15.9	15.2	15.4	15.1	16.1	14.8	15.3	0.472	3.1%			
		B	16.2	16.6	15.9	15.9	16.2	16.8	16.5	15.8	16.2	0.366	2.3%	15.2	16.7	Moderate
		C	14.0	13.9	13.3	14.3	15.0	13.9	13.4	14.9	14.1	0.622	4.4%			

S:80C-20A	**7**	A	8.3	9.3	9.2	9.7	8.4	9.4	9.3	9.6	9.2	0.521	5.7%	9.2	10.1	High
		B	9.1	8.8	9.3	8.9	9.0	8.8	9.3	8.7	9.0	0.230	2.6%			
		C	9.1	9.2	9.4	9.6	9.1	9.2	9.3	9.6	9.3	0.203	2.2%			
	14	A	10.0	11.4	11.2	11.7	10.0	11.3	11.4	11.6	11.1	0.682	6.2%	11.0	12.1	Moderate
		B	10.4	10.5	11.0	10.7	10.4	10.4	11.0	10.7	10.6	0.256	2.4%			
		C	11.1	11.0	11.3	11.4	10.8	11.1	11.1	11.6	11.2	0.249	2.2%			
	28	A	11.6	13.3	13.5	13.3	11.4	13.1	13.5	13.2	12.9	0.853	6.6%	12.9	14.2	Moderate
		B	12.5	12.5	13.3	12.6	12.6	12.5	13.5	12.5	12.8	0.407	3.2%			
		C	12.8	13.0	13.1	13.1	12.8	13.1	12.9	13.4	13.0	0.198	1.5%			
	56	A	17.0	19.2	18.4	17.9	16.2	18.6	18.6	18.3	18.0	0.975	5.4%	17.6	19.4	Moderate
		B	16.8	17.1	18.3	17.1	16.8	16.8	18.1	17.2	17.3	0.595	3.4%			
		C	17.2	17.1	18.1	18.3	17.5	17.4	17.4	18.1	17.6	0.460	2.6%			
	90	A	22.1	25.2	25.3	23.8	21.5	24.4	25.0	24.2	23.9	1.424	5.9%	23.7	26.0	Low
		B	22.0	21.7	25.2	24.2	22.8	22.4	25.2	24.1	23.5	1.404	6.0%			
		C	23.5	24.5	23.1	24.2	23.1	23.6	22.6	24.1	23.6	0.647	2.7%			
S:50C-50A	**7**	A	6.6	6.8	6.4	7.0	6.6	6.8	6.5	7.0	6.7	0.223	3.3%	6.8	7.4	High
		B	6.3	6.9	6.8	6.9	6.2	6.8	6.8	6.8	6.7	0.275	4.1%			
		C	7.5	6.2	6.8	6.9	7.8	6.2	7.0	6.9	6.9	0.557	8.1%			
	14	A	11.8	12.7	12.2	13.2	12.1	12.7	12.3	13.1	12.5	0.494	3.9%	12.5	13.7	Moderate
		B	11.6	12.3	12.5	12.6	11.6	12.0	12.2	12.6	12.2	0.410	3.4%			
		C	13.4	11.5	13.0	12.5	13.6	11.7	13.0	12.7	12.7	0.752	5.9%			
	28	A	24.9	26.2	25.9	27.2	25.6	26.4	25.8	27.8	26.2	0.918	3.5%	26.1	28.7	Low
		B	24.5	25.8	25.5	26.3	23.9	25.7	25.5	26.4	25.5	0.855	3.4%			
		C	28.7	24.9	27.1	26.2	29.3	24.6	26.3	26.6	26.7	1.647	6.2%			
	56	A	47.0	48.2	47.6	49.9	45.8	47.1	46.2	49.5	47.7	1.466	3.1%	46.1	50.7	Very Low
		B	43.6	43.4	45.5	46.3	42.6	43.8	44.6	46.2	44.5	1.376	3.1%			
		C	48.7	44.5	47.3	45.8	49.0	44.1	46.3	43.7	46.2	2.036	4.4%			
	90	A	66.1	64.7	69.3	69.6	66.8	67.9	70.9	70.6	68.2	2.233	3.3%	69.1	76.0	Very Low
		B	65.8	67.9	67.1	72.6	65.9	68.7	68.2	72.0	68.5	2.551	3.7%			
		C	74.6	67.2	71.5	69.6	73.2	69.7	67.6	70.2	70.5	2.561	3.6%			

R1:50C-50CSA	3 hour	A	25.7	26.9	25.5	27.4	25.6	27.0	25.1	27.4	26.3	0.941	3.6%	26.5	29.1	Low
		B	26.6	26.0	25.4	25.3	26.9	26.3	25.4	26.4	26.0	0.612	2.3%			
		C	26.9	26.6	27.4	27.2	27.0	26.8	27.0	27.0	27.0	0.242	0.9%			
	6 hour	A	29.4	30.7	28.7	31.0	28.8	30.4	28.6	31.4	29.9	1.130	3.8%	29.9	32.9	Low
		B	31.5	30.2	28.4	29.4	31.1	30.4	28.1	29.3	29.8	1.217	4.1%			
		C	30.1	31.1	28.7	29.6	30.7	30.8	29.7	29.4	30.0	0.815	2.7%			
	12 hour	A	29.2	29.9	28.7	30.9	29.0	30.4	29.1	30.7	29.7	0.850	2.9%	30.0	32.9	Low
		B	30.6	31.1	28.6	29.8	30.7	30.1	28.6	30.2	30.0	0.930	3.1%			
		C	30.7	30.5	29.1	29.3	31.1	31.2	29.7	29.6	30.2	0.825	2.7%			
	1	A	25.9	26.4	26.7	27.2	25.2	25.8	25.3	26.8	26.2	0.727	2.8%	26.4	29.0	Low
		B	27.4	26.7	26.0	26.5	27.5	26.7	26.0	26.4	26.7	0.563	2.1%			
		C	27.0	26.2	25.1	26.6	27.6	25.8	25.8	26.7	26.4	0.789	3.0%			
	7	A	15.3	17.1	16.1	17.5	15.8	16.6	16.1	17.2	16.5	0.765	4.6%	16.2	17.9	Moderate
		B	16.8	15.9	15.0	16.1	17.2	16.3	15.4	16.3	16.1	0.709	4.4%			
		C	16.3	16.5	15.7	16.2	17.0	15.9	15.3	16.3	16.2	0.518	3.2%			
	14	A	14.7	16.0	14.6	16.7	15.4	16.2	14.6	16.1	15.5	0.828	5.3%	15.2	16.7	Moderate
		B	15.1	14.5	13.9	14.8	15.1	14.7	13.9	15.5	14.7	0.572	3.9%			
		C	15.9	16.3	15.4	15.0	15.5	15.4	15.2	14.9	15.5	0.463	3.0%			
	28	A	16.1	16.5	15.2	17.4	15.9	15.8	15.1	17.0	16.1	0.810	5.0%	15.7	17.3	Moderate
		B	17.3	17.1	15.3	15.4	17.4	16.9	15.0	15.3	16.2	1.045	6.4%			
		C	14.8	14.6	14.6	15.2	14.8	14.4	14.8	14.7	14.7	0.233	1.6%			
	56	A	28.9	28.7	28.3	30.1	28.4	27.9	28.3	29.9	28.8	0.792	2.7%	29.3	32.2	Low
		B	32.2	30.5	27.3	29.0	32.0	29.7	26.5	28.9	29.5	2.036	6.9%			
		C	31.1	27.9	29.4	29.8	31.5	29.2	28.0	28.6	29.4	1.328	4.5%			
	90	A	33.8	34.4	34.1	34.9	32.6	32.0	33.3	34.9	33.8	1.054	3.1%	33.8	37.2	Very Low
		B	33.5	33.5	30.6	31.6	36.2	35.5	33.2	29.9	33.0	2.216	6.7%			
		C	35.8	33.2	34.3	37.6	32.1	33.4	33.1	37.2	34.6	2.042	5.9%			

R2:100C	3 hour	A	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	0.035	3.5%			
		B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.000	0.0%	1.0	1.1	High
		C	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.000	0.0%			
	6 hour	A	1.6	1.4	1.5	1.6	1.5	1.5	1.5	1.5	1.5	0.064	4.2%			
		B	1.6	1.5	1.6	1.5	1.6	1.5	1.5	1.4	1.5	0.071	4.6%	1.5	1.7	High
		C	1.4	1.4	1.6	1.5	1.5	1.4	1.6	1.5	1.5	0.083	5.6%			
	12 hour	A	3.0	2.8	2.7	3.0	3.0	2.7	2.7	3.0	2.9	0.151	5.3%			
		B	2.9	2.7	2.8	2.7	2.9	2.7	2.8	2.7	2.8	0.089	3.2%	2.8	3.1	High
		C	2.8	2.6	3.0	2.9	2.8	2.7	3.0	2.8	2.8	0.139	4.9%			
	1	A	5.1	4.8	4.9	5.2	5.2	4.8	4.9	5.3	5.0	0.198	3.9%			
		B	5.2	5.1	4.9	4.8	5.2	4.9	5.0	4.7	5.0	0.183	3.7%	5.0	5.5	High
		C	4.9	4.8	5.3	4.9	4.9	4.7	5.3	5.0	5.0	0.219	4.4%			
	7	A	8.2	7.6	7.8	8.2	8.2	7.5	7.6	8.2	7.9	0.318	4.0%			
		B	8.3	8.0	7.8	7.5	8.3	8.0	7.9	7.5	7.9	0.309	3.9%	7.9	8.7	High
		C	7.8	7.5	8.2	7.7	7.8	7.4	8.3	7.7	7.8	0.312	4.0%			
	14	A	9.3	8.6	9.1	9.4	9.5	8.7	9.1	9.4	9.1	0.334	3.7%			
		B	9.4	9.0	8.9	8.6	9.5	9.0	9.0	8.5	9.0	0.344	3.8%	9.0	9.9	High
		C	8.7	8.6	9.4	8.8	8.5	8.6	9.2	8.7	8.8	0.318	3.6%			
	28	A	10.9	9.7	10.3	10.8	11.0	9.7	10.0	10.7	10.4	0.536	5.2%			
		B	11.1	10.7	10.5	9.9	11.2	10.9	10.2	9.9	10.6	0.513	4.9%	10.3	11.4	High
		C	9.6	9.8	10.6	10.0	9.9	9.8	10.6	9.9	10.0	0.373	3.7%			
	56	A	13.7	12.4	13.1	13.6	13.7	12.2	13.1	13.6	13.2	0.595	4.5%			
		B	13.9	13.5	13.0	12.5	13.9	13.4	13.1	12.5	13.2	0.552	4.2%	13.1	14.4	Moderate
		C	12.6	12.5	13.5	12.8	12.7	12.7	13.4	12.7	12.9	0.374	2.9%			
	90	A	14.5	15.1	14.8	14.4	14.6	14.9	14.5	14.7	14.7	0.236	1.6%			
		B	16.2	15.4	14.7	14.0	16.0	15.3	14.7	14.2	15.1	0.800	5.3%	14.8	16.3	Moderate
		C	14.7	14.7	13.9	15.1	14.8	14.5	13.9	15.2	14.6	0.487	3.3%			

I-70 and Manchester - 7 day testing	**Dirk**	**Proceq 1**	A	4.9	4.9	4.8	5.2	4.8	4.9	4.9	5.1	4.9	0.141	2.9%	5.2	5.7	High
			B	5.2	5.2	4.8	5.3	5.0	5.2	4.9	5.3	5.1	0.189	3.7%			
			C	5.1	5.3	5.4	5.2	5.0	5.2	5.3	4.9	5.2	0.167	3.2%			
			D	5.0	5.1	4.9	4.8	4.9	5.0	4.8	4.8	4.9	0.113	2.3%			
			E	6.2	6.0	5.3	5.1	6.1	5.7	5.2	5.1	5.6	0.467	8.4%			
			F	6.0	5.7	5.3	5.5	5.8	5.7	5.1	5.6	5.6	0.285	5.1%			
		Proceq 2	A	4.7	4.9	4.8	5.2	4.9	5.0	4.8	5.2	4.9	0.185	3.7%	5.2	5.8	High
			B	5.1	5.4	4.9	5.4	5.0	5.2	4.9	5.4	5.2	0.220	4.3%			
			C	5.0	5.2	5.4	5.1	5.1	5.2	5.2	5.2	5.2	0.116	2.3%			
			D	4.9	5.1	4.9	4.7	4.9	5.0	4.9	4.8	4.9	0.120	2.4%			
			E	6.1	5.8	5.3	5.1	6.2	5.8	5.2	5.1	5.6	0.453	8.1%			
			F	5.8	5.7	5.4	5.6	5.8	5.8	5.3	5.6	5.6	0.191	3.4%			
	Reece	**Proceq 1**	A	5.0	5.0	5.0	5.2	4.9	5.0	4.9	5.1	5.0	0.099	2.0%	5.3	5.8	High
			B	5.1	5.3	4.9	5.3	5.1	5.3	4.8	5.4	5.2	0.214	4.2%			
			C	5.1	5.3	5.4	5.2	5.0	5.2	5.4	5.2	5.2	0.139	2.7%			
			D	5.1	5.2	4.9	5.0	4.8	5.1	4.9	4.7	5.0	0.169	3.4%			
			E	6.2	6.0	5.3	5.1	6.2	5.9	5.2	5.1	5.6	0.495	8.8%			
			F	5.8	5.8	5.4	5.4	5.9	5.8	5.3	5.4	5.6	0.245	4.4%			
		Proceq 2	A	4.8	4.9	5.0	5.2	4.9	5.0	4.9	5.1	5.0	0.128	2.6%	5.3	5.8	High
			B	5.3	5.2	5.3	4.9	5.3	5.0	5.3	4.9	5.2	0.185	3.6%			
			C	5.2	5.3	5.5	5.3	5.3	5.3	5.4	5.1	5.3	0.120	2.3%			
			D	4.9	5.2	5.2	4.8	4.8	5.2	5.1	4.8	5.0	0.193	3.9%			
			E	6.1	5.8	5.4	5.2	6.2	5.9	5.3	5.2	5.6	0.410	7.3%			
			F	5.8	5.8	5.3	5.7	5.8	5.9	5.4	5.6	5.7	0.213	3.8%			
	Mark	**Proceq 1**	A	4.9	4.9	4.9	5.1	4.8	5.0	4.9	5.1	5.0	0.107	2.2%	5.1	5.6	High
			B	5.1	5.3	4.9	5.2	5.1	5.3	4.9	5.3	5.1	0.169	3.3%			
			C	5.2	5.2	5.4	5.1	5.2	5.2	5.5	5.0	5.2	0.158	3.0%			
			D	5.3	5.0	4.8	4.8	5.0	5.0	4.8	4.8	5.0	0.093	1.9%			
			E	6.1	5.6	5.2	5.1	5.8	5.9	5.3	5.1	5.1	0.136	2.7%			
			F	6.0	5.5	5.1	5.4	6.0	5.7	5.1	5.6	5.2	0.155	3.0%			
		Proceq 2	A	4.9	5.0	5.0	4.9	4.8	5.1	4.9	5.0	4.9	0.177	3.6%	5.4	5.9	High
			B	5.2	5.1	5.2	4.9	5.2	5.0	5.2	4.9	5.5	0.391	7.1%			
			C	5.2	5.3	5.5	5.0	5.2	5.1	5.3	5.1	5.6	0.351	6.3%			
			D	5.4	5.3	4.7	4.8	5.1	5.2	4.7	4.6	5.0	0.311	6.2%			
			E	6.1	5.9	5.2	5.1	6.1	5.9	5.3	5.2	5.6	0.438	7.8%			
			F	6.0	5.8	5.2	5.3	5.8	5.7	5.3	5.4	5.6	0.297	5.3%			

I-70 and Manchester - 28 day testing	**Dirk**	**Proceq 1**	A	7.6	7.6	7.3	7.3	7.4	7.4	7.4	7.3	7.4	0.125	1.7%	7.7	8.5	High
			B	9.0	8.4	7.7	7.6	8.9	8.3	7.7	7.6	8.2	0.583	7.2%			
			C	8.5	8.5	7.8	8.2	8.5	8.4	7.6	8.2	8.2	0.344	4.2%			
			D	7.3	7.4	7.3	7.6	7.2	7.4	7.1	7.4	7.3	0.151	2.1%			
			E	7.8	7.9	7.3	7.8	7.5	7.7	7.2	7.8	7.6	0.260	3.4%			
			F	7.3	7.6	7.8	7.5	7.7	7.7	7.8	7.6	7.6	0.167	2.2%			
		Proceq 2	A	7.3	7.4	7.4	7.3	7.3	7.5	7.5	7.2	7.4	0.106	1.4%	7.7	8.5	High
			B	9.0	8.5	7.7	7.7	8.9	8.5	7.8	7.5	8.2	0.593	7.2%			
			C	8.4	8.3	7.6	8.2	8.6	8.3	7.7	8.3	8.2	0.345	4.2%			
			D	7.3	7.4	7.2	7.6	7.2	7.5	7.1	7.5	7.4	0.177	2.4%			
			E	7.5	7.7	7.3	7.8	7.4	7.9	7.4	7.7	7.6	0.217	2.9%			
			F	7.4	7.7	7.9	7.5	7.4	7.6	7.6	7.6	7.6	0.164	2.2%			
	Mark	**Proceq 1**	A	7.8	7.7	7.3	7.0	7.6	7.6	7.2	7.2	7.4	0.287	3.9%	7.7	8.5	High
			B	8.8	8.0	7.6	8.4	8.8	7.7	7.6	8.3	8.2	0.501	6.2%			
			C	8.6	8.5	8.0	8.1	8.7	8.3	7.8	7.8	8.2	0.354	4.3%			
			D	7.2	7.4	7.2	7.4	7.2	7.4	7.3	7.6	7.3	0.141	1.9%			
			E	7.4	7.7	7.3	7.9	7.6	7.7	7.3	7.8	7.6	0.230	3.0%			
			F	7.7	7.7	8.1	7.6	7.4	7.7	8.1	7.7	7.8	0.239	3.1%			
		Proceq 2	A	7.8	7.8	7.3	7.4	7.4	7.8	7.3	7.2	7.5	0.256	3.4%	7.8	8.6	High
			B	9.0	7.5	7.8	8.4	8.9	7.5	7.7	8.4	8.2	0.607	7.4%			
			C	8.7	8.5	7.9	7.6	8.9	8.6	8.1	7.9	8.3	0.462	5.6%			
			D	7.2	7.4	7.2	7.6	7.0	7.4	7.5	7.5	7.4	0.200	2.7%			
			E	7.6	8.0	7.4	7.9	7.6	7.8	7.3	7.8	7.7	0.243	3.2%			
			F	7.6	7.8	7.6	7.7	7.7	7.7	8.1	7.6	7.7	0.167	2.2%			

I-70 and Manchester - 90 day testing	**Dirk**	**Proceq 1**	A	12.0	12.1	12.5	11.6	11.6	12.3	11.9	11.6	12.0	0.34226	2.9%	11.9	13.1	Moderate
			B	13.6	12.7	12.2	13.3	13.0	12.5	12.1	13.2	12.8	0.53918	4.2%			
			C	13.4	12.9	11.8	11.7	13.2	12.7	11.6	11.6	12.4	0.7652	6.2%			
			D	11.3	11.5	11.5	11.5	11.0	11.6	11.5	11.4	11.4	0.18851	1.7%			
			E	11.5	11.6	10.9	11.1	11.2	11.1	10.9	11.2	11.2	0.25319	2.3%			
			F	11.6	12.0	11.2	12.3	11.6	11.8	11.4	12.2	11.8	0.38522	3.3%			
		Proceq 2	A	11.5	12.0	12.2	11.6	11.6	12.0	11.5	12.0	11.8	0.27775	2.4%	11.9	13.1	Moderate
			B	13.1	12.5	11.8	13.1	12.9	12.4	12.1	13.0	12.6	0.49117	3.9%			
			C	13.5	13.1	11.6	11.5	13.3	13.2	11.8	11.7	12.5	0.87983	7.1%			
			D	11.3	12.3	11.5	11.6	11.1	11.7	11.4	11.5	11.6	0.35456	3.1%			
			E	11.3	11.6	10.8	11.3	11.0	11.5	11.1	11.3	11.2	0.26152	2.3%			
			F	11.6	11.9	11.3	12.3	11.7	11.9	11.2	12.2	11.8	0.39256	3.3%			

Route 41 and Lamine River- 7 day testing	**Dirk**	**Proceq 1**	A	5.4	5.1	5.3	5.5	5.3	4.9	5.2	5.5	5.3	0.203	3.8%	5.2	5.7	High
			B	5.2	5.1	5.2	5.2	5.1	5.1	5.2	5.0	5.1	0.074	1.4%			
			C	5.3	5.1	5.0	5.1	5.2	4.8	5.0	5.0	5.1	0.151	3.0%			
			D	5.3	5.4	5.3	5.5	5.3	5.3	5.3	5.4	5.4	0.076	1.4%			
			E	5.3	5.1	4.9	5.1	5.3	5.1	5.0	5.1	5.1	0.136	2.7%			
			F	5.1	5.4	5.4	5.3	5.0	5.2	5.3	5.3	5.3	0.141	2.7%			
		Proceq 2	A	5.3	5.0	5.3	5.3	5.3	5.0	5.3	5.6	5.3	0.192	3.7%	5.2	5.7	High
			B	5.2	5.1	5.3	5.1	5.2	5.1	5.3	5.1	5.2	0.089	1.7%			
			C	5.3	5.1	5.0	5.1	5.3	5.0	5.0	5.1	5.1	0.125	2.4%			
			D	5.3	5.2	5.4	5.4	5.3	5.2	5.4	5.4	5.3	0.089	1.7%			
			E	5.3	5.2	4.9	5.1	5.5	5.1	5.0	5.1	5.2	0.185	3.6%			
			F	5.0	5.2	5.3	5.2	5.0	5.3	5.4	5.7	5.3	0.226	4.3%			
	Mark	**Proceq 1**	A	5.9	5.8	4.9	5.2	5.9	5.6	5.0	5.2	5.4	0.410	7.5%	5.2	5.7	High
			B	5.1	5.1	5.1	5.1	5.0	5.0	5.2	5.1	5.1	0.064	1.3%			
			C	5.1	5.2	4.9	4.9	5.1	5.2	4.9	4.9	5.0	0.139	2.8%			
			D	5.4	5.3	5.2	5.3	5.4	5.3	5.2	5.3	5.3	0.076	1.4%			
			E	5.0	5.3	5.1	4.9	5.0	5.2	5.0	4.9	5.1	0.141	2.8%			
			F	5.0	5.2	5.3	5.4	5.0	5.3	5.3	5.3	5.2	0.149	2.8%			
		Proceq 2	A	5.6	5.1	5.3	6.0	5.4	4.9	5.1	5.9	5.4	0.394	7.3%	5.2	5.7	High
			B	4.9	5.2	5.4	5.0	5.1	5.2	5.1	5.0	5.1	0.155	3.0%			
			C	5.3	5.0	5.0	5.1	5.2	5.0	4.9	5.0	5.1	0.130	2.6%			
			D	5.2	5.2	5.4	5.4	5.4	5.3	5.3	5.7	5.4	0.160	3.0%			
			E	5.3	5.1	5.0	4.9	5.3	5.2	5.0	5.0	5.1	0.151	3.0%			
			F	4.9	5.3	5.6	5.1	5.3	5.4	5.3	5.0	5.2	0.226	4.3%			

Route 41 and Lamine River - 28 day testing	Dirk	Proceq 1	A	9.7	9.3	9.4	9.3	9.7	9.0	9.4	9.3	9.4	0.230	2.4%	9.5	10.5	High
			B	9.3	9.4	9.7	9.6	9.4	9.3	9.7	9.8	9.5	0.198	2.1%			
			C	9.6	9.5	9.7	9.2	9.4	9.4	9.5	9.3	9.5	0.160	1.7%			
			D	9.7	9.9	9.8	10.3	9.5	9.6	9.9	9.7	9.8	0.245	2.5%			
			E	9.8	9.0	9.6	9.6	9.7	9.1	9.6	9.6	9.5	0.288	3.0%			
			F	9.8	9.4	9.4	9.4	9.7	9.3	9.3	9.4	9.5	0.185	2.0%			
		Proceq 2	A	9.7	8.9	9.4	9.4	9.7	9.0	9.4	9.2	9.3	0.292	3.1%	9.5	10.5	High
			B	9.3	9.5	9.7	10.0	9.1	9.3	9.8	9.8	9.6	0.311	3.3%			
			C	9.2	9.3	9.6	9.6	9.3	9.3	9.4	9.2	9.4	0.160	1.7%			
			D	9.6	9.8	9.8	9.9	9.8	9.8	9.9	9.9	9.8	0.099	1.0%			
			E	9.8	9.0	9.7	10.3	9.8	9.0	9.5	10.4	9.7	0.519	5.4%			
			F	9.8	9.3	9.4	9.6	9.7	9.3	9.3	9.2	9.5	0.220	2.3%			
	Claire	Proceq 1	A	9.7	9.0	9.4	9.0	9.5	9.1	9.4	9.1	9.3	0.260	2.8%	9.6	10.6	High
			B	9.2	10.3	9.5	9.6	9.3	10.2	9.8	9.5	9.7	0.399	4.1%			
			C	9.2	9.2	9.7	9.5	9.4	9.6	9.5	9.3	9.4	0.183	1.9%			
			D	10.0	10.2	10.1	9.8	9.8	10.4	9.7	9.9	10.0	0.236	2.4%			
			E	10.4	9.6	9.0	9.9	10.2	9.6	9.4	10.0	9.8	0.453	4.6%			
			F	10.0	9.6	9.3	9.3	9.8	9.5	9.3	9.4	9.5	0.260	2.7%			
		Proceq 2	A	9.8	9.5	9.5	9.1	9.7	9.3	9.5	9.2	9.5	0.239	2.5%	9.6	10.6	High
			B	9.7	9.3	10.1	9.5	9.7	9.4	10.3	9.6	9.7	0.342	3.5%			
			C	9.4	9.2	9.7	9.7	9.4	9.6	9.2	9.6	9.5	0.205	2.2%			
			D	9.9	10.4	9.7	10.0	9.8	10.4	9.6	9.8	10.0	0.302	3.0%			
			E	9.8	10.3	9.8	9.2	9.8	10.4	9.8	9.0	9.8	0.478	4.9%			
			F	9.8	9.5	9.3	9.3	9.8	9.6	9.4	9.3	9.5	0.214	2.3%			

Route 41 - 90 day testing	**Dirk**	**Proceq 1**	A	17.4	15.1	16.9	15.9	17.1	15.2	17.1	16.0	16.3	0.905	5.5%	16.5	18.2	Moderate
			B	16.5	16.4	16.5	16.1	16.1	16.3	16.6	16.3	16.4	0.185	1.1%			
			C	17.4	15.6	16.9	17.0	16.9	15.3	16.5	17.0	16.6	0.740	4.5%			
			D	16.6	16.9	17.0	17.6	16.7	16.2	17.0	17.3	16.9	0.429	2.5%			
			E	16.3	16.4	17.2	16.6	16.0	16.2	16.7	16.8	16.5	0.381	2.3%			
			F	16.2	16.1	16.5	16.5	16.5	16.0	16.4	16.7	16.4	0.239	1.5%			
		Proceq 2	A	16.7	15.5	17.1	15.7	17.1	15.2	16.9	16.2	16.3	0.758	4.6%	16.6	18.2	Moderate
			B	16.4	16.5	17.2	16.0	16.4	16.7	17.1	16.3	16.6	0.406	2.5%			
			C	17.2	15.3	16.7	17.2	16.8	15.5	16.4	17.7	16.6	0.838	5.1%			
			D	16.8	17.0	17.6	18.0	16.6	16.8	17.2	17.9	17.2	0.534	3.1%			
			E	16.0	15.8	16.4	17.3	16.6	16.0	16.8	17.0	16.5	0.533	3.2%			
			F	16.0	15.8	16.3	16.7	15.9	15.6	16.2	16.9	16.2	0.446	2.8%			

Highway 364 in STL - 7 day testing	**Dirk**	**Proceq 1**	A	6.2	6.2	6.1	6.4	6.4	6.1	6.1	6.2	6.2	0.125	2.0%	6.3	7.0	High
			B	5.8	6.0	6.0	6.3	5.9	6.1	6.3	6.2	6.1	0.183	3.0%			
			C	5.9	5.8	6.4	6.3	5.9	5.9	6.3	6.2	6.1	0.236	3.9%			
			D	6.4	6.7	6.3	6.6	6.2	6.6	6.3	6.8	6.5	0.217	3.3%			
			E	6.4	6.5	6.9	6.1	6.4	6.4	6.8	6.1	6.5	0.288	4.5%			
			F	6.8	6.9	6.6	6.4	6.8	6.7	6.4	6.2	6.6	0.245	3.7%			
		Proceq 2	A	6.2	6.2	6.1	6.3	6.4	6.2	6.2	6.4	6.3	0.107	1.7%	6.3	6.9	High
			B	5.9	5.9	6.3	6.2	5.9	6.0	6.3	6.3	6.1	0.193	3.2%			
			C	6.0	5.7	6.2	6.3	5.9	5.8	6.3	6.4	6.1	0.260	4.3%			
			D	6.4	6.7	6.3	6.6	6.4	6.8	6.3	6.7	6.5	0.198	3.0%			
			E	6.3	6.5	6.8	6.2	6.2	6.4	6.8	6.2	6.4	0.255	4.0%			
			F	6.7	6.6	6.3	6.0	6.6	6.7	6.3	6.1	6.4	0.275	4.3%			
	Mark	**Proceq 1**	A	6.6	6.3	6.2	6.0	6.3	6.3	6.3	6.2	6.3	0.167	2.7%	6.3	6.9	High
			B	5.9	5.9	6.0	6.3	6.0	6.1	6.2	6.3	6.1	0.164	2.7%			
			C	5.9	5.9	6.2	6.2	5.8	5.7	6.2	6.2	6.0	0.210	3.5%			
			D	6.9	6.4	6.5	6.3	7.0	6.3	6.5	6.6	6.6	0.262	4.0%			
			E	6.2	6.3	6.5	6.2	6.2	6.3	6.7	6.2	6.3	0.183	2.9%			
			F	6.7	6.6	6.3	6.1	6.7	6.6	6.4	6.2	6.5	0.233	3.6%			
		Proceq 2	A	6.3	6.2	6.3	6.4	6.5	6.2	6.1	6.3	6.3	0.125	2.0%	6.3	7.0	High
			B	5.9	6.0	6.0	6.3	6.0	6.0	6.0	6.3	6.1	0.151	2.5%			
			C	6.0	6.0	6.0	6.3	6.0	6.0	6.3	6.2	6.1	0.141	2.3%			
			D	6.5	6.7	6.3	6.8	6.3	6.5	6.3	6.9	6.5	0.239	3.7%			
			E	6.4	6.4	6.7	6.3	6.3	6.6	6.6	6.4	6.5	0.151	2.3%			
			F	6.7	6.6	6.6	6.2	6.7	6.7	6.5	6.1	6.5	0.236	3.6%			

Highway 364 in STL - 28 day testing	**Dirk**	**Proceq 1**	A	10.5	10.3	10.6	11.1	10.3	10.4	10.6	11.1	10.6	0.323	3.0%	10.8	11.9	High
			B	11.3	11.6	11.1	10.5	11.2	11.8	11.0	10.5	11.1	0.465	4.2%			
			C	10.4	10.6	10.5	10.7	10.6	10.6	10.4	10.7	10.6	0.119	1.1%			
			D	10.1	10.1	10.2	10.4	10.1	10.0	10.0	10.6	10.2	0.210	2.1%			
			E	11.1	11.4	11.3	11.9	10.8	11.2	11.3	11.8	11.4	0.359	3.2%			
			F	10.6	10.7	11.4	10.6	10.8	11.1	11.1	10.6	10.9	0.302	2.8%			
		Proceq 2	A	10.4	10.3	10.6	11.2	10.4	10.4	10.7	11.2	10.7	0.363	3.4%	10.8	11.9	High
			B	11.4	11.5	11.1	10.8	11.6	11.6	10.8	10.7	11.2	0.383	3.4%			
			C	10.4	10.7	10.3	10.6	10.6	10.6	10.4	10.7	10.5	0.151	1.4%			
			D	10.1	10.1	10.3	10.4	10.0	10.1	10.3	10.2	10.2	0.136	1.3%			
			E	10.9	11.5	11.2	11.8	10.7	11.5	11.0	12.1	11.3	0.475	4.2%			
			F	10.6	11.2	11.3	10.4	10.3	11.2	11.5	10.6	10.9	0.461	4.2%			
	Mark	**Proceq 1**	A	10.4	10.2	10.8	11.2	10.5	10.1	10.7	11.2	10.6	0.417	3.9%	10.8	11.9	High
			B	11.7	11.5	11.0	10.3	11.5	11.4	10.8	10.6	11.1	0.501	4.5%			
			C	10.7	10.5	10.7	10.7	10.4	10.5	10.3	10.6	10.6	0.151	1.4%			
			D	10.5	10.4	10.3	10.3	10.6	10.2	10.3	10.1	10.3	0.160	1.5%			
			E	11.1	11.4	11.3	12.0	11.2	11.5	11.0	11.7	11.4	0.330	2.9%			
			F	10.6	11.4	11.5	10.3	10.5	11.1	11.2	10.6	10.9	0.454	4.2%			
		Proceq 2	A	11.3	10.4	10.3	10.2	11.3	10.7	10.4	11.1	10.7	0.458	4.3%	10.9	12.0	High
			B	11.8	11.4	11.1	10.8	11.8	11.7	11.1	10,7	11.4	0.398	3.5%			
			C	11.1	10.6	10.7	10.4	10.7	10.6	10.6	10.4	10.6	0.220	2.1%			
			D	10.3	10.6	10.4	10.2	10.3	10.6	10.1	10.2	10.3	0.185	1.8%			
			E	11.9	11.0	11.5	11.1	11.9	10.8	11.4	10.8	11.3	0.447	4.0%			
			F	10.6	11.4	11.2	11.8	10.7	11.4	11.5	10.5	11.1	0.478	4.3%			

Highway 364 in STL - 90 day testing	**Dirk**	**Proceq 1**	A	17.6	17.8	17.9	17.9	17.6	18.1	17.4	17.5	17.7	0.238	1.3%	18.0	19.7	Moderate
			B	17.8	17.4	17.8	17	19	17.5	17.8	17.5	17.7	0.582	3.3%			
			C	16.5	17.2	17.6	16.8	16.8	16.8	16.8	16	16.8	0.467	2.8%			
			D	19	18.7	18	17.9	17.1	17.6	17.2	18.6	18.0	0.704	3.9%			
			E	18.2	19.3	20.3	18.7	19.2	18.4	17.9	19.6	19.0	0.798	4.2%			
			F	17.8	18	19	18.4	18	18.6	19.8	18.2	18.5	0.658	3.6%			
		Proceq 2	A	18.1	18	17.4	17.3	17.9	17.4	17.3	17.5	17.6	0.331	1.9%	18.1	19.9	Moderate
			B	17.2	17.7	16.8	18.5	17.6	17.6	17.5	17.6	17.6	0.481	2.7%			
			C	17.6	17.3	16.6	16.9	17.4	17.2	16.1	17.5	17.1	0.512	3.0%			
			D	19.6	17.6	17.6	18.8	19	18.8	18.8	18.2	18.6	0.699	3.8%			
			E	19.6	19.6	18	18.5	19	19.1	19.5	18.8	19.0	0.569	3.0%			
			F	18.8	18.8	20.3	18.8	17	18.1	18.5	18.5	18.6	0.913	4.9%			

MoDOT Data: I-70 and Manchester – 7 day testing

Tech.	LG	tech.	SB	tech.	ZH
meter	A	meter	A	meter	A
1	5.3	1	4.9	1	5.0
2	4.9	2	4.9	2	5.1
3	5.4	3	5.1	3	5.3
4	5.3	4	5.2	4	4.9
5	5.1	5	4.9	5	4.9
6	5.1	6	4.9	6	5.3
7	5.6	7	5.1	7	5.6
8	5.2	8	5.2	8	4.9
avg.	**5.2**	**avg.**	**5.0**	**avg.**	**5.1**
Tech.	LG	tech.	SB	tech.	ZH
meter	A	meter	A	meter	A
1	4.9	1	4.9	1	5.1
2	4.9	2	4.8	2	4.9
3	5.2	3	5.2	3	5.3
4	4.9	4	5.0	4	5.0
5	4.9	5	4.9	5	5.0
6	4.8	6	4.8	6	4.9
7	5.3	7	5.3	7	5.2
8	4.8	8	5.0	8	5.0
avg.	**5.0**	**avg.**	**5.0**	**avg.**	**5.1**
Tech.	LG	tech.	SB	tech.	ZH
meter	A	meter	A	meter	A
1	5.8	1	5.3	1	5.4
2	5.1	2	5.1	2	5.3
3	5.2	3	5.0	3	5.0
4	4.6	4	4.6	4	4.7
5	5.3	5	5.3	5	5.4
6	5.2	6	5.2	6	4.8
7	5.0	7	5.0	7	5.1
8	4.7	8	4.6	8	4.7
avg.	**5.1**	**avg.**	**5.0**	**avg.**	**5.1**

MoDOT Data: I-70 and Manchester –28 day testing

Tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Zach	tech.	Zach
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	7.7	1	7.6	1	7.8	1	8.3	1	8	1	7.8
2	7.4	2	7.5	2	7.6	2	7.9	2	7.6	2	7.7
3	7.8	3	7.8	3	7.6	3	7.7	3	8.4	3	8.3
4	7.2	4	7.4	4	8.4	4	7.6	4	7.6	4	7.6
5	7.5	5	7.7	5	7.7	5	8.5	5	7.8	5	7.8
6	7.5	6	7.3	6	7.8	6	7.8	6	7.6	6	7.4
7	7.8	7	7.8	7	7.5	7	7.8	7	8.3	7	8.4
8	7.3	8	7.1	8	8.5	8	7.5	8	7.8	8	7.7
avg.	**7.5**	**avg.**	**7.5**	**avg.**	**7.9**	**avg.**	**7.9**	**avg.**	**7.9**	**avg.**	**7.8**

Tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Zach	tech.	Zach
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	7.3	1	7.4	1	7.7	1	7.3	1	7.5	1	7.7
2	7.2	2	7	2	7.6	2	7.7	2	7.4	2	7.2
3	6.7	3	6.7	3	7	3	7.2	3	7.1	3	7
4	7.3	4	7	4	7.3	4	7	4	7.3	4	7.4
5	7	5	7.4	5	7.7	5	7.3	5	7.5	5	7.4
6	7.3	6	7	6	7.5	6	7.7	6	7.1	6	7.2
7	7	7	7	7	7.1	7	7.2	7	7	7	7.1
8	7.3	8	7.2	8	7.3	8	7.1	8	7.3	8	7.3
avg.	**7.1**	**avg.**	**7.1**	**avg.**	**7.4**	**avg.**	**7.3**	**avg.**	**7.3**	**avg.**	**7.3**

Tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Zach	tech.	Zach
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	7.8	1	7.7	1	8	1	8.4	1	7.7	1	7.8
2	8.5	2	8.6	2	7.6	2	8	2	8	2	7.5
3	8.1	3	8.1	3	7.5	3	7.7	3	8.6	3	8.7
4	7.6	4	7.8	4	8.1	4	7.6	4	8.3	4	8.2
5	7.5	5	7.7	5	7.9	5	8.5	5	7.8	5	7.7
6	8.6	6	8.7	6	7.7	6	8	6	7.8	6	7.7
7	8.1	7	8.1	7	7.6	7	7.7	7	8.7	7	8.5
8	7.6	8	7.8	8	8.5	8	7.5	8	8.3	8	8.2
avg.	**8.0**	**avg.**	**8.1**	**avg.**	**7.9**	**avg.**	**7.9**	**avg.**	**8.2**	**avg.**	**8.0**

MoDOT Data: I-70 and Manchester – 90 day testing

Tech.	SB	tech.	SB	tech.	BS	tech.	BS	tech.	JV	tech.	JV
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	14.2	1	14.2	1	14.4	1	14.2	1	13.9	1	14.3
2	12.5	2	12.7	2	14.8	2	14.9	2	12.9	2	13.0
3	14.2	3	14.3	3	14.6	3	14.3	3	14.3	3	14.8
4	14.4	4	14.4	4	13.1	4	13.0	4	14.7	4	14.9
5	14.0	5	14.2	5	14.6	5	14.6	5	14.3	5	14.3
6	12.5	6	12.8	6	14.7	6	15.0	6	12.8	6	12.7
7	14.3	7	13.9	7	14.7	7	14.3	7	14.3	7	14.7
8	14.4	8	14.6	8	13.3	8	12.9	8	14.6	8	14.8
avg.	**13.8**	**avg.**	**13.9**	**avg.**	**14.3**	**avg.**	**14.2**	**avg.**	**14.0**	**avg.**	**14.2**
Tech.	SB	tech.	SB	tech.	BS	tech.	BS	tech.	JV	tech.	JV
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	14.2	1	13.4	1	13.6	1	13.7	1	14.3	1	14.5
2	13.6	2	14.1	2	14.4	2	14.1	2	13.3	2	14.1
3	13.6	3	14.2	3	13.8	3	14.1	3	13.9	3	13.5
4	13.9	4	13.9	4	13.7	4	14.1	4	14.2	4	13.0
5	13.9	5	13.8	5	13.8	5	13.8	5	14.4	5	14.7
6	14.0	6	14.3	6	14.4	6	14.3	6	14.3	6	14.1
7	13.7	7	14.3	7	13.7	7	13.8	7	13.9	7	13.7
8	13.7	8	14.0	8	14.2	8	13.8	8	14.0	8	13.5
avg.	**13.8**	**avg.**	**14.0**	**avg.**	**14.0**	**avg.**	**14.0**	**avg.**	**14.0**	**avg.**	**13.9**
Tech.	SB	tech.	SB	tech.	BS	tech.	BS	tech.	JV	tech.	JV
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	13.2	1	13.2	1	12.9	1	13.5	1	13.1	1	13.1
2	13.8	2	13.3	2	13.0	2	13.2	2	12.7	2	13.8
3	13.8	3	13.3	3	13.2	3	13.2	3	13.7	3	13.5
4	13.3	4	12.8	4	13.8	4	14.1	4	13.7	4	13.2
5	13.3	5	13.5	5	13.6	5	13.9	5	13.5	5	13.1
6	13.4	6	14.2	6	13.2	6	13.2	6	13.1	6	14.2
7	13.4	7	13.2	7	13.3	7	13.6	7	13.5	7	13.6
8	13.1	8	12.9	8	14.7	8	13.5	8	13.3	8	13.3
avg.	**13.4**	**avg.**	**13.3**	**avg.**	**13.5**	**avg.**	**13.5**	**avg.**	**13.3**	**avg.**	**13.5**

MoDOT Data: Route 41 and Lamine River – 7 day testing

tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Treasa	tech.	Treasa
meter	**B**	meter	**C**	meter	**B**	meter	**C**	meter	**B**	meter	**C**
1	6.4	1	6.4	1	5.9	1	6.8	1	6.1	1	6.1
2	6.5	2	6.5	2	6.1	2	6.4	2	6.6	2	6.3
3	6.2	3	6.2	3	6.3	3	6.6	3	6.4	3	5.8
4	6.7	4	6.7	4	6.4	4	6.2	4	6.6	4	6.2
5	6.3	5	6.3	5	5.9	5	6.8	5	6.2	5	6
6	6.5	6	6.4	6	6.2	6	6.2	6	6.8	6	6.2
7	6	7	6.2	7	6.1	7	6.6	7	6.4	7	5.9
8	6.8	8	6.9	8	6.4	8	6.1	8	6.7	8	6.1
avg.	**6.4**	**avg.**	**6.5**	**avg.**	**6.2**	**avg.**	**6.5**	**avg.**	**6.5**	**avg.**	**6.1**

tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Treasa	tech.	Treasa
meter	**B**	meter	**C**	meter	**B**	meter	**C**	meter	**B**	meter	**C**
1	6	1	6.2	1	6.2	1	5.6	1	5.7	1	5.9
2	5.6	2	5.7	2	5.9	2	6.1	2	5.7	2	5.5
3	5.7	3	5.8	3	6	3	6.2	3	6.2	3	5.9
4	5.5	4	6	4	5.5	4	5.8	4	5.8	4	5.9
5	6.2	5	6.2	5	6.1	5	5.6	5	5.8	5	6.2
6	5.8	6	5.8	6	5.9	6	6.1	6	5.8	6	5.5
7	5.7	7	6	7	5.7	7	6	7	6.1	7	6.1
8	5.5	8	6	8	5.6	8	5.7	8	6.4	8	5.8
avg.	**5.8**	**avg.**	**6.0**	**avg.**	**5.9**	**avg.**	**5.9**	**avg.**	**5.9**	**avg.**	**5.9**

Tech.	Lucille	tech.	Lucille	tech.	JV	tech.	JV	tech.	Treasa	tech.	Treasa
meter	**B**	meter	**C**	meter	**B**	meter	**C**	meter	**B**	meter	**C**
1	6.1	1	6.2	1	6.2	1	6.3	1	6.4	1	6.5
2	6.4	2	6.5	2	6.4	2	6.2	2	6.6	2	6.5
3	6.2	3	6.4	3	6.4	3	6.5	3	6.5	3	6.6
4	6.2	4	5.9	4	6	4	6.3	4	6.5	4	6.3
5	6.3	5	6.5	5	6.2	5	6.1	5	6.5	5	6.6
6	6.5	6	6.3	6	6.4	6	6.2	6	6.7	6	6.4
7	6.1	7	6.1	7	6.4	7	6.4	7	6.1	7	6.5
8	6.1	8	6.2	8	6	8	6.4	8	6.3	8	6.2
avg.	**6.2**	**avg.**	**6.3**	**avg.**	**6.3**	**avg.**	**6.3**	**avg.**	**6.5**	**avg.**	**6.5**

MoDOT Data: Route 41 and Lamine River – 28 day testing

Tech.	JV	tech.	JV	tech.	BM	tech.	BM	tech.	BS	tech.	BS
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	13.1	1	12.4	1	13.2	1	12.8	1	13.1	1	12.9
2	13.1	2	12.9	2	13.5	2	12.3	2	13.1	2	13.0
3	13.5	3	13.0	3	13.5	3	13.1	3	13.7	3	13.1
4	12.8	4	12.0	4	12.4	4	11.9	4	12.3	4	12.1
5	12.7	5	12.4	5	13.8	5	12.9	5	13.1	5	13.1
6	13.5	6	13.1	6	12.6	6	13.1	6	13.5	6	13.4
7	13.7	7	13.0	7	13.5	7	13.4	7	13.6	7	13.1
8	12.9	8	12.1	8	12.1	8	11.9	8	12.3	8	12.0
avg.	**13.2**	**avg.**	**12.6**	**avg.**	**13.1**	**avg.**	**12.7**	**avg.**	**13.1**	**avg.**	**12.8**
Tech.	JV	tech.	JV	tech.	BM	tech.	BM	tech.	BS	tech.	BS
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	11.2	1	11.2	1	11.8	1	11.4	1	11.7	1	11.5
2	11.7	2	10.8	2	11.8	2	11.2	2	12.0	2	11.8
3	11.8	3	11.3	3	11.4	3	11.0	3	11.9	3	11.7
4	11.4	4	11.3	4	12.0	4	11.7	4	11.4	4	11.2
5	11.1	5	11.3	5	11.8	5	11.8	5	11.8	5	11.4
6	11.7	6	11.0	6	11.3	6	11.3	6	12.0	6	11.7
7	11.6	7	11.4	7	11.4	7	11.0	7	11.9	7	11.8
8	11.3	8	11.3	8	12.1	8	11.7	8	11.4	8	11.2
avg.	**11.5**	**avg.**	**11.2**	**avg.**	**11.7**	**avg.**	**11.4**	**avg.**	**11.8**	**avg.**	**11.5**
Tech.	JV	tech.	JV	tech.	BM	tech.	BM	tech.	BS	tech.	BS
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	11.5	1	11.2	1	11.4	1	11.1	1	12.3	1	11.6
2	11.2	2	11.2	2	11.6	2	11.3	2	11.4	2	11.9
3	11.6	3	11.1	3	11.6	3	11.5	3	11.9	3	11.0
4	11.4	4	11.9	4	12.1	4	11.5	4	11.8	4	11.2
5	11.4	5	11.2	5	11.5	5	11.2	5	12.1	5	11.4
6	11.2	6	11.4	6	11.8	6	11.4	6	11.4	6	12.2
7	11.9	7	11.0	7	11.7	7	11.4	7	11.8	7	11.3
8	11.5	8	11.5	8	12.1	8	11.7	8	11.7	8	11.2
avg.	**11.5**	**avg.**	**11.3**	**avg.**	**11.7**	**avg.**	**11.4**	**avg.**	**11.8**	**avg.**	**11.5**

MoDOT Data: Route 41 and Lamine River – 90 day testing

Tech.	ZH	tech.	ZH	tech.	BS	tech.	BS	Tech.	JV	tech.	JV
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	22.2	1	21.7	1	21.6	1	21.8	1	21.3	1	22.0
2	21.6	2	21.3	2	21.0	2	22.1	2	22.1	2	21.6
3	21.7	3	21.8	3	20.4	3	20.1	3	19.9	3	21.8
4	20.4	4	20.2	4	20.4	4	21.2	4	22.3	4	20.4
5	22.1	5	22.0	5	21.0	5	21.6	5	21.4	5	22.4
6	21.3	6	21.3	6	21.9	6	21.5	6	21.3	6	21.6
7	21.4	7	21.4	7	20.0	7	20.3	7	20.1	7	21.6
8	19.6	8	19.8	8	20.5	8	21.3	8	22.4	8	20.7
avg.	**21.3**	**avg.**	**21.2**	**avg.**	**20.9**	**avg.**	**21.2**	**avg.**	**21.4**	**avg.**	**21.5**
Tech.	ZH	tech.	ZH	tech.	BS	tech.	BS	Tech.	JV	tech.	JV
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	20.4	1	20.4	1	20.4	1	20.0	1	19.9	1	20.3
2	21.2	2	21.2	2	21.2	2	21.3	2	21.3	2	22.0
3	21.5	3	21.3	3	20.9	3	20.9	3	20.9	3	20.9
4	22.4	4	22.1	4	21.3	4	21.6	4	20.9	4	20.3
5	20.1	5	20.0	5	19.8	5	20.3	5	19.9	5	20.2
6	21.0	6	21.6	6	21.1	6	21.3	6	21.5	6	22.0
7	21.4	7	21.5	7	21.2	7	20.9	7	20.9	7	21.5
8	20.7	8	21.2	8	21.0	8	21.7	8	20.4	8	20.9
avg.	**21.1**	**avg.**	**21.2**	**avg.**	**20.9**	**avg.**	**21.0**	**avg.**	**20.7**	**avg.**	**21.0**
Tech.	ZH	tech.	ZH	tech.	BS	tech.	BS	Tech.	JV	tech.	JV
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	20.2	1	21.9	1	21.7	1	21.5	1	21.9	1	22.2
2	21.1	2	21.1	2	20.9	2	21.1	2	20.8	2	21.3
3	21.3	3	21.3	3	21.0	3	21.2	3	21.5	3	21.8
4	19.3	4	20.1	4	19.7	4	19.6	4	19.4	4	19.6
5	22.1	5	21.6	5	21.3	5	21.7	5	22.2	5	22.1
6	20.9	6	21.4	6	20.9	6	21.3	6	21.3	6	21.1
7	21.0	7	21.5	7	20.9	7	21.6	7	21.2	7	21.7
8	19.2	8	19.8	8	19.9	8	19.6	8	19.8	8	19.7
avg.	**20.6**	**avg.**	**21.1**	**avg.**	**20.8**	**avg.**	**21.0**	**avg.**	**21.0**	**avg.**	**21.2**

MoDOT Data: Highway 364 in St. Charles / St. Louis – 7 day testing

Tech.	TP	tech.	TP	tech.	LG	tech.	LG	tech.	ZH	tech.	ZH
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	6.5	1	6.6	1	6.8	1	6.6	1	6.5	1	6.6
2	6.6	2	6.9	2	7	2	6.9	2	6.9	2	6.8
3	6.6	3	6.8	3	7	3	7	3	6.6	3	7
4	6.6	4	6.7	4	6.8	4	6.8	4	6.8	4	6.7
5	6.7	5	6.7	5	6.7	5	6.5	5	6.6	5	6.6
6	6.9	6	6.7	6	6.5	6	6.7	6	6.7	6	6.7
7	7	7	6.5	7	6.8	7	7	7	7	7	6.6
8	6.7	8	6.4	8	6.7	8	7	8	7	8	6.8
avg.	**6.7**	**avg.**	**6.7**	**avg.**	**6.8**	**avg.**	**6.8**	**avg.**	**6.8**	**avg.**	**6.7**
Tech.	TP	tech.	TP	tech.	LG	tech.	LG	tech.	ZH	tech.	ZH
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	6.8	1	6.6	1	7	1	6.5	1	7	1	7
2	6.8	2	7	2	7.2	2	7.1	2	7.1	2	7.1
3	6.9	3	6.9	3	6.6	3	6.5	3	6.8	3	7
4	6.8	4	6.9	4	7	4	6.8	4	7	4	7.3
5	6.8	5	7.4	5	6.9	5	7.1	5	6.8	5	7
6	6.6	6	7.1	6	7.1	6	7.3	6	6.9	6	7.1
7	6.6	7	6.8	7	7.1	7	6.9	7	6.4	7	6.8
8	7	8	7.2	8	7.2	8	7	8	7.2	8	7.3
avg.	**6.8**	**avg.**	**7.0**	**avg.**	**7.0**	**avg.**	**6.9**	**avg.**	**6.9**	**avg.**	**7.1**
Tech.	TP	tech.	TP	tech.	LG	tech.	LG	tech.	ZH	tech.	ZH
meter	**A**	meter	**C**	meter	**A**	meter	**C**	meter	**A**	meter	**C**
1	7.2	1	7.1	1	7.1	1	7	1	7.4	1	7.2
2	7	2	7.3	2	7.2	2	7.4	2	7.2	2	7.1
3	6.9	3	7	3	7.1	3	7.1	3	6.8	3	6.8
4	7.4	4	7.5	4	7.4	4	7.3	4	7	4	7.4
5	7.3	5	7.3	5	7	5	7.3	5	7.2	5	7
6	7	6	7.3	6	7.4	6	7.6	6	7.1	6	7.4
7	7.1	7	6.8	7	7	7	7.1	7	7.1	7	7
8	7.6	8	7.2	8	7.3	8	7.4	8	7.2	8	7.3
avg.	**7.2**	**avg.**	**7.2**	**avg.**	**7.2**	**avg.**	**7.3**	**avg.**	**7.1**	**avg.**	**7.2**

MoDOT Data: Highway 364 in St. Charles / St. Louis – 28 day testing

Tech.	LG	tech.	LG	tech.	TP	tech.	TP	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	12.5	1	12.5	1	13.2	1	13	1	12.9	1	12.9
2	12.3	2	13.2	2	13.6	2	13.2	2	13.4	2	12.9
3	12.1	3	13.5	3	13.6	3	13.6	3	13.4	3	13.3
4	12.4	4	12.9	4	12.8	4	13.2	4	13.1	4	13.3
5	11.6	5	13	5	13.2	5	12.5	5	13	5	12.8
6	12.5	6	13.3	6	13	6	12.8	6	13.2	6	13.3
7	12.1	7	13.5	7	13.4	7	13.5	7	13.2	7	13.4
8	12.7	8	13.1	8	12.5	8	13.2	8	13.3	8	13.8
avg.	**12.3**	**avg.**	**13.1**	**avg.**	**13.2**	**avg.**	**13.1**	**avg.**	**13.2**	**avg.**	**13.2**
Tech.	LG	tech.	LG	tech.	TP	tech.	TP	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	12.2	1	12.3	1	12	1	12.5	1	12.7	1	12.5
2	12.6	2	12.7	2	12.9	2	12.7	2	12.5	2	12.3
3	12.3	3	12.7	3	12.9	3	12.9	3	13.3	3	13.1
4	12.2	4	12.2	4	12.3	4	12.4	4	13.2	4	12.5
5	12.2	5	12.5	5	12.4	5	12.7	5	12.5	5	12.6
6	12.6	6	13.2	6	12.7	6	12.8	6	12.4	6	12.3
7	12.4	7	12.6	7	13	7	13	7	13.4	7	12.8
8	12.2	8	12.6	8	12.3	8	12.2	8	12.8	8	12.8
avg.	**12.3**	**avg.**	**12.6**	**avg.**	**12.6**	**avg.**	**12.7**	**avg.**	**12.9**	**avg.**	**12.6**
Tech.	LG	tech.	LG	tech.	TP	tech.	TP	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	12.4	1	12.1	1	12	1	13.1	1	12.5	1	12.2
2	12.8	2	13.1	2	12.4	2	12.9	2	13.3	2	13.1
3	12.7	3	12.8	3	12.1	3	12.2	3	13.1	3	12.9
4	11.7	4	12.8	4	12.9	4	12.6	4	11.9	4	12.7
5	12	5	12	5	12.1	5	13.7	5	12.5	5	12.1
6	12.5	6	11.9	6	12.5	6	13.1	6	12.9	6	13.1
7	12.4	7	12.5	7	12.7	7	12.4	7	13.1	7	12.5
8	12.8	8	12.5	8	13.2	8	12.9	8	12.5	8	12.5
avg.	**12.4**	**avg.**	**12.5**	**avg.**	**12.5**	**avg.**	**12.9**	**avg.**	**12.7**	**avg.**	**12.6**

MoDOT Data: Highway 364 in St. Charles / St. Louis – 90 day testing

Tech.	JV	tech.	JV	tech.	SB	tech.	SB	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	24.4	1	24.0	1	22.6	1	21.2	1	24.3	1	24.8
2	23.5	2	23.9	2	22.5	2	23.0	2	24.0	2	23.8
3	22.4	3	23.3	3	22.9	3	23.3	3	22.6	3	22.7
4	23.2	4	23.6	4	23.4	4	22.1	4	23.5	4	23.2
5	24.2	5	24.6	5	22.8	5	21.5	5	25.0	5	25.3
6	23.5	6	24.3	6	21.7	6	22.4	6	24.7	6	24.4
7	22.9	7	23.1	7	22.4	7	23.2	7	23.3	7	23.0
8	23.3	8	23.4	8	23.2	8	22.0	8	24.1	8	23.7
avg.	**23.4**	**avg.**	**23.8**	**avg.**	**22.7**	**avg.**	**22.3**	**avg.**	**23.9**	**avg.**	**23.9**
Tech.	JV	tech.	JV	tech.	SB	tech.	SB	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	23.7	1	22.0	1	24.4	1	21.8	1	20.9	1	21.2
2	22.4	2	21.2	2	22.9	2	24.1	2	23.4	2	23.5
3	23.7	3	23.4	3	24.1	3	22.6	3	21.7	3	21.3
4	21.9	4	22.0	4	22.1	4	23.6	4	22.5	4	22.2
5	23.8	5	22.4	5	24.1	5	21.9	5	20.9	5	21.4
6	22.5	6	22.0	6	22.8	6	24.7	6	23.3	6	24.0
7	23.4	7	23.6	7	22.8	7	22.7	7	21.3	7	21.3
8	22.1	8	22.2	8	22.3	8	23.3	8	22.7	8	22.2
avg.	**22.9**	**avg.**	**22.4**	**avg.**	**23.2**	**avg.**	**23.1**	**avg.**	**22.1**	**avg.**	**22.1**
Tech.	JV	tech.	JV	tech.	SB	tech.	SB	tech.	ZH	tech.	ZH
meter	A	meter	C	meter	A	meter	C	meter	A	meter	C
1	22.4	1	22.9	1	21.3	1	21.9	1	20.8	1	21.3
2	22.6	2	22.6	2	21.4	2	21.2	2	22.2	2	22.3
3	23.7	3	22.6	3	22.3	3	21.7	3	22.8	3	23.0
4	23.0	4	24.0	4	22.2	4	22.6	4	22.5	4	22.6
5	22.5	5	22.7	5	21.3	5	22.3	5	22.0	5	23.1
6	22.8	6	23.0	6	21.7	6	22.4	6	21.9	6	22.2
7	24.6	7	22.5	7	22.9	7	21.8	7	23.6	7	23.8
8	23.4	8	23.6	8	22.6	8	23.4	8	22.6	8	22.8
avg.	**23.1**	**avg.**	**23.0**	**avg.**	**22.0**	**avg.**	**22.2**	**avg.**	**22.3**	**avg.**	**22.6**

P:100C Mix Design - Surface Resistivity (SR) Readings (Kohm-cm)

Age (days)	Sample Designation		0˚	90˚	180˚	270˚	0˚	90˚	180˚	270˚	Average	Std	COV(%)	Set Average	Curing Condition Correction	Chloride Ion Penetrability
P: 100C in Molds 7 Day Testing	Dry (0 secs)	A	11.1	11.2	11.2	11.3	11.4	11.6	11.9	11.9	11.5	0.316	2.8%	10.8	11.8	High
		B	9.8	9.9	9.9	10.0	10.0	10.1	11.2	11.3	10.3	0.609	5.9%			
		C	10.3	10.3	10.4	10.5	10.6	10.6	10.8	10.8	10.5	0.200	1.9%			
		Average	10.4	10.5	10.5	10.6	10.7	10.8	11.3	11.3	10.8	0.366	3.4%			
	15 mins lime bath	A	9.8	9.9	10.1	10.1	10.2	10.4	10.5	10.6	10.2	0.283	2.8%	9.7	10.7	High
		B	8.7	8.8	9.2	9.3	9.3	9.4	10.0	10.2	9.4	0.521	5.6%			
		C	9.0	9.2	9.7	9.8	9.8	9.9	10.0	10.0	9.7	0.373	3.9%			
		Average	9.2	9.3	9.7	9.7	9.8	9.9	10.2	10.3	9.7	0.380	3.9%			
	30 mins lime bath	A	9.7	9.8	10.0	10.2	10.2	10.3	10.4	10.4	10.1	0.266	2.6%	9.7	10.6	High
		B	8.9	9.0	9.0	9.0	9.2	9.2	9.9	9.9	9.3	0.407	4.4%			
		C	9.1	9.4	9.5	9.5	9.6	9.8	9.9	9.9	9.6	0.275	2.9%			
		Average	9.2	9.4	9.5	9.6	9.7	9.8	10.1	10.1	9.7	0.299	3.1%			
	45 mins lime bath	A	9.7	9.9	9.9	10.1	10.2	10.2	10.2	10.3	10.1	0.207	2.1%	9.6	10.6	High
		B	8.8	8.9	9.0	9.0	9.1	9.1	9.8	10.0	9.2	0.439	4.8%			
		C	8.9	9.3	9.4	9.4	9.6	9.8	9.9	9.9	9.5	0.345	3.6%			
		Average	9.1	9.4	9.4	9.5	9.6	9.7	10.0	10.1	9.6	0.310	3.2%			
	60 mins lime bath	A	9.6	9.7	9.8	10.1	10.2	10.3	10.3	10.4	10.1	0.307	3.1%	9.6	10.6	High
		B	8.8	8.8	8.9	8.9	9.2	9.4	9.7	10.0	9.2	0.452	4.9%			
		C	9.1	9.2	9.5	9.6	9.7	9.7	9.8	9.9	9.6	0.283	3.0%			
		Average	9.2	9.2	9.4	9.5	9.7	9.8	9.9	10.1	9.6	0.333	3.5%			

P: 100C in Molds 14 Day Testing	**Dry (0 secs)**	A	11.1	11.1	11.8	11.8	12.1	12.3	12.8	13.2	12.0	0.744	6.2%	12.3	13.5	Moderate
		B	12.1	12.2	12.5	12.7	13.1	13.5	13.7	13.7	12.9	0.655	5.1%			
		C	10.9	11.4	11.5	11.7	11.9	11.9	12.4	13.0	11.8	0.641	5.4%			
		Average	11.4	11.6	11.9	12.1	12.4	12.6	13.0	13.3	12.3	0.666	5.4%			
	15 mins lime bath	A	10.2	10.2	10.3	10.3	10.7	10.7	10.8	10.9	10.5	0.290	2.8%	10.7	11.7	High
		B	10.8	10.9	11.0	11.1	11.5	11.6	11.9	11.9	11.3	0.444	3.9%			
		C	9.5	9.5	10.0	10.0	10.1	10.2	10.6	11.2	10.1	0.560	5.5%			
		Average	10.2	10.2	10.4	10.5	10.8	10.8	11.1	11.3	10.7	0.420	3.9%			
	30 mins lime bath	A	9.8	9.9	10.1	10.2	10.5	10.5	10.7	10.9	10.3	0.388	3.8%	10.3	11.4	High
		B	10.3	10.3	10.4	10.5	10.8	11.2	11.2	11.4	10.8	0.450	4.2%			
		C	9.3	9.3	9.6	9.7	10.0	10.2	10.6	10.6	9.9	0.525	5.3%			
		Average	9.8	9.8	10.0	10.1	10.4	10.6	10.8	11.0	10.3	0.450	4.4%			
	45 mins lime bath	A	9.8	9.9	9.9	10.0	10.3	10.3	10.3	10.6	10.1	0.277	2.7%	10.3	11.3	High
		B	10.4	10.6	10.6	10.6	11.1	11.4	11.7	11.7	11.0	0.533	4.8%			
		C	9.1	9.2	9.5	9.7	9.8	9.9	10.4	10.6	9.8	0.528	5.4%			
		Average	9.8	9.9	10.0	10.1	10.4	10.5	10.8	11.0	10.3	0.436	4.2%			
	60 mins lime bath	A	9.7	9.7	10.1	10.1	10.4	10.5	10.6	10.6	10.2	0.372	3.6%	10.3	11.3	High
		B	10.5	10.5	10.6	10.6	11.1	11.3	11.7	11.7	11.0	0.521	4.7%			
		C	9.0	9.1	9.5	9.5	9.8	9.9	10.3	10.6	9.7	0.554	5.7%			
		Average	9.7	9.8	10.1	10.1	10.4	10.6	10.9	11.0	10.3	0.473	4.6%			

P: 100C in Molds 28 Day Testing	**Dry\ (0 secs)**	A	13.3	13.3	13.5	13.5	14.0	14.2	14.8	14.9	13.9	0.648	4.6%	13.5	14.8	Moderate
		B	12.0	12.2	12.3	12.4	12.7	12.7	13.0	13.1	12.6	0.389	3.1%			
		C	13.3	13.3	13.5	13.6	13.9	14.0	15.0	15.1	14.0	0.717	5.1%			
		Average	12.9	12.9	13.1	13.2	13.5	13.6	14.3	14.4	13.5	0.579	4.3%			
	15 mins lime bath	A	12.2	12.5	12.5	12.8	12.8	13.1	13.8	14.3	13.0	0.713	5.5%	12.4	13.6	Moderate
		B	11.3	11.5	11.6	11.6	11.6	11.7	11.7	11.9	11.6	0.173	1.5%			
		C	12.1	12.1	12.6	12.6	12.7	12.8	12.8	13.0	12.6	0.327	2.6%			
		Average	11.9	12.0	12.2	12.3	12.4	12.5	12.8	13.1	12.4	0.387	3.1%			
	30 mins lime bath	A	12.0	12.0	12.1	12.3	12.6	12.7	13.8	14.0	12.7	0.794	6.3%	12.2	13.4	Moderate
		B	10.9	11.0	11.4	11.5	11.5	11.6	11.7	11.8	11.4	0.320	2.8%			
		C	12.2	12.4	12.5	12.6	12.6	12.7	12.7	12.7	12.6	0.177	1.4%			
		Average	11.7	11.8	12.0	12.1	12.2	12.3	12.7	12.8	12.2	0.406	3.3%			
	45 mins lime bath	A	12.0	12.0	12.1	12.3	12.6	13.1	13.6	13.9	12.7	0.748	5.9%	12.2	13.4	Moderate
		B	11.0	11.1	11.1	11.3	11.3	11.6	11.7	11.7	11.4	0.283	2.5%			
		C	11.9	11.9	12.4	12.5	12.5	12.5	12.7	13.0	12.4	0.373	3.0%			
		Average	11.6	11.7	11.9	12.0	12.1	12.4	12.7	12.9	12.2	0.453	3.7%			
	60 mins lime bath	A	11.7	11.8	11.9	11.9	12.6	13.0	13.6	13.7	12.5	0.824	6.6%	12.1	13.3	Moderate
		B	11.0	11.2	11.3	11.4	11.4	11.4	11.6	11.7	11.4	0.219	1.9%			
		C	11.9	12.0	12.1	12.2	12.4	12.7	12.7	12.9	12.4	0.370	3.0%			
		Average	11.5	11.7	11.8	11.8	12.1	12.4	12.6	12.8	12.1	0.462	3.8%			

P: 100C in Molds 56 Day Testing	**Dry (0 secs)**	A	15.5	15.5	17.5	17.7	18.1	18.2	18.4	18.4	17.4	1.222	7.0%	17.1	18.8	Moderate
		B	16.5	16.5	17.3	17.3	17.3	17.7	19.2	19.5	17.7	1.124	6.4%			
		C	15.1	15.1	15.6	15.6	15.9	16.6	17.6	18.0	16.2	1.108	6.8%			
		Average	15.7	15.7	16.8	16.9	17.1	17.5	18.4	18.6	17.1	1.087	6.4%			
	15 mins lime bath	A	14.2	14.5	14.8	15.1	15.2	15.9	16.0	16.2	15.2	0.735	4.8%	15.1	16.6	Moderate
		B	15.1	15.2	15.3	15.5	15.6	16.0	16.2	16.2	15.6	0.444	2.8%			
		C	13.9	13.9	14.0	14.1	14.2	14.2	15.5	15.7	14.4	0.729	5.0%			
		Average	14.4	14.5	14.7	14.9	15.0	15.4	15.9	16.0	15.1	0.610	4.0%			
	30 mins lime bath	A	13.7	14.0	14.8	14.9	15.1	15.1	15.4	15.4	14.8	0.628	4.2%	14.9	16.3	Moderate
		B	14.7	14.9	15.5	15.6	15.7	15.8	15.9	16.3	15.6	0.524	3.4%			
		C	13.5	13.6	13.9	13.9	14.1	14.2	15.3	15.3	14.2	0.703	4.9%			
		Average	14.0	14.2	14.7	14.8	15.0	15.0	15.5	15.7	14.9	0.591	4.0%			
	45 mins lime bath	A	13.9	13.9	14.6	15.2	15.2	15.5	15.7	15.7	15.0	0.744	5.0%	14.7	16.2	Moderate
		B	14.4	14.6	14.9	15.2	15.2	15.6	15.6	15.9	15.2	0.520	3.4%			
		C	13.4	13.5	13.6	13.9	14.0	14.3	14.8	15.0	14.1	0.595	4.2%			
		Average	13.9	14.0	14.4	14.8	14.8	15.1	15.4	15.5	14.7	0.606	4.1%			
	60 mins lime bath	A	13.9	14.0	14.2	14.4	14.9	15.3	15.4	15.9	14.8	0.735	5.0%	14.7	16.1	Moderate
		B	14.5	14.9	15.1	15.5	15.6	15.6	15.7	16.0	15.4	0.490	3.2%			
		C	13.3	13.3	13.3	13.8	13.8	14.3	14.5	14.6	13.9	0.548	3.9%			
		Average	13.9	14.1	14.2	14.6	14.8	15.1	15.2	15.5	14.7	0.576	3.9%			

P: 100C in Molds 90 Day Testing	**Dry (0 secs)**	A	16.5	17.0	17.4	17.6	17.9	18.0	18.0	18.2	17.6	0.582	3.3%	17.7	19.5	Moderate
		B	15.2	15.4	16.2	16.2	16.2	16.3	17.0	17.5	16.3	0.752	4.6%			
		C	18.3	18.4	19.2	19.2	19.3	19.4	20.5	20.9	19.4	0.907	4.7%			
		Average	16.7	16.9	17.6	17.7	17.8	17.9	18.5	18.9	17.7	0.727	4.1%			
	15 mins lime bath	A	15.1	15.1	15.1	15.1	15.7	15.8	15.9	16.1	15.5	0.429	2.8%	15.7	17.3	Moderate
		B	13.8	14.2	14.2	14.3	14.3	14.3	15.2	15.3	14.5	0.521	3.6%			
		C	15.9	16.3	16.7	16.7	16.8	17.1	18.7	18.9	17.1	1.088	6.3%			
		Average	14.9	15.2	15.3	15.4	15.6	15.7	16.6	16.8	15.7	0.659	4.2%			
	30 mins lime bath	A	14.7	14.7	14.8	15.0	15.3	15.4	15.7	15.7	15.2	0.421	2.8%	15.3	16.9	Moderate
		B	13.5	13.7	13.8	14.0	14.0	14.2	14.7	14.8	14.1	0.461	3.3%			
		C	15.6	15.6	16.1	16.3	16.8	16.8	18.4	18.4	16.8	1.116	6.7%			
		Average	14.6	14.7	14.9	15.1	15.4	15.5	16.3	16.3	15.3	0.660	4.3%			
	45 mins lime bath	A	14.0	14.1	14.5	14.5	15.1	15.2	15.3	15.3	14.8	0.540	3.7%	15.1	16.6	Moderate
		B	13.5	13.5	13.7	13.7	13.8	13.9	14.5	14.6	13.9	0.424	3.1%			
		C	15.4	15.5	16.3	16.4	16.4	16.7	18.2	18.2	16.6	1.065	6.4%			
		Average	14.3	14.4	14.8	14.9	15.1	15.3	16.0	16.0	15.1	0.656	4.3%			
	60 mins lime bath	A	13.9	14.4	14.7	14.8	14.9	15.0	15.3	15.6	14.8	0.523	3.5%	15.0	16.5	Moderate
		B	13.3	13.3	13.4	13.4	13.5	13.7	14.3	14.6	13.7	0.494	3.6%			
		C	15.3	15.3	16.0	16.2	16.3	16.5	17.3	18.1	16.4	0.951	5.8%			
		Average	14.2	14.3	14.7	14.8	14.9	15.1	15.6	16.1	15.0	0.642	4.3%			

P:100C - 7 Day Testing	0 secs	A	9.4	9.4	9.4	9.7	9.8	9.9	10.0	10.1	9.7	0.285	2.9%	9.5	10.4	High
		B	8.3	8.5	8.9	8.9	9.2	9.3	9.5	9.7	9.0	0.481	5.3%			
		C	9.0	9.2	9.3	9.4	9.8	10.1	10.2	10.3	9.7	0.501	5.2%			
		Average	8.9	9.0	9.2	9.3	9.6	9.8	9.9	10.0	9.5	0.416	4.4%			
	30 secs	A	9.3	9.3	9.5	9.6	9.8	9.8	10.2	10.4	9.7	0.400	4.1%	9.5	10.4	High
		B	8.4	8.6	8.9	8.9	9.4	9.4	9.7	9.7	9.1	0.495	5.4%			
		C	9.0	9.2	9.3	9.5	9.8	9.9	10.1	10.2	9.6	0.440	4.6%			
		Average	8.9	9.0	9.2	9.3	9.7	9.7	10.0	10.1	9.5	0.440	4.6%			
	1 min	A	9.4	9.7	9.7	9.9	9.9	10.1	10.3	10.3	9.9	0.314	3.2%	9.6	10.6	High
		B	8.6	8.6	8.9	9.0	9.3	9.5	9.8	9.8	9.2	0.488	5.3%			
		C	8.9	9.2	9.4	9.6	9.9	10.2	10.6	10.6	9.8	0.635	6.5%			
		Average	9.0	9.2	9.3	9.5	9.7	9.9	10.2	10.2	9.6	0.476	4.9%			
	2 min	A	9.6	9.6	9.9	9.9	10.1	10.3	10.6	10.6	10.1	0.399	4.0%	9.7	10.7	High
		B	8.5	8.7	9.2	9.2	9.4	9.7	9.7	10.0	9.3	0.513	5.5%			
		C	9.1	9.3	9.6	9.6	9.9	10.0	10.4	10.6	9.8	0.517	5.3%			
		Average	9.1	9.2	9.6	9.6	9.8	10.0	10.2	10.4	9.7	0.471	4.8%			
	5 min	A	10.0	10.0	10.0	10.1	10.2	10.5	10.6	10.6	10.3	0.273	2.7%	9.9	10.8	High
		B	8.6	8.7	9.2	9.5	9.5	9.7	9.8	9.9	9.4	0.490	5.2%			
		C	9.3	9.3	9.5	9.8	9.9	10.3	10.8	10.9	10.0	0.634	6.4%			
		Average	9.3	9.3	9.6	9.8	9.9	10.2	10.4	10.5	9.9	0.453	4.6%			
	10 min	A	10.0	10.1	10.2	10.2	10.3	10.3	10.7	10.7	10.3	0.259	2.5%	10.0	11.0	High
		B	8.6	8.7	9.4	9.4	9.8	9.9	10.0	10.1	9.5	0.577	6.1%			
		C	9.5	9.6	9.7	9.8	10.4	10.5	10.6	10.8	10.1	0.514	5.1%			
		Average	9.4	9.5	9.8	9.8	10.2	10.2	10.4	10.5	10.0	0.436	4.4%			
	15 min	A	10.0	10.3	10.3	10.5	10.5	10.6	11.0	11.3	10.6	0.414	3.9%	10.2	11.2	High
		B	8.9	9.0	9.6	9.9	9.9	10.0	10.1	10.1	9.7	0.482	5.0%			
		C	9.7	9.7	9.8	9.8	10.5	10.6	10.6	10.9	10.2	0.496	4.9%			
		Average	9.5	9.7	9.9	10.1	10.3	10.4	10.6	10.8	10.2	0.435	4.3%			
	20 min	A	10.1	10.3	10.3	10.8	10.8	11.0	11.3	11.6	10.8	0.523	4.9%	10.4	11.4	High
		B	9.5	9.6	9.7	9.9	10.0	10.1	10.2	10.6	10.0	0.359	3.6%			
		C	9.6	9.9	10.0	10.3	10.6	10.8	10.7	11.0	10.4	0.493	4.8%			
		Average	9.7	9.9	10.0	10.3	10.5	10.6	10.7	11.1	10.4	0.452	4.4%			
	30 min	A	10.3	10.4	10.5	10.8	11.0	11.5	11.6	11.9	11.0	0.605	5.5%	10.5	11.5	High
		B	9.4	9.7	10.0	10.0	10.1	10.3	10.4	10.5	10.1	0.366	3.6%			
		C	9.8	9.9	10.0	10.3	10.6	10.7	10.8	11.0	10.4	0.452	4.3%			
		Average	9.8	10.0	10.2	10.4	10.6	10.8	10.9	11.1	10.5	0.467	4.5%			
	Giatec (0 secs)	A	9.3	9.3	9.9	9.9	10.1	10.1	10.4	10.4	9.9	0.430	4.3%	9.7	10.7	High
		B	8.9	8.9	9.1	9.1	9.5	9.6	9.6	9.6	9.3	0.318	3.4%			
		C	9.6	9.6	10.1	10.1	10.1	10.1	10.3	10.3	10.0	0.276	2.8%			
		Average	9.3	9.3	9.7	9.7	9.9	9.9	10.1	10.1	9.7	0.332	3.4%			

P:100C - 14 Day Testing	**0 secs**	A	10.6	10.7	10.9	11.1	11.2	11.2	11.9	11.9	11.2	0.491	4.4%	10.7	11.7	High
		B	9.4	9.4	10.0	10.2	10.5	10.5	10.8	10.8	10.2	0.563	5.5%			
		C	10.0	10.1	10.2	10.5	10.6	10.6	11.4	11.5	10.6	0.564	5.3%			
		Average	10.0	10.1	10.4	10.6	10.8	10.8	11.4	11.4	10.7	0.527	4.9%			
	30 secs	A	10.8	11.0	11.1	11.1	11.2	11.4	11.8	11.8	11.3	0.365	3.2%	10.8	11.8	High
		B	9.4	9.5	10.1	10.3	10.6	10.7	10.8	10.8	10.3	0.565	5.5%			
		C	10.1	10.1	10.4	10.5	10.6	11.0	11.5	11.7	10.7	0.607	5.7%			
		Average	10.1	10.2	10.5	10.6	10.8	11.0	11.4	11.4	10.8	0.495	4.6%			
	1 min	A	10.8	10.9	11.1	11.2	11.3	11.4	11.9	11.9	11.3	0.412	3.6%	10.8	11.9	High
		B	9.5	9.8	10.3	10.4	10.7	10.7	10.9	11.0	10.4	0.530	5.1%			
		C	10.2	10.2	10.3	10.7	10.8	11.0	11.5	11.6	10.8	0.554	5.1%			
		Average	10.2	10.3	10.6	10.8	10.9	11.0	11.4	11.5	10.8	0.487	4.5%			
	2 min	A	10.8	11.0	11.1	11.2	11.3	11.4	11.9	12.0	11.3	0.421	3.7%	11.0	12.1	Moderate
		B	9.8	10.0	10.3	10.4	10.7	11.0	11.2	11.3	10.6	0.554	5.2%			
		C	10.3	10.4	10.7	10.8	10.9	11.0	11.8	11.8	11.0	0.568	5.2%			
		Average	10.3	10.5	10.7	10.8	11.0	11.1	11.6	11.7	11.0	0.508	4.6%			
	5 min	A	11.1	11.1	11.4	11.4	11.5	11.6	11.9	12.0	11.5	0.330	2.9%	11.1	12.2	Moderate
		B	10.0	10.0	10.5	10.5	11.1	11.2	11.3	11.5	10.8	0.590	5.5%			
		C	10.3	10.5	10.6	10.7	11.1	11.3	12.0	12.2	11.1	0.704	6.3%			
		Average	10.5	10.5	10.8	10.9	11.2	11.4	11.7	11.9	11.1	0.531	4.8%			
	10 min	A	11.5	11.6	11.6	11.7	12.0	12.2	12.4	12.5	11.9	0.393	3.3%	11.4	12.6	Moderate
		B	10.2	10.3	10.7	10.9	11.3	11.7	11.8	11.9	11.1	0.674	6.1%			
		C	10.4	10.6	10.7	10.9	11.3	11.3	12.1	12.3	11.2	0.695	6.2%			
		Average	10.7	10.8	11.0	11.2	11.5	11.7	12.1	12.2	11.4	0.578	5.1%			
	15 min	A	11.6	11.6	11.7	11.8	12.2	12.3	12.6	12.7	12.1	0.447	3.7%	11.7	12.8	Moderate
		B	10.1	10.2	10.8	11.0	11.5	11.8	11.8	11.9	11.1	0.725	6.5%			
		C	10.7	11.1	11.2	11.6	12.3	12.3	12.5	12.7	11.8	0.746	6.3%			
		Average	10.8	11.0	11.2	11.5	12.0	12.1	12.3	12.4	11.7	0.631	5.4%			
	20 min	A	12.0	12.0	12.1	12.2	12.3	12.3	12.6	12.9	12.3	0.312	2.5%	11.9	13.1	Moderate
		B	10.5	10.6	11.0	11.2	11.7	11.7	11.9	11.9	11.3	0.569	5.0%			
		C	11.5	11.2	11.5	11.9	11.9	12.2	12.6	13.1	12.0	0.629	5.2%			
		Average	11.3	11.3	11.5	11.8	12.0	12.1	12.4	12.6	11.9	0.486	4.1%			
	30 min	A	12.0	12.1	12.4	12.4	12.5	12.5	12.6	12.7	12.4	0.239	1.9%	12.0	13.2	Moderate
		B	10.5	10.8	11.4	11.5	11.9	12.0	12.2	12.2	11.6	0.639	5.5%			
		C	11.3	11.3	11.8	11.9	12.0	12.4	12.8	13.4	12.1	0.726	6.0%			
		Average	11.3	11.4	11.9	11.9	12.1	12.3	12.5	12.8	12.0	0.520	4.3%			
	Giatec (0 secs)	A	11.0	11.0	11.2	11.3	11.3	11.3	11.4	11.4	11.2	0.160	1.4%	10.8	11.8	High
		B	9.8	9.8	10.0	10.0	10.3	10.3	10.9	10.9	10.3	0.444	4.3%			
		C	10.0	10.0	10.7	10.7	10.9	10.9	11.5	11.5	10.8	0.573	5.3%			
		Average	10.3	10.3	10.6	10.7	10.8	10.8	11.3	11.3	10.8	0.385	3.6%			

P:100C - 28 Day Testing	**0 secs**	A	12.7	12.7	12.7	12.7	12.9	13.0	13.9	14.0	13.1	0.552	4.2%	12.6	13.8	Moderate
		B	11.4	11.5	11.9	12.0	12.4	12.5	12.8	12.9	12.2	0.565	4.6%			
		C	11.7	11.8	12.5	12.5	12.6	12.6	13.0	13.3	12.5	0.540	4.3%			
		Average	11.9	12.0	12.4	12.4	12.6	12.7	13.2	13.4	12.6	0.528	4.2%			
	30 secs	A	12.6	12.8	12.9	13.0	13.0	13.2	13.9	13.9	13.2	0.487	3.7%	12.7	14.0	Moderate
		B	11.5	11.5	12.1	12.2	12.3	12.5	12.9	13.0	12.3	0.561	4.6%			
		C	11.9	12.1	12.5	12.6	12.7	12.7	13.4	13.4	12.7	0.537	4.2%			
		Average	12.0	12.1	12.5	12.6	12.7	12.8	13.4	13.4	12.7	0.521	4.1%			
	1 min	A	12.7	13.0	13.0	13.1	13.2	13.4	13.7	13.9	13.3	0.396	3.0%	12.8	14.0	Moderate
		B	11.5	11.5	12.1	12.3	12.6	12.6	13.0	13.1	12.3	0.612	5.0%			
		C	11.7	11.9	12.5	12.6	12.8	12.9	13.5	13.5	12.7	0.656	5.2%			
		Average	12.0	12.1	12.5	12.7	12.9	13.0	13.4	13.5	12.8	0.547	4.3%			
	2 min	A	12.8	12.8	13.1	13.2	13.4	13.5	13.9	14.0	13.3	0.453	3.4%	12.8	14.1	Moderate
		B	11.6	11.9	12.0	12.2	12.7	12.7	13.0	13.2	12.4	0.569	4.6%			
		C	12.0	12.0	12.7	12.8	12.8	12.9	13.3	13.5	12.8	0.537	4.2%			
		Average	12.1	12.2	12.6	12.7	13.0	13.0	13.4	13.6	12.8	0.511	4.0%			
	5 min	A	12.7	12.7	13.3	13.5	13.5	13.6	13.9	14.2	13.4	0.526	3.9%	13.0	14.3	Moderate
		B	11.6	11.7	12.5	12.5	12.8	12.9	13.1	13.5	12.6	0.656	5.2%			
		C	11.8	12.4	12.9	13.0	13.1	13.3	13.6	13.7	13.0	0.627	4.8%			
		Average	12.0	12.3	12.9	13.0	13.1	13.3	13.5	13.8	13.0	0.597	4.6%			
	10 min	A	12.7	13.0	13.2	13.5	13.6	13.7	14.1	14.7	13.6	0.632	4.7%	13.1	14.5	Moderate
		B	11.7	12.0	12.3	12.6	12.7	13.3	13.3	13.4	12.7	0.639	5.0%			
		C	12.4	12.4	13.0	13.3	13.4	13.5	13.6	13.9	13.2	0.549	4.2%			
		Average	12.3	12.5	12.8	13.1	13.2	13.5	13.7	14.0	13.1	0.593	4.5%			
	15 min	A	13.1	13.3	13.6	13.6	13.8	13.9	14.5	14.8	13.8	0.575	4.2%	13.3	14.6	Moderate
		B	11.9	12.2	12.4	12.7	12.9	13.2	13.2	13.5	12.8	0.553	4.3%			
		C	12.8	12.8	13.1	13.1	13.5	13.7	13.9	14.0	13.4	0.478	3.6%			
		Average	12.6	12.8	13.0	13.1	13.4	13.6	13.9	14.1	13.3	0.526	3.9%			
	20 min	A	13.3	13.3	13.4	13.7	13.8	14.0	14.6	14.7	13.9	0.553	4.0%	13.5	14.8	Moderate
		B	12.1	12.3	12.5	12.7	13.1	13.6	13.6	13.7	13.0	0.637	4.9%			
		C	12.6	13.0	13.0	13.5	13.6	14.1	14.3	14.4	13.6	0.665	4.9%			
		Average	12.7	12.9	13.0	13.3	13.5	13.9	14.2	14.3	13.5	0.609	4.5%			
	30 min	A	13.6	13.7	13.8	14.1	14.1	14.1	14.8	14.8	14.1	0.459	3.2%	13.7	15.0	Moderate
		B	12.3	12.3	12.7	12.7	13.6	13.6	13.8	14.0	13.1	0.696	5.3%			
		C	12.8	12.9	13.5	13.5	13.9	14.3	14.3	14.7	13.7	0.684	5.0%			
		Average	12.9	13.0	13.3	13.4	13.9	14.0	14.3	14.5	13.7	0.596	4.4%			
	Giatec (0 secs)	A	12.7	12.8	12.8	12.8	13.3	13.3	14.2	14.2	13.3	0.623	4.7%	12.8	14.1	Moderate
		B	11.9	12.0	12.1	12.1	12.2	12.2	12.6	12.6	12.2	0.259	2.1%			
		C	12.7	12.7	12.9	12.9	12.9	12.9	13.4	13.4	13.0	0.276	2.1%			
		Average	12.4	12.5	12.6	12.6	12.8	12.8	13.4	13.4	12.8	0.382	3.0%			

P:100C - 56 Day Testing	**0 secs**	A	14.5	14.6	14.8	15.0	15.0	15.1	15.5	15.7	15.0	0.413	2.7%	14.5	16.0	Moderate
		B	13.1	13.1	13.8	13.9	14.4	14.5	14.8	14.9	14.1	0.707	5.0%			
		C	13.8	14.0	14.0	14.1	14.6	14.9	15.4	15.4	14.5	0.648	4.5%			
		Average	13.8	13.9	14.2	14.3	14.7	14.8	15.2	15.3	14.5	0.577	4.0%			
	30 secs	A	14.6	14.7	14.8	14.9	14.9	15.2	15.6	15.8	15.1	0.434	2.9%	14.6	16.1	Moderate
		B	13.3	13.3	13.8	13.9	14.5	14.6	15.1	15.1	14.2	0.731	5.1%			
		C	13.6	13.7	14.0	14.4	15.0	15.2	15.4	15.5	14.6	0.773	5.3%			
		Average	13.8	13.9	14.2	14.4	14.8	15.0	15.4	15.5	14.6	0.634	4.3%			
	1 min	A	14.6	14.7	14.9	15.1	15.2	15.2	15.7	15.9	15.2	0.453	3.0%	14.6	16.1	Moderate
		B	13.0	13.3	13.8	14.1	14.6	14.7	15.0	15.1	14.2	0.782	5.5%			
		C	14.0	14.0	14.0	14.0	14.4	14.7	15.6	15.9	14.6	0.772	5.3%			
		Average	13.9	14.0	14.2	14.4	14.7	14.9	15.4	15.6	14.6	0.644	4.4%			
	2 min	A	14.8	15.0	15.1	15.1	15.2	15.3	15.6	15.9	15.3	0.351	2.3%	14.7	16.2	Moderate
		B	13.5	13.6	13.9	14.0	14.6	14.7	15.1	15.1	14.3	0.645	4.5%			
		C	13.6	13.9	14.1	14.1	14.7	15.0	15.6	15.8	14.6	0.811	5.6%			
		Average	14.0	14.2	14.4	14.4	14.8	15.0	15.4	15.6	14.7	0.595	4.0%			
	5 min	A	14.6	14.8	15.0	15.0	15.2	15.2	15.9	16.2	15.2	0.545	3.6%	14.7	16.2	Moderate
		B	13.4	13.5	13.9	14.0	14.8	15.0	15.1	15.2	14.4	0.742	5.2%			
		C	13.7	13.9	14.0	14.2	14.8	14.9	15.3	15.7	14.6	0.721	5.0%			
		Average	13.9	14.1	14.3	14.4	14.9	15.0	15.4	15.7	14.7	0.654	4.4%			
	10 min	A	14.8	14.8	15.0	15.4	15.6	15.6	15.9	16.1	15.4	0.493	3.2%	14.9	16.4	Moderate
		B	13.2	13.8	14.0	14.1	14.8	15.0	15.1	15.2	14.4	0.727	5.0%			
		C	14.1	14.2	14.3	14.6	14.9	15.3	15.7	15.9	14.9	0.694	4.7%			
		Average	14.0	14.3	14.4	14.7	15.1	15.3	15.6	15.7	14.9	0.627	4.2%			
	15 min	A	15.0	15.3	15.4	15.5	15.8	16.0	16.1	16.6	15.7	0.514	3.3%	15.1	16.6	Moderate
		B	13.8	13.9	14.2	14.3	14.8	14.8	15.2	15.5	14.6	0.612	4.2%			
		C	13.9	14.3	14.7	14.8	14.9	15.0	16.0	16.1	15.0	0.760	5.1%			
		Average	14.2	14.5	14.8	14.9	15.2	15.3	15.8	16.1	15.1	0.619	4.1%			
	20 min	A	15.0	15.3	15.4	15.5	15.6	15.8	16.3	16.6	15.7	0.530	3.4%	15.1	16.6	Moderate
		B	13.8	13.9	14.1	14.3	15.0	15.2	15.4	15.4	14.6	0.682	4.7%			
		C	13.8	14.3	14.6	14.6	15.0	15.0	15.7	15.9	14.9	0.697	4.7%			
		Average	14.2	14.5	14.7	14.8	15.2	15.3	15.8	16.0	15.1	0.623	4.1%			
	30 min	A	15.1	15.4	15.5	15.7	15.9	16.1	16.5	16.6	15.9	0.529	3.3%	15.2	16.8	Moderate
		B	13.8	13.9	14.4	14.5	14.8	15.2	15.4	15.7	14.7	0.690	4.7%			
		C	14.0	14.2	14.3	14.3	15.9	16.0	16.0	16.4	15.1	1.017	6.7%			
		Average	14.3	14.5	14.7	14.8	15.5	15.8	16.0	16.2	15.2	0.730	4.8%			
	Giatec (0 secs)	A	14.8	14.8	15.3	15.3	15.3	15.3	15.6	15.6	15.3	0.307	2.0%	14.8	16.2	Moderate
		B	14.1	14.1	14.2	14.2	14.3	14.4	14.8	14.8	14.4	0.288	2.0%			
		C	14.4	14.4	14.6	14.6	14.8	14.8	14.8	14.9	14.7	0.192	1.3%			
		Average	14.4	14.4	14.7	14.7	14.8	14.8	15.1	15.1	14.8	0.250	1.7%			

P:100C - 90 Day Testing	**0 secs**	A	14.9	14.9	15.1	15.1	15.3	15.4	15.6	16.0	15.3	0.376	2.5%	14.8	16.3	Moderate
		B	13.7	13.8	14.2	14.2	15.0	15.1	15.1	15.4	14.6	0.661	4.5%			
		C	13.8	13.9	14.1	14.5	14.8	14.9	15.5	15.8	14.7	0.731	5.0%			
		Average	14.1	14.2	14.5	14.6	15.0	15.1	15.4	15.7	14.8	0.578	3.9%			
	30 secs	A	14.8	14.8	14.9	15.2	15.2	15.4	15.8	15.9	15.3	0.428	2.8%	14.8	16.3	Moderate
		B	13.4	13.7	14.3	14.4	14.8	15.0	15.0	15.5	14.5	0.706	4.9%			
		C	13.8	13.8	14.2	14.3	14.8	14.9	15.7	15.8	14.7	0.782	5.3%			
		Average	14.0	14.1	14.5	14.6	14.9	15.1	15.5	15.7	14.8	0.625	4.2%			
	1 min	A	14.7	14.8	15.1	15.4	15.5	15.5	15.6	15.7	15.3	0.376	2.5%	14.8	16.3	Moderate
		B	13.6	13.9	14.2	14.4	14.7	14.7	14.7	15.3	14.4	0.534	3.7%			
		C	13.9	14.0	14.1	14.2	14.8	15.1	15.5	15.6	14.7	0.691	4.7%			
		Average	14.1	14.2	14.5	14.7	15.0	15.1	15.3	15.5	14.8	0.517	3.5%			
	2 min	A	15.0	15.0	15.2	15.2	15.3	15.5	15.8	16.1	15.4	0.391	2.5%	15.0	16.5	Moderate
		B	13.6	14.0	14.2	14.5	14.7	15.0	15.2	15.5	14.6	0.640	4.4%			
		C	14.5	14.6	14.9	14.9	14.9	15.3	15.6	15.9	15.1	0.486	3.2%			
		Average	14.4	14.5	14.8	14.9	15.0	15.3	15.5	15.8	15.0	0.499	3.3%			
	5 min	A	15.1	15.2	15.4	15.4	15.7	16.0	16.4	16.4	15.7	0.515	3.3%	15.2	16.7	Moderate
		B	13.8	14.2	14.4	14.5	15.1	15.1	15.5	15.7	14.8	0.664	4.5%			
		C	14.2	14.5	14.8	14.8	14.9	15.2	16.1	16.2	15.1	0.718	4.8%			
		Average	14.4	14.6	14.9	14.9	15.2	15.4	16.0	16.1	15.2	0.624	4.1%			
	10 min	A	15.4	15.4	15.5	15.5	15.6	15.8	16.4	16.5	15.8	0.444	2.8%	15.3	16.9	Moderate
		B	14.0	14.0	14.5	14.6	15.3	15.4	15.5	15.8	14.9	0.702	4.7%			
		C	14.3	14.7	14.9	15.2	15.3	15.7	16.1	16.3	15.3	0.690	4.5%			
		Average	14.6	14.7	15.0	15.1	15.4	15.6	16.0	16.2	15.3	0.594	3.9%			
	15 min	A	15.3	15.6	15.7	15.9	16.1	16.3	17.0	17.2	16.1	0.670	4.1%	15.7	17.2	Moderate
		B	14.4	14.4	14.7	14.8	15.6	15.9	16.0	16.0	15.2	0.719	4.7%			
		C	14.7	14.7	15.1	15.1	15.6	16.3	16.6	16.7	15.6	0.830	5.3%			
		Average	14.8	14.9	15.2	15.3	15.8	16.2	16.5	16.6	15.7	0.726	4.6%			
	20 min	A	15.5	15.9	16.0	16.1	16.2	16.5	17.0	18.2	16.4	0.841	5.1%	15.8	17.4	Moderate
		B	14.2	14.4	14.7	14.8	15.3	15.5	16.1	16.2	15.2	0.750	5.0%			
		C	14.6	14.8	15.5	15.8	16.0	16.1	16.5	16.9	15.8	0.789	5.0%			
		Average	14.8	15.0	15.4	15.6	15.8	16.0	16.5	17.1	15.8	0.770	4.9%			
	30 min	A	16.2	16.4	16.4	16.5	16.6	16.9	17.2	17.6	16.7	0.474	2.8%	16.1	17.7	Moderate
		B	14.5	15.0	15.2	15.2	15.9	16.2	16.5	16.7	15.7	0.787	5.0%			
		C	14.8	14.9	15.1	15.2	15.7	16.4	16.8	17.3	15.8	0.947	6.0%			
		Average	15.2	15.4	15.6	15.6	16.1	16.5	16.8	17.2	16.1	0.728	4.5%			
	Giatec (0 secs)	A	15.3	15.3	15.5	15.6	15.7	15.8	16.2	16.2	15.7	0.355	2.3%	15.3	16.8	Moderate
		B	14.5	14.5	14.8	14.8	15.4	15.4	15.5	15.6	15.1	0.460	3.1%			
		C	14.6	14.7	14.9	14.9	15.3	15.3	15.5	15.5	15.1	0.356	2.4%			
		Average	14.8	14.8	15.1	15.1	15.5	15.5	15.7	15.8	15.3	0.384	2.5%			

Bulk Resistivity (BR) Readings (Kohm-cm)

Mixture Designation	Age (days)	Sample Designation	BR Value	Set Average	BR:SR Factor
P: 100C	7	A	27.8	27.3	2.62
		B	25.9		
		C	28.3		
	14	A	33.5	32.6	2.78
		B	31.8		
		C	32.4		
	28	A	37.3	36.3	2.62
		B	34.9		
		C	36.6		
	56	A	42.9	41.7	2.61
		B	39.9		
		C	42.4		
	90	A	44.1	43.2	2.65
		B	41.7		
		C	43.8		
P: 100C in Molds (15 mins in bath)	7	A	31.3	30.1	2.80
		B	29.4		
		C	29.5		
	14	A	35.5	35.7	3.04
		B	36.0		
		C	35.5		
	28	A	39.7	39.8	2.92
		B	37.4		
		C	42.4		
P: 80C - 20A	7	A	15.7	15.3	2.69
		B	15.5		
		C	14.8		
	14	A	19.2	19.0	2.67
		B	19.2		
		C	18.6		
	28	A	26.4	26.0	2.69
		B	26.2		
		C	25.5		
P: 50C - 20A - 30S	7	A	21.0	20.8	2.61
		B	20.8		
		C	20.5		
	14	A	35.5	35.6	2.56
		B	35.1		
		C	36.1		
				AVERAGE	2.71

APPENDIX D

OTHER TESTING

Chloride Ion Diffusion Testing Data

P:100C

x (mm)	A	B	C	Average
2	0.662	1.162	1.018	0.94733
3	0.556	0.815	0.735	0.702
4	0.412	0.63	0.579	0.54033
5	0.396	0.549	0.403	0.44933
7	0.272	0.402	0.32	0.33133
9	0.175	0.315	0.252	0.24733
11	0.109	0.172	0.224	0.16833
13	0.063	0.15	0.145	0.11933

P:80C-20A

x (mm)	A	B	C	Average
2	-	1.494	2.027	1.7605
3	-	1.205	1.222	1.2135
4	0.849	0.934	1.158	0.98033
5	0.65	0.7	0.967	0.77233
7	0.469	0.403	0.598	0.49
9	0.359	0.233	0.345	0.31233
11	0.256	0.146	0.16	0.18733
13	0.173	0.072	0.14	0.12833

P:50C-20A-30S

x (mm)	A	B	C	Average
2	0.758	-	-	0.758
3	0.546	-	-	0.546
4	0.364	-	-	0.364
5	0.245	-	-	0.245
7	0.099	-	-	0.099
9	0.083	-	-	0.083
11	-	-	-	-
13	-	-	-	-

x (mm)	Chloride Ion Content (%)		
	P:100C	P:80C-20A	P:50C-20A-30S
2	0.947	1.761	0.758
3	0.702	1.214	0.546
4	0.540	0.980	0.364
5	0.449	0.772	0.245
7	0.331	0.490	0.099
9	0.247	0.312	0.083
11	0.168	0.187	-
13	0.119	0.128	-

Summary	C_s	D
P:100C	0.877633333	7.96E-12
P:80C-20A	1.741533333	3.89E-12
P:50C-20A-30S	0.893	1.72E-12

Rapid Chloride Permeability Data next to corresponding SR result. Used to make SR vs RCP figure.

	SR	RCP
P:100C	10.4179	4156
P:100C in Molds	10.7204	4012
P:80C-20A	5.70167	9686
P:50C-20A-30S	7.95667	4387
B2:85C-15A	7.75042	4290
B2L:85C-15A	7.60375	4429
MB2:85C-15A	7.73667	5148
S:80C-20A	10.065	3295
S:50C-50A	7.44792	4339
R1:50C-50CSA	29.0	1861.67
R2:100C	5.49083	5247.7
P:100C	13.8417	2794
P:100C in Molds	13.64	3193
P:80C-20A	9.68917	4029
P:50C-20A-30S	22.0092	1444
B2:85C-15A	10.3675	3674
B2L:85C-15A	10.7204	3048
MB2:85C-15A	10.5738	3947
S:80C-20A	14.1671	2158
S:50C-50A	28.7421	1197
P:100C	16.3213	2003
P:100C in Molds	17.2608	2149
P:80C-20A	16.2663	2486
P:50C-20A-30S	36.8088	789
B2:85C-15A	16.3533	2273
B2L:85C-15A	20.0063	1979
MB2:85C-15A	16.7429	2217
S:80C-20A	26.0242	1544
S:50C-50A	75.9779	528
R1:50C-50CSA	37.1571	864.667
R2:100C	16.2617	2163
High	12	4000
Moderate	21	2000
Low	37	1000

APPENDIX E

FIELD TESTING

Field Tested Bridge Deck: Temperature Considerations

Highway 136 and Shoal Creek - Putnam County - 10/28/2014

Time	Minutes Elapsed	Temp. on Bridge	Temp. on Bridge with Ice	Temp. Outside	Humidity
9:15	0	47	-	57	47%
9:30	15	46	34	54.1	50%
9:46	31	49	35	54.3	48%
10:02	47	50	37	55	47%
10:15	60	52	46	55	47%
10:35	80	60	39	58.9	45%
10:43	88	61	39	64.4	39%
10:58	103	62	39	61.8	40%

* Temperature shown in degrees F

Surface Resistivity Readings in kOhm-cm

Sample	West to East				North to South				Diagonal				Temp. (F)
A1	135.6	115.0	125.8	103.3	133.4	118.5	124.5	142.9	130.6	135.5	115.5	126.2	40
B2	5.6	8.5	8.0	8.9	6.6	6.0	7.2	7.0	5.9	8.2	8.0	7.0	37
B3	154.2	153.8	144.5	112.9	131.0	142.1	130.7	137.2	158.1	119.2	129.3	132.8	37
C2	23.7	21.5	20.9	17.4	21.8	18.1	19.8	27.0	26.5	14.1	20.3	22.5	36
D3	802	782	775	432	987	676	562	441	884	742	424	437	31
E2	30.0	27.7	32.7	31.1	26.7	26.9	32.1	32.5	25.5	26.1	31.1	29.4	33
E20	35.6	34.8	28.3	31.9	27.5	30.2	35.5	37.0	30.8	33.2	31.5	32.0	34
E3	19.3	19.9	21.4	15.8	12.9	16.7	19.4	22.3	14.3	22.7	19.6	22.9	33
F3	415	434	428	492	488	421	362	467	479	454	438	475	34
F1	62.1	127.3	287	431	188.2	197	274	257	101.2	162.7	176.5	484	29
F2	17.4	17.1	13.9	17.8	16.6	16.2	17.8	14.7	15.8	16.5	13.9	12.7	32

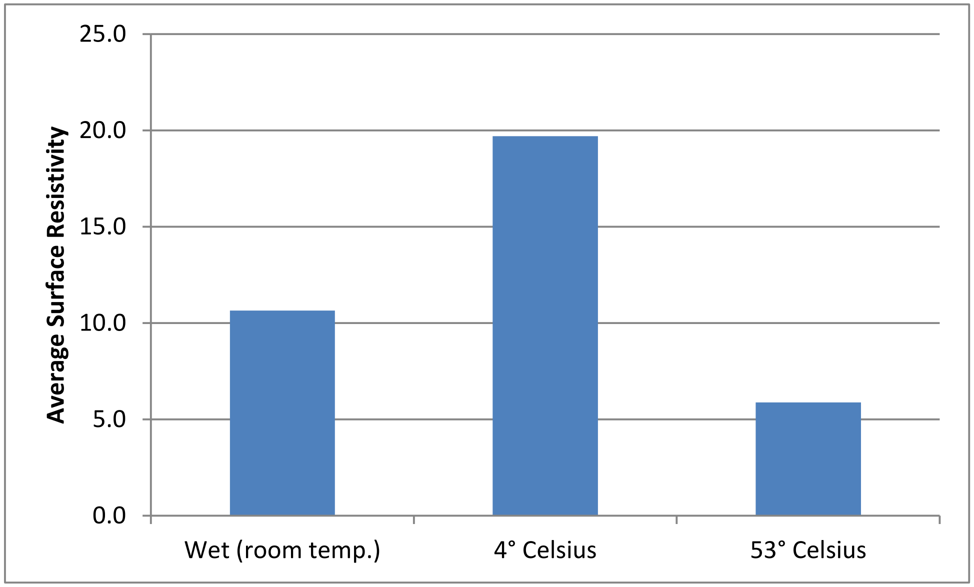
MoDOT Field Samples – All Data

I-70 KC			UMKC			MoDOT	MoDOT/UMKC comparison		Average
	SR	7	5.8	SR	7	5.1	88%	SR	105%
		28	8.5		28	7.7	91%		
		90	13.1		90	14	107%		
	RCP	7	7327	RCP	7	3463	47%	RCP	91%
		28	4694		28	4875	104%		
		90	2754		90	2630	95%		
	strength	7	4039	strength	7	3570	88%	strength	92%
		28	4894		28	4730	97%		
		90	5856		90	5340	91%		

Rte. 41 Laramie River			UMKC			MoDOT	
	SR	7	5.7	SR	7	6.1	107%
		28	10.5		28	12	114%
		90	18.2		90	21.1	116%
	RCP	7	5558	RCP	7	6799	122%
		28	3152		28	3279	104%
		90	2057		90	2163	105%
	strength	7	4799	strength	7	4270	89%
		28	5878		28	5440	93%
		90	5833		90	5470	94%

St. Louis pavement			UMKC			MoDOT	
	SR	7	6.9	SR	7	7	101%
		28	11.9		28	12.7	107%
		90	19.8		90	22.8	115%
	RCP	7	4221	RCP	7	5155	122%
		28	2936		28	2232	76%
		90	1798		90	1132	63%
	strength	7	3480	strength	7	3720	107%
		28	5015		28	4500	90%
		90	6439		90	5340	83%

MoDOT Temperature effect on SR values
(MoDOT values)



	Wet (room temp.)	4° Celsius	53° Celsius
	10.6	19.7	5.9
% Differ.		185%	55%

Air Content for all Mixtures Batched in the Lab

Mixture Designation	**Air Content (%)**
P:100C	5.1
P:100C in Molds	4.5
P:80C-20A	5.9
P:50C-20A-30S	3.5
B2:85C-15A	5.4
B2L:85C-15A	5.9
MB2:85C-15A	3.7
S:80C-20A	3.9
S:50C-50A	3.7

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VITA

Dirk Paul Hudson was born on April 28, 1992 in Weston, Missouri. Mr. Hudson attended West Platte High School where he completed numerous science and engineering projects on concrete and the effect of concrete additives on the strength of the concrete. The projects were presented regionally to varying panels of judges at fairs throughout the Midwest. Upon graduation of West Platte High School, Mr. Hudson received the valedictorian honor for placing 1 in his class academically.

Mr. Hudson attended the University of Missouri – Kansas City to continue his academic and athletic careers. Mr. Hudson received a Bachelor of Science in Civil Engineering in May 2014 while completing four years of NCAA Division 1 varsity athletics in the sports of cross country, indoor track and field, and outdoor track and field. Academically, Mr. Hudson earned cum laude honors for his undergraduate degree. Athletically, Mr. Hudson earned first team All-Western Athletic Conference (WAC) honors for his second place finish in the outdoor track 10,000 meter event. Mr. Hudson is a member of the civil engineering honor society, Chi Epsilon.

Mr. Hudson continued his education towards a Master of Science in Civil Engineering, with an emphasis in Materials Engineering and Construction Management from the University of Missouri – Kansas City. Mr. Hudson started work at a heavy civil and environmental construction company as a project engineer in January 2015. Mr. Hudson received a Master of Science in Civil Engineering and Engineering and Construction Project Management Certificate in May 2015.

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