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Determining Concrete Chloride Permeability More Efficiently

PART 1: A NEW SHERIFF IN TOWN?

OVERVIEW

The Tennessee Department of Transportation (TDOT) is considering two new technologies to determine concrete chloride permeability more efficiently:

- A. Surface Resistivity AASHTO TP 95-11 [1]
- B. Accelerated Curing as per AASHTO TP 95-11 [1] and ASTM C 1202-12 [2]

This paper is the first in a three part series of technology transfer articles. We hope that you find the information presented helpful in mixture design and evaluation. In Part 1, surface resistivity basics, statistical comparisons, logistical comparisons and correlations between surface resistivity and rapid chloride permeability will be examined. Subsequent articles will examine:

2. Accelerated vs. Normal Curing – Choosing a Curing Method
3. Possible TDOT Surface Resistivity Specifications and Mixture Design Suggestions

INTRODUCTION

AASHTO TP 95-11 surface resistivity (SR) and AASHTO T 277-07 [3] rapid chloride permeability (RCP) both provide an electrical indication of concrete's resistance to chloride ion penetration. SR measures the electrical resistance while RCP measures the charge passed; therefore, the scales are inverted as shown in Table 1. The categories (column 1) are independent of testing age. The commonly used Wenner probe (shown in Figure 1) incorporates four equally spaced electrodes that apply a voltage between the outer probes while the inner probes measure the potential difference. The handheld device then converts the measured electrical resistance into an apparent resistivity which has been correlated with chloride ion penetration.

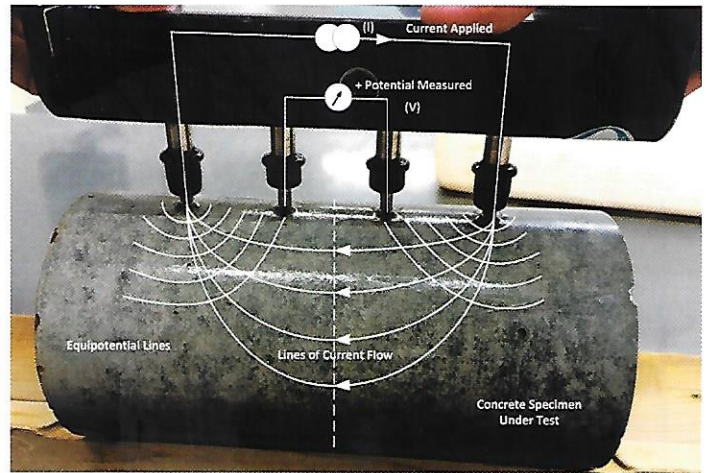


Figure 1: Schematic of AASHTO TP 95-11 Surface Resistivity

CONDUCTING A SURFACE RESISTIVITY TEST

The brief summary presented here will use 4x8-inch cylinders, although 6x12-inch cylinders are allowed by AASHTO TP 95-11. This summary lacks sufficient detail and the reader is referred to AASHTO TP 95-11 for detailed instructions on how to conduct the test. Each set for the test method is comprised of three cylinders. The top of the cylinders are marked at every 90° as shown in Figure 2. After removal from the moist room or curing tank, excess water is blotted off the cylinder and placed in a non-conductive sample holder (see Figure 3). The contact points of the electrodes are moistened prior to each reading. Readings are then taken around the cylinder specimen at 0°, 90°, 180°, and 270° twice, averaging the results for that specimen (see Figure 4). A correction factor of 1.1 is then multiplied by the average of the readings for the lime-water curing condition (see Table 2).

TABLE 1. CATEGORIES FOR SURFACE RESISTIVITY AND RAPID CHLORIDE PERMEABILITY

CHLORIDE ION PENETRATION	SURFACE RESISTIVITY TEST (4X8-INCH CYLINDERS WITH $a=1.5$ INCHES IN $K\Omega\text{-CM}$)	AASHTO T 277-07 CHARGE PASSED IN COULOMBS
High	< 12	> 4000
Moderate	12 – 21	> 2000 – 4000
Low	21 – 37	> 1000 – 2000
Very Low	37 – 254	100 – 1000
Negligible	> 254	< 100

TABLE 2. EXAMPLE DATA AND RESULT FOR A SURFACE RESISTIVITY TEST

SAMPLE ID	0°	90°	180°	270°	0°	90°	180°	270°	AVERAGE
D-25-19	23.1	24.9	22.9	22.8	22.9	25.0	22.9	23.6	23.5
D-25-20	23.3	23.8	24.2	23.8	23.4	23.1	23.9	23.7	23.7
D-25-21	23.0	23.5	23.3	22.5	21.7	22.7	22.9	22.4	22.8
Set Average									23.3
Curing Condition Correction (x 1.1 lime water tank or 1.0 for moist room)									1.1
Surface Resistivity Test Result									25.6

TABLE 3. COMPARISON OF AASHTO ALLOWABLE COEFFICIENTS OF VARIATION

STATISTICAL PARAMETER	AASHTO TP 95-11	AASHTO T 277-07
Single Operator COV (%)	6.3	12.3
Multi-laboratory COV (%)	12.5	18.0

TABLE 4. COMPARISON OF COEFFICIENTS OF VARIATION FROM TDOT PROJECT

AGE	CURING	MIXTURE	TEST METHOD	COV (%)	WINNER
28-day	Accelerated	Class D 80/20	RCP	10.7	SR
28-day	Accelerated	Class D 80/20	SR	6.3	
28-day	Accelerated	50/35/15	RCP	5.3	Neither
28-day	Accelerated	50/35/15	SR	5.0	
56-day	Normal	Class D 80/20	RCP	6.0	Neither
56-day	Normal	Class D 80/20	SR	6.2	
56-day	Normal	50/35/15	RCP	5.1	RCP
56-day	Normal	50/35/15	SR	7.8	
91-day	Normal	Class D 80/20	RCP	12.1	SR
91-day	Normal	Class D 80/20	SR	5.9	
91-day	Normal	50/35/15	RCP	10.4	Neither
91-day	Normal	50/35/15	SR	9.8	

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Figure 2: 4x8-inch Cylinders Marked for Conducting Surface Resistivity Testing



Figure 3: Conducting Surface Resistivity on Required Non-conductive Cradle



Figure 4: Surface Resistivity Readout

COMPARISON OF SR AND RCP TEST METHODS

Statistical Comparison

Table 3 shows a comparison of AASHTO allowable coefficients of variation for each method. AASHTO allowable coefficients of variation indicate that SR is clearly better. However, Tennessee Technological University (TTU) data (see Table 4) shows that there is no clear winner (2-1 SR with 3 no contests).

Logistical Comparison

RCP requires sawing of 2-inch slices from 4x8-inch cylinders (see Figure 5), epoxy coating of the 2-inch slices (see Figure 6), and chemicals in the cell reservoirs during testing (see Figure 7). SR requires no preparation or additional materials. Table 5 shows an extensive logistical comparison of the test methods and indicates a logistical knockout in which SR is a clear winner in every category.



Figure 5: Water-cooled Saw and Sawed Specimens for RCP



Figure 6: Epoxy Coating of 2-inch Slices for RCP Test

TABLE 5. COMPARISON OF LOGISTICAL FACTORS

PARAMETER	RCP	SR	ADVANTAGE
Initial Cost	Approx. \$12,000	Approx. \$3,000	SR
Recurring Costs	Chemicals, Epoxy	None	SR
Data Availability	2 days	About 10 minutes	SR
Time to Conduct	6 hours	About 10 minutes	SR
Preparation Time	1.5 days	About 15 minutes	SR
Clean Up Time	2 hours	Minutes	SR
Safety/Environmental Regulations	Specimen Sawing, Chemical Storage	None	SR
Sample Reuse	No	Yes	SR
Technician Training	Considerable	Minimal	SR

TABLE 6. RCP-SR POINTS FOR CORRELATION PLOT

MIXTURE	PROJECT	C ASH (%)	F ASH (%)	SLAG (%)	28-DAY ACCELERATED POINTS	56-DAY POINTS	91-DAY POINTS
50/25/25F	TTU Slag Study	0	25	25	0	2	2
50/30/20F	TTU Slag Study	0	20	30	0	2	2
50/35/15F	TTU Slag Study	0	15	35	0	2	2
50/25/25C	TTU Slag Study	25	0	25	0	2	2
50/30/20C	TTU Slag Study	20	0	30	0	2	2
50/35/15C	TTU Slag Study	15	0	35	0	2	2
TDOT D 20F	TTU Aggregate Variable Study	0	20	0	0	16	0
TDOT D 100PC	TTU High Perm TDOT D Study	0	0	0	3	7	0
TDOT D 25C	TTU Aborted MS Thesis	25	0	0	0	8	10
TDOT D 20F	TDOT SR Project	0	20	0	20	20	20
TDOT D 20F	SR Project Redo	0	20	0	4	0	2
50/35/15F	TDOT SR Project	0	15	35	20	20	20
50/35/15F	SR Project Redo	0	15	35	0	4	4
Total Points					47	87	68

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Figure 7: Chemical Reservoirs in RCP Test Cells

CORRELATION BETWEEN RCP AND SR

SR and RCP both provide an electrical indication of concrete's resistance to chloride ion penetration and therefore should be related. The research team reasoned that correlations would be more widely applicable if based on larger and more diverse data sets. Therefore, an attempt was made to maximize the amount and diversity of data on which answers were based. One provision made was that the data diversity would be limited to mixtures TDOT would consider using for bridge decks (no water-to-cementing materials ratio (w/cm) > 0.40, no exotic materials, etc.). A summary of all available data sets is provided in Table 6. Brief descriptions of two selected studies are provided in the next paragraph.

The unpublished TTU aggregate variable study was a preliminary attempt to determine the effect of coarse and fine aggregate type on RCP and SR. NASCAR legend Richard Petty said, "You've got to have some slow guys to make the fast guys look fast." The TTU high permeability Class D study was an attempt to provide some "slow guys." Specifically, to determine how high RCP would rise (and how low SR would sink) if the worst available TDOT approved choices were made for the coarse aggregate and portland cement-supplementary cementing materials (PC-SCM) matrix. It is important to note that the w/cm used met TDOT requirements. The worst available category referred to the poorest performing TDOT approved aggregates in the TTU aggregate variable study.

Figure 8 below shows all 202 TTU data points compared to an equation derived from the AASHTO test method category limits (see Table 1). The TTU data was regressed against the corresponding values generated by the AASHTO equation using the SR values as the independent variable. The intercept term was constrained to a value of 0. The t-test was then used to test the null hypothesis of the slope parameter being equal to 1. Using a 5% level of significance, the equations compared were significantly different from each other. However, on average, TTU data was only 3.7% higher than predicted by the AASHTO equation.

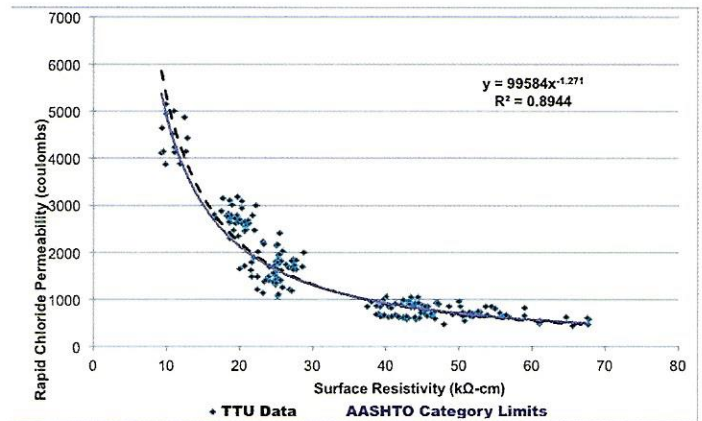


Figure 8: Comparison of All TTU Data with Equation from the AASHTO Test Method Category Limits

Table 7 below shows TTU correlations of SR and RCP with various data subsets as well as three reference correlations:

1. A correlation equation based off the AASHTO test method category limits (see Table 1)
2. A correlation from the Federal Highway Administration (FHWA) Turner-Fairbank Laboratory [4]
3. A correlation from the Louisiana Transportation Research Center (LTRC) [5]

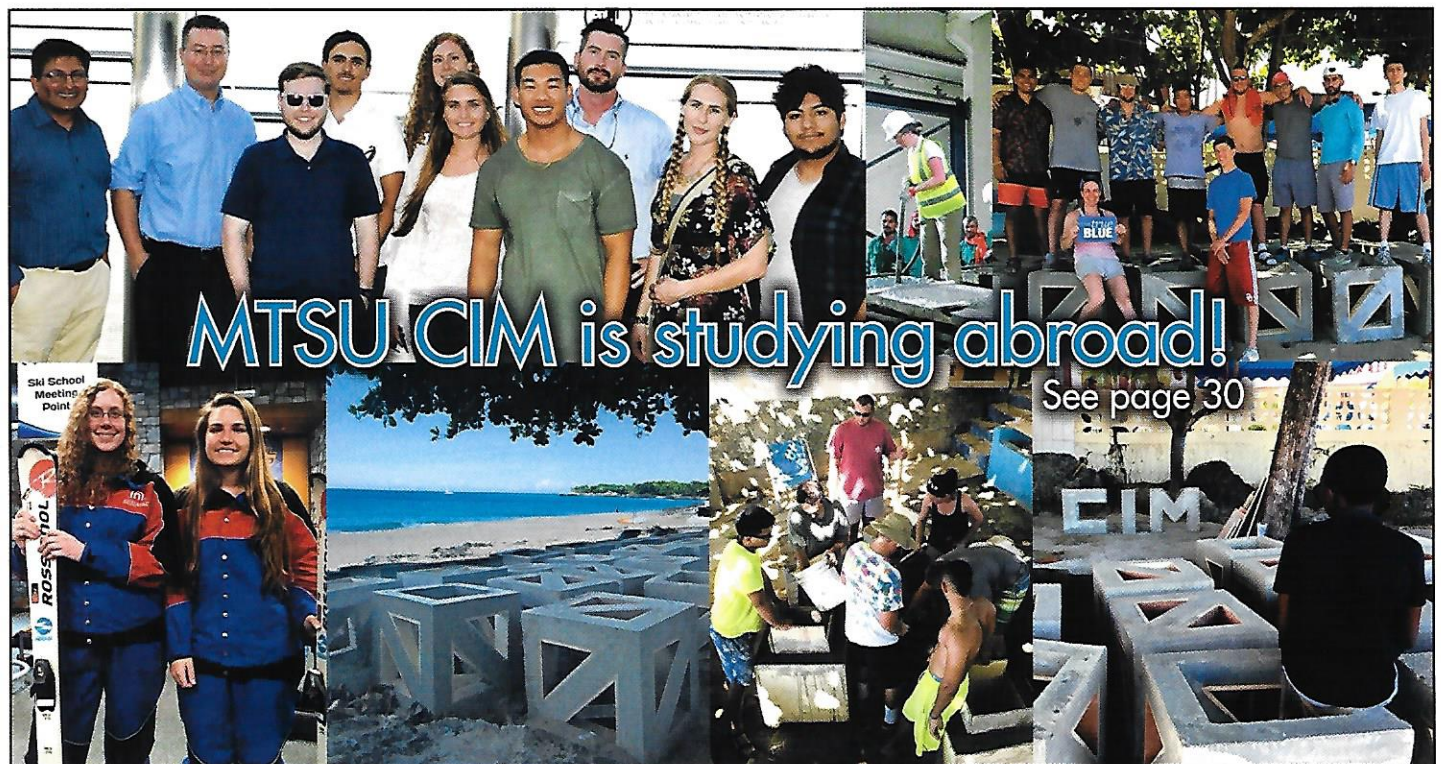
All correlations have coefficients of determination greater than 0.89, indicating strong relationships between SR and RCP.

TABLE 7. COMPARISONS OF SR-RCP CORRELATION COEFFICIENTS

CORRELATION SOURCE	CORRELATION EQUATION	CORRELATION COEFFICIENT
AASHTO Test Method Category Limits	$RCP=79074(SR)^{-1.206}$	0.9999
FHWA Turner Fairbank Laboratory	$RCP=98441(SR)^{-1.35}$	0.9200
LTRC	$RCP=39647(SR)^{-0.944}$	0.8922
All TTU Data	$RCP=99584(SR)^{-1.271}$	0.8944
TTU 91-day Data	$RCP=125451(SR)^{-1.316}$	0.9168
TTU 56-day Data	$RCP=104446(SR)^{-1.253}$	0.9601
TTU 56- and 91-day Data	$RCP=114533(SR)^{-1.285}$	0.9524
TTU 28-day Accelerated Data	$RCP=81780(SR)^{-1.299}$	0.9772

TABLE 8. SR VS. RCP SUMMARY

PARAMETER	ADVANTAGE
Accuracy	Not Known
Variability (Precision)	Slight Edge SR (AASHTO Allowable)
Cost	Clearly SR (more than 4:1)
Time	Clearly SR (minutes vs. days)
Ease of Operation	Clearly SR
Safety	SR (no chemicals or sawing)
Overall	Clearly SR



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CONCLUSIONS

There is a new sheriff in town—SR is clearly superior to RCP as shown in Table 8.

DISCLAIMER

The opinions expressed herein are those of the authors and not necessarily the opinions of the FHWA, the TDOT, the LTRC, or the Tennessee Concrete Association (TCA).

REFERENCES

AASHTO TP 95-11. "Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration." American Association of State Highway and Transportation Officials. Provisional Standards, 17th edition, June 2013.

ASTM C 1202-12. "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration."¹ American Society for Testing and Materials **Annual Book of ASTM Standards**. Vol. 04.02, 2014, pp. 677-684.

AASHTO T 277-07. "Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration." American Association of State Highway and Transportation Officials. Standard Specifications for Transportation Materials and Methods of Sampling and Testing Part 2A. 2011.

FHWA-HRT-13-024 Surface Resistivity Test Evaluation as an Indicator of Chloride Permeability of Concrete.

"Evaluation of Surface Resistivity Measurements as an Alternative to Rapid Chloride Permeability Tests for Quality Assurance and Acceptance," Rupnow and Icenogle, Louisiana Transportation Research Center.

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