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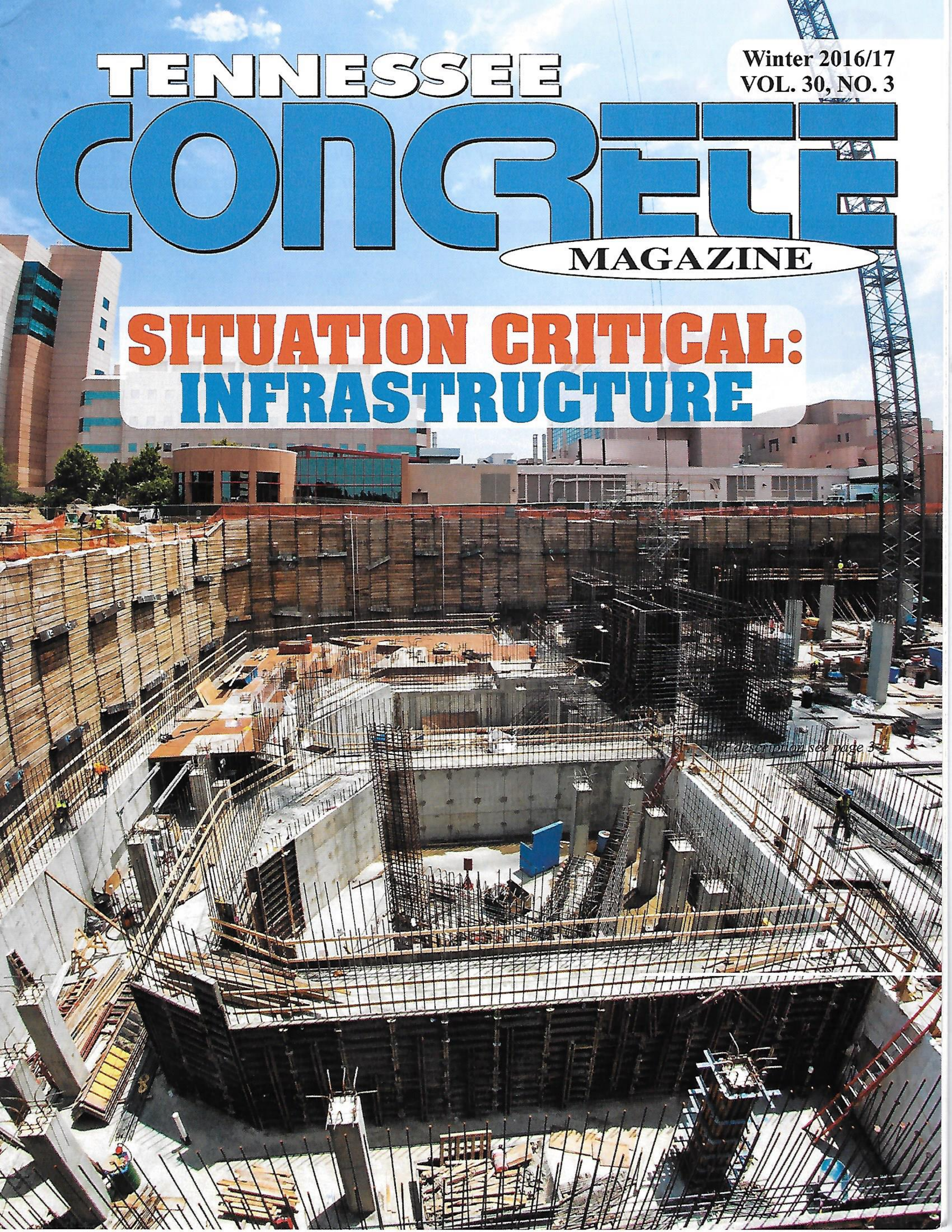

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by L. K. Crouch, James Locum, Aaron Crowley, Sarah Dillon, Daniel Badoe and Heather P. Hall

Determining Concrete Chloride Permeability More Efficiently

PART 2: ACCELERATED VS. NORMAL CURING—CHOOSING A CURING METHOD

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 second 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 2, the choice between normal and accelerated curing will be examined. The final article will provide recommendations for possible TDOT surface resistivity specifications and mixture design suggestions.

INTRODUCTION

AASHTO TP 95-11 [1] surface resistivity (SR) and ASTM C 1202-12 [2] rapid chloride permeability (RCP) test methods now mention, but do not mandate, accelerated moist curing. The accelerated moist curing consists of immersing the cylinders for 7 days at 73°F followed by 21 days at 100°F in lime-saturated water. AASHTO TP 95-11 [1] indicated that accelerated moist curing has been found useful in more rapidly determining the effects of slower reacting supplementary cementing materials (SCMs).

TDOT RESEARCH MIXTURES AND TESTING PROTOCOL

Two mixtures were selected for the TDOT research, as shown in Table 1. The TDOT Class D mixture with 20% Class F fly ash substitution was selected because it is commonly used and therefore representative of many low SCM substitution mixtures. The 50/35/15 mixture, which was not a Class D mixture at the time of selection but is now an acceptable Class D mixture in the new January 1, 2015 TDOT specifications [3], was selected as a representative of high SCM substitution mixtures. Table 2 shows the comparison of the two mixtures to the TDOT specifications at the time of selection. Please note that other than the SCM substitution levels, the mixtures are very similar. Five validation batches (data not shown) indicated that both mixtures met TDOT plastic and hardened property requirements for Class D portland cement concrete (PCC). Table 3 shows the testing protocol for the SR-RCP batches.

SR Data Quality

Table 4 shows SR mean results, minimum result, maximum result, range of results, and allowable range of results at each age tested for the TDOT Class D mixture. Table 5 shows the same information for the 50/35/15 mixture. The allowable range was determined by first multiplying the test method multi-laboratory coefficient of variation (COV) by a factor from ASTM C 670 [4] for the number of results (the factor for 10 results was used since the table contained no multiplier for 20 results). Finally, the product was multiplied by the mean result to obtain the allowable range. The multi-laboratory precision was used since AASHTO T 22 [5] states that the preparation of cylinders by different operators would probably increase the variation above multi-laboratory precision criteria. All SR test results for both mixtures met the acceptable range requirements.

COMPARISON OF NORMAL AND ACCELERATED CURING METHODS

Comparison of Ability to Predict Later Age Values

Figure 1 shows correlations between 28-day normally cured SR results and later age SR results. Figure 2 shows correlations between 28-day accelerated curing SR results and later age normally cured SR results. The ability to successfully predict later SR results was judged based on the coefficient of determination values. Table 6 shows a comparison of coefficients of determination for SR prediction. This certainly was a close fight; both curing methods produced very strong correlations with later age SR values. The scorecard (Table 6) shows a slight edge for normal curing. However, as close as this aspect of the contest was, the winner should be determined based on some other criteria.

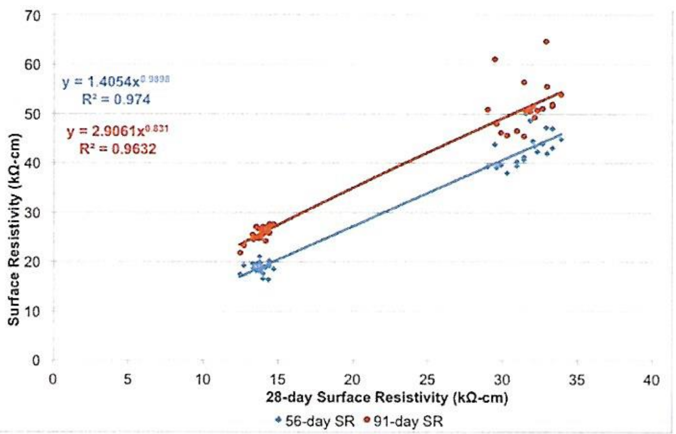

Figure 1: Correlations between 28-day SR and Later SR

TABLE 1. MIXTURES SELECTED FOR THE TDOT SR RESEARCH

Component	TDOT Class D	50/35/15
Type I Portland Cement	496-lbs/CY	310-lbs/CY
Class F Fly Ash	124-lbs/CY	93-lbs/CY
Grade 120 Slag	0-lbs/CY	217-lbs/CY
No. 57 Limestone (SSD)	1857-lbs/CY	1854-lbs/CY
River Sand (SSD)	1118-lbs/CY	1118-lbs/CY
Water	229.5-lbs/CY	229.5-lbs/CY
Design Percent Air	7 percent	7 percent
Air-entraining Admixture	0.5-oz/cwt (3.1-oz/CY)	1.55-oz/cwt (9.6-oz/CY)
Mid-range Water Reducer	0.1-oz/cwt (0.6-oz/CY)	1-oz/cwt (6.2-oz/CY)
High-range Water Reducer	3-oz/cwt (18.6-oz/CY)	2.1-oz/cwt (13.0-oz/CY)

TABLE 2. COMPARISON OF SELECTED MIXTURE ATTRIBUTES TO TDOT SPECIFICATIONS

Quantity/Ratio/Percentage	TDOT 604.03 Class D PCC Requirement (2006)	TDOT Class D	50/35/15
Cementing Materials Content	620-lbs/CY minimum	620-lbs/CY	620-lbs/CY
Water-to-Cementing-Materials-Ratio	0.40 maximum	0.370	0.370
(%) Fine Aggregate by Total Aggregate Volume	44 maximum	38	38
(%) Fly Ash Substitution (by weight) for Portland Cement	20 maximum (Class F)	20	15
(%) Slag Substitution (by weight) for Portland Cement	35 maximum	0	35

TABLE 3. TESTING PROTOCOL FOR RCP AND SR BATCHES

Parameter or Test Method	Quantity
Number of Batches per Mixture	20
Size of each batch (ft³)	1.35
Rapid Chloride Permeability (AASHTO T 277-07)	• 3 samples cut from separate 4x8 cylinders per batch @ 28 days of accelerated curing • 3 samples cut from separate 4x8 cylinders per batch @ 56 days of normal curing • 3 samples cut from separate 4x8 cylinders per batch @ 91 days of normal curing
Surface Resistivity (AASHTO TP 95-11)	• 3 4x8 cylinders per batch @ 28 days of accelerated curing • 3 4x8 cylinders per batch @ 28 days of normal curing • 3 4x8 cylinders per batch @ 56 days of normal curing • 3 4x8 cylinders per batch @ 91 days of normal curing
Compressive Strength (AASHTO T 22-10)	Surface resistivity cylinders were tested in compression following surface resistivity testing

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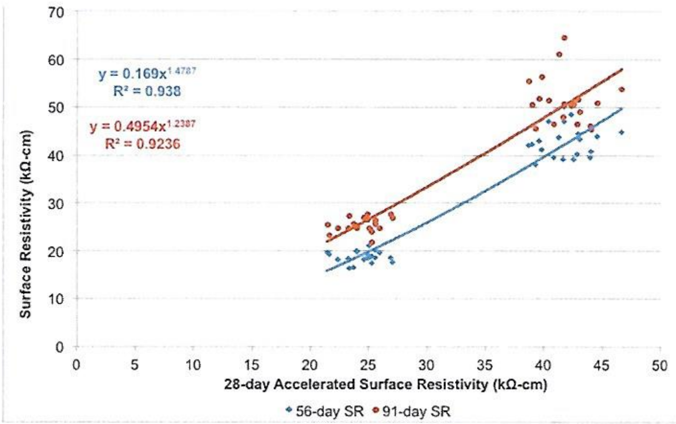

Figure 2: Correlations between 28-day Accelerated SR and Later Normally Cured SR

Prediction Time Ambiguity

Technical literature is somewhat ambiguous about what "time" or "equivalent age" accelerated curing is associated with:

1. Ozyildirim of the Virginia Transportation Research Council (who developed the method) states that accelerated curing produces results equivalent to 6 months of standard curing in TRR 1610 [6];
2. HPC Bridge Views Issue 67 May/June 2011 [7] states that accelerated curing provides results equivalent to 90 days of standard curing;
3. Several states, in a recent unpublished survey from TDOT research, use accelerated curing in lieu of a 56-day normal curing for RCP.

The research team was curious and attempted to solve the mystery. Mean values of normally cured SR for each mixture at all three ages (from Tables 4 and 5) were plotted in Figure 3. The linear regression equations were obtained using Microsoft Excel. Using the regression equations and the individual 28-day accelerated curing SR results, a time along the regression line (for normal curing) was calculated. The calculated "times" are also shown in Figure 3. The calculated "times" were then averaged to produce a mean age for each mixture. For the TDOT Class D mixture the mean age was 85.2 days. For the 50/35/15 mixture the mean age was 57.9 days. Unfortunately, the analysis seems to indicate that the mean age depends on the mixture (more particularly the PC-SCM matrix composition) being tested. The mean age may also depend on other factors. However, the extreme similarities (see Tables 1 and 2) of the two mixtures precludes the research team from investigating other factors with the currently available data.

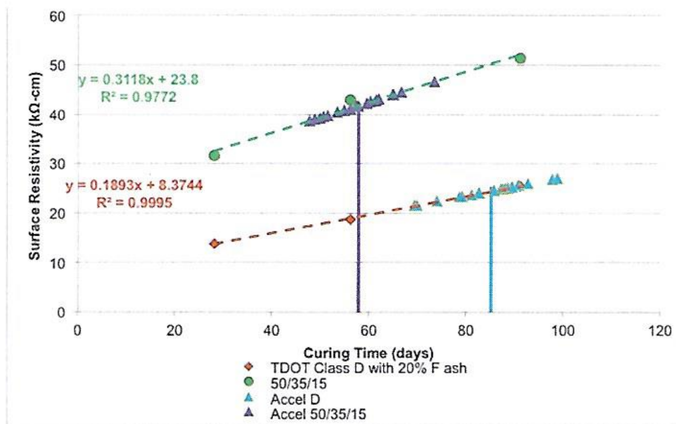

Figure 3: Mean Normally Cured SR Results versus Time with Calculated Equivalent Ages of Accelerated Curing SR Results

Logistical Comparison

Figure 4 shows the accelerated and normal curing tanks for the project. Figure 5 shows insulation (top, bottom, and sides) used on the accelerated curing tank. The insulation reduces the size of the water heater needed while also providing more time prior to temperature reduction outside of the specified range if the water heater power is lost. Figure 6 shows the larger water heater required for accelerated curing. The smaller in-tank water heater required for normal curing can be seen in Figure 4. Figure 7 shows the more elaborate plumbing required for accelerated curing. The small circulation pump for normal curing can be seen in Figure 4. Figure 8 shows the data acquisition package, thermocouple wires and computer required for temperature monitoring of both tanks. The computer battery back-up system (also shown in Figure 8) is not sufficient for the water heater for accelerated curing; a much higher wattage back-up system would be required. Table 7 shows a logistical comparison of normal and accelerated curing. The scorecard (Table 7) indicates a knockout victory for normal curing.

TABLE 4. SR MEAN RESULTS AND RANGES FOR THE TDOT CLASS D MIXTURE (kΩ-cm)

Category	Mean Value of Results	Minimum Value of Results	Maximum Value of Results	Allowable Range	Meets Allowable Range?
28-day SR	13.8	12.4	14.7	7.7	Yes
28-day Accelerated SR	24.5	21.5	27.1	13.7	Yes
56-day SR	18.8	16.5	21.2	10.5	Yes
91-day SR	25.5	21.9	27.7	5.8	Yes

TABLE 5. SR MEAN RESULTS AND RANGES OF RESULTS FOR THE 50/35/15 MIXTURE (kΩ-cm)

Category	Mean Value of Results	Minimum Value of Results	Maximum Value of Results	Allowable Range	Meets Allowable Range?
28-day SR	31.6	29.0	33.3	17.7	Yes
28-day Accelerated SR	41.9	38.7	46.7	23.5	Yes
56-day SR	43.0	38.1	50.2	24.1	Yes
91-day SR	51.4	45.4	64.7	28.9	Yes

TABLE 6. COMPARISON OF COEFFICIENTS OF DETERMINATION FOR LATER AGE SR PREDICTION

Predictor	Attempting to Predict	Correlation Coefficient
28-day Accelerated Curing	56-day	0.9380
28-day Normal Curing	56-day	0.9740
28-day Accelerated Curing	91-day	0.9236
28-day Normal Curing	91-day	0.9632

TABLE 7. COMPARISON OF LOGISTICAL FACTORS

Parameter	Accelerated	Normal	Advantage
Water Heater	Larger and more expensive	Smaller and less expensive	Normal
Water Circulation	Pump, PVC pipe and hoses	Pump and hoses	Slight Edge Normal
Insulation	Required	Not needed or minimal	Normal
Battery Backup	Higher capacity more expensive	Lower capacity less expensive	Normal
Response Time (before falling out of temp range)	2 to 3 hours	Much longer (close to lab temp)	Normal
Monitoring Equipment	Computer, data acquisition package and thermocouples	Computer, data acquisition package and thermocouples	None
Power Consumption	Higher	Lower	Normal

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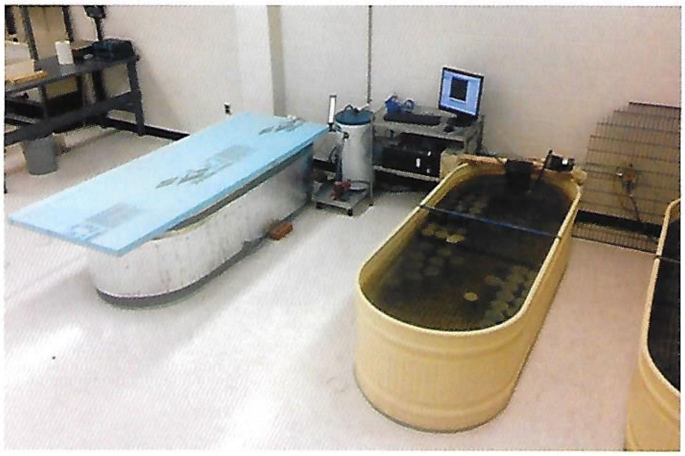

Figure 4: Accelerated (left) and Normal (right) Curing Tanks for the Project

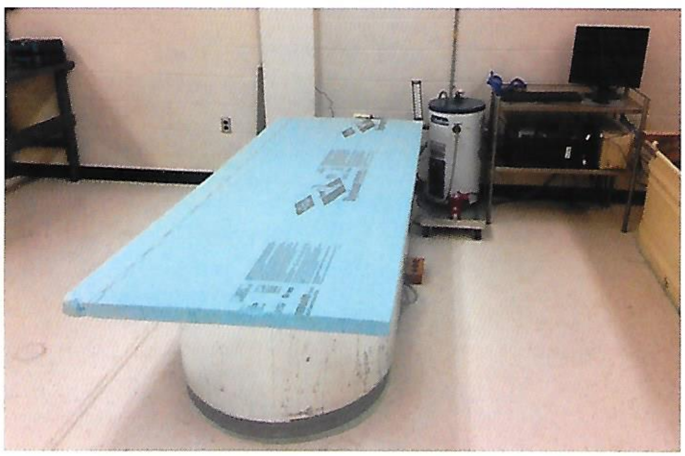

Figure 5: Close Up of Accelerated Curing Tank

Figure 6: Close Up of Water Heater for Accelerated Curing Tank

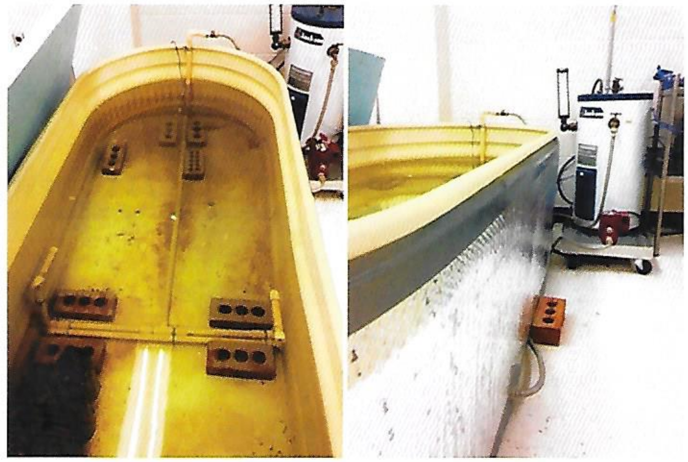

Figure 7: Plumbing for Accelerated Curing: Internal (left); External (right)

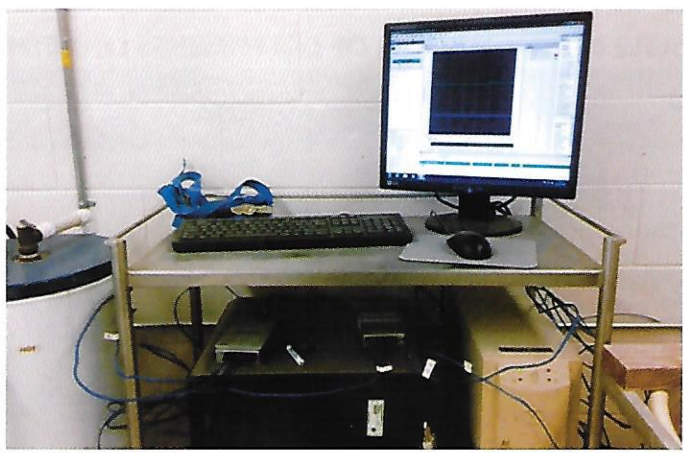

Figure 8: Temperature Data Acquisition Package, Computer, and Battery Back Up

SUMMARY

Table 8 shows a summary comparison of normal and accelerated curing. Normal curing of SR specimens is strongly preferred over accelerated curing.

DISCLAIMER

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

TABLE 8. SUMMARY COMPARISON OF NORMAL AND ACCELERATED CURING

Parameter	Accelerated
Certainty (equivalent age)	Normal Curing
Predicting Later Values (Correlations)	Slight Edge to Normal Curing
Cost	Normal Curing
Time	Same
Ease of Operation	Normal Curing
Fail Safety (Response Time)	Normal Curing
Overall	Normal Curing

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