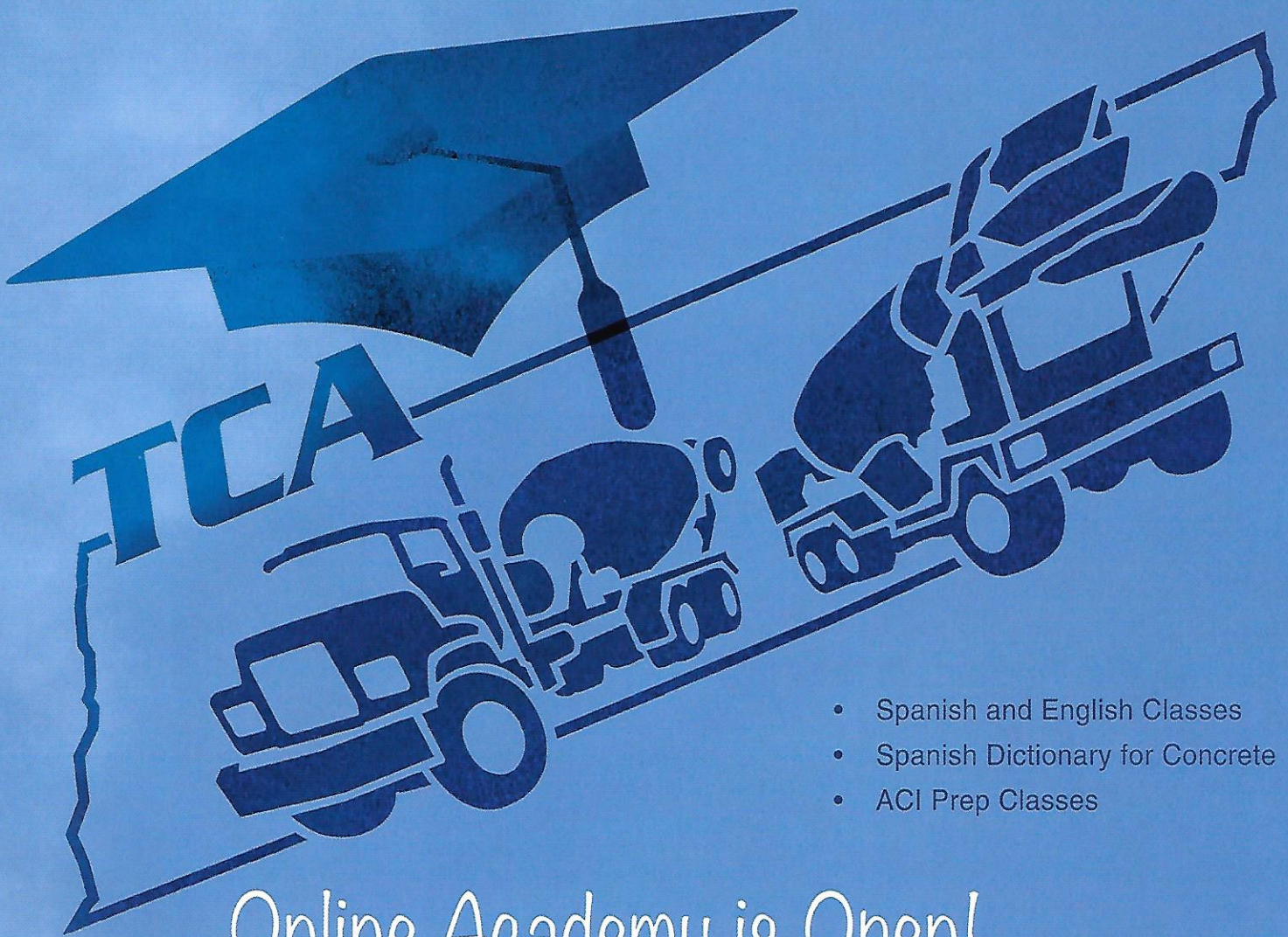


# TENNESSEE CONCRETE MAGAZINE

Fall 2018  
VOL. 32, NO. 2



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# Determining Concrete Chloride Permeability More Efficiently

## Part 3: Possible TDOT Surface Resistivity Specifications and Mixture Design Suggestions

### 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]

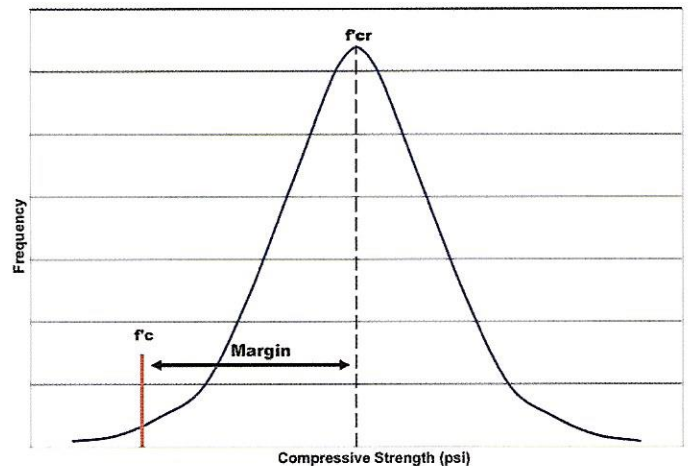
This paper is the final installment in a three part series of technology transfer articles. We hope that you find the information presented helpful in mixture design and evaluation. Part 3 presents possibilities for a TDOT surface resistivity specification and mixture design suggestions.

### 56-DAY SURFACE RESISTIVITY SPECIFICATION POSSIBILITIES

Table 1 shows the American Association of State Highway and Transportation Officials (AASHTO) category limits for surface resistivity (SR) and rapid chloride permeability (RCP). The chloride ion penetration categories, as listed in Table 1, would make reasonable standards for a SR specification for a TDOT Class D, bridge deck, mixture. TDOT recently considered establishing a new Class D-LP (lower permeability) portland cement concrete (PCC) mixture specification [3]. Prior to investigating SR, a limit of 1,200-coulombs at 56 days determined with the RCP test as per AASHTO T 277-07 [4], was under consideration. Table 2 shows possible TDOT specification limits for SR. Even if TDOT sets a different specification limit, the information presented should still be helpful.

The American Concrete Institute (ACI) recommends a statistically-based overdesign factor, known as margin, when designing concrete mixtures for compressive strength (see Figure 1). The authors recommend a similar procedure for designing concrete to meet a possible TDOT SR specification. The equation recommended is shown below:

$$[\text{Target} - (\text{Multiplier}) * (\text{Multi-lab COV from AASHTO TP 95-11}) * (\text{Target})] = \text{Specification Limit}$$



**Figure 1: Relationship between Design (target) Compressive Strength  $f_{cr}$ , Required (specified) Compressive Strength  $f_c$  and Overdesign Margin (distance between them)**

### Selecting an SR Target Value

Table 3 shows AASHTO coefficients of variation (COV) for SR. The multi-laboratory COV will be used herein for two reasons. It is recommended by AASHTO if the cylinders were prepared by more than one technician, and it is also more conservative. The multiplier for the COV is a measure of how conservative the mixture designer wants to be. A higher probability of meeting the specification requires a larger multiplier which would correspond to a greater mixture cost. Table 4 shows the corresponding multipliers for various probabilities which range from extremely conservative to a 50-50 chance of meeting the specification. Table 4 also shows target design values for the five possible TDOT SR specifications at all five probabilities.

### What SR Values Can Be Expected from a TDOT Class D Mixture at 56 Days?

Tables 5 and 6 display the mean 56-day SR results of several portland cement and supplementary cementing material (PC-SCM) combinations from four different Tennessee Technological University (TTU) projects. The number of SR replicates for each project is shown in row 1 of each table under the corresponding project title. The last column in each table shows a weighted (by number of replicates) average for each PC-SCM combination. The PC-SCM combinations selected are all permitted by TDOT specification 604.03 [5]. All PC-SCM combination mixtures met

**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. POSSIBLE 56-DAY SURFACE RESISTIVITY SPECIFICATIONS**

POSSIBLE 56-DAY RAPID CHLORIDE PERMEABILITY SPECIFICATION LIMITS (COULOMBS)	AASHTO CATEGORY LIMITS	CORRELATION EQUATION	ROUNDED EQUIVALENT 56-DAY SURFACE RESISTIVITY SPECIFICATION LIMIT ( $K\Omega\text{-CM}$ )
4000	Moderate Limit	–	12
3000	–	$SR = 11494(RCP)^{0.829}$	18
2000	Low Limit	–	21
1200	–	$SR = 11494(RCP)^{0.829}$	32
1000	Very Low Limit	–	37

**TABLE 3. AASHTO ALLOWABLE COEFFICIENTS OF VARIATION FOR SURFACE RESISTIVITY**

STATISTICAL PARAMETER	AASHTO TP 95-11
Single Operator COV (%)	6.3
Multi-laboratory COV (%)	12.5

**TABLE 4. TARGET VALUES FOR SELECTED PROBABILITY OF MEETING 56-DAY SURFACE RESISTIVITY SPECIFICATIONS**

PROBABILITY OF MEETING SPECIFICATION	MULTIPLIER FOR COV	SR TARGET FOR 56-DAY 12 ( $K\Omega\text{-CM}$ )	SR TARGET FOR 56-DAY 18 ( $K\Omega\text{-CM}$ )	SR TARGET FOR 56-DAY 21 ( $K\Omega\text{-CM}$ )	SR TARGET FOR 56-DAY 32 ( $K\Omega\text{-CM}$ )	SR TARGET FOR 56-DAY 37 ( $K\Omega\text{-CM}$ )
> 99%	3.00	19.2	28.8	33.6	51.2	59.2
90%	1.65	15.1	22.7	26.5	40.3	46.6
80%	1.30	14.3	21.5	25.1	38.2	44.2
70%	0.85	13.4	20.1	23.5	35.8	41.4
50%	0.0	12	18	21	32	37

\*100 PC is grey, 20F & 25F is red, 25C is orange, 35SL is green, 30SL20F & 35SL15F are blue

# Determining Concrete Chloride Permeability More Efficiently

## Part 3: Possible TDOT Surface Resistivity Specifications and Mixture Design Suggestions

TDOT 604.03 plastic and hardened property requirements. For comparison, all PC-SCM combination mixtures had a water-to-cementing materials ratio (w/cm) of 0.37, and the fine aggregate was 38% of the total aggregate by volume. The SR results presented are not necessarily the results that will be obtained but rather a good estimate of what to expect.

Tables 4, 5, and 6 are color coded to show what PC-SCM combination could be expected to produce the desired results. TTU researchers do not have extensive data on a PC-SCM combination mixture that is in compliance with TDOT 604.03 SCM requirements and has a mean SR result greater than 47 kΩ-cm at 56 days. TTU researchers do have data on several PC-SCM combination mixtures that meet the plastic and hardened property requirements of TDOT 604.03 but fail to meet the SCM requirements while having a mean SR well in excess of 47 kΩ-cm at 56 days. However, that is a story for another day.

### Hitting the SR Target Value

When an SR target value for mixture design has been selected, consult Tables 5 and 6 to determine the most economical (or available) PC-SCM combination that has a good chance of hitting the target SR value. Next, produce at least three small batches of various mixture designs; however, more batches would be preferable. These batches should meet TDOT 604.03 specifications while varying either the SCM dosage rate or the w/cm but not both. Conduct SR at 56 days and plot the results (y-axis) versus the variable (x-axis). Locate the SR target value on the y-axis and proceed horizontally to the curve. Afterward, proceed vertically to the x-axis and read the variable corresponding to the SR target value. It is important to note that the target value is interpolated along the curve which should never be used to extrapolate outside of the data set to determine the variable amount to use for a final trial mixture. A few batches of the final trial mixture should then be produced to confirm the SR result.

Figure 2 shows an example of the procedure. The hypothetical mixture designer wants greater than a 99% chance of meeting a 32 kΩ-cm 56-day SR specification. Table 4 indicates a target SR value of 51.2 kΩ-cm. The mixture designer decides to try a 50% PC, 35% slag, and 15% Class F fly ash mixture meeting TDOT 604.03 specifications. The variable chosen is w/cm. Four batches of each of four different w/cm ratio mixtures (all meeting TDOT 604.03 plastic and hardened property requirements) are produced and tested for SR at 56 days. Using the plotted results, the w/cm

ratio (0.363) corresponding to the SR target value (51.2 kΩ-cm) is determined as shown in Figure 2.

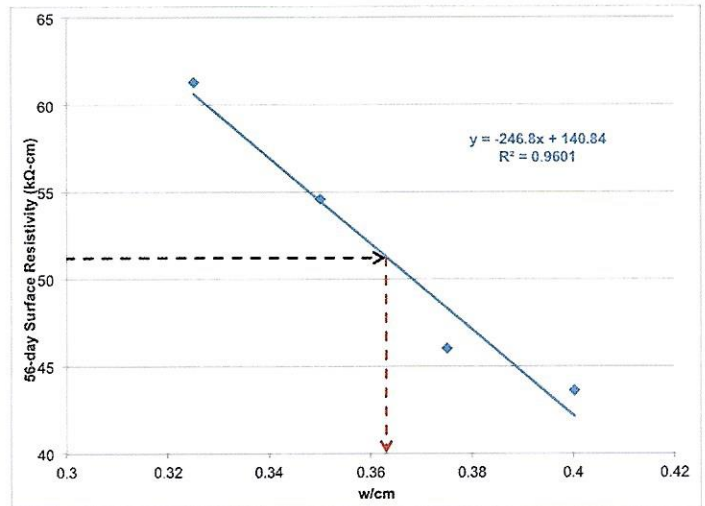


Figure 2: Plot for Determining w/cm Corresponding to SR Target Value

### 28-DAY SR SPECIFICATION POSSIBILITIES

If concrete chloride permeability could be determined more rapidly, bridge deck mixture design development, mixture design submittals, quality control, and quality assurance testing could all be streamlined. Therefore, a 28-day SR specification would be preferable to a 56-day SR specification. However, accuracy should not be sacrificed for speed. The second article in this series showed that 28-day normal curing was slightly better than 28-day accelerated curing at predicting later age SR results and vastly superior to accelerated curing in logistics. Figure 3 shows 28-day SR results as a function of 56-day SR results. There is no doubt that this seems backwards, but the regression equation is needed to determine what 28-day SR result corresponds to a certain 56-day SR result. Table 7 shows the 28-day SR results equivalent to the possible TDOT SR specification limits from Table 2.

**TABLE 5. 56-DAY MEAN SURFACE RESISTIVITY RESULTS FOR PC AND FLY ASH MIXTURES**

MIXTURE	C ASH (%)	F ASH (%)	TTU EFFECT OF SCMs (3X)	TDOT SR (20X)	TTU TDOT CLASS D MIXTURES (6X)	TTU APPROVED AGGREGATES (6X)	WEIGHTED MEAN
100 PC	0	0	14.0	–	14.3	–	14.2
20F	0	20	17.9	18.8	17.4	16.5	18.1
25F	0	25	22.2	–	19.7	–	20.5
25C	25	0	18.0	–	16.0	–	16.7

**TABLE 6. 56-DAY MEAN SURFACE RESISTIVITY RESULTS FOR MIXTURES CONTAINING SLAG**

MIXTURE	SLAG (%)	F ASH (%)	TTU EFFECT OF SCMs (3X)	TDOT SR (20X)	TTU TDOT CLASS D MIXTURES (6X)	TTU APPROVED AGGREGATES (6X)	WEIGHTED MEAN
35SL	35	0	–	–	33.2	–	33.2
30SL20F	30	20	–	–	47.0	–	47.0
35SL15F	35	15	44.8	43.0	46.3	41.0	43.4

**TABLE 7. POSSIBLE 28-DAY SURFACE RESISTIVITY SPECIFICATIONS**

POSSIBLE 56-DAY SURFACE RESISTIVITY SPECIFICATION LIMIT (KΩ-CM)	CORRELATION	EQUATION	EQUIVALENT 28-DAY NORMALLY-CURED SURFACE RESISTIVITY SPECIFICATION LIMIT (KΩ-CM)
12	TDOT SR Project Data	$SR_{28} = 0.7153(SR_{56}) + 0.5558$	9.1
18			13.4
21			15.0
32			23.4
37			27.0

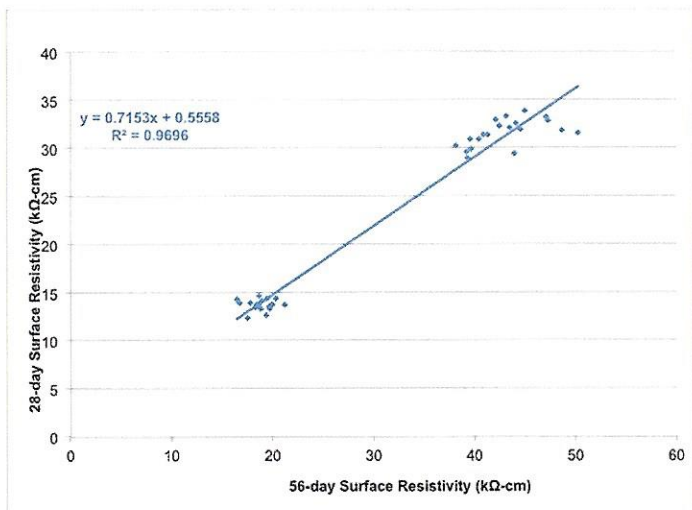
**TABLE 8. TARGET VALUES FOR SELECTED PROBABILITY OF MEETING 28-DAY SURFACE RESISTIVITY SPECIFICATIONS**

PROBABILITY OF MEETING SPECIFICATION	MULTIPLIER FOR COV	SR TARGET FOR 28-DAY 9.1 (KΩ-CM)	SR TARGET FOR 28-DAY 13.4 (KΩ-CM)	SR TARGET FOR 28-DAY 15.0 (KΩ-CM)	SR TARGET FOR 28-DAY 23.4 (KΩ-CM)	SR TARGET FOR 28-DAY 27.0 (KΩ-CM)
> 99%	3.00	14.6	21.4	24.0	37.4	43.2
90%	1.65	11.5	16.9	18.9	29.5	34.0
80%	1.30	10.9	16.0	17.9	27.9	32.2
70%	0.85	10.2	15.0	16.8	26.2	30.2
50%	0.0	9.1	13.4	15.0	23.4	27.0

\*100 PC is grey, 20F & 25F is red, 25C is orange, 35SL is green, 30SL20F & 35SL15F are blue

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## Part 3: Possible TDOT Surface Resistivity Specifications and Mixture Design Suggestions



**Figure 3: Plot for Determining w/cm Corresponding to SR Target Value**

### Selecting an SR Target Value

Table 8 shows various probabilities and the corresponding multipliers. Table 8 also shows target design values for the five possible 28-day TDOT SR specifications at all five probabilities.

### What SR Values Can Be Expected from a TDOT Class D Mixture at 28 Days?

Tables 9 and 10 display the mean 28-day SR results of several PC-SCM combinations from four different TTU projects. The number of SR replicates for each project is shown in row 1 of each table under the corresponding project title. The last column in each table shows a weighted (by number of replicates) average for each PC-SCM combination. The PC-SCM combinations selected are all permitted by TDOT Specification 604.03. All PC-SCM combination mixtures met TDOT 604.03 plastic and hardened property requirements. For comparison, all PC-SCM combination mixtures had a w/cm of 0.37 and the fine aggregate was 38% of the total aggregate by volume. The SR results presented are not necessarily the results that will be obtained but rather a good estimate of what to expect.

Tables 8, 9, and 10 are color coded to show what PC-SCM combination could be expected to produce the desired results. TTU researchers do not have extensive data on a PC-SCM combination mixture that is in compliance with TDOT 604.03 SCM requirements and has a mean SR result greater than 33 kΩ-cm at 28 days. TTU researchers do have data on several PC-SCM combination mixtures that meet the plastic and hardened property

requirements of TDOT 604.03 but fail to meet the SCM requirements while having a mean SR well in excess of 33 kΩ-cm at 28 days. Again, that is a story for another day.

### Hitting the SR Target Value

The graphical procedure is identical to that used for determining the 56-day variable (SCM dosage or w/cm) corresponding to the SR target value except 28-day data is used.

## WHAT IS NEXT?

The next planned article, although not part of the current series, is closely related: Going Past Current TDOT 604.03 SCM Specifications to Further Reduce Chloride Permeability.

## 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.

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5. Tennessee Department of Transportation, **Standard Specifications for Road and Bridge Construction (Section 604.03)**, January 1, 2015.

**TABLE 9. 28-DAY MEAN SURFACE RESISTIVITY FOR PC AND FLY ASH MIXTURES**

MIXTURE	C ASH (%)	F ASH (%)	TTU EFFECT OF SCMs (3X)	TDOT SR (20X)	TTU TDOT CLASS D MIXTURES (6X)	TTU APPROVED AGGREGATES (6X)	WEIGHTED MEAN
100 PC	0	0	12.0	–	13.3	–	12.7
20F	0	20	12.9	13.8	12.5	12.5	13.3
25F	0	25	14.1	–	13.5	–	13.7
25C	25	0	12.6	–	13.1	–	12.9

**TABLE 10. 28-DAY MEAN SURFACE RESISTIVITY FOR MIXTURES CONTAINING SLAG**

MIXTURE	SLAG (%)	F ASH (%)	TTU EFFECT OF SCMs (3X)	TDOT SR (20X)	TTU TDOT CLASS D MIXTURES (6X)	TTU APPROVED AGGREGATES (6X)	WEIGHTED MEAN
35SL	35	0	–	–	26.6	–	26.6
30SL20F	30	20	–	–	32.3	–	32.3
35SL15F	35	15	31.4	31.6	34.6	30.2	31.9

## ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the support of TDOT and FHWA. Special thanks to Gary Head, Jamie Waller, and Bill Trolinger.

We also wish to thank Frank Lennox of Buzzi-Unicem, Meagan Dangle of Lafarge North America, and Denny Lind of BASF for their extensive donations of portland cement, slag, chemical admixtures and silica fume to the project. The authors appreciate the procurement help provided by Alan Sparkman and the Tennessee Concrete Association.

In addition, the authors would like to thank Mark Davis and Perry Melton for their patience and skill in fabrication, maintenance, and repair of the equipment. We would also like to thank Lee Rogers, and Jacob Brooks for their help with the project.

Further, we appreciate the support of the TTU Department of Civil and Environmental Engineering.

Finally, the authors appreciate the administrative and information technology support provided by the TTU Center for Energy Systems Research, particularly Tony Greenway, Etter Staggs, and Linda Lee.

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