Florida Department of
TRANSPORTATION

FDOT Use of Resistivity Measurements in the Qualification of Concrete Mix Designs for Use in Extremely Aggressive Environments

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Environmental Classifications

Table 1.3.2-1 Criteria for Substructure Environmental Classifications

Classification	Environmental Condition	Units	Steel		Concrete	
			Water	Soil	Water	Soil
Extremely Aggressive (If any of these conditions exist)	pH		< 6.0		< 5.0	
	Cl	ppm	> 2000		> 2000	
	SO_4	ppm	N.A.		> 1500	> 2000
	Resistivity	Ohm-cm	< 1000		< 500	
Slightly Aggressive (If all of these conditions exist)	pH		> 7.0		> 6.0	
	Cl	ppm	< 500		< 500	
	SO_4	ppm	N.A.		< 150	< 1000
	Resistivity	Ohm-cm	> 5000		> 3000	
Moderately Aggressive	This classification must be used at all sites not meeting requirements for either slightly aggressive or extremely aggressive environments.					

pH = acidity ($-\log_{10}H^+$; potential of Hydrogen), Cl = chloride content, SO_4 = Sulfate content.

Table 1.3.3-1 Chloride Intrusion Rate/Environmental Classification

Chloride Intrusion Rate	Classification
≥ **0.016** lbs/cy/year	Extremely Aggressive
< **0.016** lbs/cy/year	Moderately Aggressive

Source: Structures Design Guidelines, Volume I of FDOT Structures Manual

SR is the FDOT Durability Test for Extremely Aggressive Exposures

- Easy and quick to perform
- Has been correlated to RCPT test
- RCPT test has been correlated to Bulk Diffusion

Table 2 Surface Resistivity - Permeability

Chloride Ion Permeability	Surface Resistivity Test kΩ–cm
High	< 12
Moderate	12 – 21
Low	21 – 37
Very Low	37 – 254
Negligible	> 254

FDOT requires a minimum value of 29 kΩ-cm at 28 days for use in extremely aggressive exposures

Table 2 from FM 5-578 Florida Method of Test For Concrete Resistivity as an Electrical Indicator of its Permeability

FDOT SR Primarily Done on Concrete for Extremely Aggressive Exposure

Until recently, surface resistivity (SR) was only required when the concrete mix contained silica fume, since it was typically required for use in extremely aggressive exposures

Ternary Components	Number of Mix Designs	Average Surface Resistivity (kΩ-cm)	Surface Resistivity Range (kΩ-cm)	Number of Distinct Values
PC-FA-SF	170	44.4	28.3 - 123.1	109
PC-FA-Slag	5	38.9	32.5 – 54.4	5
PC-FA-MK	6	49.0	29.5 – 86.8	6
PC-FA-UFFA	2	30.5	29.0 – 31.9	2
PC-Slag-SF	14	40.6	29.5 – 106.1	9
PC-Slag-MK	2	66.7	63.7-69.6	2

Brief History of FDOT Structural Concrete Used in Extremely Aggressive Environments

Year	Changes (Specs for Piling in Extremely Aggressive Environment)
1982	No permeability test requirement No SCMs used in extremely aggressive environments Class IV, min 5500 psi, min PC = 658 lb, max w/cm = 0.41
1994	FA and Slag allowed in extremely aggressive environments Class V Special, min 6000 psi, min PC = 752 lb, max w/cm = 0.37
1999	FA, Slag, and SF allowed in extremely aggressive environments RCP ≤ 1000 coulombs (AASHTO T 277) only when SF used Max w/cm = 0.37 (0.35 for SF)
2004	FA, Slag, SF, and MK allowed in extremely aggressive environments RCP ≤ 1000 coulombs (AASHTO T 277) only when SF or MK used Max w/cm = 0.37 (0.35 for SF or MK)
2005	RCP ≤ 1000 coulombs (AASHTO T 277) or SR ≥ 37 kΩ-cm (FM 5-578) only when SF or MK used

Brief History of FDOT Structural Concrete Used in Extremely Aggressive Environments

Year	Changes (Specs for Piling in Extremely Aggressive Environment)
2007-07	FA, Slag, SF, MK, and UFFA allowed in extremely aggressive environments SR ≥ 29 kΩ-cm (FM 5-578) only when SF, MK, or UFFA used Max w/cm = 0.37 (0.35 for SF or MK) (0.30 for UFFA)
2017-01	AASHTO T 358 adopted to replace FM 5-578 SR value ranges established for environmental exposures: Extremely Aggressive Environments > 29 kΩ-cm Moderately Aggressive Environments 17 to 29 kΩ-cm Slightly Aggressive Environments < 17 kΩ-cm

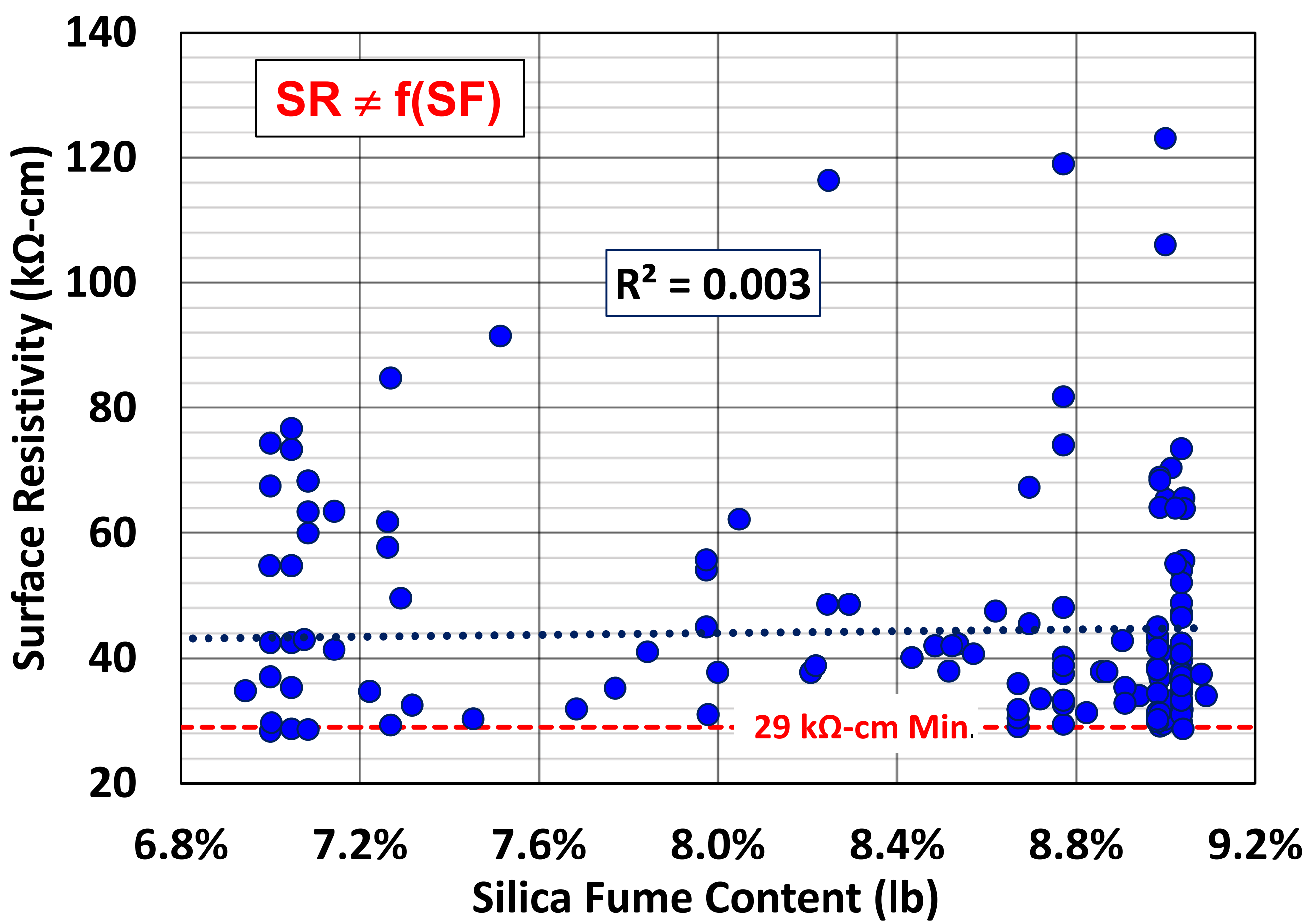
SR Should be Inversely Related to Permeability of Concrete

Common methods used to decrease the permeability of concrete include

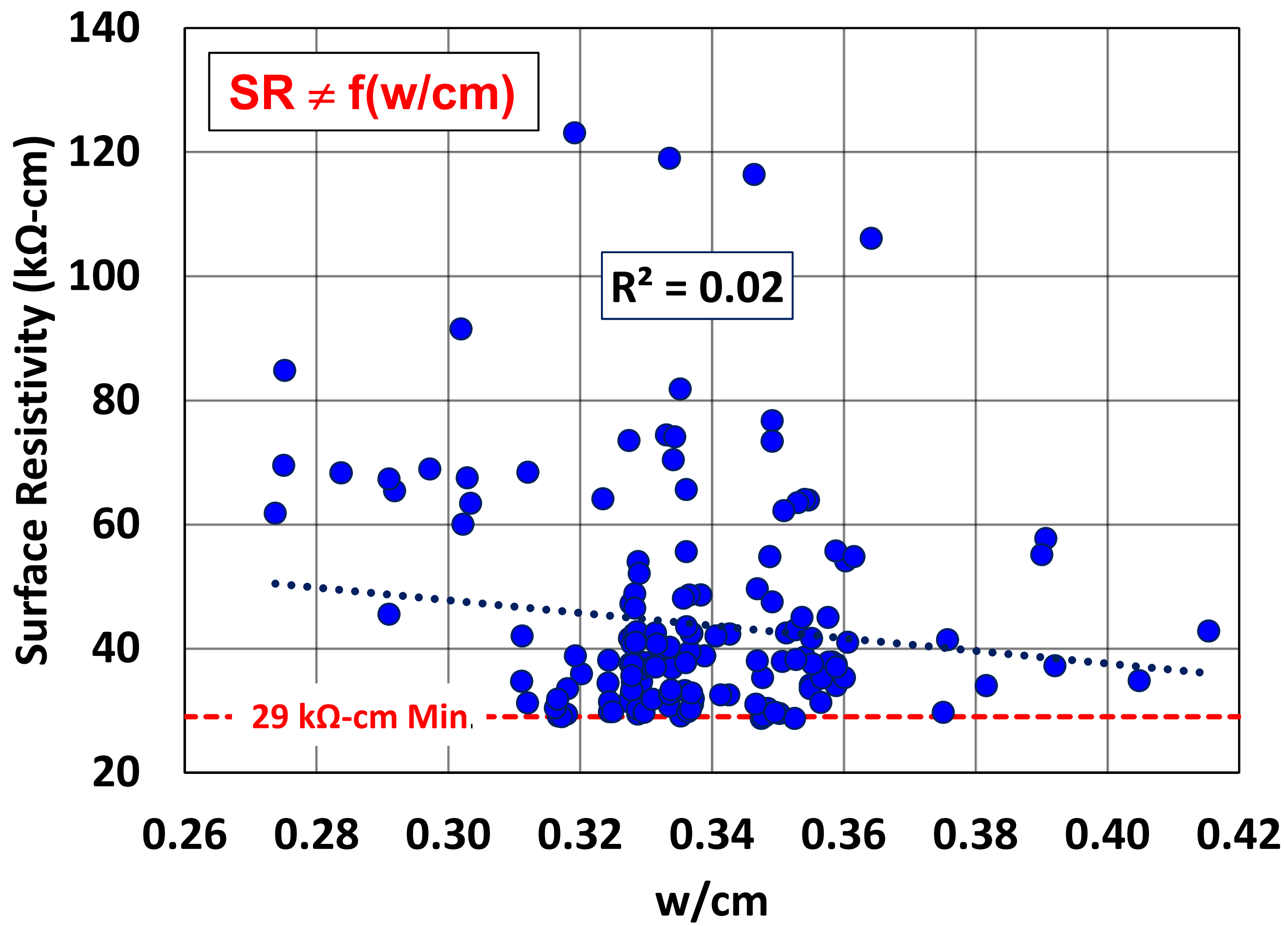
- Increasing the SCM content (silica fume)
- Lowering the w/cm

All FDOT SR data was plotted to establish how well it correlated with respect to these expected dependencies

FDOT Surface Resistivity Does Not Correlate to Silica Fume Content



FDOT Surface Resistivity Does Not Correlate to w/cm



Conclusions / Comments

- SR may not be the best method to gage permeability / penetrability
- Each binary and ternary combination of cementitious materials may require different scales to relate SR values to permeability
- Is it valid to use the bulk diffusion coefficient to determine the cover thickness needed to prevent the chloride content at the reinforcing steel from reaching the critical concentration needed to initiate corrosion during the desired service life (effect of age at start of test, curing temperature, testing temperature, etc.?

Questions?