Surface Resistivity as a Performance Test for Transport Properties

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Motivation

- **Deterioration of reinforcement concrete**
- **Cracking, spalling, reduction,**
- **Loss of structural capacity**

Background

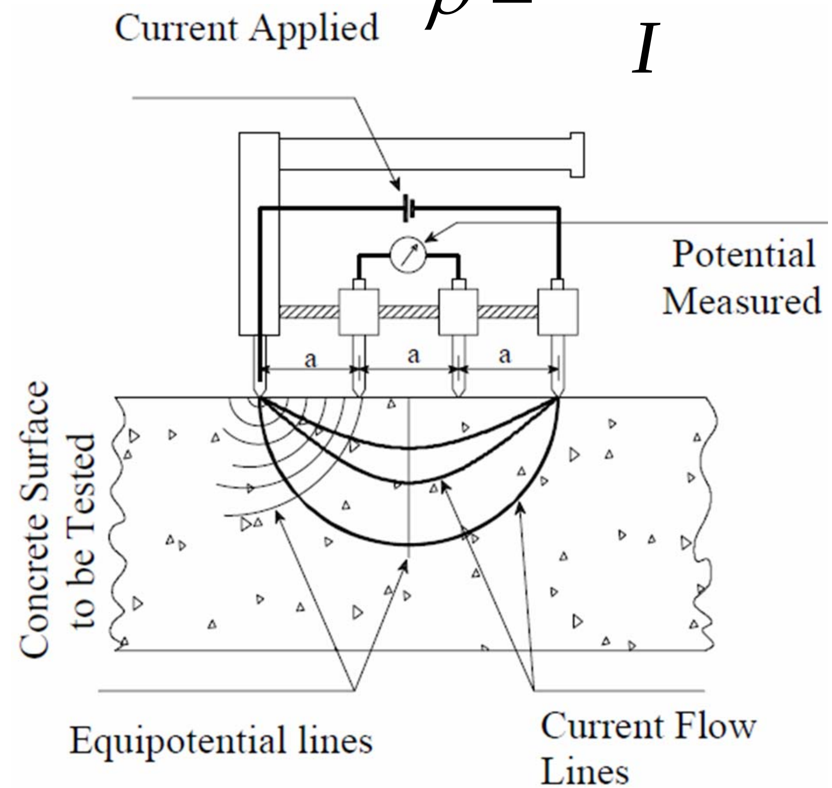
- Resistivity of the concrete is used to estimate the quality of concrete (High resistivity – less permeable concrete)
- Low resistivity with corrosion initiated likely indicative of potentially high corrosion rate
- Recently a good correlation has been established between rapid chloride permeability test and Resistivity on laboratory specimens
- Good correlation chloride diffusivity vs. surface Resistivity on lab saturated conditions has been obtained

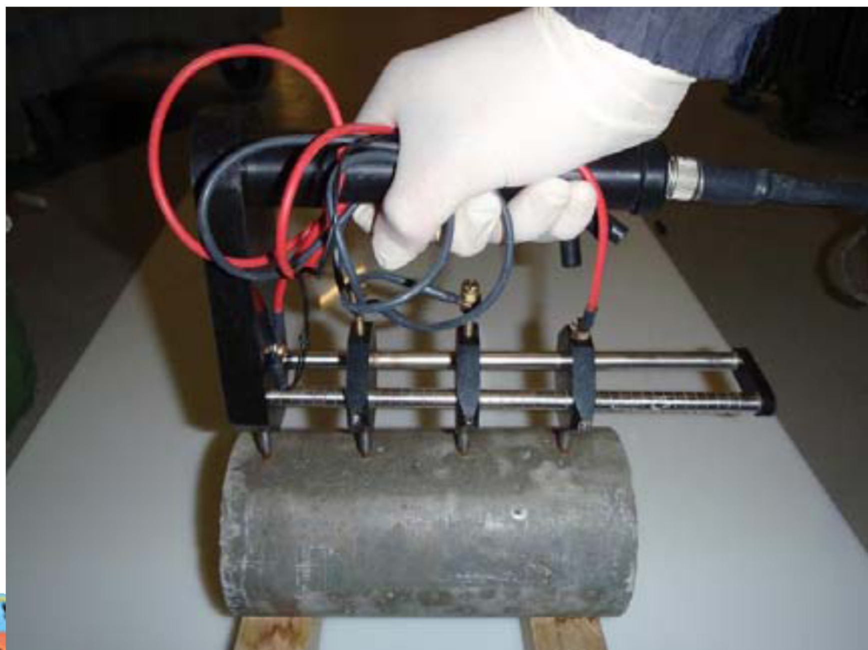
Background

$$\rho = \frac{2\pi aV}{I}$$

Surface Resistivity

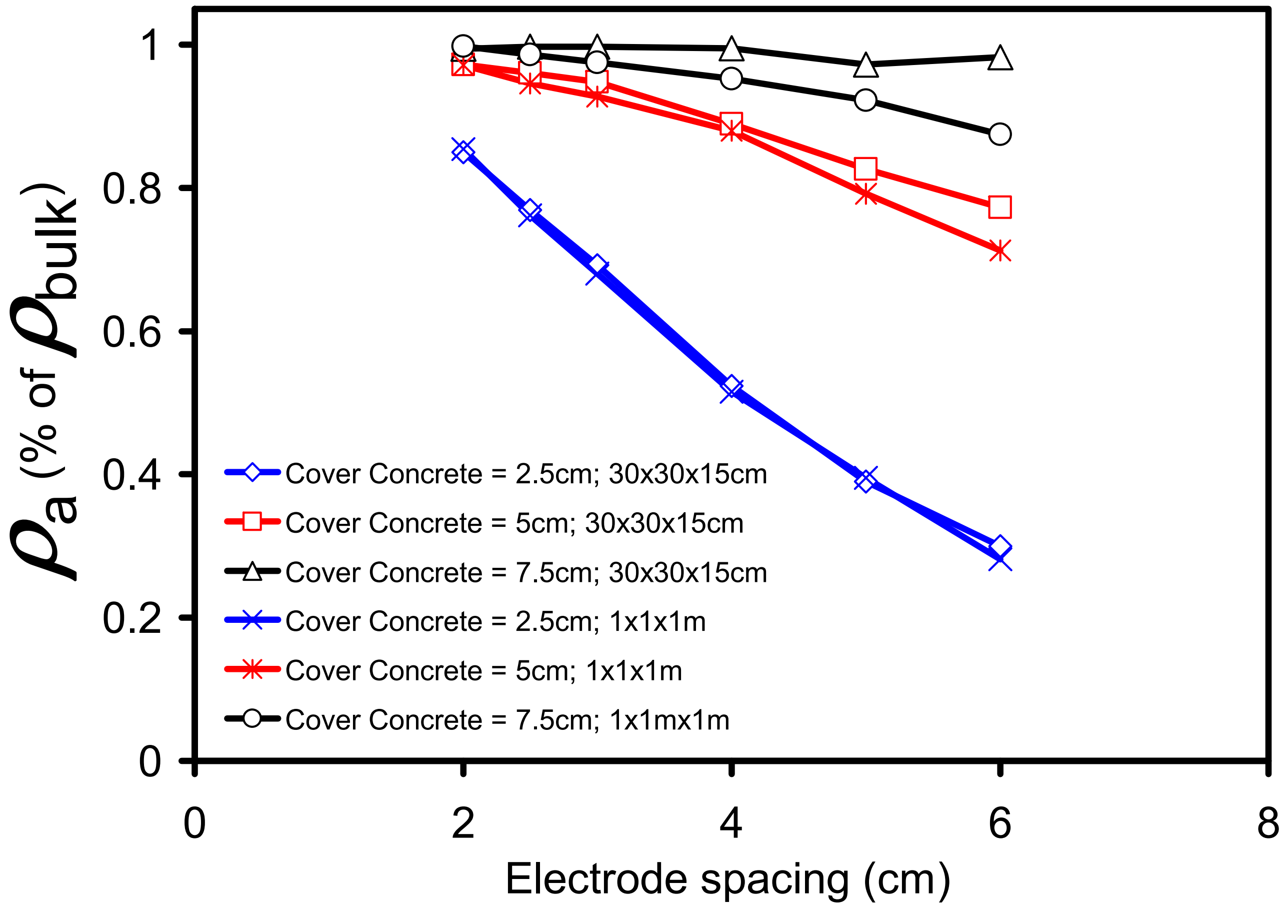
- Non-destructive method.
- Used to estimate the quality of concrete. (permeability)
- $\rho = KR = \frac{KV}{I} = \frac{2\pi aV}{I}$ (semi infinite)
- Indicative of potentially high corrosion rate when corrosion has initiated. (Langford)





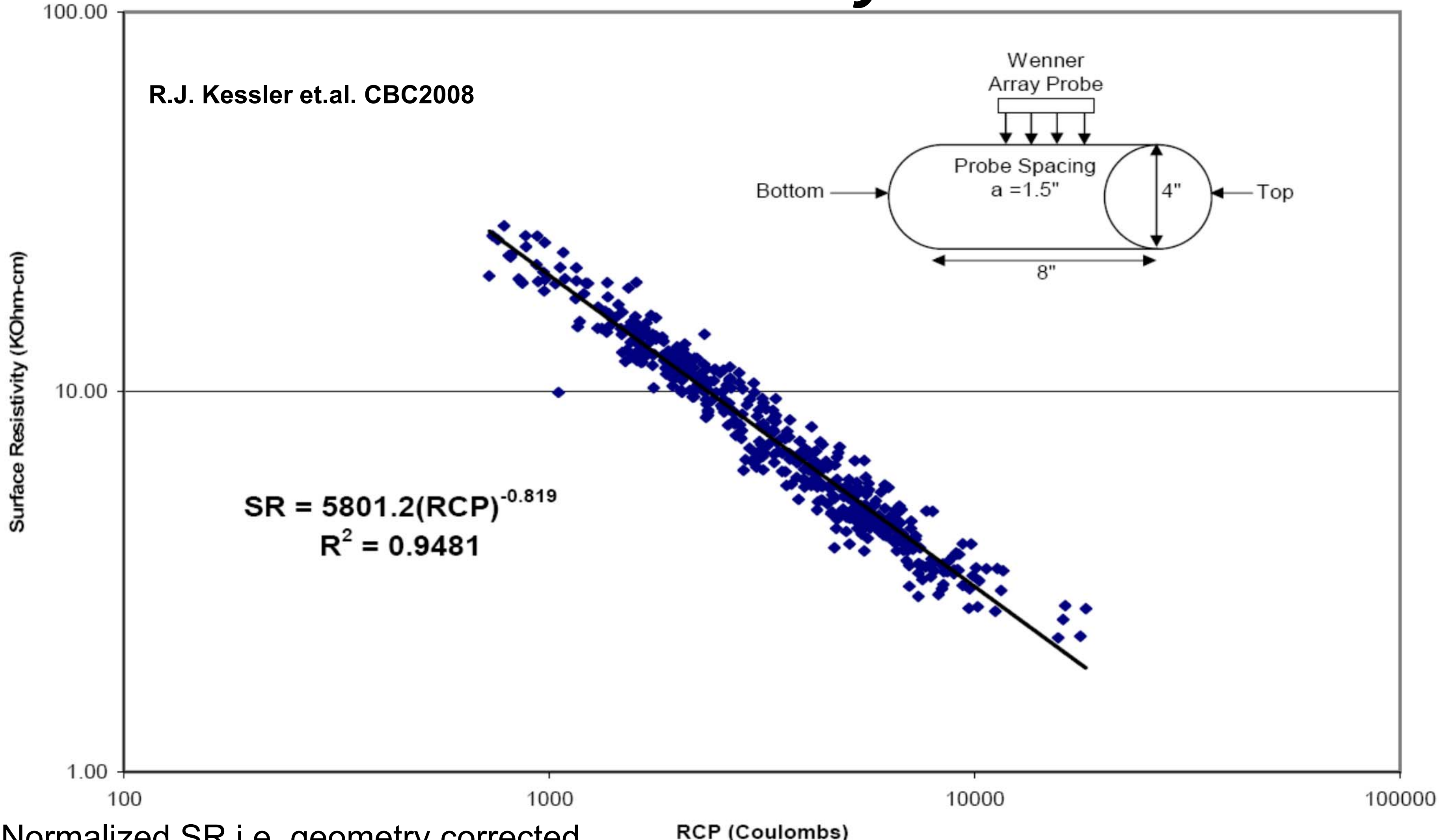
Resistivity (KΩ.cm)	Corrosion rate
< 5	Very high
5 - 10	High
10 - 20	Low/Moderate
> 20	Negligible

Rebar Presence and Concrete Cover effect on SR



Modeling of apparent resistivity of single layer concrete with single rebar with different cover concrete, specimen dimension: 1mx1mx1m vs. 30 cm x 30 cm x 15 cm

Surface Resistivity vs. RCP



*Normalized SR i.e. geometry corrected

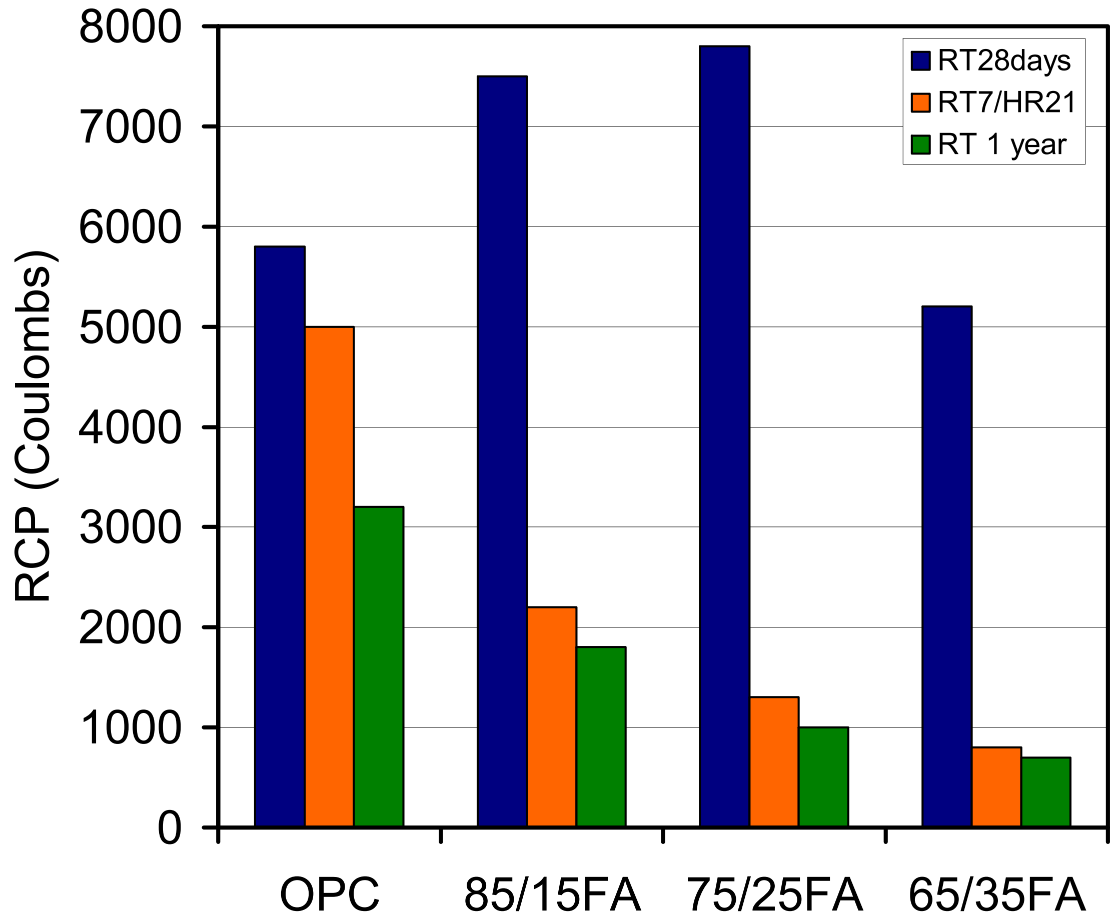
RCP versus Surface Resistivity				
Chloride Ion Permeability	RCP Test Charged Passed (coulombs)	Surface Resistivity Test		
		4 X 8 Cylinder (Kohm-cm) a=1.5 k=1.8 (Measured)	6 X 12 Cylinder (KOhm-cm) a=1.5 k=1.41 (Measured)	Semi-Infinite Slab (Real)
High	>4,000	< 12	< 9.5	< 6.7
Moderate	2,000-4,000	12 - 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

Kessler et.al. Corrosion/2005

↑ Normalized

Accelerated Curing

Concrete with Slow Reacting Pozzolans (Celik Ozyildirim 2000)

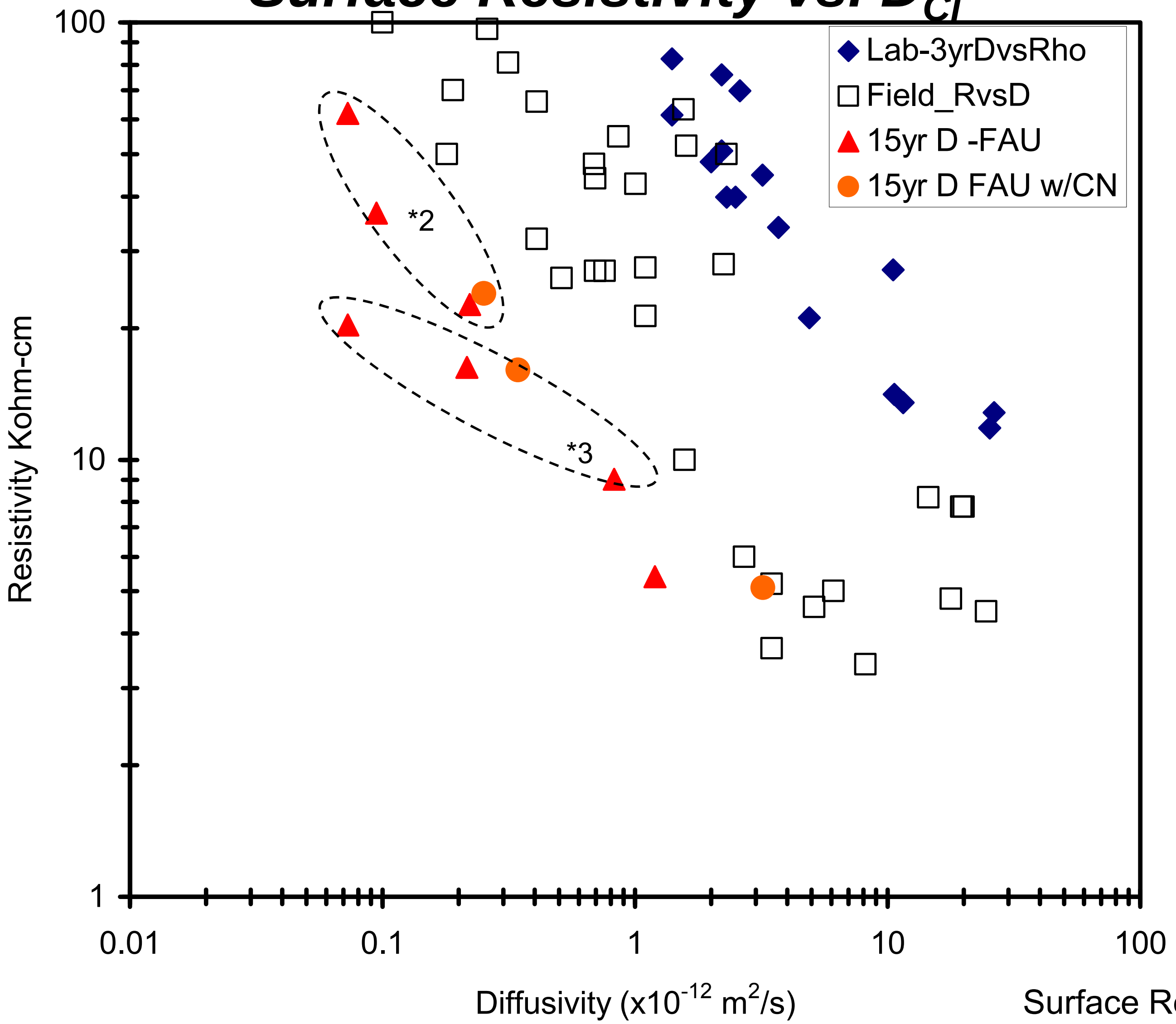


RT=23°C
HT=38°C

FA: Fly ash
w/cm =0.45

No Surface Resistivity was performed by VTRC

Surface Resistivity vs. D_{Cl^-}



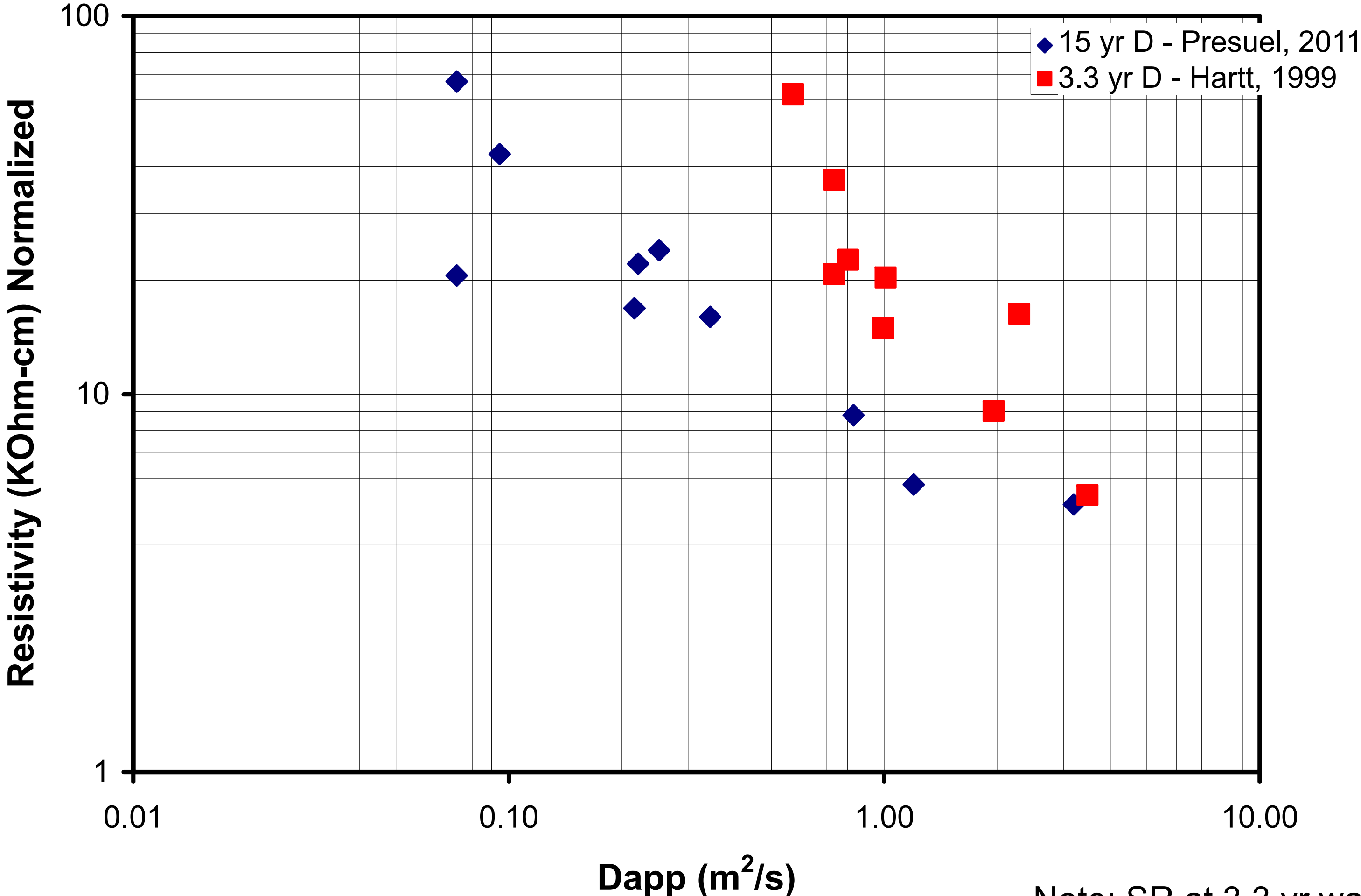
Kessler, 2008
Sagues, 1992
Presuel, 2011
Presuel, 2011

Note: 15 yr – w/cm 0.37

*2- Concrete with FA (20,35, 50),
**3 Concrete with SF (6, 15, 27),
not marked OPC

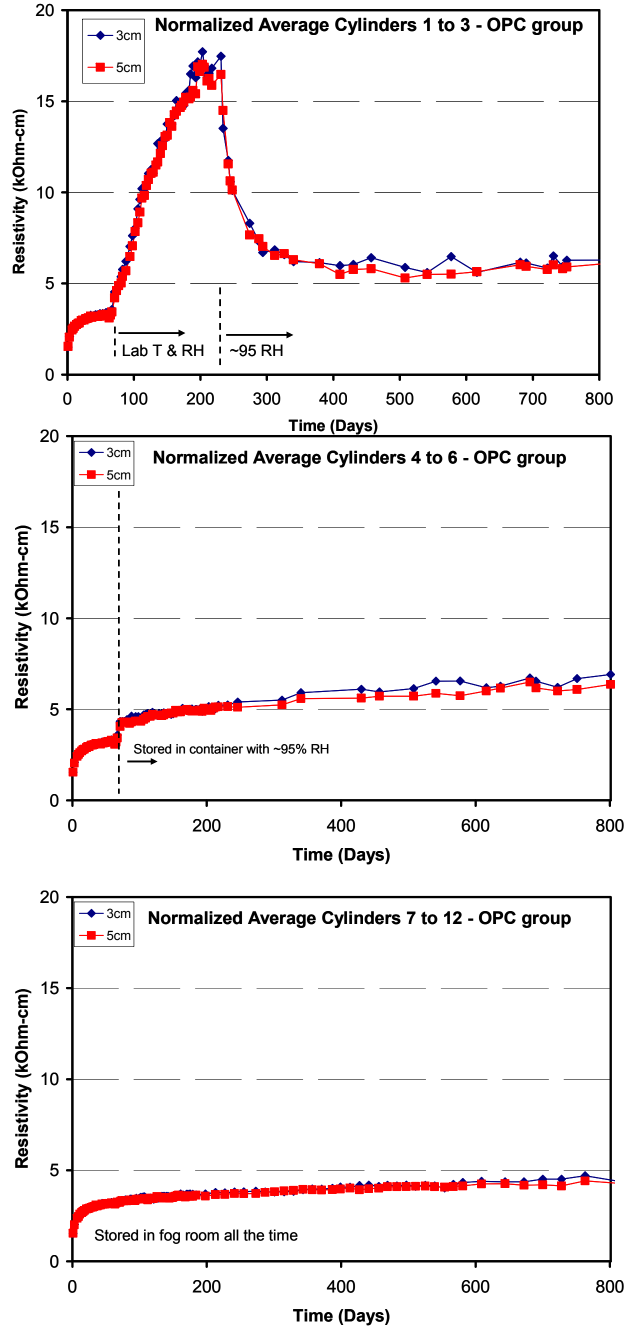
Surface Resistivity on saturated concrete

Surface Resistivity vs. D_{Cl^-}
D measured after 3.3 yrs and 15 yrs

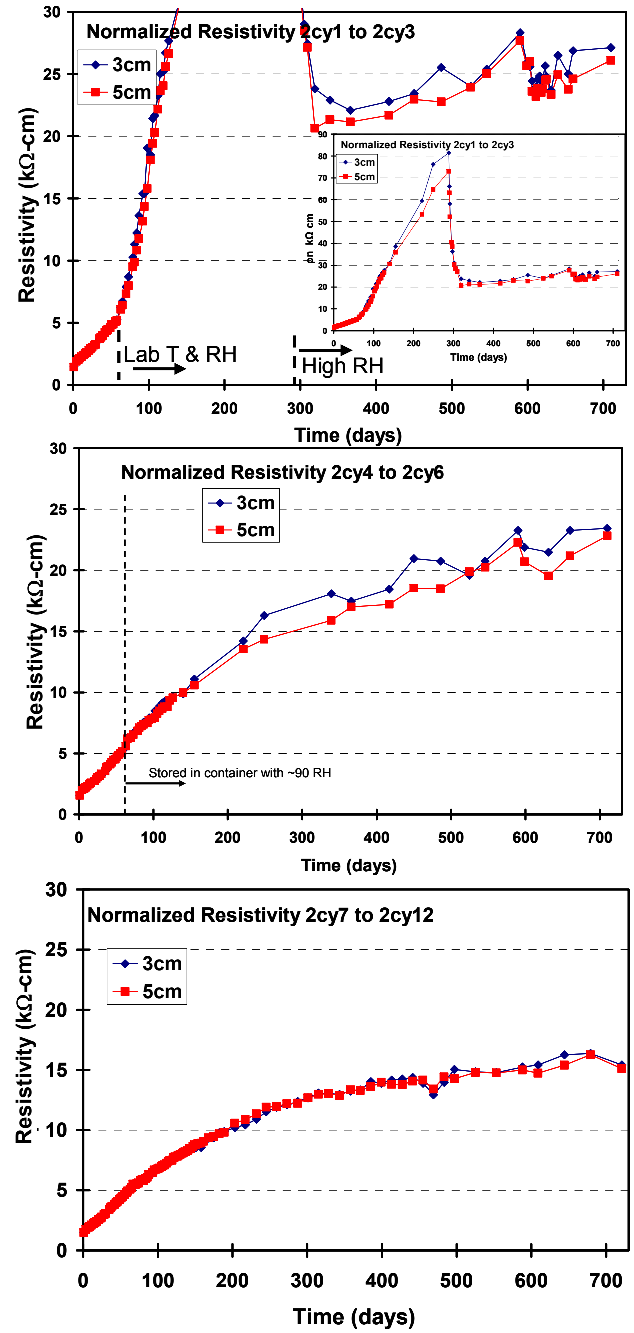


Note: SR at 3.3 yr was not measured

Resistivity vs. Time under various Environmental Exposures

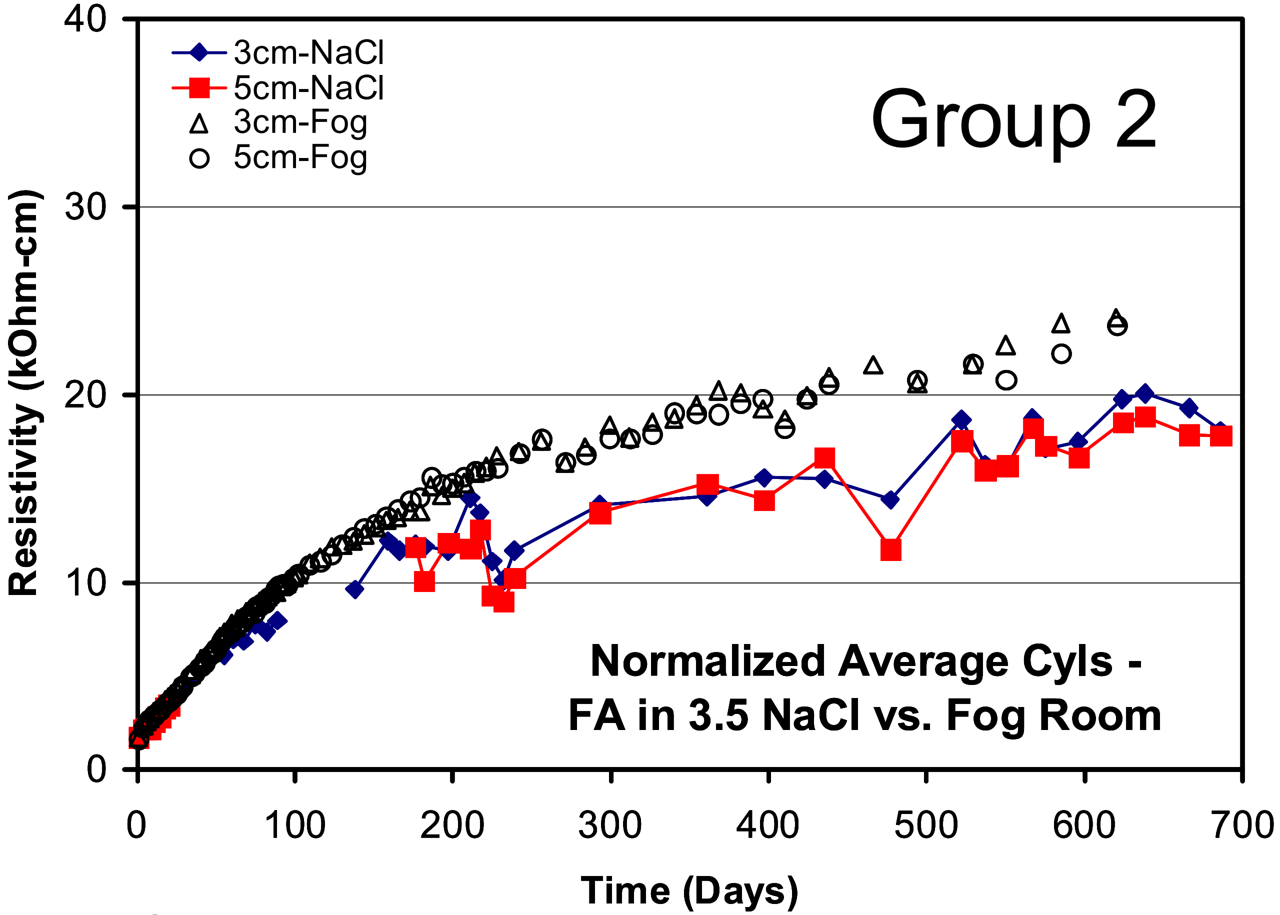


OPC Concrete



20% FA Concrete

Effect of NaCl on Surface Resistivity

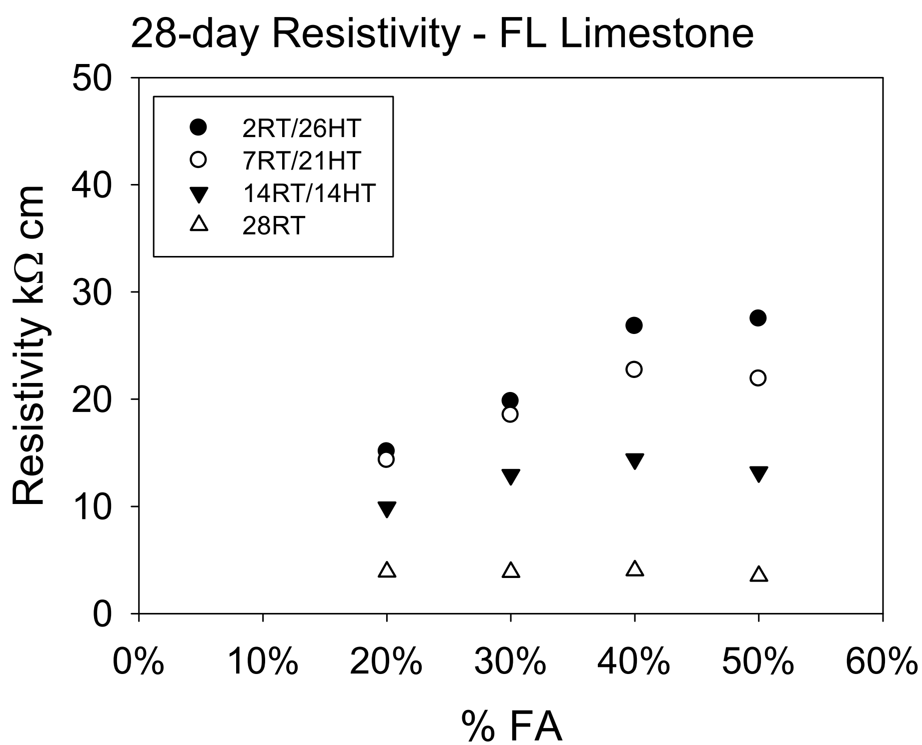


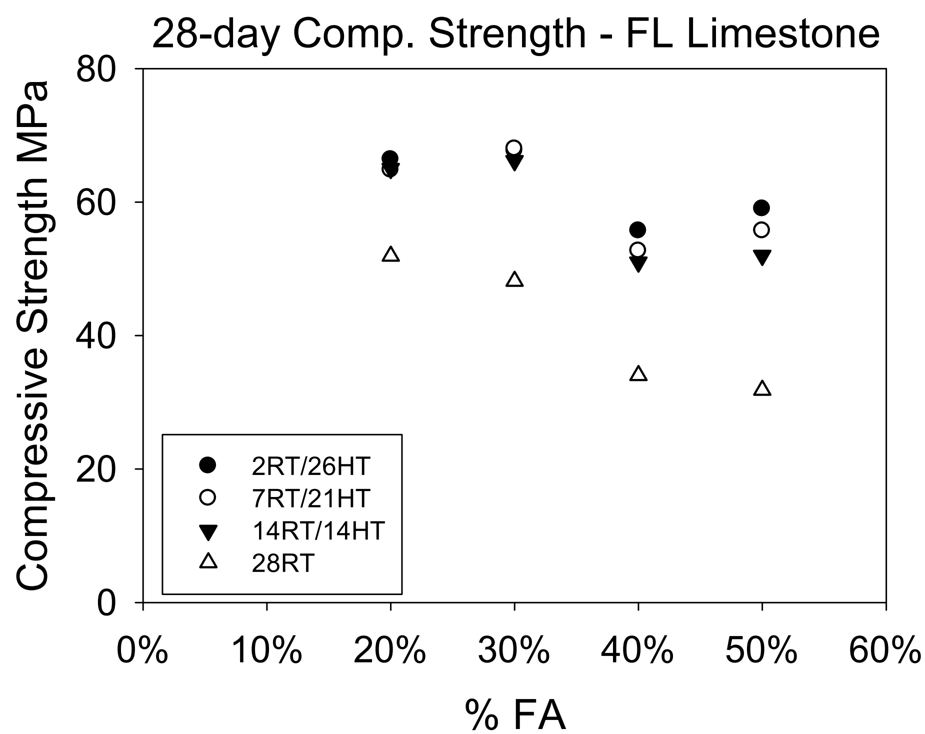
4x8 -Concrete Cylinders.

Those exposed to chlorides exposed to NaCl 60 days after casting.

Towards Performance Based Concrete

Resistivity of Concrete with Slow Reacting Pozzolans Subjected to Accelerated Curing – Immersed in $Ca(OH)_2$ at ~38 ºC





Bulk diffusivity tests in 15% NaCl are being performed on these concretes.

Field work objective

- Investigate the feasibility of extending correlation D_{Cl^-} vs. Lab. Surface Resistivity to field surface resistivity measurements

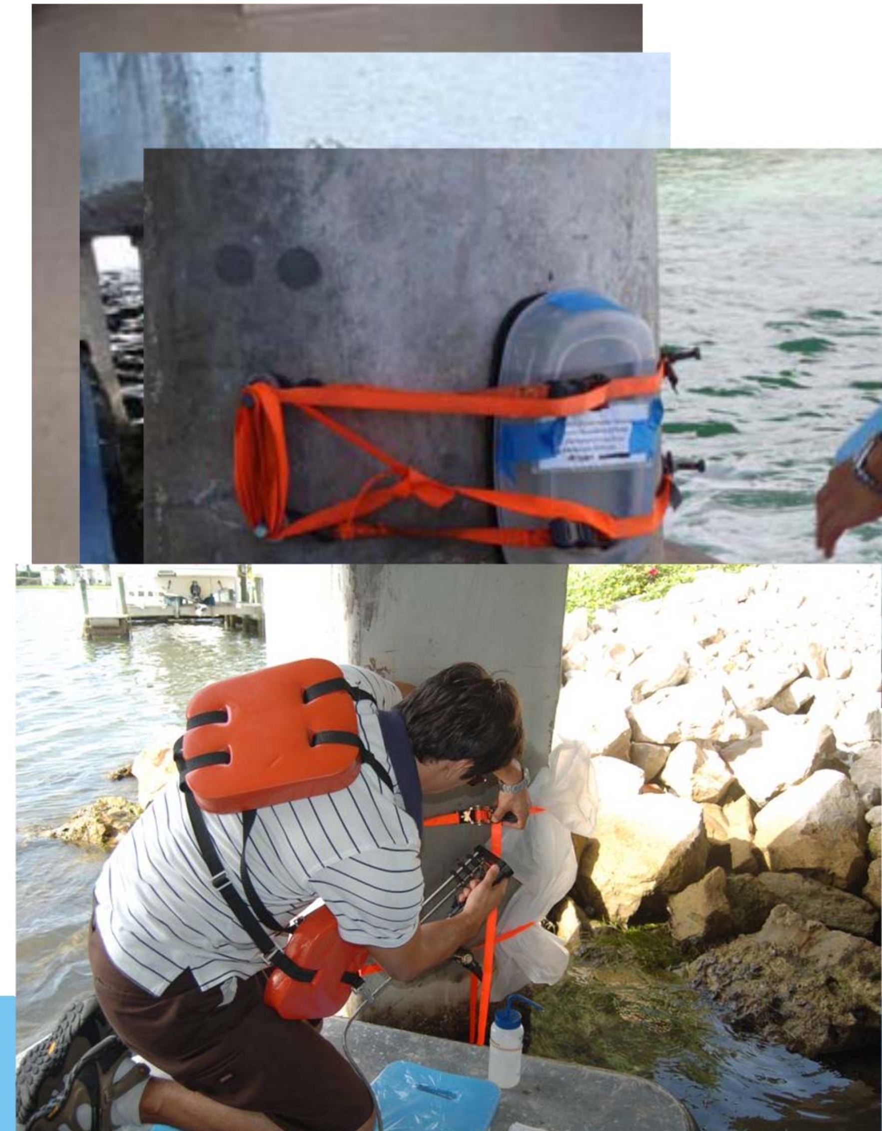
Approach

- Surface resistivity measurements on bridge substructures
- Surface resistivity measurements on cylindrical cores obtained during field visits
- Chloride Diffusivity from field cores

Field: Surface Resistivity Measurements

Measured: Profiles of ϱ vs. elevation.
Approach: Increased moisture content with water.
Method: 1.6 gallons plastic containers.
Edge-grip rubber seal on containers, tied down to piles, and filled with fresh water.
Track of SR during 3 to 4 days.

Additional Measurements:
Concrete cover
Moisture meter (0-20 scale)
First measurements as-is. Then containers placed and measurements taken every 24 hours.





Conditioning using: 1.6 gallon filled water container, tie-down.

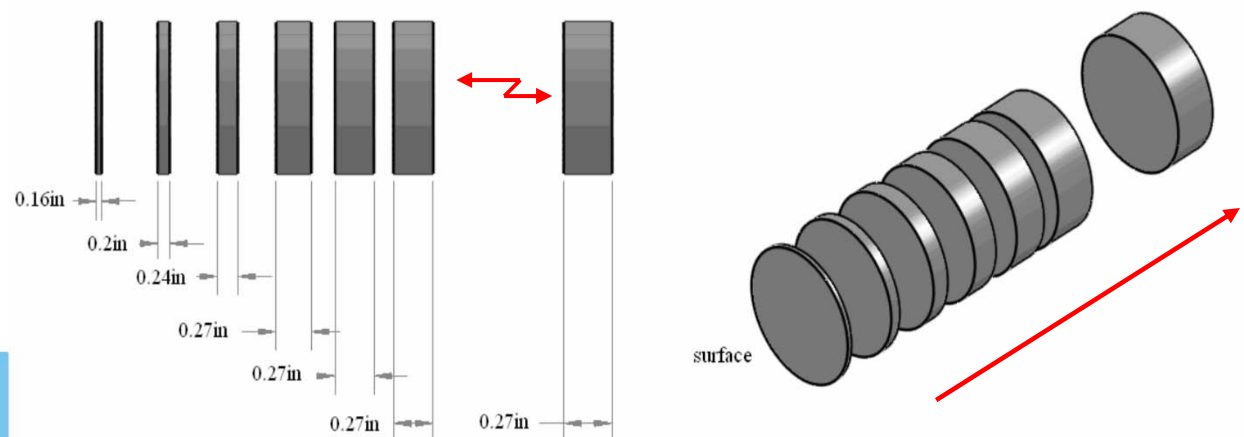
Field Obtained Concrete Cores

2 to 4 cores drilled per selected pile

2 purposes:

- SR_{wet} (high humidity)
- D_{Cl}

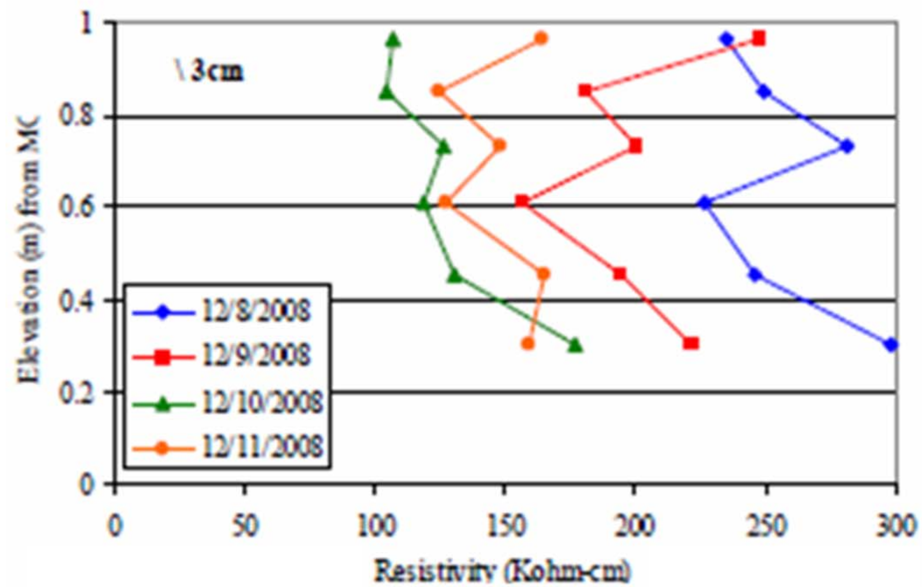
More than 300 cores in ± 80 pile structures

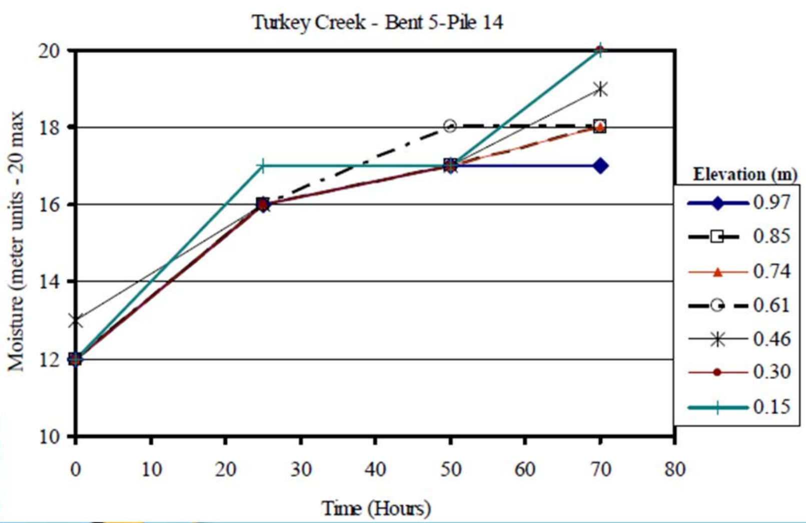


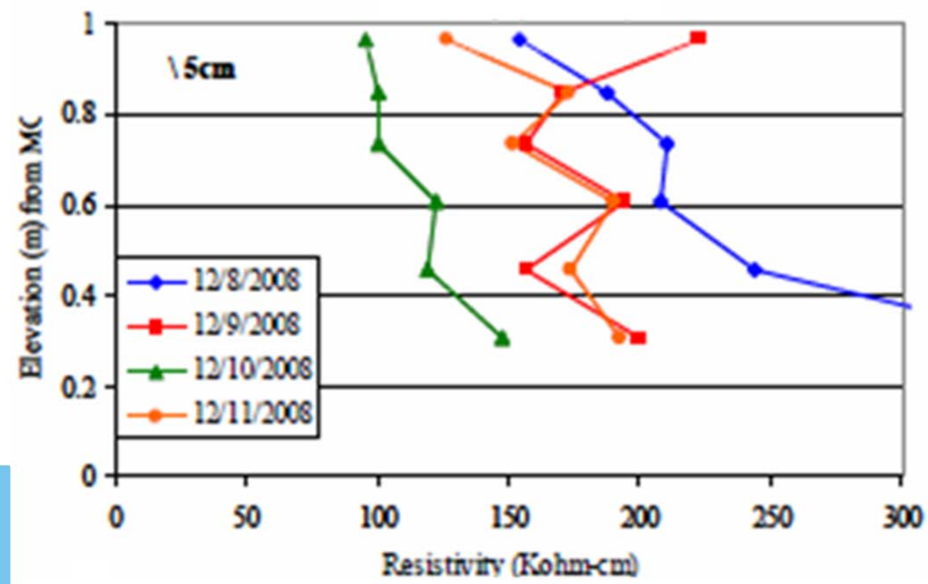
Field results:

Turkey Creek, Melbourne FL.

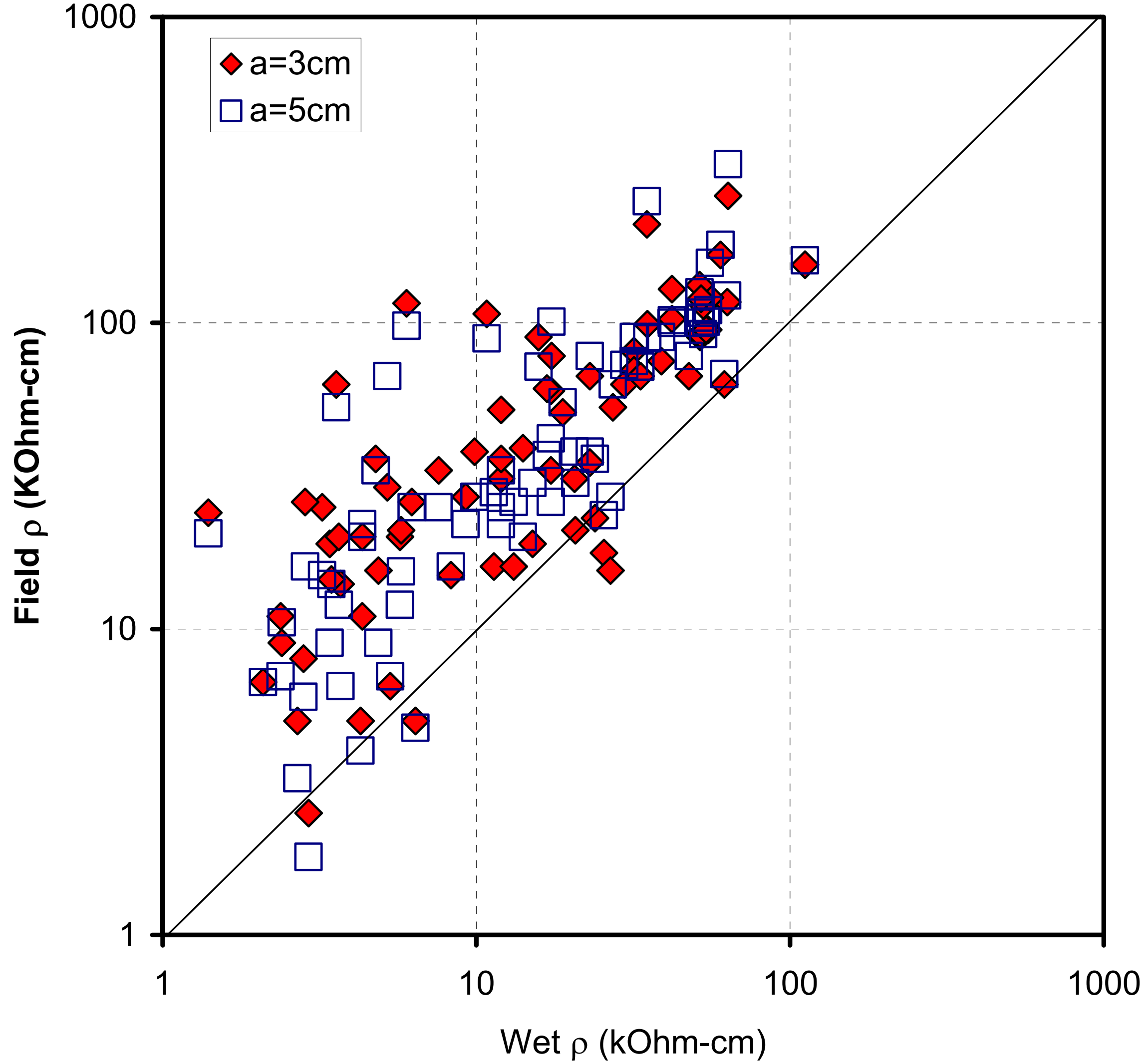
- Bent 5, Pile 14
- 10 year-old
- SR normalized (Temp. @ 21°C)
- 135 ° orientation
- SR decreases as moisture increases



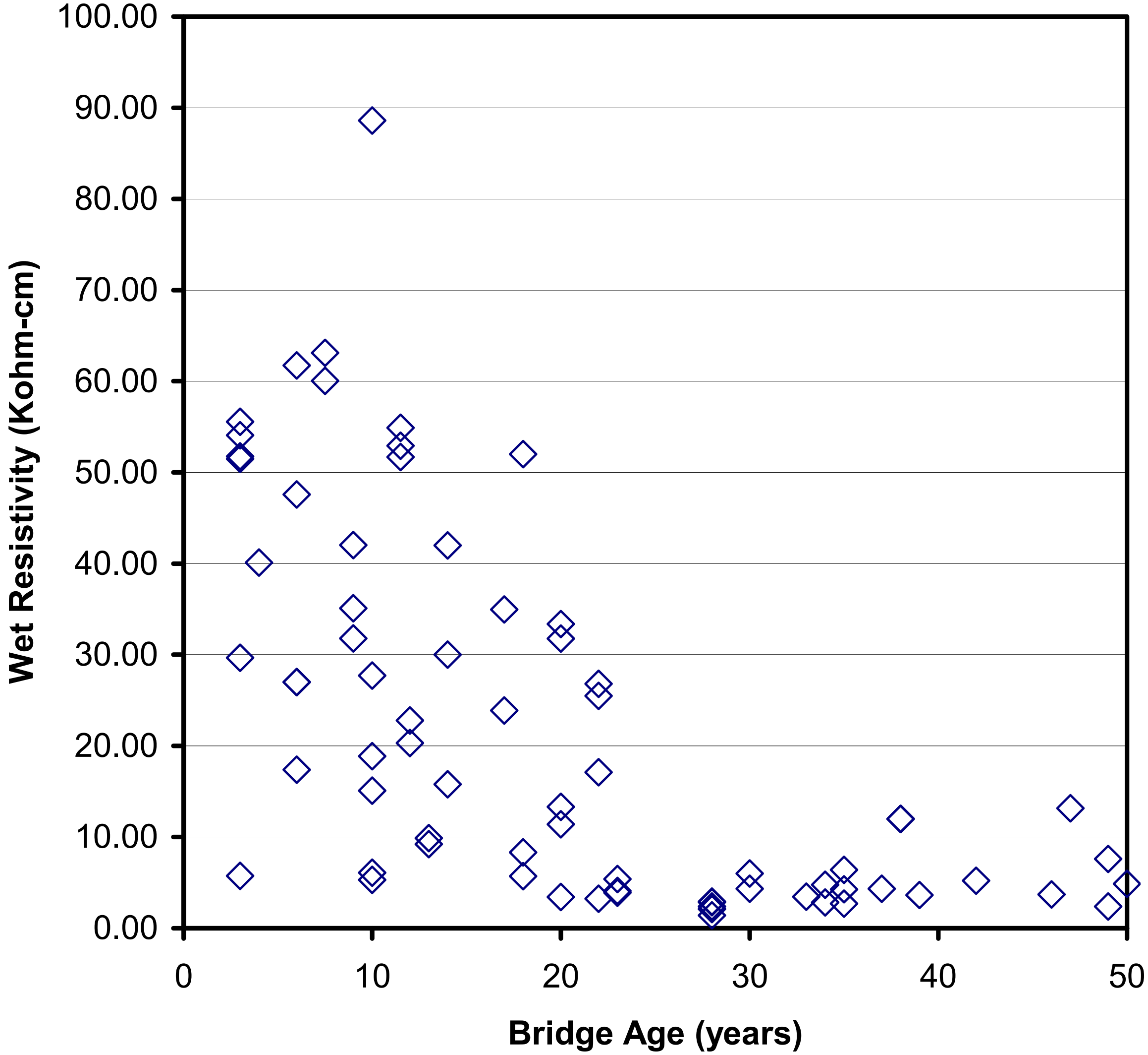




SR_{field} vs. SR_{wet}

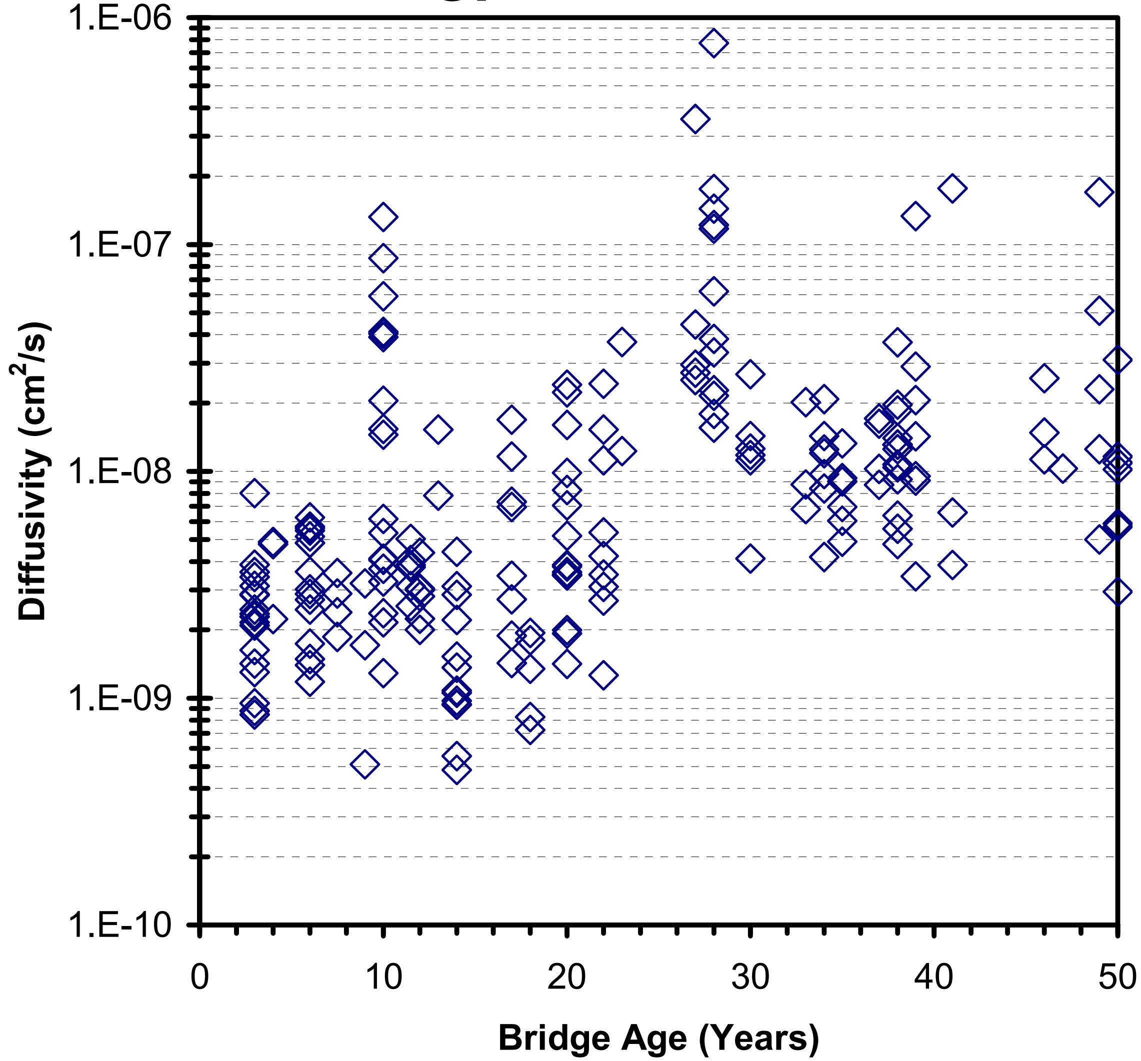


SR_{wet} vs. Age



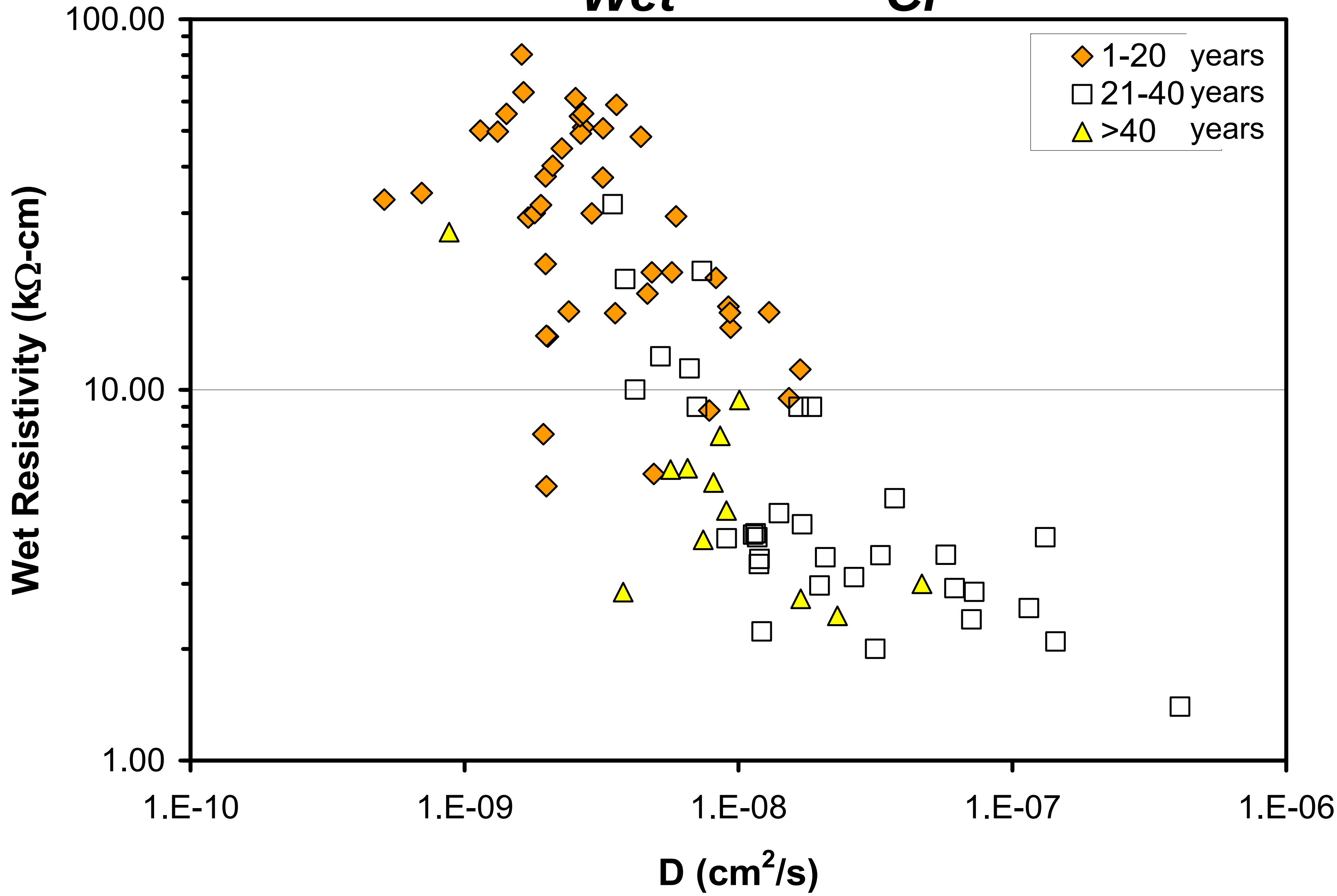
- **Lower SR for > 20 year-old**
- **Higher SR for < 20 year-old**

D_{Cl} vs. Age



Most newer bridge structures have low D_{Cl}
Older bridges show higher D_{Cl}

SR_{Wet} vs. D_{Cl}



100.00
10.00
1.00
Wet Resistivity (kΩ-cm)
1.E-10
1.E-09
1.E-08
1.E-07
1.E-06
D (cm²/s)
1-20 years
21-40 years
>40 years

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Conclusions

- Concrete with Fly Ash replacement cured in a fog room needs more than 400 days to reach final resistivity value.
- Immersion in 3.5 NaCl solution reduced the SR value measured by 20% on FA concrete when compared to saturated SR measured value.
- Environmental conditions have a significant effect on the SR value measured. Exposure to laboratory temperature and relative humidity produces a monotonic increase in the measured SR value.

Conclusions

- Conditioning method increase the moisture content of the concrete layer closer to the surface.
- SR_{wet} < 10 Kohm-cm for bridges > 20 year-old, SR_{wet} usually > 10 Kohm-cm for newer bridges
- SR_{wet} vs. D_{cl} showed a good correlation, older bridges had higher D_{cl} and lower SRwet
- When comparing SR_{wet} to SR_{field}, showed that conditioning approach does not completely saturate the outer-surface concrete

Thank you for your attention!

Any Questions?

Acknowledgments

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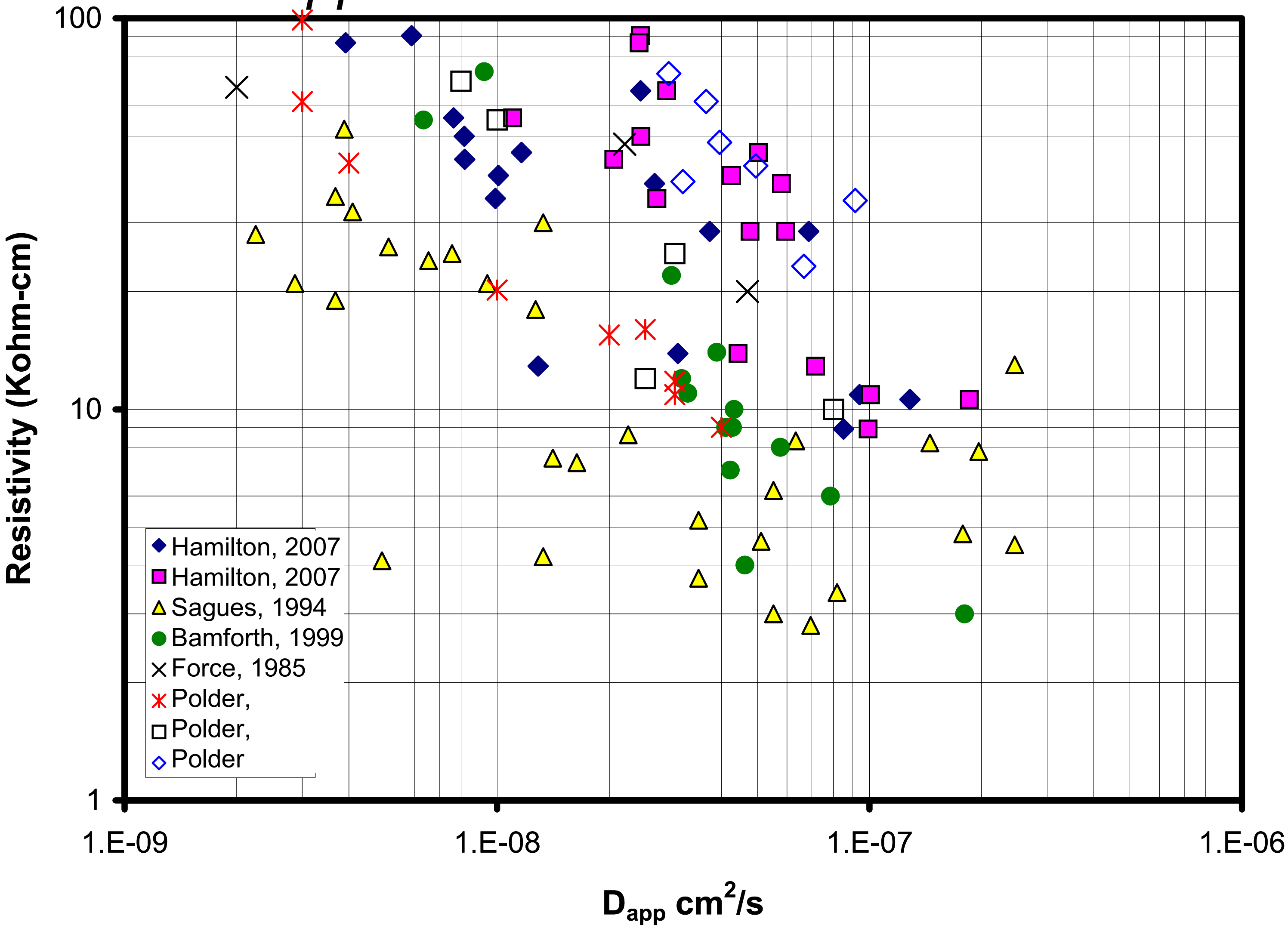
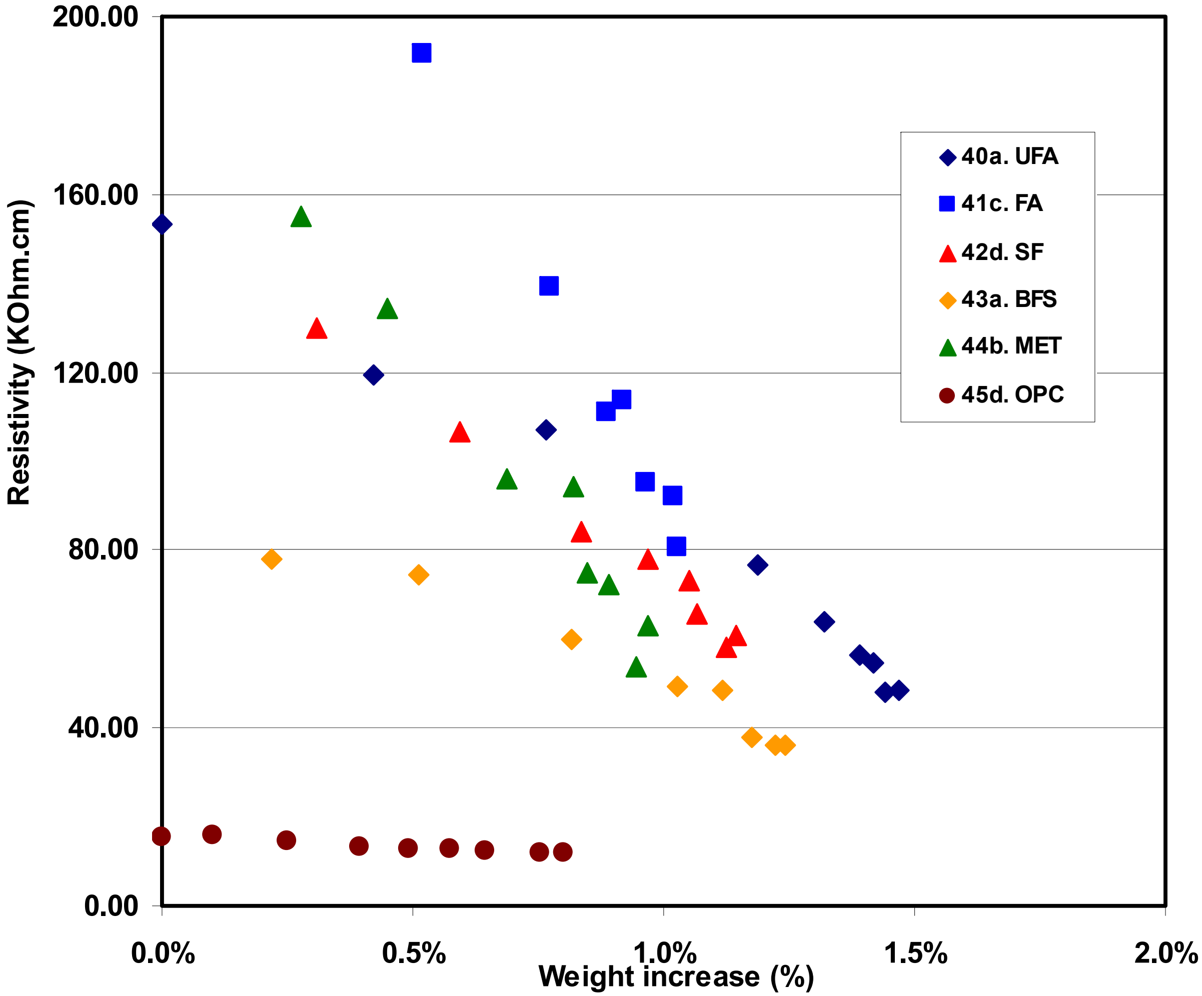
D_{app} values vs. Resistivity



Moisture content effect on Resistivity



Weight increase due to water uptake after 1 day at 60ºC, then exposed in high humidity environment.

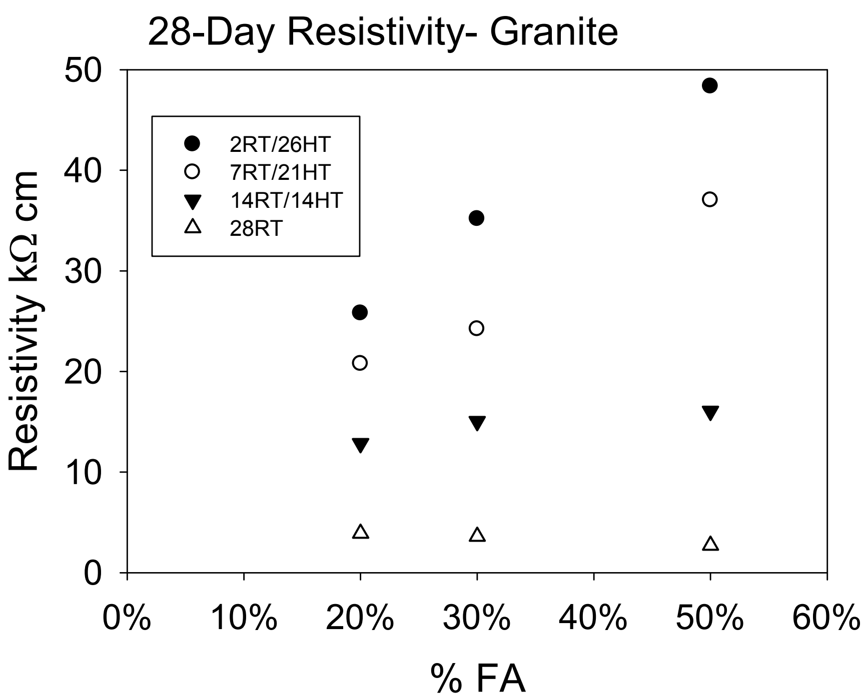
UFA gained the most Weight

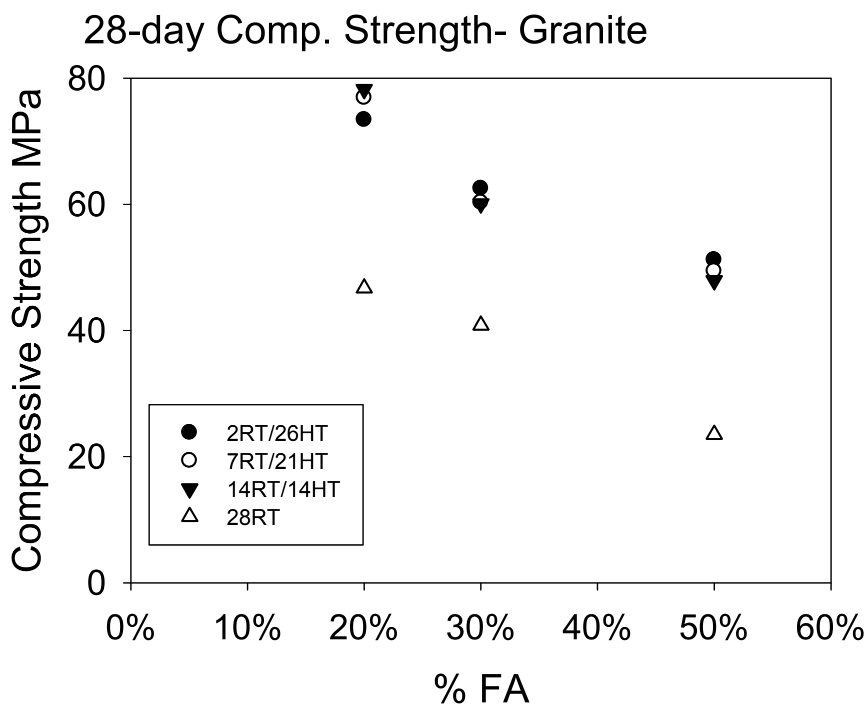
OPC clearly the lowest SR_{wet}, followed by BFS

Note # in Series is CoreID

Towards Performance Based Concrete

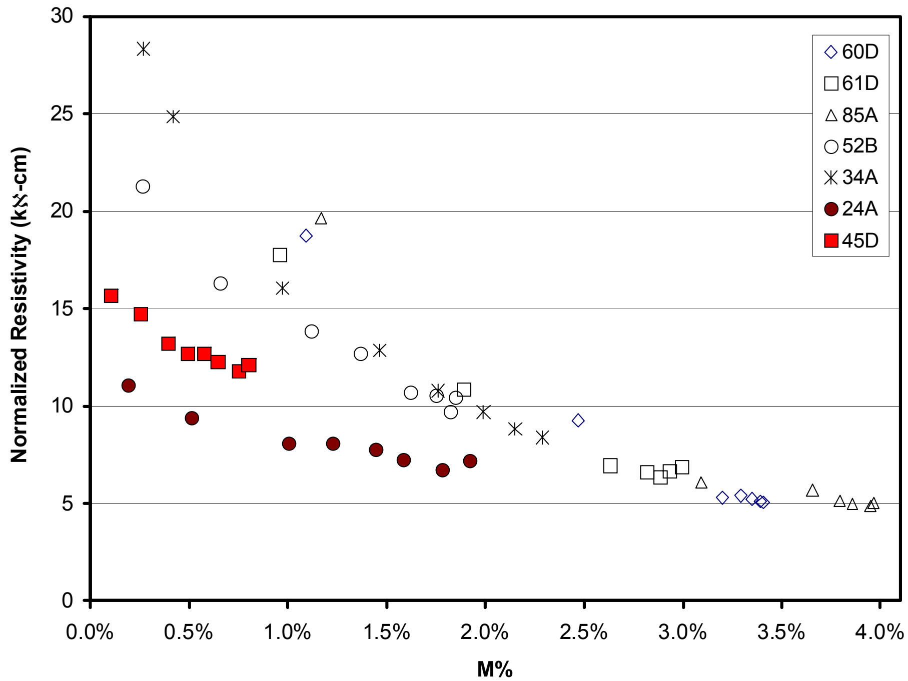
Resistivity of Concrete with Slow Reacting Pozzolans Subjected to Accelerated Curing – Immersed in $Ca(OH)_2$ at ~38 C

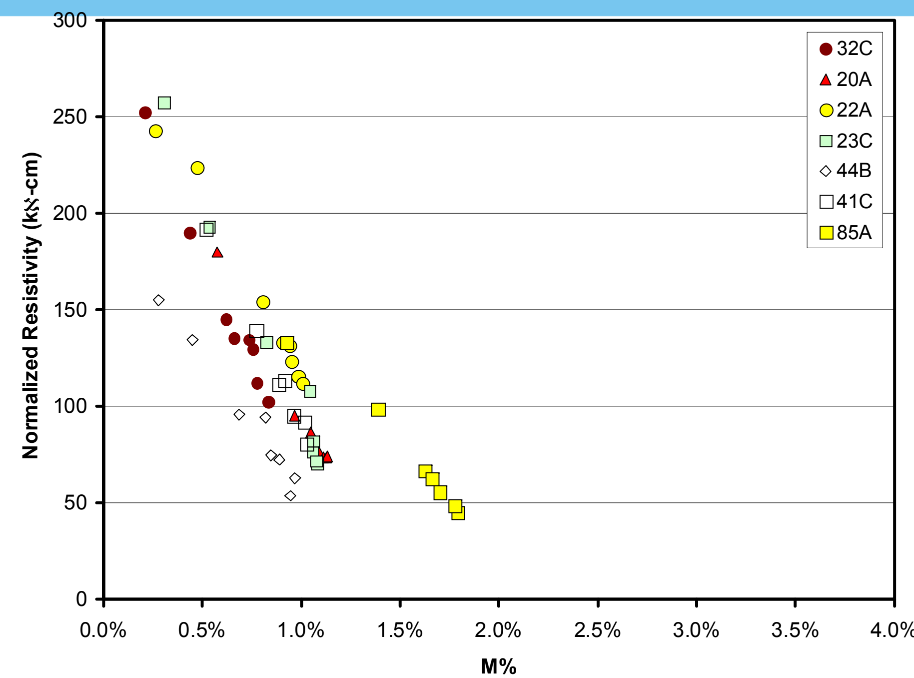


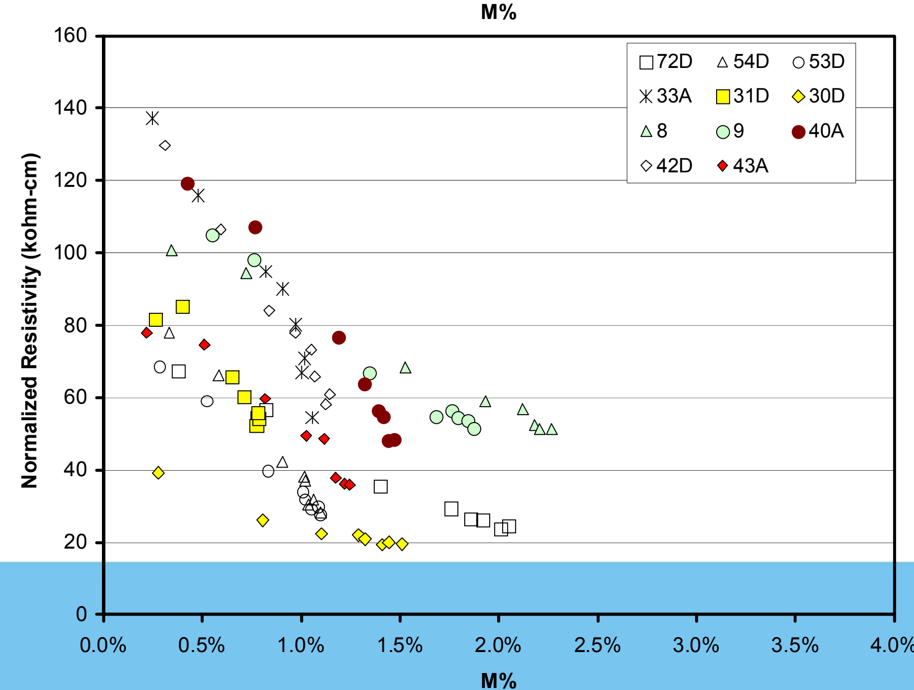


Back-up slide

Moisture content effect on Resistivity







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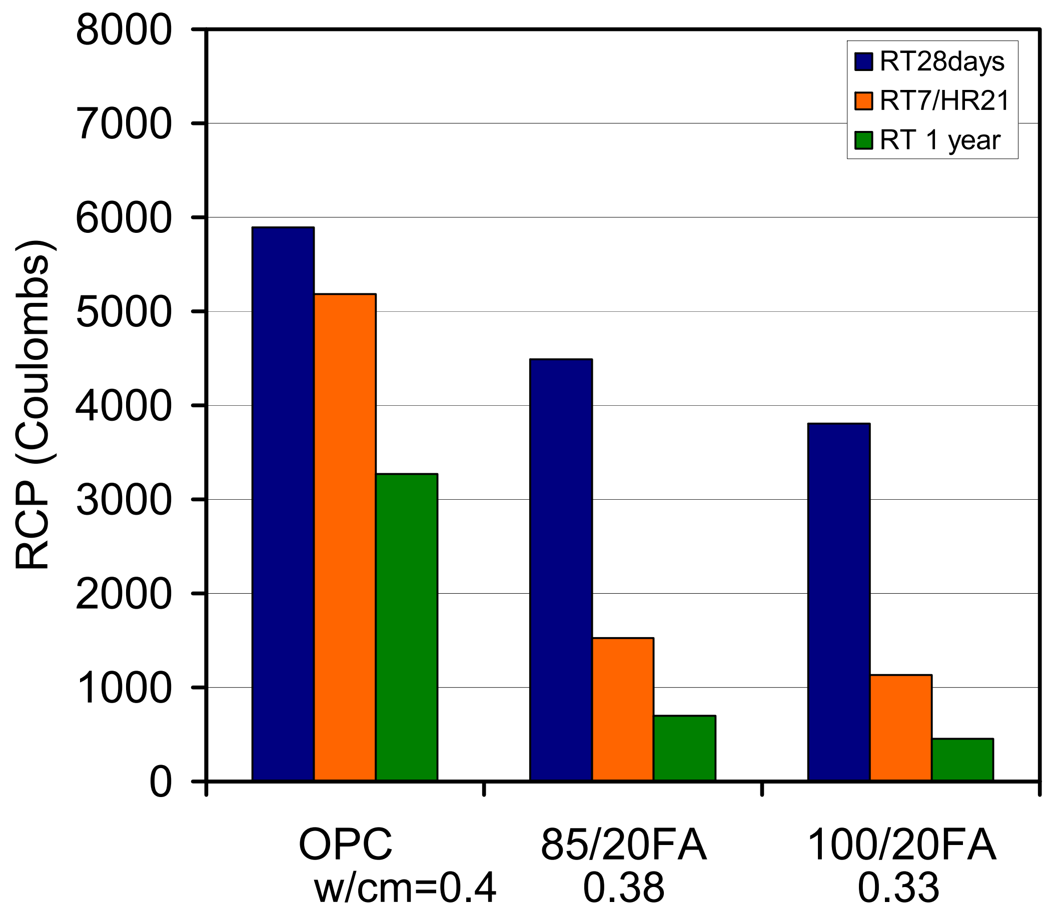

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