Electrical Methods to Characterize and Monitor Concrete

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WEB SESSIONS

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WEB SESSIONS

Evaluation of Saturation Techniques for In-situ Surface Electrical Resistivity Measurements

By Dr. Michelle Nokken and Jose Sanchez Marquez

Agenda

1. Basic Definitions

Resistivity - an intrinsic property that describes how resistive the material is to the flow of electric current,

$$V = IR$$

Resistivity, ρ, is the Resistance normalized by the length, L, and cross sectional area, A.

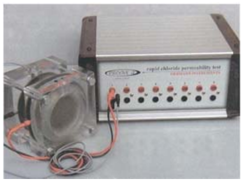
$$\rho = R\,\frac{A}{L}$$

Conductivity, material's ability to conduct an electric current

2. Resistivity Background

1980	FWHA study (Whiting)
1983	AASHTO T277
1991	ASTM C1202
2002	FDOT study for alternate methods
2004	FM5-578
2011	AASHTO T95
2012	ASTM C1760

3. Methods of measuring Resistivity



ASTM C1202
ASTM C1760

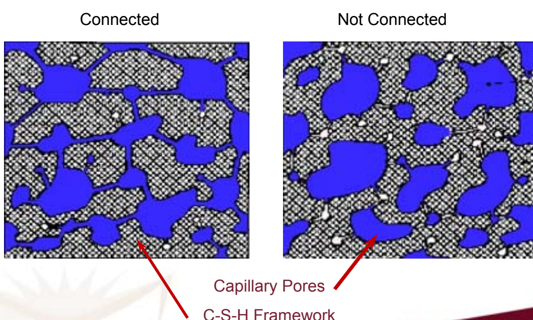
AASHTO TP-95

4. Why Electrical Resistivity is related to Permeability ?

When a voltage is applied, it creates an electric potential gradient that drives the flow of electrons through the concrete. More tortuous path more difficult for the electrons to pass through, **Higher electrical Resistivity**.

Water contains ionic species such as chlorides or sulfates with a more tortuous path more difficult for the fluids to pass through, **low permeability.**

5. Pore network



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Resistivity
1. Basic Definitions
2. Resistivity Background
3. Methods of measuring Resistivity
4. Why Electrical Resistivity is related to Permeability
5. Pore Network

Saturation Effect
6. **According to Previous Research**
7. **Factors influencing Resistivity**
8. **Effect of Saturation**

Objectives

Mixture Design

Experimental Program
9. Increasing saturation between moist cured and lime saturated samples
   - Methodology
   - Comparison between Mixes
   - Saturation time Differences
   - Comparison all ages
10. Increasing saturation in slabs
   - Methodology
   - Sensor's characteristics
   - Slab's characteristics
   - Geometry results at 28 – 56 Days
   - RH results
11. Increasing saturation between dry and lime saturation
   - Methodology
   - Mix 75TI-25FA
   - Mix 100TI

Observations

Conclusion

Recommendations
1. Partially Saturated Elements
2. In-situ Saturation Method

6. According to Previous Research

- SCMs tend to have a more complex and refined pore networks giving the concrete a higher tortuosity and a lower permeability.
- Increasing w/cm generates greater porosity, fewer interruptions to flow, and concrete tends to have a lower tortuosity and higher permeability.

7. Factors Influencing Resistivity

- Tortuosity / Pore structure
  - Water to cement ratio
  - SCM (amount and type)
  - Age and curing
- Chemical Admixtures
- Temperature (~2%/^{o}C)
- **Saturation**

8. Effect of Saturation

- At low levels of saturation, resistivity cannot be measured, usually is zero, but after a minimum period of immersion (5 min), it is possible to obtain resistivity values.
- AASHTO T95 requires a minimum of 7 days at 100% humidity.
- ASTM method is considering 7 days in a limewater tank maintained at 23C ± 2C.
- Limewater reduces resistivity by 10% (Kessler et al., 2008)
- However, is important to know how much time is necessary to saturate the sample or element in order to achieve a **reliable value?**

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Objectives

1. **Understand how the moisture (saturation) content influences the overall measured resistivity response.**
2. Investigate differences between geometry (cylinders, cores, slabs and structures (columns)).
3. Develop an adequate method to saturate in-situ concrete in order to achieve reliable Surface Resistivity Values.

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Mixture Design

Mix Information			Cement Type (%)		Pozzolan (%)		No. Of Samples (10x20 cm)	f'c 56 Days
Mix	w/cm	Air (%)	Type I/II (TI)	Limestone (L)	Fly Ash (FA)	Slag (S)		
100TI	0,40	6	100	-	-	-	6	45,31
	0,51	8	100	-	-	-	5	37,52
	0,60	4	100	-	-	-	4	36,07
	0,52	6	100	-	-	-	5	26,46
50TI-50S	0,54	4,5	50	-	-	50	5	62,34
	0,52	8	50	-	-	50	5	39,95
	0,57	5	50	-	-	50	5	43,75
	0,63	7	50	-	-	50	5	34,79
50L-50S	0,32	5		50			5	49,72
	0,48	4		50			5	49,83
	0,48	5		50			5	46,95
	0,50	6		50			5	36,99
50TI-30FA-20S	0,36	7	50		30	20	5	48,26
	0,40	4	50		30	20	5	42,53
	0,53	5	50		30	20	5	28,26
	0,64	7	50		30	20	5	30,34
50TI-20FA-30S	0,37	4			20	30	5	50,73
	0,41	4			20	30	5	41,59
	0,53	5			20	30	5	28,11
	0,64	5,5			20	30	5	24,83

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Methodology

1. For the first 7 days samples were stored in limewater solution (calcium hydroxide) at room temperature ~23 ±2°C.
2. Stored in high humidity (90%+) until testing.
3. Removed at 28, 56 and 91 days.
4. Measured resistivity for 3 days at each age. (Returned to moist curing until next test time).
5. During 72 hours the resistivity of every sample was measured 7 times at different saturation degrees (0 – 1 – 3 – 6 – 24 – 48 – 72 hours)

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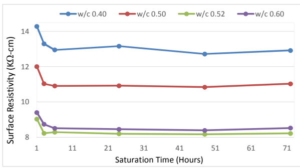
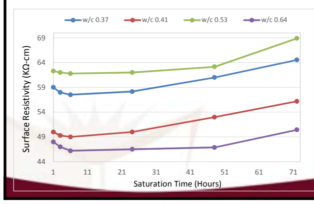
Comparison between Mixes at 28 Days

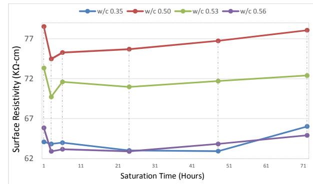


Mix 100T1
- Significant decrease up to 6 hours.
- Stable after 6 hours.
- Average difference of **-9.5 %** was observed between the first measurement and the last one.



Mix 50TI-20FA-30S
- Less decrease up to six hours.
- Increases observed after 6 hours.
- Average difference of **+3.5 %** was observed between the first measurement and the last one.

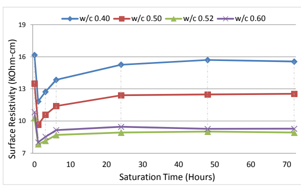
Comparison between Mixes at 28 Days



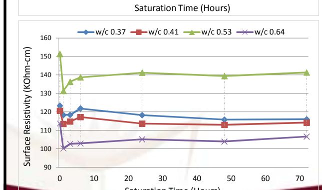
Mix 50L-50S
- Significant decrease up to 6 hours.
- Increases observed after 24 hours.
- Average difference of **– 2,2 %** was observed between the first measurement and the last one
- Similar to Mix 50TI-50S and 50TI-30FA-20S

At 28 days 3 Kind of different behavior were observed during the time test was conducted at different times (hours) for the total 5 mixes

Comparison between Mixes at 91 Days

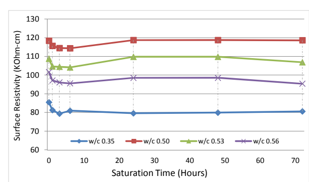


Mix 100TI
- Most changes observed up to 6 hours.
- Stable after 24 hours.
- Average difference of **-8 %** was observed between the first measurement and the last one.



Mix 50TI-20FA-30S
- Most changes observed up to 6 hours.
- Stable after 24 hours.
- Average difference of **-6.5 %** was observed between the first measurement and the last one
- Similar to Mix 50TI-50S

Comparison between Mixes at 91 Days



Mix 50L-50S
- Most changes observed up to 6 hours.
- Stable after 24 hours.
- Average difference of **-1,7 %** was observed between the first measurement and the last one
- Similar for Mix 50TI-50S

At 91days also 3 Kind of different behavior were observed during the time test was conducted at different times (hours) for the total 5 mixes

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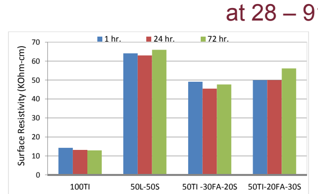
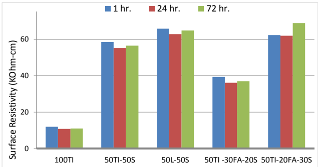
Saturation time Differences - Mixes w/c 0.40 at 28 – 91 Days



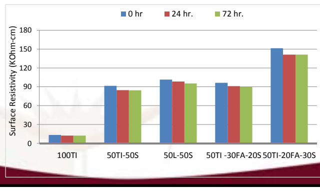
28 days
The average difference between 1 hour saturation and full saturation was only **~ 2%**.

91 days
The average difference between humidity air conditions was only **~3%**.

Saturation time Differences - Mixes w/c 0.50 at 28 – 91 Days



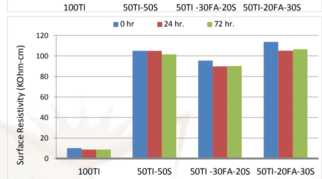
28 days
The average difference between 1 hour saturation and full saturation was only **~ 2%.**



91 days
The average difference between humidity air conditions was **~7%.**

Saturation time Differences - Mixes w/c 0.60 at 28 – 91 Days

28 days
The average difference between 1 hour saturation and full saturation was only ~ **2%.**



91 days
The average difference between humidity air conditions was **~3%.**

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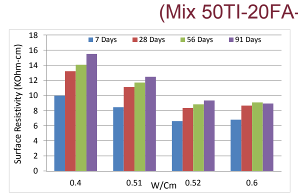
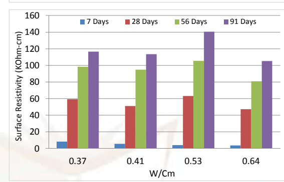
Comparison between (Mix 100TI) and (Mix 50TI-20FA-30S) all ages

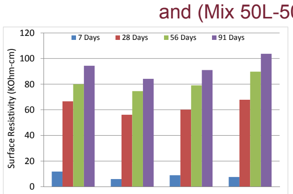


Mix 100TI
shows what happen when the W/Cm is increase (0,4 to 0,60) generates greater porosity, concrete tends to have a lower tortuosity for the electrons are easy to pass trough the pore network (higher permeability).

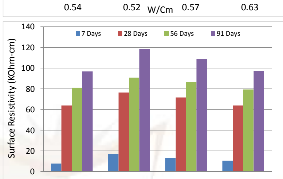


Mix 50TI-20FA-30S
Resistivity values don't decrease when the W/Cm increase.

Comparison between (Mix 50TI-50S) and (Mix 50L-50S) all ages



Mix 50TI-50S
shows also a contradictory behavior, the resistivity values don't decrease when the W/Cm increase.



Mix 50L-50S
This can of behavior was also observed by (Rupnow et al., 2011) for those concrete mixes containing slag

It seems that the effect of using SCMs generates a more complex and refined pore networks and it is not affected by the increase of w/cm. At the end the concrete is going to have higher tortuosity and a lower permeability

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   - Mix 100TI

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1. Partially Saturated Elements
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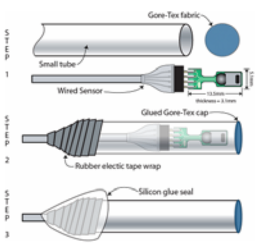
Methodology

1. Two mixtures were selected (100T1 and 50TI-20FA-30S) with same w/cm equal to 0.40. The main idea, was verify if the same influence of saturation was observed in the slabs.
2. Similar curing as previously (7 days limewater)
3. Sensors (Temp/RH) installed at various depths, five in total were installed and located in order to measure the internal relative humidity and temperature in concrete laboratory specimens

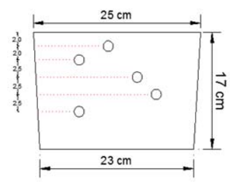
Sensor's characteristics



Lange et al., 2008

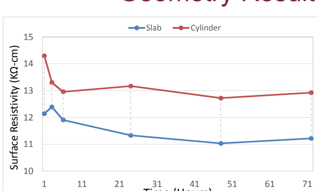
The sensor has a range of 0-100% RH with an accuracy of +/- 2%.

Slab's characteristics

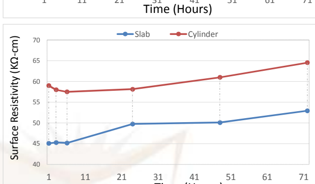


Sensor locations, every 20, 40, 65, 95 and 115 mm depth

Geometry Results – 28 days

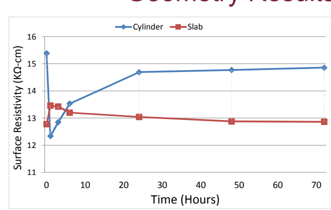


Mix 100TI
After applying the cell constant correction factor modified for circular concrete slabs K=1.32 (Morris et al.,1996) Slab was 13% less than the cylinder samples.

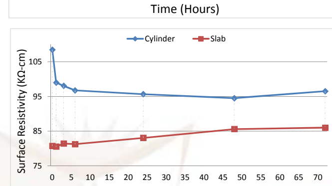


Mix 50TI-20FA-30S
Slab was 17% less than the cylinder samples.

Geometry Results – 56 days

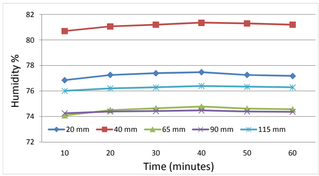


Mix 100TI
Slab was 12% less than the cylinder samples.

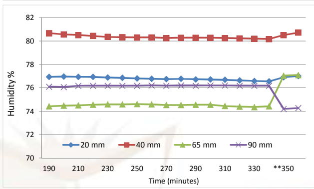


Mix 50TI-20FA-30S
Slab was 11% less than the cylinder samples.

RH Results



1 Hour
Constant behavior



No significance changes in the relative humidity after 6 hours of monitoring

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- **Mix 75TI-25FA**
- **Mix 100TI**

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2. In-situ Saturation Method

Methodology

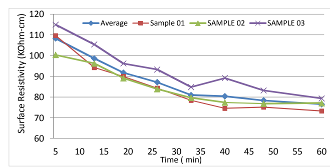
Two mature mixtures were tested,

1. Mix 2 - 75% Portland Cement and 25% Fly ash (3 cylinders). Saturated with tap water
2. Mix 5 - 100% Portland Cement (3 cylinders). Saturated with limewater.

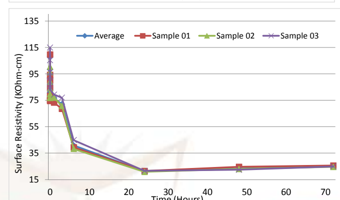
Cylinders were mature (~5 years) and stored in air during this period of time.

The test cylinders were immersed in solution. At different times the surface resistivity was measured.

Mix 75TI-25FA

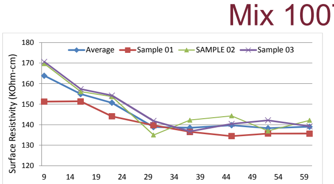


Mix 75TI-25FA – 1 hour:
- The first measurement was made after 5 min.
- Average difference of **-18%** between the first measurement and the last one

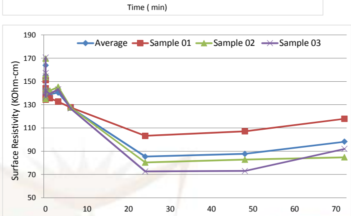


Mix 75TI-25FA (0 to 72 hours)
- After 24 and until 72 hours the resistivity values remain constant.
- Average difference of **-78%** between the first measurement and the last one.

Mix 100TI



Mix 100TI – 1 hour:
- The first measurement was made after 9 min.
- Average difference of **-12%** between the first measurement and the last one



Mix 100TI (0 to 72 hours)
- Increases observed after 24 hours
- Average difference of **-44%** between the first measurement and the last one.

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Observations

Using the Wenner four-probe device

1. Requires the storage of samples in limewater solutions or 100% humidity.
2. Low permeability concretes may not obtain saturation even after long immersion times, owing to self-dessication (internal drying). Also observed in samples with high permeability properties
3. Storage in limewater may provide additional curing and/or leaching that is not representative in actual field structures

Conclusions

- Saturation for 24 hours appears to be sufficient.
  - Differences between 1, 24 and 72
- Differences observed between cylinders and slabs (even with correction)
- Tap water may be feasible for saturation purposes.

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1. **Partially Saturated Elements**
2. **In-situ Saturation Method**

Recommendations

Due to, on the field is difficult to accomplish full saturation as in the laboratory. However, if two new alternatives approach can be develop,

1. Resistivity measurements on partially saturated elements.
2. Develop an adequate method to saturate in-situ concrete elements.

The cost of testing (in terms of time and money) could be significantly reduced if reliable measurements can be made on it.

1. Partially Saturated Elements

Once the degree of saturation change, the pore solution conductivity and the solutions connectivity also changes.

An universal expression was developed to characterizes the pore structure of concrete (formation factor) plus an empirical expression for the effects of partial saturation.

1. Partially Saturated Elements

Using the following expression (Weiss et al.,2013),

$$\sigma_c = \left(\frac{\sigma_p}{S}\right)\left(\frac{1}{F}\right)(S^n)$$

Each term is independent and they are related to well defined properties of the matrix and the solution filling its pores.

1. Partially Saturated Elements

σ_c — Concrete conductivity. A high concrete conductivity means that the pore network is less tortuous, more permeable and with a low resistivity value.

$\left(\frac{\sigma_p}{S}\right)$ — Pore solution conductivity (attributable to the mixture design and subsequent concentration of water loss

$\left(\frac{1}{F}\right)$ — Accounts the total pore space

(S^n) — Accounts the connectivity of the fluid in the pore space, S is known as degree of saturation, n is known as saturation coefficient . According to (Weiss et al.,2013) the value of "n" for concretes is between (3,5 - 5)

2. In-situ Saturation Method

Presuel-Moreno et al.,2010, using a container attached to a concrete element with any kind of pressure under water. The container was left for 1 to 3 days.

2. In-situ Saturation Method

After that it was showed that a correlation existed between samples tested directly in the field and cores drill samples in the laboratory under wet conditions.

Now, using a combination of a number of anchored clamping pliers and a vacuum system plate to attach the device to the concrete element similar to principle used in the German Water permeation Test (GWT).

2. In-situ Saturation Method

Once is attached, pressure is applied to a chamber containing water to increase the ratio penetration into the concrete (rapid saturation).

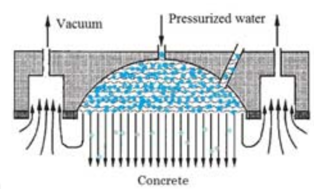
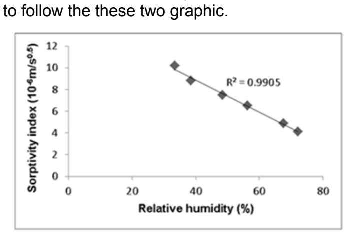


Figure xx, rapid saturation

2. In-situ Saturation Method

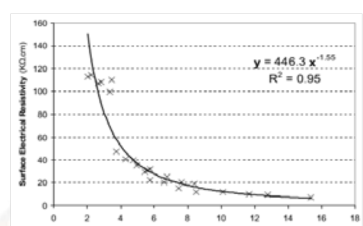
In order to estimate an average water depth penetration is possible to follow the these two graphic.



(Nokken and Mohammadi, 2013). Knowing the concrete humidity is possible to estimate the capacity of absorption of the element .

2. In-situ Saturation Method

Also, using just the resistivity value is possible to obtain the sorptivity coefficient (Shahroodi 2010).



Thank you,

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