American Concrete Institute®
Advancing concrete knowledge

Emerging Technologies

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

ACI
WEB SESSIONS

Dr. R. Doug Hooton, is a Fellow of ACI, ASTM, American Ceramic Society, and the Engineering Institute of Canada. He is the 2011 ACI Arthur R. Anderson Award winner and a member of numerous ACI committees including ACI Committees 329, Performance Criteria for Ready Mixed Concrete and 201, Durability of Concrete. He is a professor and NSERC/Cement Association of Canada Senior Industrial Research Chair in Concrete Durability and Sustainability in the Department of Civil Engineering at the University of Toronto. His research over the last 35 years has focused on the durability performance of cementitious materials in concrete as well as on performance specifications and performance tests.

ACI
WEB SESSIONS

Evaluating Concretes Using Rapid Test Methods for Fluid Penetration Resistance

R. Douglas Hooton, University of Toronto
A. Shahroodi, Northeast Concrete &
Ester Karkar, Lafarge Canada

ACI Toronto
October 22, 2012

All types of deterioration are affected by resistance to water ingress

ASTM Methods for Fluid Ingress
(subcommittee C09.66)

- C1556: Chloride Bulk Diffusion (based on Nordtest NT 443)
- C1585: Measurement of Rate of Absorption of Water
- C1202: Rapid Chloride Penetration (based on AASHTO T277)
- C1760: Bulk Electric Conductivity
- In progress: Resistivity tests and a 1-point rapid water absorption test.

November 2010 Concrete International

Testing Transport Properties in Concrete

Assessing key indicators of durability

BY D. STEPHEN LANE, RACHEL J. DETWILER, AND R. DOUGLAS HOOTON

Performance Specs need Performance Tests

- Durability of concrete depends on preventing penetration of water and aggressive ions.
- We need accurate and precise standard tests that can be used to measure penetration resistance of concrete.
- To be used in specifications, these tests need to be as simple and rapid as possible, but still relate to performance.
- We also need acceptance limits for different exposure conditions.

Where do we measure Performance?

Prequalification (model input tests)	Identity Testing		
	Acceptance at Chute		
		Accept at Point of Placement	
			Accept in-place

Rapid Index Tests

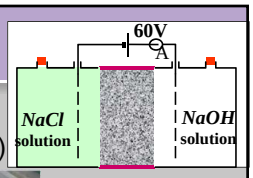
- Chloride diffusion tests maybe ok for prequalification on major projects, but they are impractical (too expensive and slow) for use in construction acceptance.
- Rapid index tests that can be related to fluid penetration resistance are more practical for quality control.

Rapid Index Tests

The following methods are discussed:

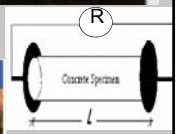
- ASTM C1202 (AASHTO T277) as used in the Canadian CSA A23.1
- ASTM C1760 1 minute resistivity /conductivity obtained from C1202 test
- Rapid Migration Test (Nordtest NT Build 492)
- Surface Electrical Resistivity
- Bulk Electrical Resistivity

Rapid Index Tests

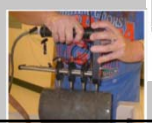


- ASTM C1202 (coulombs)
- NT Build 492:

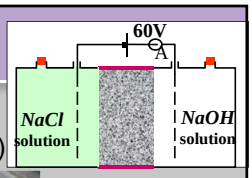
- Bulk Resistivity: $\rho = R (A/L)$



- Surface Resistivity:



Rapid Index Tests

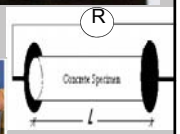


- ASTM C1202 (coulombs)

2 days to complete

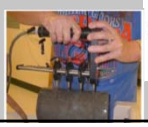
- NT Build 492:

- Bulk Resistivity: $\rho = R (A/L)$

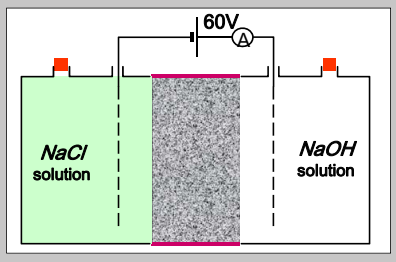


One minute to complete

- Surface Resistivity:



Rapid Chloride "Permeability" ASTM C1202



Voltage is applied and current passing through concrete is measured and integrated over 6 hours to get charge passed in Coulombs

A Rapid Index test for conductivity (connectivity) of the pore system. It does not measure permeability or chloride ingress. But it is a reasonable index test in most cases.

ASTM C1202

- It measures the electric current flowing through the capillary pore system of the concrete.

This test has been criticized due to:

1) the influence of pore solution conductivity on results,

2) due to heating at high currents since conductivity rises with temperature and

  - Above ~2000 coulombs, the temp rise has an effect. McGrath and Hooton (1997) suggested using the 30min. Value x 12 to predict the 6 hour value and minimize the heating effect.
  - Also, ASTM has developed C1760, a 1 min. alternative version to just measure conductivity (inverse of resistivity).

Effects of Using Different solutions in ASTM C1202 Cells

Concretes, ~8 Years old		Std. Test NaCl/ NaOH	NaOH/ NaOH	Beer/ Beer
0.5 w/cm 40% Fly Ash (9 years)	Charge passed, Coulombs	100	92	52
	Rating:	Negligible	Negligible	Negligible
0.55 w/cm 100% PC (7 years)	Charge passed, Coulombs	2261	2218	1174
	Rating:	Moderate	Moderate	Low

So don't use beer as an electrolyte!

Results are in: Beer is a poor conductor

So kids, don't try this at home!

(or in ASTM C1202 tests)

Electrical Conductivity of Fluids

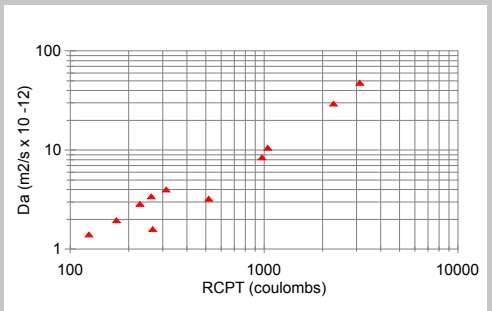
Solution	3.0% NaCl	0.3 M NaOH	Beer (5%)
Electrical conductivity (at test temp.) mS/cm	45.3	61.8	1.16
Electrical conductivity (Temp corrected to 25C) mS/cm	50.7	69.2	1.38
Temperature	19.5 °C	19.4 °C	16.5 °C

Lashley 2007

Usefulness of C1202 for Now

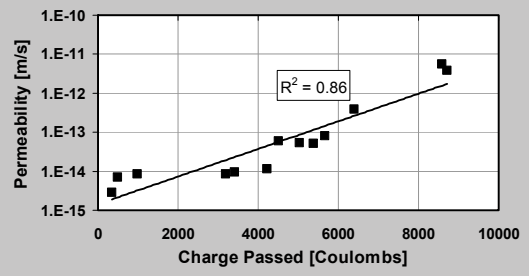
- It is an awkward conductivity test, but is used world wide and many labs can do it.
- It is still a useful rapid index test which relates to the resistance of the concrete pore system to fluid penetration.
- It was adopted in the Canadian CSA A23.1 in 2004.
- But it is relatively expensive and takes ~48h to complete.
- ~24h if use new ASTM C1760 1-min. conductivity version of test.

Relationship of D_a and RCPT



Titherington and Hooton 2004

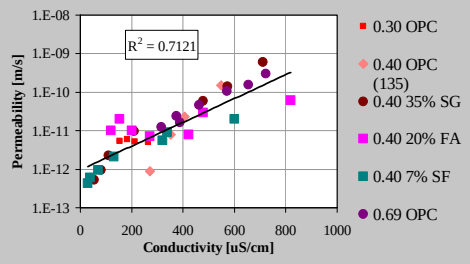
Water Permeability vs. ASTM C 1202
(at 28 days)



Nokken and Hooton 2003

Water Permeability vs. 5 min. Conductivity (essentially C1760)

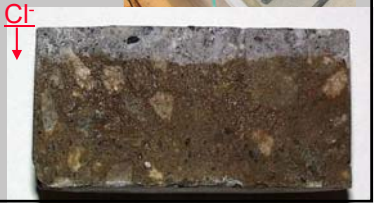
Note: Resistivity is the inverse of Conductivity



Nokken and Hooton, 2003

Nordtest NT492 Rapid Migration Test

- Concrete disk is sealed in rubber tube over electrode in NaCl sol'n.
- The top surface is immersed in NaOH sol'n. with electrode.
- Voltage is applied
- Split & spray with $AgNO_3$



The RMT is used to Measure Non-steady State Migration Values

$$D_{nssm} = \frac{0.0239(273+T)L}{(U-2)t}\left(x_d - 0.0238\sqrt{\frac{(273+T)Lx_d}{U-2}}\right)$$

$D_{nssm} \equiv$ *Diffusion Coefficient*, x 10^{-12} m^2/s

$U \equiv$ Applied Potential, V

$T \equiv$ Temperature of Solution, ^oC

$L \equiv$ Speciment Thickness, mm

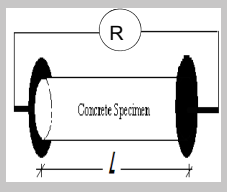
$x_d \equiv$ Average Penetration Depth, mm

$t \equiv$ Test Duration, Hours

But is still takes 10-48h to get a result

Bulk Resistivity

- Simply measure the electric resistance through a saturated, surface-dry concrete cylinder or core prior to strength tests



And calculate resistivity accounting for Area and Length of sample

$\rho = R\ (A/L)$

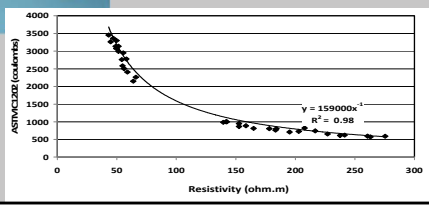
Various Commercial pieces of equipment are now available

Bulk Resistivity Test vs ASTM C1202

The resistivity Test take less than 1 minute and the same sample can then be used for strength testing

German "Merlin"

Uses fixed frequency of 325 Hz



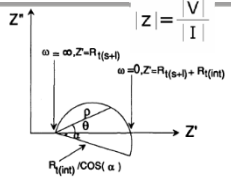
Giatec RCon Bulk Resistivity Device

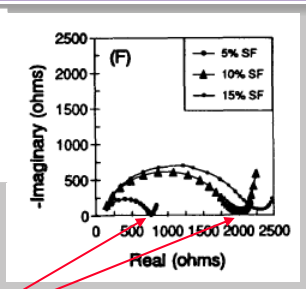
Reading Range	Frequency spectrum	Phase measurement
1 ~ 100 Ω	1Hz ~ 30KHz	0 ~ 180°
100 ~ 1000 Ω		
1 ~ 10 KΩ		
10 ~ 100 KΩ		
100 KΩ ~ 1 MΩ	1Hz ~ 10KHz	

Allows changing frequency to reduce impedance effects

AC Impedance Measurements

$$|Z| = \frac{|V|}{|I|}$$



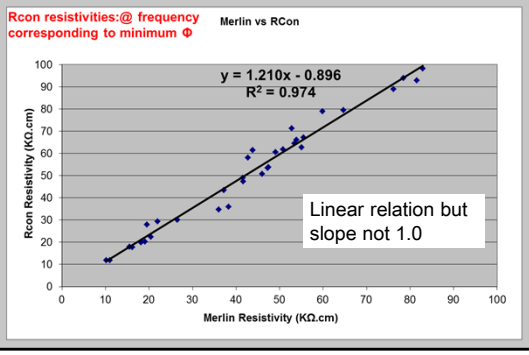


Measures resistance over a wide range of frequencies.

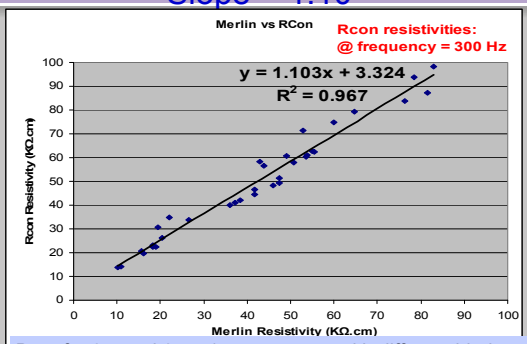
True resistance is where electrode arc drops to x-axis (no impedance)

Ref: Ping et al, CCR 2003

Merlin vs RCon @ optimum frequency: Slope = 1.21

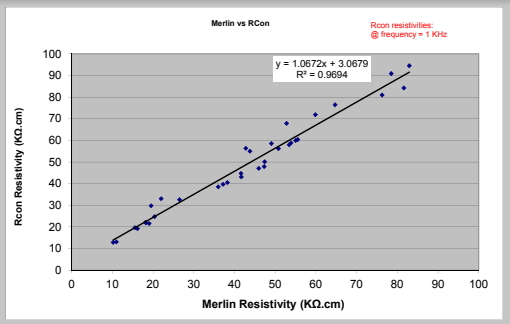


Merlin (325Hz)vs RCon @ 300Hz: Slope = 1.10



Data for 0.4 and 0.5 w/cm concretes with different binders

Merlin (325Hz)vs RCon @ 1 kHz: Slope = 1.07

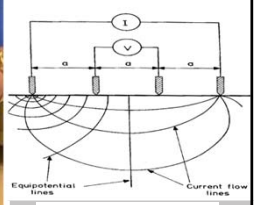


Data for 0.4 and 0.5 w/cm concretes with different binders

Surface Electrical Resistivity

(Wenner probe) FLDOT/LaDOT, AASHTO TP95

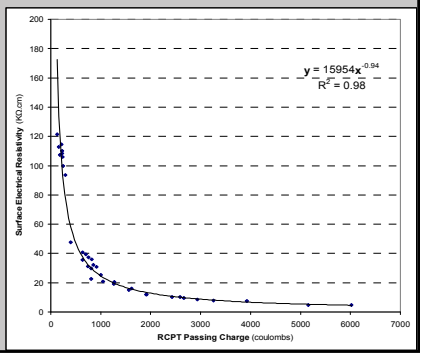
The Wenner probe applies an alternating current (AC) between the two outer electrodes. The voltage drop is measured by two inner probes.



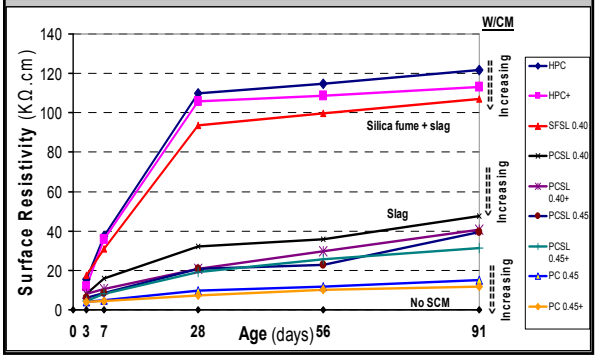
$$\rho = 2\pi a \frac{V}{I} \quad \text{(ohm-m)}$$

Surface Electrical Resistivity as an Indicator for ASTM C1202

- Surface Electrical Resistivity vs RCPT Charge Passed



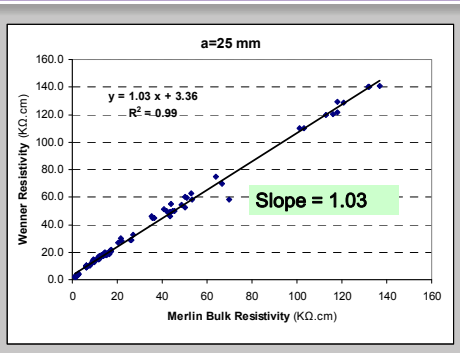
Surface Resistivity of 100x200 mm Concrete Cylinders



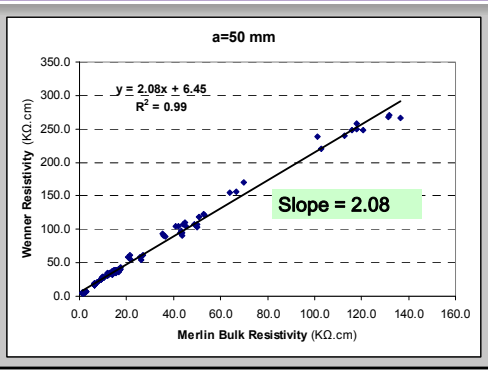
Wenner Probe spacing

- Surface Resistivity values calculated from Wenner probe measurements assume that the electrodes are in contact with a semi-infinite body of concrete.
- The optimum probe spacing depends on geometry of the specimen being measured.
- For 100 x 200 mm cylinders, the optimum spacing is 25mm (Millard et al 1991).

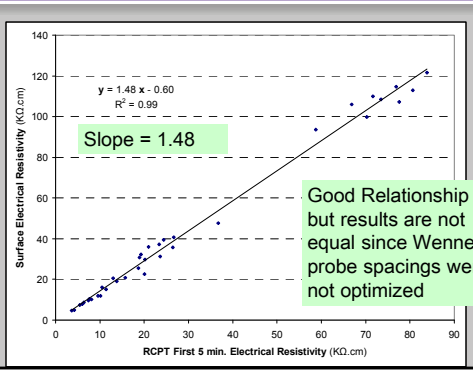
Wenner Probe Resistivity at optimum probe Spacing of 25 mm vs Merlin Bulk Resistivity



Wenner Resistivity at probe Spacing of 50 mm vs Merlin Bulk Resistivity

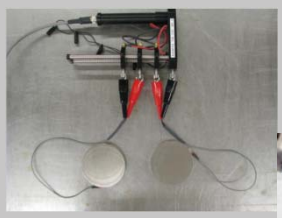


Wenner Probe Surface Resistivity vs 5 min. Resistivity Values obtained from ASTM C1202



Bulk AC Resistivity using "hot wired" Wenner Probe

(from J. Weiss Pooled Fund Study)



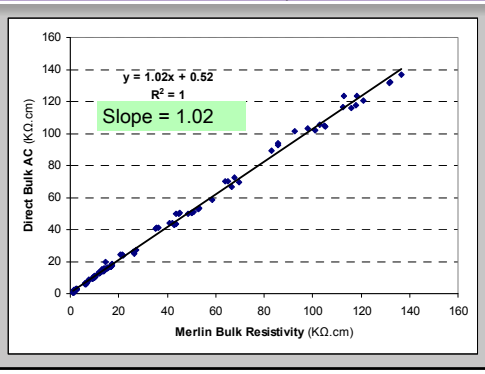
Wires from plates are attached to Wenner probe tips.

Wet sponges are used to make connections

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

Now marketed by Proceq

Bulk Resistivity (using electrode plates connected to Wenner Probe) vs Merlin device



ASTM C1202 vs Surface Resistivity (AASHTO TP95-11)

Chloride Penetration	56-Day Rapid Chloride Permeability Charge Passed as per ASTM C1202 (Coulombs)	28-Day Electrical Resistivity of Saturated Concrete (kΩ.cm)
High	>4,000	<9.5
Moderate	2,000-4,000	9.5-16.5
Low	1,000-2,000	16.5-29
Very Low	100-1,000	29-199
Negligible	<100	>199

[1] AASHTO TP 95-11, "Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration"

Also, for acceptance, we need to develop statistical average and single value limits

1000 coulombs @56d = 290 ohm-m @28d

(Germann data 1000 coulombs @ 28d= 206 ohm-m at 28d)

Selecting a Resistivity Test

1. The fixed-low frequency bulk resistivity Merlin device gives the same values as the "Hot-wired" Proceq Wenner probe device (also at low fixed freq.), Wenner surface values but not ASTM C1760 values.
2. The variable high-frequency Rcon and Solartron devices give similar resistivity values (J. Weiss).

- However, the above 2 groups of tests give different resistivity values, but there appears to be a linear relation between them.
- Which type should be standardized? What test limits??

Next Step in Adoption of Durability-Based Performance Tests

1. Bulk Resistivity Testing has the potential to replace ASTM C1202 as a rapid index test for QA testing and can be performed on a cylinder before strength testing.
2. Resistivity is both rapid and repeatable but is affected by the test method.
3. But first, a standard test method needs to be adopted by CSA or ASTM before it can be referenced in CSA A23.1.

The ideal Identity Test? scratch and sniff