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Electrical Methods to Characterize and Monitor Concrete

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Elizabeth Nadelman is a Ph.D. student in Civil Engineering at the Georgia Institute of Technology. She received her bachelor's degree from Princeton University, where she developed an interest in improving the durability of cement-based materials while studying freeze-thaw damage to concrete for her senior thesis. She is currently investigating the early-age properties and long-term performance of concrete made with limestone cements, seeking to develop more sustainable concretes that can be tailored to achieve both optimal early-age properties and enhanced long-term durability. Elizabeth is a current ARCS Scholar and the recipient of the Hardin Fellowship.

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Extensions of Surface Resistivity Testing for Optimization of Concrete Binary and Ternary Blends

Elizabeth Nadelman
Kimberly E. Kurtis

Georgia Institute of Technology

Motivation

What do these three structures have in common?


Alkali-silica reaction


Freeze-thaw damage


Corrosion

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4 Images: FHWA, PCA, R. Moser

Motivation

The degradation of cement-based materials often involves the transport of *something* from the environment to the material.


Alkali-silica reaction:
Transport of water, alkalis


Freeze-thaw damage:
Transport of water


Corrosion:
Transport of water, Cl^-, CO_2

To ensure concrete's long-term durability, it is essential to limit its permeability.

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5 Images: FHWA, PCA, R. Moser

Motivation

To ensure concrete's long-term durability, it is essential to limit its permeability.

↓

Need to design concrete specifically to achieve low permeability.

↓

Need fast, non-destructive method of assessing concrete permeability *during mix design stage.*

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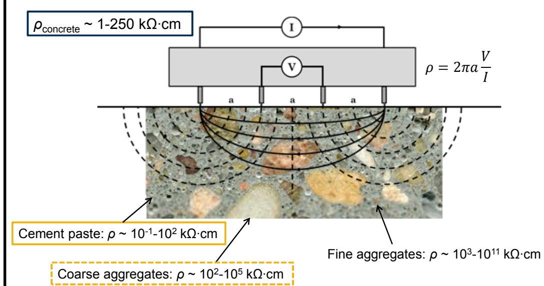
Outline

- Electrical Properties of Concrete
  - Relation to Permeability
  - Relation to Reaction Rates
- Experiment Results
  - Evaluation of Conventional Concrete Mixtures
  - Evaluation of Limestone Cement Mixtures
- Conclusions and Potential Applications

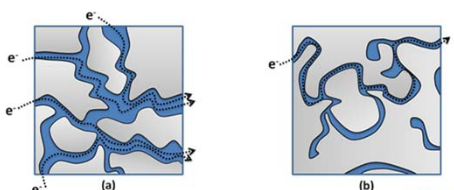
Electrical Properties of Concrete



Wittington, McCarter & Forde, *Mag. Conc. Res.*, 1981

Electrical Properties of Concrete: Relation to Permeability

- Cement paste contains a dense network of interconnected pores through which the electrons will flow.
  - Less interconnected, more tortuous porosity makes electron flow more difficult → higher resistivity
  - Also more resistant to water flow → lower permeability



Electrical Properties of Concrete: Relation to Permeability

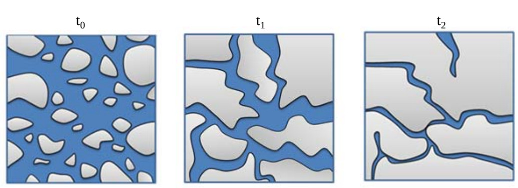
Electrical resistivity measurements can provide a good indicator of concrete's permeability, since both properties are predominantly controlled by the interconnectivity and tortuosity of the pore network.

AASHTO TP95-11

Permeability Classification	SR Limits (kOhm-cm)
High	< 12
Moderate	12 – 21
Low	21 – 37
Very Low	37 – 254
Negligible	> 254

Electrical Properties of Concrete: Relation to Reaction Rates

- Porosity becomes more refined due to hydration and secondary reactions, which reduce interconnectivity over time.
  - SR increases over time as a function of the degree of hydration and secondary reaction rates.
  - SR vs. time curves can be used to evaluate degree of hydration and secondary reaction rates.



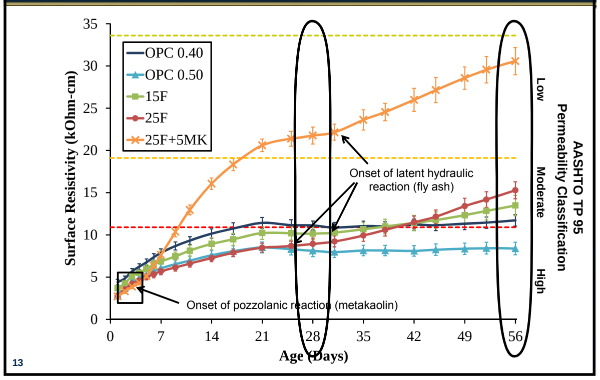
Evaluation of Conventional Portland Cement Mixes

- (3) 4"x8" concrete cylinders prepared for each mix
  - Varied w/cm and SCM content
  - Aggregate types (crushed granite & natural sand) and quantities kept constant
  - Cured continuously in limewater (73ºF)

Mix Type	Mix ID	w/cm	Class F Fly Ash (% wt.)	Metakaolin (% wt.)
Conventional OPC mixes (varying w/cm)	OPC 0.40 OPC 0.50	0.40 0.50	0 0	0 0
Conventional OPC mixes (varying SCM content)	15F 25F 25F+5MK	0.40 0.40 0.40	15 25 25	0 0 5

- Surface resistivity measured periodically for 56 days

Conventional Portland Cement Mixes



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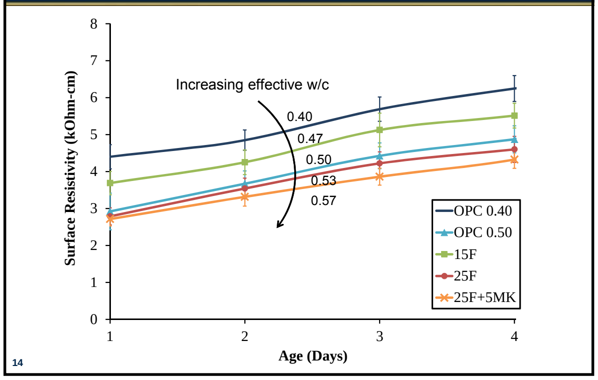
Conventional Portland Cement Mixes



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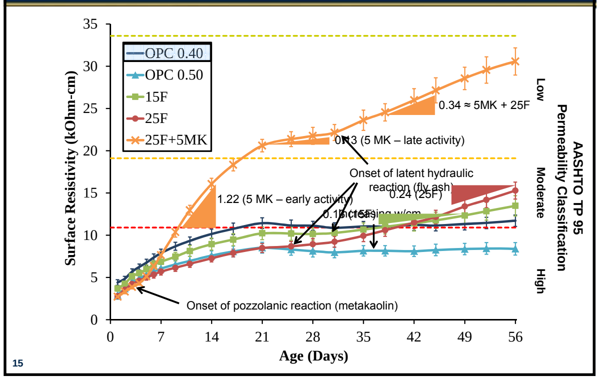
Conventional Portland Cement Mixes



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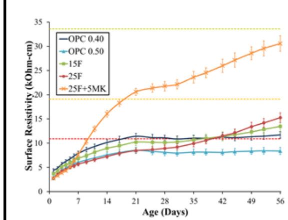
Conventional Portland Cement Mixes



- Decreasing cement content shifts resistivity curve downward.
- Adding Class F fly ash slowly increases resistivity after about 28 days at a rate roughly proportional to its dosage.
- Adding metakaolin rapidly increases resistivity between about 4 and 21 days, but has less effect on resistivity after about 21 days.

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Evaluation of Portland Limestone Cement Mixes

- (3) 4"x8" concrete cylinders prepared for each mix
  - Used ASTM C 595 Type IL cements (10% LS) with varied fly ash content
  - Aggregate types (crushed granite & natural sand) and quantities kept constant
  - Cured continuously in limewater (73ºF)

Mix Type	Mix ID	w/cm	Limestone (% wt.)	Class F Fly Ash (% wt.)
Limestone cement mixes (varying SCM content)	10LS 10LS+15F 10LS+25F	0.40 0.40 0.40	10 10 10	0 15 25

- Surface resistivity measured periodically for 56 days

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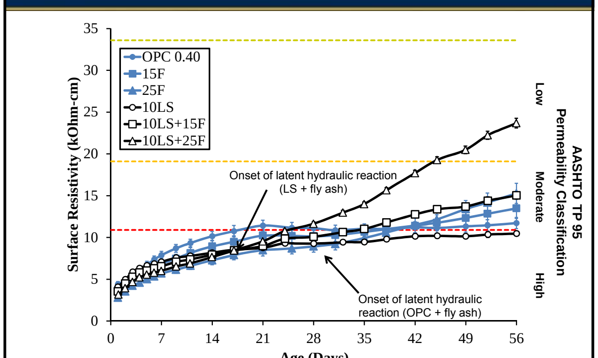
Limestone Cement Mixes



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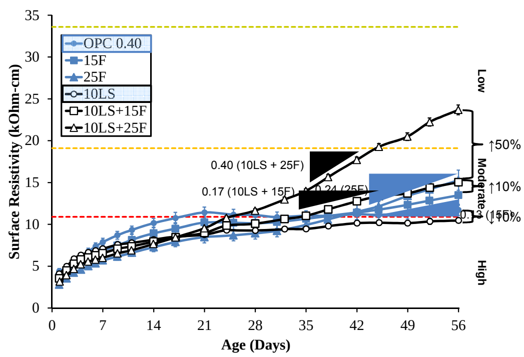
Limestone Cement Mixes



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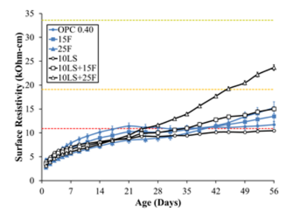
Limestone Cement Mixes



- Replacing a portion of portland cement with less reactive limestone shifts resistivity curve downward.
- Adding Class F fly ash to limestone cement concrete accelerates onset of latent hydraulic reaction and increases reaction rate.

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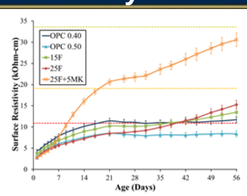
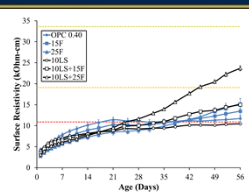
Effect of Binder Composition on Resistivity Rate Curves





Influence of	On Surface Resistivity	On Permeability
Increasing w/cm	↓ at all ages	↑ at all ages
Fly ash	↓ at early ages ↑ after ~ 28 days	↑ at early ages ↓ after ~ 28 days
Metakaolin	↑↑ for first ~ 14 days	↓↓ for first ~ 14 days
Limestone – no fly ash	↓ at all ages	↑ at all ages
Limestone – with fly ash	↓ at early ages ↑ after ~ 14 days	↑ at early ages ↓ after ~ 14 days

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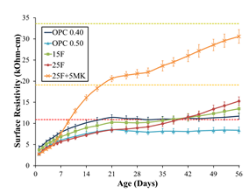
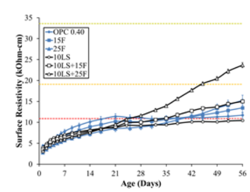
Conclusions

- Surface-resistivity testing is a fast, non-destructive tool for indirectly assessing the permeability of concrete.
- It is particularly useful for mix design applications, where it is important to understand how binder composition will affect permeability and microstructural development over time.





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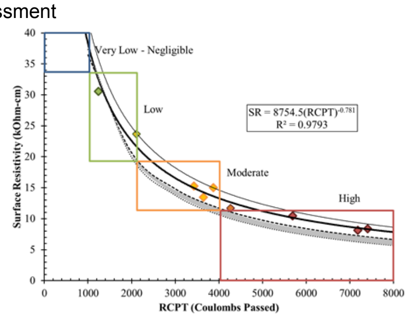
Future Work and Potential Applications

- Relate SR to other methods currently used for permeability assessment



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Future Work and Potential Applications

- Relate SR to other methods currently used for permeability assessment
- Relate SR to compressive strength development
  - Permeability (SR) and strength both related to internal structure of concrete (El Ashkar, et al., 2012)
- Better understanding of the influence of aggregates on resistivity measurements is needed

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  - Rachel Corbin (HS)

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Thank you!

Questions?

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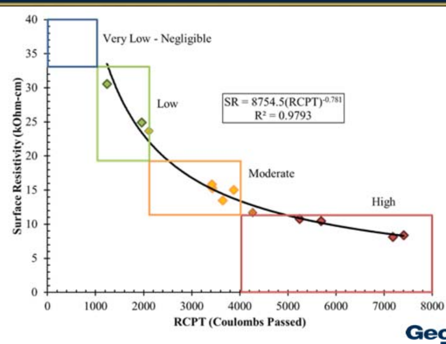
Comparisons to RCPT



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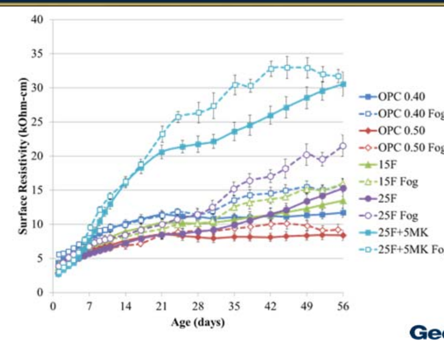
Effect of curing



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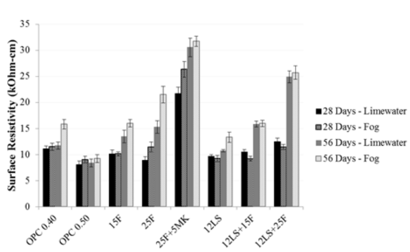
Effect of curing



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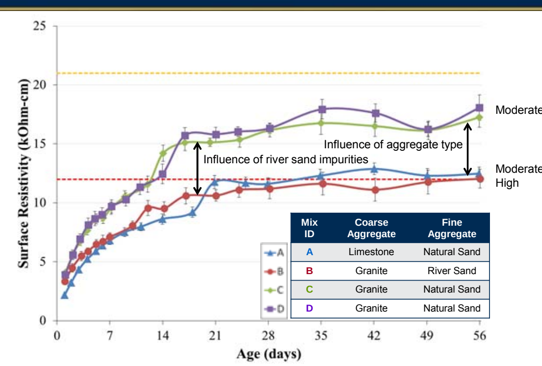
Influence of Aggregates



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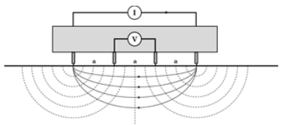
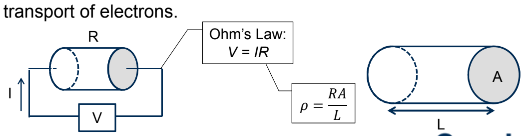
Electrical Properties of Concrete



- **Resistivity (ρ)** refers to the concrete's ability to resist the transport of electrons.



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