# Durability Properties of High Early Strength Concrete with Alternative Cement and Accelerated Portland Cement

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# Outline

# Introduction

- High Early Strength Concrete (HESC)
  - Rapid strength gain >3000 psi f'c in 3 hours
  - High paste contents
  - Good durability and performance

- Project Goals
  - Provide Oregon Department of Transportation with designs meeting the above criteria of HESC
    - Proprietary and non-proprietary materials
    - Calcium Sulfoaluminate Cement (CSA)
      - Polymer modified and pure CSA blended with ordinary portland cement (OPC)
    - Accelerated Type III Cement (T3A)
      - Non-chloride accelerator
  - Reduces closure time required for construction
  - Mechanical properties
  - Durability properties

# Objective of Study

Focus of this presentation is:

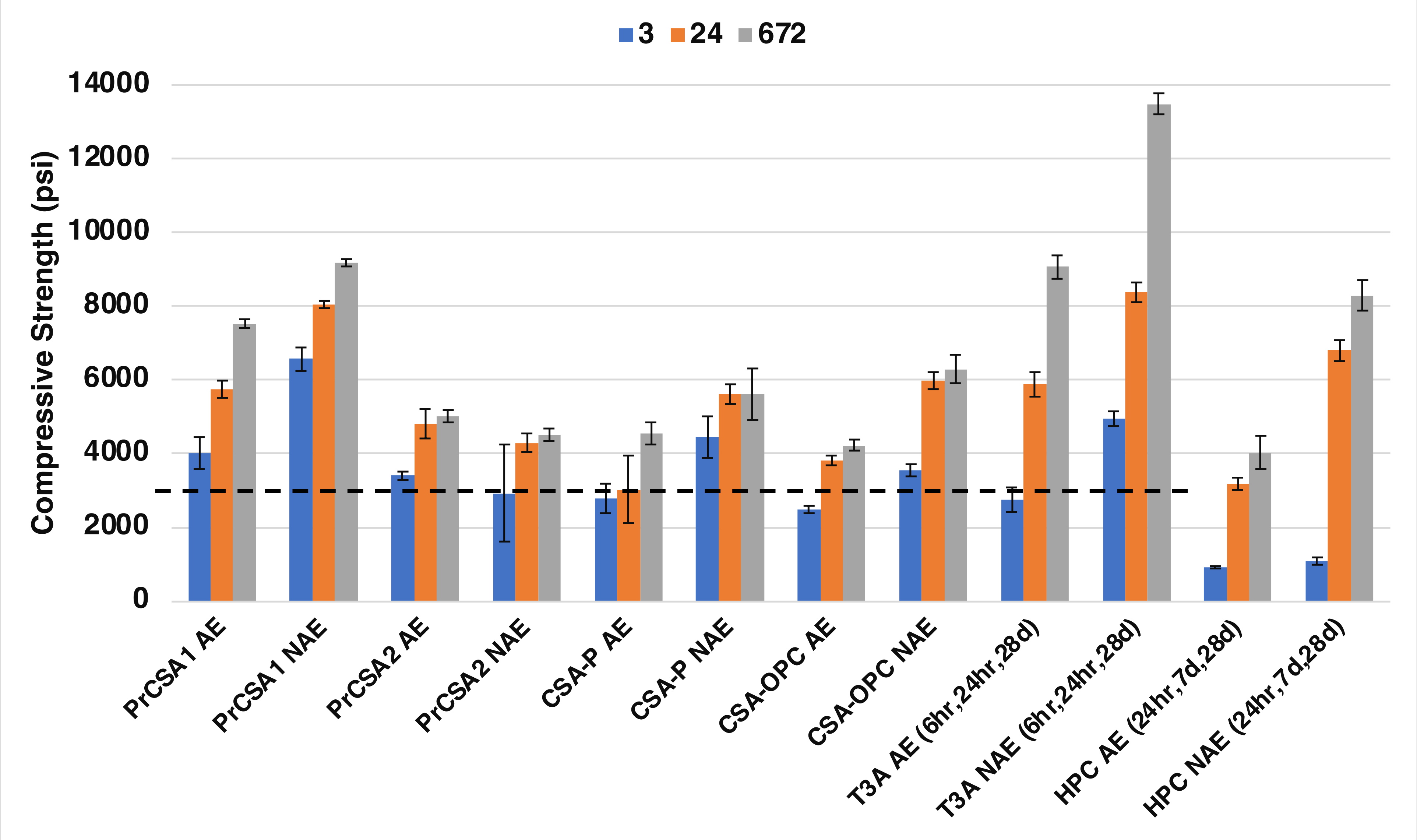
- Mixture designs
- Strength development within 3-6 hours
    - With and without air entrainment
- Freeze-thaw durability
- Electrical properties
    - Bulk and Surface resistivity (Concrete w/o air entrainment)
    - Pore solution resistivity (Pastes)
- Challenges and remaining work

# Mixture Designs

| Cement | Description |
|---|---|
| PrCSA1 | Proprietary CSA with polymer modifier and other dry batched admixtures at plant |
| PrCSA2 | Proprietary CSA with dry batched admixtures at plant |
| CSA-P | Non-proprietary CSA with liquid polymer modifier added in laboratory |
| CSA-OPC | Non-proprietary CSA (80%) with OPC (20%) |
| T3A | Type III cement with 3% accelerator added by wt. of cement |
| HPC | High performance concrete design, 66% PC, 30% FA, 4% SF |

- Concrete mix having cement 658 lb/yd$^3$, rock 1601 lb/yd$^3$ , sand 1260 lb/yd$^3$, w/c of 0.38 for CSA and 0.36 for OPC
- No additional air entrainment for resistivity concrete samples and 7% air targeted for freeze-thaw samples
  - Integral air entrainment in proprietary systems reduces ability to control air

# Strength Development

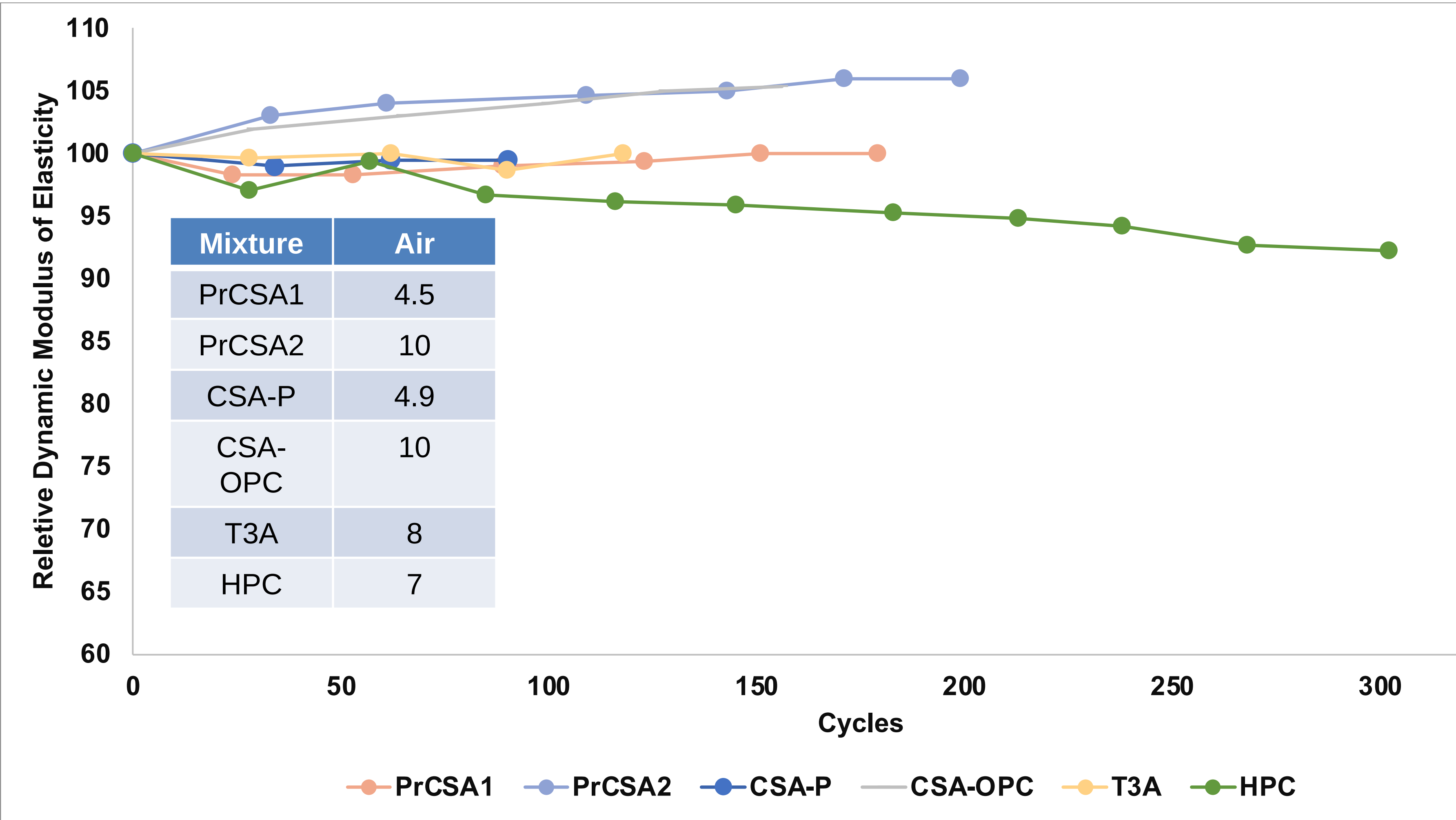



AE– Air entrained

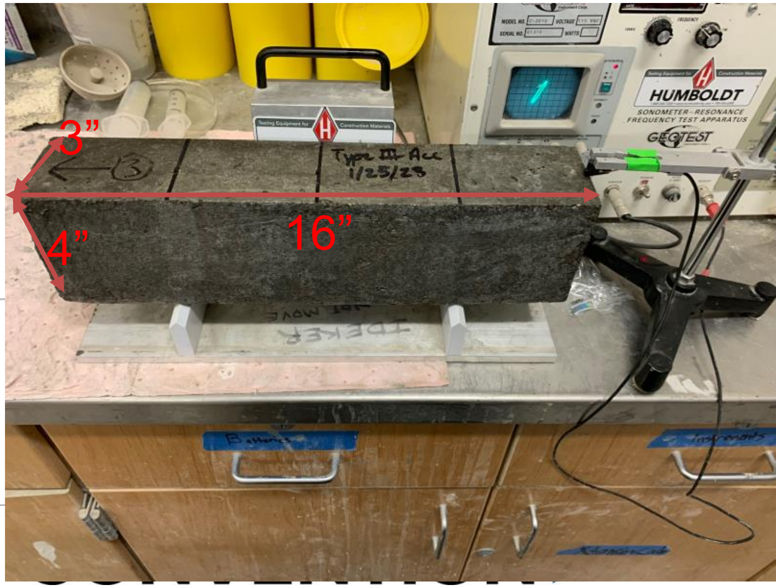
NAE – Non-air entrained

# Freeze-Thaw Durability

ASTM C666 Procedure B, DM > 90 is good performance, <60 DM is failure, 3”x4”x16” beams




| Mixture | Air |
|---|---|
| PrCSA1 | 4.5 |
| PrCSA2 | 10 |
| CSA-P | 4.9 |
| CSA-OPC | 10 |
| T3A | 8 |
| HPC | 7 |



# Electrical Properties

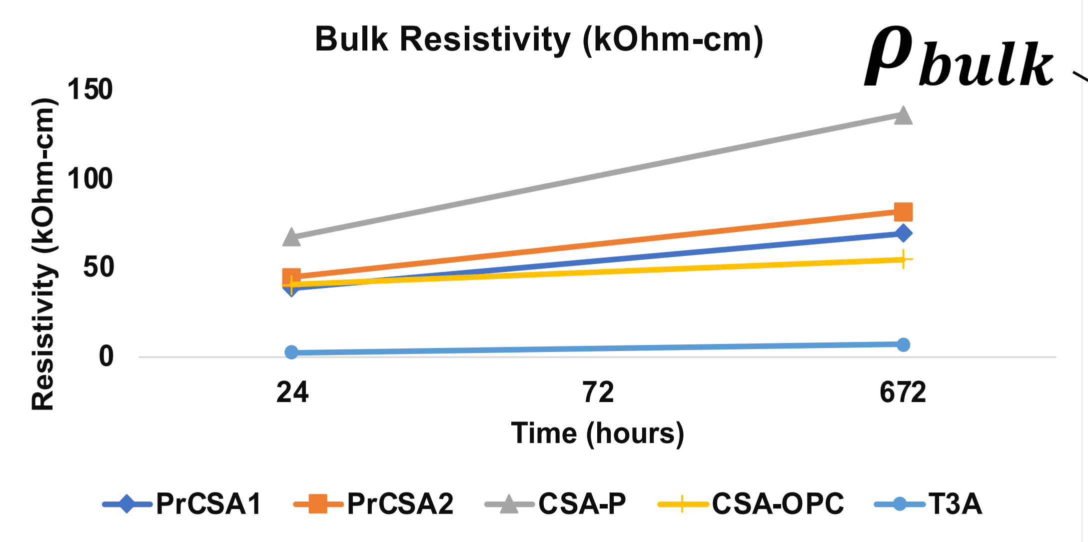

- Sealed cure

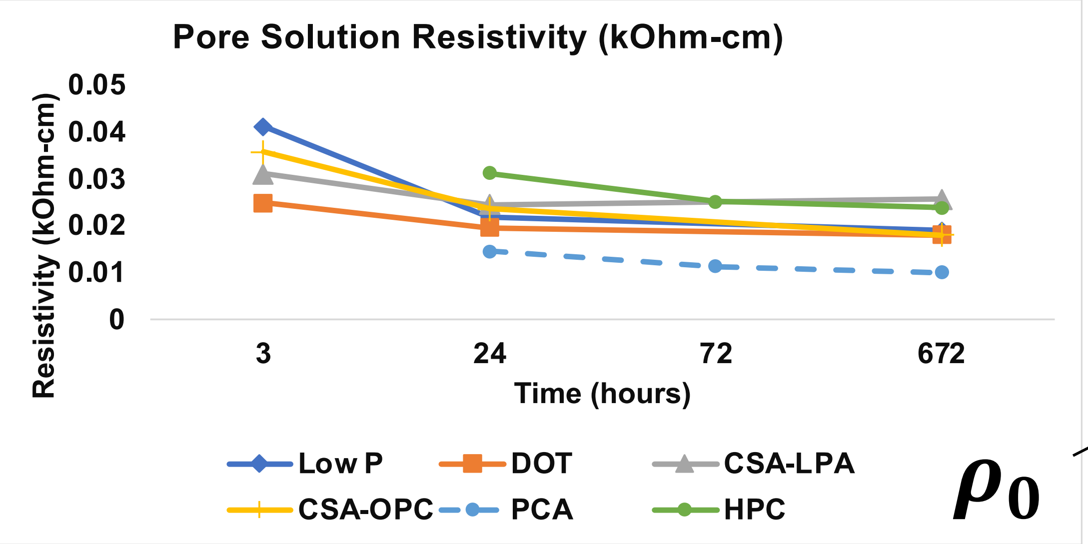
- Resistivity measured 3 ways:
  - Continuous resistivity of concrete/mortar using Giatec SmartBox sensor
  - Bulk resistivity of concrete at 28 days
  - Surface resistivity of concrete at 24 hours and 28 days
    - 24-hour measurement converted to bulk resistivity using geometric factor

- Degree of saturation at 28 days

- Pore solution of pastes done at 3 hours, 24 hours and 28 days
  - 1, 3, and 28 days for HPC and T3A
  - Solution extracted via hydraulic press set up [Siva T CCR paper]

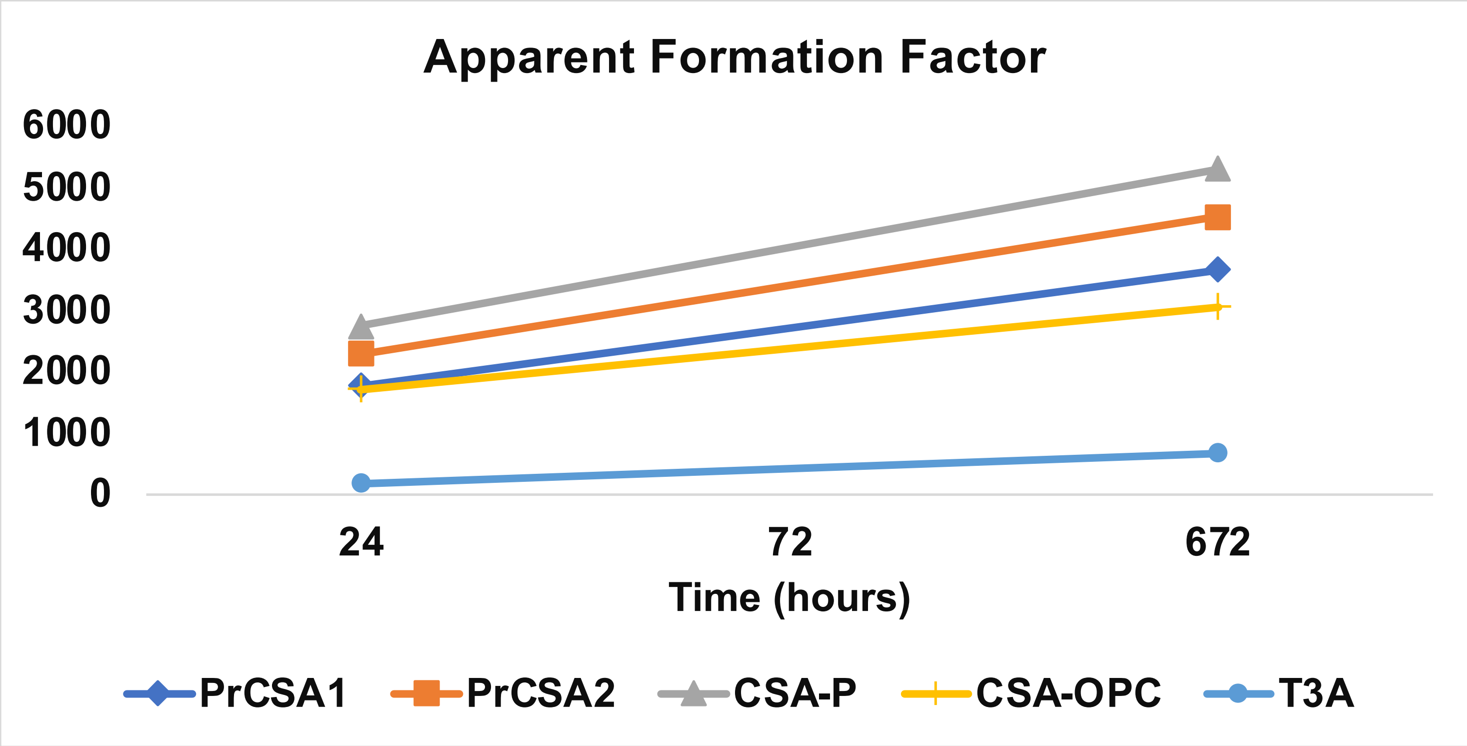
# Electrical Properties




$$F_{apparent} = \frac{\rho_{bulk}}{\rho_0} = \text{Apparent Formation Factor}$$

# Electrical Properties




- PCA formation factor is typical of HPC from literature [Weiss, 2016]
- Very high values from alternative cements
  - Must correct for degree of saturation
- Are electrical property values representative of durability for these alternative systems?
  - Moffatt & Thomas, 2018

# Electrical Properties

- PCA formation factor is typical of HPC from literature [Weiss, 2016]
- Very high values from alternative cements

Apparent Formation Factor

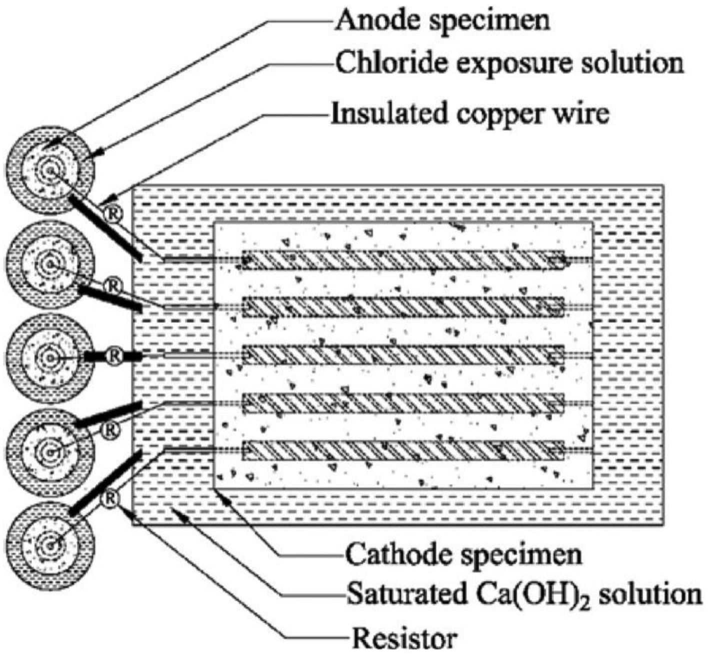
**Table 4—Diffusion results after 180 days ponding and RCPT results at 91 days**

| Cement type | Surface concentration $C_s$, % | Diffusion coefficient $D_c$, $0^{-12}$ $m^2/s$ ($in.^2/y$) | RCPT, Coulombs |
|---|---|---|---|
| PC | 0.84 | 6.94 (0.339) | 3444 |
| PC-CAC-CS | 0.94 | 1.62 (0.079) | 2710 |
| CSA(1)-$C_2S$ | 1.14 | 28.7 (1.402) | 1110 |
| CSA(2)-PC | 0.93 | 3.49 (0.170) | 3374 |
| HEPC | 0.95 | 3.29 (0.161) | 1710 |

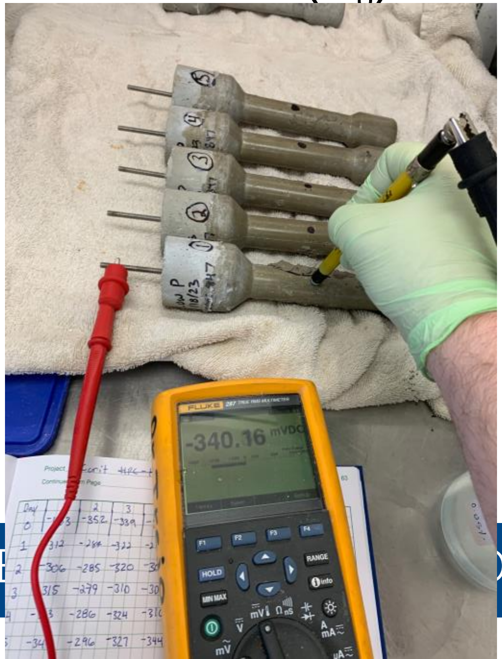
PrCSA1 PrCSA2 CSA-P CSA-OPC T3A

# Challenges and Remaining Work

- Early setting time (<30 minutes) for CSA mixtures
- No established testing approach for durability of alternative cements
- Determine critical chloride thresholds ($Cl_{crit}$) influenced by different anodic and cathodic environments
  - Oregon State University Critical Chloride Threshold Test
    - Trejo, Vadey, & Halmen 2021
    - Half-cell potential vs. Cu-$CuSO_4$ electrode
  - Assess corrosion rate of embedded reinforcement
    - Determined by polarization resistance ($R_p$)




[Trejo, Vadey, & Halmen 2021]



# Challenges and Remaining Work

- Conclude freeze-thaw cycling
- Continuous resistivity data with SmartBox Sensors
- Determine degree of saturation of concrete samples for electrical properties
- Pore solution pH with probe and ion concentration by x-ray fluorescence

# Summary

- 3000-psi can be achieved within 3-hours
- T3A continues to gain substantial strength up to 28 days
- High freeze-thaw performance looks achievable even with less than 6% entrained air
- Alternative cements produce very high electrical resistivities that influence formation factor
    - Needs to establish relationship of electrical properties to durability of CSAs

# Thank you

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