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Integration of Wave-Based Sensing into Engineering Decisions

Present at Purdue Geotechnical Society Workshop in Honor of Vince

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Xiong (Bill) Yu, Ph.D., P.E.
Assistant Professor, Department of Civil Engineering, Department of Electrical Engineering and Computer Science, Case Western Reserve University, OH, USA, 216-368-6247, xxy21@case.edu

About Myself

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Purdue University

- Ph.D. Civil Engineering, 2003
- M.S. Electrical and Computer Engineering, 2002

Tsinghua University, China

- M.S. Civil Engineering (Geotechnical Engineering), 2000
- B.S. Civil Engineering (Hydraulic Structural Engineering), 1997
- B.S. Computer Science, 1997

Research Interest

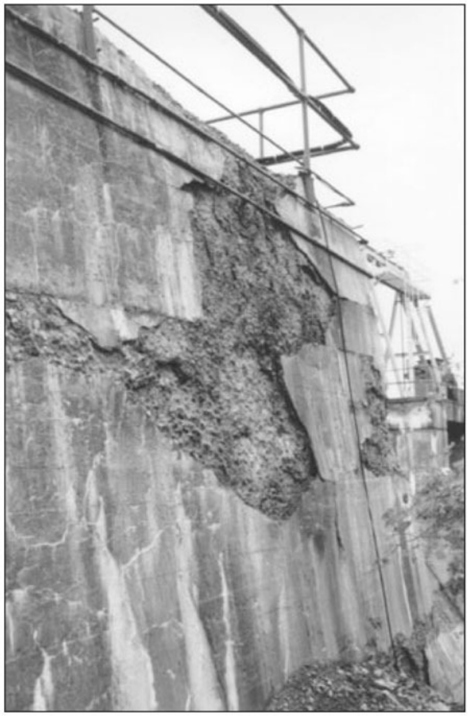
- Current program affiliation
  - Geotechnical engineering
  - Infrastructure engineering
  - EECS

- Current research focus
  - Design and analyses of civil infrastructures
  - Civil engineering materials
  - Sensor technology and field instrumentation
  - Sustainability (green design, risk assessment, environmental geotechnology, etc)

Instrument Assisted Criteria for Freezing Damage of Concrete

Introduction

- Freeze-thaw damage of pavement in cold region
  - Pavement structure
    - Thermal crack
    - Debonding
  - Subgrade properties
    - Stiffness
    - Strength
    - Drainage
    - Thermal expansion (earth pressure..)



Preventing Freezing Damages of Early Stage Concrete

- Important for concrete pouring in cold weather
- Significant cost added for heat curing or construction delay
- Highly empirical at this moment
  - ODOT mandate 5-day thermal curing

Mechanism of Freezing Damages

- Volume of water expand while freezing
- Migration of moisture in micro-pores
- Mechanical criteria for preventing freezing damage
  - Phase criteria: $V_{air}>10\%V_{free\ water}$
  - Strength criteria: $f_{c,t}>p_{ice\ crystal}$

Investigated

Laboratory Tests

Name	Design 28 day strength	Slump	Water-cement ratio	Actual w-c ratio
Ordinary	4000 psi	4 inch	0.53	0.648
High strength	8000 psi	2 inch (6 inch actual)	0.26	0.552
Self-consolidating	6000 psi	6 inch	0.31	0.33

- Experimental program
  - Specimen preparation simulate actual production process
  - Subject to different curing conditions
  - Both 4 inch and 6 inch molds prepared,2000 lbs concrete within 1 hour
    - 60 4 inch
    - 30 6 inch

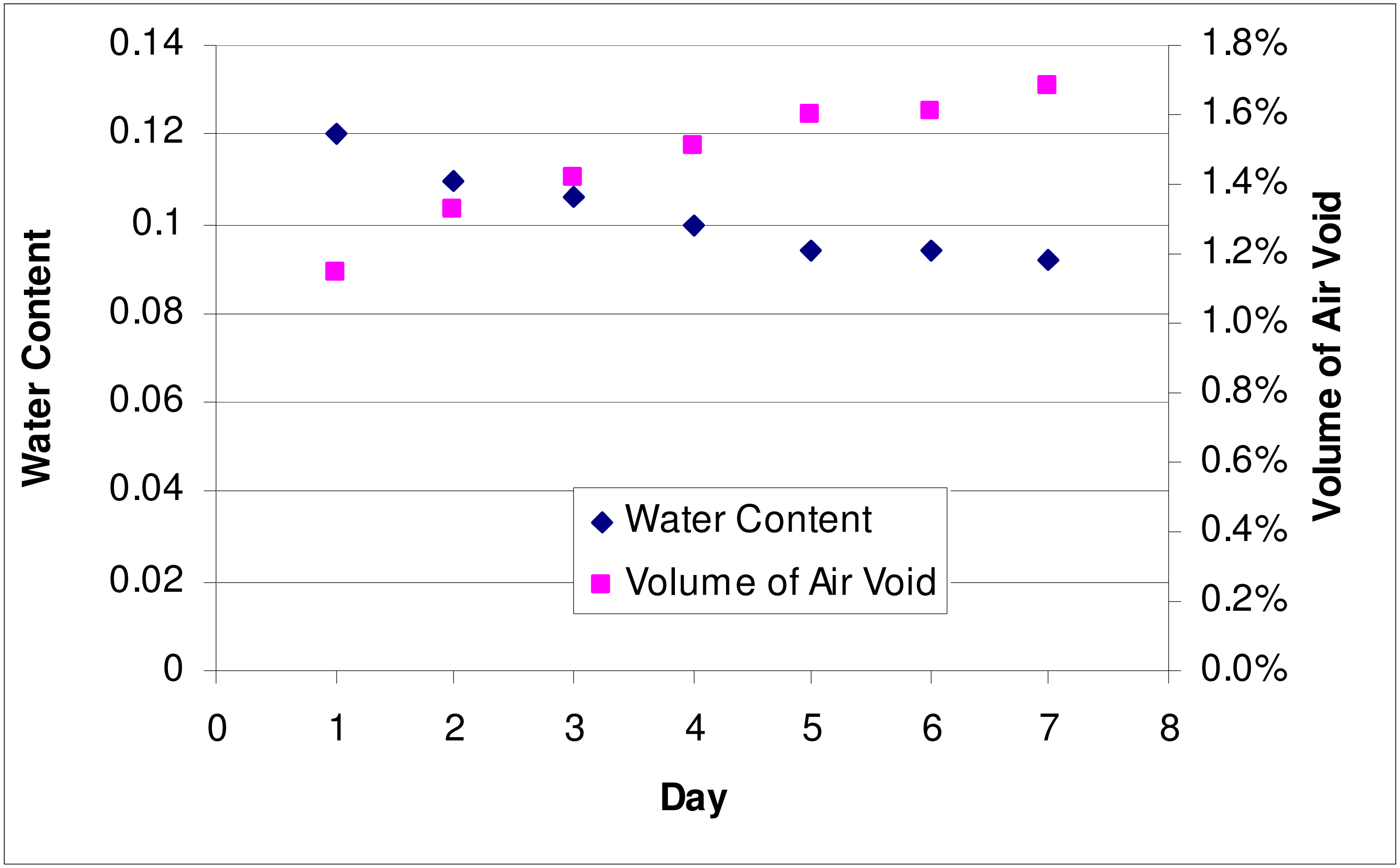
- ☐ Monitor under controlled curing conditions

Finished specimen with sensors

Monitoring system: Serial or USB

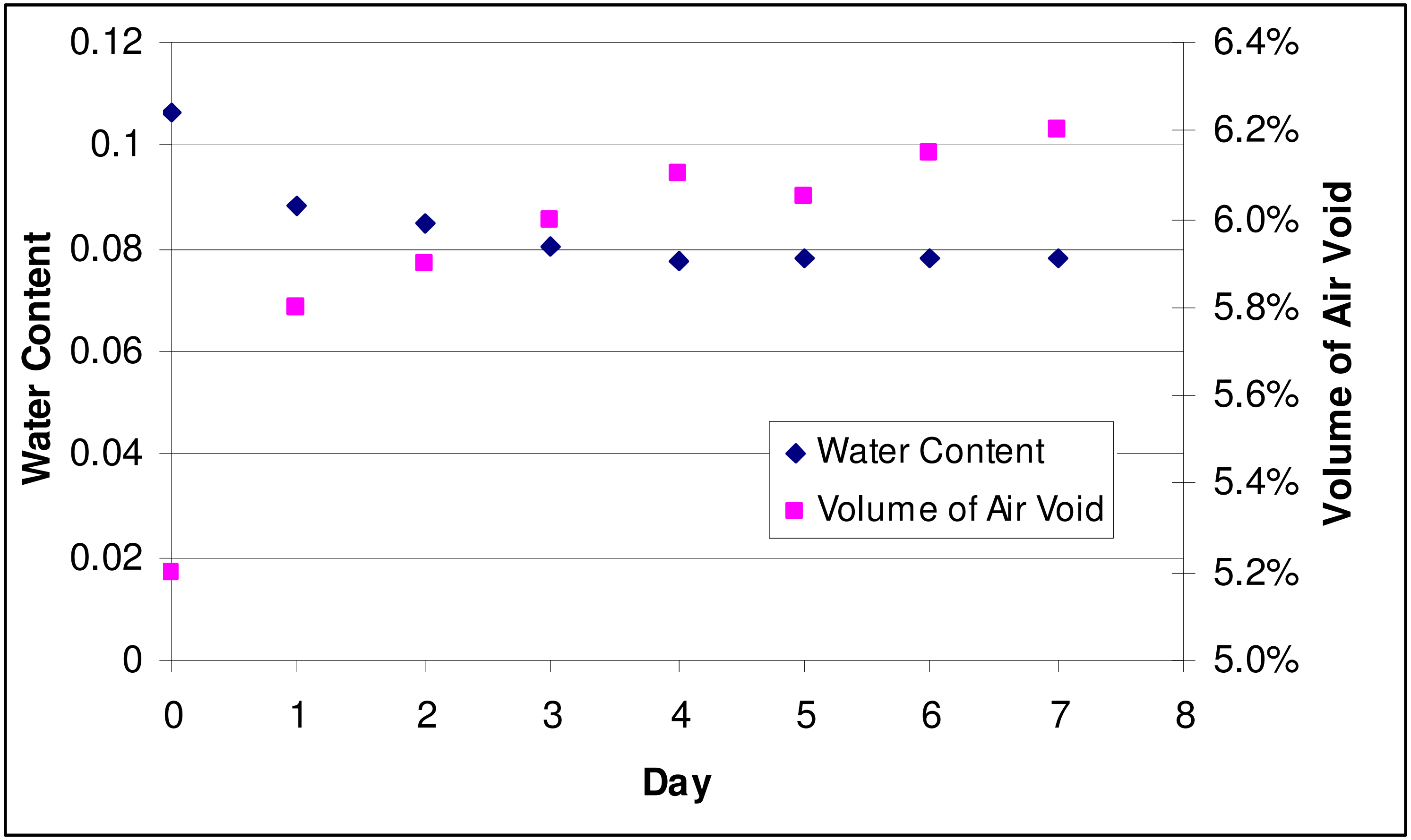
Estimation of air content

- ☐ Air void content during curing process: ordinary concrete without air entry admix



Estimation of air content

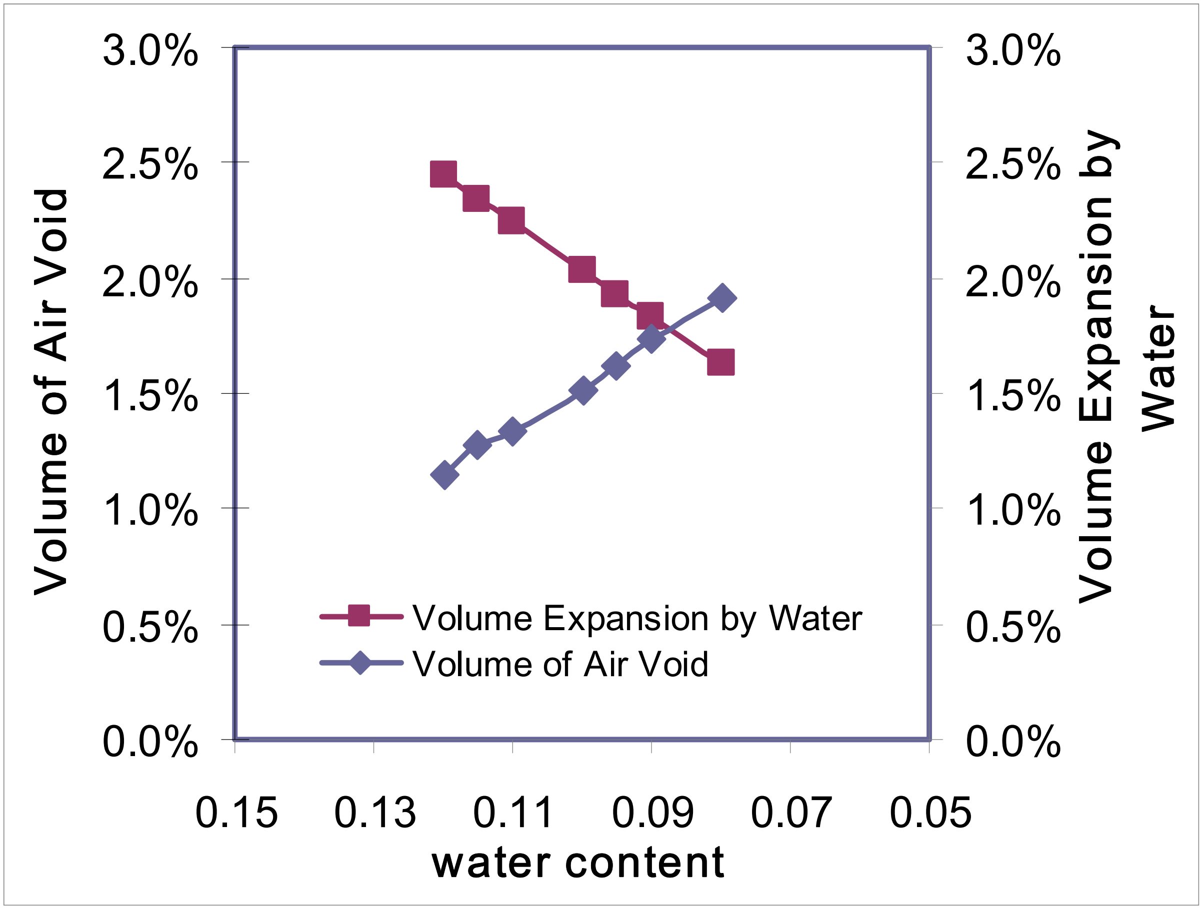
- Air void content during curing process: high strength concrete with air entry admix



Estimation of air content

- Early freezing damage assessment: Concrete mix with no air entry admix
  - Water content
  - Air void content

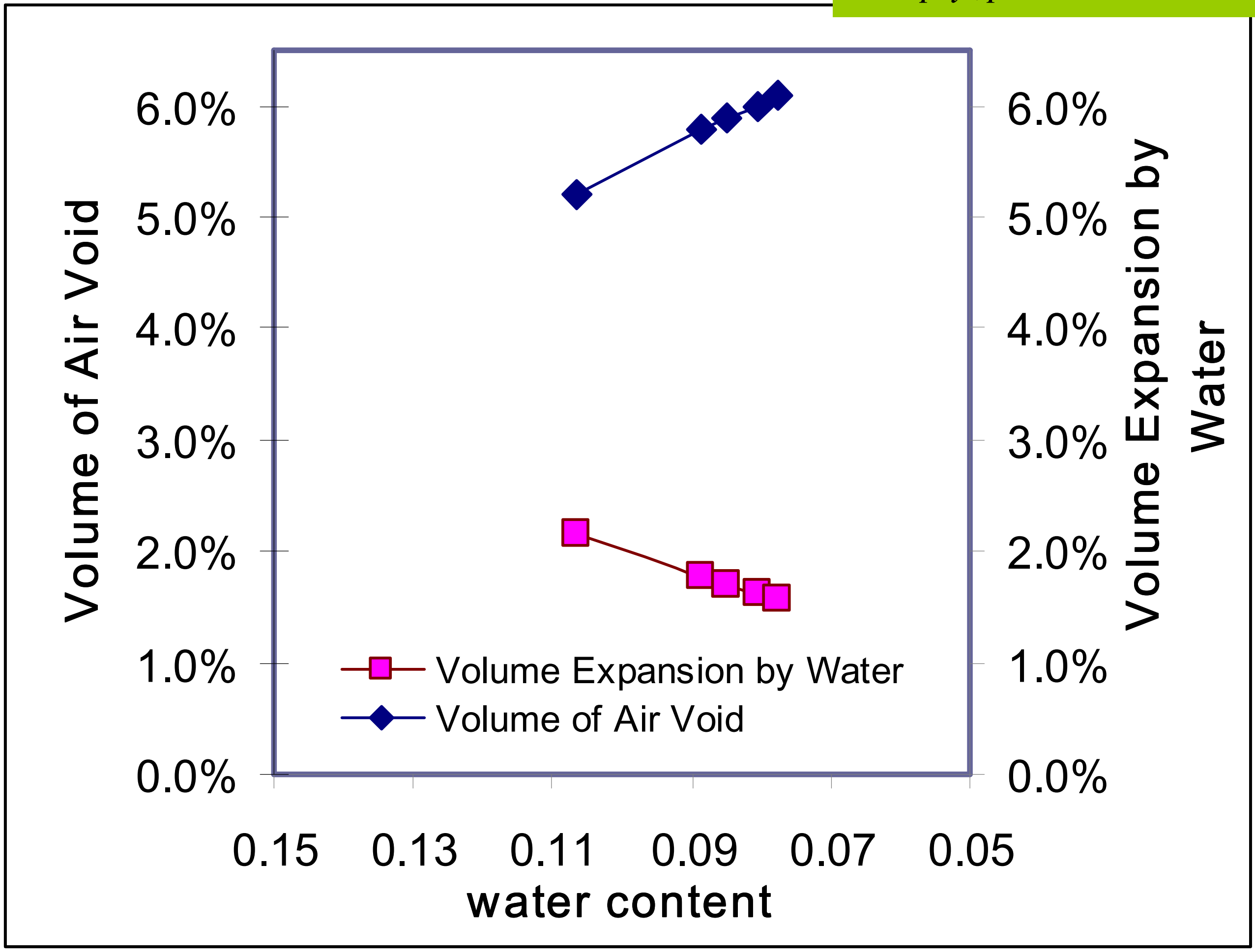
$$V_{empty,pore} \geq 10\% V_{free,water}$$



Estimation of air content

- ☐ Concrete mix with air entry admix

$$V_{empty,pore} \geq 10\% V_{free,water}$$



Yan Liu, Case Western Reserve University
330-475-5792, yxl192@case.edu

Assistance in the Spring Load Restrictions

Spring Load Restrictions

- Commonly used for pavement preservation
  - Around 20 states and foreign regions

Pavement Load Reduction During Thaw (%)	Expected Increase in Pavement Life (%)
20	62
30	78
40	88
50	95

Isotal 1993

Implementation of SLR

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Country	Start of SLR	End of SLR	Restriction	Technology for Determining Restriction
France	n/a	n/a	2.5- 4-, 6-, 8- ton for single dual tire axles	Frost depth measurements
Finland	April	May	Gross weights” 4-, 8-, 12-, 18 ton; total shutdown	FWD, experience
Iceland	30 cm of thaw	n/a	Depends on vehicle type and axle configuration	Frost depth measurements
Sweden	April	May	4-,6-,8-ton per axle	FWD, frost depth measurements, experience
Norway	5-15 cm of thaw	Min 90% of summer bearing capacity	Change yearly	FWD, frost depth measurements
	Prediction	4-8 weeks after imposing	As needed	

Practice in U.S.

State	Start of SLR (around)	End of SLR (around)	Restriction	Technology for Determining Restriction
North Dakota	March 15	June 1	Differs between trunk highways and county roads	Deflection measurement and experience
South Dakota	February 28	April 27	6-,7- ton per axle	Deflection measurement and experience
Iowa	March 1	May 1	No overloads	Road Rater and experience
Wisconsin	March 10	May 10	No overloads	Deflection measurement and experience
Michigan	Every March	Late May	70% of gross weight for HMA roads	experience
Minnesota	March	May	5-,7-, 9-ton per axle	Design testing and experience

Freeze-Thaw Measurements

- Frost tubes (plastic fluorescent dye tubes)
  - Manual, subjective, slow responses
- Resistivity probe
  - Subjective
- Thermal method
  - No discretion of freeze-thaw status
  - Affected by salt and pressure

Implementation Challenges

- Technology for freeze-thaw status
  - Mechanistic relationships
  - Sound load restriction practice
    - Level
    - Duration

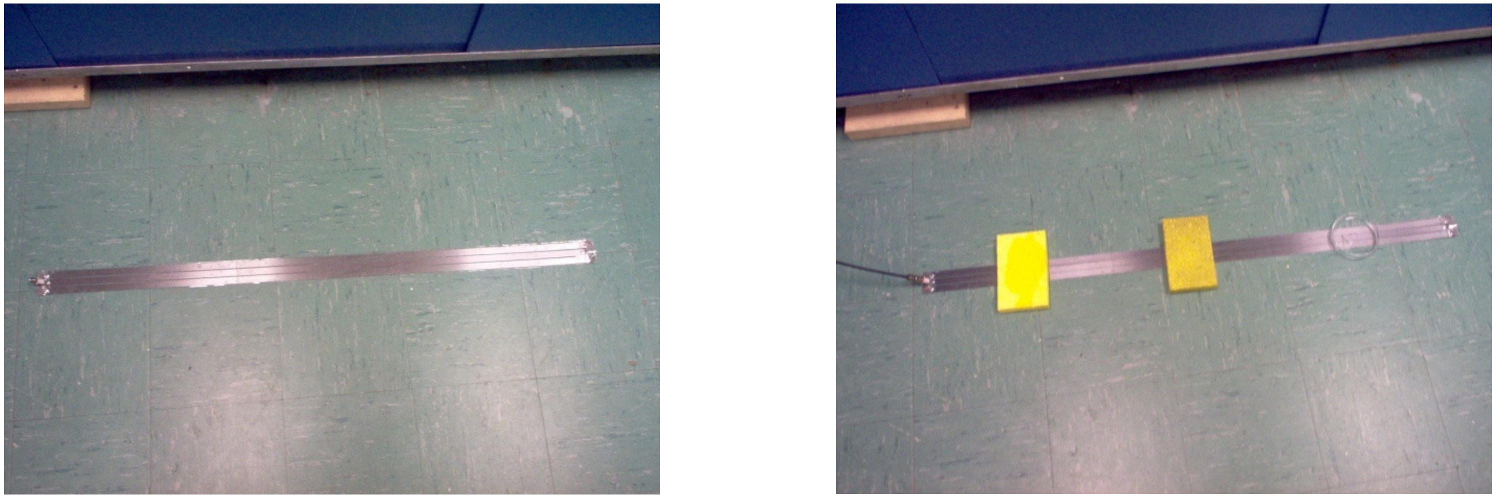
Dielectric Constant of Phases

- Air: 1
- Soil solids: ~ 3-7
- Water: 81
- Ice: ~ 3

→ TDR for freeze-thaw measurement?

Distributive Sensing

- Example of Sensor Responses



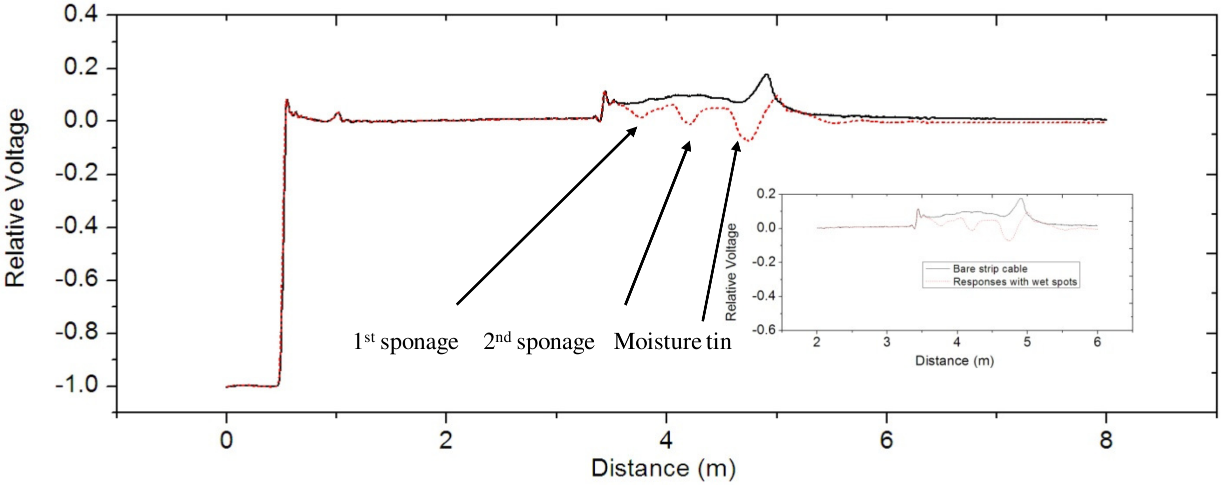
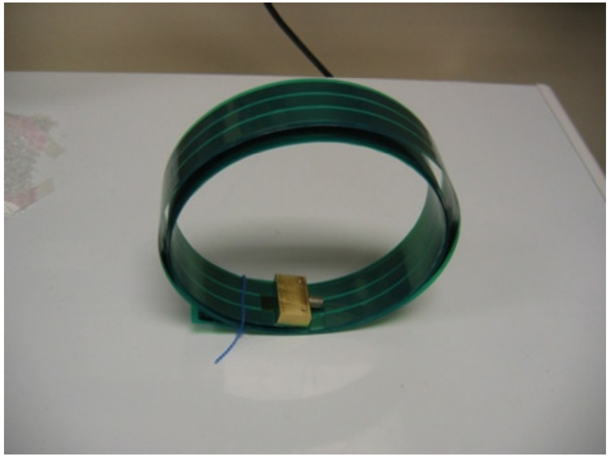


Figure TDR signal for bare strip sensor and that with moisture spot along it

Comparison with Existing Probes

- Mobility
- Installation
- Cable
- Labor

a)



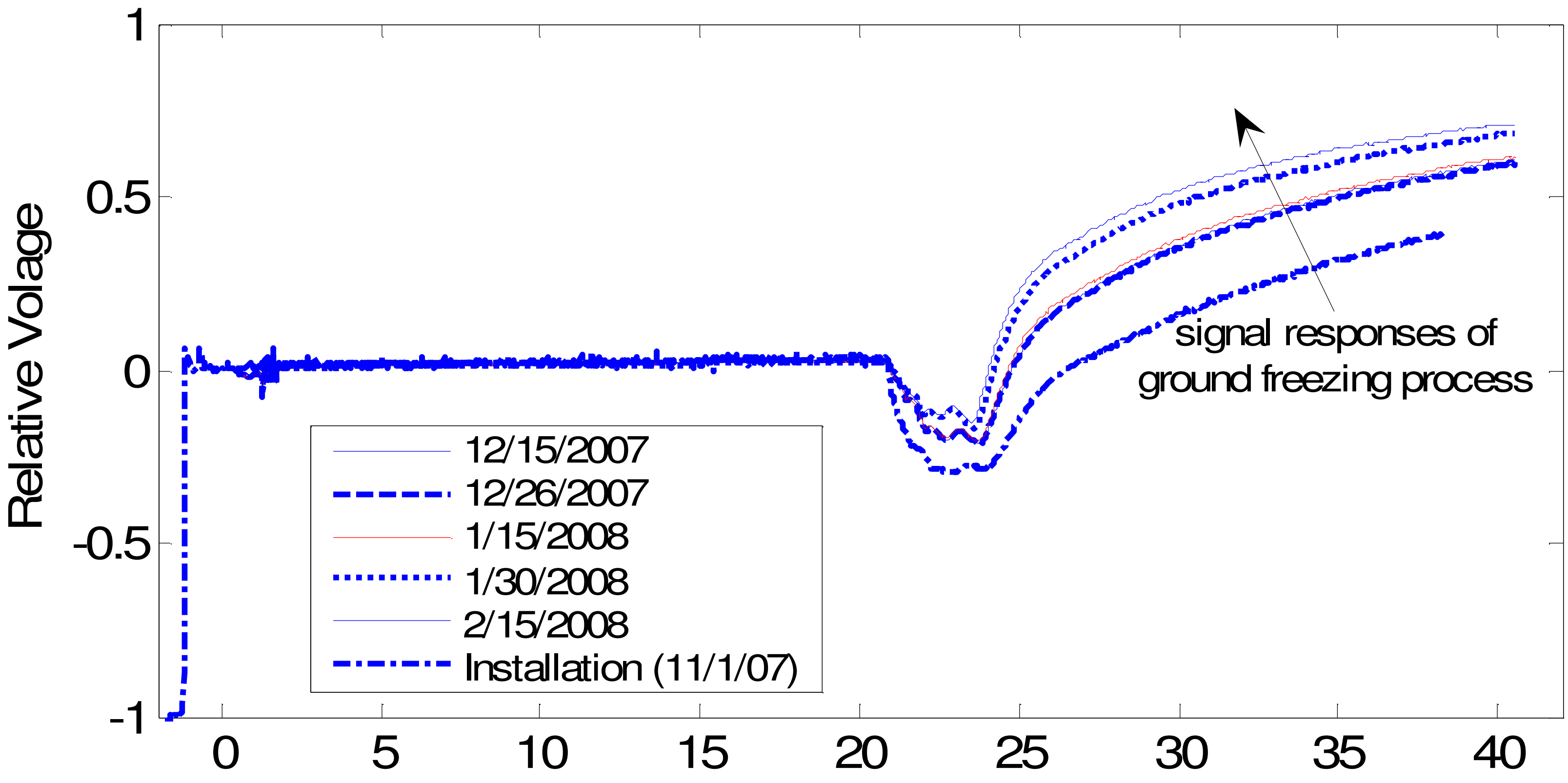
b)

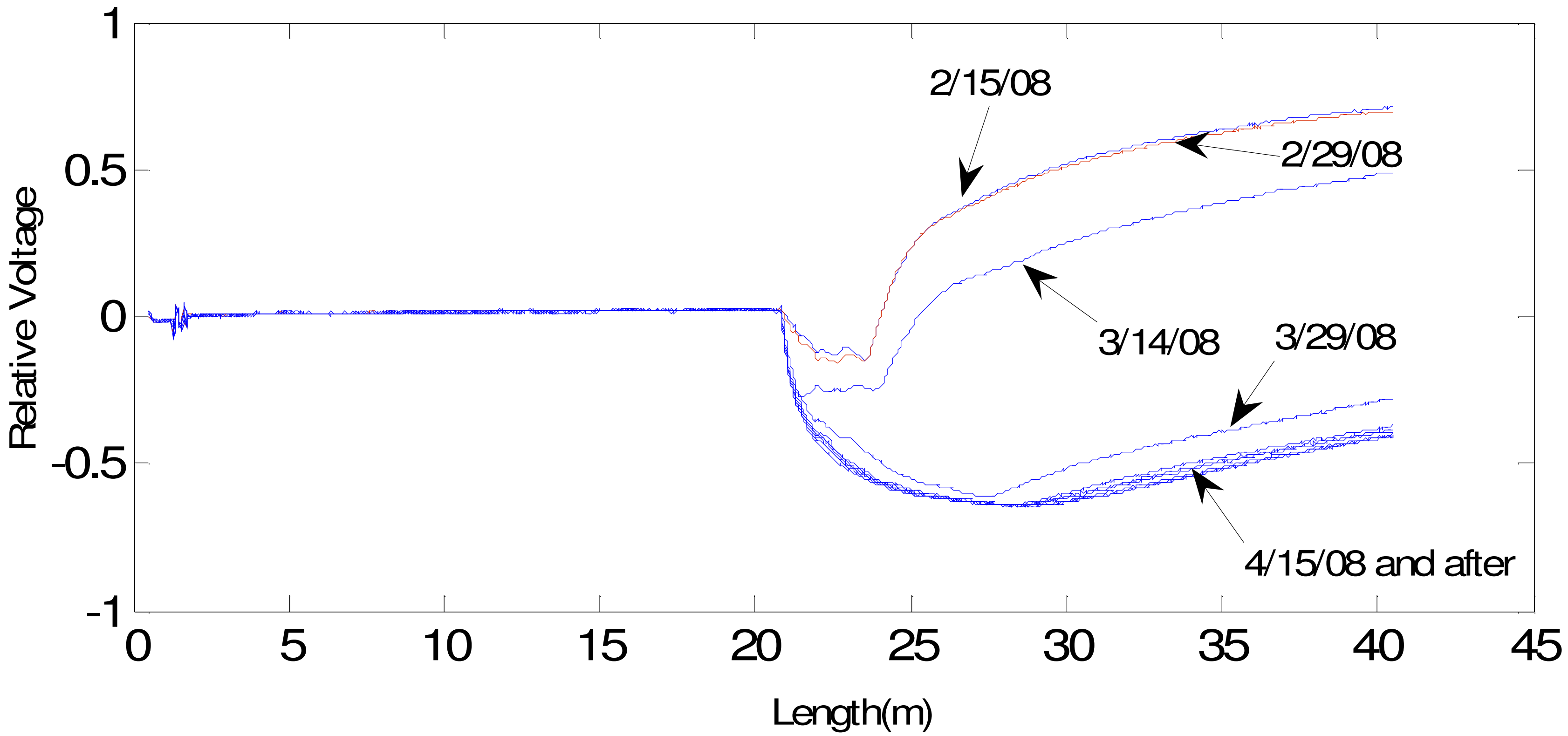
c)

d)

Field Installation

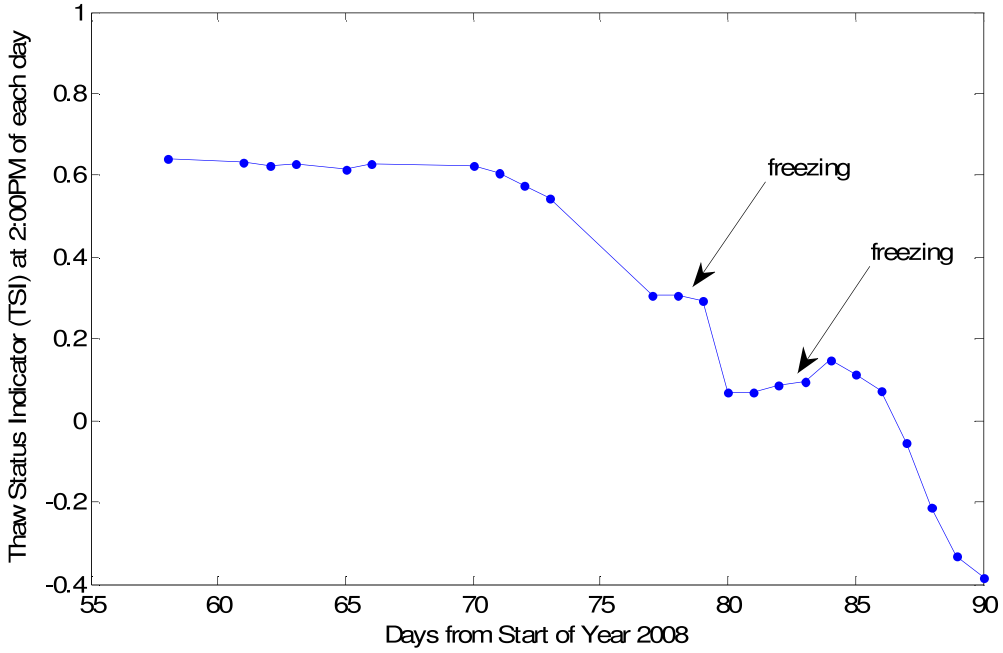
Freezing Process

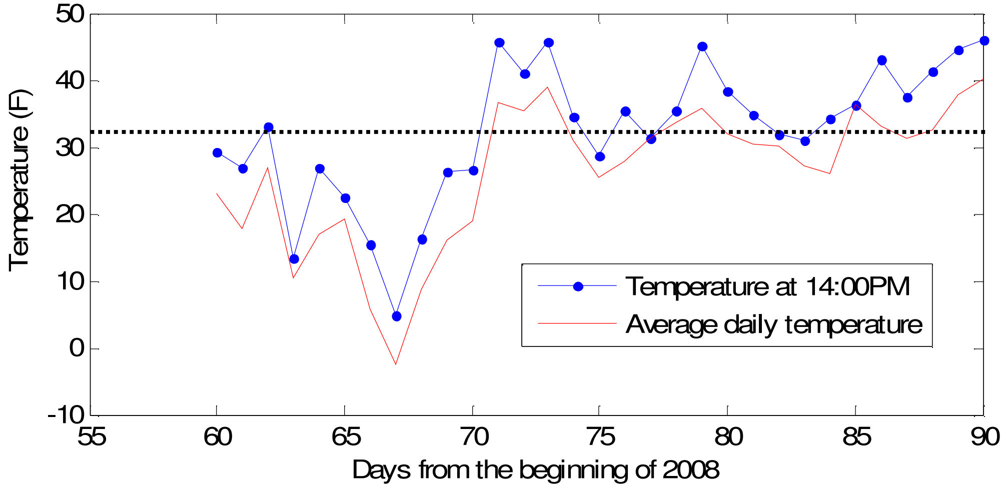




SLR can be lifted around one month earlier?

Schematic Presentation

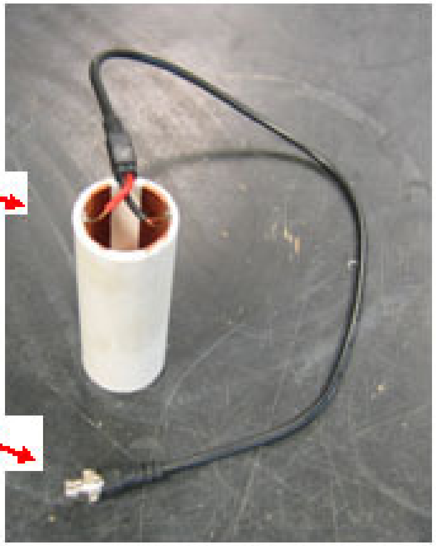




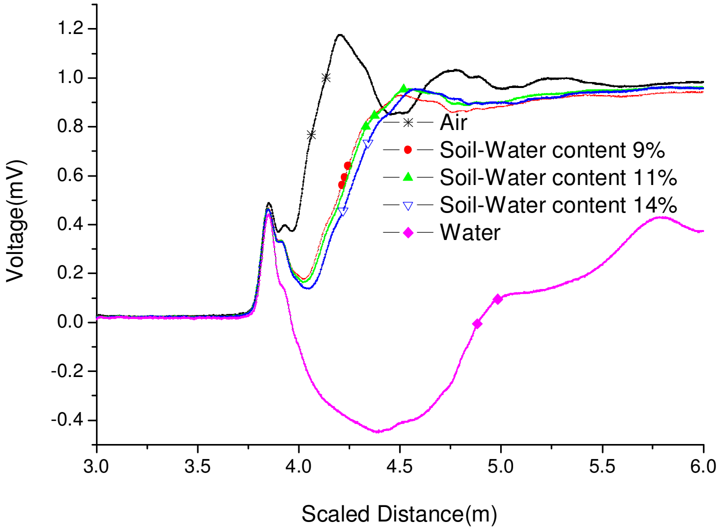
TDR PVC Sensor

Soil specimen fits closely into the hollow TDR tube sensor

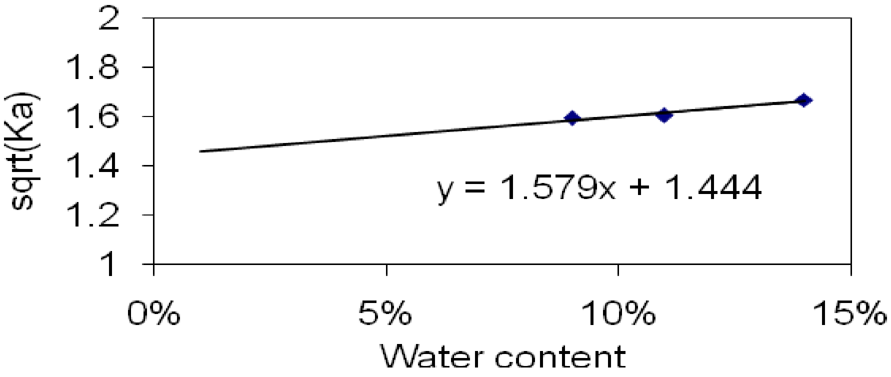
Connect to TDR electronics



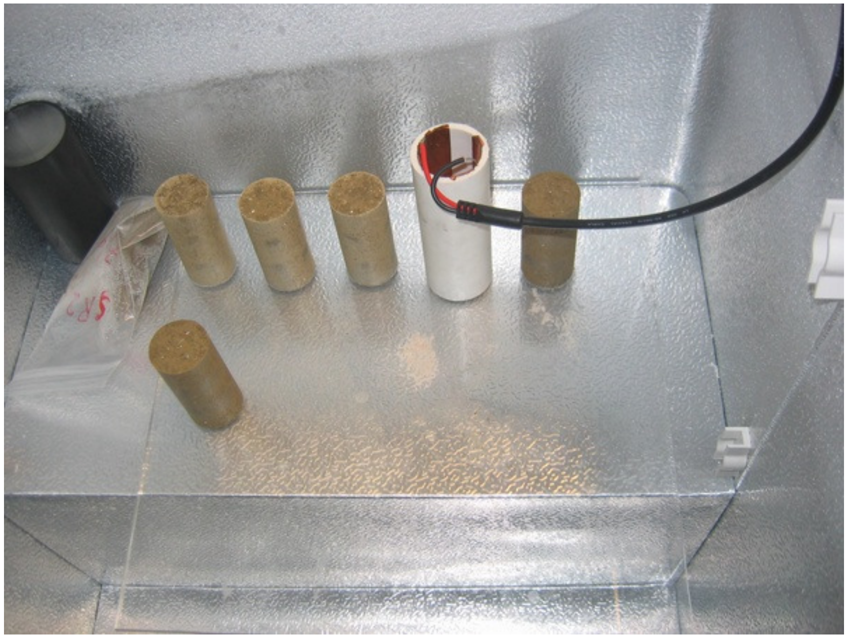
Sensor



Waveforms of different materials



Validation of measurements of the sensor

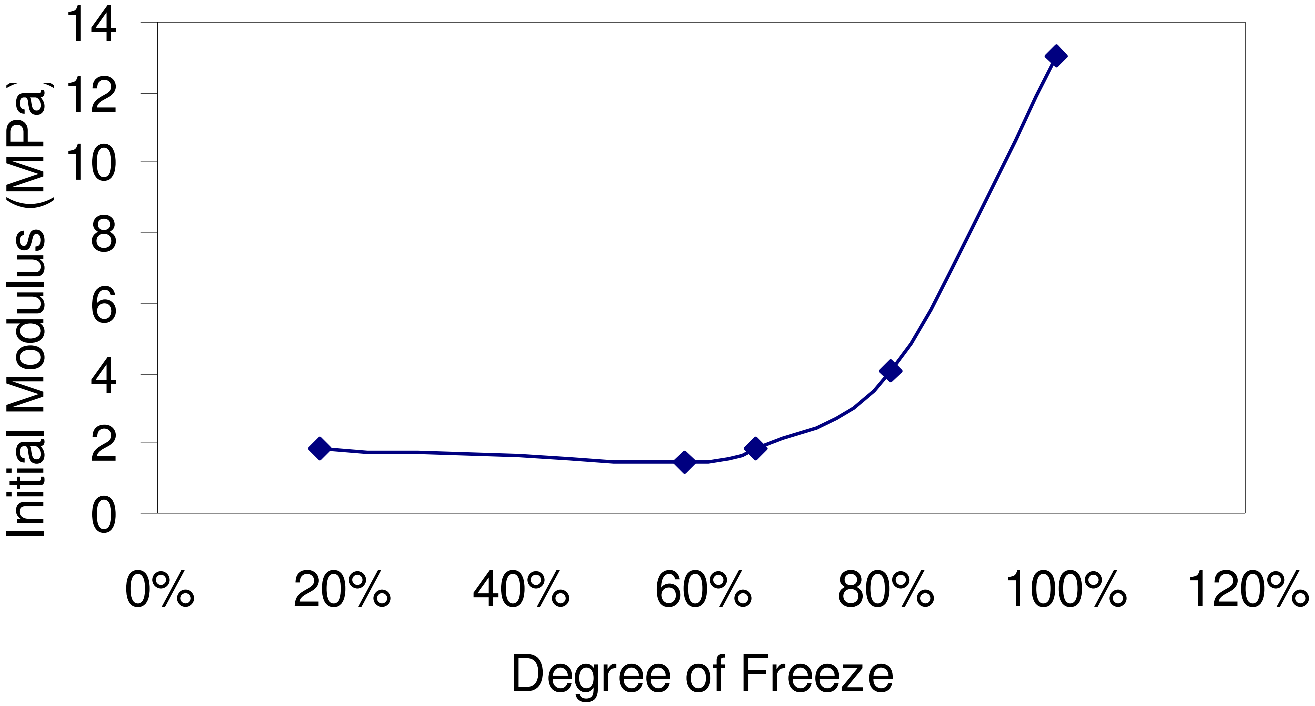


Soil Specimen being frozen and monitored

Unconfined Compression Test

Mechanical Behaviors Based on Degree of Freeze/thaw

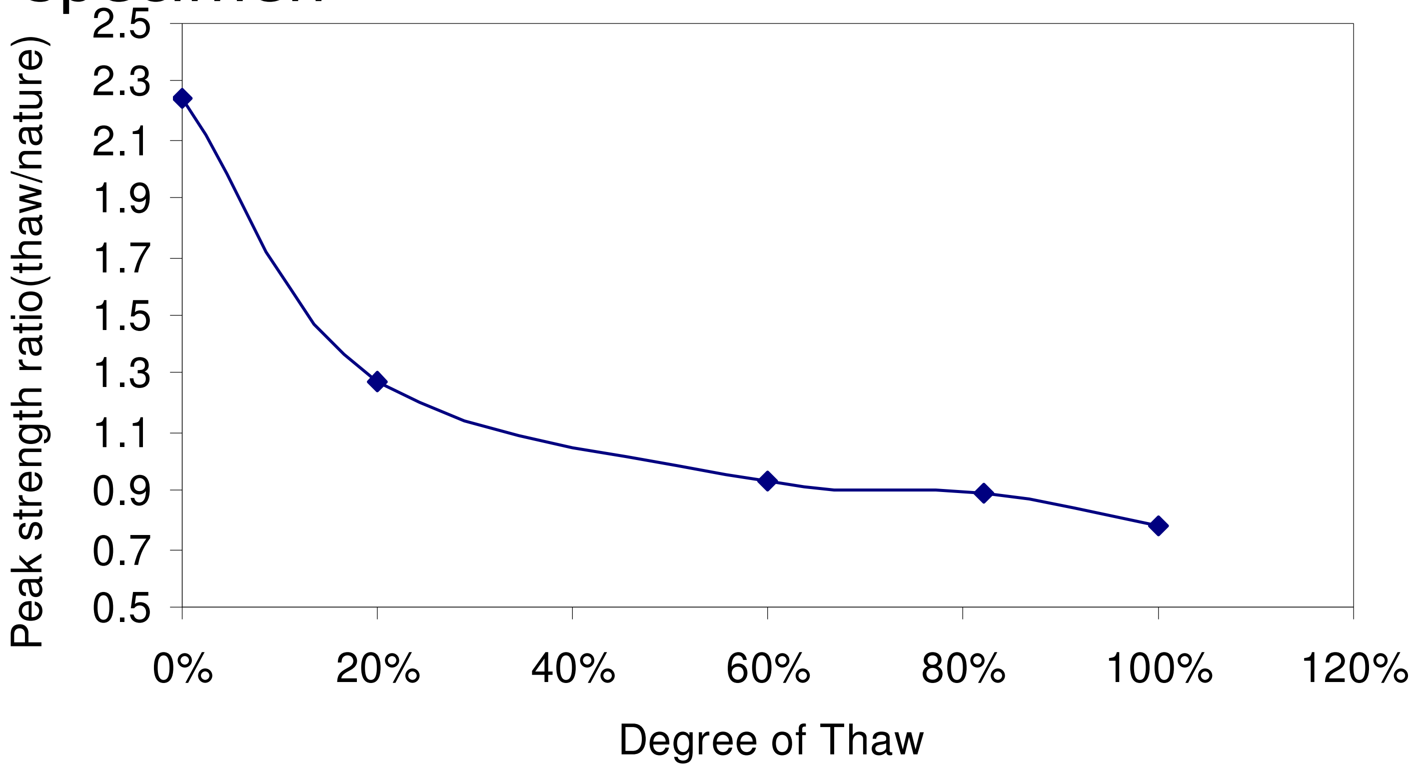
- Initial modulus of frozen specimen



Initial modus versus degree of freeze

Mechanical Behaviors Based on Degree of Freeze/thaw

- Peak strength of thawed specimen



Ratio of peak strength between specimens at different thawing stage and that of the virgin sample

Waves Go Beyond and Support Traditional Civil Engineering

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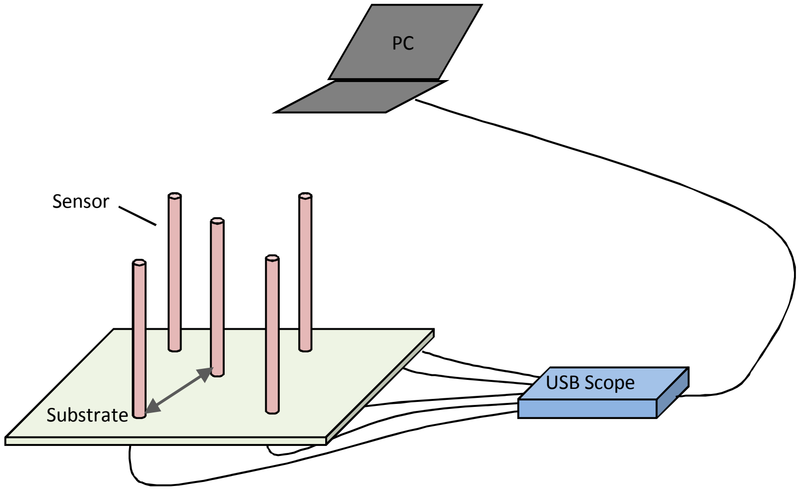
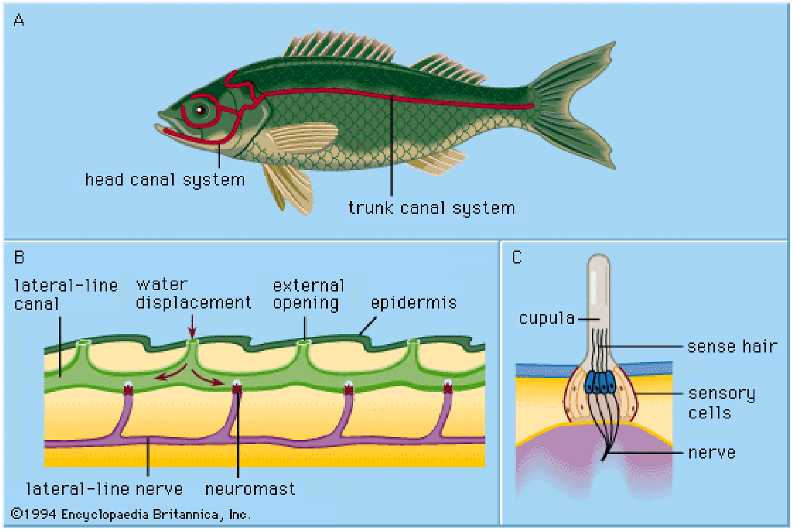
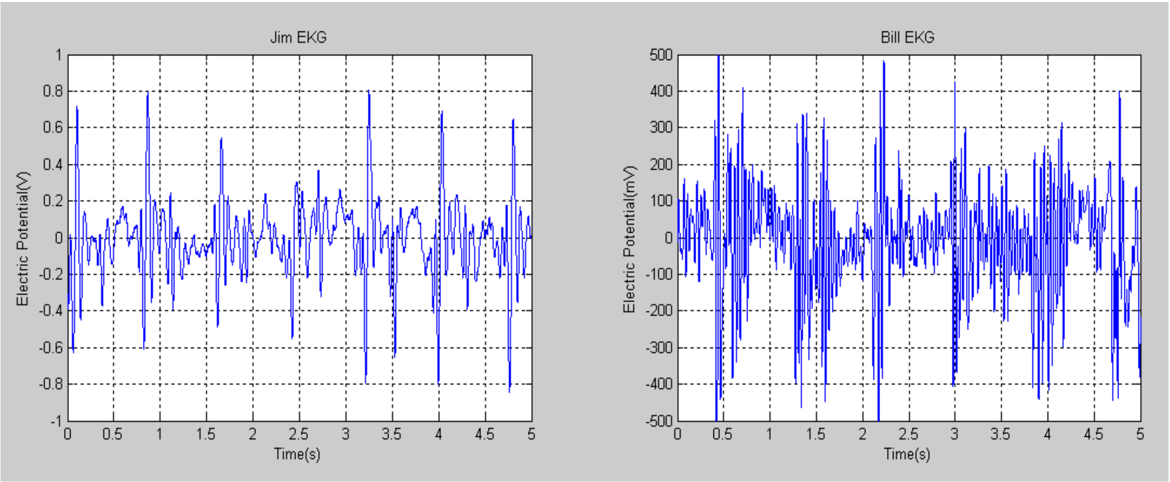
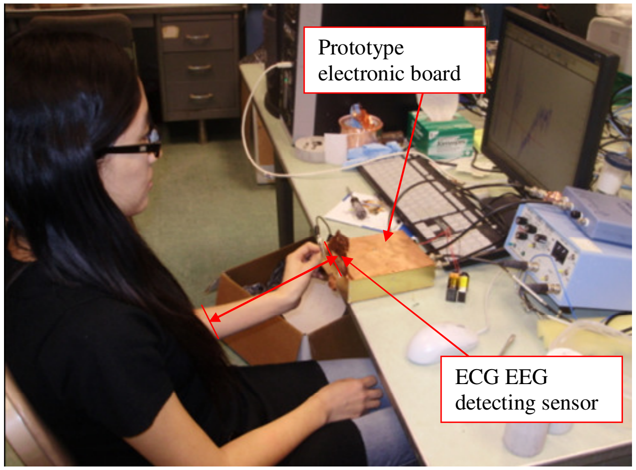




Tao et al. 2010





Sun et al. 2010

Conclusion

- EM Wave Technologies have great potential in infrastructure applications
- Understanding the principles and explore innovations is the key
- Requires interdisciplinary collaborations and close integration with professionals in engineering practice

Acknowledgements

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  - Undergraduate Researchers (Pete Simko, Yuan Gao, Andrew Bittleman, Pete Simko, Cassandra McFadden, Paul Mangola, Jingsi Lang, Donald Cartwright, Alex Potter-weight, Randall Beck, Vanessa Penner,Peter Frank, Ben Ma, Rebecca Ciciretti, Joseph Brenner, Javanni Gonzalez, Vanessa Penner, Grant Mott, etc)
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Thank you!