Seasonally Frozen Soil Effects on the Seismic Performance of Highway Bridges

AUTC Project #107014

Update Presentation
to the Project Advising Board

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Aug. 7, 2009

Acknowledgement

- Sponsors
  - Alaska University Transportation Center (AUTC)
  - Alaska Dept. of Transportation and Public Facilities
  - Alaska EPSCoR

- Co-Workers
  - Prof. J. Leroy Hulsey (UAF)
  - Dr. Feng Xiong, Dr. Utpal Dutta, Dr. Jens Munk (Faculty, SOE of UAA)
  - Mr. Qiang Li, Mr. Gang Xu, and Mr. Ruel Binonwangan (Graduate Students)

Outline

- Introduction
- Selection of foundation type and a bridge for study
- Numerical prediction for unfrozen and frozen conditions
  - Pile Behavior
  - Bridge Behavior
- Experimental study for unforzen and frozen conditions
  - Test Piles
  - Instrumentation of the selected bridge supported by steel-pipe piles
  - Data collection and analysis plan
- Summary

How can Seasonal Freezing Affect Bridge Behaviour?

- Frozen Soils are substantially stiffer than unfrozen soils; shear modulus changes by up

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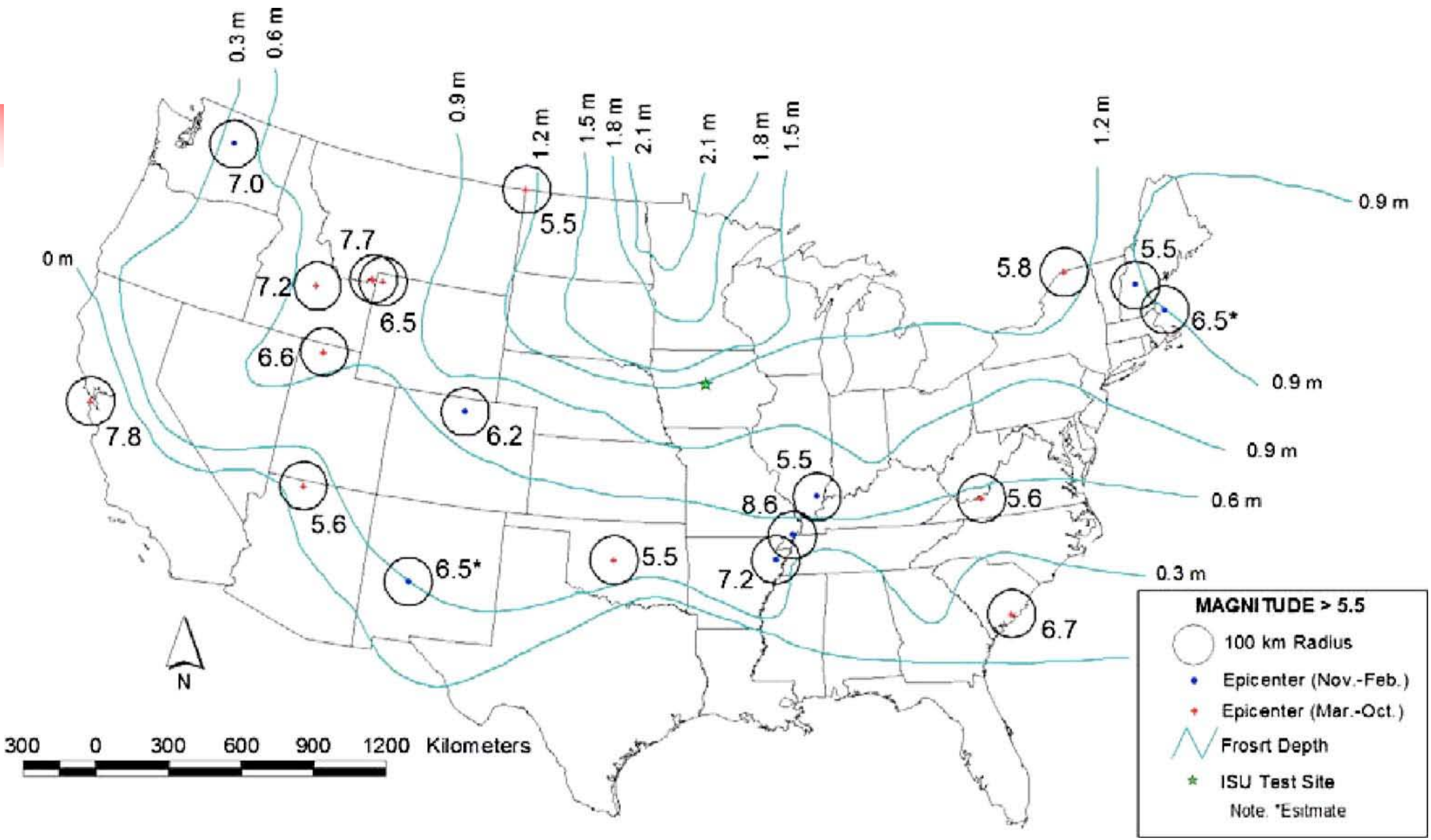
High Seismicity and Existence of Seasonal Frost in Alaska and other regions

- High seismicity in most part of Alaska
- Seasonally frozen soils across the state
  - Arctic/Sub-Arctic climate with mean annual temp. from +4 - -12 ^{o}C
  - Frost penetration: 2 m (6-7’) in South-Central to 0.5 m (1.5) in North Slope
- Extensive distribution of significant seasonal frost and seismicity in the continental United States

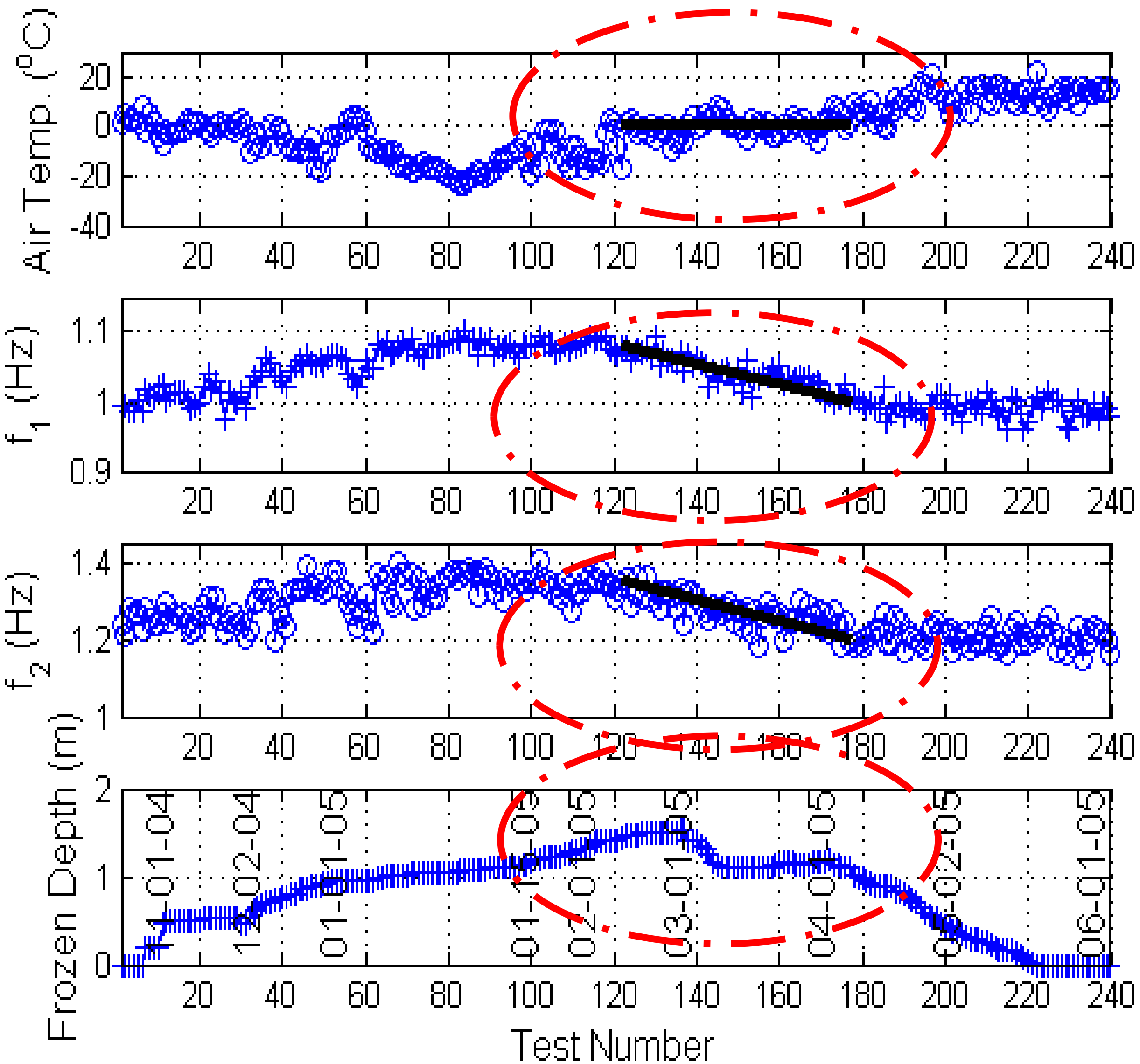


Seasonal frost depth contours in the continental United States and epicenter locations and magnitudes of the largest seismic events in various states from historical records (Sritharan et al. 2008)

Previous Study Results - 1

- Observed frozen soil effects on a bridge (the Port Access Viaduct) from a previous study at UAA and soil-pile test results from ISU

Previous Study Results - 2



Study Objective and Approach

- Systematic investigation of seasonal frost on bridge substructure and overall behaviour under dynamic and seismic loading conditions
- Approaches including numerical simulation and field experiment
  - Two integral parts: large-scale large-deformation simulation and testing of pile performance and full-scale experiments and simulation of a full bridge
  - Involving three Universities: UAF, UAA and Iowa State

Selection of Foundation Type and Test Bridge-1

- Selection Criteria
  - Foundations commonly used by AK DOT & PF, i.e. Steel-pipe piles filled with concrete
  - Representative (native) soils
  - Bridge of manageable size and relatively simple geometry

Selection of Foundation Type and Test Bridge-2

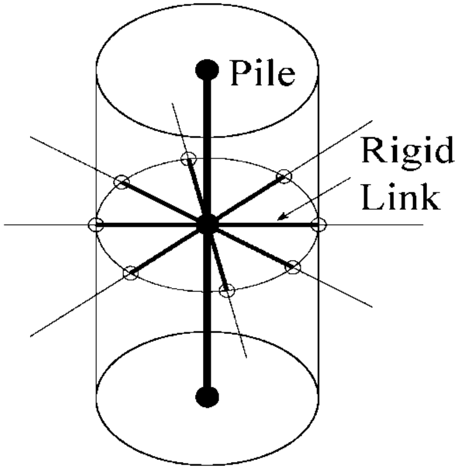
- Selected Bridge: North Fork Campbell Creek Bridge – Constructed in 2007

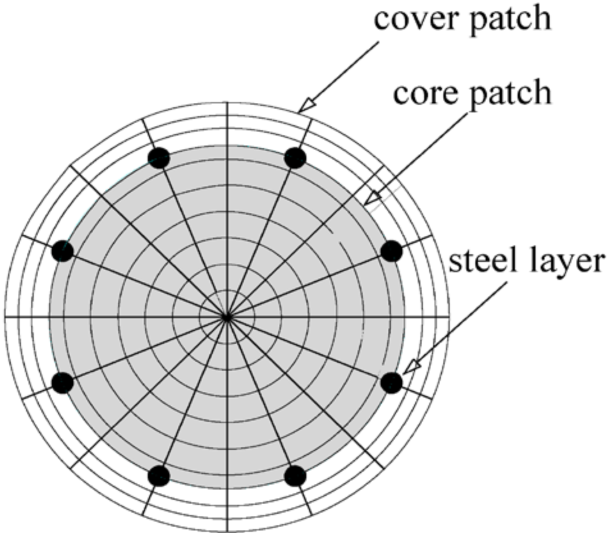
Single Pile Performance

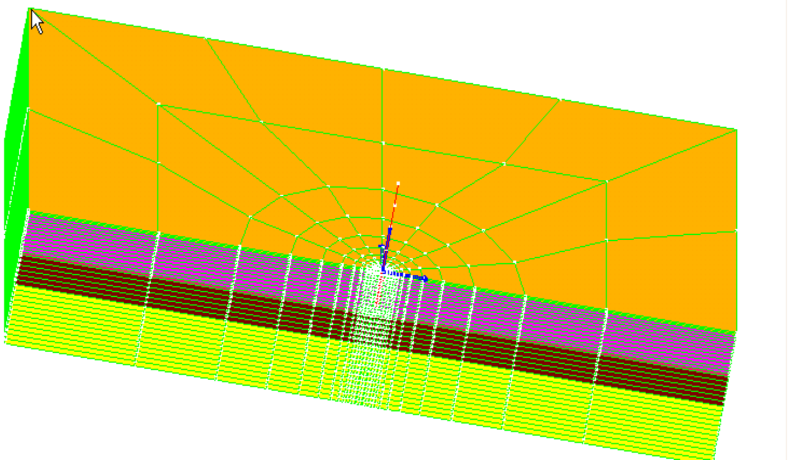
- Two testing piles and one reaction piles constructed in the ‘08 summer
- To be tested in ‘09 summer and ‘09-’10 winter

Performance Prediction

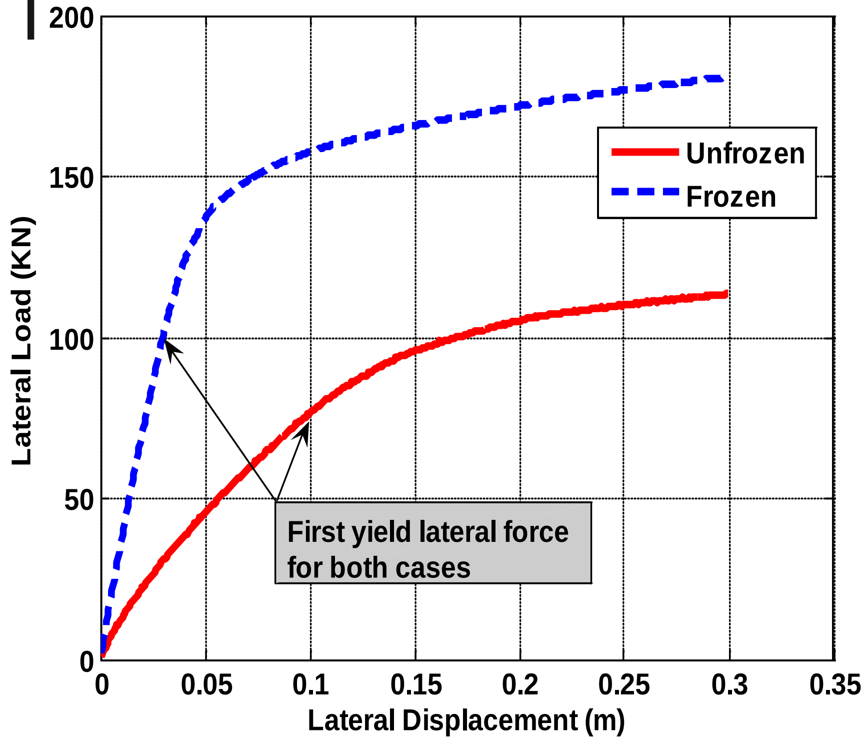
- Finite Element Modelling by using OpenSees Platform (http://opensees.berkely.edu. Open source software)
- Proper interface elements
- Fiber elements for reinforced concrete filled steel pipe pile
- Confining effects on reinforced concrete strength: Mander's Model
- Brick elements for soils: Elastic-plastic material model for soils

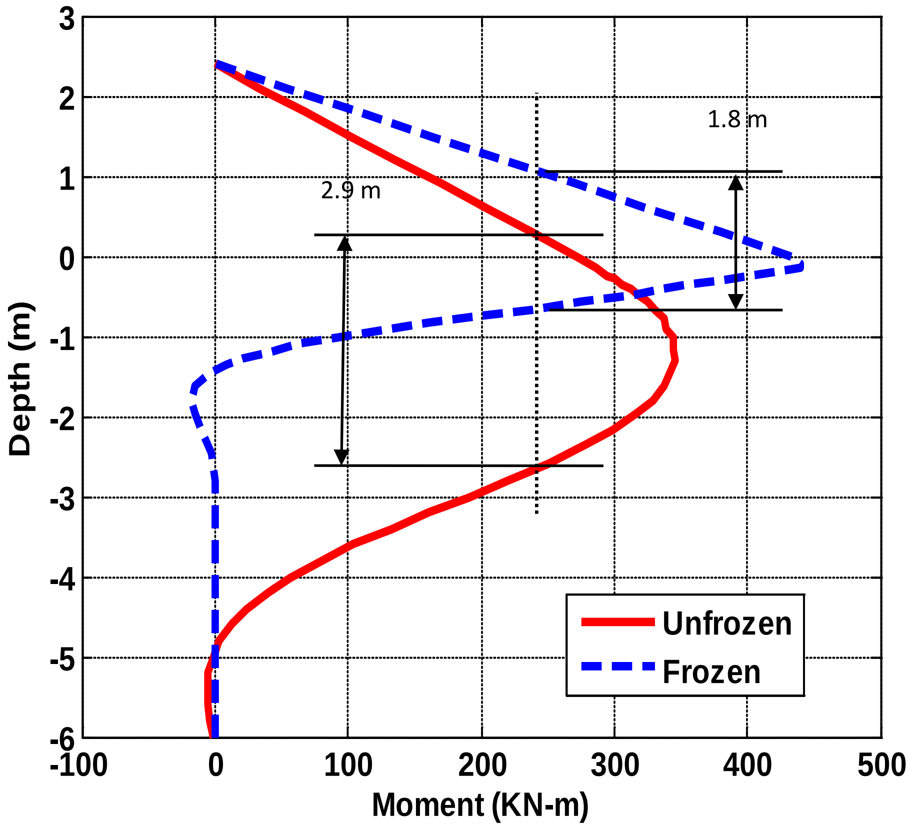






Performance Prediction - 1





Performance Prediction - 2

- Pile lateral yield force increases 30%, displacement capacity at lateral yield force decreases 70%
- At a Pile Head disp. of 0.3 m:

	Lateral Force at Pile Head (kN)	Max. Bending Moment (kN-m)	Max. Bending Moment Depth (m)	Equivalent Fixity Depth (m)
Frozen	181	440	0.15 (0.38*D)	0.5 m (1.25D)
Unfrozen	113.5	345	1.1 (2.75*D)	1.16m (2.9D)

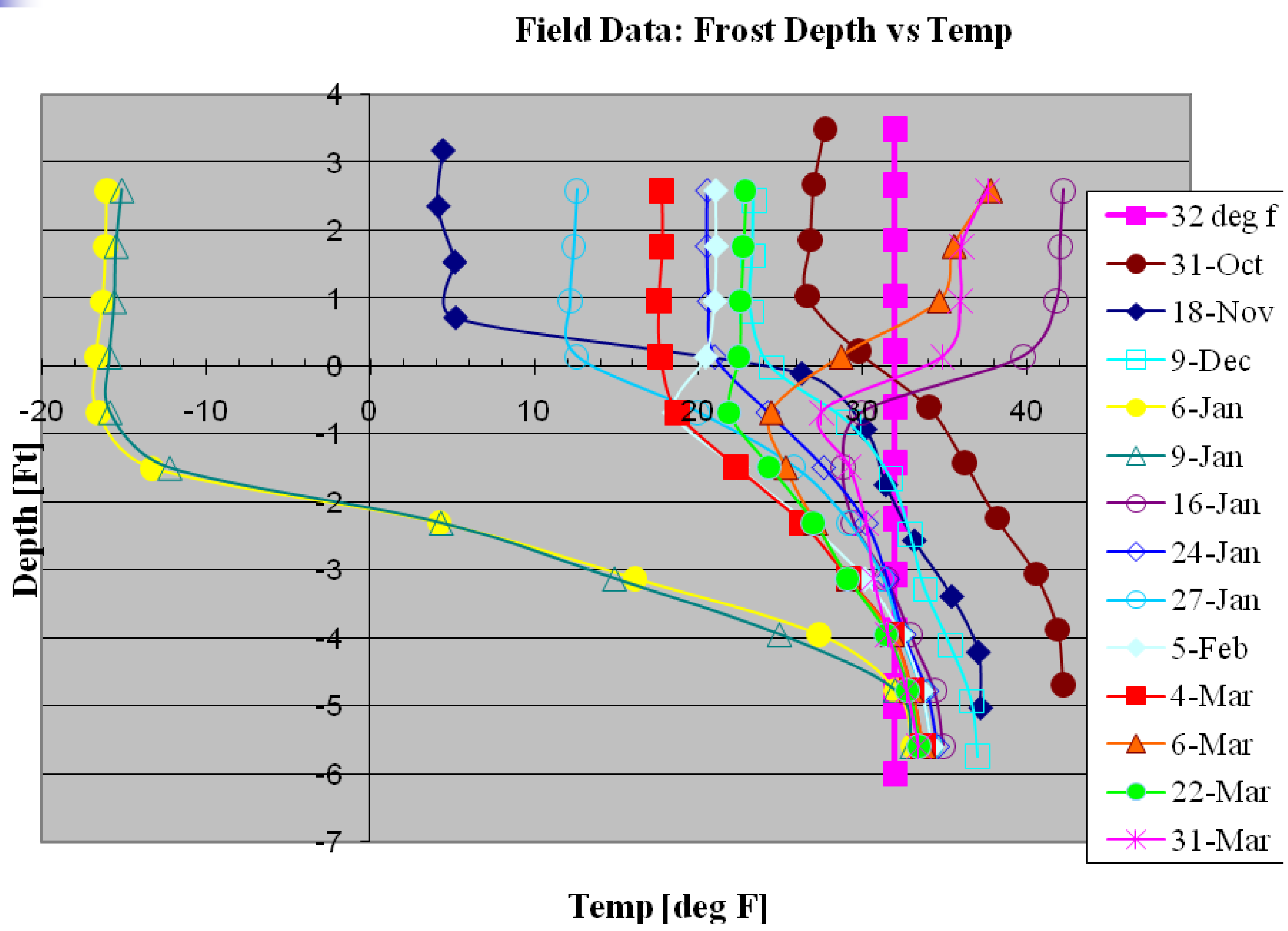
- Bending moment profile much larger in frozen condition; plastic hinge zone reduced by 40% in frozen condition.

Full Bridge Performance

- Field Monitoring
  - Environment conditions including air temperature, ground temperature/frost penetration, etc.
  - Dynamic/seismic performance including traffic-induced and earthquake-induced vibration data collection
- Data collection and analysis
- Numerical Simulation

Ground Temperature/Frost Observation Facilities

Frost Penetration Observation Data



Frost Depth Estimation Using Modified Berggren's Equation

$$X = \lambda\sqrt{\frac{48k_{ave}nFI}{L}}$$

X - depth of freeze

λ - dimensionless coefficient which takes into consideration the effect of temperature changes in the soil mass and accounts for sensible heat changes

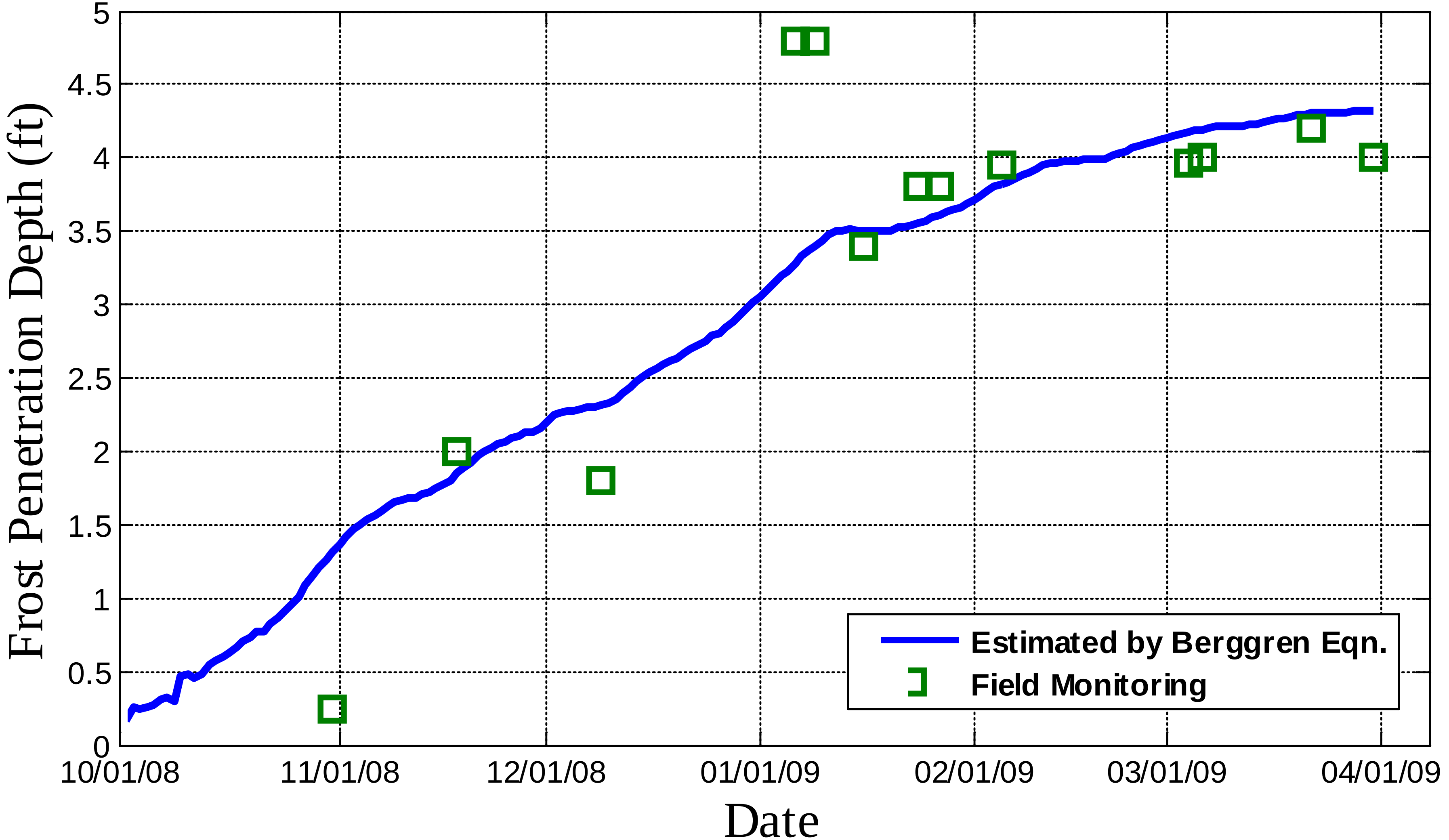
k_{ave} -average thermal conductivity of soil

n – conversion factor for air freezing index to surface freezing index

FI -air freezing index

L -latent heat

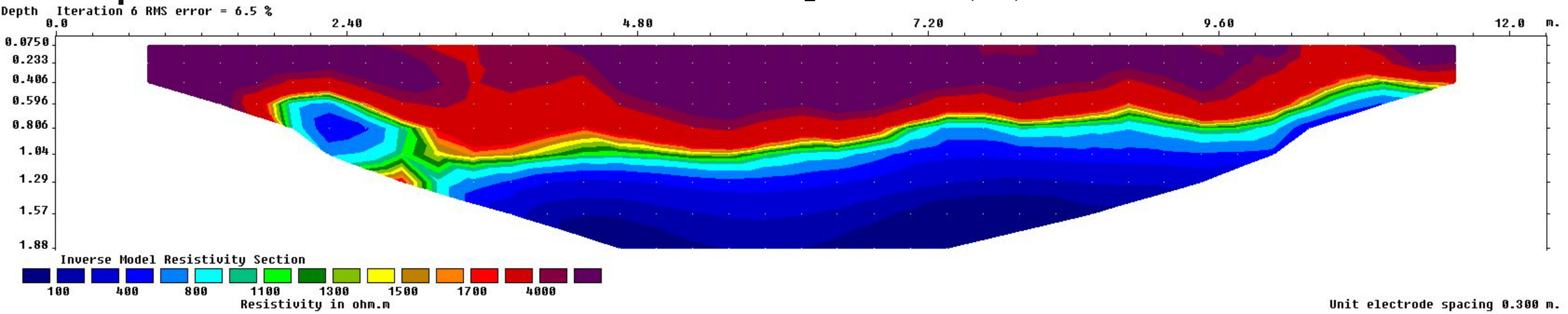
Frost Penetration Observation Results and Analysis



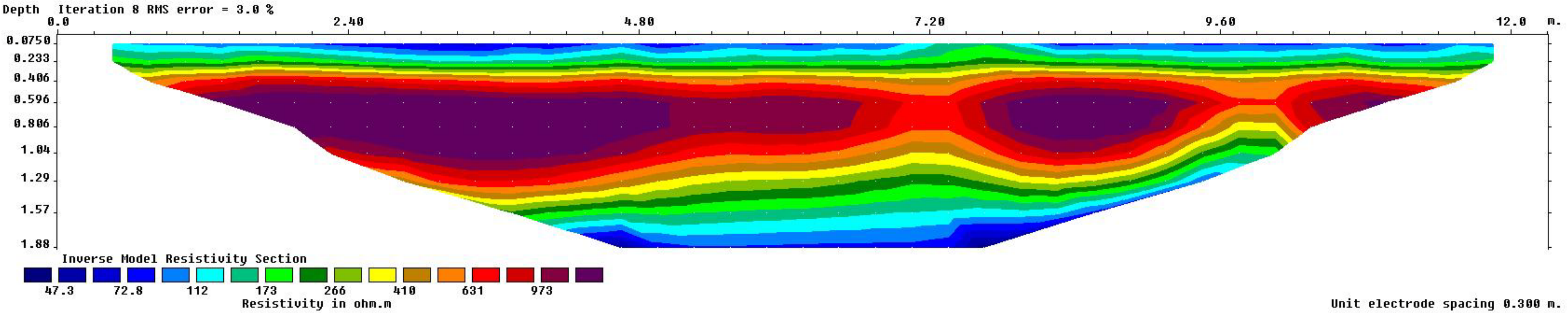
Frost Penetration by Resistivity Mapping

Frost Penetration by Resistivity Mapping - Results

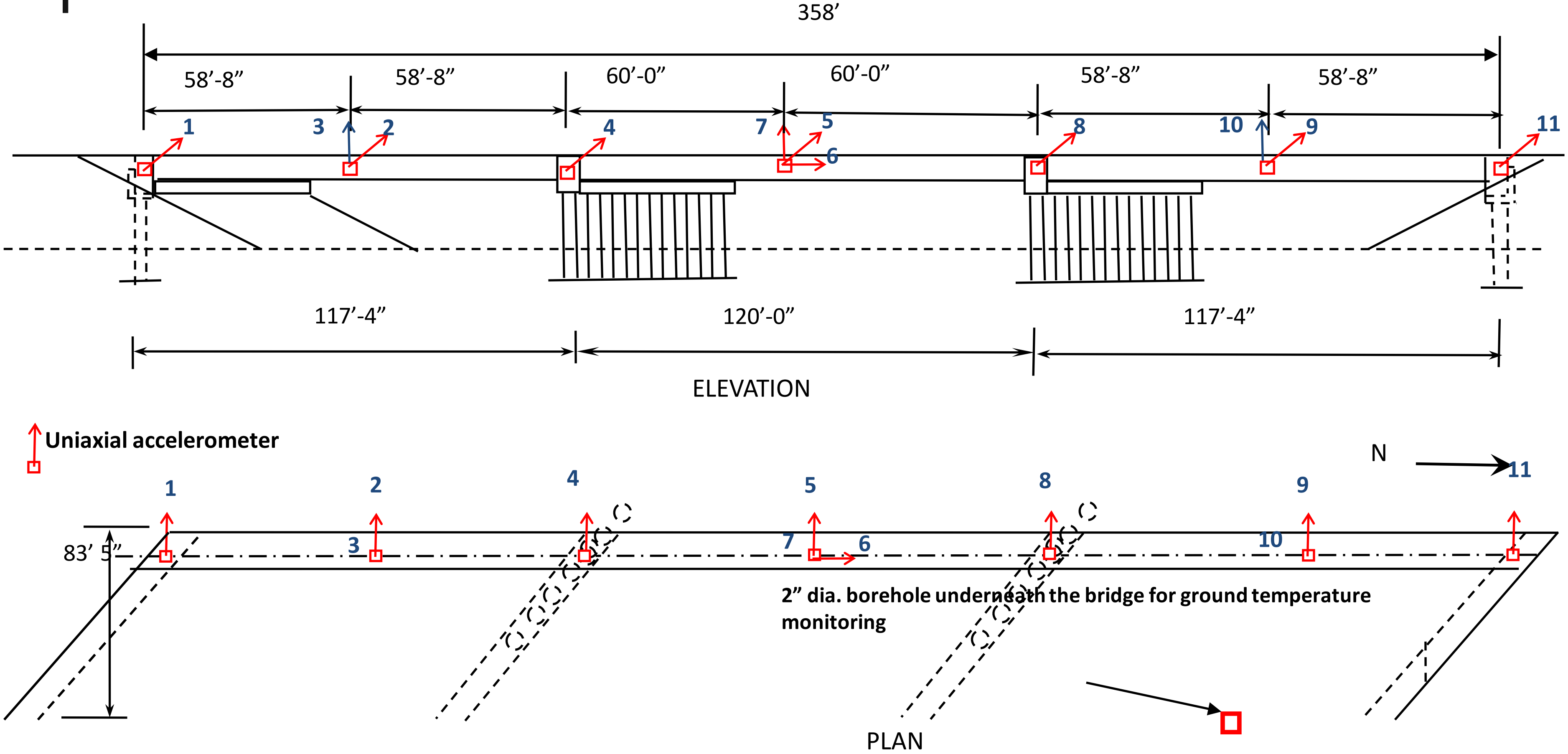
December 9, 2008 Top 0.6 m (2') frozen



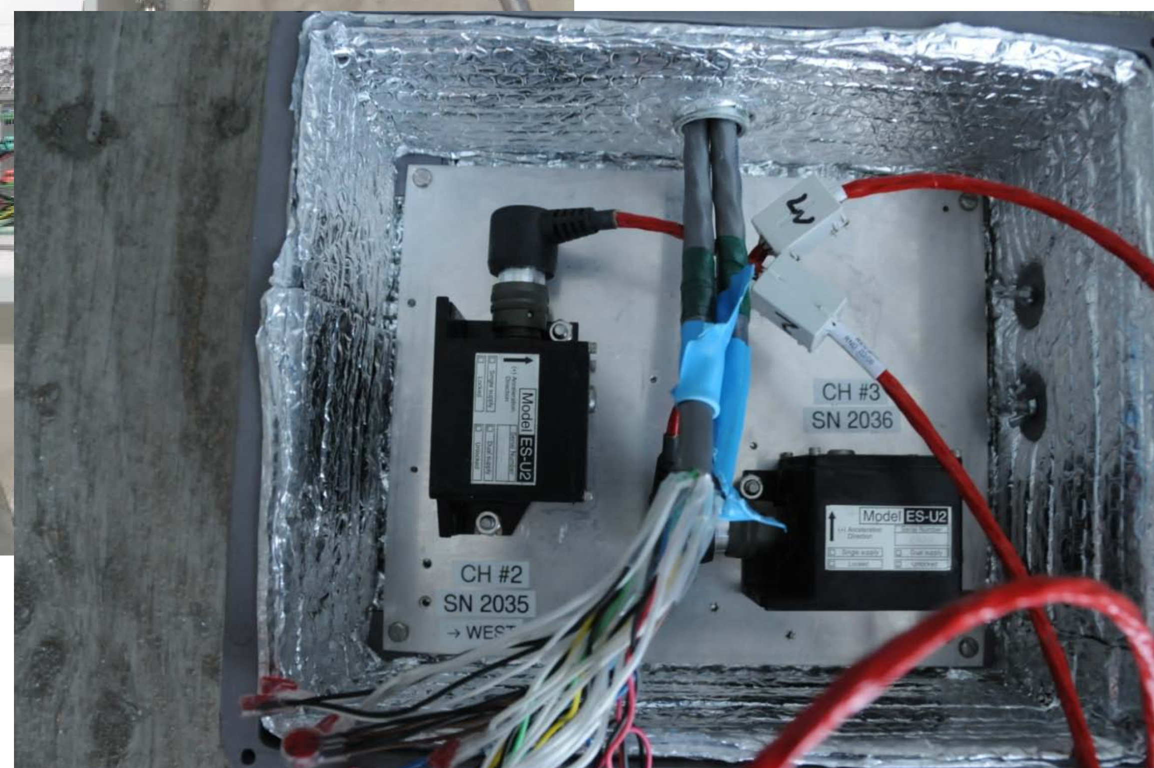
May 19, 2009 Top 0.4 m (1.3') thawed



Seismic Instrumentation Plan

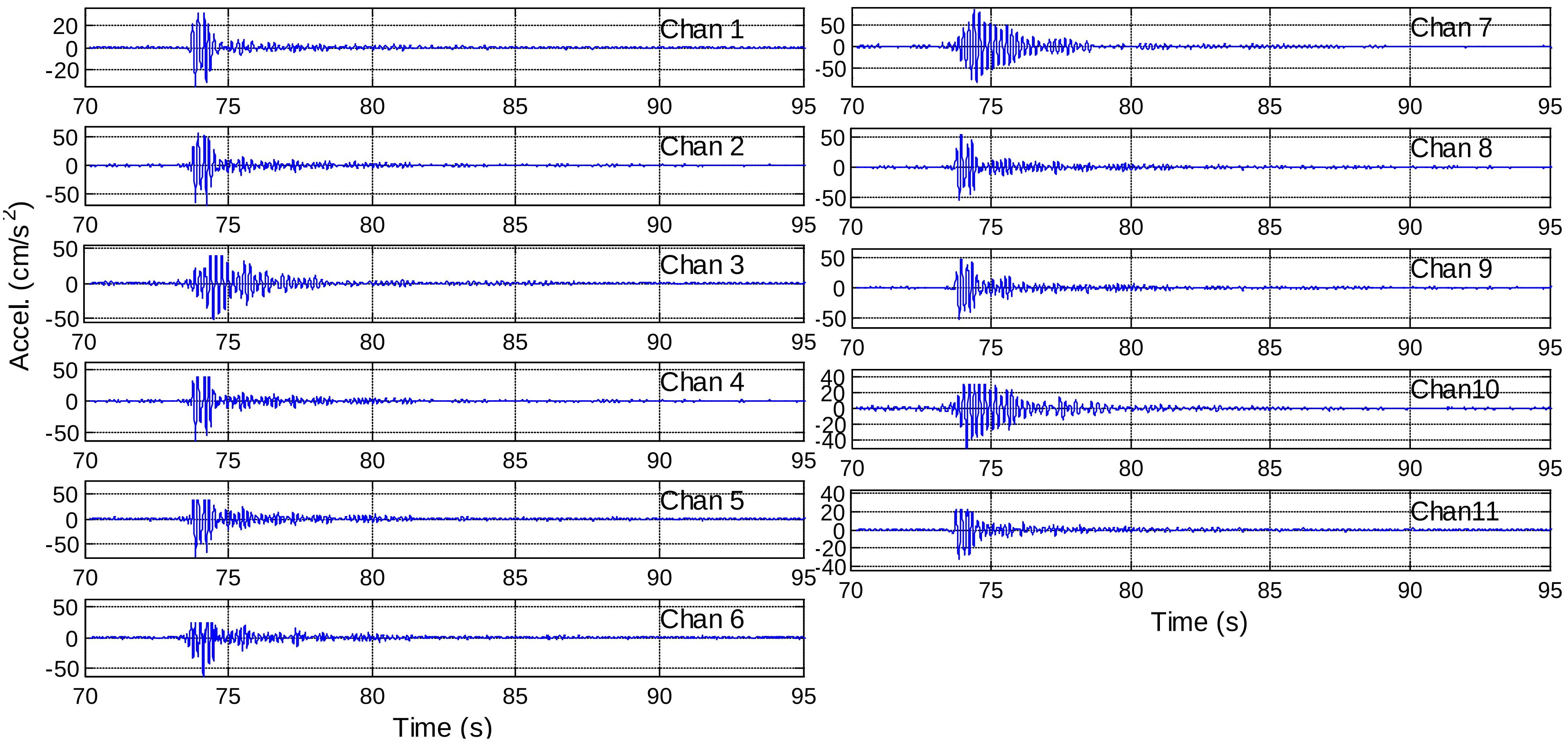


Seismic Performance Monitoring Facilities

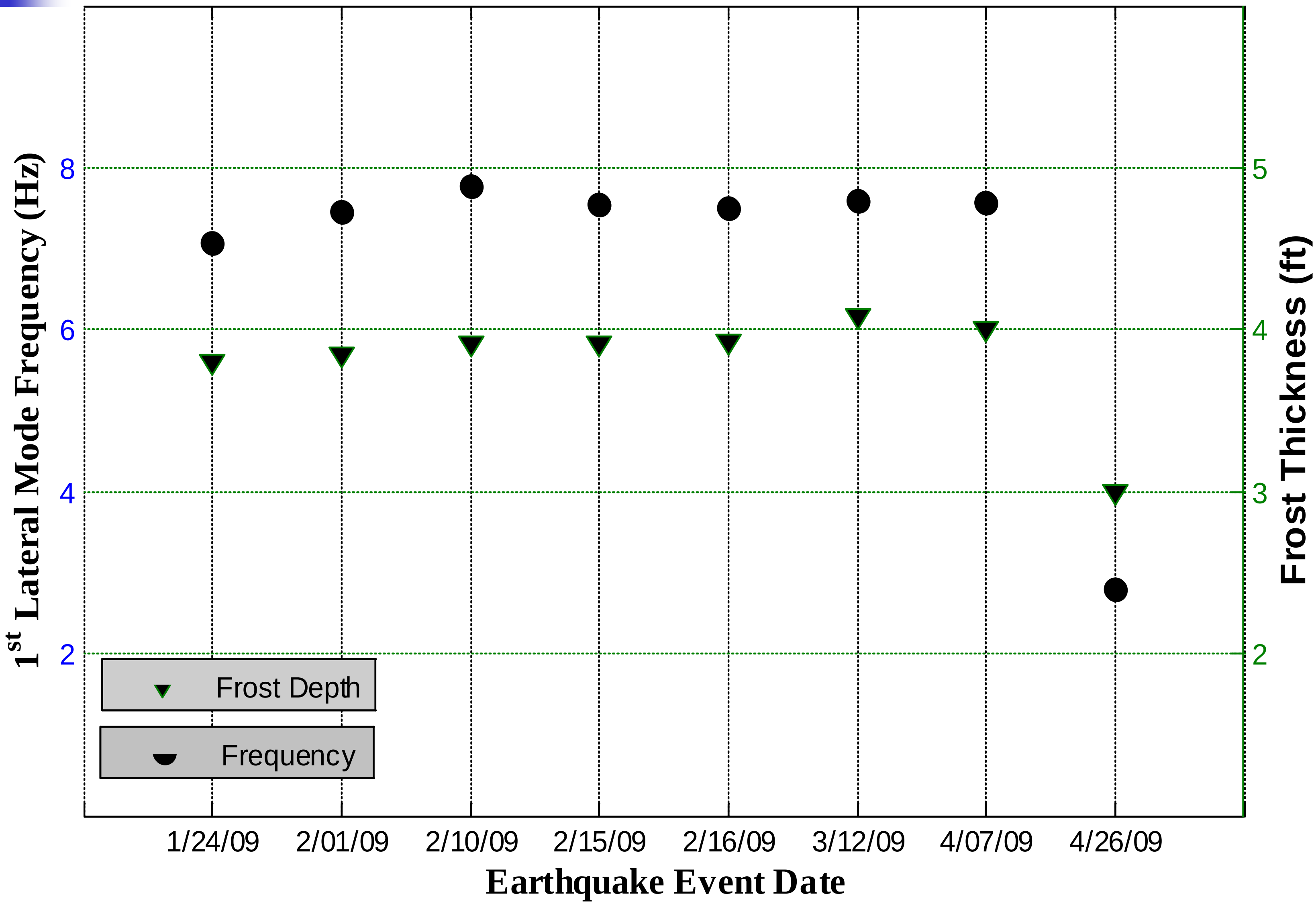


Seismic Response Data

- A total of 8 earthquakes with M_L varying from 3.3 to 5.7 recorded so far
- Acceleration of Apr. 7, 2009 Earthquake (M_L=4.7)

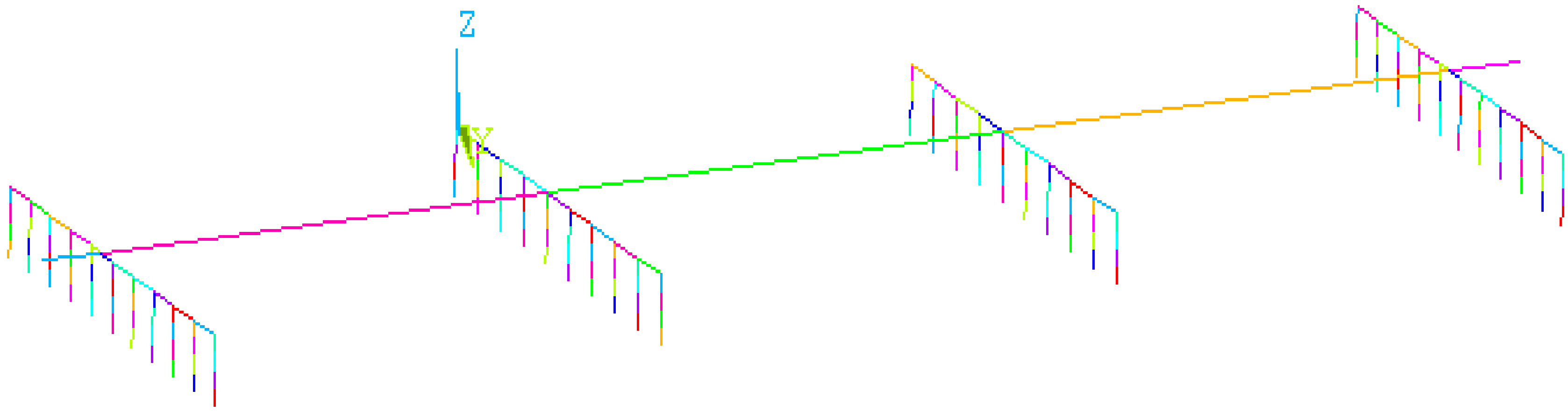


Seismic Performance Monitoring Results



Performance Prediction – Entire Bridge

- Modelling by using OpenSees Platform
- Simplified beam models
- Soil freezing effects models by varying fixity point obtained from pile modeling and testing
- On going



Summary

- A project focusing on the seasonally frozen ground effects on the seismic behavior of highway bridges in cold regions has been initiated
- This project consists of two integral parts: element testing including material and pile testing, and bridge testing.
- Numerical simulation results indicate the seasonal freezing has great impact on the lateral behavior of the soil-pile system
- Field work progresses as planned.
- Once completed, it will provide evidence for code improvement to account for seismic design of bridges in cold regions.

Thank You!