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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**Co-Workers**
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- 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 to two orders of magnitude.

Overall bridge dynamic properties change significantly, altering foundation plastic hinge location.
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 °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

First yield lateral force for both cases

Unfrozen
Frozen

Lateral Load (kN)

Lateral Displacement (m)

Depth (m)

Moment (kN-m)
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:

<table>
<thead>
<tr>
<th></th>
<th>Lateral Force at Pile Head (kN)</th>
<th>Max. Bending Moment (kN-m)</th>
<th>Max. Bending Moment Depth (m)</th>
<th>Equivalent Fixity Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen</td>
<td>181</td>
<td>440</td>
<td>0.15 (0.38*D)</td>
<td>0.5 m (1.25D)</td>
</tr>
<tr>
<td>Unfrozen</td>
<td>113.5</td>
<td>345</td>
<td>1.1 (2.75*D)</td>
<td>1.16m (2.9D)</td>
</tr>
</tbody>
</table>

- 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

1” PVC Pipe

Portable Data Collector

Temperature Acquisition Cable
Frost Penetration Observation Data

Field Data: Frost Depth vs Temp

Temp [deg F]

Depth [ft]
Frost Depth Estimation Using Modified Berggren’s Equation

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

X - depth of freeze
\( \lambda \) - 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

Uniaxial accelerometer

2" dia. borehole underneath the bridge for ground temperature monitoring
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

![Graph showing Seismic Performance Monitoring Results]

- **Earthquake Event Date**: 1/24/09, 2/01/09, 2/10/09, 2/15/09, 2/16/09, 3/12/09, 4/07/09, 4/26/09
- **Frost Thickness (ft)**: 2, 3, 4, 4, 4, 4, 4, 3
- **1st Lateral Mode Frequency (Hz)**: 2, 3, 4, 4, 4, 4, 4, 3

- **Legend**:
  - ▼: Frost Depth
  - □: Frequency

**Graph Notes**:
- Frost Depth and Frequency are plotted against the earthquake event date.
- The graph shows trends in frost depth and lateral mode frequency over time.
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
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!