Seismic Response and Structural Health Monitoring of the Port Access Viaduct in Anchorage, Alaska

Presented to

Alaska Seismic Hazards Safety Commission

Zhaohui (Joey) Yang

Asst. Professor, UAA

December 5, 2006

Acknowledgement

- Sponsors
  - NSF and State of AK Funded EPSCoR Program
  - Alaska Dept. of Transportation and Public Facilities
  - U.S. Geological Survey's ANSS Program
  - UAA
- Co-Workers
  - Dr. Uptal Dutta and Dr. Helen Liu, UAA
  - Mr. Elmer Marx, Mr. Richard Pratt from AK DOT&PF
  - Dr. Niren Biswas, UAF
  - Dr. Feng Xiong, Sichuan Univ., China. Visiting UAA currently.

Outline

- Introduction
- Strong-motion instrumentation of the Port Access Bridge: Phase I & Phase II
- Implementation of Phase I and Phase II
- Results from Phase I
  - Seismic and ambient data collection
  - Study of bridge structural dynamic properties
  - Variation of structural dynamic properties vs. environmental variables
  - Analytical modeling of seasonal frost effects on bridge dynamic and seismic behavior
  - Conclusions on seasonal frost effects on bridge structures
- Status of seismic instrumentation and study of bridge infrastructures: A brief comparison between AK and CA
- Major issues for future study

Motivation

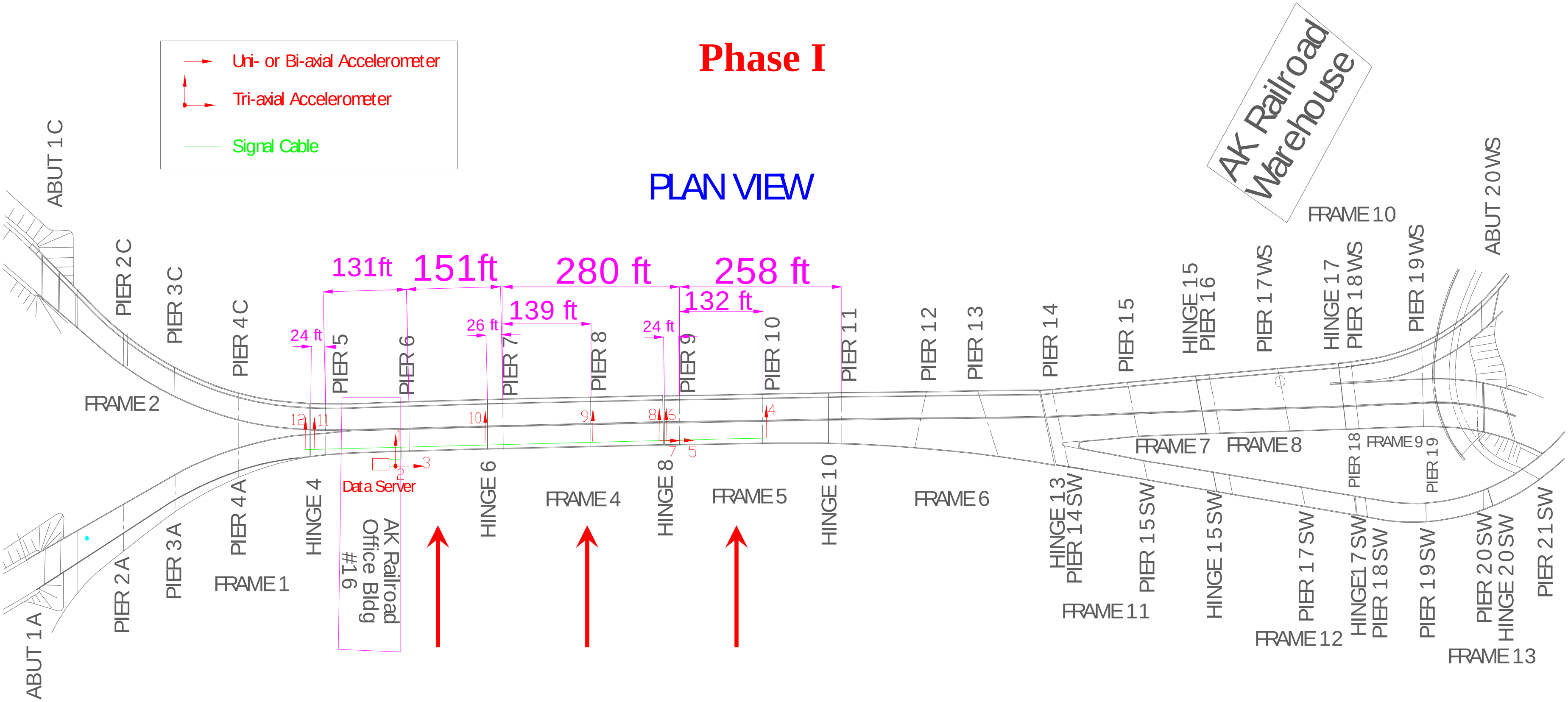
- High seismicity in south-central Alaska
- Essential facility connecting POA with Alaska highway system, serving 90% of Alaskans
- No recorded bridge data available in Alaska

Project Phases: I and II

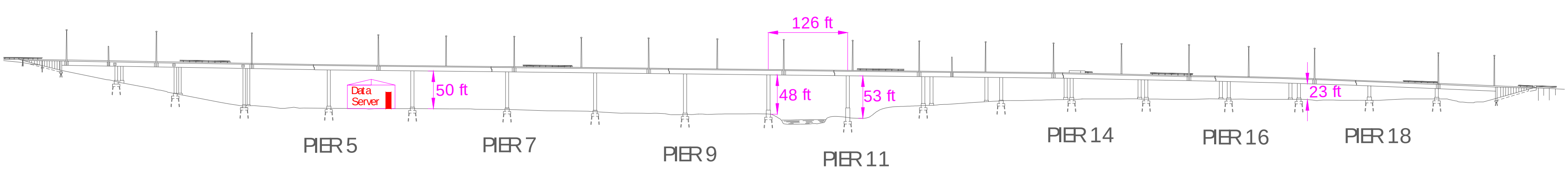
- Phase I
  - May 2003 – Dec. 2004
  - Sponsors: AK EPSCoR, AK DOT, and UAA
  - System: 12-sensor system, three frames instrumented
  - Implementation: Completed in Nov. 2004 and operational since then
  - Data: 21 earthquakes (3.5-5.5) recorded and over 400 train-induced vibrations
- Phase II
  - August 2005 – Sept. 2007
  - Sponsors: USGS's ANSS Program and UAA
  - System: 27-sensors, entire bridge covered
  - Implementation: Started in Oct. 2006 and anticipated to complete by the end of this year or early next year.
  - Data: N/A

Instrumentation Design for Port Access Bridge, Anchorage, AK

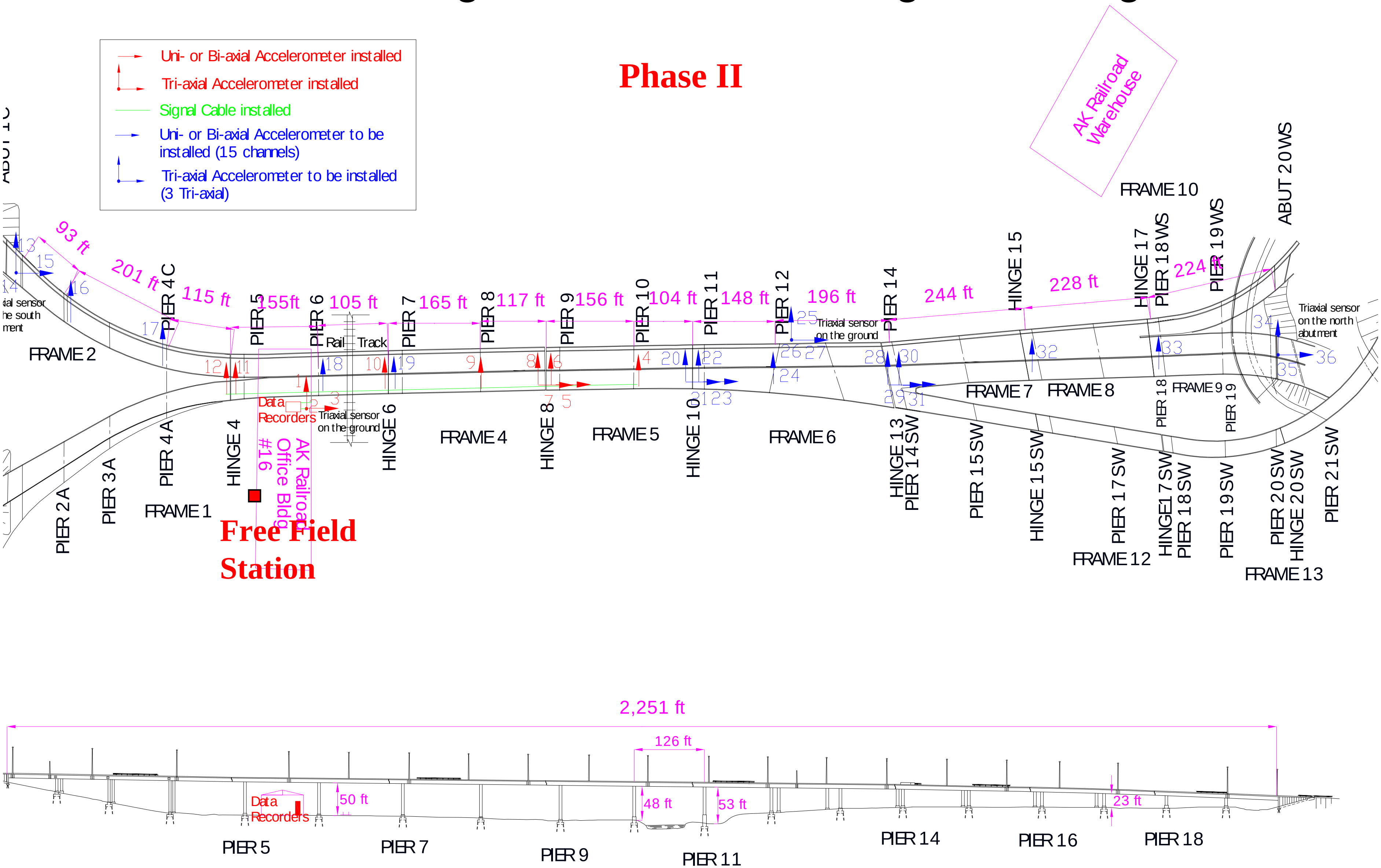
Phase I



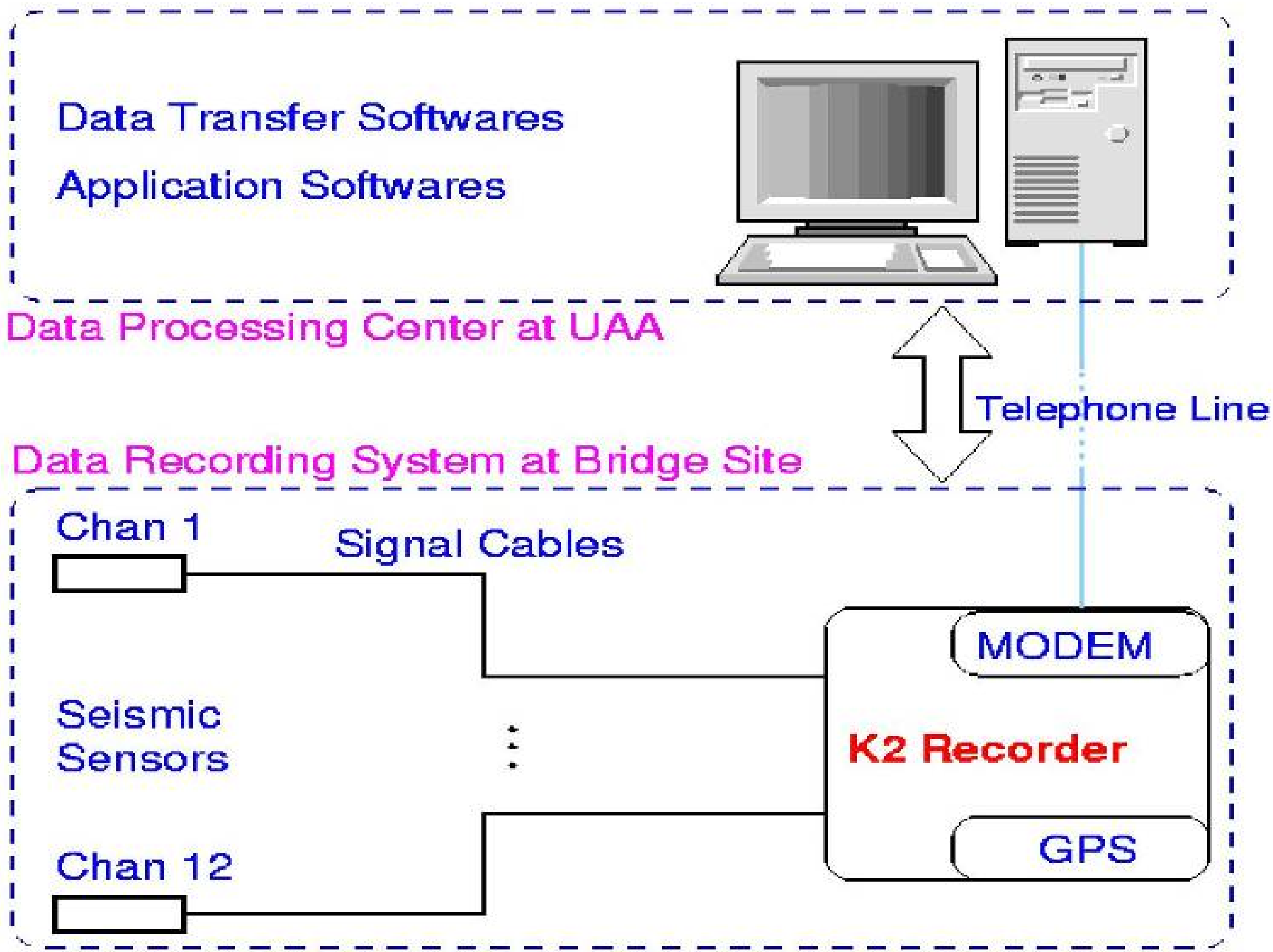
ELEVATION VIEW



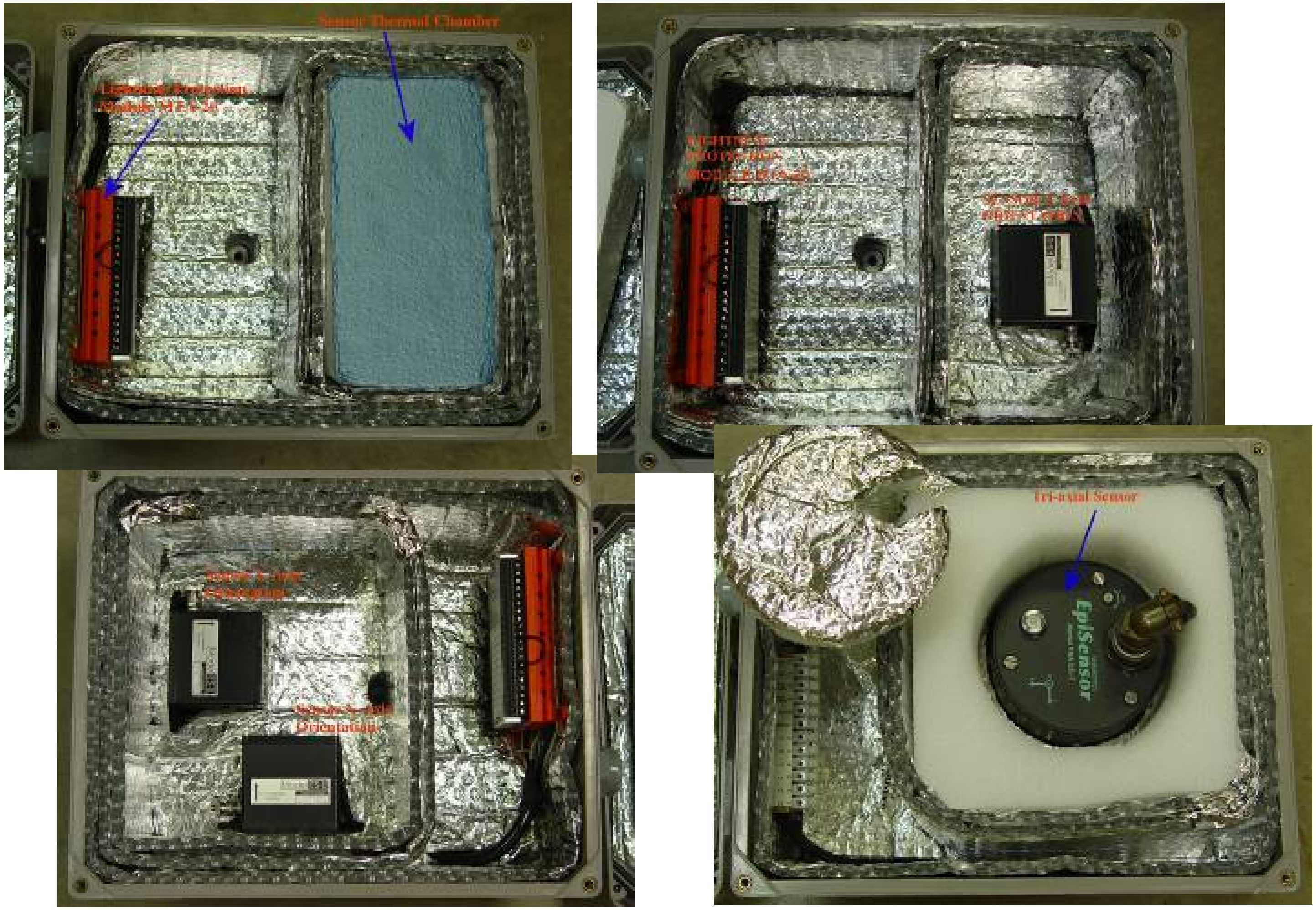
Instrumentation Design for Port Access Bridge, Anchorage, AK



Implementation of Phase I:
Data Acquisition System

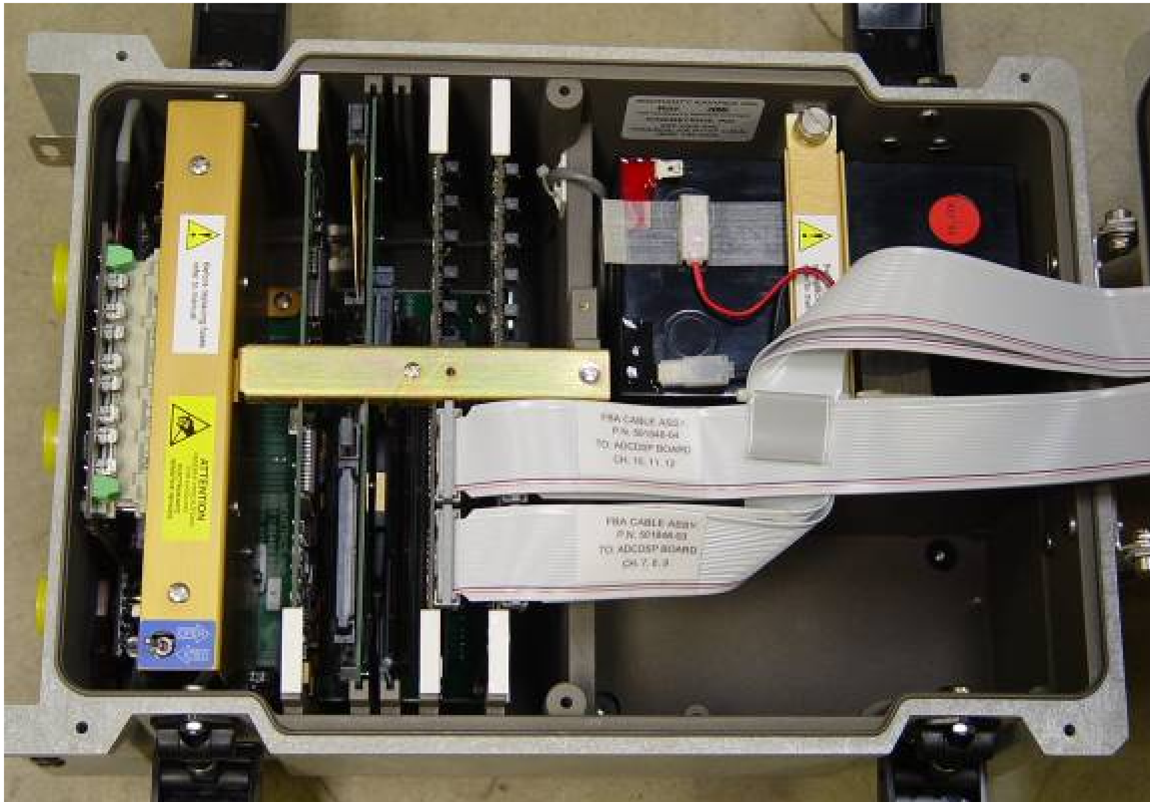


Instruments - Sensors



- Uniaxial, bi-axial, and triaxial sensor units
- Custom-designed sensor enclosures with insulation layer

Instruments - Data Recorder

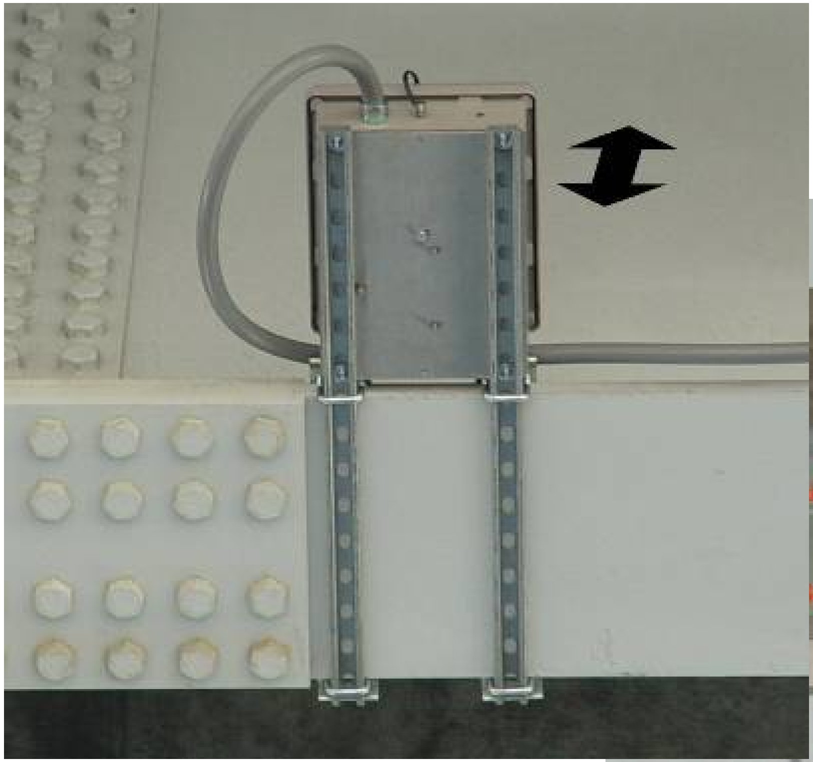


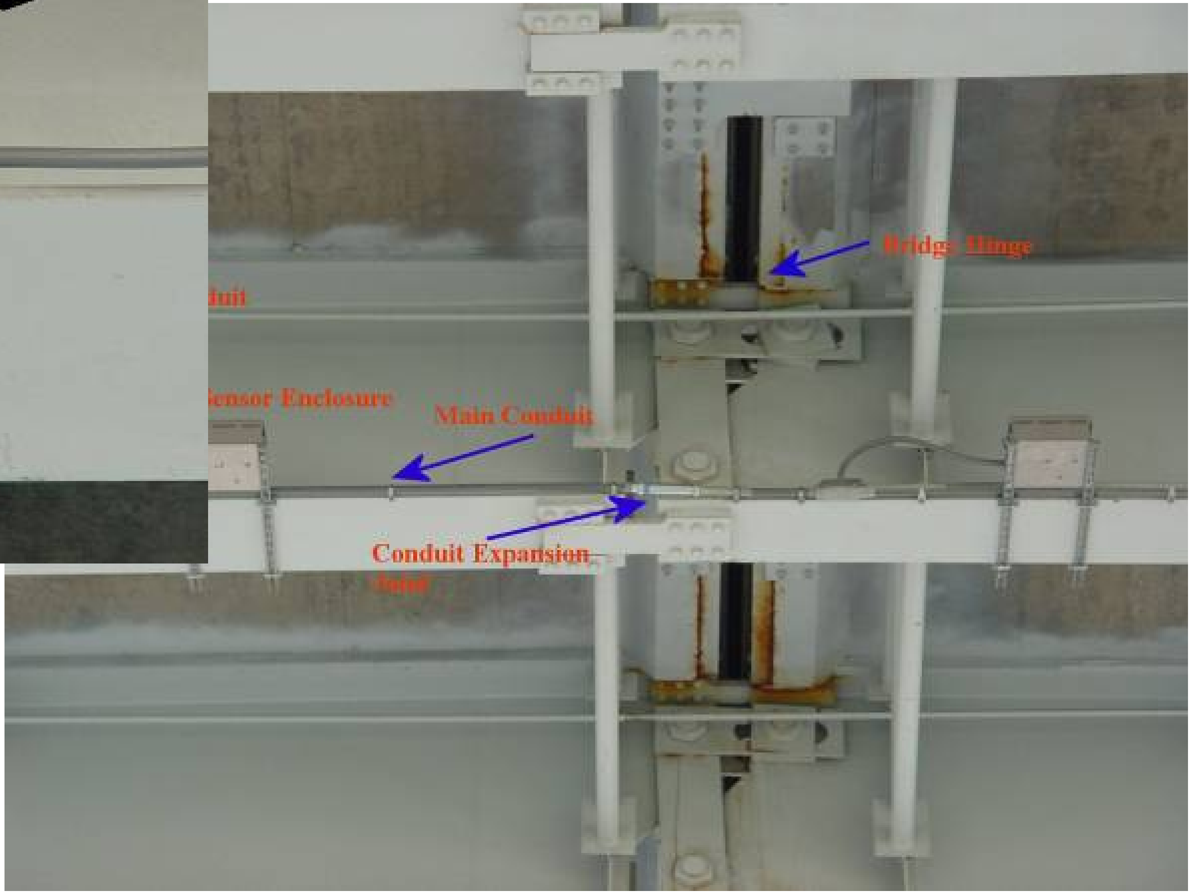
- K2 Data recorder – Portable PC with DAQ
- 128 Mb flash memory to store events locally
- Operated on batteries, which are re-charged

Installation - 1

- Installed according to DOT requirements
- Major cost on installation

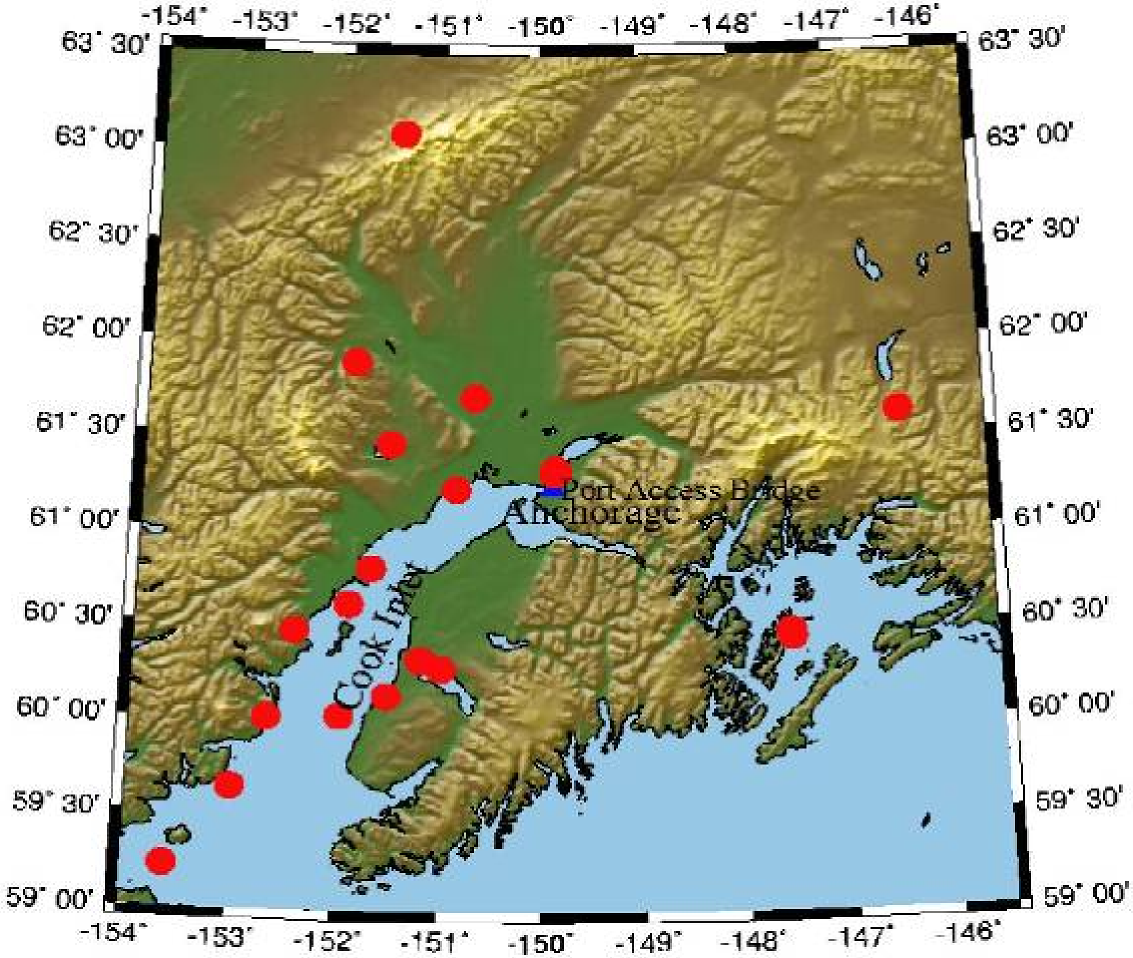
Installation - 2



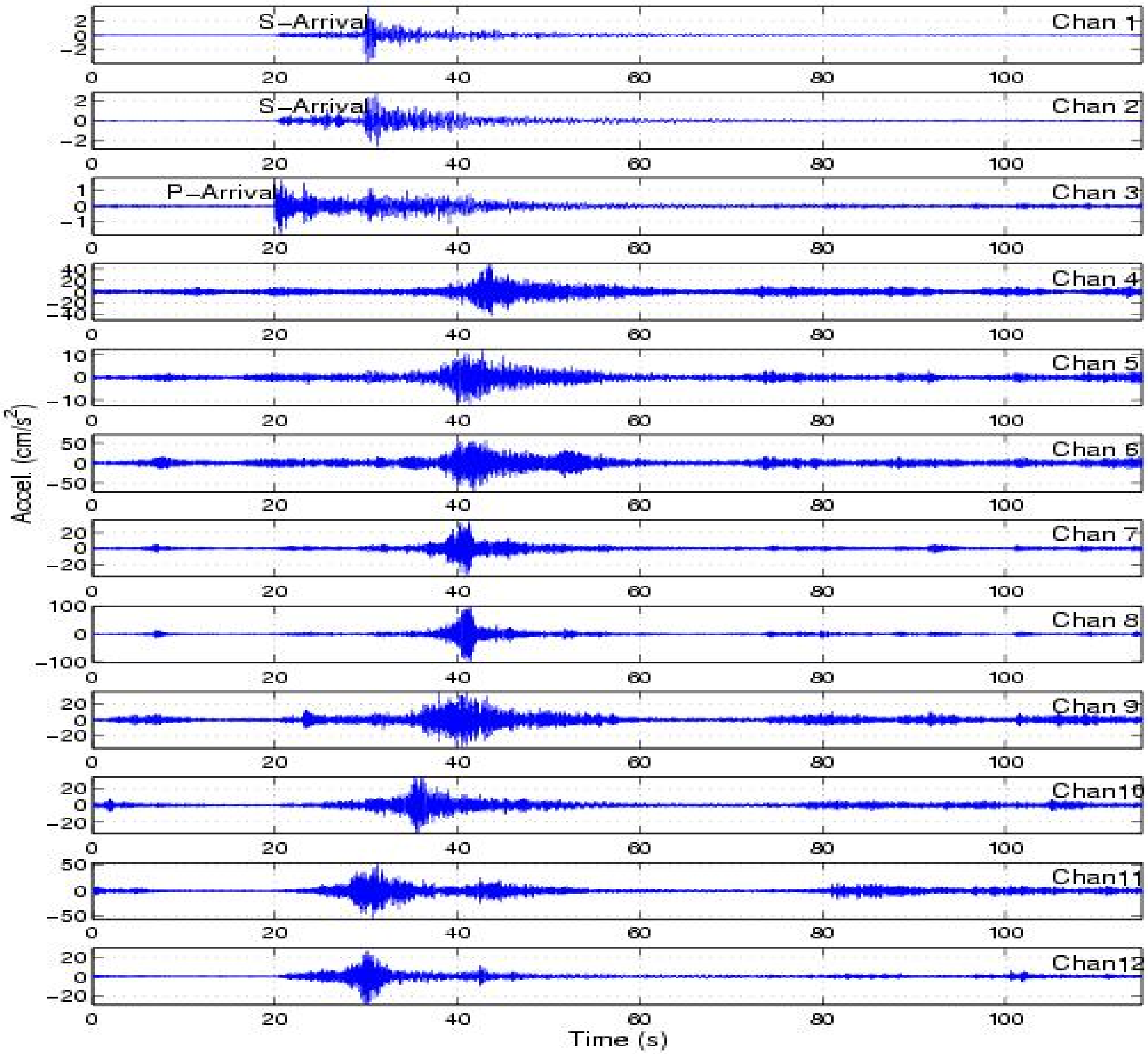


Results from Phase I
Data Collection

- 21 earthquakes ($3.5 < M_L < 5.5$) and more than 400 train-induced vibrations recorded from Nov. 1, 2004 – Dec. 31, 2005



Recorded Earthquake – 10/17/04 (M_L=4.3)

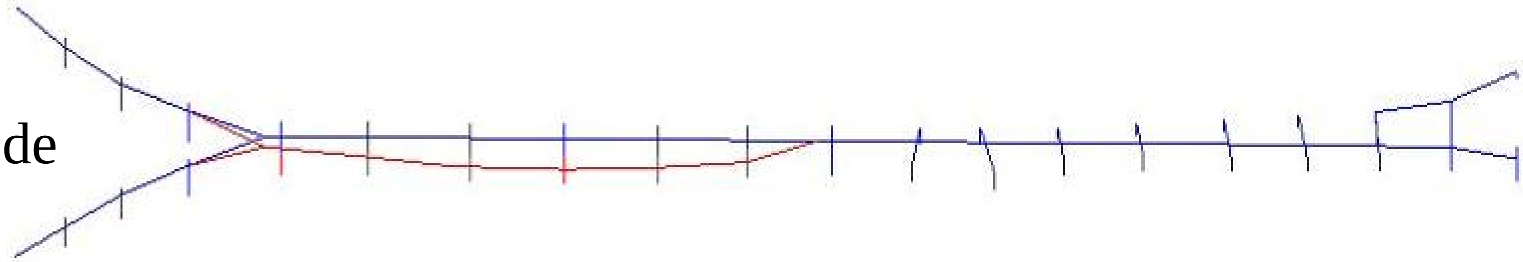


Structural Dynamic Properties - Modal Frequencies and Damping

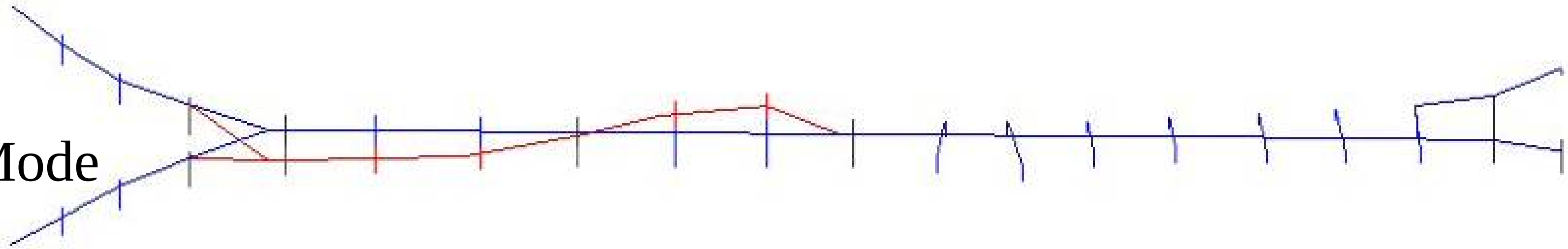
Event	1^{st} Mode		2^{nd} Mode		3^{rd} Mode	
	f (Hz)	ξ (%)	f(Hz)	ξ (%)	f (Hz)	ξ (%)
Ambient Noise (10/25/04)	1.017	0.64 ± 0.01	1.280	2.29 ± 0.10	2.063	0.84 ± 0.01
Train Noise (10/19/04)	0.987	0.84 ± 0.01	1.269	2.15 ± 0.01	1.993	0.78 ± 0.01
Earthquake (10/17/04)	0.994	2.36 ± 0.13	1.235	1.55 ± 0.07	1.995	0.63 ± 0.01
Earthquake (11/07/04)	0.979	2.28 ± 0.06	1.215	0.80 ± 0.03	2.072	0.73 ± 0.01

Mode Shapes

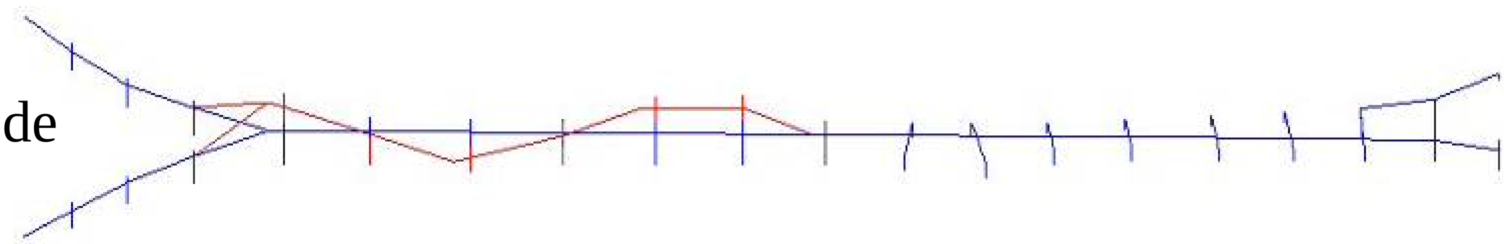
1st Mode



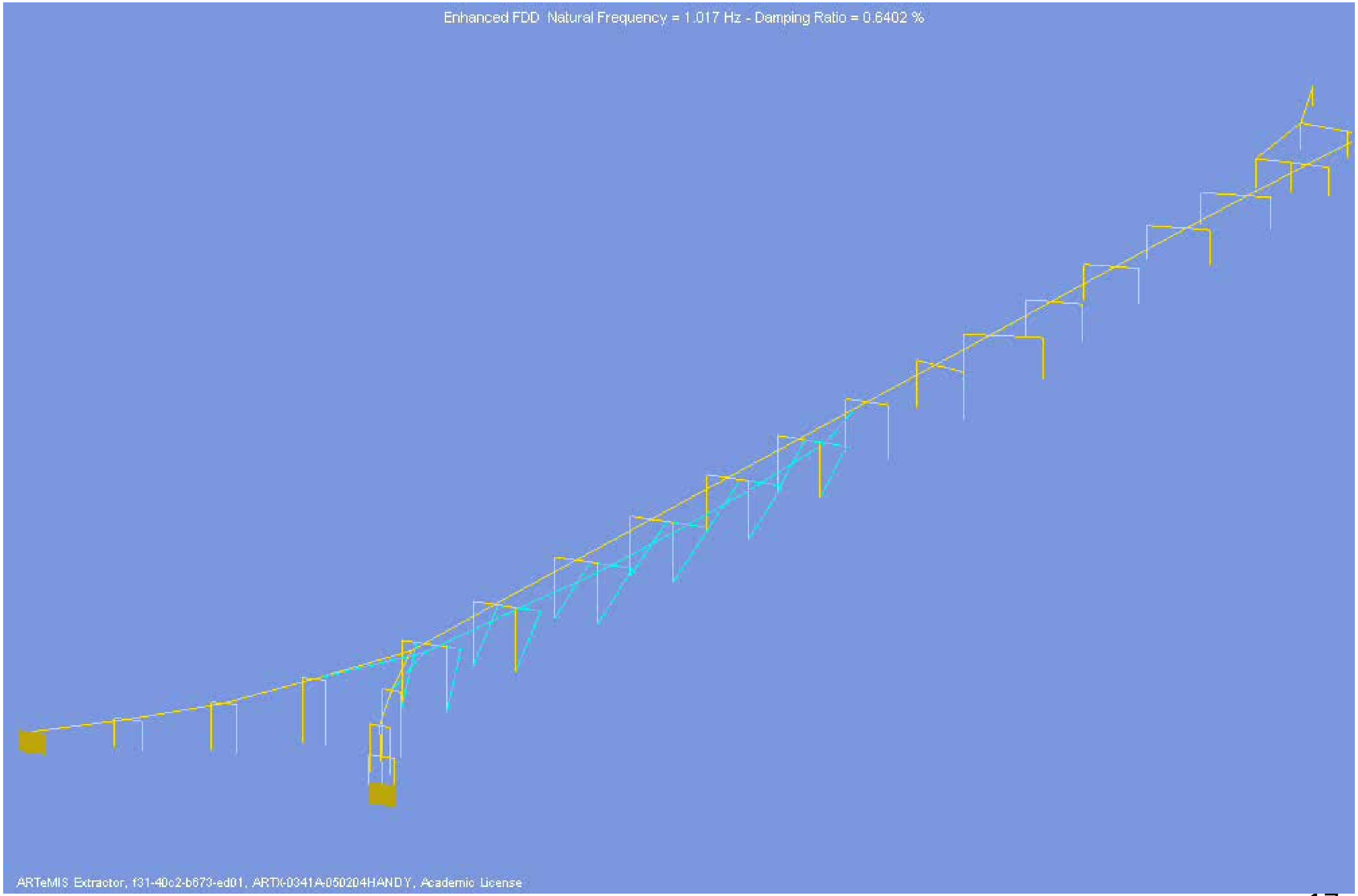
2nd Mode



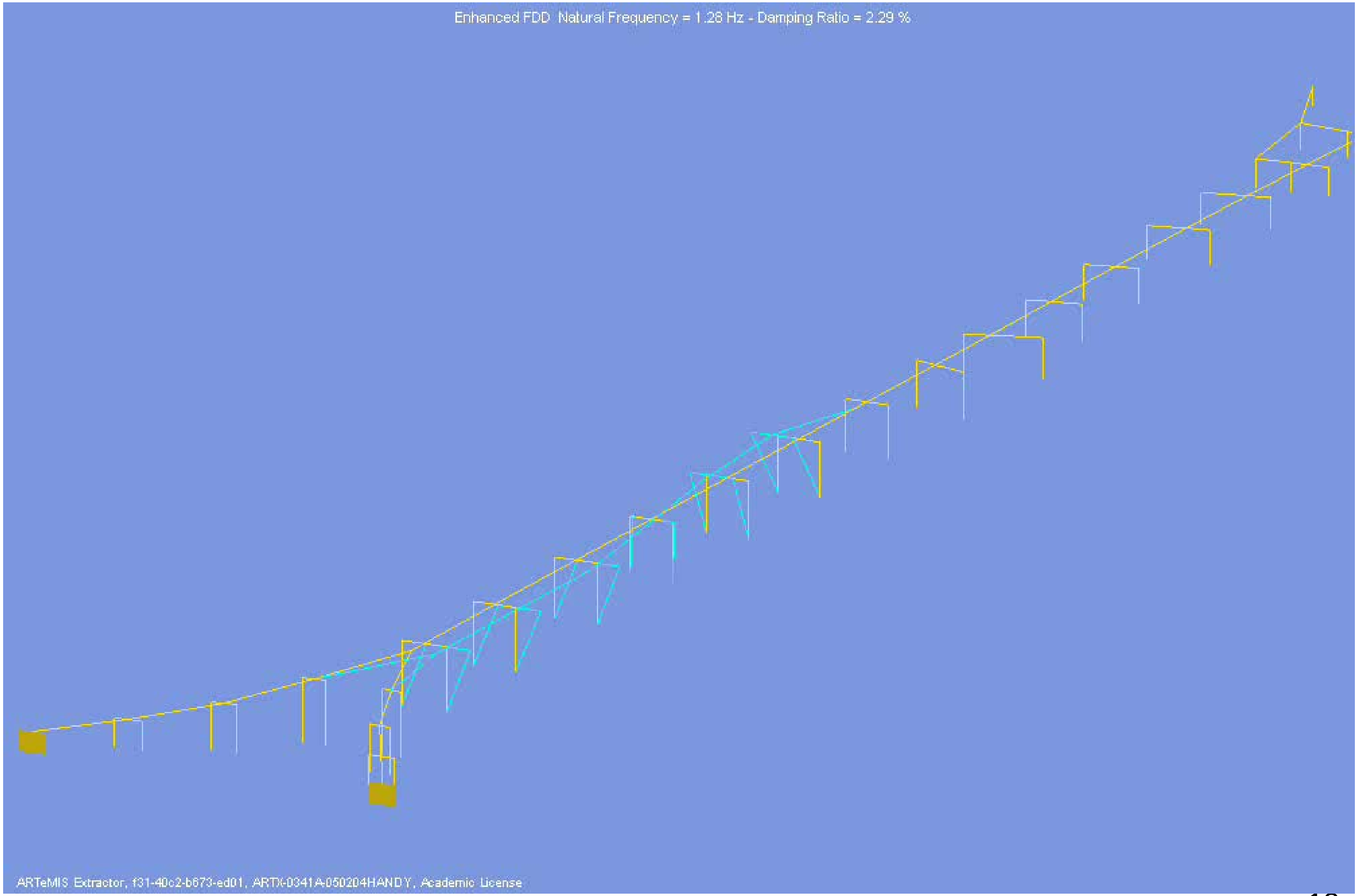
3rd Mode



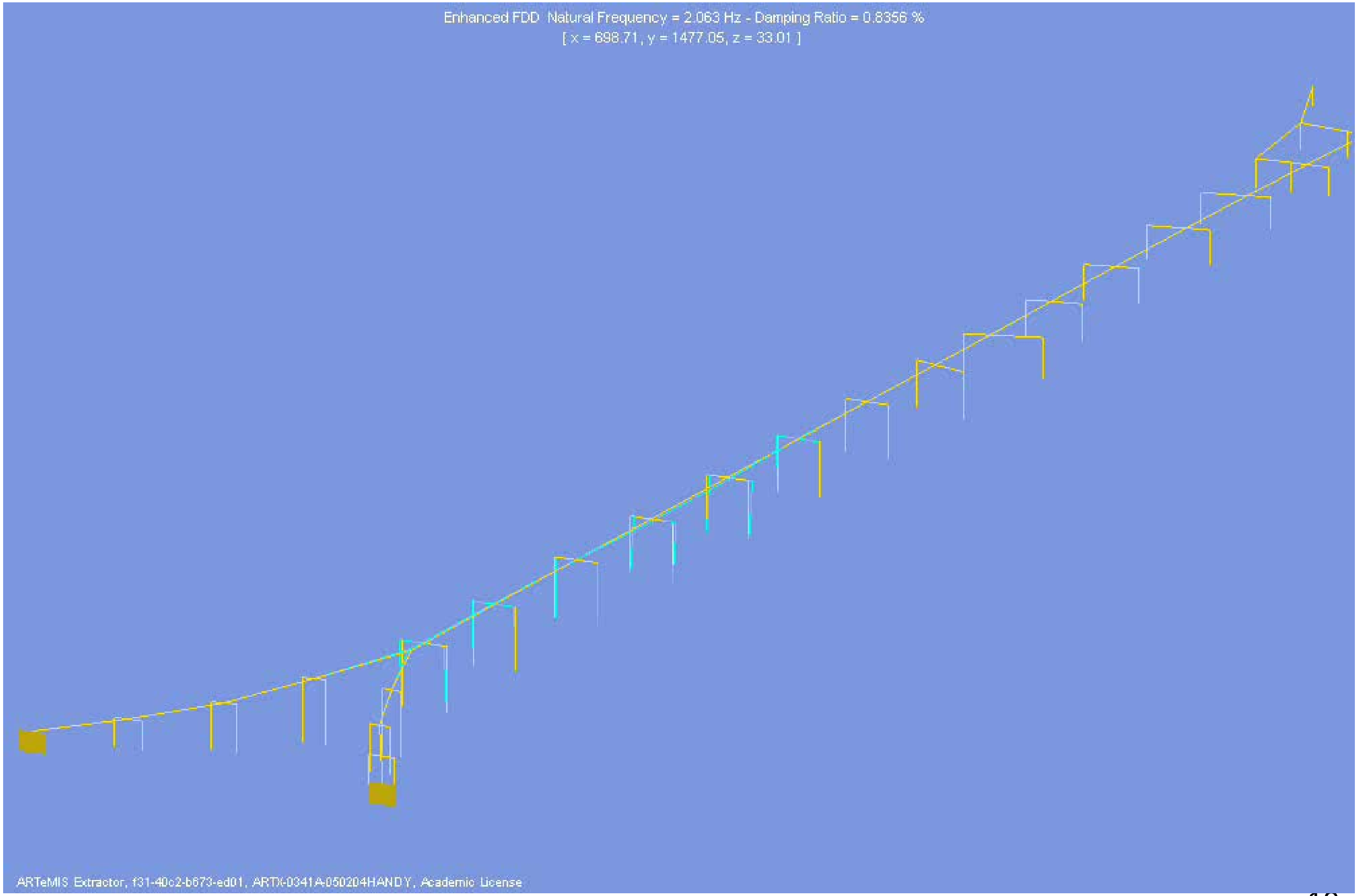
Bridge Mode Animation – 1st



Bridge Mode Animation – 2nd



Bridge Mode Animation – 3rd



Variation of Modal Frequencies vs. Environ. Variables

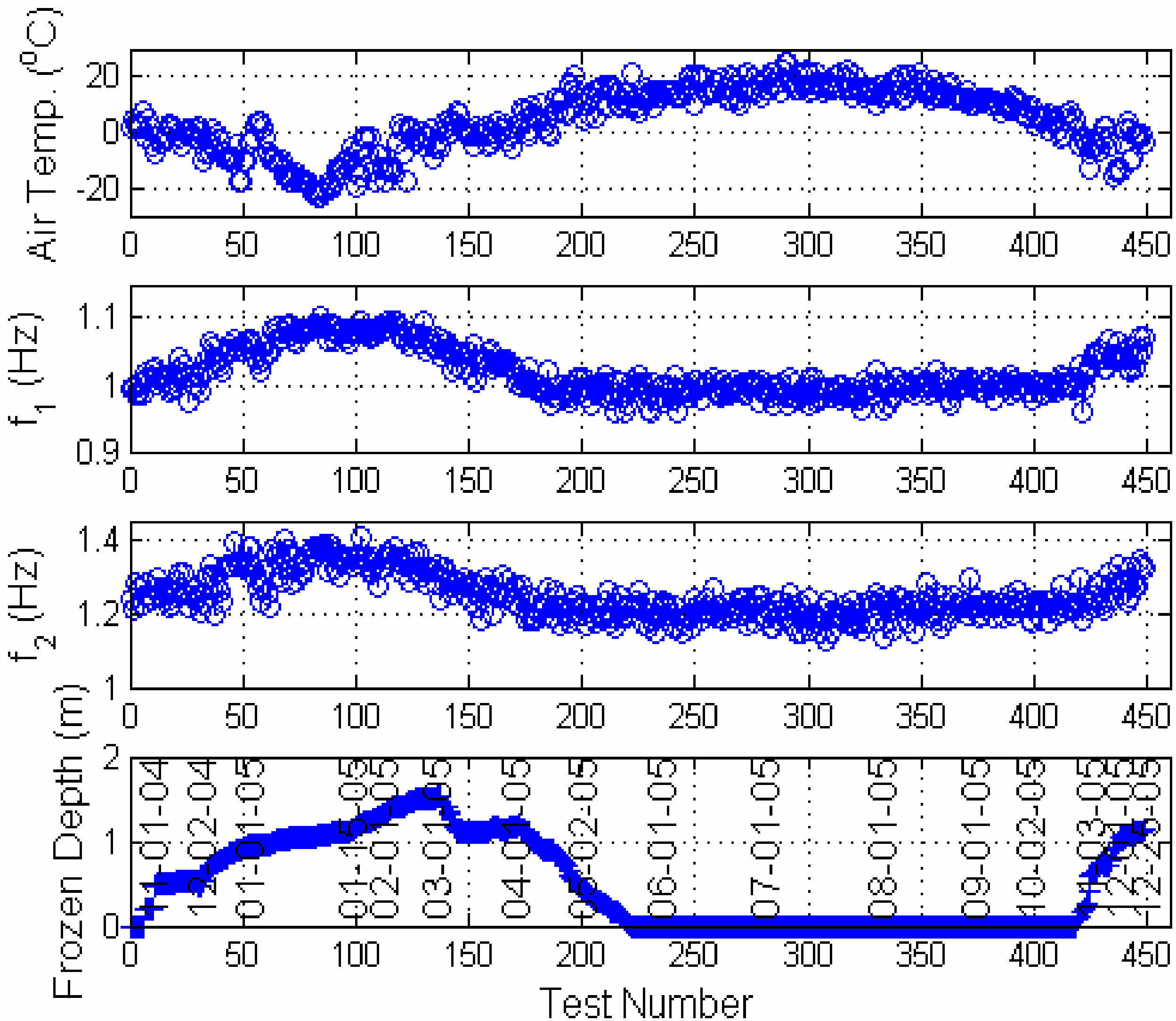
- Air Temperature
- Frozen depth D estimated by Stefan eqn. and verified by GPR testing:

$D = D_F - D_T$

$$D_F\,(\text{ft}) = \sqrt{\frac{48 k_f FI}{L}}$$

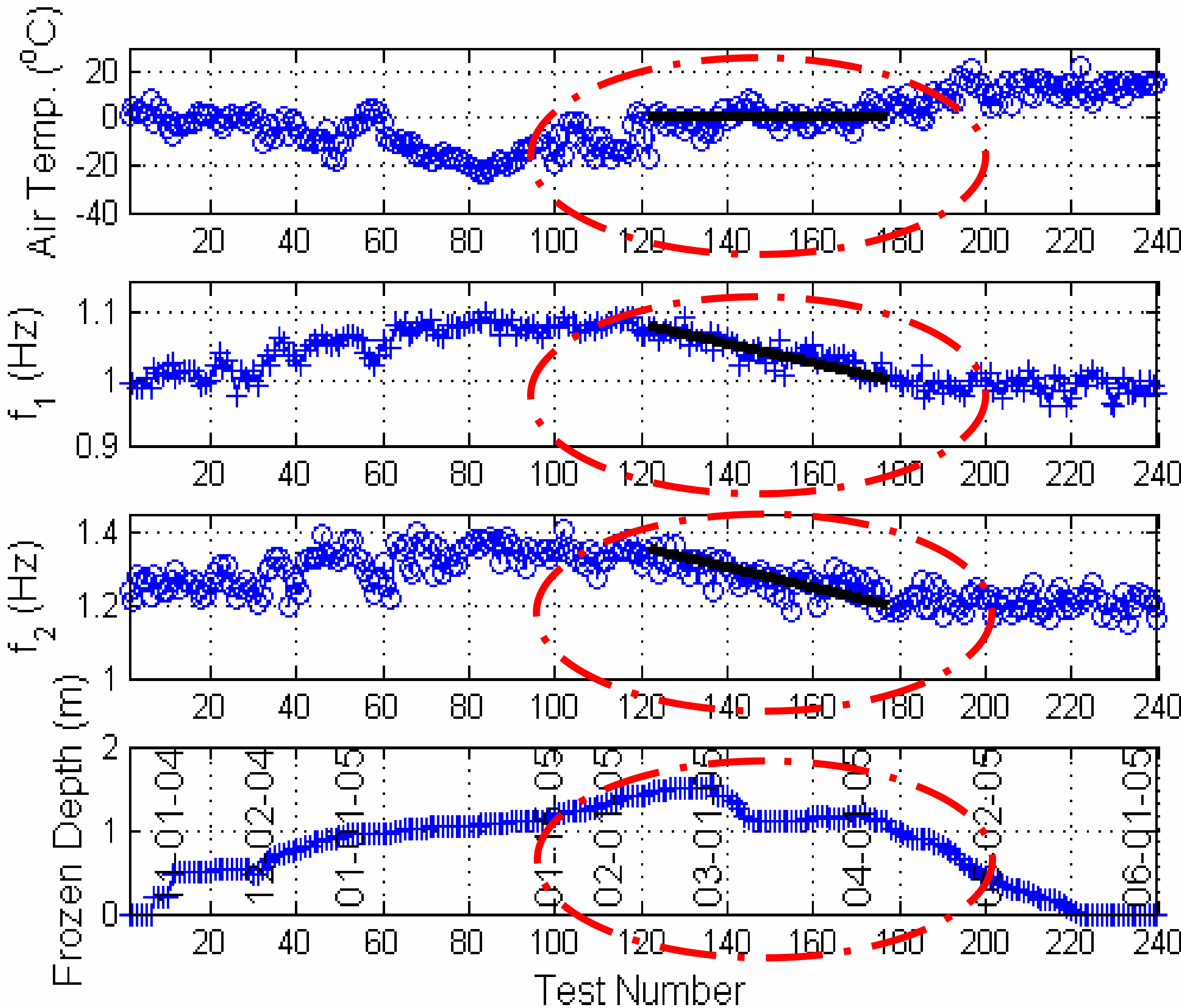
$$D_T\,(\text{ft}) = \sqrt{\frac{48 k_u TI}{L}}$$

- Systematic change (12 %) of structural dynamic properties clearly observed within one year

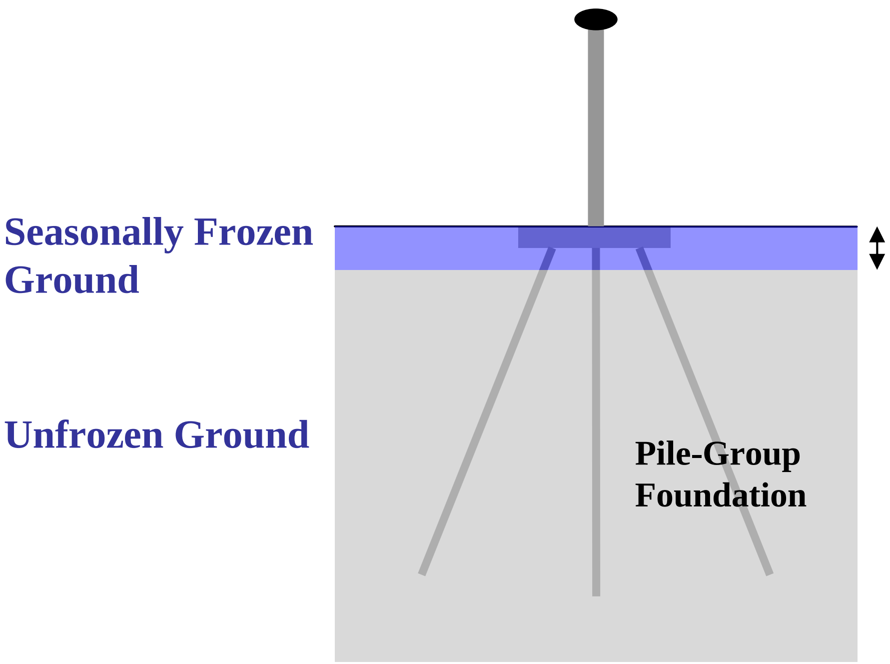


Seasonal Frost Effects on Bridge Dynamic Properties

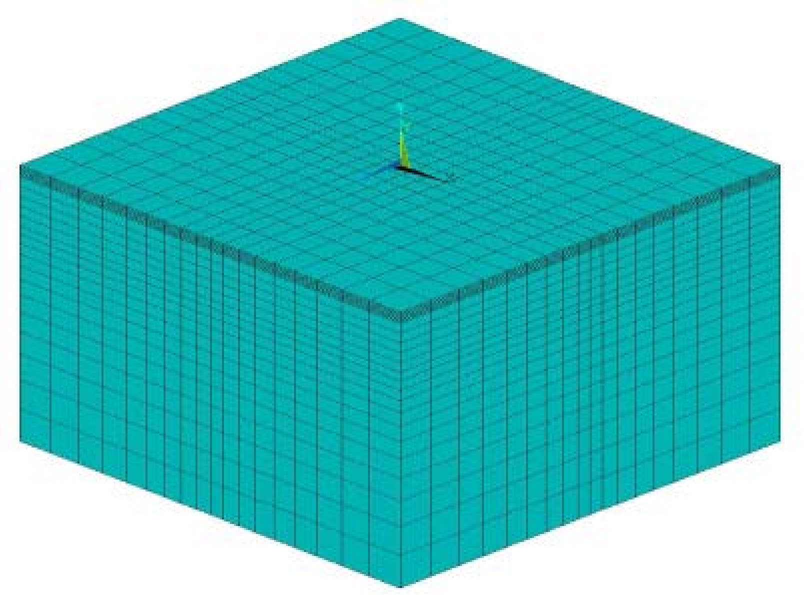
- Primary reason for the change: the seasonally frozen ground.
- Implication to engineering design
  - Design load
  - Failure mode of foundation system



Verification of Seasonal Frost Effects - Method



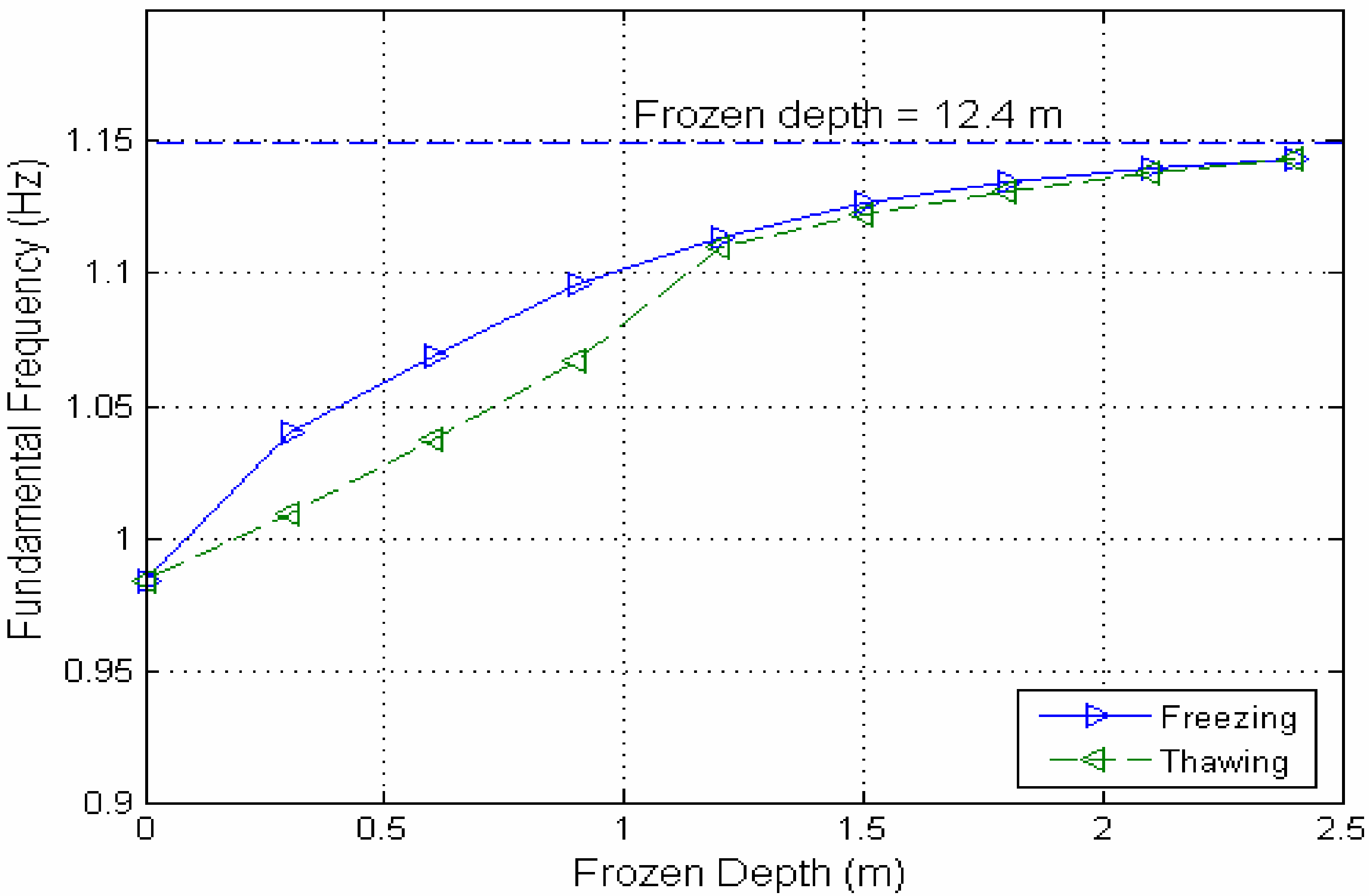
Sketch of a bridge pier/foundation system



Finite Element mesh

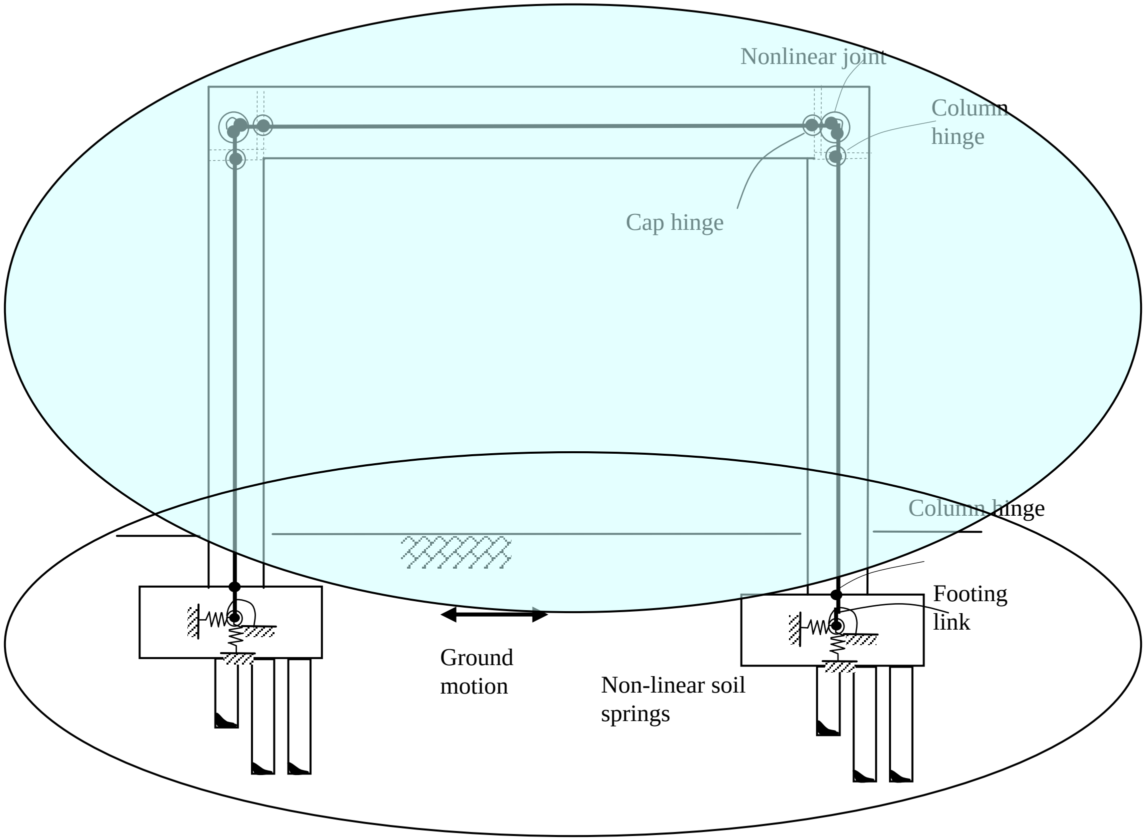
- Verify the effects of seasonal frost on the bridge dynamic properties
- Develop simple numerical models for practicing engineers to apply in design.

Verification of Seasonal Frost Effects - Results



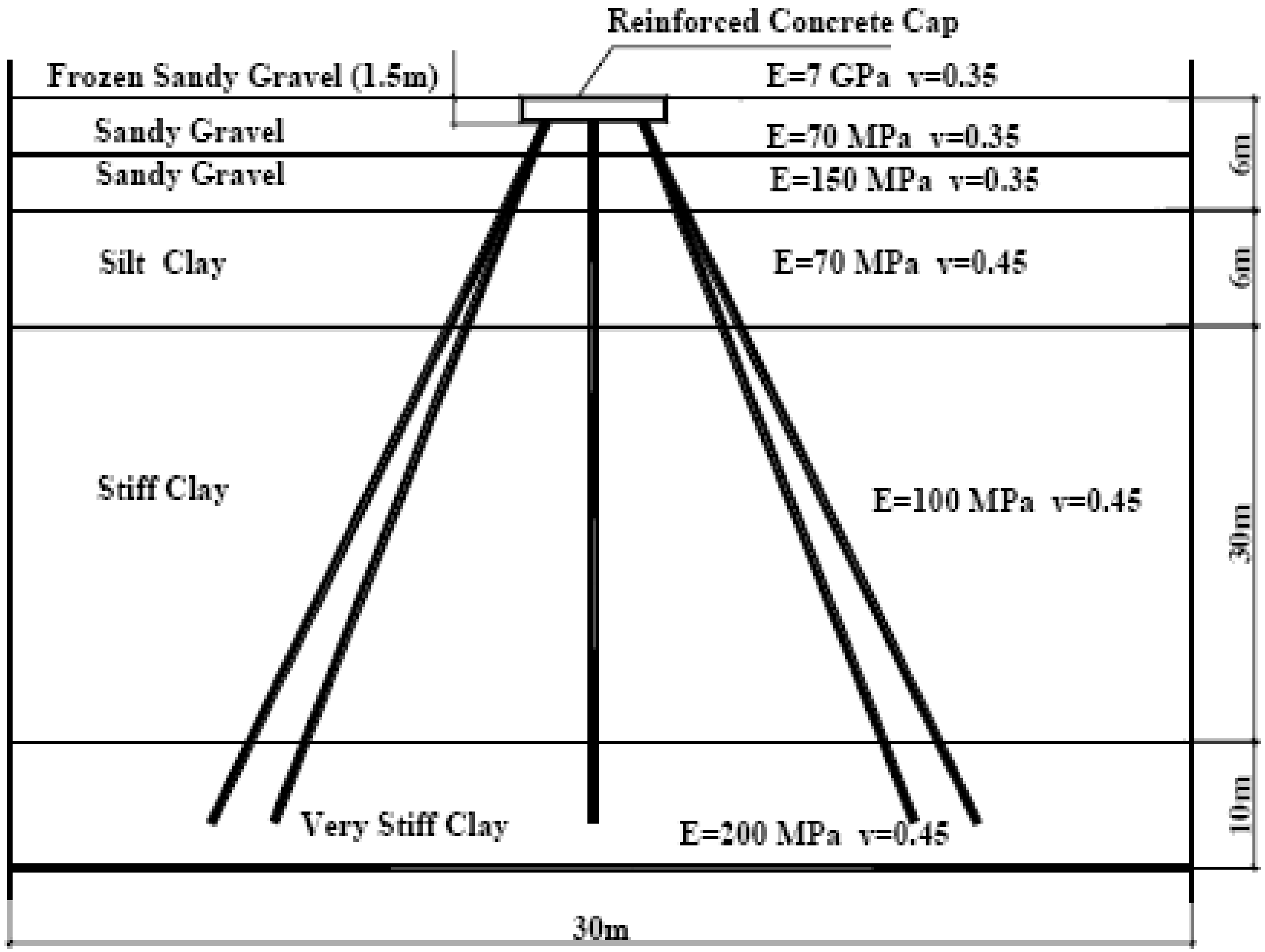
- Good agreement found between observation and FEM; Both show 12% of change when frost depth varies from 0 to 2 m
- System sensitive to freezing of soils at 0-1.5 m, not sensitive to freezing of soils deeper than 2.0 m

Analytical Modeling of Seasonal Frost Effects on Bridge Seismic Behavior



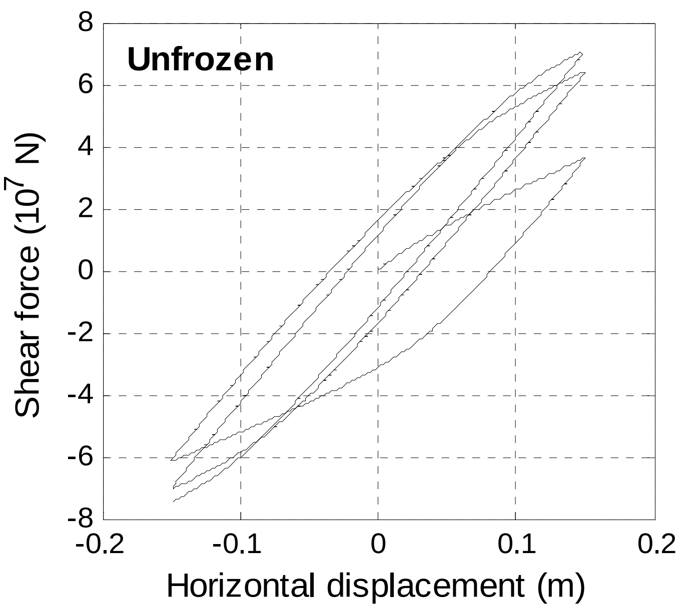
- Two subsystems: the Pile-Soil subsystem & Bridge Bent-Foundation subsystem, to facilitate modeling of structure detail
- Computer modeling: static and push-over analysis

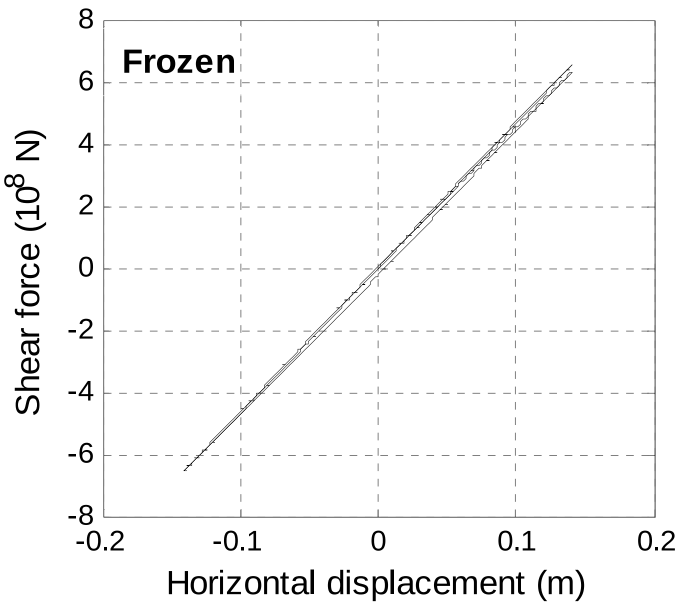
Analytical Model for the Pile-Soil Subsystem



- Model focusing on foundation and soils
- Cyclic analysis to study foundation behavior

Frost Effects on the Pile-Soil Subsystem - Results

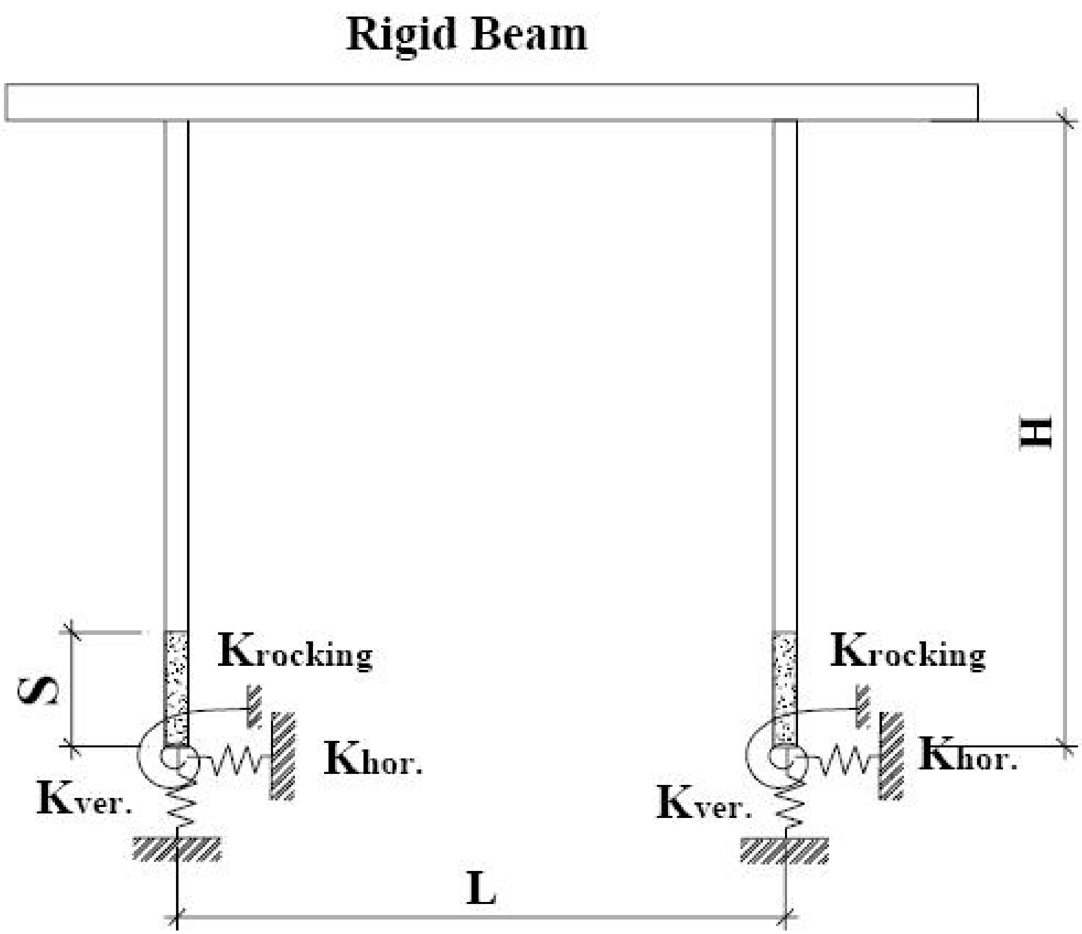




Soil Spring Coefficient	Un-frozen	Depth of frozen soil (m)							
		0.5	Change (times)	1.0	Change (times)	1.5	Change (times)	2.0	Change (times)
$K_{hor.}$ ($\times 10^8$ N/m)	4.84	24.5	**5.1**	39.4	**8.1**	46.6	**9.6**	49.6	**10.3**
$K_{ver.}$ ($\times 10^8$ N/m)	11.5	11.7	1.0	13.4	1.2	15.2	1.3	17.3	1.5
$K_{rock.}$ ($\times 10^8$ N.m/rad)	48.0	78.1	1.6	130.0	2.7	196.0	4.1	237.0	4.9

- Quite different behavior for unfrozen and frozen conditions
- Horizontal stiffness increasing by 10 times

Frost Effects on Bridge Bent – Foundation Subsystem



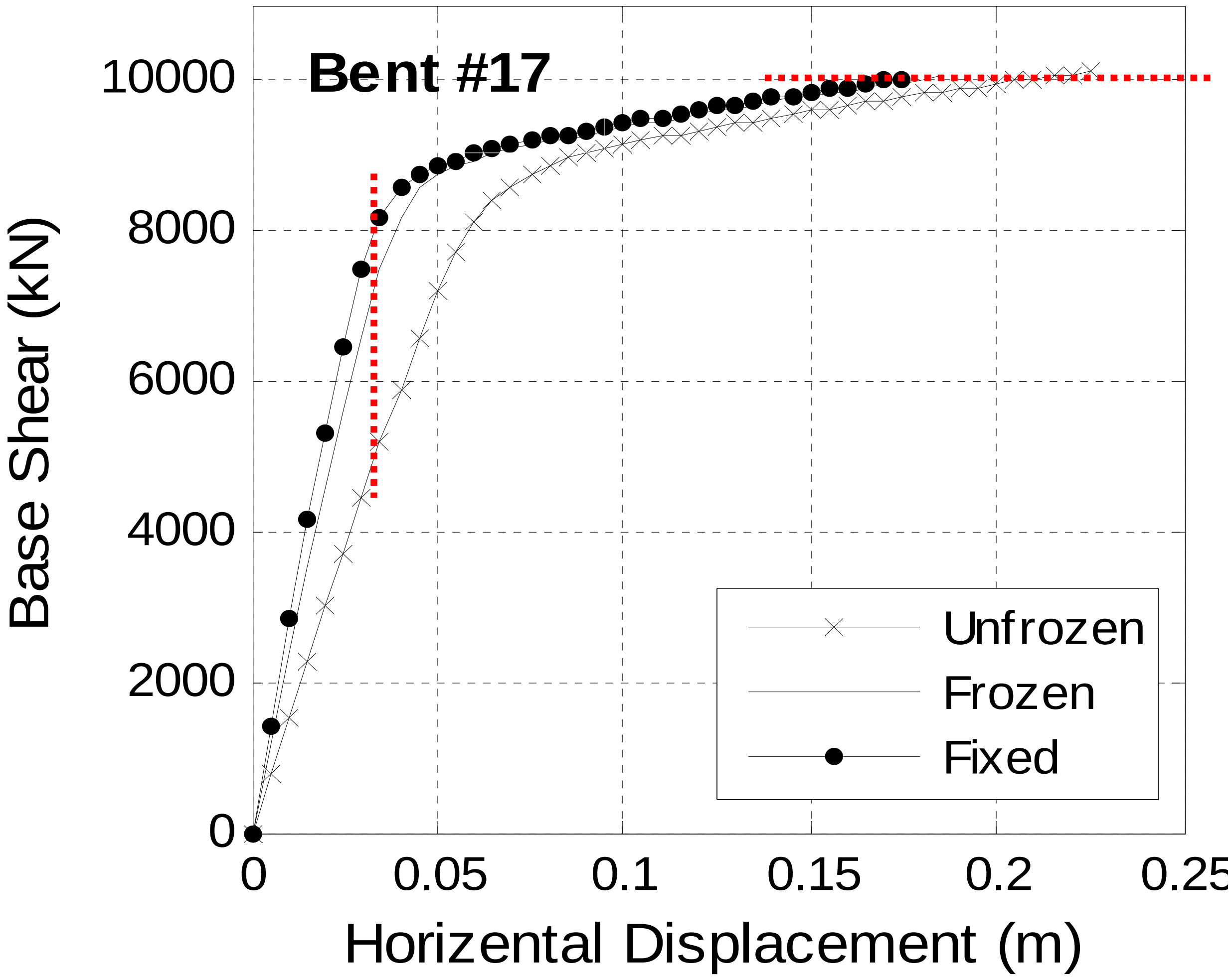
- Model focusing on superstructure detail (hollow column and concrete fill, H/L)
- Modal analysis and push-over analysis

Frost Effects on Dynamic Properties of Bridge Bent - Foundation Subsystem

Bent	H/L	Unfrozen	Frozen		Fixed	
		Frequency (Hz)	Frequency (Hz)	Change from unfrozen	Frequency (Hz)	Change from frozen
#4A	3.33	0.83	0.85	3.3%	0.87	2.4%
#3A	2.34	1.20	1.26	5.0%	1.29	2.4%
#7	1.37	0.99	1.09	10.1%	1.13	3.7%
#2A	1.17	2.13	2.32	8.9%	2.41	3.9%
#13	0.55	1.60	1.90	18.8%	2.04	7.4%
#17	0.48	2.18	2.73	25.2%	3.01	10.3%

- Six typical bents selected for analysis
- Influence to individual bents is different
- Influence increases with increasing overall stiffness
- Fundamental frequency changed by 25%, or 50-60% change in stiffness

Frost Effects on Shear Demand and Lateral Displacement Capacity



- Lateral displacement capacity decreasing by 20%
- Shear demand at yielding increases by 50%

Conclusions from Phase I Study

- Significant variability in modal frequencies is observed. The variations in f_1 is about 12%
- Main environmental variables: *seasonally frozen ground and air temperature*, with seasonally frozen ground being the dominating factor.
- FEM results agree well with the observations. The dynamic properties are sensitive to the freezing of soils at 0-1.5 m deep but not sensitive to soils deeper than 2.0 m.
- Significant impact in the stiffness of the soil-pile system due to the soil freezing observed. The stiffness in the horizontal direction could increase by *about 10 times* compared with unfrozen condition

Conclusions from Phase I Study – Cont’d

- The frozen soil has quite different impact on the dynamic properties of different bents. The maximum increase in frequency is 25%.
- The shear demand increases by 50% under frozen soil condition for Bent #17.
- The ultimate lateral displacement capacity decreases by 20% for Bent #17 under frozen soil condition.
- Future research will focus on more in-depth analysis and proposing design code improvement accounting for the seismic effects of seasonal frost on civil structures

List of Related References

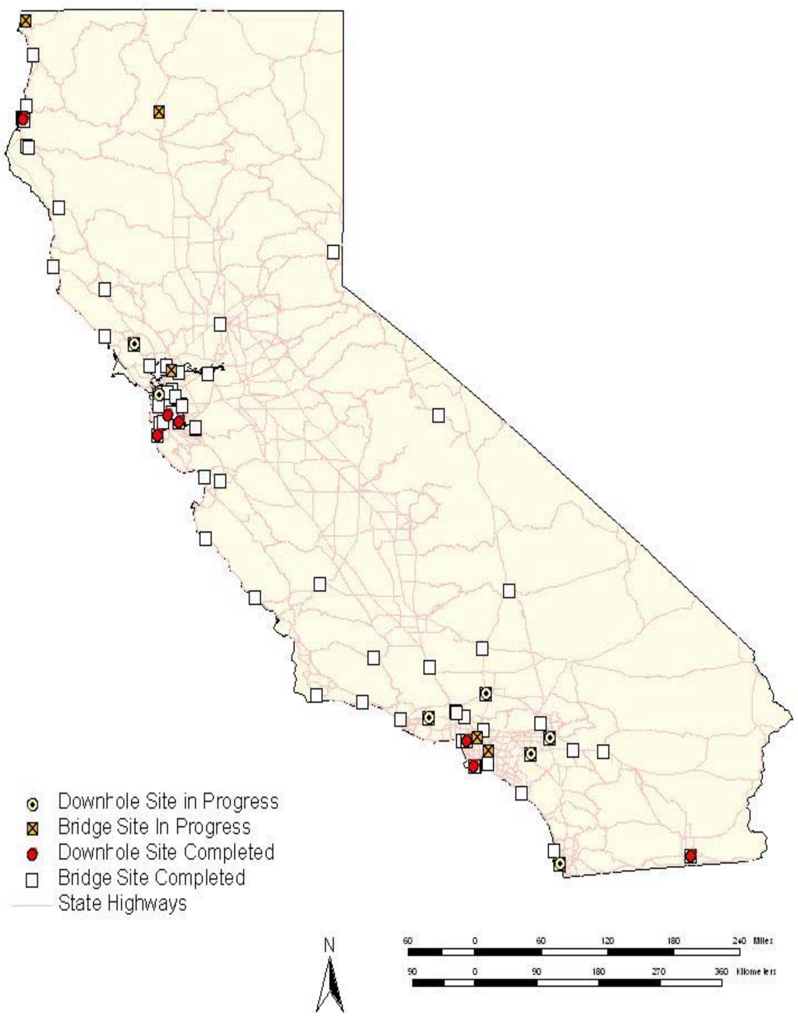
- Xiong, F., **Z. Yang**, and U. Dutta. "Effects of Seasonally Frozen Soil on the Seismic Behavior of Bridge Bent-Foundation-Soil System." Submitted to Structures Congress 2007, Long Beach, CA.
- **Yang, Z.**, Dutta, U., Xiong, F., Biswas, N. and Benz, H. (2006b). "Seasonal Frost Effects on the Seismic Behavior of a Twenty-Story Office Building." Submitted to *International Journal of Cold Regions Science and Engineering*, Sept. 2006.
- **Yang, Z.**, Dutta, U., Zhu, D. and Biswas, N. (2006a). "Effects of Seasonal Frost on Soil-Foundation-Structure Interaction." Accepted for publication in *ASCE Journal of Cold Regions Engineering*, Feb. 2006.
- **Yang, Z.**, and U. Dutta and D. Zhu. Seasonal Frost Effects on the Dynamic Interaction of Soil-Foundation-Structure Interaction System. *Proceedings of 13th International Conference on Cold Regions Engineering*, University of Maine, Orono, Maine, July 23-26, 2006.
- **Yang, Z.** and D. Zhu. Experimental Investigation of the Dynamic Properties of Frozen Soils. *Proceedings of 2005 Joint ASME/ASCE/SES Conference on Mechanics and Materials (McMat05)*, Baton Rouge, LA, June 1-3, 2005.
- **Yang, Z.**, U. Dutta, H. Liu, R. Pratt, E. Marx, N. Biswas, and D. Zhu. Strong-Motion Instrumentation and Structural Health Monitoring of the Port Access Bridge, Anchorage, Alaska. *Proceedings of 2005 Joint ASME/ASCE/SES Conference on Mechanics and Materials (McMat05)*, Baton Rouge, LA, June 1-3, 2005.
- **Yang, Z.**, U. Dutta, M. Celebi, H. Liu, N. Biswas, T. Kono and H. Benz. Strong-Motion Instrumentation and Structural Response of the Atwood Building in Downtown Anchorage, Alaska. *Proceedings of the 13th World Conference on Earthquake Engineering (13WCEE)*, Vancouver, Canada, August 1-6, 2004.

Seismic Instrumentation and Study of Bridges:

A Status Review for California and Alaska

Status of Seismic Instrumentation of California

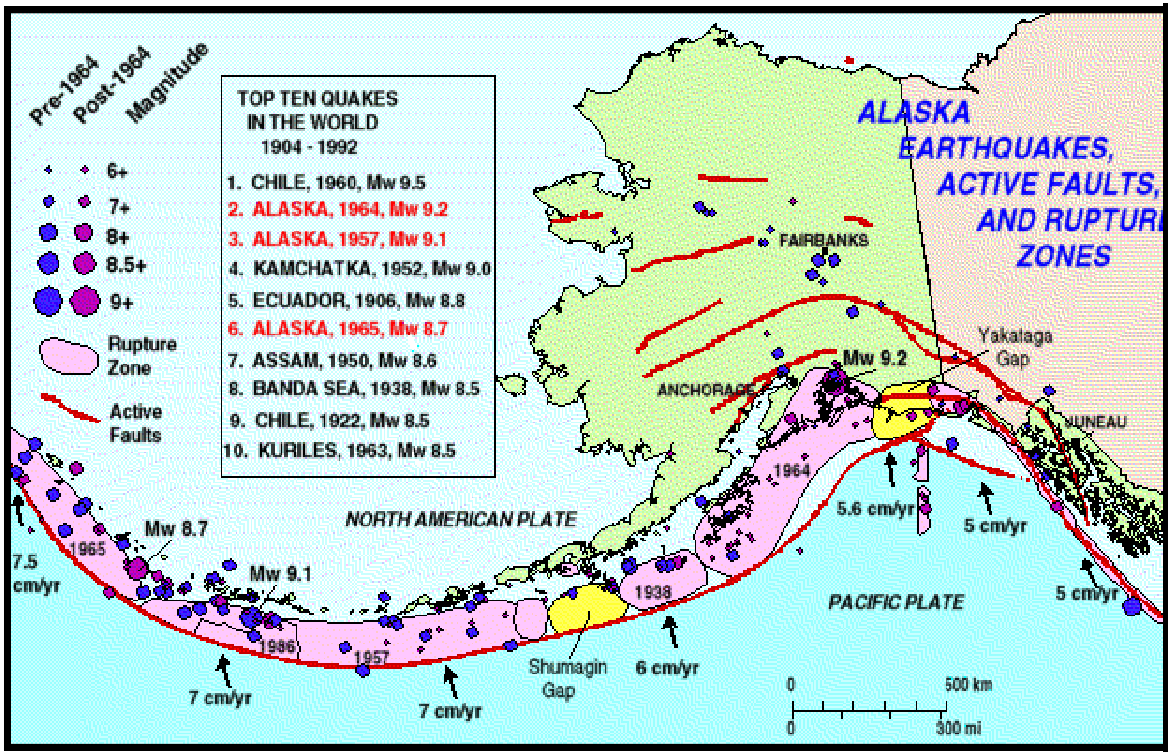
- 65 Bridges State-wide Instrumented by California Division of Mines and Geology (CDMG) and Cal-Trans
- Cost for strong motion sensor installation usually less than 1% of the seismic retrofit cost
- Tremendous amount of data collected from Loma Prieta Earthquake (1989) and North Ridge Earthquake (1994)
- Extremely useful for design, structural health monitoring, and other purposes (e.g. Seismic gates)



Status of Seismic Instrumentation of Alaska

- So far, only one (1) bridge (the Port Access Viaduct) instrumented in Alaska
- Many other bridges are lifeline structures for local community
- Instrumentation and monitoring are important to their safe operation and data collection during strong earthquake is critical for improved design

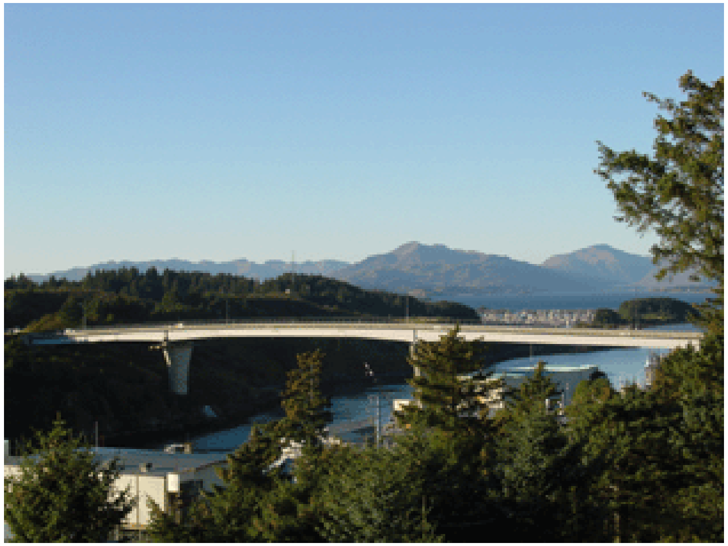
Geological Settings of Alaska and California



- Both are very seismically active areas
- Subduction zone earthquakes causing major threats to the infrastructure in Alaska
- Deep frost penetration in Alaska
- Unique opportunities to collect data for improved bridge design

Unique Opportunities in Alaska - 1
the Kodiak-Near Island Bridge in Kodiak, AK

- 4-span, continuous steel plate girder bridge with a concrete deck, connecting downtown Kodiak with the Near Island
- Seismically upgraded using Friction PendulumTM seismic isolation bearings
- Enabling the existing bridge piers and foundations to elastically resist 0.45g earthquake spectra
- Unique opportunity to collect seismic response data from a retrofitted bridge under subduction zone earthquakes



Unique Opportunities in Alaska - 2
the John O'Connell Bridge in Sitka, AK

- Cable-stayed steel girder truss bridge, 450-ft long span
- Connecting downtown Sitka to Japonski Island where the airport is located
- Offering opportunity for collecting seismic response data from long-span suspension bridge under strike-slip earthquakes

Major Issues for Future Study and A Wish List

- Continuing research into seasonal frost impact on seismic design of bridges
- Recommending bridge design code provisions to account for frost effects
- Funding from State of Alaska and other sources to instrument more bridges
- Funding to support study on the seismic performance of bridges in cold regions