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Seasonally Frozen Soil and its Implications for Alaskan Bridges

by Zhaohui (Joey) Yang and J. Leroy Hulsey

Soil conditions change dramatically from winter to summer in Alaska. As a foundation material, frozen soils are much stiffer than unfrozen soils, and the soil modulus can change by as much as two orders of magnitude as the soil moves from unfrozen to frozen.

In other words, the top five to eight feet of foundation material at a bridge site, which behaves like soil in the summer, acts like concrete in the winter.

Similarly, the interaction between bridge substructures and soils will vary greatly depending on the season, especially during seismic events.

Currently, how soil freezing affects bridge behavior has not been systematically studied, and no design code addresses it. How does the soil-foundation-structure interaction affect bridge response in winter? How does that effect differ in summer? How would a bridge structure designed according to current AASHTO standards respond to a seismic event in winter? Some evidence suggests that a highway bridge would respond to an earthquake quite differently in different seasons.

Project Scope

This two-year project seeks to provide engineers with the necessary tools to appropriately design bridges in order to mitigate or take advantage of these effects.

This project, jointly funded by AUTC and AKDOT&PF, is led by a team of experts drawn from UAF, UAA and Iowa State University (ISU). Project objectives are to understand how seasonally frozen ground affects the seismic response of bridges by conducting experiments and analyses; and to help establish design guidelines for including these effects in bridge seismic analysis, including modeling, analyzing, and detailing of bridge structures.

An Alaska bridge experiencing seasonally frozen soils effects. Photo by Z. Yang.

Research Progress

To coordinate this joint effort, this project is divided into two phases. Phase I focuses on testing and analytical modeling of bridge pile foundations in various soil conditions typical for Alaska. Phase II focuses on field testing and analytical modeling of a short-spanned bridge supported by pile foundations. Since the start of this project last August, much progress has been made in Phase I as well as in preparations for Phase II.

One key issue of the Phase I work is to design a pile configuration that will allow the available instrumentation to handle and collect sufficient data; this requires that researchers first predict pile performance under various soil conditions.

To this end, The UAA research group conducted a "Blind Prediction" using the Three-Dimensional nonlinear Finite Element approach. By "Blind Prediction" we mean that there is no communication with regard to the details of test piles. At the same time, the UAF group used a p-y approach to predict pile performance.

One interesting thing is that when the teams met in March 2008, they found that both had come to the

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The AUTC Newsletter is published semi-annually by the **Alaska University Transportation Research Center**, Institute of Northern Engineering, University of Alaska Fairbanks, to inform readers about our research and outreach activities.

AUTC addresses issues related to research and technology themes as identified in the Highway Research and Technology Report (April, 2002), including the impact of climate change on permafrost, reducing construction and maintenance costs of transportation infrastructure, improving air quality during the winter months, and other measures to address multi-modal issues facing Alaska and the nation's transportation community.

For more information about our research, please contact us:

AUTC
P.O. Box 755900
Room 245 Duckering Building
Fairbanks, AK 99775-5900

Or visit our web site:
http://www.uaf.edu/ine/AUTC

Director
Billy Connor
ffbgc@uaf.edu

Program Assistant
Saundra Jefko
autc@uaf.edu

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UNIVERSITY OF ALASKA FAIRBANKS

Director's Notes

I've often stated that transportation is the lifeblood of any civilization. After World War II, when the United States truly joined the world economy, our reliance on freight rapidly increased. At the same time we became a mobile society, and the nation's transportation infrastructure also expanded rapidly.

In the past, developing transportation infrastructure was the purview of engineers, who focused on cost, performance and economic impact. This began to change in the mid-twentieth century when we became aware of how transportation impacted our social fabric. Environmental impacts became a crucial component of the planning and design process. Today, climate change, wildlife habitat connectivity, and congestion have become critical issues.

The issues surrounding transportation have become so complex that no one discipline or organization can address them successfullly. We can no longer afford to research individual issues in an isolated environment.

All of us are stakeholders in our transportation systems. We all have needs, desires, and knowledge which can improve the effectiveness of our transportation system while minimizing its adverse impacts. Our best practice is to take advantage of this knowledge, forming close partnerships with transportation agencies (both local and national), industry and the public. As UTCs, we must look beyond our own self-interests and work together to meet the diverse, complex needs of our nation as a whole.

This newsletter is dedicated to our partners at the University of Alaska Anchorage (UAA) and the University of Alaska Southeast (UAS). Each of the three University of Alaska campuses bring their own expertise and talents to the AUTC partnership.

The School of Engineering (SOE) at UAA under the leadership of Dean Rob Lang provides expertise and talent in a number of fields, including structures, geotechnical, coastal engineering, geomatics, hydrology, and materials. I certainly appreciate the efforts of Dr. Jang Ra, our Associate Director on the UAA campus. He provides local support for AUTC.

UAS, the smaller of the three campuses and primarily a teaching campus, also is acting on a strong interest in transportation research, primarily from the environmental and the social vantage. Dr. Pat Brown, the AUTC Associate Director on the UAS campus and the most recent to join our ranks, provides our link to the southeast. Dr. Brown is working with UAA and UAF to establish a program that allows students to take the first year of their engineering curriculum in Juneau, then move to either UAA or UAF to complete their engineering education. In the future we hope to expand this to a two-year program.

The lead article is an excellent example of cooperation between multiple campuses. Each researcher brings expertise to the problem of seismic soil structure interaction in frozen ground. Yang (at UAA), Hulsey (UAF) and Sritharan (Idaho State University) are combining their efforts to reveal new, unanticipated structure reactions during earthquakes that occur when even just a few inches of seasonal frost are present.

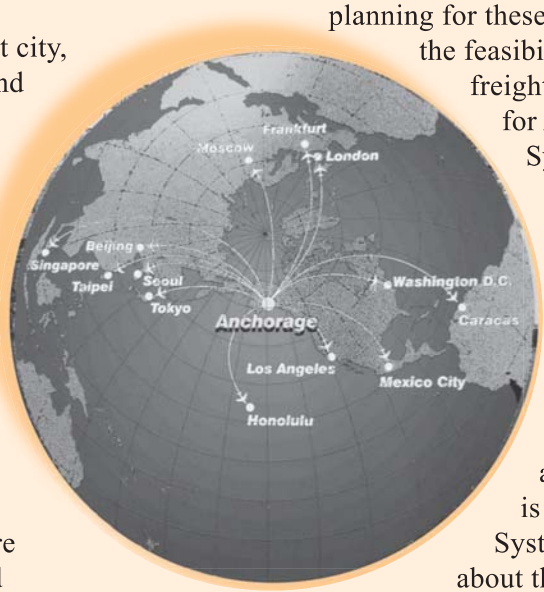
One last thought: Partnerships trump competition every time.

University of Alaska Anchorage: AUTC Pulse Point for Urban Transportation Research

In this third year of RITA support, UAA is working to build its capacity for conducting research in urban transportation. UAA researchers are contributing to five outreach and research projects in areas ranging from soil technician training to seismic research in support of bridge design.

With the help of AUTC funding, UAA has established a permanent transportation faculty position in the School of Engineering. This position will strengthen the transportation expertise available to Alaska, particularly in materials research.

UAA, located in Alaska's largest city, is at a confluence of people, goods, and services as they enter and leave the state. Its researchers have access to a wide range of environmental areas, where the climate can range from maritime to sub-arctic, including both wetland and mountainous terrain.



Toward the Future

While researchers like Zhaohui Yang (see front page story) are providing vital information for improving Alaska's road infrastructure now, other faculty are looking toward the future, and a wide range of transportation opportunities.

In the coming years, notes Associate Director Jang Ra, "Alaska's strategic location will make it an important site for moving goods and people all over the world."

The Alaska Department of Transportation and Public Facilities envisions Anchorage as the major center for intermodal transportation, and UAA intends to be the center for intermodal transportation research.

Ra points to the Ted Stevens Anchorage International Airport as one good indicator of this growth. A jet flying out of TSAIA can reach 95% of the industrial world within 9 air hours, and TSAIA serves as a refueling point for 90% of Asian-North American cargo jet traffic. Ra believes this phenomenal growth trend in air transport will continue, and may also extend to surface transport modes, such as a natural gas pipeline running from the North Slope to the Lower 48 states.

There is also a good possibility that the much-discussed Northern Sea Route will become a viable shipping lane as more of the Arctic ice melts.

A Wide Network of Expertise

UAA's Engineering, Science and Project Management Graduate Department has lead the way in planning for these changes. ESPM Staff researched the feasibility of developing an intermodal freight monitoring system based on ITS for Alaska. Intelligent Transportation Systems (ITS) use information, communication and electronic technologies to solve transportation problems. Sponsored by the Alaska Department of Transportation & Public Facilities in 2001, the PAYLOAD project identified possible application areas and the infrastructure necessary to those applications. Topping this wish list is an Alaskan Information Technology Systems Research Center. To learn more about this project, visit: soe.uaa.alaska.edu/espm/Payload/.

UAA engineers are adept at partnering with other disciplines at the university. One good example is the College of Business and Public Policy Logistics and Supply Chain Department, which conducts research in related areas and trains logistics specialists.

One 2008 AUTC project will draw on their expertise in Radio Frequency Identification (RFID) to seek out possible efficiencies in freight movement and construction materials. To learn more about this project, contact UAA's Oliver Hedgepeth at afwoh@uaa.alaska.edu.

Photo captions: Top right: Dr. Jang Ra, AUTC Associate Director at the University of Alaska Anchorage. Photo by K. Hansen.

Middle: This map depicts Alaska's potential as a world hub for intermodal transportation of energy, goods, and people. Graphic courtesy of the UAA PAYLOAD Project.

AUTC Associate Director for the UAS campus, Dr. Patrick Brown. Photo courtesy of UAS Arts & Sciences staff.

University of Alaska Southeast: Launching a New Program for Young Engineers

From robotic mini-snowmobiles to discussions on sustainable energy and nuclear awareness, the University of Alaska Southeast brings its own distinct flavor to the AUTC partnership.

UAS is an open-enrollment public university serving a diverse student body of just over 5000. Roughly 3800 students attend the main UAS campus in Juneau. UAS promotes student achievement and faculty scholarship, lifelong learning opportunities, and quality academic programs. This year UAS set a new record: 348 graduates took degrees for the 2007-08 academic year.

UAS provides extensive expertise in such areas as landscape analysis, environmental science, biology, and the social sciences – all key areas to planning modern transportation systems – to other AUTC researchers.

In the future, Alaska can look to UAS as a new source of engineers, as well.

Growing a New Program

This fall the Juneau campus will launch a new program, a pre-engineering certificate with emphasis areas in Computer Systems, Electrical, and Mechanical Engineering. These pre-engineering courses will be taught on-site. “We are very pleased to offer this new option for students to begin a degree program in Engineering by taking their first year of classes at UAS,” said Patrick Brown, Dean of Arts and Sciences and AUTC Associate Director for UAS.

After the first year, students will transfer to larger programs, such as those available at UAA or UAF, to continue an engineering degree. According to Brown, this program was designed to help address an expected shortage of engineers in Alaska.

The new curriculum will be guided by the UAS Engineering Advisory Board, which met in early May to celebrate UA Board of Regents’ approval of the program. The committee also asked for input and support from the local engineering committee. “We see our role to prepare students to enter a bachelor’s program at a higher level,” said former UAS Provost Robbie Stell. Regent Carl Marrs believes the program will help retain students who might otherwise drop out at the challenging beginning stages of larger engineering programs.

The Future

The next step for the new program is to build its infrastructure. A search to appoint a faculty position is underway.

Dr. Matt Heavner, UAS faculty and chair of the search committee, recently visited with faculty and department chairs of engineering programs at UAF and UAA to ensure course transferability, and to ask for advice on developing curriculum and recruiting strategies for students. UAS will begin by offering Engineering Practices (ENGR-151) in the fall. In addition, faculty and staff are producing a student handbook and a website tailored to the new program; both will be published in the fall.

To learn more about this new program, vist the UAS School of Arts & Sciences web site (www.uas.alaska.edu/artssciences/).

Below: The UAS Juneau campus is located in Alaska’s beautiful capital city. The campus enjoys the maritime climate of the southeast “panhandle”. The Mendenhall Glacier is in clear view of the main campus. Photo by Todd Paris, UAF Marketing and Communications.

New Research Projects in the Pipeline

2008 Project Update

AUTC invited 16 proposals into the Phase Two process of our second request for proposals. Of these 16, AUTC selected 10 for funding. These top ten represent $1.1 million in new research funding.

AUTC also responded to the AKDOT&PF Needs Statement by supporting six additional projects with expertise from UAA and UAF. Our website (http://www.uaf.edu/ine/AUTC/AUTCindex.html) has a complete listing of all AUTC projects.

This spring, AUTC elected two small grant ideas for Rapid Response Funding.

Professor Ming Lee, UAF, is working with Washington State University Professors Shane Brown and Shihui Shen, to develop and implement a course module in highway geometric design; this project will ultimately lead to an online learning program. They hope to test the module by the summer of 2009.

Professor Jing Zhang and student Michael Golub are working on a "Feasibility Study of Electric Cars in Cold Regions." One of their goals is to make recommendations for integrating electric cars into current transportation systems. They are also testing how well the vehicles will operate in subzero temperatures.

Left: This summer Golub (left) offered a workshop on converting a gas-powered car to use electric power supplied by batteries. Here Golub checks battery voltage while student Matt Balazs watches.

Photo by K. Hansen.

Seasonally Frozen Soil (continued)

same conclusions regarding some key aspects of pile configuration.

Figure 2 *(below)* shows the lateral load versus the lateral deflection predicted by the UAA group for the same pile under unfrozen and frozen soil conditions. The overall stiffness of the pile changes significantly when soils freeze seasonally. For example, for a lateral load of 18,000 lbf (80 kN), the deflection of the pile will decrease from more than 5" (5.6 cm) to less than 2" (4.5 cm) under frozen conditions. The depth at which the maximum bending moment occurs, which corresponds to the location of plastic hinge zone, will move upward substantially, from about 2D in unfrozen conditions to less than 1D in frozen conditions.

Short-term Action List

Since April, the team has selected a site for pile testing and finalized the pile configuration based on their prediction results, available testing facilities, and advice from the research teams and technical advisors. Next steps include:

- ► Finalizing an instrumentation plan for pile testing and full-scale bridge experimentation
- ► Obtaining a permit from AKDOT&PF for full-scale bridge experiments
- ► Procuring instrumentation for pile and bridge testing
- ► Beginning sensor installation on the selected bridge

The implementation process is in full swing this summer, and the majority of the field construction work will be completed by the end of August, with the experiments continuing through the winter to the end of next summer.

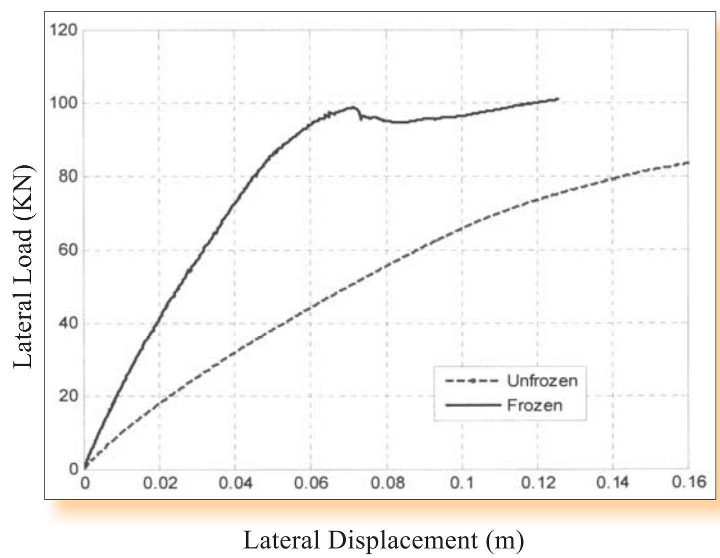


Figure 2. Lateral load vs. lateral deflection for steel pipe pile under unfrozen and seasonally frozen soils. Graph by Z. Yang.

The Life of a Bridge

by J. L. Hulsey

The recent collapse of the I-35W Bridge in Minneapolis, Minnesota was a harbinger of things to come, if we don't find a way to better understand how our transportation infrastructure ages.

Departments of Transportation across the nation, as well as many legislatures, are aware that many bridges in this country suffer from structural issues – some only minor, some not. In the face of budget restrictions and scarce human resources, these problems are getting worse, and at the moment, we have no reliable way to know when a bridge reaches the end of its working life – before it fails.

Bridges are like human beings; each has a given lifespan and each is different. Consider that a person goes to the doctor and says "my arm hurts." The doctor focuses on the problem, diagnoses it based on the evidence, and helps the patient either heal or adapt. But what if there is no clear sign of illness? Or if no doctors are available? If a more or less healthy person asks, "How long do I have to live?" the best a doctor can do is make an educated guess.

The same can be said if you ask a structural engineer how long a given bridge will be able to carry its load. We often say bridges have a 50 year life, but this is just a guess, and 50 is an arbitrary number that doesn't take into account the day-to-day life of the bridge and the stresses it undergoes. For example, consider a bridge designed to carry normal traffic such as cars and trucks. Every day, this bridge carries both in good and adverse weather conditions. Weather causes materials to deteriorate, and subsequently, the structural strength decreases with time; every day the structure experiences some level of damage and its service life gets a little shorter.

In addition to weather, other factors cause damage, including vehicle-to-structure collisions, heavy trucks that exceed design load (such as some truck crossing the bridge late some night when it is very cold and the material is brittle). This minimal but irreversible damage accumulates until the bridge fails, sometimes disasterously, as it did in Minneapolis.

Bridges in the United States need an army of engineers to systematically examine and diagnose each one, but most governments don't have the funds and expertise to devote to this task. It is imperative that we find a cost-efficient way to check the health of every bridge regularly.

One possibility is to develop sensors that can be incorporated into a bridge to collect data on such things as strains, stress threshold, crack locations, and support reactions. Engineers could use this information to understand how much damage might be occurring at a given time in the life of a structure. These "smart structures" could give engineers the capability to monitor bridge health more closely and systematically.

To accomplish this goal will require motivation and – as always – money. Our infrastructure, and our use of it, continue to grow, but the resources devoted to maintaining it keep shrinking. If we don't change this trend soon, we'll have a nationwide health crisis, both for bridges and the people who must cross them.

Top right: J. Leroy Hulsey. Photo by Kala Hansen. Bottom Left: AKDOT&PF personnel remove decking from the E.L. Patton Bridge, which crosses the Yukon River. Middle: Close-up of wear to asphalt and wood bridge decking. Both photos by Zach Jerla.Right: Bridge support under the E.L. Patton Bridge. Photo by Mikhail Kanevskiy.

AUTC Contributes to the Ninth International Conference on Permafrost

by Sandra Boatwright

AUTC researchers and staff joined researchers from all over the world in making a success of the Ninth International Conference on Permafrost, hosted by UAF this year, June 29 - July 3. NICOP participants focused on developing a comprensive view of the thermal, ecological, and engineering state of permafrost throughout the globe.

Our researchers organized field trips, presented material on the challenges of transportation design, construction, and maintenance in permafrost regions and on frozen ground engineering, as well as presenting their work on AUTC projects such as "Preservation of the Alaska Highway."

AUTC also provided outreach funding to reduce conference costs for young investigators and for publishing an extensive set of research proceedings.

Larry Hinzman *(left)*, Chair of the NICOP Program Committee and Director of the International Arctic Research Center, called the conference "a resounding success.... People felt the conference was a good investment of their time."

Larry Hinzman welcomes scientists to NICOP. Seated (l to r) are Mead Treadwell, Chair of the US Arctic Research Commission; Brian Rogers, UAF Interim Chancellor; Larry Hartig, Commissioner for Alaska's Department of Environmental Conservation; and Douglas Kane, Chair for the local NICOP Planning Committee and Director of UAF's Water & Environmental Research Center. Photo by Todd Paris, UAF Marketing and Communications.

Alaska Transportation Research Center
University of Alaska Fairbanks
P.O. Box 755900
Fairbanks, Alaska 99775-5900

America's Arctic University
UAF
University of Alaska Fairbanks