Final Report for Period: 09/2010 - 08/2011
Submitted on: 07/06/2012
Principal Investigator: Rix, Glenn J.
Award ID: 0530478
Organization: Georgia Tech Research Corp
Submitted By:
Rix, Glenn - Principal Investigator
Title:
NEESR-GC: Seismic Risk Mitigation for Port Systems

Project Participants

Senior Personnel

Name: Rix, Glenn
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: DesRoches, Reginald
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Erera, Alan
Worked for more than 160 Hours: Yes
Contribution to Project:
Dr. Erera is responsible for developing port operations models that to estimate throughput given different damage/repair states for port facilities.

Name: Werner, Stuart
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Bostrom, Ann
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Boulanger, Ross
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Boulanger participates in the planning of geotechnical centrifuge tests to evaluate liquefaction remediation techniques at the UC-Davis NEES equipment site.

Name: Gregory, Robin
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Gregory is responsible for planning and organizing panels and workshops to obtain input from a variety of port stakeholder groups on perception of seismic risks and port performance objectives.

Name: Roeder, Charles
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Roeder is responsible for planning and performing tests to evaluate alternative pile configurations and pile-deck connection details to improve the seismic performance of pile-supported marginal wharves.

Name: Lehman, Dawn
Worked for more than 160 Hours: No

Contribution to Project:
Dr. Roeder is responsible for planning and performing tests to evaluate alternative pile configurations and pile-deck connection details to improve the seismic performance of pile-supported marginal wharves.

Name: Taylor, Craig
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Taylor is responsible for seismic risk analysis including the use of stochastic dominance approaches to evaluating alternative seismic risk mitigation strategies.

Name: Rathje, Ellen
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Rathje is responsible for evaluating the effectiveness of prefabricated vertical drains as a liquefaction mitigation technique using the University of Texas and UC-Davis NEES equipment sites.

Name: Gallagher, Patricia
Worked for more than 160 Hours: Yes
Contribution to Project:
Dr. Gallagher is responsible for evaluating the effectiveness of coloidal silica grout as a liquefaction mitigation technique using the University of Texas and UC-Davis NEES equipment sites.

Name: Assimaki, Dominic
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Assimaki is responsible for developing numerical models of pile-supported wharves in liquefiable soil.

Name: Kausel, Eduardo
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Kausel is responsible for developing numerical models of pile-supported wharves in liquefiable soil.

Name: Whittle, Andrew
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Whittle is responsible for developing soil constitutive relationships to use in numerical models of pile-supported wharves in liquefiable soil.

Name: LaFave, James
Worked for more than 160 Hours: No
Contribution to Project:
Dr. LaFave is responsible for collaborating with Drs. Roeder and Lehman to perform full-scale tests on pile-deck connections at nees@UIUC.

Name: Leon, Roberto
Worked for more than 160 Hours: No
Contribution to Project:
Dr. Leon is responsible for performing tests at nees@Buffalo to investigate the dynamic response of container cranes.

Post-doc

Name: Yang, Walter
Worked for more than 160 Hours: Yes
Contribution to Project:
Dr. Walter Yang is responsible for developing numerical simulation models in OpenSees for the wharf structures being studied on this project. Dr. Yang is also investigating coupling between the wharf and crane structures and developing preliminary fragility

relationships for wharf structures.

Name: Reneckis, Dziugas

Worked for more than 160 Hours: Yes

Contribution to Project:

Conducted planning, analysis, design, fabrication and construction of large-scale structural concrete pile-to-wharf connection hybrid tests in the NEES MUST-SIM facility.

Graduate Student

Name: Marinucci, Antonio

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Marinucci is reponsible for working with his advisor, Dr. Ellen Rathje, to assist in evaluating prefabricated vertical drains as a liquefaction mitigation method.

Name: Conlee, Carolyn

Worked for more than 160 Hours: Yes

Contribution to Project:

Ms. Conlee is reponsible for working with her advisor, Dr. Patricia Gallagher, to assist in evaluating colloidal silica grout as a liquefaction mitigation method.

Name: Desai, Shivang

Worked for more than 160 Hours: No

Contribution to Project:

Shivang Desai is working with Dr. Craig Taylor at the University of Southern California to review literature on stochastic dominance.

Name: Ak, Aykagan

Worked for more than 160 Hours: No

Contribution to Project:

Graduate research assistant working with Dr. Alan Erera to develop port operations models to support seismic risk analysis

Name: Corral, Gonzalo

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate research assistant working under the supervision of Drs. Andrew Whittle at MIT to investigate the properties of soils treated with colloidal silica grout.

Name: Varun, Varun

Worked for more than 160 Hours: No

Contribution to Project:

Graduate research assistant working with Dr. Dominic Assimaki at Georgia Tech to develop numerical models of soil-structure interaction for pile-supported wharves.

Name: Vytiniotis, Antonios

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate research assistant working with Drs. Andrew Whittle and Eduardo Kausel at MIT.

Name: Jellin, Amanda

Worked for more than 160 Hours: Yes

Contribution to Project:

Working with Drs. Charles Roeder and Dawn Lehman at the University of Washington to evaluate the seismic performance of pile-deck connections.

Name: Kamai, Ronnie

Worked for more than 160 Hours: Yes

Contribution to Project:
Working with Dr. Ross Boulanger at the University of California, Davis to perform centrifuge tests to evaluate the performance of prefabricated vertical drains and colloidal silica grout.

Name: Ausdemore, David

Worked for more than 160 Hours: No

Contribution to Project:
Working with Dr. Ann Bostrom at Georgia Tech on stakeholder interaction aspects of the project.

Name: Spencer, Laura

Worked for more than 160 Hours: Yes

Contribution to Project:
Working with Dr. Glenn J. Rix at Georgia Tech to evaluate the small-strain properties of soils treated with colloidal silica grout.

Name: Ivey, Lindsay

Worked for more than 160 Hours: Yes

Contribution to Project:
Working with Dr. Glenn J. Rix at Georgia Tech to assess the geotechnical conditions at potential field testing sites and assisting the development of the acceptable risk framework.

Name: Kosbab, Benjamin

Worked for more than 160 Hours: Yes

Contribution to Project:
Working with Dr. Reginald DesRoches at Georgia Tech to evaluate the seismic performance of container cranes.

Name: Jacobs, Laura

Worked for more than 160 Hours: Yes

Contribution to Project:
Working with Dr. Reginald DesRoches at Georgia Tech to evaluate potential retrofit methods to improve the seismic performance of container cranes.

Name: Howell, Rachelle

Worked for more than 160 Hours: Yes

Contribution to Project:
Rachelle Howell is a graduate research assistant working under the supervision of Dr. Ellen Rathje at the University of Texas at Austin. She is supported by a Graduate Research Supplement under this project.

Name: Cucura, Jeffrey

Worked for more than 160 Hours: Yes

Contribution to Project:
Jeffrey Cucura is a graduate research assistant working under the supervision of Dr. Patricia Galagher at Drexel University.

Name: Brackmann, Emily

Worked for more than 160 Hours: Yes

Contribution to Project:
Emily Brackman is a graduate research assistant working on pile-related research under the supervision of Dr. Charles Roeder and Dr. Dawn Lehman at the University of Washington.

Name: Liu, Fang

Worked for more than 160 Hours: No

Contribution to Project:
Fang Liu is a graduate research assistant working on implementing stochastic dominance methods for quantitative seismic risk analysis under the supervision of Dr. Craig Taylor at the University of Southern California.

Name: Stringer, Stuart

Worked for more than 160 Hours: No

Contribution to Project:
Developed evaluation criteria for battered piles. Collaborative work on furthering experimental research with PEER and Concrete Technology and PCMAC-supported research efforts.

Name: Guerra, Jesse
Worked for more than 160 Hours: Yes
Contribution to Project:
Conducted planning, analysis and design for large-scale structural concrete pile-to-wharf connection hybrid tests in the NEES MUST-SIM facility.

Name: Caiza, Pablo
Worked for more than 160 Hours: No
Contribution to Project:
Conducted analyses of the large-scale structural concrete pile-to-wharf connection tests from the University of Washington.

Name: Shafieezadeh, Abdollah
Worked for more than 160 Hours: Yes
Contribution to Project:
Responsible for developing OpenSees numerical models of various pile-supported wharf configurations and assisting with the development of fragility models for wharves.

Name: Scharks, Tim
Worked for more than 160 Hours: Yes
Contribution to Project:
Responsible for implementing the survey of port engineers, the logistics for our research with the Port of Oakland, and collaborating on the mental models interview study. He is also lead assistant on the development of the decision model for analysis of the interviews.

Name: Reimann-Garretson, Lori
Worked for more than 160 Hours: Yes
Contribution to Project:
Responsible for the mental models interviews to date. She has also transcribed about half of the interviews, developed the contact list for the port engineers survey, is assisting with the logistics of the remaining group meetings, and will be contributing to the analysis and reporting of the interview results.

Name: Hudson, Rebecca
Worked for more than 160 Hours: No
Contribution to Project:
Responsible for the transcription and analysis of the mental models interviews.

Undergraduate Student

Name: Lindsey, Chris
Worked for more than 160 Hours: No
Contribution to Project:
Mr. Lindsey is a FACES (Facilitating Academic Careers in Engineering and Science) Scholar working with Dr. Reginald DesRoches at Georgia Tech on dynamic response of container cranes. FACES is a National Science Foundation-sponsored effort between Georgia Tech, Morehouse, Emory University and Spelman. Its aim is to increase the number of African-Americans attaining doctorates in engineering and science. The ultimate goal of the FACES program is to alter the 'face' of the engineering and science professoriate, such that it includes a greater number of African-Americans. An essential part of realizing these goals is to motivate African-Americans to enter graduate school. The academic year undergraduate research program is the component of FACES that addresses this need.

Name: Goff, Jason
Worked for more than 160 Hours: No
Contribution to Project:

Mr. Goff is a FACES (Facilitating Academic Careers in Engineering and Science) Scholar working with Dr. Glenn Rix at Georgia Tech on liquefaction remediation techniques. FACES is a National Science Foundation-sponsored effort between Georgia Tech, Morehouse, Emory University and Spelman. Its aim is to increase the number of African-Americans attaining doctorates in engineering and science. The ultimate goal of the FACES program is to alter the 'face' of the engineering and science professoriate, such that it includes a greater number of African-Americans. An essential part of realizing these goals is to motivate African-Americans to enter graduate school. The academic year undergraduate research program is the component of FACES that addresses this need.

Name: Schleiffarth, Lynne

Worked for more than 160 Hours: No

Contribution to Project:

Lynne Schleiffarth is an undergraduate CEE student working on gathering information on berth and crane configurations for use in developing a hypothetical port for illustrative risk analysis under the supervision of Dr. Reginald DesRoches.

Name: Shand, Lamarr

Worked for more than 160 Hours: Yes

Contribution to Project:

Lamarr Shand was an undergraduate student at Rensselaer Polytecnic Institute and participated in the Facilitating Academic Careers in Engineering and Science (FACES) program at Georgia Tech.FACES is a National Science Foundation-sponsored effort between Georgia Tech, Morehouse, Emory University and Spelman. Its aim is to increase the number of African-Americans attaining doctorates in engineering and science. His support was provided by the FACES program.

Name: Stuart, Daniel

Worked for more than 160 Hours: No

Contribution to Project:

Aided in construction of pile test specimens at the University of Washington.

Technician, Programmer

Name: Parks, Jillison

Worked for more than 160 Hours: Yes

Contribution to Project:

Ms. Jill Parks is responsible for developing the project website.

Other Participant

Name: Kano, Seiji

Worked for more than 160 Hours: No

Contribution to Project:

Working with Dr. Ross Boulanger at the University of California, Davis to perform centrifuge tests to evaluate the performance of prefabricated vertical drains and colloidal silica grout.

Research Experience for Undergraduates

Name: Johnson, Linden

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Johnson from Albany State University worked as an REU student with Drs. Reginald DesRoches and Glenn Rix in Summer 2006 to investigate the dynamic response of container cranes and liquefaction remediation methods.

Years of schooling completed: Sophomore

Home Institution: Other than Research Site

Home Institution if Other: Albany State University

Home Institution Highest Degree Granted(in fields supported by NSF): Master's Degree

Fiscal year(s) REU Participant supported: 2006

REU Funding: REU supplement

Name: Koneri, Nathan

Worked for more than 160 Hours: Yes

Contribution to Project:

Nathan Koneri is an undergraduate student at Albany State University, a Historically Black College and University (HBCU) located in Albany, GA. He worked with the project during Summer 2007 while supported by an REU supplement.

Name: Bingham, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Developed and implemented the instrumentation plan for large-scale structural concrete pile-to-wharf connection hybrid tests in the NEES MUST-SIM facility.

Years of schooling completed: Freshman

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Associate's Degree

Fiscal year(s) REU Participant supported:

REU Funding: REU supplement

Organizational Partners

Port of Seattle

The Port of Seattle is our primary case for the study of decision and risk perception research in port systems.

Port of Oakland

The Port of Oakland (POAK) is a second case for the study of decision and risk perception research in port systems.

Ellington Cross LLC

We are working with Scott Ellington of Ellington Cross LLC to plan and conduct the full-scale field test of prefabricated vertical drains and colloidal silica grout at a site near Charleston, SC. Ellington Cross LLC is a soil-improvement contractor and is donating all of the prefabricated drains being used for the test and is installing them.

Manson Construction, Inc.

Mr. Bill Cooke of Manson Construction, Inc. has provided pro bono assistance on construction procedures, costs, and time that are used in developing repair models for pile-supported wharf structures that allow one to estimate the time and cost associated with repairing earthquake-induced damage to these structures.

Pacific Earthquake Engineering Research

The Pacific Earthquake Engineering Research (PEER) Center Ground Motion Selection and Modification Working Group provided valuable data and assistance with selecting a suite of earthquake ground motions for use in developing wharf and crane fragility models.

Southern California Earthquake Center

The Southern California Earthquake Center (SCEC) Seismic Hazards and Risk Analysis Focus Group provided valuable assistance with the selection of a suite of earthquake ground motions for use in developing wharf and crane fragility models.

University of Tokyo

Professor Ikuo Towhata at the University of Tokyo provided facilities, equipment, and personnel to help with performing 1-g shake table tests to evaluate the effectiveness of soils treated with colloidal silica grout to reduce kinematic loading on pile foundations. Professor Towhata also participated in the review and analysis of the data from the tests. Professor Patricia Gallagher from Drexel University and Ms. Laura Spencer from the Georgia Institute of Technology spent several months at the University of Tokyo as part of an IREE supplement to this award.

URS Corporation

Dr. Paul Somerville of URS Corporation provided valuable assistance with the selection of a suite of ground motions for use in developing wharf and crane fragility models.

US Geological Survey

Dr. Nicolas Luco of the US Geological Survey provided valuable assistance with the selection of a suite of ground motions for use in developing wharf and crane fragility models.

Liftech Consultants, Inc.

Mr. Erik Soderberg and Mr. Michael Jordan of Liftech Consultants, Inc. have provided valuable assistance on the design and construction of container cranes and pile-supported wharf structures.

Portland Cement Association

The Portland Cement Association (PCA) has provided financial support via a fellowship to a student at the University of Washington. The fellowship has allowed the scope of research on the seismic performance of pile connections to be expanded beyond that supported by this project alone.

Concrete Technology Corporation

Concrete Technology Corporation has provided pile specimens for testing at the University of Washington and NEES MUST-SIM facility.

Prestressed/Precast Concrete Manufacture

The Prestressed/Precast Concrete Manufacturers Associates of California (PCMAC) have provided pile specimens for tests at the University of Washington and NEES MUST-SIM facility.

Other Collaborators or Contacts

External Advisory Board:
? Tom Armstrong, Georgia Ports Authority
? George Fotinos, Ben C. Gerwick, Inc.
? Susumu Iai, Kyoto University
? Michael Jordan, Liftech Consultants, Inc.
? Tom LaBasco, Port of Oakland
? Bob Maruska, Port of Seattle
? Richard Sanders, Willis Re
? Nathaniel Seeds, APL Limited
? Dick Wittkop, Moffat and Nichol

Pile Advisory Group:
? Bob Harn, Berger/Abam Engineers
? David Pierce, PND Engineers, Inc.
? Tom McCollough, Moffat and Nichol

? Millard Barney, Concrete Technology Corp.
? Farhad Rowshanzamir, Reid Middleton
? Brian Harris, Port of Seattle

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Graduate research assistants Carolyn Conlee (Drexel University) and Rachelle Howell (University of Texas at Austin) were in residence at the University of California Davis to participate in performing geotechnical centrifuge tests with the NEES Equipment Site staff.

In June 2008, graduate research assistants Laura Spencer (Georgia Tech) and Antonios Vytiniotis (MIT) attended the 4th International Conference on Earthquake Geotechnical Engineering in Thessaloniki, Greece.

In August 2007, graduate research assistant Laura Jacobs (Georgia Tech) participated in the NEESit Summer Institute at the University of California at San Diego. During this workshop she learned about the tools that NEESit makes available to NEES researches. She also learned how to format and store data for the NEES repository. During the annual project meeting she presented this information to the other members on the project team.

In August 2007, graduate research assistants Ben Kosbab and Laura Jacobs (Georgia Tech) participated in a research planning meeting with engineers at Liftech Consultants, Inc. in Oakland, CA.

In September 2007, Ben Kosbab and Laura Jacobs (Georgia Tech) participated in the NEESinc shake table workshop in Reno, NV. While there, they learned about the various aspects of the planning process for a shake table experiment.

Graduate research assistants Ronnie Kamai and Carolyn Conlee have presented the results of their research at seminars held at UC Davis in February 2008.

In February 2008, graduate research assistants Ben Kosbab and Laura Jacobs participated in an experiment pre-planning meeting with staff from the NEES@Buffalo Equipment Site in preparation for tests planned for Summer 2008.

In April 2008, graduate research assistants Ben Kosbab and Varun (GT) and Antonios Vytiniotis (MIT) participated in the OpenSees Parallel Computing Workshop at the University of California at Berkeley.

Graduate research assistants Carolyn Conlee (Drexel), Rachelle Howell (UTA), Lindsay Ivey (GT), Ronnie Kamai, (UC Davis), Laura Spencer (GT), and Varun (GT) participated in the conference on Geotechnical Earthquake Engineering and Soil Dynamics IV in Sacramento, CA on May 18-22, 2008. Ronnie Kamie, Laura Spencer, and Varun presented papers during oral breakout sessions.

Ben Kosbab (GT) and Laura Jacobs (GT) participated in the NEESit Road Show at Georgia Tech in July 2008, and learned the details regarding data ingestion into the NEEScentral repository.

During Fall 2008, Dr. Patricia Gallagher (Drexel) and Ms. Laura Spencer (GT) visited the University of Tokyo to conduct 1-g shake table tests to evaluate the effectiveness of soils treated with colloidal silica grout in reducing forces on pile foundations due to kinematic loading.

In October 2008, Ben Kosbab (GT) and Laura Jacobs (GT), along with undergraduate research assistant Lynne Schleiffarth, accompanied Dr. DesRoches and Dr. Leon to the world?s largest container crane production facility owned and operated by ZPMC (in Shanghai, China), where they spoke with ZPMC personnel regarding construction practices and pertinent design details.

Undergraduate student Lynne Schleiffarth (GT) participated in OpenSees Workshop in Berkeley, California.

In May 2009, Laura Jacobs (GT) and Dr. Leon participated in an experiment pre-planning meeting with staff from the NEES@Buffalo Equipment Site in preparation for tests planned for Fall 2009.

Graduate research assistant Varun (GT) will participate in the International Conference on Performance Based Design in Earthquake Geotechnical Engineering (IS Tokyo 2009), Tsukuba, Japan in June 2009.

Graduate research assistants Rachelle Howell (UTA), Antonios Vytiniotis (MIT), and Lindsay Ivey (GT) will particpate in the NEES Annual Meeting in Honolulu, HI in June 2009.

In July 2009, graduate research assistant Antonios Vytiniotis (MIT) attended the NEES Graduate Summer Internship, at UC San Diego.

Outreach Activities:

Graduate research assistant Amanda Jellin (University of Washington) served as a volunteer at the Design Squad event at the Pacific Science Center in Seattle. This is a program covered by the local public television station to increase student's knowledge of engineering.

Graduate research assistant Amanda Jellin (University of Washington) presented a discussion of her work and opportunities in engineering to the Seattle Summit K-12 alternative school.

Professors Reginald DesRoches, Glenn J. Rix, and Alan Erera presented lectures to the Research Experience for Teachers (RET) and Georgia Intern Fellowship for Teachers (GIFT) program on the basics of structural dynamics, geotechnical engineering, and port logistics.

Graduate research assistant Laura Jacobs (Georgia Tech) helped with the RET and GIFT program. She gave a lecture on similitude and how to create models for earthquake testing. Additionally, she provided guidance and advice to the students as they created a 1:50 scale model of a container crane out of wood. She helped them to run their shake table experiments and analyze and understand the data they collected.

Graduate research assistant Laura Jacobs (Georgia Tech) presented information about the NEESR Grand Challenge: Seismic Risk Management for Port Systems research project to a group of Fulton County math and science teachers.

In November 2007, Graduate research assistants Ben Kosbab and Laura Jacobs (Georgia Tech) and other GT students visited an elementary school to encourage lifelong participation in engineering and the sciences.

Graduate research assistant Varun (Georgia Tech) made a presentation on damage caused by soil liquefaction and performed a demonstration using an educational shake table at local elementary school as part of an outreach program organized by Georgia Tech Earthquake Engineering Research Institute (EERI) Chapter.

In November 2008, graduate research assistant Ben Kosbab (Georgia Tech) and other GT students presented to the GT Chinese Student Association in regards to the Sichuan earthquake to increase earthquake understanding and improve awareness and preparedness.

Dr. Ann Bostrom wsa appointed a member of the Applied Technology Council (ATC)-58-1 Project Steering Committee in September 2008.

Dr. Rix was appointed a member of the Applied Technology Council (ATC)-76-2 Project Technical Committee.

Dr. Rix, Dr. Werner, Dr. Kosbab (former GT Ph.D. student), and Mr. Stuart Stringer (University of Washington) presented a one-day short course on 'Seismic Design and Risk Analyses for Container Ports' at the ASCE Ports 2010 technical conference in Jacksonville, FL on April 15, 2010.

A series of three webinars organized by EERI and NEEScomm to present the outcomes of the project in the areas of (1) geotechnical engineering, (2) structural engineering, and (3) seismic risk analysis is in the planning phase for late summer 2012.

Journal Publications

Varun, Assimaki, D., and Gazetas, G., "A simplified model for the lateral response of large diameter caisson foundations", Soil Dynamics and Earthquake Engineering, p. 268, vol. 29, (2009). Published, 10.1016/j.soildyn.2008.02.001

Ak, A. and Erera, A. L., "A nested tabu search algorithm for the berth allocation problem", Transportation Science, p. , vol. , (2009). Accepted,

Taylor, C.E., Rix, G.J. and Liu, F., "Exploring financial decision-making approaches for use in earthquake risk decision processes for ports", Journal of Infrastructure Systems, p. 406, vol. 15, (2009). Published, 10.1061/(ASCE)1076-0342(2009)15:4(406)

Gregory, R., Harstone, M., Rix, G. J., and Bostrom, A., "Seismic risk mitigation decisions at ports: multiple challenges, multiple perspectives", Natural Hazards Review, p. 88, vol. 13, (2012). Published, 10.1061/(ASCE)NH.1527-6996.0000043

Howell, R., Rathje, E., Kamai, R., and Boulanger, R., "Centrifuge modeling of prefabricated vertical drains for liquefaction remediation", Journal of Geotechnical and Geoenvironmental Engineering, p. 262, vol. 138, (2012). Published, 10.1061/(ASCE)GT.1943-5606.0000604

Jacobs, L.D., Kosbab, B.D., Leon, R.T., and DesRoches, R., "Seismic behavior of a jumbo container crane including uplift", Earthquake Spectra, p. 745, vol. 27, (2011). Published, 10.1193/1.3610238

Varun and Assimaki, D., "A generalized hysteresis model for biaxial response of pile foundations in sands", Soil Dynamics and Earthquake Engineering, p. 56, vol. 32, (2012). Published, 10.1016/j.soildyn.2011.08.004

Varun and Assimaki, D., "A non-linear dynamic macroelement for soil-structure interaction analyses of pile-supported waterfront structures", International Journal of Numerical and Analytical Methods in Geomechanics, p. , vol. , (2012). Accepted,

Varun, Assimaki, D., and Shafieezadeh, A., "Soil-pile interaction simulations in liquefiable soils via dynamic macroelements: formulation and validation", Soil Dynamics and Earthquake Engineering, p. , vol. , (2012). Submitted,

Ivey, LM; Rix, GJ; Werner, SD; Erera, AL, "Framework for Earthquake Risk Assessment for Container Ports", TRANSPORTATION RESEARCH RECORD, p. 116, vol. , (2010). Published, 10.3141/2166-1

Yang, C.-S. W., DesRoches, R., and Rix, G. J., "Numerical fragility analysis of vertical-pile-supported wharves in the Western United States", Journal of Earthquake Engineering, p. 579, vol. 16, (2012). Published, 10.1080/13632469.2011.641063

Shafieezadeh, A., DesRoches, R., Rix, G. J., and Werner, S. D., "Seismic performance of pile-supported wharf structures considering soil-structure interaction in liquefied soil", Earthquake Spectra, p. , vol. , (2012). Accepted,

Shafieezadeh, A., DesRoches, R., and Rix, G. J., "Three-dimensional wharf response to far-field and impulsive near-field ground motions in liquefiable soils", Journal of Structural Engineering, p. , vol. , (2012). Submitted,

Scharks, T., Bostrom, A., Reimann-Garetson, L., and Rix, G. J., "Risk decision making and seismic risk preparedness at North American seaports: analysis of a system-wide survey", Earthquake Spectra, p. , vol. , (2012). Submitted,

Burden, L. I., Rix, G. J., and Werner, S. D., "Forecasting earthquake losses in port systems", Earthquake Spectra, p. , vol. , (2012). In preparation,

Lehman, D., Roeder, C., and Stringer S., "Seismic performance evaluation of pile-to-wharf connections", Journal of the Precast Concrete Institute, p. , vol. , (2012). Accepted,

Chiaramonte, M., Arduino, P., Lehman, D., and Roeder C., "Seismic analyses of conventional and improved marginal wharves", Earthquake Engineering and Structural Dynamics, p. , vol. , (2012). Submitted,

Books or Other One-time Publications

Ak, A., "Berth and Quay Crane Scheduling:
Problems, Models, and Solution Methods", (2008). Thesis, Published
Bibliography: PhD dissertation, Georgia Institute of
Technology

Brackmann, E.M., "Performance Tools for Piles and Pile-to-
Wharf Connections", (2009). Thesis, Published
Bibliography: MS Thesis, University of Washington

Vytiniotis, A., "Numerical simulation of the response of
sandy soils treated with pre-fabricated
vertical drains", (2009). Thesis, Published
Bibliography: MS Thesis, Massachusetts Institute of
Technology

Conlee, C.T., "Dynamic properties of colloidal silica soils
using centrifuge model tests and a full-

scale field test", (2010). Thesis, Published
Bibliography: PhD Dissertation, Drexel University

Howell, R., "Centrifuge testing of prefabricated vertical drains for liquefaction remediation", (2008). Thesis, Published
Bibliography: MS Thesis, University of Texas at Austin

Kosbab, B.D., "Seismic performance evaluation of port container cranes allowed to uplift", (2010). Thesis, Published
Bibliography: PhD Dissertation, Georgia Institute of Technology

Marinucci, A., "Effectiveness of prefabricated vertical drains on pore water pressure generation and dissipation in liquefiable sand", (2010). Thesis, Published
Bibliography: PhD Dissertation, University of Texas at Austin

Varun, "A non-linear dynamic macroelement for soil-structure interaction analyses in liquefiable sites", (2010). Thesis, Published
Bibliography: PhD Dissertation, Georgia Institute of Technology

Ak, A. and Erera, A. L., "Simultaneous berth and quay crane scheduling for container ports", (2006). Conference proceedings, Published
Bibliography: INFORMS 2006 Annual Meeting, Pittsburgh, PA

Ak, A. and Erera, A. L., "Simultaneous berth and quay crane scheduling for container ports", (2007). Book, Published
Bibliography: INFORMS 2007 Annual Meeting, Seattle, WA

Assimaki, D. and Varun., "Nonlinear 3D finite element simulations of soil-structure interaction for pile-supported wharfs: Preliminary results from the NEES-GC project on Seismic Risk Mitigation for Port Systems", (2007). Book, Published
Bibliography: Proceedings, International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2007), Rethymno, Crete, Greece

Assimaki, D., Varun, and Gazetas, G., "A simplified model for the linear analysis of transversely loaded caisson foundations", (2007). Conference proceedings, Published
Bibliography: Proceedings, International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2007), Rethymno, Crete, Greece

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Web/Internet Site

URL(s):

http://www.neesgc.gatech.edu

Description:

Main project website: Please see the attached file for a summary of website activity

Other Specific Products

Product Type:

Data or databases

Product Description:

Data from 23 large-scale experiments performed at NEES Equipment Sites at the University of California - Davis, University of Texas at Austin, University at Buffalo, and University of Illinois at Urbana-Champaign have been archived at the NEEShub Project Warehouse at http://nees.org/warehouse/project/86.

Sharing Information:

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Contributions

Contributions within Discipline:

We have implemented all of the necessary features needed to run a free-field analysis of soil embankments underlying pile-supported marginal wharf structures in OpenSees. These include using effective force input on the bottom of the model, creating accurate absorbing boundaries on the sides, and also modeling the small deformation soil-water interaction. We have also implemented a version of the Dafalias-Manzari constitutive soil model to provide more accurate numerical solutions of soil response to dynamic loads, under much more numerically demanding conditions. These conditions involve large stresses that drive the model to critical state, states that are almost completely plastic, and situations with very low effective stresses.

A macroelement has been developed for soil-structure interaction analyses of piles in liquefiable soils that efficiently captures the fundamental mechanisms of saturated granular soil behavior. The macroelement has been coded in the OpenSees platform for integration in soil-structure interaction analyses for this project and disse?mination to the engineering community.

Centrifuge and field test results on soils treated with colloidal silica grout show a reduction in both lateral spreading and settlement compared to untreated soils. Similarly, centrifuge and field tests have showed that prefabricated vertical drains are effective in dissipating

the excess pore water pressures both during and after shaking and reducing the associated deformations. There was a 30-60% improvement in the horizontal deformations and a 20-60% improvement in the vertical settlements. The impact of the PVDs on the excess pore water pressure response was sensitive to the characteristics of the input motion. The drains were more effective in reducing the peak excess pore water pressures when the input motion built up gradually in intensity such that there was more time for the pore water to flow to the drains. However, even during those events in which the pore water did not have time to flow to the drains during shaking, the drains still increased the rate of excess pore water pressure dissipation, prevented the loosening of soil near the low-permeability interface and the associated localized shear deformations, and reduced the overall horizontal and vertical deformations.

Research on the seismic performance of precast/prestressed concrete pile-to-wharf connections at the University of Washington and University of Illinois has resulted in alternative connection concepts and construction practices to better resist damage during earthquakes.

A series of fragility functions were developed for critical wharf components using the results from the two and three-dimensional wharf models. The capacities or limit states used to develop fragility curves were derived from numerical simulations, experimental results, and expert judgment. Fragility analysis of wharf components showed that the relative movement of the wharf with respect to the landside rail is the most susceptible component to slight and moderate damage. However, pile sections are the most vulnerable components of the wharf to extensive damage primarily due to the large deformation demands on the piles at the interface of loose and dense sand layers. Furthermore, fragility curves of the three-dimensional wharf model were found to exhibit larger probabilities of failure compared to the corresponding quantities from the two-dimensional wharf model. This finding is not particularly surprising since longitudinal and torsional responses of the wharf in the three-dimensional wharf model contribute to component responses.

Numerical and experimental simulations of the seismic performance of container cranes indicate that existing cranes, especially stout cranes and those not specifically detailed for ductility, are not expected to achieve the seismic performance objectives of many ports. Due to their potential for damage and/or collapse, container cranes designed using previous and current standards can significantly contribute to port seismic vulnerability. To address this deficiency, performance-based design recommendations are provided which encourage the comparison of demand and capacity in terms of the critical portal deformation, using the derived portal uplift theory to estimate seismic deformation demand. Simplified methods and basic design factors are proposed and demonstrated which enable practitioners to conveniently design for reliable achievement of seismic performance objectives.

We have developed new fast nested tabu search heuristics for simultaneous container port berth and crane scheduling problems, extending the types of port operational problems approximately-solvable in practice. The solution methodologies developed for a variety of berth and quay crane scheduling problems have been extensively tested on representative sample problems, and have shown very strong performance characteristics.

We have developed a more efficient algorithm for the second-order stochastic dominance approach through the use of random walks, a simplified numerical integration procedure, and new electronic technologies.

Contributions to Other Disciplines:

We have proved theoretical results regarding the lower bounds developed for the single and multiple berth scheduling problems, and the simultaneous berth and quay-crane scheduling problem. Each of the lower bounds developed is new to the research literature, and each has

been proven to be computable in polynomial time. In contrast, the exact optimization problems have been shown to be in the NP-hard problem class, and thus it is not likely that polynomial algorithms exist for their solution. Additionally, each lower bound is provably stronger than the well-known linear relaxation bound obtained by relaxing the integrality constraints in the mixed-integer programming problem formulation.

Contributions to Human Resource Development:

A large number of students and others have participated in this project and/or received financial support for their education including:

2 post-doctoral researchers
25 graduate research assistants
8 undergraduate research assistants
6 high school students
2 high school science teachers

Contributions to Resources for Research and Education:

Project team members have contributed to the OpenSees finite element software framework, by improving code and creating new elements. The drain elements have been implemented in the framework to work with quad-up elements. The Dafalias-Manzari (2004) model integration procedure has been improved, in order for the model to realistically predict the Critical State Behavior. Also, a plane strain material wrapper has been created, that allows for any material developed for three-dimensional stress states to be used for two-dimensional plane strain analyses. Finally, a new macroelement for modeling soil-pile interaction in liquefiable soils has been implemented in OpenSees and has been made available for other researchers to use.

Contributions Beyond Science and Engineering:

Current practice for seismic design and retrofit of container port structures typically considers only the seismic performance of the structures themselves. They do not directly consider how damage and downtime of these structures might disrupt the overall port system?s ship handling operations and the regional, national, and even international economic impacts that could result from extended earthquake-induced disruption of a major container port. The research performed in this study focused on developing a framework that allows one to perform a probabilistic analysis of seismic risks to port-wide system of berths comprised of wharf and crane structures and conduct sensitivity analyses that illustrate how port-system risks and losses may be affected by alternative seismic upgrade and port repair strategies.

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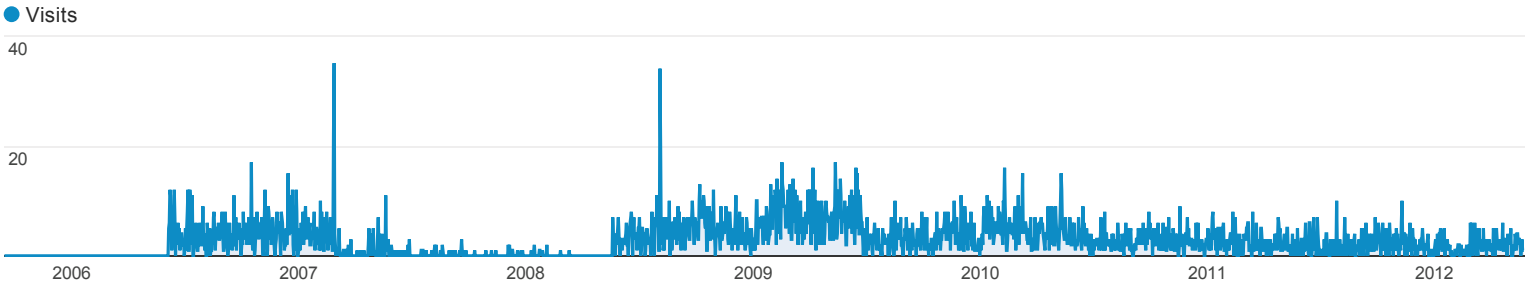

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3.	zh-cn	172	2.58%
4.	en-gb	95	1.43%
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10.	ko	53	0.80%

Major Research Findings

The overall research goal of the project was to develop a framework for conducting seismic risk analyses for container ports. Specific research activities to achieve this goal were focused in four primary areas: (1) dynamic response and fragility of pile-supported marginal wharves, (2) dynamic response and fragility of container cranes, (3) port operations and logistics during periods of disruption caused by earthquake-induced damage, and (4) decision making under uncertainty. Major findings in each of these areas are summarized below.

Dynamic Response and Fragility of Pile-Supported Marginal Wharves

The centrifuge model tests and field test both show soils treated with colloidal silica to reduce their liquefaction potential are an effective means to reduce pore pressure response and reduce the shear strains induced when subjected to large dynamic loads. Data from the centrifuge tests and full-scale field test showed that the installation of the prefabricated vertical drains (PVD) provided significant pore pressure generation and densification. Therefore, the PVD installation provides an additional component of soil improvement: densification. After drain installation, large-scale shaking was performed, and a significant decrease in pore pressure generation was observed.

Test results on alternative types of pile-deck connections show minimal damage and strength loss relative to current practice and achieving performance-based design objectives. These results have been combined with prior test results on connections. By separating the connection responses into several common categories, individual connection-rotation based fragility curves have been developed for three repair-specific damage states. These curves would be appropriate for performance-based evaluation of older, current, or innovative connections in port construction.

Nonlinear time history analyses of the pile-supported wharf structure were performed. For strong ground shaking, the results of these analyses demonstrate that:

1. Liquefaction-induced movements of the soil embankment impose large deformations in the piles and pile-deck connections that are sufficient to severely damage the wharf;
2. Large relative horizontal displacements can develop between the structurally separate landside crane rail and the wharf deck (which supports the seaside crane rail);
3. Severe damage to the wharf occurs in (a) pile sections near the interface of liquefiable and non-liquefiable sand layers, (b) pile sections close to the surface of the embankment, and (c) pile-deck connections as indicated in Figure 4-4, which shows the curvature ductility demand, deformed shape, and location of plastic hinges for the wharf subjected to a ground motion time history with a peak horizontal ground acceleration (PGA) of 0.64g;
4. The damage patterns observed in this study coincide with damage patterns observed in historic cases of wharf damage in past earthquakes; and

5. Batter piles experience large axial forces that may exceed the tensile capacity of the piles.

For small-to-moderate levels of ground motion intensity, liquefaction of the embankment soils did not occur and damage to the wharf structures was minor.

A series of fragility functions were developed for critical wharf components using the results from the two and three-dimensional wharf models. The capacities or limit states used to develop fragility curves were derived from numerical simulations, experimental results, and expert judgment. Fragility analysis of wharf components showed that the relative movement of the wharf with respect to the landside rail is the most susceptible component to slight and moderate damage. However, pile sections are the most vulnerable components of the wharf to extensive damage primarily due to the large deformation demands on the piles at the interface of loose and dense sand layers. Furthermore, fragility curves of the three-dimensional wharf model were found to exhibit larger probabilities of failure compared to the corresponding quantities from the two-dimensional wharf model. This finding is not particularly surprising since longitudinal and torsional responses of the wharf in the three- dimensional wharf model contribute to component responses.

Dynamic Response and Fragility of Container Cranes

A theoretical tool for estimation of seismic demand was developed that accounts for the uplift behavior of the container crane, and finds that the "safety valve" design assumption can be unconservative. This portal uplift theory is verified with detailed finite element models incorporating frictional contact elements and experimental shake-table testing of a scaled jumbo container crane allowed to uplift. Using the verified models developed in this work, fragility curves and downtime estimates were developed for three representative container cranes. The results indicate that existing container cranes, especially stout cranes and those not specifically detailed for ductility, are not expected to achieve the seismic performance objectives of many ports. To address this deficiency, performance-based design recommendations were provided that encourage the comparison of demand and capacity in terms of the critical portal deformation, using the derived portal uplift theory to estimate seismic deformation demand. Simplified methods and basic design factors were proposed and demonstrated, which enable practitioners to conveniently design for reliable achievement of seismic performance objectives.

Port Operations and Logistics During Periods of Disruption

The following findings resulted from the seismic risk analyses of containers ports that have been impacted by earthquakes:

1. Business interruption losses make up the largest portion of the total losses experienced at port systems. Risk analyses that neglect or underestimate the business interruption losses will significantly underestimate the total losses experienced at a port due to earthquake disruption, especially for large earthquakes.
2. It is possible that business interruption losses equal zero for a given earthquake. This was especially true for earthquakes that caused little to no disruption.

However, some larger earthquakes still resulted in relatively long repair times and no business interruption loss. No business interruption loss for larger earthquakes was more common at larger terminals because some portions would remain undamaged and so incoming ships could still be serviced without having to be displaced.

3. The downtime associated with wharf repair had the largest influence on determining whether or not business interruption losses occurred. Most earthquakes required some form of wharf repair, while very few earthquakes required crane repair.
4. Mitigation options that reduce the repair times within the framework have the greatest effect in decreasing the overall total cost. The repair incentive mitigation was the most successful option when economically compared to the others. Force majeure (allowing ships to dock at other terminals other than the one to which they are assigned) was also effective in reducing total cost. These results occurred because reducing repair times has a direct correlation to the business interruption loss, which makes up the majority of the total losses in port systems.
5. The physical mitigation options studied (wharf and crane upgrades, installation of drains) were the least successful in reducing total losses. Physical mitigation options showed significant reductions in loss at very small exceedance rates, and only very small loss reductions in larger exceedance rates. While each option reduced overall total losses, the implementation costs were so large that overall, the options were not cost effective.

Decision Making Under Uncertainty

While no single governance structure characterizes a majority of seaports and risk decision making is decentralized, as expected, the degree of privatization does not appear to influence seismic risk planning, contrary to expectations. Also contrary to prior findings and expectations, most respondents reported that their port's primary strategic goal is local or national economic development.

In support of our first hypothesis, ports report a diversity of management and governance structures as well as varied operating status. Interestingly, ports report a greater diversity of governance than found in an earlier study. In support of our second hypothesis, risk decision making in seaports is decentralized, with local governments, private entities, and other port stakeholders exercising varying levels of influence on current operations and future construction decisions. Port authority commissions are ranked by far the most influential stakeholder in both current operations and decisions regarding future construction. Local community groups have less influence at private sector ports than at those managed by central governments or public-private partnerships, whereas port tenants, and port operators wield less influence at ports managed by central governments than at those managed privately or by public-private partnerships.

As anticipated, ports with higher seismic hazard tend to have better seismic risk planning and management, although not all are prepared for disruptive seismic events. Engineering- based measures of seismic hazard are predictive of seismic planning, controlling for management, perceived probability of disruptive seismic events, and privatization.

In sum, our survey results suggest three major observations:

1. First, risk management and governance configurations at North American seaports are highly variable, with many disparate influences on operations and planning. Respondents rated shippers, unions, ocean carriers, insurance providers, and retail trade as having significantly less influence on future construction than on current operations. As noted above, the influence of local community groups on current operations varies significantly depending on port management, as does the influence of port tenants and operators on future construction decisions.
2. Second, while subjective probabilities of disruptive seismic events and preparedness increase with increases in an engineering-based measure of seismic hazard, some higher-hazard ports report no plans to assess seismic vulnerability and have informal or no seismic mitigation plans. Of the high-seismic-hazard ports responding, a majority (61.1%, n=11) report having only informal or no seismic mitigation plans. Ten of 23 (43.5%) report not having plans to conduct a seismic vulnerability assessment.
3. Finally, high-seismic-hazard ports were no more likely to prioritize safety enhancements, instead giving priority to facilities expansion. This reinforces the GAO's (2007) conclusion that ports have not prioritized all-hazards disaster planning strategies.

Our survey leaves several questions open that deserve further research. Among these is why we did not find a relationship between degree of privatization and profit or ROI as a primary management goal. This may reflect the complex management and governance configurations at North American seaports, and especially the history of public ownership of American tidelands and waterways. Given the acknowledged importance of seaports for local and national economic development, future research should further investigate the status of planning and risk preparedness at high-hazard ports.

Major Research Activities

The overall research goal of the project was to develop a framework for conducting seismic risk analyses for container ports. Specific research activities to achieve this goal were focused in four primary areas: (1) dynamic response and fragility of pile-supported marginal wharves, (2) dynamic response and fragility of container cranes, (3) port operations and logistics during periods of disruption caused by earthquake-induced damage, and (4) decision making under uncertainty. Major activities in each of these areas are summarized below.

Dynamic Response and Fragility of Pile-Supported Marginal Wharves

Several types of pile-supported marginal wharves that are representative of those currently in service at west-coast ports in the U.S. were modeled to assess their dynamic response and to develop fragility relationships. The seismic response of the wharf structures was evaluated using two-dimensional (2D) and three-dimensional (3D) finite element models developed in OpenSees that integrated contributions from project team members on the response of embankments containing liquefiable soils, dynamic soil-pile interaction in liquefiable soils, soil improvement methods for developed sites, the behavior of pile-deck connections, and the seismic response of the wharf structure.

Numerical simulations of the free-field response of soil embankments were performed using non-linear, time-domain, finite element methods with coupled flow and deformations in OpenSees. A macroelement was developed for soil-structure interaction analyses of piles in liquefiable soils that captures efficiently the fundamental mechanisms of saturated granular soil behavior. The dynamic behavior of soils treated with colloidal silica to reduce their liquefaction susceptibility was studied through centrifuge model tests at the NEES equipment site at the University of California, Davis and a complimentary, full-scale field test using the mobile shakers from the NEES equipment site at the University of Texas at Austin. Centrifuge tests at UC-Davis and a field test at a natural site in South Carolina using the mobile shakers from UT-Austin were also performed to investigate the performance of prefabricated vertical drains as a means of reducing the liquefaction susceptibility of soils.

To mitigate damage to connections between the piles and wharf deck, several structural concepts were evaluated including (1) intentional debonding of the headed reinforcing bars, (2) supplemental rotation capacity through the addition of a cotton duck bearing pad and (3) supplemental material to sustain the lateral deformations while minimizing deck damage.

Dynamic Response and Fragility of Container Cranes

Research was performed to examine the effect that uplift response has on the seismic demand of portal-frame structures such as container cranes. One primary objective of this work is to develop methodologies for realistically modeling this effect, and to serve as a foundation for the design and evaluation of new and existing container cranes. The seismic behavior of container cranes was investigated by two large-scale experiments utilizing the six-degree-of-freedom shake table at the NEES facility at the University at

Buffalo. The characterization of uplift and derailment behavior was of particular interest. The first phase of testing was conducted on a 1/20th scale model and focused on the uplift and elastic behavior. The Phase II test was designed to be representative of a modern jumbo crane. It was also designed such that no inelastic action would develop prior to uplift (as is the common design practice).

Port Operations and Logistics During Periods of Disruption

Using an optimization-based heuristic scheduling technique to simulate port operations during periods of disruption, the decision-making of terminal operators was simulated to determine: (1) what arriving vessels may be turned away or will go another port, (2) what times will arriving vessels be berthed, (3) where will they be berthed within a particular terminal complex, and (4) which cranes will be assigned to the vessels and when. The scheduling technique makes these decisions by assigning berth space and cranes to each ship that are available at the time after the earthquake when the ship is scheduled to arrive at the port. These assignments maximize an objective function that seeks to mimic the objectives of the terminal operators, balancing the need to process containers quickly given available resources while avoiding excessive delay to any arriving vessels. The technique uses a rolling time horizon that considers the schedule of arriving vessels several days into the future; berth and crane assignments are updated daily based on the new information. It also has the ability to allow arriving ships to berth only at their planned destination terminal or to allow them to use available berths within other terminals as a result of possible "force majeure" agreements between terminal operators.

The inputs to the port operations model include the day-by-day, port-wide system damage state and the schedule of arriving ships within some period of time that extends from the time of earthquake occurrence up through the time when normal port operations are restored (i.e., when all of the damaged infrastructure is repaired). Models for estimating the number of arriving ships and their characteristics (e.g., length and TEU capacity) was based on data from the Marine Exchange of Southern California, which tracks ship arrivals and departures from the Ports of Los Angeles and Long Beach. The model outputs the number of TEUs not able to be processed because of earthquake-induced damage can be tabulated for each terminal and berth. Business interruption losses may be estimated using financial information such as the revenue derived by the port and terminal operator for each TEU or the cost per hour for delayed ships. Adding these business interruption losses to the repair and/or replacement costs for wharves and cranes in each terminal yields the total port-wide losses due to damage from a given earthquake.

Decision Making Under Uncertainty

To better understand seismic risk perception and management practices within the ports community, a survey was sent to 126 North American seaports. The surveys targeted the chief engineer or equivalent title at each port.