Seismic Vulnerability of Lifelines: Then and Now

Earthquake Research Affiliates Meeting on Lifelines

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Michael Mahoney, Senior Geophysicist

DHS/FEMA, Mitigation Directorate

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nehrp
National Earthquake Hazards Reduction Program

Early FEMA Lifelines Work

- One of FEMA's early projects on the seismic protection of lifelines was a study of the impact of co-located lifelines in the Cajon Pass in southern CA; printed in 1992.
- The project was undertaken when a rail accident in the Cajon Pass resulted in a fire involving a fuel pipeline, which subsequently impacted other co-located utilities.
- The project developed a screening tool for assessing the impact of co-located lifelines, and used that tool to assess collocation in the Cajon Pass (including an inventory).
- The screening tool predated FEMA's HAZUS GIS-based loss estimation software and other GIS applications.

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Cajon Pass Study Studies

- **Collocation Impacts on the Vulnerability of Lifelines during Earthquakes with Applications to the Cajon Pass, California: Study Overview (FEMA 221)**
  - Study summary of lifeline systems located along the Cajon Pass in southern California. The study included analyses of communication lifelines, electric power lifelines, fuel pipelines, and transportation lifelines. The report evaluates how collocation may influence each lifeline's seismic vulnerability. A brief description of the screening tool developed during the study is provided.

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Cajon Pass Study Studies

- **Inventory of Lifelines in the Cajon Pass, California (FEMA 225)**
  - Provides an inventory of the major lifeline systems in the Cajon Pass and describes the earthquake and geologic analysis tools available to identify and define the level of seismic risk to those lifelines. The vulnerabilities occurring from the siting of multiple lifeline systems in confined and at risk areas due to their interactions from natural and manmade disasters are evaluated.
  - Potential mitigation techniques for communication lifelines, electrical power lifelines, fuel pipelines, and transportation lifelines are identified.
  - The report also discusses seismic hazards and predictive models for evaluating damage potentials associated with seismic hazards.

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Cajon Pass Study Studies

- **Collocation Impacts on the Vulnerability of Lifelines during Earthquakes with Applications to the Cajon Pass, California (FEMA 226)**
  - Report presents a new analysis method to identify the increase in the seismic vulnerability of individual lifeline systems (communication systems, electric power systems, fuel pipelines, and transportation lifeline) due to their proximity to other lifelines in the Cajon Pass.
  - The objective of the study was to determine how the time to restore full service would be affected by the collocation of several types of lifelines in the same congested corridor, as applied to the Cajon Pass lifelines.
  - A design program, AutoCAD, is used to develop overlays of the lifeline routes with seismic and geologic information presented in the inventory report (FEMA 225).

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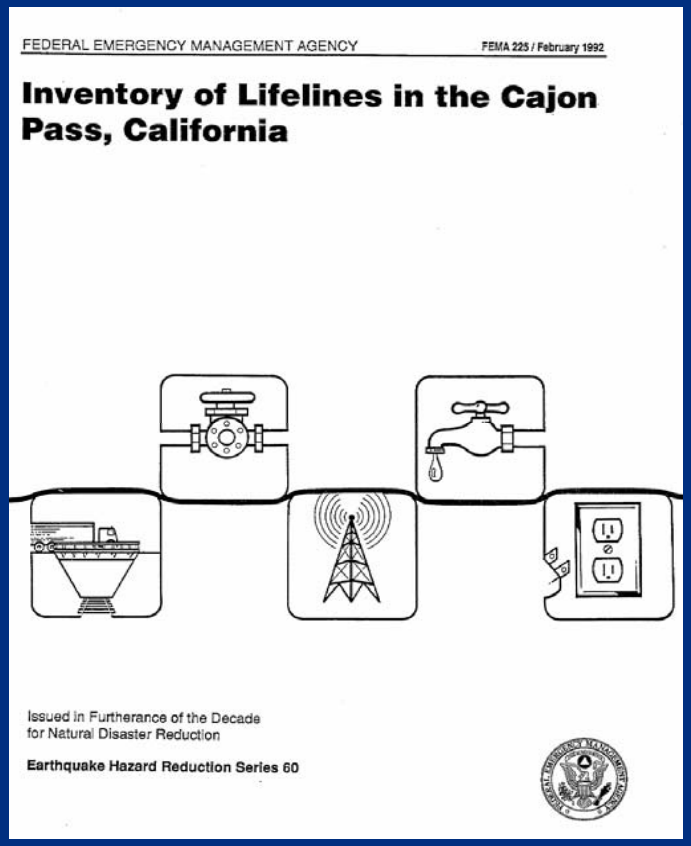
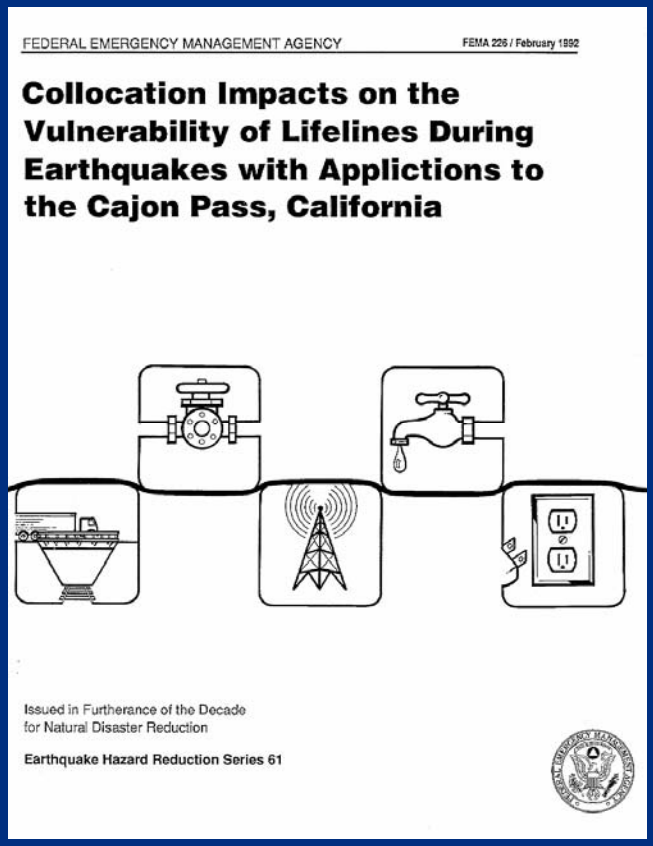
Cajon Pass Study Studies





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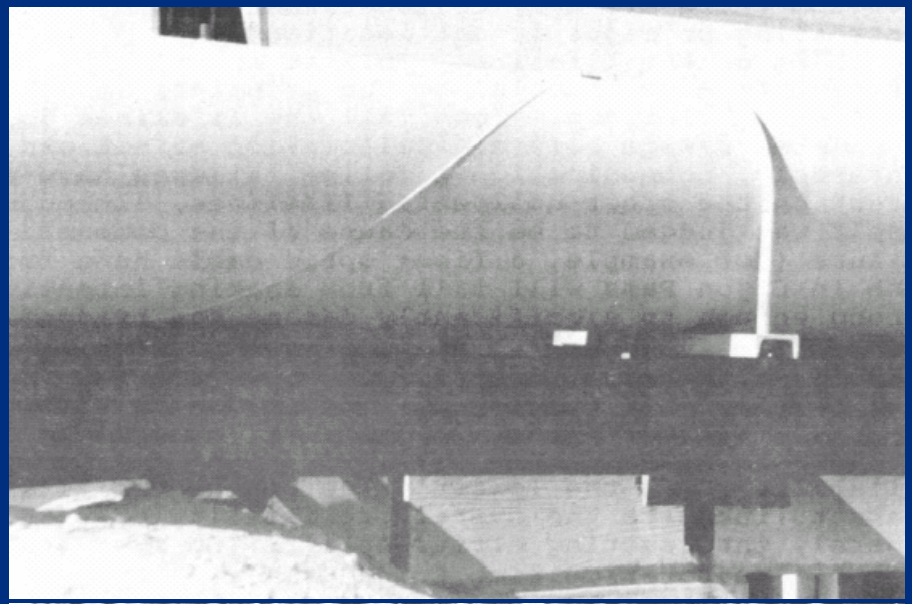
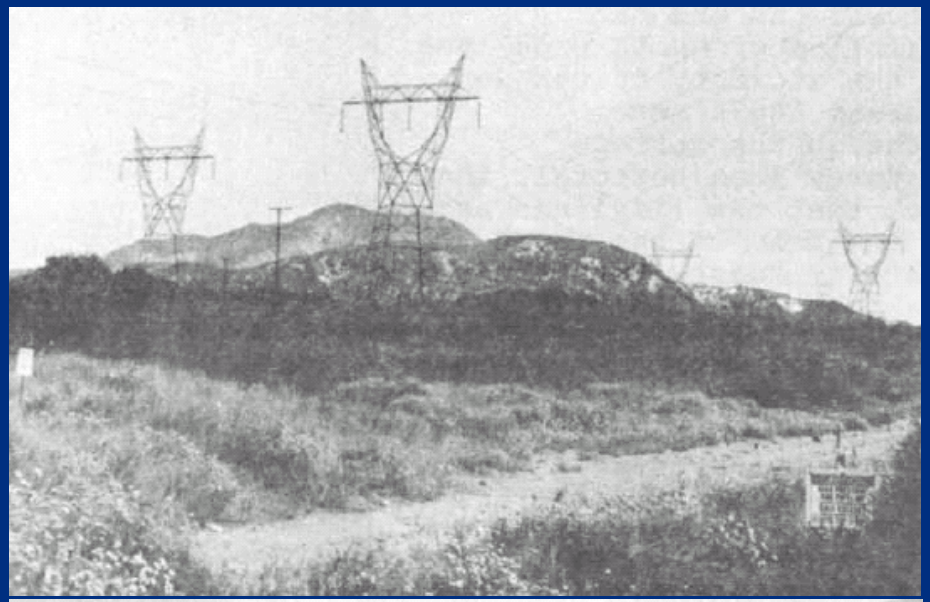
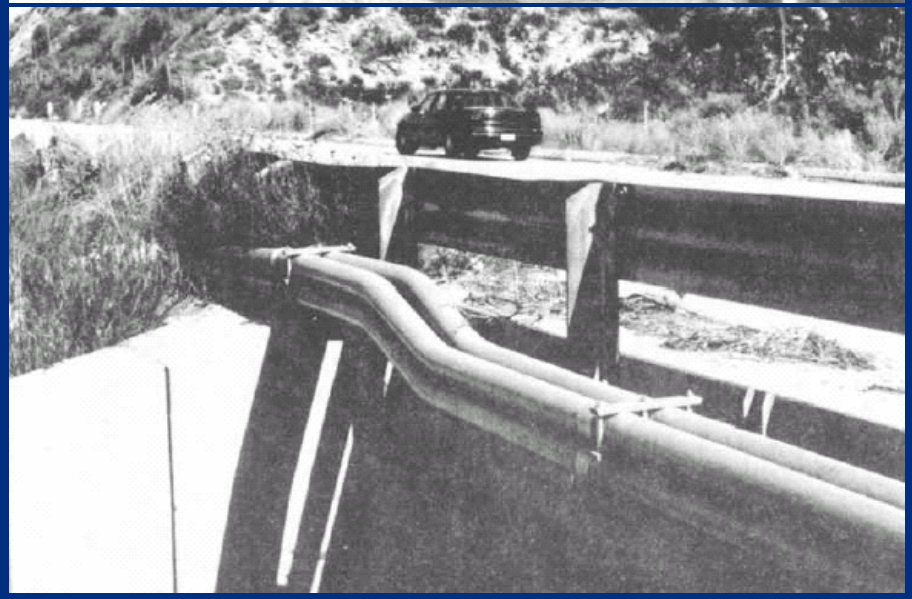
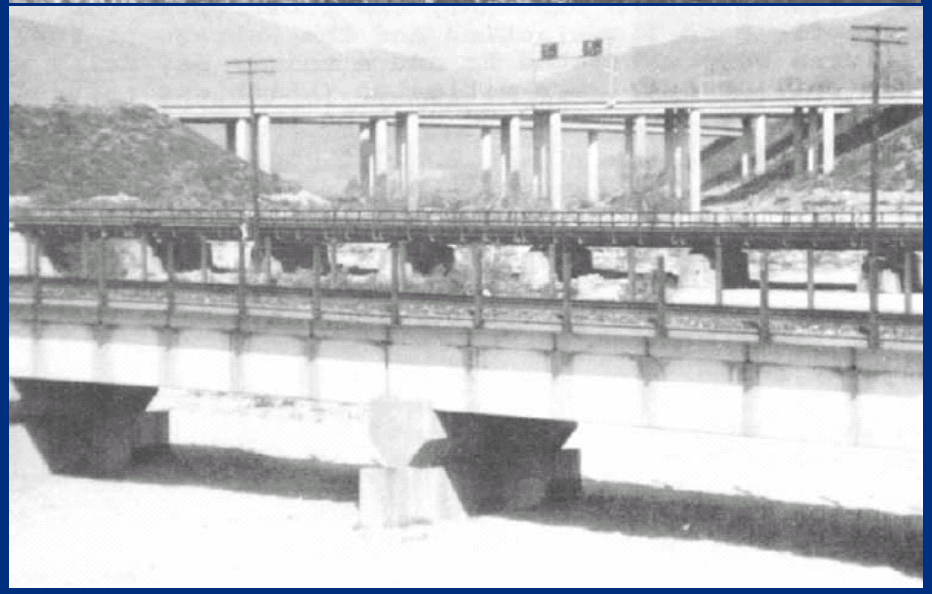
Examples of Collocation









Other FEMA Lifelines Publications

- Earthquake Resistant Construction of Electric Transmission and Telecommunication Facilities Serving the Federal Government (FEMA 202)
- Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States (FEMA 224)
- Earthquake Resistant Construction of Gas and Liquid Fuel Pipeline Systems Serving or Regulated by the Federal Government (FEMA 233)
- Plan for Developing and Adopting Seismic Design Guidelines and Standards for Lifelines (FEMA 271)

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FEMA Lifelines Activities

- 1990 - National Earthquake Hazards Reduction Program (NEHRP) Reauthorization directed FEMA, in consultation with NIST, to prepare a plan for developing and adopting design and construction standards for lifelines with private sector input.
- 1996 - The Plan for Developing and adopting Seismic Design Guidelines and Standards for Lifelines was published as FEMA 271.
- 1997 - HAZUS loss estimation program released.
- 1998 - FEMA issued the contract to establish the American Lifelines Alliance (ALA).

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HAZUS (Hazards US)

- HAZUS-MH is a GIS-based risk assessment software program for estimating potential losses from earthquakes, floods, and hurricane winds.
- HAZUS-MH takes into account various impacts:
  - Physical damage: to classes of buildings and infrastructure;
  - Economic loss: lost jobs, business interruptions, repair costs;
  - Social impacts: impacts to people, requirements for shelters and medical aid.

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HAZUS Risk Assessment Model

- HAZUS-MH earthquake module is the most mature.
- HAZUS includes default data on some lifeline systems
  - i.e.: Federal highways and bridges
- Other lifelines can easily be entered into HAZUS if in GIS.
- Use of HAZUS GIS data for lifeline systems would allow for both identification and assessment of collocated lifelines.
- See HAZUS website: www.fema.gov/hazus

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American Lifelines Alliance

Mission: To reduce risk to the nation's utility and transportation systems from natural and manmade hazards by promoting the development and use of standards by the affected system.

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ALA Lifeline System Focus

- **Utility**
  - **Electric Power**
  - **Natural Gas**
  - **Liquid Fuel**
  - **Telecommunications**
  - **Water**
  - **Wastewater**
- **Transportation**
  - **Highways**
  - **Rail**
  - **Waterways**
  - **Ports & Harbors**
  - **Air**
- **Control & Monitoring Systems**

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ALA Key Customers

- Lifeline Operators
- Communities
- Engineers
- Risk Management Professionals
- Policy Makers

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General ALA Approach

- Facilitate the creation, adoption, and implementation of national consensus guidelines:
  - Focus on existing practice and needs
  - Use existing Standards Development Organizations (SDOs)
  - Address lifeline systems and their key components, not buildings
- Utilize industry and Corresponding Advisors to generate project ideas.
- Increase awareness at public venues and through focused studies and pilot projects.

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Lifeline Mitigation

- Redundancy
- Operational Resiliency
- Rapid Damage Repair

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ALA Matrix of Guidelines and Standards for Design and Assessment of Lifeline Systems for Natural Hazards

TELECOMMUNICATIONS	Load Specification				Design Guidance			
Component	Seismic	Ice/Snow	Wind	Flood	Seismic	Ice/Snow	Wind	Flood
System Reliability								
Transmission Towers & Poles		●	●			●	●	
Buried Cables	❍			❍	❍			
Underwater Cables								
Aboveground Cables*	❍	❍	❍		❍	❍	❍	
Switching Equipment*	❍				❍			
Cable Trays*	●	●	●		❍	❍	❍	
Elect./ Mechanical Equip.*	●	●	●		●	●	●	
PORTS AND INLAND WATERWAYS	Load Specification				Design Guidance			
Component	Seismic	Ice/Snow	Wind	Flood	Seismic	Ice/Snow	Wind	Flood
System Reliabilty					❍			
Piers/Wharves	❍				❍			
Breakwaters/Jetties	❍				❍			
Sea Walls	❍				❍			
Container Handling*	●	●	●		●	●	●	
Cargo Movement*	●	●	●		●	●	●	
Marine Oil Terminals*	●	●	●		●	●	●	
Elect./ Mechanical Equip.*	●	●	●		●	●	●	

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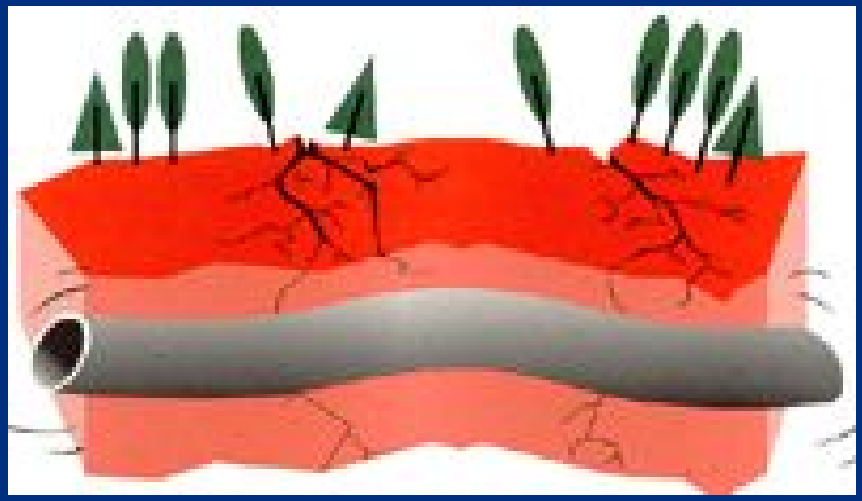
Completed Projects

(available on ALA website)

- *Seismic Fragility Formulations for Water Systems*

  ASTM converting to a consensus standard



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Completed Projects

(available on ALA website)

- *Guideline for the Design of Buried Steel Pipe*
  - Being developed by American Society of Mechanical Engineers (ASME) B31 Code Committee

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Current Projects

- *Guidelines to Define Natural Hazard Performance Objectives for Water Systems*

Facilitate informed risk reduction decision-making

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Future Projects

Lifeline	Guideline
Aboveground Steel Tanks	Seismic Design
Utility and Transportation Lifeline Systems	System Reliability for All Hazards
Electric Power Transmission Towers and Distribution Poles	Natural and Man-Made Hazards Design
Wastewater Systems	Natural and Man-Made Hazards Design
Oil and Natural Gas Pipeline Systems	Natural and Man-Made Hazards Design

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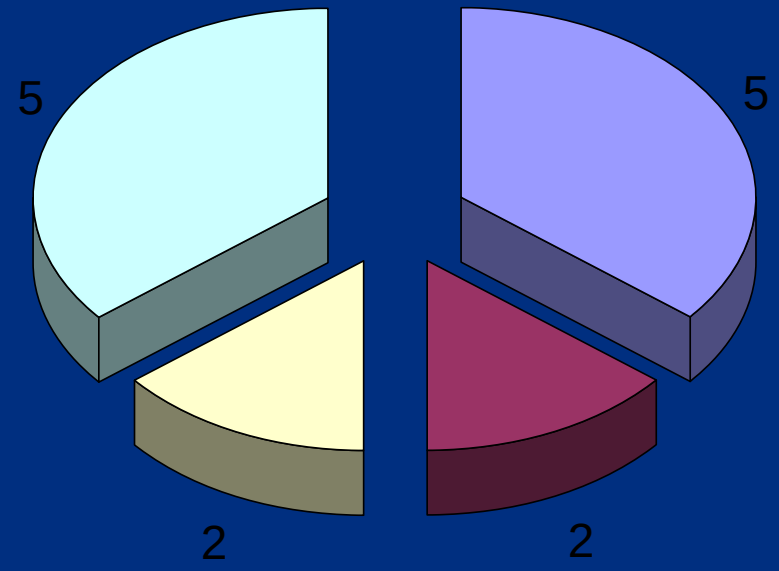
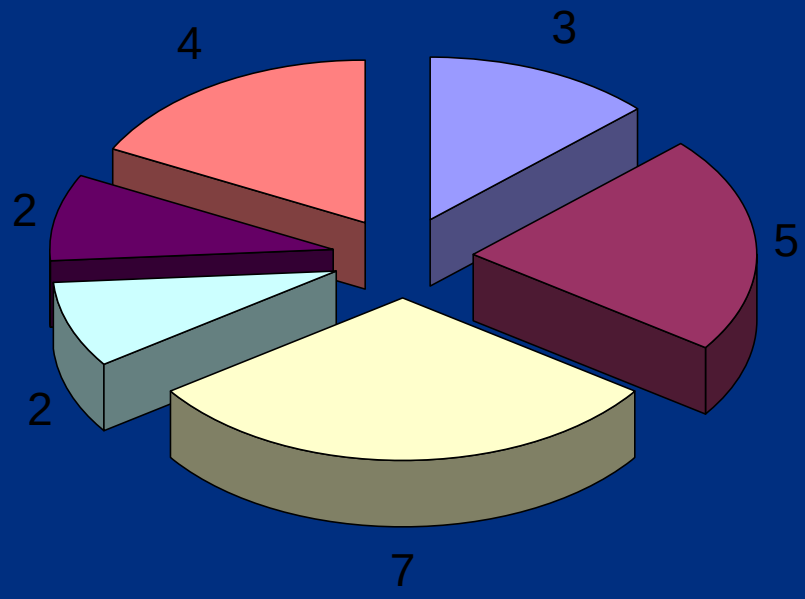
Distribution of ALA Projects





- Earthquake
- Flood
- Ice
- Multihazard

- Electric Power
- Oil and Gas Pipelines
- Water
- Equipment/Piping
- Transportation
- Waste Water

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ALA is a Partnership

ALA Goal is to Seek Partners in the Public and Private Sectors to Collaborate to Identify And Support Mutually Beneficial Projects.

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Current Status of ALA

FEMA provided initial start-up funding for five years.

ALA was always intended to become a self-sustaining organization.

Due to recent budget "reallocations" FEMA no longer provides funding.

www.americanlifelinesalliance.org

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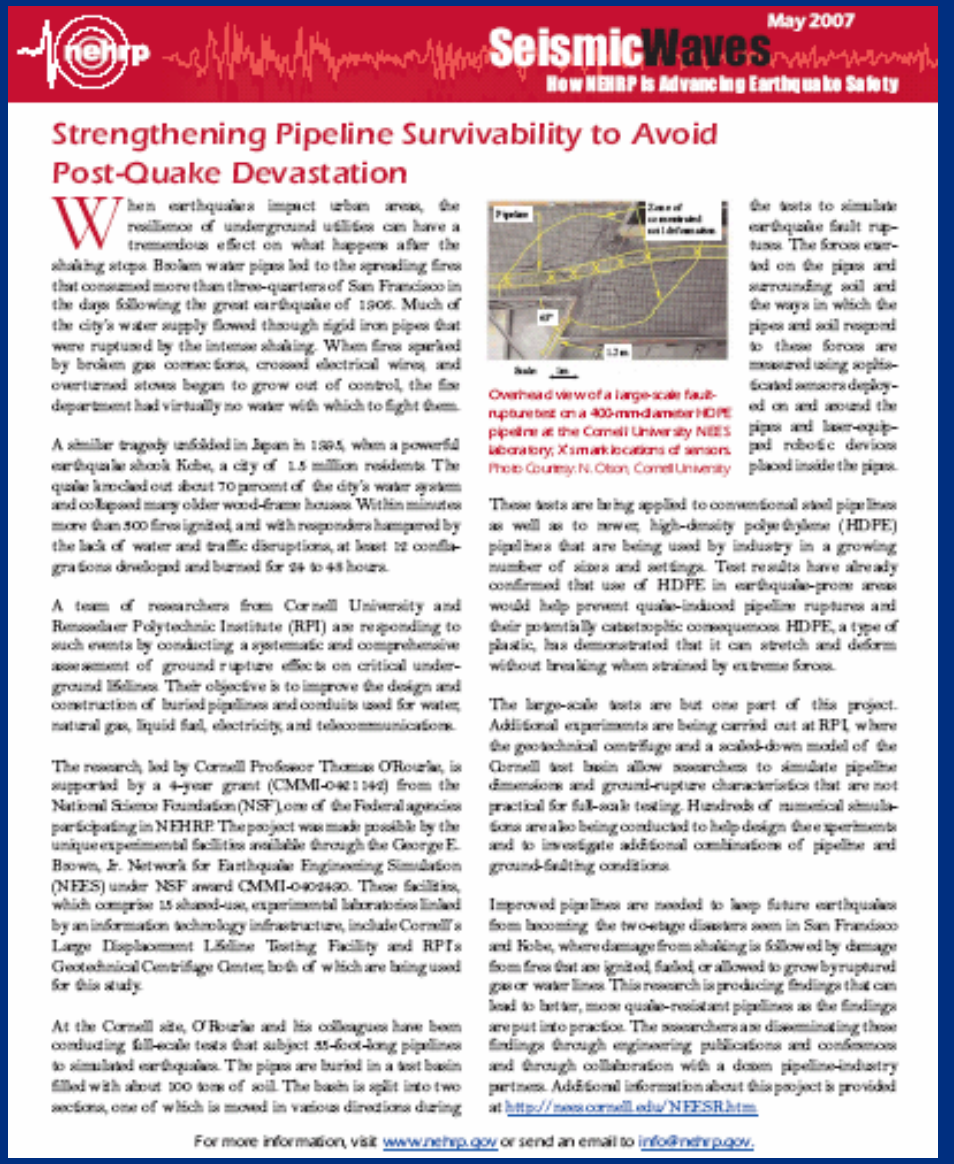
NEHRP Lifelines Research

- Under NSF Network for Earthquake Engineering Simulation (NEES), lifelines-related research is taking place.
- Example of pipeline in soil testing taking place at Cornell recently published on www.nehrp.gov.
- Also describes geotech centrifuge work at RPI.



NEHRP SeismicWaves May 2007
How NEHRP is Advancing Earthquake Safety

Strengthening Pipeline Survivability to Avoid Post-Quake Devastation

When earthquakes impact urban areas, the resilience of underground utilities can have a tremendous effect on what happens after the shaking stops. Broken water pipes led to the spreading fires that consumed more than three-quarters of San Francisco in the days following the great earthquake of 1906. Much of the city's water supply flowed through rigid iron pipes that were ruptured by the intense shaking. When fires sparked by broken gas connections, crossed electrical wires, and overturned stoves began to grow out of control, the fire department had virtually no water with which to fight them.

A similar tragedy unfolded in Japan in 1995, when a powerful earthquake shook Kobe, a city of 1.5 million residents. The quake knocked out about 70 percent of the city's water system and collapsed many older wood-frame houses. Within minutes more than 500 fires ignited, and with responders hampered by the lack of water and traffic disruptions, at least 12 conflagrations developed and burned for 24 to 48 hours.

A team of researchers from Cornell University and Rensselaer Polytechnic Institute (RPI) are responding to such events by conducting a systematic and comprehensive assessment of ground rupture effects on critical underground lifelines. Their objective is to improve the design and construction of buried pipelines and conduits used for water, natural gas, liquid fuel, electricity, and telecommunications.

The research, led by Cornell Professor Thomas O'Rourke, is supported by a 4-year grant (CMMI-0421342) from the National Science Foundation (NSF), one of the Federal agencies participating in NEHRP. The project was made possible by the unique experimental facilities available through the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) under NSF award CMMI-0402490. These facilities, which comprise 15 shared-use, experimental laboratories linked by an information technology infrastructure, include Cornell's Large Displacement Lifeline Testing Facility and RPI's Geotechnical Centrifuge Center, both of which are being used for this study.

At the Cornell site, O'Rourke and his colleagues have been conducting full-scale tests that subject 55-foot-long pipelines to simulated earthquakes. The pipes are buried in a test basin filled with about 100 tons of soil. The basin is split into two sections, one of which is moved in various directions during the tests to simulate earthquake fault ruptures. The forces exerted on the pipes and surrounding soil and the ways in which the pipes and soil respond to these forces are measured using sophisticated sensors deployed on and around the pipes and laser-equipped robotic devices placed inside the pipes.

Overhead view of a large-scale fault-rupture test on a 400-mm-diameter HDPE pipeline at the Cornell University NEES laboratory. X's mark locations of sensors. Photo Courtesy: N. Olson, Cornell University

These tests are being applied to conventional steel pipelines as well as to newer, high-density polyethylene (HDPE) pipelines that are being used by industry in a growing number of sizes and settings. Test results have already confirmed that use of HDPE in earthquake-prone areas would help prevent quake-induced pipeline ruptures and their potentially catastrophic consequences. HDPE, a type of plastic, has demonstrated that it can stretch and deform without breaking when strained by extreme forces.

The large-scale tests are but one part of this project. Additional experiments are being carried out at RPI, where the geotechnical centrifuge and a scaled-down model of the Cornell test basin allow researchers to simulate pipeline dimensions and ground-rupture characteristics that are not practical for full-scale testing. Hundreds of numerical simulations are also being conducted to help design the experiments and to investigate additional combinations of pipeline and ground-faulting conditions.

Improved pipelines are needed to keep future earthquakes from becoming the two-stage disasters seen in San Francisco and Kobe, where damage from shaking is followed by damage from fires that are ignited, fueled, or allowed to grow by ruptured gas or water lines. This research is producing findings that can lead to better, more quake-resistant pipelines as the findings are put into practice. The researchers are disseminating these findings through engineering publications and conferences and through collaboration with a dozen pipeline-industry partners. Additional information about this project is provided at http://nees.cornell.edu/NEESR.htm.

For more information, visit www.nehrp.gov or send an email to info@nehrp.gov.

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