National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Lifeline Systems

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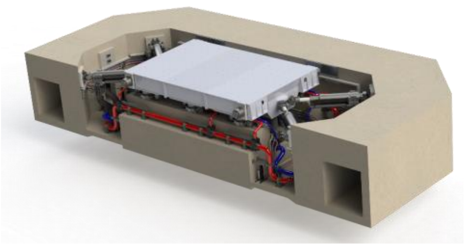


Joint Academia-Industry NHERI Workshop
NHERI@UC San Diego

September 21-22, 2020
University of California, San Diego

- Purpose:
    - identify and formulate grand challenge research needs to improve seismic design codes and standards, foster academia-industry collaborations, and map the future directions of research using the newly upgraded 6-DOF LHPOST
- Role:
    - present views and vision to fill the knowledge gaps in earthquake engineering

Outline

- Lifeline Systems Overview
- Current Challenges
- Resilience
- Direction in developments
- Some research needs applicable to 6-DOF LHPOST
- Conclusions

Lifeline Infrastructure Systems

- Infrastructure Systems = the physical and organizational structures and facilities needed for the operation of a society or enterprise
- Lifeline Infrastructure Systems:
  - Water
  - Wastewater
  - Storm Water/Inundation Protection
  - Electric Power
  - Communication
  - Gas and Liquid Fuels
  - Transportation
  - Solid Waste
- Socio-Technical Systems: Lifeline systems include the physical infrastructure and the organizations that manage them

Lifeline Infrastructure Systems

- Large geographically distributed systems
- Made of numerous interlinked specialized components
- Interdependent
- Consist of a variety of subsystems
  - May have separate owners and operators
  - All must coordinate to provide services to end users

Current Lifeline System Challenges

- Limited codes and standards governing seismic design of lifeline systems
  - Some well developed while non-existent for other systems & components
- Inconsistent approaches and criteria
- Wide range of regulations (from none to multi-jurisdictional)
- Need to create resilient lifeline systems consistent with community resilience goals
  - Community resilience goals are limited to non-existent in most cities
  - Lifeline systems need to develop resilience on their own, but have limited guidance
- Disparate recovery-based goals across lifeline systems (if they exist)
- NEHRP Functional Recovery

Lifeline System Resilience

- Multi-Dimensional
- Robustness, Redundancy, Rapidity, Resourcefulness (Bruneau et al., 2003)
- Physical testing mainly deals with Robustness, sometimes Redundancy, and may include some aspects of Rapidity and Resourcefulness.
- Physical testing is important to help create resilient lifeline systems

Current Momentum in Lifeline Earthquake Engineering

- Framework for recovery-based objectives
- Develop and improve existing codes, standards, and guidelines
- Establish design levels for which systems can meet the recovery-based objectives (i.e., ability to provide basic services in timely manner)
- Establish design levels for each component to ensure the system can cost-effectively meet the recovery-based objectives.
- Define how to meet the objectives by:
  - Designing new components, subsystems, and systems, and
  - Modifying existing components, subsystems, and systems

Lifeline System Research Needs

Large multi-degree of freedom shake table offers many opportunities to undertake research for improving the seismic design of lifeline systems

Specialized Equipment (some examples)

- Wind turbines subjected to multi-directional shaking
- Communication Towers
- Pumps/turbines
- Large valves in piping systems (inertial shaking + axial wave propagation)

Axial strain

Buried

Interaction of Multiple System Components

- Modeling portions of stations, refineries, networks
  - Electric Power receiving and distribution stations
  - Electric power and communication poles
    - Effects of swaying cables, resulting forces, touching and causing electrical faults
  - Above and below ground interconnected piping systems
    - Using common fittings for oil, gas, and water networks

Interaction of Multiple System Components

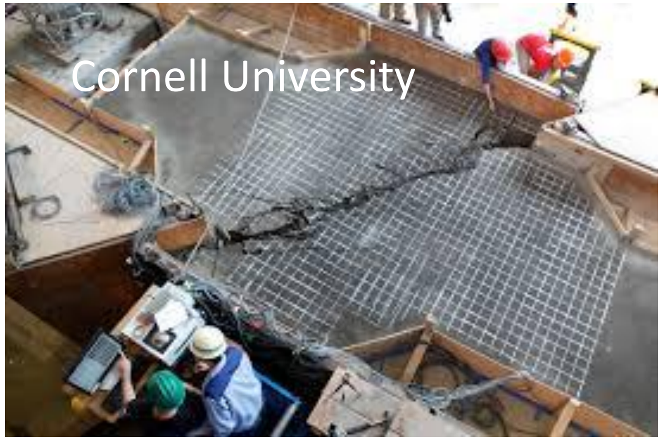
- Include effects of shaking and differential ground movements
  - Small ground displacements can have large impacts on interconnected components in electric power stations, refineries, treatment systems, etc.
  - Incorporate ability to slightly offset some components representing permanent ground movement using soil-displacement or another platform on the shake table

Gravity wall structure displaced

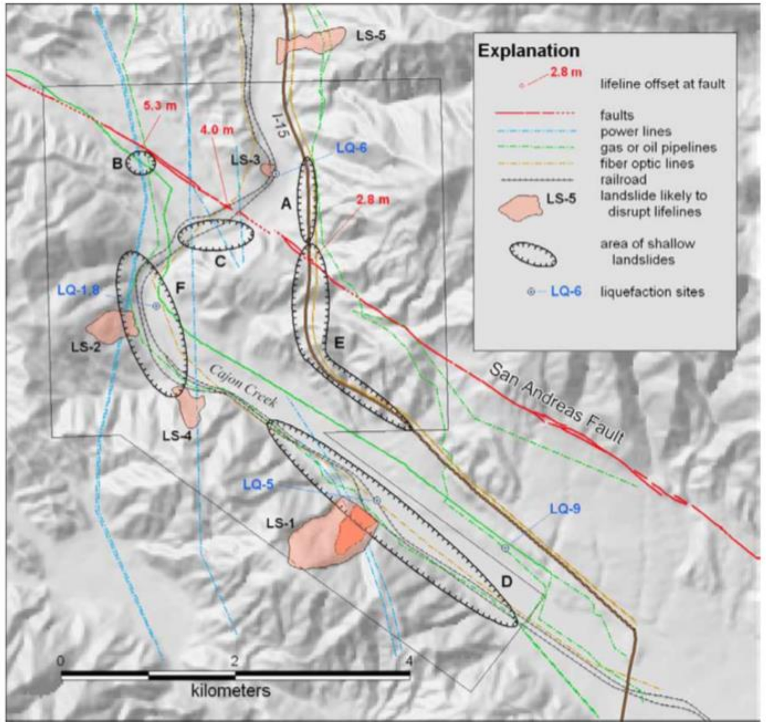
Resulted in ~3” settlement, ~6” horiz. movement

Fault Rupture

- Use table to simulate fault rupture
  - Confirm behavior of large diameter pipelines vs. smaller pipelines tested in the Cornell box
  - Behavior of collocated lifelines in a corridor crossed by a fault (e.g., SAF @ Cajon pass, & other locations)
  - Fault rupture through different types of tunnel liners
  - How rupture propagates upward through weaker soils, including liquefied soils, and effects on shallow buried utilities



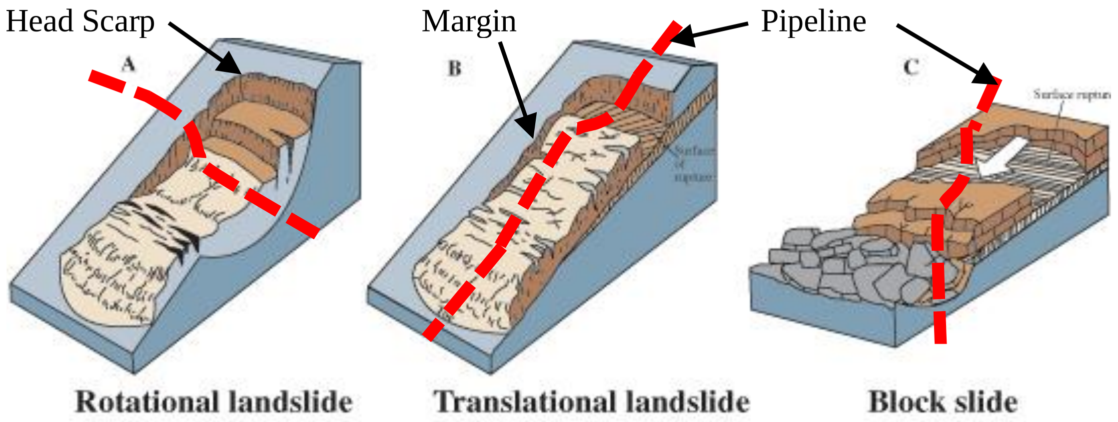
Co-located lifelines crossing fault



Example tunnel liners

Landslides

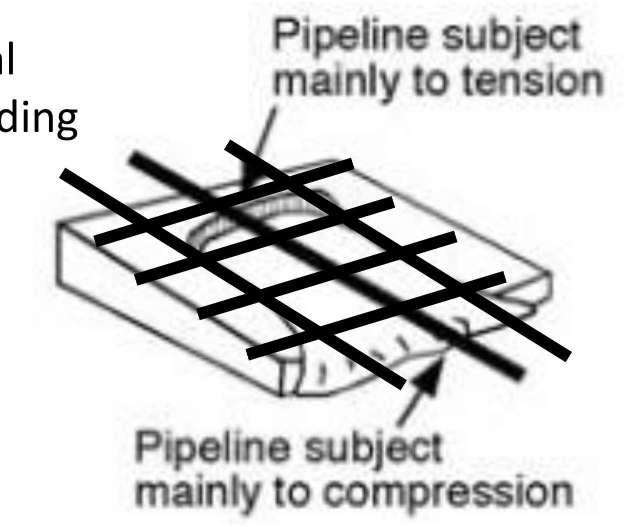
- Use soil box to simulate landslides
- Simulate landslides and pipe crossings,
  - axially,
  - longitudinally,
  - obliquely
- Measure pipe strains and effects of both landslide margins.
- Compare to idea of fault rupture simulates margin of landslides.



Liquefaction

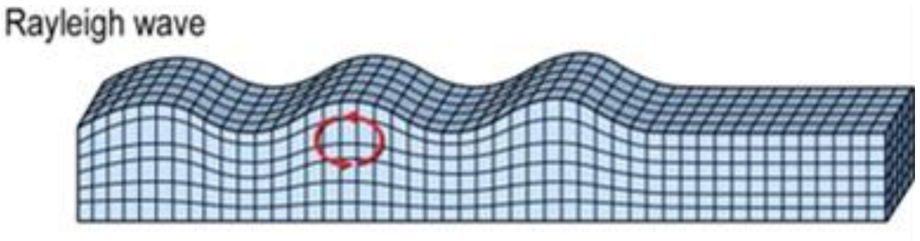
- Buckling of large diameter pipelines embedded in liquefied soils
- Mechanics of uplift/floating of buried pipelines & other structures
  - Methods of preventing
- Effects of lateral spreading on buried pipe network (distribution/collection network) & effects on appurtenances and connections

Lateral Spreading



Courtesy JWRC

Wave Propagation



- Simulate Rayleigh waves and measure ground strains.
  - Need to confirm R-wave strains on buried pipelines.
- Long linear lines – If table can simulate differential movement at each support
  - Multi-supported pipelines: investigate behavior of different types of supports
    - Piers w/ simple foundation on soil (allowed to rock) having different connections to pipe
    - Piers with deep foundations semi-rigidly anchored to ground with different connections to pipe
  - Pipe connections to piers:
    - Pipe resting in saddle
    - Pipe in saddle with ring straps
  - Address wave propagation w/ spacing of piers moving different at each location.

Ring girder on pile supported pier, damaged from lateral spreading 1971 & 1994

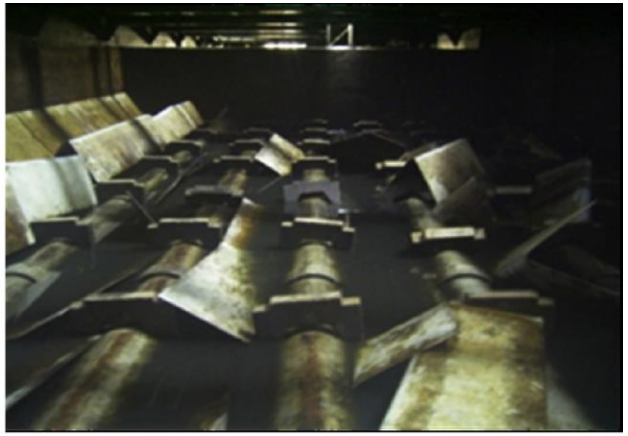
LA Aqueduct on concrete saddles bearing on soil, no ring girders, intense shaking 1971 & 1994
No failure

Water Sloshing

- Model impacts of sloshing on specialized treatment systems (water & wastewater)
  - Baffles
  - Clarifiers

Baffle Boards, Moniwa WTP before the event.

Baffle Boards, Moniwa WTP after the event.

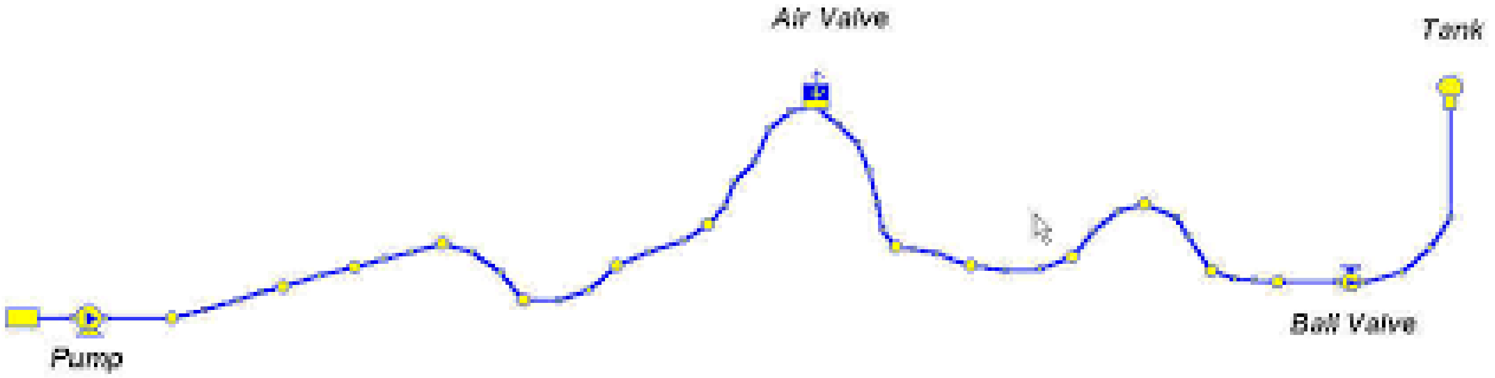


2011 Mw9.0 Great East Japan Earthquake (ASCE, 2017)

Clarifier

Water Pipelines

- Generation of seismic-induced surge pressures
- Mechanisms & effects



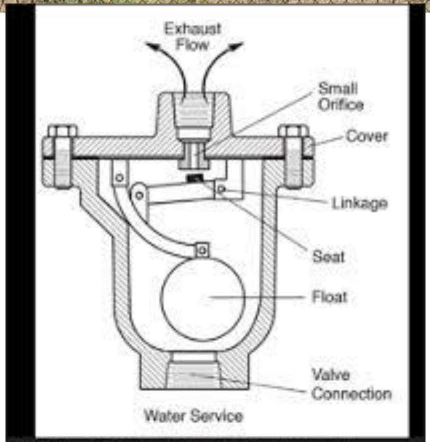
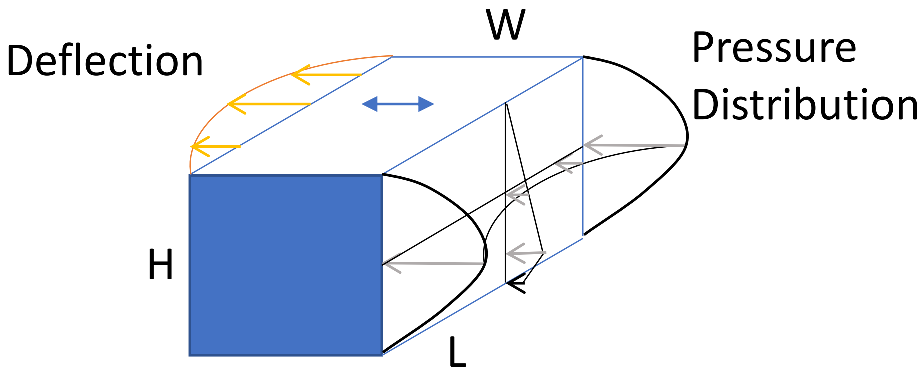


Figure 2. Construction of an air release valve

Buried Box Structures

- 3D modeling of buried concrete box structures.
  - Common structures in lifeline systems.
- Account for
  - variation in Length, Width, and Height changing stiffnesses,
  - lateral force resisting system changing lateral deflections along wall length
    - variation in soil pressures along all sides.
  - effects of variation in burial depth.
- May be best coupled with centrifuge testing for efficiency.



Cut & cover tunnels/box culverts have different responses

Subway Stations

- Multi-level subway stations are complex soil-structure interaction problems
- Subway station-tunnel interface

Conclusions

- Lifelines are large complicated systems made of numerous specialized components
- There are limited codes, standards, and guidelines dictating their seismic design
- There is a need to create/improve standards incorporating recovery-based design consistent across all lifeline systems
- Several potential research ideas have been presented
- These are just some of many testing concepts which may be applied to lifeline systems

SAVE THE DATE

ASCE | INFRASTRUCTURE RESILIENCE

UCLA

San Fernando Earthquake Conference – 50 YEARS OF LIFELINE ENGINEERING

Understanding, Improving & Operationalizing Hazard Resilience for Lifeline Systems

~~February 9, 2021~~ > **February 7-11, 2022**

ASCE *Lifelines* Conference ~~2021~~ 2022

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