Lifeline Systems

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• 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)
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
Damaged equipment & connections

Gravity retaining structure
Lushan, China 2013

Electric Power substation

Displacement cracks
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

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/floatation 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

![Image of pipeline subject to lateral spreading](image_url)

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

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

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