NORTHRIDGE 20
SYMPOSIUM

Lifelines – General Performance in 1994 and Future Directions in Resilience

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Impacts 1994 – Lifelines

- Significant damage to multiple lifelines
- Major damage too:
  - Interstate highways - bridges
  - Power systems
  - Water and wastewater systems
  - Communication systems
  - Gas/oil
  - Hospitals
- Not any faulting damage and minor damage to rail, ports

Road, Highway Bridge Vulnerabilities

- Debris blocking roads
- Landslides
- Subsidence - lateral spreading
- Bridge approach settlement
- Bridge column/support failure
- Complex interactions with abutment and bridge deck supports and seats
- Interactions with other structures and collocated lifelines
- Highway damage impeded response and recovery times

Lateral Spread

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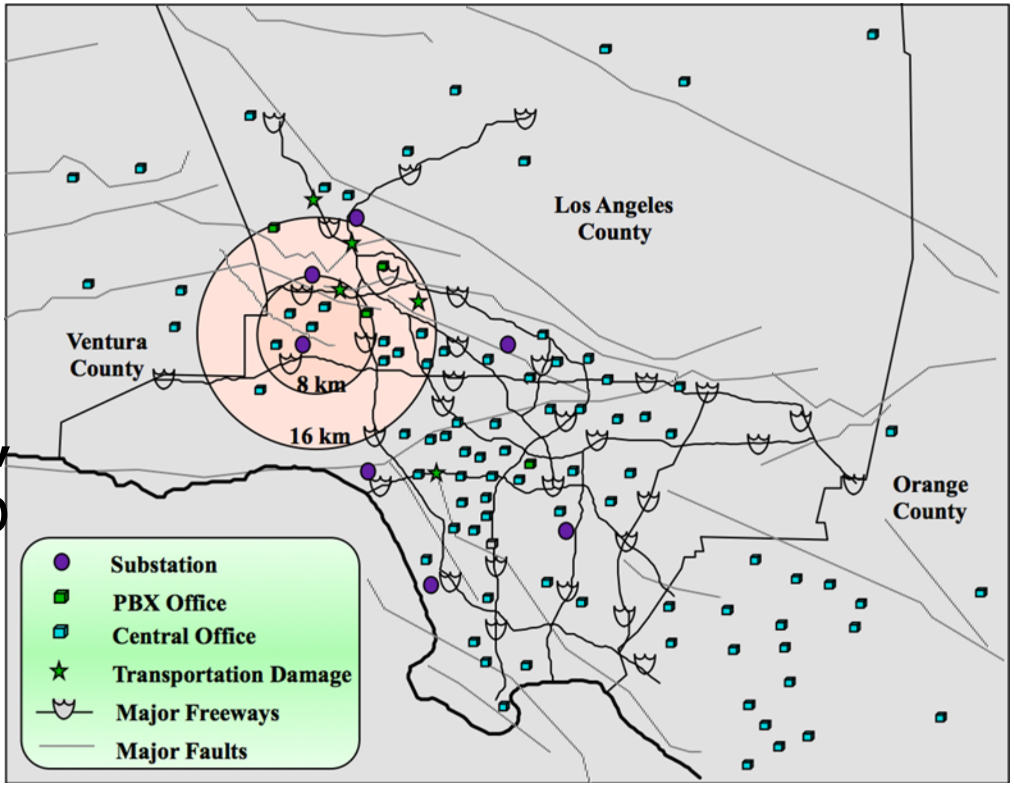
Railroad Damage

- There was no major damage to local rail
- Only one train was derailed due to a seismic wave
  - Caused a diesel and chemical spill
- Most rail relied on the CUBE system.
- Most communicate by radio from remote dispatchers
- Most stop all trains at Mw 5.0 or greater. All tracks are inspected before trains move.
- Commuter rail, light rail and subway picked up displaced highway commuters

Telecommunications

Damaged telecom facilities in 1994

- Approximately 50 CO's had some damage.
- 5 had severe damage
- None shut down
- Minor damage included cable racks, switches and backup power (UPS, generators) and HVAC



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Wastewater

- Sloshing in treatment plant tanks caused damage to mechanical equipment
- Redundancy (spare tankage) allowed for diversions and repairs.
- Major pipeline failures recent earthquakes due to:
  - Liquefaction
    - Joint separation, floating manholes,
  - Inflow/infiltration increase flows and sediments to treatment plants
  - Repairs/recovery are slow due to other priorities, lack of CCTV equipment (out of sight, out of mind)

Liquid Fuels

- Three main crude oil pipelines from northern California
- Only one was damaged (circa 1925) resulting in spills and fires
- Two terminal facilities were undamaged
- No tank damage but sloshing caused spills
- Most damage caused by failed acetylene welds on old pipes

Lifeline Failure Interactions

- Water break ---> Road washout
- Road/bridge closure ---> Failure to repair lifelines and deliver fuel and parts
- Tank failure ---> No water for fires, no water for residents
- Sewer failure ---> Water contamination, red tag for homes
- Electrical failure ---> Water/sewer pumping/treatment, telecommunications, controls and SCADA

Recent Developments Since 1994

- Christchurch New Zealand
  - Major liquefaction caused extensive damage to roads, sewer and water systems
  - Unclear whether or not this could have been mitigated
- Kashiwazaki and Sendai Japan
  - Liquefaction and land movement also caused extensive damage to water, sewer and natural gas systems
  - After Kobe, improvements had been made to both the water and natural gas distribution systems to divide systems into blocks to increase restoration times.
  - This was not based on any code or guidelines just practice in Japan

Add Photos

Sendai Japan

- Sendai area had two major improvements prior to the recent earthquake and tsunami.
  - Sendai Airport was located near the ocean in a flood plain and was highly susceptible to liquefaction. They provided pressure relief wells around the runway preventing damage. Once the runway was cleared of tsunami debris, it was ready for use.
  - Sendai LNG plant storage tanks. The tanks were designed to prevent uplift from liquefaction (and coincidentally tsunami inundation) which performed very well.

Controls and SCADA

- Electrical controls and control communications apply to all lifelines
- Damage to electrical distribution increases demands on UPS and generation
- Fuel demands and distribution need (for generation) are often unknown and complicated by fuel transportation and availability

Recent Developments Since 1994

- TCLEE has prepare monographs on all major earthquakes with lessons learned and suggestions for improvements. This also included guidelines for lifelines.
- The former ALA was established to develop guidelines for the improvements and increase resiliency of major lifelines.
- IEEE has done extensive shake table testing on major electrical transmission components to improve resilience.
- However, there are many public/private lifelines and it is up to them to adopt these guidelines.
- Most changes are voluntary (like Japan) to adopt new standards to mitigate damage.

Damage Mitigation

Restrained batteries (Algeria 2004)

Strapping and Bracing
Equipment Prevents Damage (Japan 2007, Loma Prieta USA 1989)

Lessons Learned

- Initial efforts focus on people, relocation & relief
- Utility (lifeline) buildings can be the "weak link"
- All engineered facilities (to current codes/ standards) perform well
  - Certainly minimizes restoration times
- Site effects (soil issues) always cause unforeseen damage
- Repair materials & spare parts are essential for reducing response times
  - Locate fuel, part and equipment at multiple locations throughout the region

Recommendations

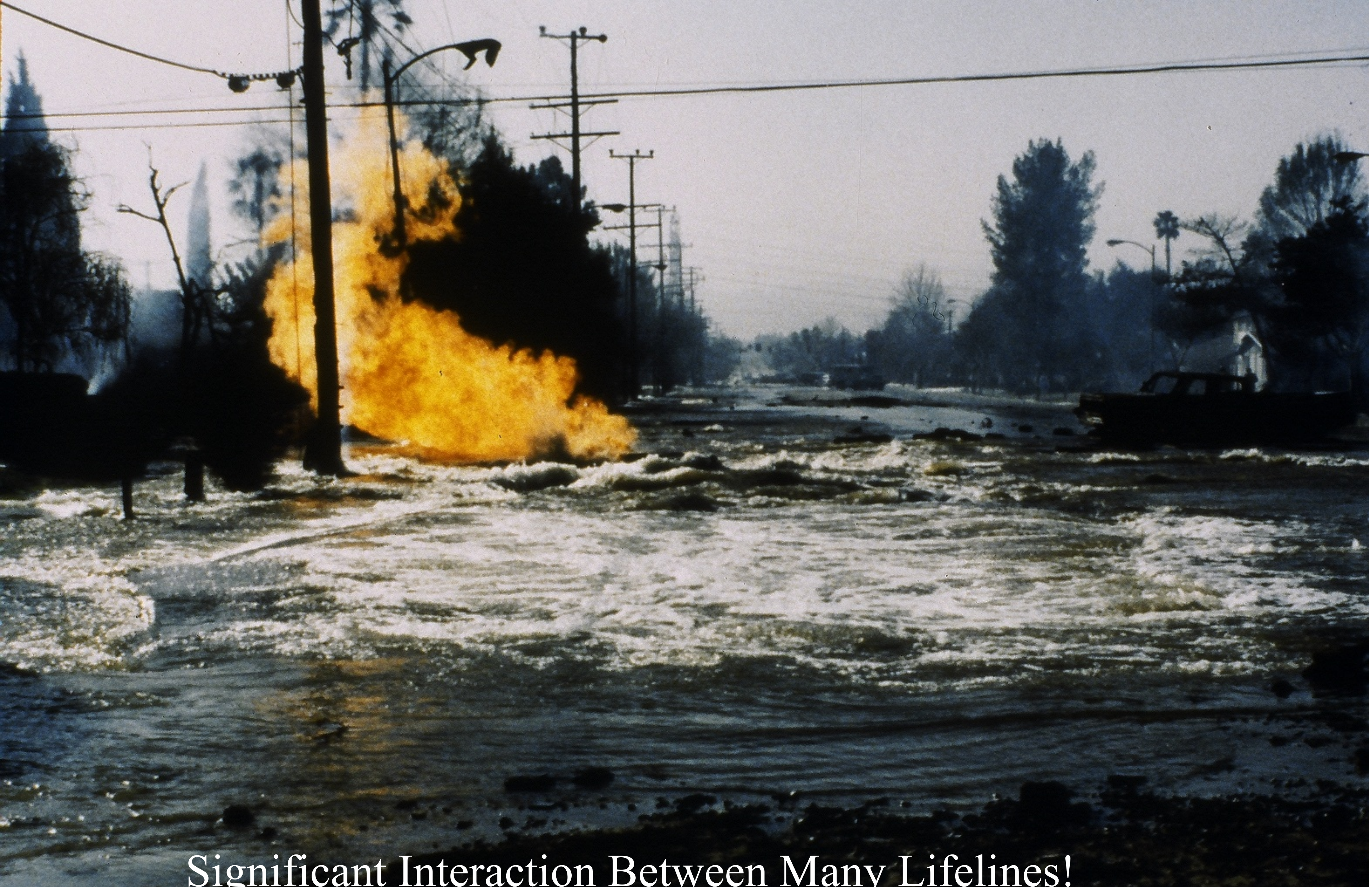
- Identify Earthquake Hazard Zones
  - Faulting
  - Liquefaction
  - Landslides
- Identify Mitigation/Bypass Measures
- Prepare an Emergency Response Manual
- Conduct Long Duration Emergency Simulations
  - Communications
  - Load Tests
- Conduct an earthquake vulnerability assessment

Watermain Bypass (Japan 2007)

Recommendations

- Importance factors need to be developed and agreed to by co-located lifelines to prioritize capital improvement and increase resilience and recovery
- Old, non-conforming systems need to be identified and replaced as prioritized by their importance

Northridge USA
1994



Significant Interaction Between Many Lifelines!