# INFRASTRUCTURE INTERACTIONS – RESPONSE AND RECOVERY TIME

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**ABSTRACT:**

This paper covers the interaction of various public works facilities after a major earthquake. It shows how damage to one facility can impact damage response recovery times to others that are also damaged. Both domestic and international examples will be cited showing lessons learned from specific earthquakes as related to emergency preparedness and response. Examples will be given demonstrating how minor, inexpensive preventive measures can greatly reduce damage, repair times and impacts on other facilities. Recommendations will be made related to emergency preparedness, disaster planning, emergency simulations, and loss prevention.

**KEYWORDS:** Earthquake, Infrastructure, Emergency response

## 1. FORWARD

Much of this information was collected during post-earthquake investigations conducted by the Earthquake Investigations Committee (EIC) of the Technical Council of Lifeline Earthquake engineering (TCLEE), American Society of Engineers (ASCE). The EIC is established to initiate, organize, train for, coordinate and evaluate the performance of lifelines following earthquakes. Members of the committee are employees of lifeline industries, consulting engineers, and academics from the United States, Canada and Europe and Asia. Members of the investigation team coordinate with other groups and may participate in groups organized by other organizations. They gather performance data, both good and bad, from earthquakes in order to provide information for practitioners to improve the performance of lifeline systems. The international earthquakes that have been investigated by this committee include: the 1985 Chile, 1988 Soviet Armenia, 1990 Philippines, 1991 Costa Rica, 1992 Turkey, 1995 Kobe, 1999 Turkey (Izmit), 1999 Chi Chi (Taiwan), and 2001 El Salvador earthquake. United States earthquakes investigated include: 1989 Loma Prieta, 1992 Landers, 1994 Northridge, 2000 Napa, and 2001 Nisqually earthquakes. More recently this committee has collected infrastructure damage data for earthquakes in India, Summatra, Peru, Algeria, Japan along with other hazards including Hurricane Katrina and the Pacific Northwest Storms of 2007.

## 2. EARTHQUAKE HAZARDS – SOIL INTERACTIONS

Most infrastructure components are either buried in the ground or constructed on top of the ground. In addition to the horizontal and vertical ground shaking of infrastructure facilities, the reaction of the soils to the shaking can be even more important. Some soil characteristics subject to earthquake shaking include: liquefaction, landslides, faulting, amplification and construction methods.

### *2.1 Liquefaction*

Liquefaction of soils that facilities are buried in or constructed on can have many different effects; foundations can sink or otherwise be displaced; buried facilities can float; and lateral spreading in sloped soils can have a significant impact. Figure 2.1 shows liquefaction damage at a wastewater treatment plant in Japan. Figure 2.2 shows how lateral spreading stretched a power line in Algeria.

Figure 2.1 – Liquefaction induced settlement

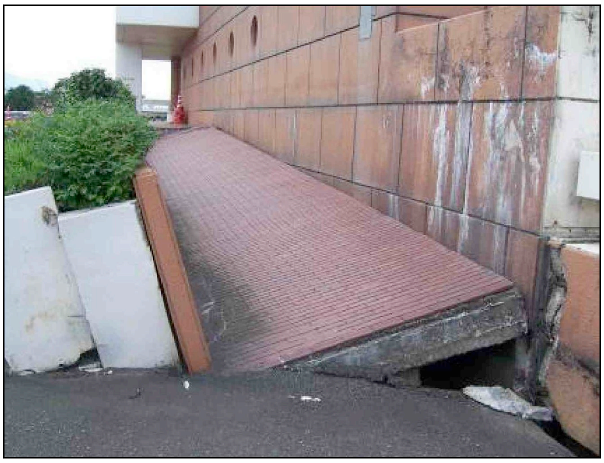

Figure 2.2 – Liquefaction causing lateral spread stretching on power lines

### *2.2 Landslides*

Shaking of the ground can trigger significant landslides in susceptible soils. Any infrastructure components constructed on or below these landslides will be damaged or destroyed. Figure 2.3 shows how a landslide can block a highway. Figure 2.4 shows how a highway on a landslide can be swept away.

Figure 2.3 – Large rockfall blocks a highway in Japan

Figure 2.4 – Landslide swept old highway (on right) down slope

### *2.3 Faulting*

The obvious impact of an earthquake is where there is surface faulting. This does not occur for all earthquakes, but when it happens, the damage can be significant. There can be both horizontal and vertical displacements typically ranging from 1 to 20 meters horizontally and 1 to 10 meters vertically. Any infrastructure facilities buried or founded directly on the fault will be significantly damaged. Figure 2.5 shows a pier in Kocaeli earthquake, Turkey damaged from an approximate 1 m horizontal displacement.

Figure 2.5 – Offset in track on pier

### *2.4 Other Soil Interactions*

In addition to the direct soil interactions, certain soil types can amplify earthquake impacts creating more damage than otherwise would have been expected. Poorly compacted or placed fill can also result in subsidence, movement or sliding that can damage any facilities constructed on or through them.

## 3. WATER AND WASTEWATER VULNERABILITIES

Water and wastewater systems are often vulnerable to serious damage due to shaking and ground displacements from an earthquake. Both systems have many similar components such as pipelines, tanks and pumps that require special attention during the design and construction process to prevent damage.

Some of the vulnerabilities include:

- Pipeline joint failures. This could include compression, tension and deflection failures.

- Lateral and vertical displacements. This type of damage could be from faulting, subsidence, liquefaction, and landslide. This could impact facilities such as pipelines, adjacent structures and electrical systems.

- Water sloshing. This is a major cause of damage to tanks and tank appurtenances. Sloshing can damage baffles, weirs, scrapers and other equipment in sedimentation tanks rendering them unusable. Sloshing can also cause water storage tanks to move off of their foundations destroying the inlet/outlet piping and making it impossible to return the tank to service. Figures 3.1 and 3.2 show evidence of some violent uplift during the Landers Earthquake in California.

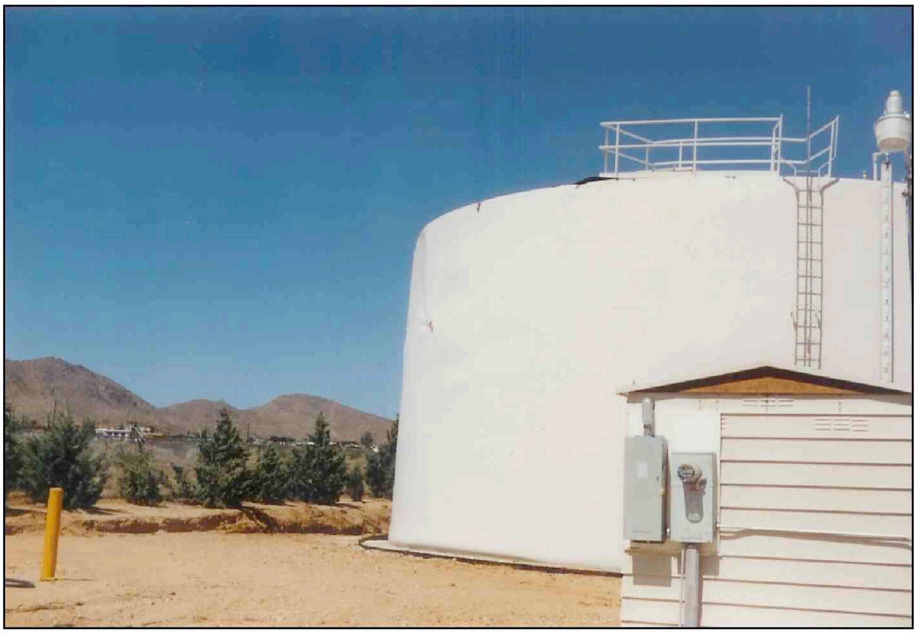

Figure 3.1 – Roof plate damage due to sloshing uplift

Figure 3.2 – Piping damage due to tank rocking and elephant foot failure

- Power outages.  Most water and wastewater facilities require power for pumps, treatment units and control systems.  Many facilities are equipped with emergency generators to handle most or all of the load demands.  However, in many cases, the emergency generator is undersized, fails, or runs out of fuel and the facility is rendered useless.

- Hydraulic surges.  Pressurized water and sewer systems can be subject to water hammer and vacuum effects when pipelines break allow water to drain faster than intended.  Water hammer can overpressurize and damage components throughout the system.  Pipe breaks can cause tanks that have undersized air vents to implode.

- Electrical panel movement.  Many treatment plants, pump stations and other electrical facilities have control panels for electrical switchgear and controls.  Often, these panels are not anchored and can move or even fall over.  When this occurs, electrical connections a broken causing equipment failure. Figure 3.3 shows typical seismic bracing of control panels.


Figure 3.3 – Seismic Control Panel Bracing in Japan

- Unanchored piping and equipment. As with electrical panels, other unanchored facilities can slide or fall over and fail. This could include computers, lab equipment, pumps, chemical storage tanks, process piping and other similar equipment. Figures 3.4 and 3.5 show some good examples of proven seismic bracing for chemical feed piping and computer monitors.

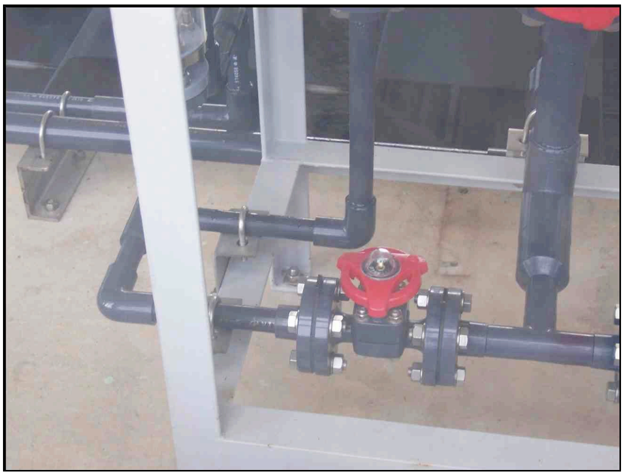

Figure 3.4 – Well anchored chemical feed piping

Figure 3.5 – A well braced computer monitor

- Rigid connections. Pipelines constructed without flexible couplings can be subject to stresses that will cause them to fail. This is especially true at wall/ground interfaces where differential movement between a structure and the ground can put extra stress on a pipeline.

## 4. ROAD, HIGHWAY AND BRIDGE VULNERABILITES

Transportation systems are quite vulnerable to damage during major earthquake events. Roads and highways are founded on soil and subject to movements as described in Section 2. Quite often, damage can be repaired using temporary paving or simply recompacted soil. Figures 4.1, 4.2, and 4.3 how typical damage from lateral spreading, landslides, liquefaction and subsidence.

Figure 4.1 – Rock netting dragged onto road by landslide in Japan

Figure 4.2 – 3 meter subsidence cause by liquefaction

Figure 4.3 – Lateral spreading caused damage to the road and a water line

Bridges have the geotechnical issues associated with the foundations and abutments. In addition, the structural design must withstand the additional stresses placed on components by the earthquake movements. Bridges are critical infrastructure links and often contain many, non-road related utilities. Critical bridges need to be identified so that contingency repair or bypass plans can be made.

Quite often, the abutments are damaged by movement of the main structure or subsidence. This damage is typically repair using asphalt or dirt fill. Damage to columns varies on the location and magnitude, but even partial column failure can result in a collapse. Lateral movements can cause the bridge deck to pull off of abutment or column seats resulting collapse of the span.

## 5. EMERGENCY RESPONSE INTERACTIONS

Failures of one infrastructure component can cause another, unrelated component to fail or cause its repair time to be lengthened. Some examples of this interaction include:

- A major watermain break could cause a sink hole. This would make the road impassible or at a minimum, reduce its capacity. In addition, other co-located facilities such as buried sewer, electrical and gas could also be damaged.
- Bridges and bridge abutments can fail causing numerous co-located utilities to fail. In addition, transportation failures hinder life saving activities and restoration efforts.
- Power plants, transmission towers and distribution lines can fail causing treatment plants, pump stations and controls to fail. This could result in loss of water, contaminated water and loss of life.
- Sewer pipelines and treatment plants can fail contaminating water supplies and receiving water bodies.

There are numerous other combinations of interactions, many of which can cascade failures into one another. For example, a power outage could cause water pumps to stop creating a pressure surge that breaks a pipeline. The pipeline break could wash out a road and take out co-located utilities such as gas, communications and power.

## 6. LESSONS LEARNED

Having documented earthquake damage in both the United States and around the world, there are many lessons to be learned, both good and bad. In general, all engineered facilities perform to restorable levels after an earthquake. There may be building code differences in different countries, but any application of a code or standard to the design helps prevent damage and save lives. However, in those instances where adopted codes are not enforced, or corruption compromises construction materials and methods, sub-standard construction can cause significant infrastructure failures. If this occurs in a critical building, such as a control building, the building can fail causing damage to what would have been otherwise sound control equipment.

After a major event, emergency response protocols dictate that efforts focus on rescue and housing with little consideration to public works restoration or repair. At first, as people are displaced, public works demands are low in the damaged areas. However, critical infrastructure is necessary to evacuate victims, bring in rescue teams, distribute relief supplies and begin restoration of the infrastructure. In those instances where public works officials are a part of the first responders, the infrastructure repair time line is reduced.

Some other specific lessons learned include:
Site effects (mostly soil issues) can cause unforeseen damage if not identified prior to design or construction.
Having repair materials and spare part available are essential for reducing repair times and restoring the infrastructure facility.
Mutual aid is very beneficial for restoring a functioning infrastructure. Aid from other, undamaged areas can provide critical manpower and equipment that can be used to shorten restoration times. Have mutual aid agreements in place prior to an earthquake will even shorten this time further.

## 7. RECOMMENDATIONS

Based on these lessons learned, there a basic recommendations that can be analyzed or implemented by agencies to lesson damage, reduce response times and lessen infrastructure restoration effort. Some of these include:

- Prepare and Emergency Response Manual. This manual should outline all necessary emergency responses from a first responder and subsequent responder level. Interaction with other agencies should be included to improve and enhance communications.
- Conduct emergency simulations. Simulate responses after and earthquake. Include all infrastructure agencies in the simulation to assure communications systems are in place and compatible and to verify if one portion infrastructure is dependent on another. Generators should be run under full load to determine fuel consumption and provide assurance that they will function for a long duration. Consider bypass and detour routes. Practice back-up communications systems.
- Maintain adequate supplies of materials, parts and fuel inventories. Inventory critical components and maintain them in a location that will not be damaged by the earthquake. Provide braced shelving and shelf bins to avoid spillage of emergency supplies.
- Provide flexible connections for critical piping and conduits. This is especially true at structural interfaces and ground penetrations.
- Provide anchors and seismic bracing for critical equipment. Include seismic straps for computers, monitors, telemetry equipment and communications equipment.
- Establish potable water quality testing procedures. Develop a boil water notice procedure to be implemented immediately after an earthquake.
- Provide for system redundancy and isolation. Determine earthquake hazard areas (faults, landslides, and liquefaction) and develop plans for bypassing critical facilities. Develop detour routes for emergency traffic.
- Conduct and earthquake vulnerability assessment. Tour infrastructure facilities to determine likely vulnerabilities during and earthquake. Once they are identified, take preventative measure to either prevent damage to the facility or make so it can rapidly be restored to service.