Reestablishment of transport systems after an earthquake and establishment of lifeline systems

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BACKGROUND
Social order relies on a complex network of infrastructure lifeline systems. When a disaster strikes, restoring lifeline systems is at the heart of restoring social organization.

At the center of lifelines is a multimodal transport system. Highways are among the oldest of lifelines. There are generally significant impacts to transport lifeline systems following an earthquake. These systems can often be interrupted and destroyed as a result of landslides, failed bridges, geographic proximity to a fault line, and liquefaction. Bridges are usually the most vulnerable link. Following a seismic event, the reestablishment of critical throughways and corridors is essential to recovery efforts. Although each event is site specific, by looking at case studies of past disasters, several lessons can be learned.

UNITED STATES EXPERIENCE
The Loma Prieta Earthquake occurred on 17 October 1989 in the San Francisco Bay Area of California (United States). The earthquake was caused by a slip along the San Andreas Fault and measured 6.9 on the Richter scale. Though the earthquake only lasted about 15 seconds, it was responsible for widespread damage, killing 67 people, injuring 3,757, and leaving 8,000 homeless. Transport, utilities, and communications were extensively disrupted. Eighteen bridges were closed to traffic. Damage sustained by the California highway system is one of the legacies of the Loma Prieta Earthquake.
The Northridge Earthquake occurred on 17 January 1994 in the city of Los Angeles, California. The earthquake registered 6.7 on the Richter scale, but the ground acceleration was the highest recorded in an urban area in North America. The earthquake caused about USD 15 billion in damages and was responsible for 72 deaths and over 12,000 injuries. Six bridges failed, and four others sustained such extensive damage that they required replacement. Some of the busiest freeways across the state, the Santa Monica Freeway (I-10), the Antelope Valley Freeway (SR 14), and the Golden State Freeway (I-5) Interchange were interrupted by the Northridge Earthquake. Despite the extensive damage, all structures were operational 10 months following the earthquake.

The Nisqually Earthquake occurred on 28 February 2001 in the city of Seattle, Washington. The earthquake measured 6.8 on the Richter scale and lasted approximately 45 seconds. Considering the duration of the earthquake, damage was fairly minimal, with no deaths reported and around 400 injuries. Damage varied across the region and was generally linked to soil conditions. Most bridges suffered light structural damage and a majority were only briefly closed or never closed at all. A few structures, predominantly constructed before 1980, required prolonged closures. Prior to the Nisqually Earthquake, the city of Seattle and Washington State Department of Transportation had undertaken a bridge seismic retrofit program, which is credited with limiting the structural damage caused by the earthquake in 2001.

**GENERAL APPROACH**
In any major recovery effort, the situation demands simultaneous actions at an accelerated pace. While unique site conditions and resources dictate specific recovery efforts, the case studies above provide general lessons. Following any catastrophic hazard, the California Department of Transportation (Caltrans) prioritizes its relief efforts as follows: (i) public safety, (ii) protect and preserve facilities, and (iii) reopen the transport system as quickly as possible.

Within the transport system, essential lifelines are prioritized to efficiently allocate resources. Following the Northridge Earthquake, for example, all leadership entities including federal, state, local, and industry leaders took a hands-on approach in the reestablishment efforts. Personnel was organized and allocated to maximize individual strengths.

In June 1994, five months after the Northridge Earthquake, a task force was assembled to gather and identify crucial information about the recovery process. Consisting of expert representatives, the task force interviewed 80 people from Caltrans, industry, and federal highways and sent out 140 questionnaires to contractors. The recommendations that were developed from these data are discussed throughout this note.

**Preparation and planning**
To mitigate the negative impact to transport lifeline systems after an earthquake, evidence from previous case studies has demonstrated that preparation greatly influences the success of recovery efforts. Post-earth-
earthquake response efforts can be enhanced by (i) improving design standards and methods through research and analysis of past events, and (ii) identifying vital lifeline connections within the transport system and strengthening/retrofitting those structures accordingly.

In all of the case studies, pre-earthquake mitigation strategies significantly reduced transport infrastructure damage and economic losses. Several examples support this.

Prior to the Loma Prieta Earthquake, hinge and joint restrainers were implemented on many bridges located near the epicenter. This is credited with preventing the collapse of many of these structures. In the case of the Northridge Earthquake, between 1971 and 1981 significant progress in developing and implementing seismic design standards was made. Newer structures (those constructed after 1981) sustained much less damage than those constructed before 1971.

Prior to the Northridge Earthquake, 122 bridges had been retrofitted as a result of a legislation plan implemented following the Loma Prieta Earthquake. As a result, none of these structures were damaged. Typical structural damage from the Northridge Earthquake included short column shear failures on Route 118 such as the Mission/Gothic underpass and in Santa Monica. Several of these structures were scheduled for retrofit but the work had not yet commenced at the time of the earthquake; it is thought that they would have been preserved had the retrofit taken place. Most of the affected bridges in the Nisqually Earthquake were structures in the Puget Sound Region that had not been retrofitted. In “Competing Against Time,” a report of the governor’s Board of Inquiry on the 1989 Loma Prieta Earthquake, recommendations emphasized the importance of implementing seismic safety provisions. It was recommended that lifeline transport system agencies:

- Establish a seismic policy and goals, and implement seismic practices to meet them.
- Perform earthquake-vulnerability analyses and evaluations of key structures and install seismic instrumentation.
- Institute independent seismic safety reviews for key structures.
- Conduct a vigorous program of professional development in earthquake engineering disciplines at all levels of their organizations.

Other recommendations that complemented this approach included to provide incentives to local agencies for implementing seismic safety provisions (from the Geotechnical Board, National Research Council).

Limiting the destruction of transport systems as a result of any disaster, in conjunction with improving the response to such an event, can aid in the efficiency of
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Reestablishment efforts. In the event of an earthquake, responders can draw from other disaster relief plans. For example, prior to the 1984 Summer Olympics, the city of Los Angeles developed an extensive emergency preparedness and traffic management plan. California had also developed a statewide Incident Command System (ICS) in response to several fires that swept across Southern California during the 1970s. The ICS organized the coordination between municipal, county, state, and federal fire authorities to address recurring problems that arose during fire fighting efforts. The ICS has since served as a comprehensive model for hazard management and has subsequently been adopted by the Federal Emergency Management Agency (FEMA) for national use. Federal emergency response was coordinated through the ICS following the Northridge Earthquake.

Specific to earthquake recovery, recommendations from analysis of the Northridge recovery efforts included developing prioritized lists of vital public facilities. Jim Roberts, former chief deputy director for Caltrans emphasized:

- The importance of having prepared emergency plans (comprehensive and function specific).
- An emergency operations center.
- Emergency phone rosters.
- Maintaining a system of trained supplementary personnel (e.g., volunteer engineers).
- Establishing agreements between neighboring states during a response and recovery seminar.

Recommendations following both the Loma Prieta and Northridge Earthquakes showed the importance of implementing periodic simulated training exercises. These exercises helped to evaluate emergency response plans and test the weaknesses of existing lifeline systems. Simulation exercises are extremely valuable in getting people prepared and able to respond immediately in the event of a disaster.

Emergency response

As evidenced in all three case studies, immediate responses to public safety required that staff navigate obstructed lifelines. Following the Northridge Earthquake, for example, rescue crews included a structural engineer to identify hazardous conditions during rescue operations. By having this type of expertise on hand as a resource for rescue/recovery crews, the safety of emergency response efforts was enhanced.

Initial assessments

In any hazardous event, one of the most significant preliminary challenges is obtaining a reliable assessment of total damage and losses. In the United States, initial estimates of potential economic and life losses after a natural disaster are often determined through the use of computer software. Hazards U.S. Multi-Hazard (HAZUS) software, developed by FEMA, is a simulation tool applicable to various hazardous events. HAZUS has the potential to assist in forecasting damage and identifying key structures to be inspected within hours after an earthquake.
Immediately following the Northridge Earthquake, HAZUS helped to identify the extent of initial bridge inspections required. Typically, in damaged regions following an earthquake, key support and rescue personnel are preoccupied by the damage sustained to their own homes. As a result, damaged regions are supplemented with trained staff/personnel from other regions to carry out required inspections and assist in the recovery efforts.

In the Northridge Earthquake, once key staff members were identified, inspection teams were put together and generally comprised: (i) a field maintenance engineer (with experience assessing damaged structures and various structure types) and (ii) a design/seismic engineer. The intent of having both a maintenance inspector and an engineer was to balance ground experience inspection efforts with theoretical design knowledge. Once initial inspections were completed, inspection reports were directed into a centralized command center.

Following the Nisqually Earthquake, the initial estimate of potential damage and losses was produced using a HAZUS model. While HAZUS is a helpful tool in quickly identifying potential losses, the software projected much greater economic and life losses than what actually occurred. The unrealistic output was generally attributed to an inaccurate model of the seismologic parameters, soil conditions, and the tendency of the software to exaggerate losses in small to moderate earthquakes. As a result, recovery efforts should be based on multiple sources of information, not just the earthquake magnitude.

In assessing the damage following the Nisqually Earthquake, inspections were performed on all structures within a 73 mile radius of the epicenter. Structures in this region were owned by different agencies, including the state, counties, and cities, and all maintained separate inventory records of bridges. Each agency was contacted and a damage report was developed to ensure consistency and accuracy of collected information. From this, the Washington State Department of Transportation (WSDOT) provided an electronic form to develop a database, the Washington State Bridge Inventory (WSBI). The WSBI provided information for nearly all of the bridges in the state.

**Communications**

Modern communications technology has significantly contributed to successful recovery efforts after major disasters. Cellular phones greatly enhanced communications in the recovery efforts for the Loma Prieta, Northridge, and Nisqually Earthquakes. Amidst power outages and overwhelmed phone services, emergency workers and leaders turned to cellular phones and radios. On-site fax machines were used to maintain formal documentation, including hard copy records of contract documents.

Following the Northridge Earthquake, Caltrans established a single point of contact to coordinate the flow of all disaster-related information. In addition to managing internal communications within and among agen-
Overall, in the cases studied, communications efforts focused on three types of systems: (i) radios, (ii) cellular phones, and (iii) landline phone systems. All three proved equally important in ensuring operational communications at all possible times, and all three should be considered in earthquake recovery plans.

Traffic management

Effective traffic management after an earthquake is vital to successful disaster recovery and requires significant coordination. After the Northridge Earthquake, an emergency transportation relief task force was created to manage damaged/affected transport lifelines. The task force consisted of representatives from the Federal Highways Administration, Caltrans, Los Angeles County Metropolitan Transportation Authority, the city of Los Angeles, the counties of Los Angeles and Ventura, and the California Highway Patrol. All agencies created subcommittees and convened every morning for a period of time after the earthquake. Immediate traffic management control measures consisted of using detours previously developed for other hazards including spills or high traffic event scenarios. Preselected detours were immediately accessed to initiate preliminary traffic management.

Furthermore, sophisticated traffic control centers in Los Angeles were used to make changes in signal timing, monitor intersections with cameras, coordinate traffic response, and direct roadway service patrols from a central location. Other means of managing traffic included establishing a ferry system to alleviate vehicular traffic, scheduling night deliveries for truckers to open up critical lifelines during the day, and creating numerous vanpools. Van and carpools were given preference on shorter, limited-capacity, detour routes to discourage single passenger cars.

Damage sustained on the Route 14 Freeway disrupted the only freeway connection to several large and densely populated cities in California. Temporary railway stations were instantaneously constructed on existing rail routes along the corridor. Four stations were constructed within a month of the earthquake with two stations constructed within the first seven days. This commuter rail line supplemented transportation for a vast number of commuters.

Additional lessons learned from the Northridge Earthquake included conclusions reported by the Transportation...
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Reestablishment of transport systems after an earthquake and establishment of lifeline systems following a review of the transportation decisions made in response to the earthquake:

- Providing immediate transportation solutions took precedence over the opportunity to change motorist behavior.

- Stabilization of traffic conditions took several weeks to several months.

- Where sufficient alternate routes existed, motorists continued driving; where convenient detours were not available, transit options became much more attractive.

- Availability of accurate traffic data was critical in developing emergency detours.

- Areas with well-developed traffic-management centers were able to accommodate sudden traffic changes more easily.

Reestablishment process

In the case of the Loma Prieta Earthquake, disputes over the cost and expected levels of repairs caused significant recovery delays. One example of delays included a peer review that was established by the California Department of Transportation immediately after the earthquake. The purpose of the team was to review aspects of the reconstruction; however, they did not convene until March 1990, five months after the earthquake and after repairs had begun. Many repairs that had begun before the review had to be redone or abandoned, resulting in substantial delays. Considerable delays and economic waste could have been avoided if peer review panels had been preselected in anticipation of a seismic event.

The reestablishment process following the Northridge Earthquake was unparalleled to previous earthquake recovery efforts in the United States with regard to its organization. All efforts focused on avoiding red tape by streamlining processes. Governor Pete Wilson exercised emergency powers to significantly reduce the time required to issue construction permits. The director of Caltrans empowered the districts to approve emergency contracts and, thus, expedited recovery efforts. All actions helped to empower people and local control, while management provided general overall direction and coordination.

Reconstruction of the transport system was executed through various types of contracts including time and materials contracts and variations of bid contracts. Initially, emergency time and materials contracts called force accounts were issued for demolition and shoring of damaged structures. This was followed by traditional bid contracts issued through the construction branch. Bids were submitted only hours or days after plan, specification, and estimate packages were issued. Some contracts...
were awarded the same day as the bid opening, and were immediately provided the Notice to Proceed with the construction time starting at midnight that evening. Contracts were modified to establish parameters (e.g., equipment rental rates) that would typically be intended for a standard working day, not continuous construction.

As the reestablishment process continued, innovative financing contributed to the success of the project. Contractors incurred significant expenses by scheduling double shifts, using equipment twenty-four hours a day seven days a week, and paying premiums for immediate deliveries of materials. To alleviate potential cash flow issues, payments to contractors were made in two-week increments instead of one month. In other instances, when the oft-rushed initial cost estimates varied from actual costs, reconstruction efforts were prepared to acquire supplemental money as needed for particular projects. Effective organization and financial solutions prevented potential delays in the reconstruction.

Efficient project operations prevented potential delays during the reestablishment process. After the Northridge Earthquake, disputes and decisions on project sites were settled in hours. Hotlines were established to expedite answers/responses to contractors in the field and helped to reduce paperwork. Above all, work was based upon trust, pride, and a mutual respect developed among officials and contractors. This was essential for completing work while formal documentation could be completed.

**Reconstruction technical challenges/solutions**

After the Loma Prieta Earthquake, dramatic failures of the Cypress Viaduct and a critical link of the San Francisco–Oakland Bay Bridge required complete reconstruction of the freeways on new alignments. The reconstruction of highways after the Loma Prieta Earthquake proved to be more challenging than the reconstruction after the Northridge and Nisqually Earthquakes. In contrast, reconstruction efforts after Northridge were accelerated by replacing damaged facilities in-kind and in-place. This limited right of way and environmental impact throughout the reestablishment process. This approach further assisted recovery efforts by making use of as-built plans and other available data, which expedited the redesign process. On several occasions, updated as-builts were used for bidding purposes and full plans were provided at a later date. On a few bridge replacement projects, both steel and concrete were evaluated to provide flexibility to bidding contractors. Engineers were assigned directly to project sites to provide immediate assistance with calculations.

Legislation also contributed to the challenges faced by reconstruction crews after the Loma Prieta Earthquake. Existing laws were partial to repairing facilities back to their pre-earthquake condition. This condition was not always the safest; for example, several of the damaged structures were designed to endure seismic loads. In a report published by the National Research Council, a
recommendation was made to allow flexibility in policies to execute appropriate repairs of damaged or collapsed facilities. Had this been in place during the Loma Prieta Earthquake, it would have enabled the construction of new structures with improved seismic resistance during the repair effort.

**KEY LESSONS**

Reestablishment of lifelines after an earthquake is an extremely complex process. Networks of transport, utilities, communications, and other lifeline systems are all interdependent. All entities can benefit from a detailed evaluation of the reestablishment processes following an earthquake. This reduces the timelines associated with reconstruction and shows the optimal processes for the future.

In assessing the lessons learned from the three case studies from the United States, the key lessons are:

- Advance preparations mitigated damages.
- Redundant arterials provided traveler mobility.
- Traffic management centers provided operations.
- Public transportation and other mode alternatives provided travelers with commuting options.
- Innovative contract bidding and construction methods minimized construction time and increased accountability.
- The multimodal response did not change traveler behavior.

Further, in all of the case studies it was evident that the recovery process was facilitated through preparation. Examples include prior contracts with construction crews, information provided to inspectors, and execution of detours. Such research can continue to improve planning and response efforts, which have the ability to prevent direct and secondary losses during extreme events.

**End Note**

References


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