AFTERSHOCK

Dealing with the Highway Crisis After the Loma Prieta Earthquake

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The afternoon of October 17, 1989, was clear and warm in the San Francisco Bay area. As millions of television viewers awaited the start of the World Series game in San Francisco's Candlestick Park, the earth shook. What viewers witnessed, before their screens went blank, was the largest magnitude earth movement in the mainland United States since the San Francisco earthquake of 1906.

The Loma Prieta Earthquake, named after the peak and ridge near its epicenter, lasted for 15 seconds and had a Richter magnitude of 7.1. Its impact was felt by a major portion of California's inhabitants and by its economy. The most immediate and serious results were collapsed buildings, highways, and bridges with a resulting loss of 62 lives; fires; loss of electric power; ruptured water and gas lines; and earth slides. The aftereffects—failure of water lines, formerly undiscovered damage to buildings, and main highways awaiting full service use—are still being felt today.

Effect on the Highway System

The most significant damage was caused to the state highway system. Local roads were less affected. The major highway service disruptions occurred in San Francisco and Oakland, with the failure of the main bridge between the two cities causing the most concern. Within 48 hours, more than 1,500 bridges were inspected—many of them several times because aftershocks added further damage. Of these bridges, 74 suffered minor damage, 23 major damage, and 13 were closed within a short time. Of the 13, 1 was reopened after five hours and 2 others within two days. Only 5 remain closed today.

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Failures

The following major highway system failures occurred:

Route 1: Twin 800-foot bridges on a freeway section of this major coastal route collapsed as the supporting piles sheared off at the bottom of the pile caps. In some instances, the piles then penetrated the deck.

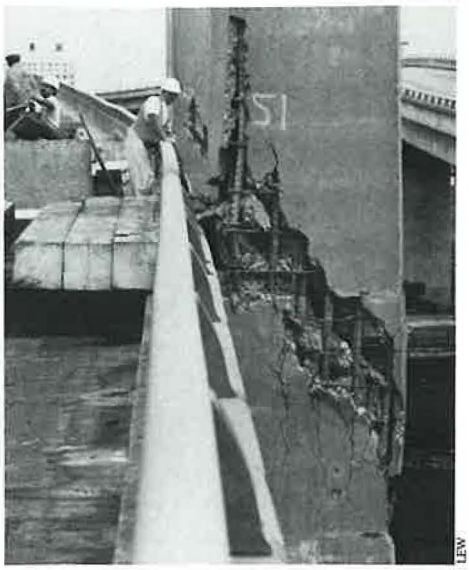
Route 17: Several large and many smaller slides occurred along this four-lane expressway, the main highway between the San Francisco area and Santa Cruz. Median barriers in several locations became retaining walls as slides occurred on both sides of the highways. By breaching the barrier in several places, it was possible to restore restricted traffic over the route soon after the earthquake while emergency slide removal efforts were under way.

Traffic mitigation was handled by a combination of rerouting, time restrictions, emergency bus and rail services, and convoying during the slide removal work. Repair of pavement heave, buckling, median barriers, and drainage systems was also accomplished while the slide removal work was continuing. The facility was restored to full service in 35 days.

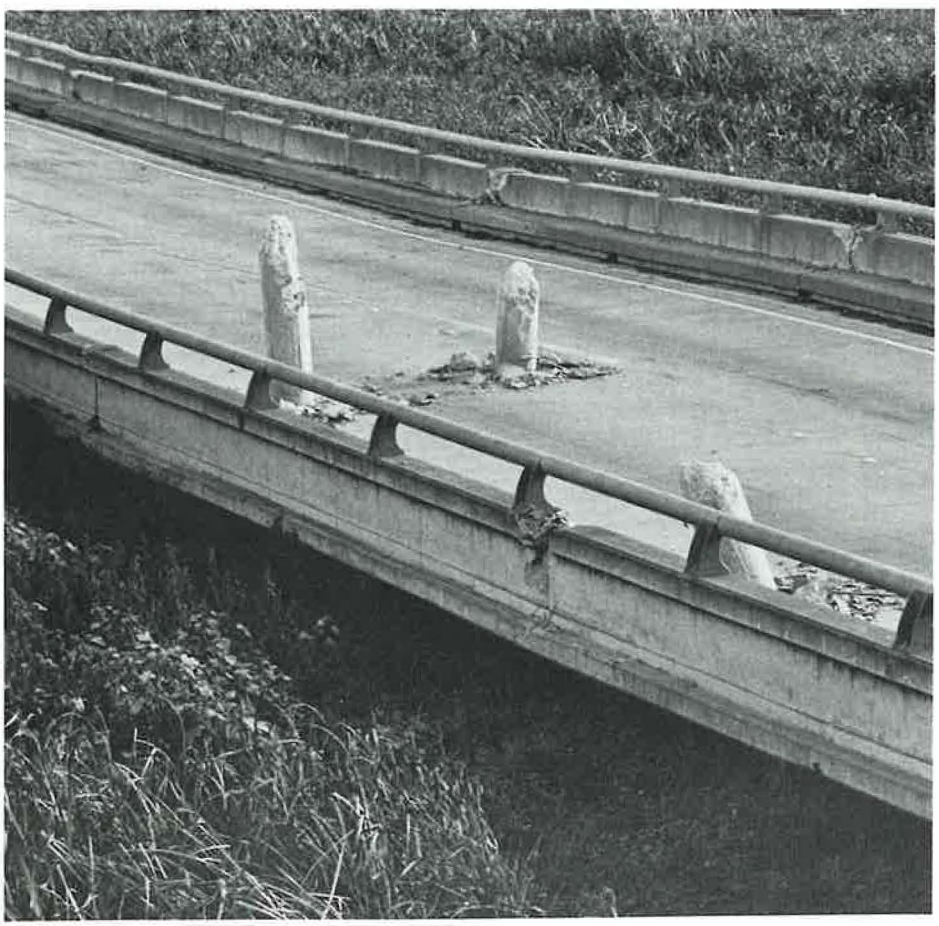
San Francisco Freeways: No structures on the freeway system within San Francisco completely failed, but severe damage to columns on various structures required closure of three major routes. One of these, the Embarcadero Viaduct (Route 480), is a major traffic distribu-

tor and collector between the San Francisco Bay Bridge and central San Francisco, Chinatown, and the Fisherman's Wharf areas. Portions of the closed areas were soon restored to service, but routes 101, I-280, and I-480 will not be completely opened until the spring of 1991 because repair and retrofitting of structures will entail considerable construction. Of these three closures, the loss of the Embarcadero portion of Route 480 has caused the most discussion because it has rekindled the debate about the need for the present viaduct. The state has agreed to follow the wishes of the city on any reconstruction. At this time the future of the viaduct is uncertain.

San Franciso-Oakland Bay Bridge: The Bay Bridge was closed after the failure of two 50-foot closure deck spans over a main longitudinal stiffening tower. These spans linked the 506-foot truss span to the west with a 289-foot truss span to the east. The failures occurred when the anchor bolts on the tower end of the east truss span gave way. This allowed the truss to move and the top roadway span to move off its bearing support. It moved more than the 5.5-inch width of the bearing seats, causing the top span to fall onto the lower span.



Earthquake damage: (*above*) diagonal cracking of columns on I-280; (*below*) penetration of deck by supporting piles on bridge at Struve Slough between Monterey and Santa Cruz.



Cypress Viaduct on I-880: This one-and-a-half-mile long, three-level structure collapsed over the north half of its length. The most important contributing factors to the collapse were inadequately confined vertical column reinforcing steel (according to today's standards), and the seismic response of soft soils.

Service Restoration

Rescue and removal operations continued around the clock for about a week. Immediately after all rescue was completed in a section, the section was demolished and removed from the area.

Testing

The University of California at Berkeley and the California Department of Transportation (Caltrans) collaborated on a full-scale test of a standing portion of the Cypress Street Viaduct to determine its natural frequency and dynamic response and to test proposed column retrofit techniques for future rehabilitation of San Francisco viaducts. A two-span section containing three bents (points of support) was isolated and fitted with reaction frames and large hydraulic jacks. Both low-intensity vibration tests and high-intensity static load tests were conducted on both the as-built and retrofitted structure. This was a rare opportunity to gather data from a full-scale bridge structure, and the information will be used in analyzing the mode of failure and the effect of retrofitting such structures for today's earthquake forces.

Retrofitting

On the basis of these tests and research conducted at the University of California at San Diego, the bridge seismic retrofit program is being accelerated. More than 400 bridges with single columns at the bents are being analyzed and the appropriate column retrofitting details are being designed.

Several contracts, each containing many bridges, have been advertised for construction and two projects in the Los Angeles area were placed under construction in April 1990. Caltrans also plans to advertise several projects each month during 1990 and 1991 so that all 400 bridges can be retrofitted by mid-1992. Bridges with multiple column bents are a lower risk and will be retrofitted beginning in late 1991, with work completion anticipated by the middle of 1994. In addition, Caltrans and Los Angeles and Santa Clara counties have the responsibility to manage the retrofitting of all locally owned bridges in high-risk earthquake zones. It is expected that most of that work can be completed by the summer of 1992. The double-deck viaducts in San Franciso are a special case, and retrofitting in stages was planned to start in spring 1990. Further research must be conducted before final retrofitting can be completed.

San Francisco-Oakland Bay Bridge failure after anchor bolts on truss span gave way, resulting in collapse of two closure deck spans.

Transit Response

Because of its longstanding commitment to public transportation and the rich mix of services, the Bay Area was able to marshall a substantial array of transit alternatives. The variety and depth of public transportation services already in place allowed a comprehensive and flexible system of rail, bus, and water transport, complemented by new highway high-occupancy vehicle facilities, to be put in place virtually overnight. Without a strong local transit funding base, some degree of redundancy, expansion capacity, and widespread use of transit, such a response might not have been possible.

Public transit agencies responded with all available resources. The Bay Area Rapid Transit (BART) system, designed to withstand earthquakes of 8.0 magnitude and greater, came through essentially unscathed. The system was completely reopened about nine hours after the occurrence of the earthquake. Because electrical power was knocked out for all of San Francisco, emergency backup lighting was needed in BART trains and stations within the city. Limited propulsion power was fed through the Transbay Tube from the East Bay to allow all San Francisco trains to be moved safely into stations for off-loading. Fears of gas leaks in nearby office buildings caused service at two downtown San Francisco BART stations to be interrupted for several hours.

San Francisco Muni service stopped because of the loss of power. The Muni Metro light rail system, the electric trolley system, and the cable cars all came to a halt. Some passenger evacuations from the underground light rail line had to be undertaken, but there were no injuries to patrons. Full Muni service was restored within a few days.

With the Bay Bridge out of operation and BART closed initially for safety inspection, thousands of commuters were stranded in downtown San Francisco. AC (Alameda-Contra Costa Transit District) Transit, with more than 100 buses in San Francisco for the evening commute, set out on alternate routes north and south out of San Francisco, along circuitous routes crossing other bridges or circumnavigating the Bay. AC quickly rerouted its buses in the East Bay to increase service to BART stations and to the makeshift ferry terminal in downtown Oakland. Private ferry operators began emergency service from San Francisco to the Oakland terminal immediately, and continued all night until all stranded commuters had been transported.

Plans for Recovery

The day after the earthquake, plans were made to hold a regionwide meeting to evaluate emergency transportation needs. The Metropolitan Transportation Commission (MTC), the regional transportation planning agency for the nine Bay Area counties, and Caltrans agreed that the appropriate forum would be the regular monthly meeting of the region's Transit Operation Coordinating Council (TOCC), already scheduled for the following day. Attendance was broadened to include not only the larger public transit operator members of TOCC, but also most smaller public operators, private bus and ferry operators, port authorities, and federal and state emergency response officials.

Because most normal business activity was disrupted by the earthquake, trans-

portation needs for the remainder of the week were not critical. TOCC members agreed that Monday, October 23, would be the day on which most commuters would try to resume their normal travel patterns. Planners assumed that a three- to six-month period would be required for emergency service to be in effect. In the interim, TOCC focused on accomplishing four immediate objectives:

1. Find out how each agency was responding and what resources they have available to provide additional transit service;
2. Put all available service on the street, and worry about funding later;
3. Put together comprehensive information for the public and see that it reached commuters over the weekend; and
4. Set up a monitoring system to form a basis for adjusting service in response to demand.

The key elements of the transit response were to (a) add to BART's capacity, (b) promote and support the new ferries, (c) provide new park-and-ride locations, (d) increase public information on a large scale, especially for those who had never used transit, and (e) expand all bus and commuter rail service in all markets as commuters adjusted to the new travel realities.

Putting Plans to Work

Caltrans, MTC, and the transit operators held a major press briefing on Saturday, October 21, to describe the scope of the emergency transit services. The message to the public was

- If you do not have to travel, stay home.
- If you must travel, plan ahead and use public transit.
- If you cannot use public transit, use carpools, but do not drive alone.
- If you are an employer, allow your employees to work flexible hours, work at nights or on weekends, or work at home.

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Above: **BART system was closed for safety inspection after earthquake but reopened after nine hours, essentially undamaged.**
Left: **Ferry operators carried stranded commuters to and from San Francisco and East Bay terminals.**

Monday, October 23, came and went and the anticipated gridlock did not take place. A heavy rainstorm at rush hour wreaked havoc with the new ferry service, but most of the systems in place operated satisfactorily and many commuters decided to stay at home an extra day.

To keep up with the continuing changes in demand as commuters tried alternate routes and modes, special, expanded TOCC meetings were held weekly. Other developments included the institution of new joint fare instruments, breaking down years of resistance and forming the basis for new regional cooperation, and the installation of a new regional 800 telephone number to answer commuters' questions about available modes of travel. This, too, had been discussed for a number of years and now forms a basis for plans to further expand information to the public.

With the reopening of the Bay Bridge in mid-November, the largest part of the emergency was over, but travel patterns were still disrupted by the collapse or damage to the freeway system on both sides of the Bay Bridge. The special TOCC meetings continued through mid-December, when it was judged that service and demand patterns were stable.

Impact on Travel Behavior

Instant Research

The earthquake provided an instant, if chaotic, travel behavior research laboratory. A variety of data-collection projects was started almost immediately, although most of these projects have not yet produced conclusive results. These include traffic counts on all bridges, vehicle classification and occupancy counts, surveys of small and large businesses, a survey of trucking firms to determine impacts on goods movement, and a survey of motorists using the alternate routes when the Bay Bridge was closed.

The MTC Regional Travel Survey of about 10,000 households is now in the field. Coordinated with the 1990 Census, this first major regional travel behavior survey in a decade includes questions about post-earthquake travel pattern changes.

It will be months before all these data are collated and analyzed, but they should provide a wealth of information to help understand how travelers make choices. Until that time, the following summaries give an indication of how the typical Bay Area traveler has coped with the emergency.

Bay Bridge Corridor Demand and Capacity

The morning peak period mode split in April 1989 is shown in Figure 1. Of the more than 100,000 commuters who travel westbound toward San Francisco between 5 and 10 a.m., 66 percent were already using public transit or in carpools. It was believed that BART and the new ferries might be able to transport 10,000 or more travelers per half hour. If they changed their travel to fill in the early and late shoulders of the peak, it appeared possible to continue to carry the normal load if spread over five hours.

The change in morning peak transbay modes before, during, and after the bridge closure is shown in Figure 2. During the closure, there was a 10 to 15 percent reduction in total transbay person trips. The automobile trips shown were estimated from the change in travel on the bridges to the north and south of the Bay Bridge. Although the surveys will eventually help to explain the falloff in travel, it appears that discretionary transbay tripmaking all but ceased. After the reopening, total person trips approached previous levels, but a significant reduction in carpool use apparently has occurred. This may be because the approaches to the bridge have become so congested that the travel time advantage of the toll-free carpool lane through the toll plaza has been significantly reduced.

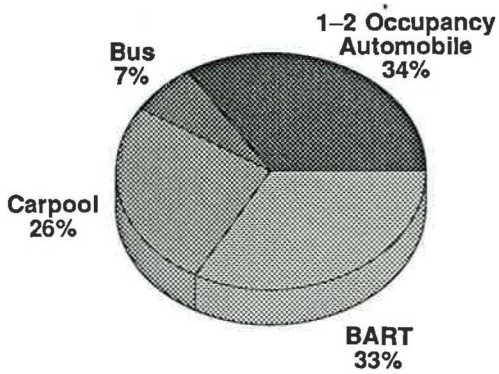

FIGURE 1 Bay Bridge corridor travel modes data before earthquake.

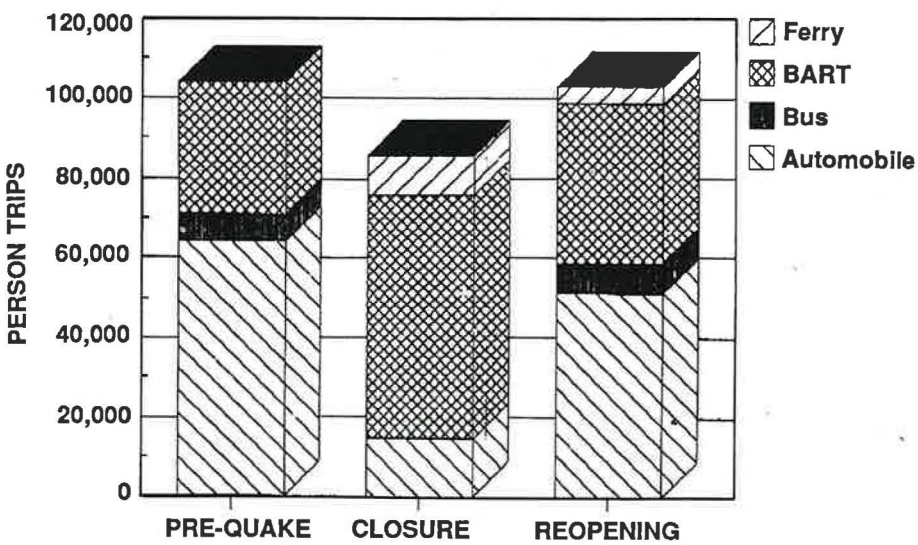

FIGURE 2 Bay Bridge corridor travel modes before, during, and after earthquake caused bridge closure.

Longer-Term Trends in Transit Use

Both 24-hour and peak period vehicle volumes have slowly built up to near pre-earthquake levels but significant numbers of people are no longer driving. BART, which experienced record-setting use during the month that the Bay Bridge was closed (more than 350,000 travelers each day), has retained a substantial number of its new weekday patrons and continues an upward trend.

Ferry service has also increased. Before the earthquake, existing ferries carried about 6,200 patrons a day. At the peak of the bridge closure, old and new ferries carried almost 30,000 patrons, and still carry nearly double the pre-earthquake level. Of the four new ferry services instituted during the emergency, only two remain, and their future depends on service and funding plans now being studied.

One of the results of the heightened post-earthquake coordination was the institution of new transit transfers and tickets among operators. The response to the latter was dramatic. After the bridge reopening and the expected holiday period falloff in multiride ticket sales, March sales climbed back to near-record levels.

Follow-Up

As survey results are presented and digested, more will be learned about how to provide transit services that respond to disasters and continuing market demands. For example, the large park-and-ride lots were notably unsuccessful as transfer points to buses that were then routed to BART or ferry terminals. Even in an emergency, the extra transfer appeared to be an unattractive option.

Lessons Learned

Clearly, much has been learned from the structural engineering perspective and the benefits of that experience will be helpful far beyond the Bay Area. Other factors have also emerged.

Redundancy

The earthquake provided a forceful reminder of the fragility of a regional economy dependent on bridges, tunnels, and landslide-prone highways. It also highlighted the long-term need for federal, state, or local support to continue the expansion of regional public transportation facilities to ensure that the region's transportation system is diversified and able to withstand shocks to parts without catastrophic damage to the whole. The earthquake has reinforced both the wisdom of past investments and the need to maintain and expand the new water-borne transit links forged after the bridge collapse. Rather than conveying the concept of wasteful duplication, redundancy has come to represent prudent planning in earthquake country.

Coordination

Another result of the catastrophe was the realization that coordination must be continuously nurtured. Few metropolitan areas are as organizationally complex as the Bay Area, but coordination mechanisms, in place for many years, worked smoothly when put to the test.

Communication

Speedy and effective communication with the public, such as that which helped prevent the predicted gridlock following the earthquake, played a vital part in coping with the crisis. As important, however, was the intra- and interagency communication so necessary to providing service and responding to changing needs. Response critique efforts have identified problems that occurred within transit agencies and among different agencies because of equipment limitations and failures, as well as procedural failures. In emergencies, people must know whom to call to coordinate a response, and a system must be in place to effect that communication. Both steps demand attention.

Lessons Applied

Although the reopening of the Bay Bridge in November 1989 was a significant achievement, transportation problems in the region are far from over. The freeway system in San Francisco will not be restored for many months and may take years depending on which options are chosen for the Embarcadero Freeway. The Cypress structure in Oakland will not be replaced, and its successor will not be built for several years. The region must deal with this crippled road network on a long-term basis at the same time that it seeks to identify, retrofit, or replace other transportation structures at risk in future seismic events.

As geologists gauge the probabilities for future major Bay Area earthquakes, the Loma Prieta earthquake was in all likelihood only a foretaste of what awaits the region when the major faults slip again closer to the heavily urbanized core. The ability to effectively manage that catastrophe will not be limited by the dedication or resourcefulness of Bay Area citizens, but instead by the failure to learn from lessons such as those so dramatically presented in 15 seconds that October afternoon.