EFFECTS OF THE OCTOBER 1989 EARTHQUAKE ON
THE TRANSPORTATION SYSTEM IN THE
SAN FRANCISCO BAY AREA

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ABSTRACT

The October 17, 1989, 7.1 magnitude earthquake that hit the San Francisco Bay Area claimed 62 lives and caused at least $8 billion in property damage. It was the largest earthquake to hit the contiguous forty-eight states since the great San Francisco earthquake of 1906. While major damage was confined to fairly limited areas, the earthquake created major disruptions in the region's transportation system, some of which continue to this day.

This paper chronicles the damage to the transportation system and the steps taken immediately after the earthquake to restore the transportation system, and reports on the continuing monitoring effort to determine if there were long-lasting effects on travel behavior.

The Bay Area's transportation network was not paralyzed immediately after the earthquake, as some had feared, because of a variety of factors. Among the most significant were the existing structure of inter-agency coordination that allowed efficient management of the system, and the availability of alternate routes and modes around damaged facilities. A massive public information effort also helped educate travelers and employers to their options.

Several key facilities have not been re-opened as of one year after the earthquake. The Bay Bridge was repaired and re-opened in only one month, but the Cypress Structure in Oakland was demolished and no plans are yet established for its replacement. In San Francisco, portions of three major elevated freeways were damaged. The Embarcadero Freeway (State Route 480) has been closed since the earthquake, and is the subject of on-going debate about whether to tear it down and replace it with a surface/subsurface roadway along the waterfront. Interstate 280, a major route into San Francisco from San Mateo County to the south, has also been closed since the earthquake, as plans for reinforcing it are being re-examined. A portion of U.S. Route 101 has similarly been closed pending redesign.

The result of all of these continuing disruptions in the transportation network is that congestion has increased in some areas and mode shifts have occurred, toward transit, but away from carpools. The latter problem is apparently due to continuing congestion on the eastern approach to the Bay Bridge, which has reduced the travel time benefit for using the carpool lanes through the Bay Bridge toll plaza.
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The earthquake that struck the San Francisco Bay Area on October 17, 1989, while the largest to hit the contiguous forty-eight states since the great San Francisco earthquake of 1906, was not unexpected. Geologists had long warned of the likelihood of a "significant seismic event" on one of the many Bay Area fault lines. The U.S. Geological Survey had even recently quantified the probabilities, giving a quake of 6.5 or greater magnitude in the southern Santa Cruz Mountains a 30% probability over a thirty year period.1 Nor were the experts greatly surprised about the types and locations of physical damage. It was well known that structures on land fill and soft soil surrounding the edges of the Bay were vulnerable to severe shaking, as were any unreinforced masonry buildings, or wood-framed structures not securely tied down to their foundations. Building failures in all these categories were widespread.

What was surprising to many was the catastrophic failure of two critical traffic arteries, the San Francisco-Oakland Bay Bridge and the double-deck portion of Interstate 880 in West Oakland, known as the Cypress Structure. Three other elevated freeway segments in San Francisco were also severely damaged and remain closed. Even though the region's six million people returned to their normal patterns of activity very quickly after the earthquake, the disruption to the transportation network continues.

This paper describes the immediate effects of the earthquake on the region's transportation system, the efforts to restore the system, and the continuing monitoring of travel impacts.

II. BAY AREA SETTING

A. SAN FRANCISCO BAY AREA

The nine-county San Francisco Bay Area is home to nearly six million people, making it the fifth largest metropolitan area in the country. The U.S. Census now also includes a tenth county, Santa Cruz, in its definition of the San Francisco "Consolidated Metropolitan Statistical Area," boosting the expanded region's population over six million and into fourth place nationally.

The bulk of the region's population lives within a few miles of the Bay, concentrated along the relatively flat plain between the Bay and the surrounding hills. The more heavily populated urban core stretches from San Francisco, south through San Mateo
County, into Santa Clara County at the southernmost tip of the Bay, and up through Alameda and Contra Costa Counties on the eastern Bay shore. The other four counties to the north (Marin, Sonoma, Napa, and Solano) are rapidly urbanizing, but are still substantially rural in character. (See Map 1)

The same geologic forces that created the Bay Area's striking topography are responsible for its seismic activity. The East Bay hills and the coastal mountains exactly delineate the location of the two major earthquake fault systems: the Hayward in the east and the San Andreas on the west. The bulk of the region's population lies between the two fault lines.

B. REGIONAL TRANSPORTATION SYSTEM

The region's extensive system of freeways, bridges, tunnels, and local roads is complemented by one of the most diversified public transportation networks in the country: (See Map 2)

San Francisco Municipal Railway (Muni), one of the oldest municipally operated transit systems in the U.S., operating diesel and electric trolley buses, light rail, and cable cars;

Alameda-Contra Costa (AC) Transit, the first California special transit district, operating buses in the urbanized core of the East Bay and over the Bay Bridge to San Francisco;

Bay Area Rapid Transit (BART), the first of the new generation of U.S. rail rapid transit systems, operating over 71 miles of track with 34 stations in three counties;

Golden Gate Bridge, Highway, & Transportation District, responsible for the Bay Area's most recognizable landmark, also operates buses and ferries linking Marin and Sonoma Counties to San Francisco;

San Mateo County Transit (SamTrans), operates buses within the county and contracts for bus service to San Francisco;

Santa Clara County Transit, operates buses and the region's newest light rail service within the county;

Peninsula Commute Service (CalTrain), the commuter rail service that has been provided along the 47-mile corridor between San Jose and San Francisco since 1864, now operated by Southern Pacific under contract with the California Department of Transportation, Muni, SamTrans,
and Santa Clara;

Central Contra Costa Transit Authority (CCCTA), one of the region's newer operators, providing bus service in the rapidly growing suburban area east of the Oakland-Berkeley Hills; and

Vallejo Transit, a city-owned bus system on Solano County's Bay shore that also contracts for ferry service to San Francisco and express bus service to BART.

In addition to these nine, there are fifteen other public transit systems that provide local service with from one to twenty-five buses. While some of these other transit agencies are in the central area and serve BART stations, the nine listed above were the most affected by the earthquake.

C. TRANSPORTATION ORGANIZATION IN THE REGION

There is no single governmental authority responsible for all transportation in the region. Caltrans is responsible for the region's highways and seven transbay toll bridges; the eighth is the responsibility of the independent Golden Gate Bridge District. Transit service is provided, as described above, by a complex web of cities, counties, and independent transit districts. The major airports and seaports are operated by separate, independent commissions linked to city or county governments. A non-profit agency, RIDES for Bay Area Commuters, provides carpool and vanpool services throughout most of the region.

The only common link among all of these disparate agencies is the Metropolitan Transportation Commission (MTC), the regional transportation planning agency for the nine-county area. MTC is responsible for developing and updating a regional transportation plan, and must annually assemble and oversee the array of federal, state, and regional funding programs that keep all of these agencies rolling. In addition to the normal duties of a Metropolitan Planning Organization (MPO), MTC has responsibilities under state law to foster continuing coordination among the many transportation entities in the area. It was this role that helped set the stage for effective post-earthquake recovery.

In 1980, MTC established a Transit Operator Coordinating Council (TOCC) to serve as the principal regional forum for discussion of transit policy issues and the resolution of coordination problems. The previous year, the Regional Transit Association (RTA) had been formed as an independent "joint powers agency" among the region's six largest transit systems. The TOCC now encompasses eleven operators and the RTA seven. In practice, the RTA and TOCC work together, with MTC providing technical and administrative support to both, and meetings of the TOCC and the
III. THE LOMA PRIETA EARTHQUAKE

A. WHAT HAPPENED

The San Andreas fault runs over 800 miles from Mexico along the length of the California coast, until it veers offshore just north of San Francisco. The San Andreas represents the major boundary between the North American and the Pacific plates, with the Pacific plate moving northward relative to the North American.

On Tuesday, October 17, 1989, at 5:04 PM Pacific Daylight Time, the fault ruptured along a 25-mile-long segment at a depth of about eleven miles, stopping 3-4 miles below the surface. Displacement at the break in the fault was about six feet horizontally and four feet vertically, although there was no distinct surface break typical of past movements along the San Andreas. Instead, there was a very broad area of ground cracks near the epicenter, which was approximately 60 miles southeast of San Francisco and 10 miles northeast of Santa Cruz. The earthquake was named after Loma Prieta Mountain, the 3,800 foot peak that dominates the sparsely populated area near the epicenter.

The shaking from the main shock, rated at 7.1 magnitude, lasted only fifteen seconds, but there were over 5,000 measurable aftershocks in the two months following the earthquake, 94 measuring magnitude 3.0 or greater, 22 measuring 4.0 or more. Shaking was felt over an area of 400,000 square miles.

B. DAMAGE OVERVIEW

General

Sixty-two lives were lost, forty-two in the collapse of the Cypress Structure in Oakland. Only one person died in the Bay Bridge collapse, apparently after driving the wrong way on the bridge, directly into the gap. Over $6 billion in property damage was estimated initially, with total damage expected to top $8 billion, the costliest natural disaster in U.S. history. 3,750 were injured and over 12,000 left homeless.

The principal damage to buildings occurred in downtown Santa Cruz, downtown Watsonville, part of downtown Los Gatos, Stanford University (Palo Alto), and the Marina District of San Francisco. Santa Cruz and Watsonville were hardest hit, with extensive damage to most of their central business districts; about half of all buildings in both CBD's collapsed or were damaged beyond repair, devastating the local economy and the tax base.

Electrical power to the city of San Francisco and parts of San Mateo County was completely lost due to failures at generating
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plants, substations, and distribution facilities, and was not fully restored for nearly thirty-six hours. Other power outages were scattered and temporary. Telephone lines and facilities were generally undamaged, but were severely overloaded after the earthquake, causing some service disruptions. There was no major damage to dams, aqueducts, or sewage treatment facilities, although there were hundreds of breaks in water lines.

There was extensive damage to the Port of Oakland and to the main runway of the Oakland Airport, but other airports and seaports had minimal damage.

In general, three factors contributed to keeping the casualties to a minimum: (1) the ground shaking from the main shock lasted only fifteen seconds, not long for a quake of this magnitude; (2) even though it was the peak of rush hour, many people were watching the third game of the World Series (between two Bay Area baseball teams), and therefore not as exposed to danger; and (3) the weather was mild (warm, clear, and windless), so that major fires, such as in the Marina District, were not fanned into firestorms, and rescue efforts were not hampered.

Transportation System Damage: Santa Cruz Area

The major transportation system disruptions near the epicenter included the failure of the 800-foot Struve Slough bridges on the Coast Highway (State Route 1) south of Santa Cruz, and the landslides that blocked a twelve-mile long section of State Route 17, the major four-lane highway connecting Santa Cruz and San Jose.

Soil movement of up to three feet caused the supporting pilings of the Struve Slough bridges to shear off, some penetrating the bridge deck. Replacement bridges were opened within three and one-half months. Route 17 was blocked in several locations by major slides that covered portions of each side of the roadway; the median barrier often acted as a retaining wall for the slides. Limited traffic was allowed shortly after the earthquake by removing portions of the median barrier so that carpools and bus convoys could be escorted through the open lanes as clearance work progressed. Full service on Route 17 as restored on December 1.

Transportation System Damage: San Francisco (See Map 3)

The Embarcadero Freeway (State Route 480) is an elevated structure along the eastern waterfront that provides distribution from the Bay Bridge to the financial district, Chinatown, and the northern waterfront. The structure was opened about the same time as the Cypress. Extensive cracking in many of the support columns and some shedding of the concrete surface ("spalling"), exposing the underlying steel, led to immediate closure of the facility. Wood and steel bracing were installed to prevent collapse, but no further work was undertaken, pending a final decision by the city.
government on whether it wanted to proceed with repairs or demolish the structure. The mayor has become a strong supporter of the proponents of tearing down the Embarcadero, which they considered an eyesore, so that a more aesthetically pleasing surface/subsurface roadway could be built. The argument over the freeway has continued since it was first opened. As cost estimates to repair the facility begin to approach the costs of demolition and replacement, the arguments have begun to shift to funding availability rather than the relative transportation merits.

Interstate 280, which begins in northeast San Jose, travels the length of San Mateo County, and terminates some distance south of downtown San Francisco. The freeway had originally been planned to connect to the Bay Bridge, but the San Francisco "freeway revolt" of the 1960's permanently stopped that highway connection and several others. The portion of I-280 that is double-decked, from the interchange with U.S. 101 in southeastern San Francisco, northward to its terminus, was closed immediately after the earthquake. Cracks similar to those on the Embarcadero Freeway were observed. A new seismic design review panel report has recommended more extensive retrofitting than had been previously planned, so the facility may not be re-opened until early 1991.

A portion of Route 101 west of the Civic Center was also closed due to similar support column problems, and is subject to the same redesign and retrofit schedule as I-280.

It has been theorized that if the ground shaking had been twice as long (more typical for a 7.1 magnitude earthquake), that all three of the San Francisco freeways could have suffered the same fate as the Cypress.

Transportation System Damage: The Bay Bridge

Thanks to the World Series coverage by the Goodyear blimp, the national television audience got a more immediate and comprehensive look at the damage to the Bay Bridge than did many of us locally. The San Francisco-Oakland Bay Bridge, opened in 1936, is a connected series of truss, cantilever, and suspension bridges that span over four and one-half miles. The bridge passes through Yerba Buena Island, the Coast Guard headquarters, in the middle of the Bay. The Bay Bridge carries five lanes of traffic on each of two decks, the upper deck westbound toward San Francisco, the lower deck eastbound to Oakland.

The break in the bridge was confined to a fifty-foot section connecting truss spans on the eastern side of the bridge, near Oakland. The collapse occurred when 1" diameter anchor bolts attaching the eastern edge of the section sheared off when the bridge was thrust ten inches to the east and five inches north. This pulled the upper deck section off of its western support, causing it to crash onto the lower deck. A massive steel tower at
that point prevented the collapsed decks from dropping into the Bay.

Bridge traffic was unusually light due to the World Series, so only two vehicles were caught in the collapse, and there was only one fatality.

The shock of seeing the Bay Bridge damage led many to doubt the estimates of a speedy repair. Caltrans began immediately to cut and remove the damaged decks, beginning an around-the-clock effort. While work progressed on repairing the damaged section, Caltrans took the opportunity to catch up on routine bridge maintenance; painting and paving that would have taken six months was finished while the bridge was closed to traffic. Caltrans also had to make extensive repairs to the pavement on the Eastshore Freeway (Interstate 80) and the approaches to the toll booths, where soil subsidence created massive cracks and tilting.

In exactly one month, the bridge was re-opened, with a controversial bridge opening party held on Friday, November 16. Some felt a party was inappropriate given the loss of life in the earthquake, while others thought a community party would be a good way to demonstrate how the area was rebounding from the disaster. Several thousand people took the opportunity to pay $5 for a bus ride from the San Francisco or Oakland sides to walk on the bridge up to the repaired section, listen to speeches by transportation officials and political leaders, and hear a local children's chorus perform. The repaired section itself was still closed off, allowing the damp concrete to cure for a few more hours. The first vehicles across (Caltrans bridge tow trucks) led the parade from the toll plaza later that evening.

Transportation System Damage: The Cypress Structure (See Map 4)

The eastern approach to the Bay Bridge is fed by a complex interweaving of three major freeways: Interstate 80 (the Eastshore Freeway) from the north, Interstate 580 (the MacArthur Freeway) from the east, and Interstate 880 (the Nimitz Freeway) from the south. All three meet in a large interchange that Caltrans calls the Distribution Structure, but is known locally as "The Maze."

The Cypress Viaduct, opened in 1957, was California's first continuous double-deck freeway. It carried four lanes of I-880 in each direction between The Maze and the elevated portion of the Nimitz west and south of downtown Oakland. The double-deck structure above Cypress Street in West Oakland was about 1.5 miles in length, and collapsed over more than half its northern portion, from 18th to 34th street. In general, the upper deck supports failed, and the upper deck collapsed onto the lower deck; the lower deck generally did not collapse to the ground.

Initial estimates of hundreds of casualties were based on the
worst case of rush-hour traffic, bumper-to-bumper the entire length of the Cypress. Due to the World Series, traffic was very light. Because of the complete collapse of the upper deck onto the lower, it was impossible to reach all survivors and ascertain the number of victims until equipment was brought in to cut through the upper deck.

As soon as a section was cleared of casualties, it was demolished. Rescue and demolition were done round the clock for the first week; later, demolition was confined to 6AM-10PM to ease the burden on the adjacent residents of the neighborhood. Demolition of the entire 1.5-mile began October 31 and was completed in January. One two-span section in the southern, uncollapsed portion was used as a full-size laboratory for two months to test failure modes and retrofit options. The results of those tests are being used to design a retrofit program for 400 similar bridges state-wide.

After all demolition was completed and all rubble removed, local streets in the vicinity were repaved, and Cypress Street is now an expansive parkway. Political debate continues on how and where to replace the Cypress. The West Oakland community and many city leaders do not want either a surface or elevated facility to divide the community again. Other options would route a new freeway to the west, across railroad, port, or military property, but would be costly. It is still not known how long any option would take to complete, how much it might cost, or whether federal emergency funds would be available.

With the Cypress gone, north-south traffic between I-80 and I-880, and Bay Bridge traffic to and from I-880 to the south must weave through a complex, circuitous route involving the I-980/I-880 connector, the I-580/I-980/Route 24 interchange, and the I-580/I-80 split. Traffic that used to use four lanes on the Cypress is now squeezed into one or two lanes on portions of this new maze.

IV. IMMEDIATE TRANSPORTATION RESPONSE

A. HIGHWAY SYSTEM

In addition to damage assessment and repair, Caltrans began immediately to make operational improvements on the undamaged portions of the freeway system to accommodate the new traffic patterns. The first of these was completed the second day after the earthquake, and seventeen other projects were completed by the week the Bay Bridge re-opened. Projects included restriping lanes to create more capacity or better flow, paving shoulders or medians to provide additional lanes, establishing new HOV lanes, and providing appropriate signing for these changes.

One action taken while the Bay Bridge was closed may not have been consistent with good transportation planning. The Governor
decided that while the bridge was closed, it would be best to eliminate toll collection on all of the other state-owned bridges in order to speed traffic flow. The fact that this strategy might also serve to reduce the use of carpooling and transit (since "free" carpool lanes would have no cost advantage and transit operators still had to charge a fare) was apparently not discussed.

### B. TRANSIT SYSTEM

The Bay Area's long-standing commitment to public transportation and the diversity of available services provided a strong base for building a flexible response to the new travel demands. The heart of the transit response was: put all available capacity on the street, worry about funding later, get the word out on new services, and monitor the results. That response was initiated immediately.

**Immediate Response the Night of the Earthquake**

San Francisco Muni service was greatly disrupted by the loss of power in the city. The Muni Metro light rail system, the electric trolley buses, and the cable cars all came to a halt, and the subway stations were plunged into darkness. With no back-up power in the Market Street subway, some passenger evacuations were accomplished by flashlight, with no injuries. Full Muni service would not be restored until Friday morning.

BART trains came to an immediate halt when the earthquake struck, including three trains that were in the Transbay Tube. The system immediately went from automatic to manual control, and all trains were slowly moved into the nearest stations to off-load all passengers. Because BART has limited back-up power both on-board and in its stations, and power from the East Bay could be fed through the Transbay Tube, all passengers could be safely taken to stations, no patrons were trapped in trains, and no evacuations were necessary.

With the Bay Bridge closed and BART shut down for a thorough safety inspection, thousands of commuters were stranded in downtown San Francisco. Some companies put employees up for the night in nearby hotels, but most people wanted to get back to their homes and families, no matter how long it took.

AC Transit had over 100 buses in San Francisco for the evening commute back to the East Bay, so it loaded them up and took off on alternate routes north and south out of San Francisco, along circuitous routes crossing other bridges or circumnavigating the Bay. With neither buses nor BART available, the private ferry operators, Red & White Fleet and Blue & Gold Fleet, began operating free service from San Francisco to Oakland, making round trips throughout the night until all those who wanted a ride were served. It was estimated that 5,000 commuters were evacuated that way. In
Oakland, AC quickly re-routed its buses to serve the makeshift ferry terminal at the foot of Broadway in downtown Oakland, and buses from CCCTA came in to pick up ferry passengers who needed to go to the eastern suburbs. AC also provided increased service to East Bay BART stations as BART began restoring East Bay service.

Immediate inspections showed that transit facilities had come through essentially unscathed. The BART system had been designed to withstand an 8.0+ magnitude earthquake, and the seismic joints in the Transbay Tube performed flawlessly. The Tube is sunk in a trench in the bottom of the Bay, at depths of over 100 feet below the surface of the Bay. Only minor seepage was detected, and that was believed to have been from a long-standing condition unrelated to the earthquake. The West Oakland BART station is at 7th & Cypress, and that station and the elevated approach to the Tube were only a few blocks from the collapsed portion of I-880. The fact that there was no damage was due to a combination of good luck and exceptional design. After an inch-by-inch inspection of the system, BART was prepared for full, normal automated service throughout its system by 6 AM Wednesday morning.

Planning for Recovery -- the First Week

Since most normal business activity had slowed or ceased following the earthquake, transportation needs for the remainder of the week were not deemed to be critical. Many downtown San Francisco office buildings were either awaiting damage inspection, or were closed pending inspection for gas leaks before electrical power could be restored. While BART was up and running, its two main downtown San Francisco stations were closed because station power could not be turned back on while gas leaks in the area were being investigated. Elsewhere, schools, offices, stores, and public buildings were closed for safety inspections.

The MTC offices were not severely damaged, and we soon discovered that all the transit agencies were similarly back in business. We immediately began planning for a regionwide meeting to evaluate emergency transportation needs. The regular meeting of the TOCC was already scheduled for the next day, Thursday. MTC and Caltrans agreed that it was the appropriate forum for bringing the entire transportation community together to develop a coordinated response to the earthquake's devastation. In Sacramento, there had briefly been talk of appointing a "transportation czar" for the Bay Area, but Caltrans had strongly recommended that this was not needed because of the existence of effective inter-agency coordination in the region. They were soon proved right.

The normal attendance at TOCC was broadened to include not only the larger public transit operator members of TOCC, but also most smaller public operators, private bus and ferry providers, port authorities, Coast Guard, Highway Patrol, State Public
Utilities Commission, and federal and state emergency response officials, among others. The "Special TOCC," as it was going to be called, focused in on service for Monday morning, October 23, when we presumed most people would try to resume their normal activities. The fear was that if all the commuters tried to resume their previous travel habits, the remaining portions of the transportation network would become gridlocked.

The day after the earthquake, no one could estimate how long the Bay Bridge would be out of service. We assumed a three- to six-month time frame for emergency services, but several immediate objectives were identified:

1. Determine how each agency was responding, and what resources they had to provide additional services;

2. Put all available service on the street, leaving the usual worrying about how to pay for it to later;

3. Assemble a comprehensive public information program, and get it out to commuters over the weekend; and

4. Set up a monitoring system to form a basis for adjusting service in response to demand.

We did a quick calculation of the dimensions of the transportation problem we faced in the transbay corridor. Based on a spring 1989 survey, we estimated there were about 100,000 persons travelling westbound during an extended 5-10 AM peak period. Given the shape of the peak and the maximum capacity estimated to be available by loading up BART and the promised ferry services, we thought we might be able to accommodate most travelers if we could get them to travel earlier or later, and shift to transit. (Figure 1)

After working frantically Wednesday, Thursday, and Friday to coordinate services and information, Caltrans, MTC, and the transit operators scheduled a major press briefing on Saturday morning, October 21, at the San Francisco Ferry Building. Elaborate press packets were provided, containing descriptions of all emergency services that would be in place on Monday morning. Last minute changes in the packets were being stapled together as the press briefing began. Maps and guides to the new services, including maps of how to get to four new East Bay ferry terminals, were widely distributed. The MTC graphics department even made the maps available in computerized form so that they could be quickly incorporated into newspaper production over the weekend.

The message to the public was simple:

- If you don't have to travel, stay home.
- If you do have to travel, plan ahead and use public transit.
If you can't use public transit, use carpools, but don't drive alone.

If you're an employer, allow your employees to use flexible hours, work nights or weekends, or work at home.

Everyone held their breath as Monday morning came. What was not expected was a major rainstorm (during California's fourth drought year) that hit just in time for the morning commute, wreaking havoc with the new ferry service. Fortunately, many people seemed to stay home an extra day, so the much feared gridlock did not materialize.

What became clear during that first week, however, was that people were flocking to BART in unprecedented numbers. By week's end, transbay ridership was up 100% over pre-quake levels.

Organizing for the On-going Response

To keep up with the continuing changes in demand as commuters tried alternate routes and modes, the special, expanded TOCC meetings were held weekly. Daily reports of BART, ferry, and traffic data on all of the bridges were compiled by MTC and faxed to all TOCC members and discussed at the weekly meetings. Plans for service adjustments were agreed to at these meetings, and joint public information releases were prepared. A strategy encompassing the following factors evolved in an ad hoc fashion: (1) increasing service levels, (2) improving access to transit, (3) increasing public information, (4) introducing new joint fare instruments, and (5) enhancing communication and coordination among the participants.

Increasing Service Levels

BART became the key player in providing transbay capacity. Because of limitations in its automatic train control system, BART could not substantially increase the number of trains in operation during the peak, but it could lengthen the trains by putting all available cars into service. Additionally, BART began its full level of peak service earlier in the morning, and continued that high level of service later in the evening. BART was also able to get more peak period runs out of its trains by turning back some trains in downtown San Francisco, sending them back for another East Bay load, rather than sending them through to the San Francisco/Daly City terminal. For the first time since it began operation in 1972, BART began 24-hour operations on October 23. After the bridge re-opened, BART discontinued all-night service December 1, but continued starting full peak service between 4-5 AM, and continuing afternoon peak service until 7 PM.

This added BART service was not without cost. BART began falling behind in routine car maintenance as car-miles piled up
faster than overhaul facilities could handle. Fortunately, BART was within weeks of opening its new Daly City yard. BART was able to begin some maintenance work at Daly City even as construction was still being finished. With the new shops opened ahead of schedule, BART could begin working off its maintenance backlog. 24-hour service also presented BART with track maintenance issues it had never faced. One BART manager observed that this overload was a good dress rehearsal for what lies ahead when BART's ambitious extension plans come to fruition.

While a large part of the story, BART was not the only game in town. The new ferry services, hastily assembled by private operators contracting with Caltrans, were a continuing source of hope and frustration. Existing Golden Gate and Vallejo services was augmented, while new ferries were initiated from the East Bay cities of Richmond, Berkeley, Oakland, and Alameda to downtown San Francisco.

Continued state or federal funding was never assured, so service plans could never be solidified for more than a few weeks at a time. Vessel availability varied, as an eclectic fleet of local commute and tourist ferries was augmented by three ferries brought down from Puget Sound commute duty to join other ferries brought up from Catalina Island tourist service. With the Bay Bridge toll booths temporarily vacant, underemployed toll-takers were pressed into service as ferry ticket sellers. Ferry service from Vallejo was also augmented, and suffered the same problems of uncertainty. After tallying significant success in the weeks before the bridge re-opened, the constant schedule and service changes and uncertainty over continued funding took their toll on ferry ridership. The extra Vallejo service was curtailed due to funding problems, and the East Bay ferries were eliminated from Richmond and Berkeley. Ferries had attracted a loyal, vocal, but small following.

All other transit systems were able to respond to increased demands in their service areas. SamTrans was readying the opening of a new park-and-ride lot to serve the Daly City BART station (on the San Francisco/San Mateo County border) when the quake struck. The lot immediately filled, as did SamTrans' free shuttle bus to BART. (Figure 2) SamTrans commuter service to downtown San Francisco showed some increases, as did the special bus (the DB Express) across the Dumbarton Bridge, the southernmost of the transbay crossings. (Figure 3) CalTrain, like SamTrans commute service, experienced increased demand due to the closure of I-280 into downtown San Francisco. (Figure 4) CalTrain was able to lengthen its trains to accommodate the increases.

CalTrain was also able to briefly extend service south from San Jose to Watsonville and Salinas to help provide an alternate route while Highway 17 was shut down by slides. The special service was discontinued November 10 due to funding and liability
difficult commute

3. Suppressing the trip -- not taking it or accomplishing the same activity at a more convenient time or location.

Based on limited pre- and post-earthquake vehicle occupancy counts, it appeared that a significant number of trips were suppressed during the Bay Bridge closure, perhaps up to 10-15%. With increased BART use, total transbay trip-making after the bridge re-opened reached approximately the pre-quake level, but the modal mix had changed. The most significant change was a dramatic drop in carpool use. (Figure 6) The only obvious explanation for this is that the severe congestion on the East Bay approaches to the Bay Bridge has greatly reduced the effectiveness of the toll-free carpool lanes through the toll plaza, since carpoolers must suffer in the approach queue along with everyone else before they reach their diamond lanes.

The results of BART's increased service levels were dramatic. BART ridership, which had been hovering just over 200,000 rides per day, leaped to a maximum of over 350,000 before the bridge re-opened. (Figure 7) BART estimates that it has retained about 15% of that increase, equivalent to 1-2 years of normal growth. The peaking curve shows that BART accommodated the increased riders with both a broader and higher peak period, made possible by shifts in work schedules. (Figure 8) While overall growth was impressive, BART's "Owl service" experiment generated few riders, except on a few week-end nights. (Figure 9)

VI. LONGER-TERM EFFECTS

Six months after re-opening of the Bay Bridge, traffic levels on the bridge have stabilized, but have not fully returned to pre-quake levels, either in the 6-9 AM peak or for the full day. (Figure 10) Over the broader 5-10AM peak, however, traffic on the Bay Bridge and the three other transbay bridges seems to be about back where it was. (Figure 11) This supports the conclusion that the congested approaches to the east end of the Bay Bridge are acting to meter the traffic into the toll plaza. The new plateaus in traffic may simply represent new capacity equilibrium levels, given the access constraints. AC transbay bus ridership is slightly ahead of where it was pre-quake, based on very limited data (Figure 12), while ferry ridership has fallen off to insignificant levels. (Figure 13)

The earthquake provided an instant, if chaotic, travel behavior research laboratory. More will be known about longer-term changes when the mass of data collected during the spring and summer compiled and analyzed, and when the Fall 1990 transbay corridor counts are repeated.
A variety of data collection efforts were begun or planned almost immediately following the earthquake, although most have not produced conclusive results as of this writing. These include:

- Traffic counts on all the bridges
- Vehicle classification and occupancy counts at key locations
- Daily BART and ferry patronage reporting
- Telephone household survey of transbay travelers one week before the Bay Bridge re-opened
- Survey of ferry riders while the Bridge was closed
- Re-survey of former ferry users
- Survey of transbay BART riders while the Bridge was closed
- Surveys of small and large businesses to determine (a) economic impact, and (b) how they assisted their employees in getting to work
- Survey of trucking firms to determine impacts on goods movement
- Survey of motorists using the alternate routes when the Bridge was closed

The MTC Regional Travel Survey of about 10,000 households is now being concluded. Coordinated with the 1990 Census, this first major regional travel behavior survey in a decade was modified to include 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.

VI. LESSONS LEARNED AND FOLLOW-UP NEEDED

A. WHAT HAVE WE LEARNED?

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

Redundancy

We have now been forcefully reminded of the fragility of a regional economy dependent on bridges, tunnels, and landslide-prone highways. In investments, it is well established that diversification is the best protection against unanticipated setbacks. Similarly, beyond the immediate need for repair or replacement of facilities, there is a long-term need for Federal, State, and 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 transportation options beyond simply responding to current demand. "Redundancy" no longer should be read as "wasteful duplication," but rather as prudent planning in earthquake country.

**Coordination**

A second lesson is that coordination must be continuously nurtured. There are few metropolitan areas as organizationally complex as the Bay Area. Fortunately, coordination mechanisms had been in place for many years, so that operating personnel and managers of the many different agencies generally knew each other well and were prepared to pitch in to a joint effort without hesitation.

**Communication**

Communicating quickly and effectively to the public was a prime reason why the disastrous gridlock that had been predicted never materialized. As important, however, was the intra- and interagency communication so necessary to providing service and responding to changing needs. Our continuing response critique has identified problems that occurred in communications both within transit agencies and between different agencies due to equipment limitations and failures, as well as procedural failures. In emergencies, you first need to know whom to call to coordinate a response; then a system needs to be in place to effect that communication. Both steps demand our attention.

**B. FURTHER FOLLOW-UP**

A critique of the overall regional response is now underway, led by reconvening the special, expanded TOCC meetings that served so well during the emergency. Three broad areas of concern have surfaced: (1) Internal (restoration), (2) Mutual (coordination), and External (on-going).

A focus on internal needs will first ensure that a transportation agency is capable of assessing its risks and taking steps to mitigate them, developing plans and training to respond effectively, and restoring its services as best it can with its own resources. This reflects the stark reality that each organization must act in the first hours following a major disaster as though it must rely solely on its own resources.

The second focus, mutual concerns, calls for a more systematic identification of opportunities for coordinated disaster planning. This may include technical agreements on issues such as standards for back-up power and communications so that equipment may be jointly purchased and interchanged. It may also encompass mutual
aid agreements to provide services in each other's territories, as may be required, or simply open-ended discussions of likely disaster scenarios and possible coordinated service responses.

The third area of concern was one which caused the most confusion among the transportation agencies. Few of them had any previous dealings with the emergency response system, its agencies and funding. Transportation agencies generally did not know whom to call, or to whom to respond. These external relationships need to be explored in advance of a disaster so that responsibilities and expectations can be more realistic. Some legislative or regulatory changes may also be needed to overcome any uncertainties about which organization can or should make certain decisions, or which funding source might be available for which kind of emergency services.

To the extent we can explore these concerns on our own, we will document needed improvements, and then seek additional resources as needed to address them. We hope to evolve a network of complementary emergency response plans that will prepare us for the next, inevitable event.

B. TO BE CONTINUED

While the region will soon celebrate the first anniversary of the re-opening of the Bay Bridge, the transportation problems due to the earthquake are far from over. The freeway system in San Francisco will not be restored for many more months, and may take years depending on which options are chosen. 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 as a long-term fact of life at the same time as it seeks to identify, retrofit, or replace other transportation structures at risk in future seismic events.

Geologists have recomputed the probabilities for the next major Bay Area earthquakes, based on new measurements since the Loma Prieta earthquake. Their conclusion: there is a 67% probability of a 7.0 magnitude earthquake on one of the region's five major faults in the next thirty years. There is no disagreement that the October 1989 "moderate" quake was merely a hint of what awaits the region when the major faults slip again more proximate to the heavily urbanized core. The ability to effectively manage that catastrophe will depend again on the dedication and resourcefulness of our citizens, institutions, and transportation professionals. It will also depend on how closely we have paid attention to the harsh lessons Mother Nature so emphatically thrust our way in fifteen seconds that October afternoon.
NOTES


Box 2, Folder 6

Item 1

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