

THE LOMA PRIETA, CALIFORNIA, EARTHQUAKE OF OCTOBER 17, 1989:
STRONG GROUND MOTION AND GROUND FAILURE

MARINA DISTRICT

PERFORMANCE OF EMERGENCY-RESPONSE SERVICES
AFTER THE EARTHQUAKE

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rary loss of computer-aided dispatch. A fire that grew to near-conflagration proportions demonstrated both the strengths and weaknesses of emergency response. The fireboat *Phoenix*, the San Francisco Fire Department's Portable Water Supply System, and the tactics and training for using them were critical in controlling the fire. In contrast, the city's Auxiliary Water Supply System was poorly utilized because of overwhelmed procedures for emergency operations, communication, and command and control.

INTRODUCTION

The earthquake severely tested the preparedness of emergency-response services throughout the San Francisco Bay area. San Francisco itself sustained moderate to strong ground shaking, with intensities ranging from VI to IX on the modified Mercalli intensity (MMI) scale (Benuska, 1990). The most severe damage occurred in the Marina District, an area of approximately 1/2 mi² with 14,000 residents at the end of the San Francisco peninsula. This area, assigned an MMI of IX by the U.S. Geological Survey, became the focus of the city's most intensive police and fire-service involvement. This report discusses the effectiveness of police, fire, and ambulance emergency services in the Marina District during the early hours after the earthquake. We first briefly review the setting of the Marina District and San Francisco's emergency-response capabilities before the earthquake, and we then describe police, ambulance, and, especially, fire-service response. We conclude with a summary of the lessons learned.

THE MARINA DISTRICT
BEFORE THE EARTHQUAKE

Building collapses, gas leaks, and a large fire made the Marina District the primary focus of emergency response in the city of San Francisco. A total of 7 Marina District buildings collapsed, and 63 more were declared unsafe to enter or occupy. Police and emergency medical services were not generally overwhelmed, despite tempo-

San Francisco's Marina District, located at the north end of the San Francisco peninsula (fig. 1), is primarily a residential neighborhood, bounded on the north by San Francisco Bay; on the south by Lombard Street, a major transit corridor; on the east by Fort Mason; and on the west by the Palace of Fine Arts and the Presidio of San Francisco

(figs. 1, 2). The land that composes the Marina District was reclaimed from San Francisco Bay, filled in stages during the years 1869 to 1917 (Bonilla, 1990). The 1915 Panama-Pacific International Exposition was held on the site of the Marina District; afterward, streets and lifeline services were installed, and the land was auctioned for housing. A typical Marina District apartment building is a 1920's-era wood-frame structure of one to three stories above a ground-level garage. Walls are typically constructed of stucco over straight wood sheathing, although some buildings have unreinforced-masonry or reinforced-concrete first stories.

SAN FRANCISCO POLICE DEPARTMENT

On October 17, 1989, the San Francisco Police Department (SFPD) employed 1,768 officers, of whom approximately a third were on duty at 5:04 p.m. P.d.t. (Lt. Harper, oral commun., 1991). Officers operate out of nine police stations, or districts (fig. 3). Above the district level are

three commanders, each in charge of three police districts; the Marina District is contained within the SFPD's Northern District.

The SFPD is responsible for emergency telephone (or 911) service. All calls to the 911 exchange are received at the Hall of Justice (fig. 1) at 6th and Bryant Streets. A dispatch officer determines whether the emergency is police related; if not, the call is routed to the appropriate municipal unit, such as the fire department or the paramedics, using a transfer line routed through Pacific Bell's central office on McCoppin Street. If the emergency is police related, the dispatch officer uses a computer-aided-dispatch (CAD) system to order the appropriate police district to respond.

SAN FRANCISCO FIRE DEPARTMENT

On October 17, 1989, the San Francisco Fire Department (SFFD) employed approximately 1,300 firefighters and officers, not including staff at headquarters, training

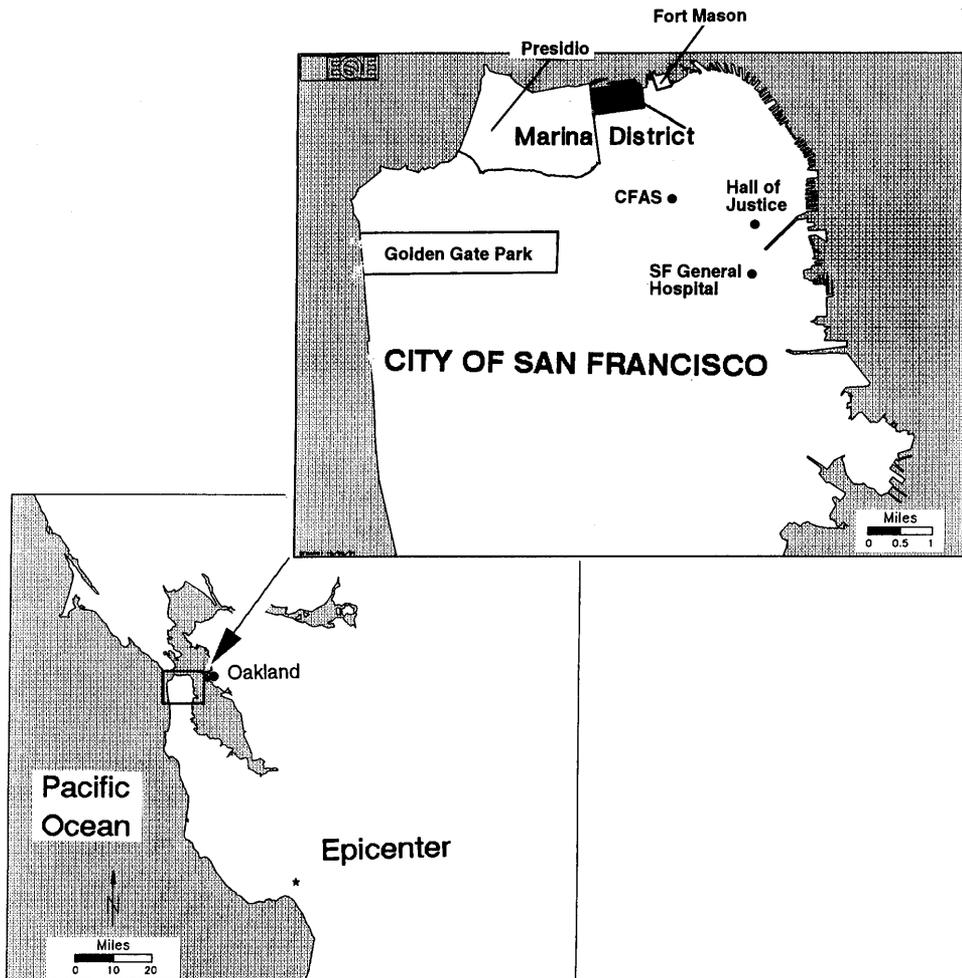


Figure 1.—Sketch maps of San Francisco Bay area and city of San Francisco, showing location of the Marina District (shaded area). CFAS, Central Fire Alarm Station.

center, and other support services. San Francisco's 41 fire stations are divided among 10 battalions of three to five stations each (fig. 4); each battalion is commanded by a battalion chief. The 10 battalions are organized into four divisions under the command of a division chief: three within the city of San Francisco and one at San Francisco International Airport. Department Chief Frederick Postel was out of town at the time of the earthquake. Three deputy chiefs, Michael Farrell, John Boscacci, and Frank Scales, report to Chief Postel; Deputy Chief Farrell was the acting chief in Chief Postel's absence. The units in service at 5:04 p.m. included 41 engine companies, 18 truck

companies, 2 rescue companies, 1 air-service company, 1 fireboat company, and 1 equipment unit.

The SFFD typically responds to a 911 call as follows. When the call is received, the caller speaks first to a police dispatch officer. If the emergency is within the purview of the SFFD, the call is transferred to the SFFD's communications center at the Central Fire Alarm Station (CFAS, fig. 1) in Jefferson Square Park, on Turk Street between Gough and Laguna Streets. The caller then speaks to an SFFD dispatcher, who directly contacts the appropriate responding units. In an emergency such as an earthquake, the SFFD's communications center is designated the city's

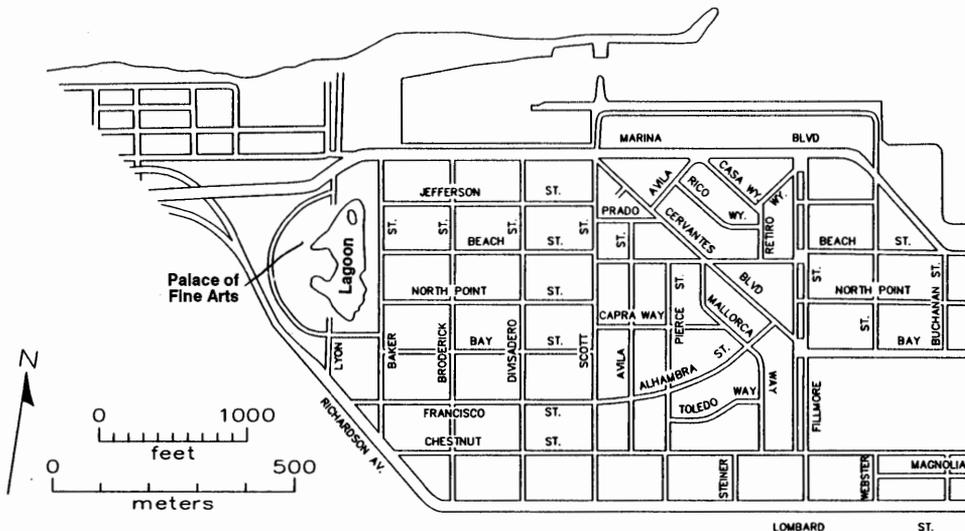


Figure 2.—Marina District, showing street grid.

MARINA DISTRICT

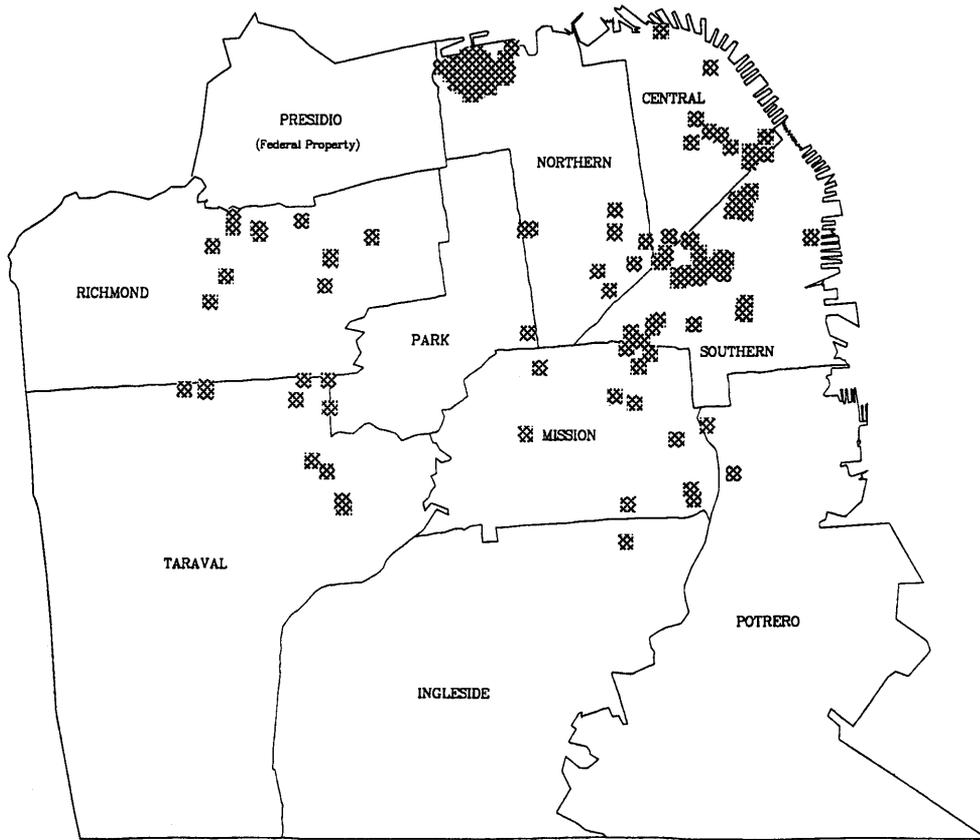


Figure 3.—Sketch map of San Francisco, showing locations of SFPD districts and areas of most extensive damage (shading). Map courtesy of SFPD.

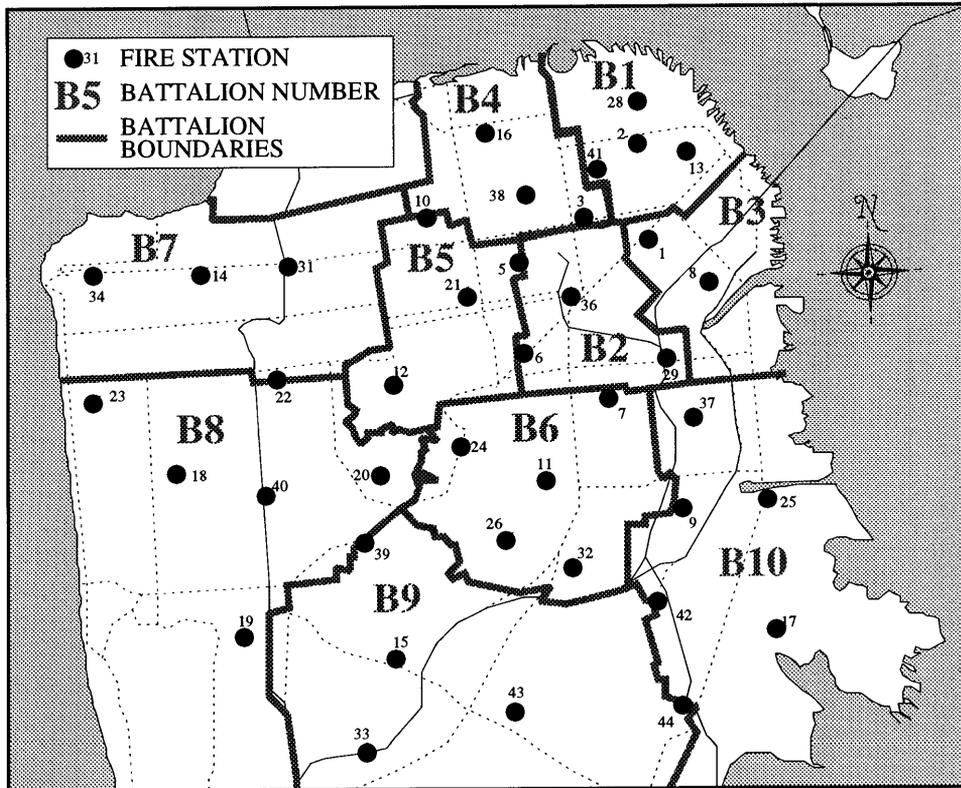


Figure 4.—Sketch map of San Francisco, showing locations of SFPD battalions and fire stations.

Emergency Operations Center (EOC), where the mayor, city-department heads, and all command and control are based.

Within minutes of the earthquake, 27 fires had broken out throughout the city, and the SFFD would turn out for more than 400 incidents in the next 4 hours (San Francisco Fire Fighters Local 798, 1990), the most significant of which were the fire and building collapses in the Marina District.

Normally, the SFFD has three available systems of water supply: the Municipal Water Supply System (MWSS), the Auxiliary Water Supply System (AWSS), and the Portable Water Supply System (PWSS). The MWSS serves the dual purpose of supplying potable water and providing water to fire hydrants. The AWSS is intended solely to ensure adequate water flow and pressure for firefighting purposes; it is separate and redundant to the MWSS, and is owned and controlled by the SFFD. Built in the decade after the 1906 earthquake and fire, the AWSS is concentrated primarily in the urbanized part of the city of 1906, still the central business district (fig. 5). It has been gradually extended to other parts of the city, although the original part still constitutes most of the AWSS. The AWSS network in the Marina District is mapped in figure 6.

The AWSS has been described in detail elsewhere (Scawthorn and others, 1990a, b). Briefly, it consists of several components:

- *Static supplies:* The 10-million-gal reservoir at Twin Peaks, the 750,000-gal Jones Street Tank, and the 500,000-gal Ashbury Tank (fig. 5).

- *Pump stations:* Two stations, each capable of pumping water from San Francisco Bay into the underground-pipe system at 10,000 gal/min and 300-lb/ft² pressure.
- *Pipe network:* 129 mi of cast-iron and ductile-iron pipe serving approximately 1,500 dedicated high-pressure hydrants. The pipe network is divided into three pressure zones: Twin Peaks, upper, and lower.
- *Fireboats:* At the time of the earthquake, San Francisco possessed only one fireboat, the *Phoenix*, whose pump capacity is 9,600 gal/min at 150-lb/ft² pressure. Fireboats may hook into the AWSS and pump seawater into the pipe network at any of five manifolds.
- *Cisterns:* In addition to the above components, San Francisco has 151 underground cisterns, again largely in the northeast quadrant of the city. These cisterns are generally of concrete construction, with a 75,000-gal capacity, about 1-hour supply for a typical SFFD pumper.

Control of the AWSS is centered at the Jones Street tankhouse, where gages provide pressure readings at a limited number of points in the network. A few gate valves can be operated remotely from this tankhouse by a signal transmitted over land lines. The water pressure in the lower pressure zone can be increased by opening valves at the tankhouse, and the Twin Peaks pressure zone can be "cut in" by remotely operating valves located at the Ashbury Tank. Remotely operable valves are presently powered by Pacific Gas & Electric Co. (PG&E), the local electric utility, but are being converted to a backup emergency battery system.

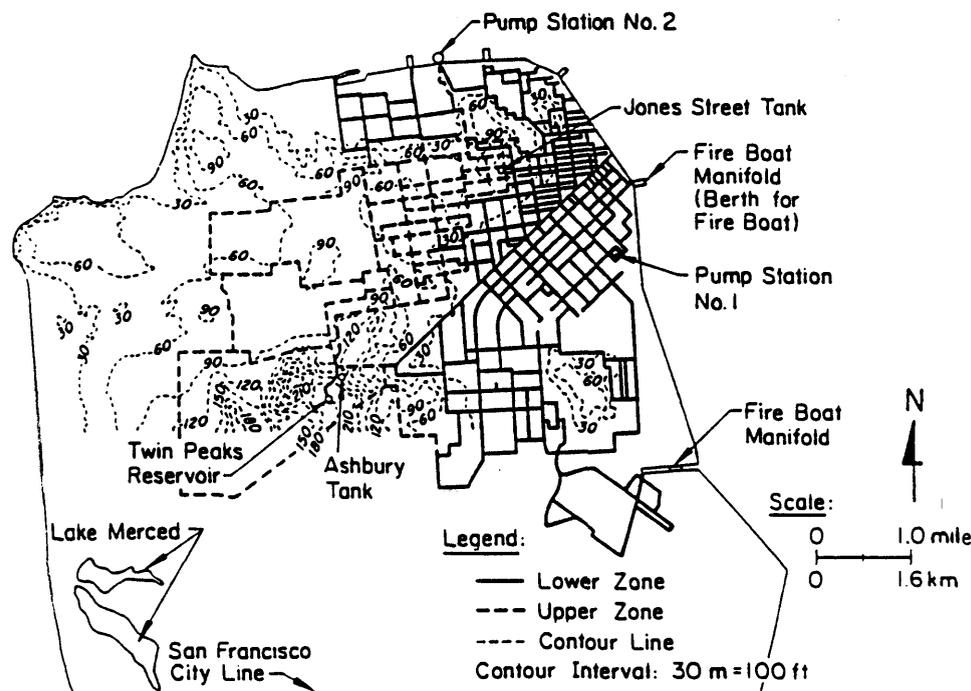


Figure 5.—Sketch map of San Francisco, showing location of AWSS pipe network. After Scawthorn and others (1990).

Although the AWSS provides high assurance of firefighting water supply in the northeast quadrant of the city, major fires can and do occur far from the AWSS pipe network. Experience in the 1906 earthquake, as well as in subsequent California earthquakes in 1971 (San Fernando) and 1983 (Coalinga), had also taught that earthquakes can damage piped water supply. In recognition of this fact, and to provide additional flexibility in deployment and to extend further the "reach" of the AWSS, since 1985 the SFFD has developed the PWSS. Its basic components are:

- Hosetenders, trucks capable of carrying 5,000 ft of large (5 in. diam) hose, with a high-pressure monitor for a master stream.
- Hose ramps, which allow vehicles to cross the hose when it is charged.
- Gated inlet Wye, allowing water supply into large-diameter from standard-diameter fire hose.
- Gleeson valve, a pressure-reducing valve connected to portable hydrants to draw water from the portable main at usable pressure.
- Portable hydrants, which allow water to be distributed from large-diameter hose.

Hosetenders, which carry all the hose, hydrants, valves, and other fittings, are capable of laying 5,000 ft of hose in about 20 minutes. Hose lengths are intermittently fitted with portable hydrants, permitting water supply at many locations along the hose. Hose can thus be gridded and, in

effect, provide a system of above-ground water mains. At the time of the earthquake, the SFFD had four PWSS hosetenders.

SAN FRANCISCO DEPARTMENT OF PUBLIC HEALTH, PARAMEDIC DIVISION

Emergency medical calls to the 911 exchange are routed to the Paramedic Division's Centralized Medical Dispatch Center (CMED) for response. Ambulances and crews are located at a staging area in Golden Gate Park (fig. 1) near Stanyan and Haight Streets. Normally, 15 ambulances are stationed there, and crews are available for 11 or 12 ambulances, with the others held in reserve. At the time of the earthquake, 11 ambulance crews were scheduled for duty.

EARTHQUAKE DAMAGE IN THE MARINA DISTRICT

The earthquake caused severe damage and widespread liquefaction-induced, permanent ground displacements in the Marina District. Seven buildings in the Marina District collapsed; their locations are shown in figure 7. These were the only buildings in San Francisco or Oakland that collapsed in the earthquake, although several structures in

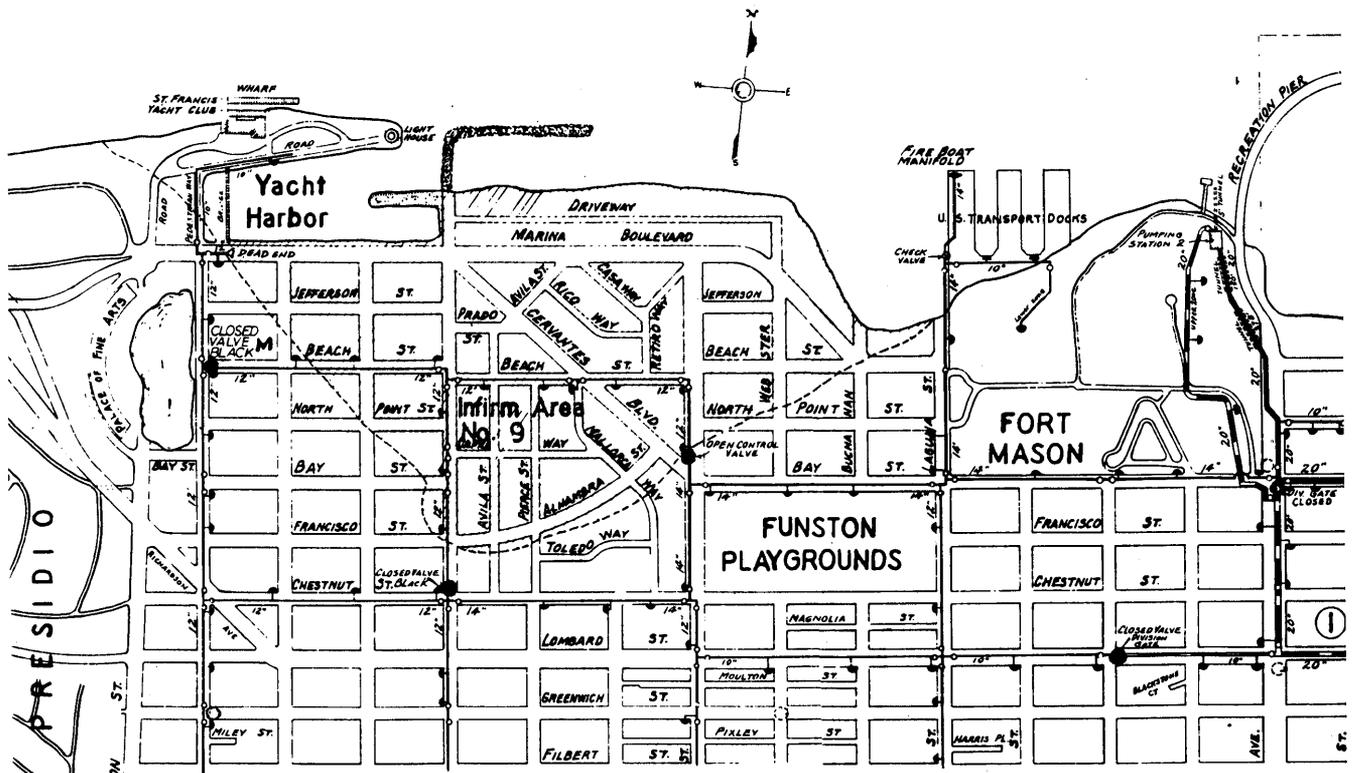


Figure 6.—Marina District, showing location of AWSS pipe network (heavy lines). Map courtesy of SFFD.

San Francisco and Oakland (fig. 1), outside the Marina District, sustained the loss of upper-story facades. At one brick building in downtown San Francisco, an upper-story facade collapsed, killing five people. Several other Marina District structures were on the verge of collapse. Eventually, 63 Marina District structures that had not collapsed were declared unsafe (red tagged), and many more were declared damaged and of questionable safety (yellow tagged); the locations of these structures are shown in figure 8.

The earthquake also caused widespread damage to underground facilities and other utilities. Electric power failed, and traffic signals went dark at a time when commuters were driving home, resulting in heavy, slow traffic in many places. The MWSS immediately sustained 123 main and service-line breaks within the Marina District, and 35 others outside the district (O'Rourke and others, 1990). The result in the Marina District was a total loss of flow to customers and to MWSS fire hydrants. The AWSS was undamaged in the Marina District. Elsewhere, however, the

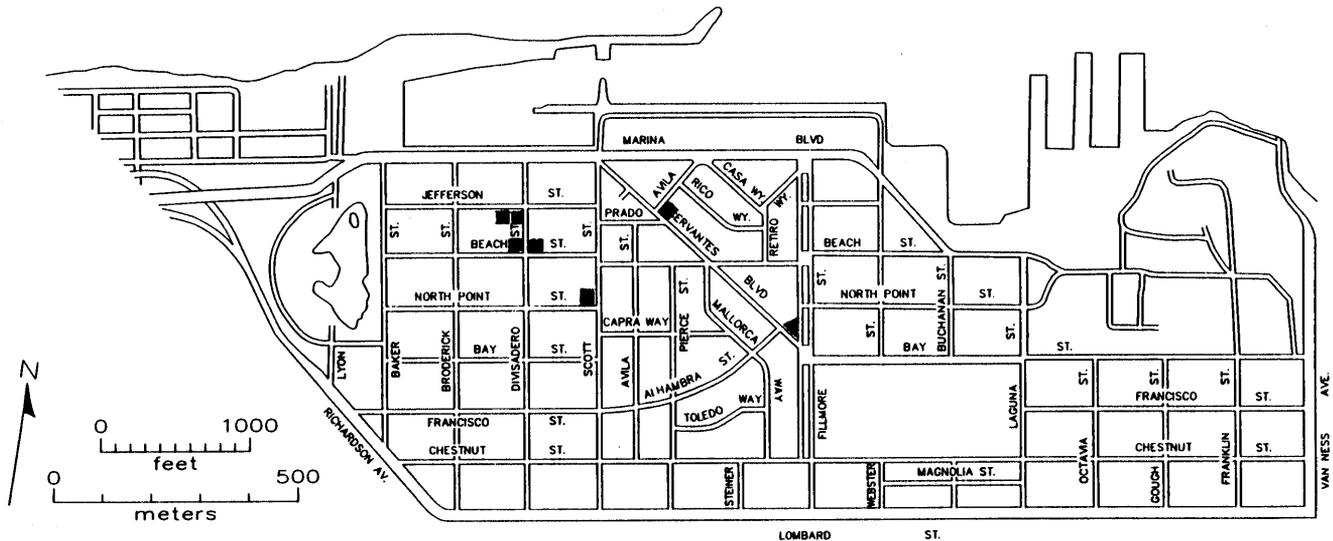
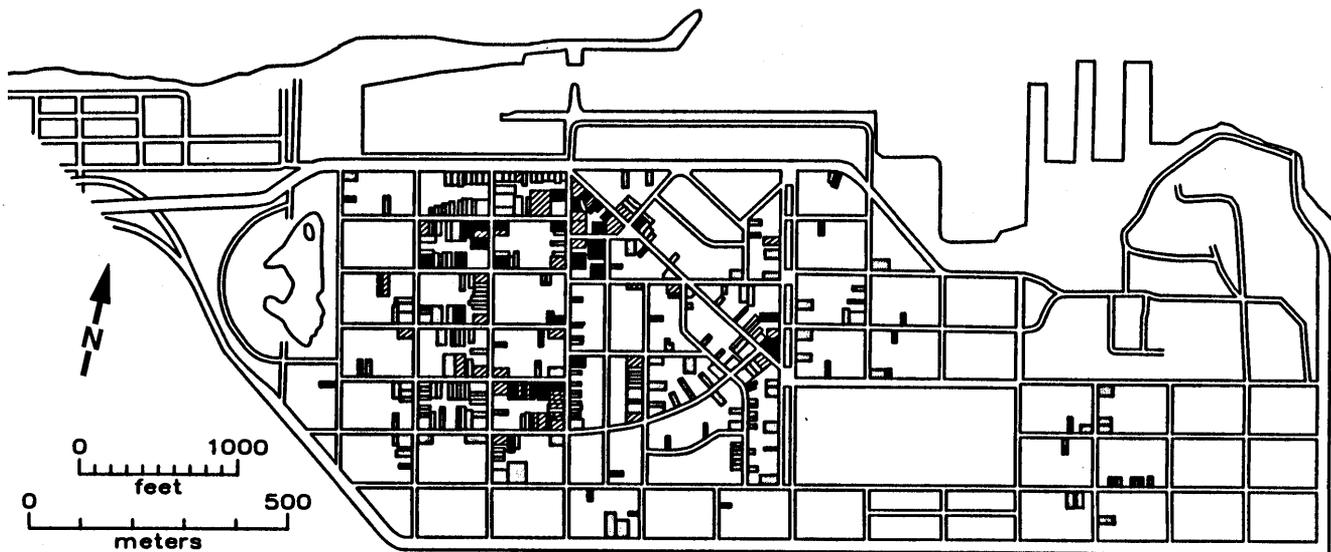


Figure 7.—Marina District, showing locations of collapsed buildings (dark areas). Base map from U.S. Geological Survey (1990).



- Buildings with Red Tags and demolished structures
- ▨ Buildings with both Red and Yellow Tags
- Buildings with Yellow Tags

Figure 8.—Marina District, showing locations of damaged buildings. From Seekins and others (1990).

AWSS sustained one main break, one hydrant-branch break, and five hydrant-elbow breaks that soon made it ineffective (though not inoperative) in the Marina District. Long delays in getting a dial tone led many users to believe that the telephones were not working (Benuska, 1990). PG&E's low-pressure gas-distribution system sustained numerous breaks in the Marina District; soon after the earthquake, the smell of natural gas pervaded the district.

In summary, this was the situation confronting SFPD and SFFD personnel responding to the Marina District immediately after the earthquake: Traffic was stopped or severely congested at several key points in the city; people frightened by the earthquake were filling the streets; 7 structures had collapsed; 63 more structures were severely damaged, some of which threatened to collapse; building occupants were trapped, injured, or both; the odor of escaping gas filled the air, raising fears of fire; and, although the SFFD did not know it yet, MWSS fire hydrants in the Marina District lacked all pressure, and the high-pressure AWSS zone serving the Marina District was rapidly draining through breaks south of Market Street.

SFPD RESPONSE

Damage to lifelines immediately reduced SFPD telecommunication and data-processing capabilities. The loss of commercial power and water, and limited interruption of telephone service, combined to force a temporary shut-down of the SFPD's computerized dispatch, and disrupted communications with the SFFD and the Paramedics Division. According to the SFPD's earthquake report:

Mainframe equipment was physically shifted by the force of the earthquake, there was some minor failure of ancillary equipment, and the emergency power source failed because the generator's cooling system uses water (which was unavailable when the main was broken). . . . When emergency generator power failed, the mainframe went down, and so did the Computer Aided Dispatch (CAD) system. The 911 transfer line to other municipal units such as the fire department and paramedics was not operational, due to Pacific Bell's McCoppin Street switch failure.

Nonetheless, the emergency did not overwhelm the SFPD's ability to respond. The SFPD estimated that "police resources could have dealt successfully with twice the affected area and one additional major perimeter if other conditions (e.g., no major aftershocks, lack of looting, few reported offenses) remained the same."

Soon after the earthquake, the SFPD transmitted by local broadcast media an order recalling all off-duty police officers and canceling all leaves. Many officers returned to duty on their own initiative, before the recall order was announced.

SFPD involvement was most extensive in their Northern District, which contains the Marina District, where activities focused on crowd and access control. A Marina Command Perimeter was established to control access into the

more severely damaged part of the Marina District between Marina Boulevard, Chestnut Street, Baker Street, and Fillmore Street (fig. 9). The SFPD had some difficulty maintaining access control in the days after the earthquake. According to the SFPD's earthquake report:

Reports of "tourists," tour buses, residents, interested third parties, and others attempting to enter affected areas and buildings are numerous. . . . changes in "policy" were made with enough frequency that maintaining access control became difficult; and many citizens were angered by the resulting delays and miscommunications. The authority of Parking Control Officers was often challenged when they were used to man the Marina perimeter. . . . This began to occur on October 18 and may have been largely due to confusion and the use of non-sworn personnel to man barricades.

SFFD RESPONSE

FIRST RESPONSE: BUILDING COLLAPSE AT 2 CERVANTES BOULEVARD

The SFFD's first recorded dispatch after the earthquake was at 5:06 p.m. P.d.t., according to official SFFD tape transcripts. The first response to the Marina District was at 5:11 p.m., when the communications center dispatched Engine 16 in reply to a report of people trapped at Fillmore Street and Cervantes Boulevard. Engine 16 arrived at the site by 5:14 p.m.; its crew reported finding the four-story structure at Fillmore Street and Cervantes Boulevard collapsed, with people trapped inside. The death toll from this collapse would turn out to be three, including Diane Laufer, 40, Paul Harris, 48, and 3½-month-old Scott Dickinson. Engine 16 also reported discovering a ruptured gas main nearby, and they asked the communications center to call PG&E, the owner of the main, to send crews to deal with the break. The communications center ordered Engine 16 to handle it themselves. Just 3 minutes later, at 5:17 p.m., they reported, "Get PG&E . . . gas all over the place."

The Battalion 4 chief on duty, Victor Shannon, heard Engine 16's initial report to the communications center regarding the collapsed building. Shannon signaled that he was going to respond to the scene, and he ordered that a rescue squad be dispatched as well. Rescue Squad 2 arrived 6 minutes later, at 5:20 p.m.

A MAJOR GAS LEAK

At 5:23 p.m., Chief Shannon reported a major gas leak at Mallorca Way and Alhambra Street, that police were on the scene, and that PG&E was needed to deal with the gas leak right away. This leak turned out to be a cracked miter joint in a 12-in.-diameter steel feeder main, the only leak in the high-pressure steel feeder system in the Marina District; numerous other leaks in the district were in the low-

pressure cast-iron and steel system. Then, 3 minutes later at 5:26 p.m., Shannon requested more trucks at the scene; Truck 5 responded.

COMMUNICATION PROBLEMS

At 5:28 p.m., Station 16 called the communications center, reporting "the collapse on Beach Street; there's a fire now in the collapse at Beach, between Divisadero and Broderick." This was the first indication of a fire in the Marina District on the SFFD's tape transcripts.

The communications center, however, did not acknowledge the message. Immense radio traffic was making contact extremely difficult. After analyzing the tape transcripts of radio communications between the communications center and field units, SFFD analysts later concluded:

Throughout this time [from 5:04 until 7:30 p.m.], field units and the communications center interfered with one another on the radio. Units were cut off, and many messages were not acknowledged. Some field units failed to wait 1 second for the radio repeaters to open; thus, the first parts of their messages were not heard. Radio traffic was so heavy that units could not get through to the communications center. When they did, they were often not heard.

FIRE, COLLAPSE, AND TRAPPED VICTIMS AT BEACH AND DIVISADERO STREETS

As Station 16 had reported, two four-story apartment buildings had collapsed at Beach and Divisadero Streets (fig. 10). The building on the northeast corner had collapsed onto Beach Street, covering an MWSS fire hydrant. Of its south facade, only one story remained; two stories remained at its rear on the north side (fig. 11). Sherra Cox, who was trapped in the rear of this building, would become the object of a difficult and dangerous rescue. Of the building on the northwest corner, two stories remained upright, leaning forward over an AWSS fire hydrant on the corner (fig. 12). This was the structure where the fire, which would eventually consume four buildings, began. As this building smoldered, a husband and wife, William and Janet Ray, lay trapped in a lower floor.

At about 5:30 p.m., Chief Shannon ordered Engine 38 to Cervantes Boulevard and Fillmore Street to assist with the rescue. He then requested an ambulance and another truck company, and he reported that a baby had been found in the collapsed building. The communications center dispatched both Truck 9 and Engine 41 to the scene.

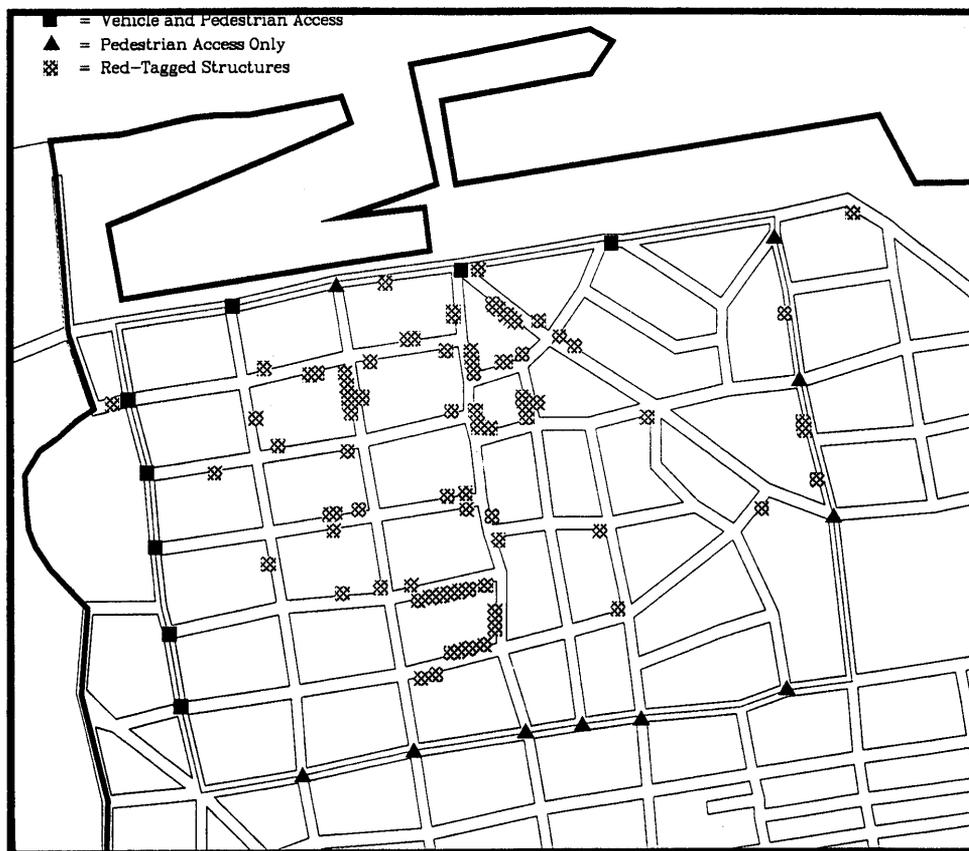


Figure 9.—Western part of the Marina District, showing location of SFPD North District's Marina Command Perimeter (outline). Map courtesy of SFPD.

At 5:35 p.m., Engine 10 reported a gas leak in front of 2359 Francisco Street, near Broderick Street. The crew of Engine 10 spent the next 20 minutes closing gas shutoff valves on Francisco Street while the fire three blocks to the north smoldered and grew.

At 5:37 p.m., the first unit to report from the fire scene was Truck 16, commanded by Capt. Robert Jabs. According to his report, Truck 16 had been on the way to the building collapse at Fillmore Street and Cervantes Boulevard when they were stopped by two off-duty police offi-



Figure 10.—Two collapsed apartment buildings at Beach and Divisadero Streets. Building in foreground is 3701 Divisadero, where fire started; building in background is 2090 Beach Street, where Sherra Cox was trapped. Photograph taken at about 5:20 p.m. P.d.t. October 17, 1989, from Beach Street; view northeastward.



Figure 11.—Collapsed building at 2090 Beach Street, after fire was much advanced. Note firefighter directing water onto exposed side of building. Photograph by S.P. Harris, taken at about 7:00 p.m. P.d.t. October 17, 1989.

cers and told that buildings had collapsed, trapping people inside. Capt. Jabs ordered Truck 16 to Divisadero and Beach Streets, where they found the collapsed buildings. He radioed the communications center of Truck 16's location and of the situation: "We're at Divisadero and [garbled]. We've got 10 or 12 buildings collapsed. There's one starting on fire. We've got people trapped. We're going to need an engine company." The SFFD's tape transcripts indicate that the communications center mistook Truck 16 for Engine 16 and ordered Truck 10 to respond to the fire scene to assist Engine 16. As late as 5:47 p.m., the communications center believed that Engine 16 was at the fire.

RESCUE AT 3701 DIVISADERO STREET

Capt. Jabs could see some of the trapped occupants of the northeast corner building at 2090 Beach Street. Civilians had been first on the scene and heard voices coming from inside this building. Because both corner buildings were in danger of further collapse, Capt. Jabs split his company of five and attempted both rescues. He sent firefighters Howard Cross and Wayne Martin into the northeast corner building, while he and the two remaining firefighters, John Reed and Thomas Bailon, began to search the burning building. Reed and Bailon went inside, while Capt. Jabs, aided by several civilians, tried to reach the trapped occupants from the side of the building, but they found the task

impossible. Meanwhile, Reed and Bailon used axes to cut open the floor, and found the two trapped occupants, Janet Ray and her husband, William Ray. Capt. Jabs recorded, "They were trapped beneath debris from the collapsed building. I entered the building with four or five civilians to begin extraction." The building was on fire.

An explosion shook the building, and Capt. Jabs ordered the civilians out. He later wrote:

Smoke was now starting to fill the floor ... and I could see flames coming from the front of the building. We could not free the trapped victims from the debris, so I had power saws and jacks brought into the building. We were racing against time, as the fire was spreading rapidly, and the only defense we had was a 1/2-inch hose line working under reduced pressure. Voices from outside the building called, saying, "The building is going to collapse!" I looked out the window and saw that the top floor of the building was fully involved with fire. At this point, we chose to continue rescue attempts. Heat and smoke drove us from the building, but the male victim had crawled out through the hole we cut in the floor. Myself and a male civilian carried the victim across the partially collapsed roof to safety and awaited an ambulance.

Janet Ray, 28, perished.

PG&E ARRIVES

By 5:52 p.m., two PG&E workers had arrived at Alhambra Street and Mallorca Way, determined that the gas leak was in the high-pressure system, and had Chief Shannon radio the communications center to ask for an additional PG&E crew.



Figure 12.—Collapsed building at 3701 Divisadero shortly after the earthquake. SFFD units had not yet arrived. Note dust or smoke from incipient fire at right. Photograph taken at about 5:20 p.m. October 17, 1989, from intersection of Beach and Divisadero Streets; view northwestward.

ENGINE 41 ARRIVES AT THE FIRE

Firefighters Reed and Bailon were still attempting to cut through the floor of 3701 Divisadero Street when the first engine to report from the fire, Engine 41, arrived at 5:52 p.m. It had been ordered to report to Cervantes Boulevard and Fillmore Street to assist there, but when it arrived, a column of smoke was visible over the rooftops, and so Chief Shannon ordered Engine 41 to continue on to the fire. According to a report by Lt. Peter Cornyn of Engine 41, when Engine 41 reached Beach and Divisadero Streets, the fire was still small. Firefighters Baker and Fitzpatrick hooked up to the AWSS hydrant immediately in front of the burning building, leading a line from the hydrant to Engine 41. The engine was positioned on Beach Street to utilize its deck gun. Three large lines were led from the engine: one to the west end of the building, a second to the middle, and a third to Divisadero Street. Firefighters manned and charged the lines, but they found that the system pressure was inadequate to supply all three. According to Lt. Cornyn's report:

Two large lines were left charged, but the hose stream didn't reach the fire. The fire was starting to escalate. Both ready lines were lead to the fire and charged, but there wasn't enough pressure to slow the fire down. At this point, Engine 41 was moved to Divisadero Street to escape the heat from the escalating fire.

Engine 41 withdrew to Divisadero Street, ripping the hose still connected to the hydrant in front of the burning building. While Engine 41 was still attacking the fire from Beach Street, Engine 2 from the Presidio Fire Department (PFD) arrived by way of Marina Boulevard. They attempted to draw water from an MWSS hydrant on the north side of the building, but they found the hydrant dry. They positioned their apparatus on Divisadero Street to the north of the burning building and, using water from their tank, provided protection for Capt. Jabs and the firefighters in 3701 Divisadero Street until the rescuers were forced from the building. When its water tank was empty, PFD Engine 2 was repositioned on Jefferson Street.

At 5:55 p.m., the communications center ordered Engine 14 to respond to Beach and Divisadero Streets, but then reversed the order, saying that a unit would be called from the PFD.

At 5:56 p.m., Engine 10 reported discovering another gas leak at 2240 Francisco Street. They asked whether they should ignore it and respond to the fire, which was only three blocks away. The communications center misunderstood this signal and believed that Engine 10 was going to the fire. Radio communication was confused; 3 minutes later, Engine 10 reported that they were available.

At about 5:55 p.m., Chief Shannon arrived at the fire and found the building in flames. At 5:58 p.m., he ordered Engine 16 to assist with the fire. The communications center reported to Shannon that a PFD unit was coming to the fire.

AWSS WATER PRESSURE LOW

At 6:01 p.m., Chief Shannon reported that the fire crews were putting water on the fire but that system pressure was very low. This is the first recorded report that pressure in the AWSS system was low in the Marina District. The pressure had dropped because of breaks sustained by the AWSS in the lower pressure zone south of Market Street.

At 6:09 p.m., Truck 10 reported that two buildings were now on fire and were burning out of control. They requested at least one, preferably two, additional engines. The communications center dispatched Engine 14 to the fire. At the time, Engine 14 was 4 mi away at 25th Avenue and Geary Boulevard. Engine 10 again reported that they were at Scott and Alhambra Streets, four blocks from the fire, and asked whether they should report to the fire. They received no response and eventually informed the communications center that they were responding to the fire. From the previous communication with Engine 10, the communications center seemed to think that there was a fire at Scott and Alhambra Streets, and at 6:15 p.m. they ordered Engine 31 to a fire at that intersection.

AWSS WATER SUPPLY NEVER EXHAUSTED

At 6:13 p.m., Engine 10 arrived at the fire and drove to Beach and Broderick Streets. The crew tested the low-pressure hydrant on the southeast corner and found it almost dry. They then hooked up Engine 10 to the AWSS hydrant on the northeast corner. The crew led two 3-in.-diameter hoses from the hydrant to the building immediately west of the fire, 2130 Beach Street. They found they had enough water to operate both leads, but only at reduced pressures. According to firefighter William Koenig of Engine 10, the pressure in the AWSS system ranged from 0 to 40 lb/in² at the engine. Somewhat later, Koenig reported:

Both big lines were receiving 50 to 60 psi, certainly not the best. . . . It was necessary to prime No. 10 on about five to six occasions; however, most of the time water was there. . . . As the water supply fluctuated during this period, it was necessary to close down a line or two, depending on the fire situation.

Radiated heat began to ignite window casings on the building directly opposite the fire on Beach Street. In response, Koenig reported, "All lines were shut down to allow Lt. Donham [Truck 5] to have increased pressure to enable him to reach the third-floor window to extinguish this fire."

At 6:16 p.m., Engine 21 reported from the Marina District. Chief Shannon ordered Engine 21's crew to attack the fire from the west along Beach Street. They tried the AWSS hydrant at Beach and Broderick Streets, which was supplying lines, but they saw that the lines were limp, as

if the capacity of the hydrant were being exceeded. Its crew moved Engine 21 to the southeast corner of Beach and Baker Streets, tested the AWSS hydrant there, and found that it appeared to have enough water. They placed two Gleeson valves on the hydrant, led two lines to Beach and Broderick Streets, and charged the lines. According to the report by Capt. Guido Costella of Engine 21, "After charging both lines, the water supply went to zero."

DRAFTING FROM THE LAGOON

Engine 21 abandoned the AWSS hydrant and fixed on another source of water: the lagoon at the Palace of Fine Arts, just two blocks to the west (fig. 13). According to Capt. Costella's report:

We broke the lines at Beach and Broderick, connected both lines into E14 [Engine 14], and proceeded with E21 back to Baker and Beach. Our . . . plan was to draft from Palace of Fine Arts lagoon. All access to the lagoon was blocked. We found a car with the owner able to move it, and we were able to drive down the pathway.



Figure 13.—Western part of Marina District, showing location of fire relative to lagoon at the Palace of Fine Arts. Photograph taken October 18, 1989.

We used one length of 6-inch suction [a rigid hose that does not collapse under vacuum from the engine's pump] to draft. We were supplying two 3-inch hose leads to E14 at Beach and Broderick and one supply lead to E3 that was working on Beach Street.

"Once the relay was established," recorded firefighter Koenig, "water was no problem, with both big lines now receiving 100 psi and the big multiversal in operation continuously." The fire by now had advanced westward to the three-story building at 2130 Beach Street. Before long, according to Koenig, "without warning, the second building, now 75 percent in flames from east to west, collapsed . . . into the first fire building and out into the street."

FIREBOAT PHOENIX DISPATCHED

At 6:16 p.m., Chief Shannon reported that the AWSS in the Marina District was running out of water, and he requested the fireboat *Phoenix* to respond to the fire. About this time, off-duty Battalion 4 chief, Greg Abell, arrived in the Marina District. Water pressure in the AWSS hydrants in the district had been low since the first fire crews had arrived, and there was no pressure in the MWSS hydrants. In response, Chief Abell called for a PWSS hosetender, carrying portable water-supply equipment, to lay an aboveground water main supplied with seawater pumped from the St. Francis Yacht Club Harbor by the *Phoenix*.

The communications center immediately dispatched Engine 22 and Hosetender 22 to the Marina, informing them they would lead from the fireboat. At 6:19 p.m., Chief Abell informed the communications center that the fire was five alarm. The communications center informed Chief Abell: "The fireboat's responding. They don't have a [firefighting] crew." This situation was normal. At the time of the earthquake, the fireboat *Phoenix* was assigned only its officer, Lt. Robert Banchemo, Pilot Arvid Hanneras, and Engineer Nate Hardy. Lt. Banchemo, when later questioned on what, in his opinion, could be done in the future to improve response, replied, "A: Have crew assigned to the fireboat. We couldn't wait for a cover co[mpany] the night of the quake."

Also at 6:19 p.m., Truck 2 reported that it was responding to the Marina District, and Truck 5 left the collapse at Fillmore and Cervantes Streets to respond to the fire.

TWIN PEAKS RESERVOIR HELD IN RESERVE, PWSS ARRIVES

By 6:24 p.m., Engine 21 was asking the communications center about extra water supply to the AWSS. They were at the AWSS hydrant at Beach and Baker Streets, and were requesting water. The communications center did not know whether extra pressure had been cut in from the Twin Peaks Reservoir, and they informed Engine 21 that the Jones Street Tank had detected a leak. Within a few minutes, the communications center informed Chief Shan-

non that the Twin Peaks Reservoir had not been cut in and was being held in reserve.

About this time, Hosetender 25 arrived at Marina Boulevard and Divisadero Street, having been dispatched by telephone. This was the first PWSS equipment to arrive in the Marina District; its use would turn out to be critical. Normally, a hosetender and its engine travel together; one firefighter drives the hosetender, while two firefighters and the officer travel in the engine. Hosetender 25, however, had been dispatched alone to the Marina District, and carried only the driver.

By coincidence, Hosetender 25 arrived just as two off-duty firefighters, Tom Kuhn and Steve Jones, returned to duty from their homes in Marin County. On their way into the city, the two firefighters had seen the fire and reported directly to the Marina District; they also saw PWSS Hosetender 25. Both firefighters Kuhn and Jones were normally assigned to Station 8, which houses another PWSS hosetender, No. 8. The two were assigned to assist Hosetender 25.

The now-complete crew of Hosetender 25 began immediately to make the initial 5-in.-diameter hose lead. It ran from Marina Boulevard up Divisadero Street to Beach Street and included two portable hydrants, with 900 ft of 5-in.-diameter hose. Hosetender 25 was then positioned on the east flank of the fire (fig. 14); from this position, they would be able to protect the buildings across, and farther north on, Divisadero Street.

By 6:27 p.m., the Division 2 chief, Assistant Chief Harry Brophy, had arrived in the Marina District, becoming the incident commander. He repeated the request for additional PG&E crews: "Send the PG&E out here to the area of Cervantes and Fillmore. You've got major gas in that area. Major gas leak . . . There's gas all over the place . . . You're gonna have a major one if we do not get it now."

By 6:41 p.m., Engine 21 was attempting to draft water from the lagoon at the Palace of Fine Arts, but its crew was having trouble getting the engine to the water because all access was blocked by parked cars. Engines 22 and 31 had attempted to draft water directly from the bay at the foot of Divisadero Street, but because of low tide, they were unable to find adequate access to the water over the harbor-bank riprap.

At 6:46 p.m., the second PWSS truck, Hosetender 22, arrived at the fire, along with Engine 22. It was ordered to lead hose up from Divisadero Street and Marina Boulevard one block south to Jefferson Street, along Jefferson Street one block west to Broderick Street, on Broderick Street one block south to Beach Street, and down Beach Street to the south flank of the fire. This hose lead was 3,000 ft long and had three portable hydrants. Chief Brophy had set it out to provide water all around the perimeter of the fire, preparing to make a stand on Jefferson Street to the north with aerial ladders and hand lines.

Hosetender 22 was positioned on Beach Street to open up its own monitor on the fire's south flank.

THE PHOENIX ARRIVES AT THE FIRE

About the same time as Hosetender 22 began to lay its hose, the Phoenix was arriving at the yacht harbor. It had trouble getting into position at the foot of Divisadero Street because of the outgoing tide. The water was so low that the *Phoenix* was dragging bottom, its screws churning mud. After the *Phoenix* was in position, the tide continued to drop, grounding the fireboat on the harbor bottom.

Engine 36, which had led hose from the high-pressure hydrant at Chestnut and Divisadero Streets, found that they had run out of hose half a block from the fire. Chief Brophy was still urgently calling for more hose.

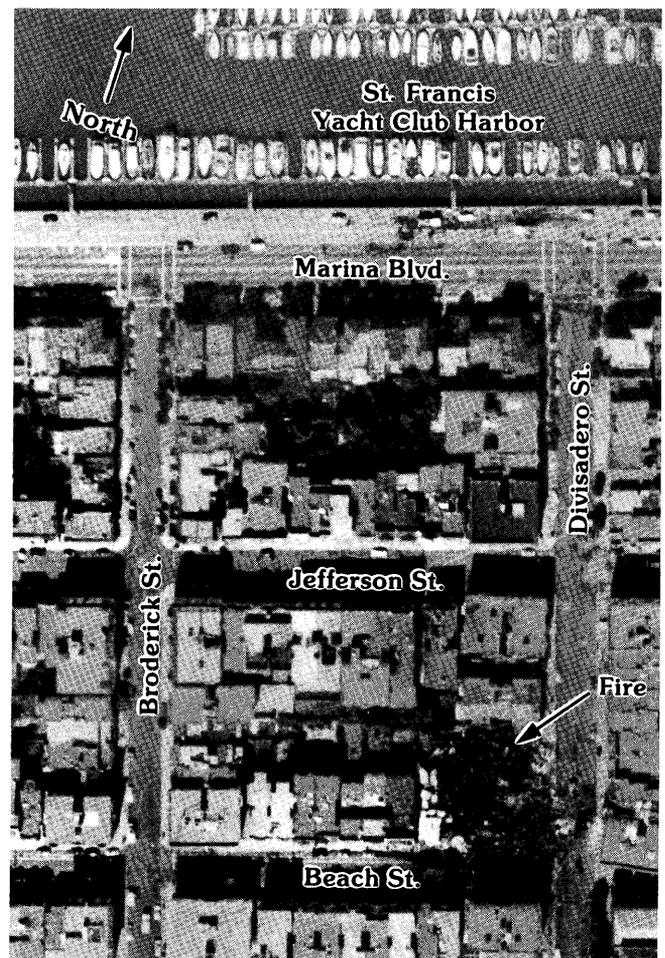


Figure 14.—Northwestern part of Marina District, showing location of the St. Francis Yacht Club Harbor. Hosetender 25 was located immediately to right of fire. PWSS hose leads from yacht harbor are visible on Divisadero and Broderick Streets. Photograph taken October 18, 1989.

At 6:57 p.m., Chief Abell reported that the fireboat had been hooked up and was ready to pump water. This was a turning point. Chief Brophy recorded, "Upon the arrival of the Fireboat . . . we changed from a defensive mode to offensive." Despite being aground, the *Phoenix* was able to pump because its intake sea chests were off the bottom and still under water. The fireboat's first lines had been put into the gated inlet Wye supplying Hosetender 25's 5-in.-diameter hose leads. Hosetender 25 had already been set up for some 10 minutes before receiving water from the *Phoenix*. The fire's radiant heat burnt the paint on the side of the truck but did not force it to withdraw as it waited for water. As soon as the *Phoenix* was hooked up, Chief Brophy ordered the line charged.

Hosetender 25 now had water and immediately opened up its high-pressure battery monitor on the fire's east flank. The effect was immediate and dramatic. Flowing 900 gal (3 tons) of water per minute, with 90 lb/in² of tip pressure and a 150-ft horizontal reach, Hosetender 25's monitor issued a powerful stream that knocked down the tremendous radiant heat threatening the exposure buildings on the east side of Divisadero Street. The fire in the buildings burning to the north began to darken.

THREAT OF A CONFLAGRATION ENDED

At 7:00 p.m., Hosetender 8 was the last of the PWSS to arrive, 3 minutes after Hosetender 25 opened its monitor on the fire. Chief Brophy ordered it to make a lead from the fireboat, up Marina Boulevard to Broderick Street, south to Jefferson Street, and then east to Divisadero Street. This route provided an additional portable water main on the north flank, with three more portable hydrants and 2,400 ft of 5-in.-diameter hose supplying pumpers and aerial trucks on this side of the fire.

At 7:17 p.m., Chief Shannon reported that headway was being made against the fire. Then, 7 minutes later, a second aboveground main from the fireboat was ready to be charged. The fire was still out of control by 7:29 p.m., when the transcript ends. Half a block was still ablaze, but Chief Shannon was by then confident that the fire would go out, recording, "The threat of a big conflagration is over." About 9:30 p.m., the fire was brought under control.

RESCUE OF SHERRA COX

Even while the *Phoenix* was still maneuvering into the yacht harbor, firefighter Gerald Shannon of Truck 9, Capt. Robert Boudoures of Truck 10, and firefighter Jerome Polizzi of Truck 2 had been working for some time on the difficult rescue of Sherra Cox. She was trapped in a lower floor of the collapsed four-story building at 2090 Beach Street, on the northeast corner of Divisadero and Beach

Streets, directly across Divisadero Street from the fire. The heat of the fire was causing the buildings facing it to smoke, and igniting curtains inside their windows. The building containing Shannon, Boudoures, and Cox caught fire several times during the rescue; each time, the firefighters outside extinguished the flames. The heat was intense, but Shannon did not retreat; he had promised Cox that he would not leave until he brought her out. "After I saw her," he stated, "I just couldn't leave."

The rescue of Sherra Cox took 2 hours. Relief from the heat came when Hosetender 25's monitor opened up; all the crew of Truck 9 could feel the cooling effect of the water being put on the fire. Cox was pulled out on a backboard and taken to San Francisco General Hospital (see fig. 1). She later underwent surgery for a fractured pelvis (New York Times, 1989).

Relief began to come for the initial responders late into the night. Engine 41 was relieved around 11:30 p.m., and Engine 10 around midnight. Firefighters continued mopping-up operations for several days (fig. 15). The fire damaged seven structures, destroying four buildings containing 33 apartments and flats (Sanborn Map Co., 1988): 3701 Divisadero (21 apartments), 2130 Beach (12 apartments), 3717-19 Divisadero (2 flats), and 3723-25 Divisadero (2 flats). SFFD estimates place the losses from this fire at \$7.4 million (fig. 16).

SIGHTSEERS AND VOLUNTEERS

Civilians had been the first on the scene at 3701 Divisadero Street, and they remained long into the battle with the fire, some helping, some hindering. By 6:30 p.m., sightseers were becoming a problem, and Chief Abell instructed the communications center to notify the media to ask people to stay off the highways. Chief Brophy was becoming concerned about civilians as well; in a fragmented transmission recorded on the tape transcripts he said: ". . . people off to Marina Greens and Chestnut to the other. We have major, major damage. Buildings down everywhere. Gas leaks everywhere. Police Department seal off the area. Get civilians out."

At 6:33 a.m., the fire was still out of control (fig. 17), and the police were having trouble evacuating civilians. At 6:35 p.m., Chief Brophy radioed the communications center. Again, the transmission is fragmented, but its urgency is apparent: "The situation down here in the Marina is devastating. We've 20 or 30 buildings here off their foundations . . . this is a national . . . police cannot handle the sit. . . ."

EMERGENT VOLUNTEERS

At 6:40 p.m., Chief Brophy requested all available hosetenders to the scene:

Get me all the hosetenders with the 5-inch hose that you can afford. Have them report in on Jefferson right where the yacht harbor is down there . . . Divisadero. We're going to have to take water from the bay. . . We have three blocks that are going to be involved. We'll have to give away some houses to make a stop, but we need the hose. We have the manpower to pull it; we've got a lot of volunteers, but get it here.

Indeed, there were plenty of volunteers (fig. 18). An offduty police officer at home in his apartment on Divisadero Street near Beach Street felt the earthquake, took his daughter out of the building, went back inside to get his shield, and emerged again to take control of the area. Civil-



Figure 15.—Mopping-up operations on fire. Photograph taken October 18, 1989, from southeast corner of Beach and Divisadero Streets.



Figure 16.—Northwestern part of Marina District, showing area near Beach and Divisadero Streets. Fire destroyed corner building, another immediately to west, and two more immediately to north.

ians in the Marina District took it upon themselves to go from house to house, shutting off gas. Engine 41, while setting up at Divisadero and Beach Streets, was assisted by civilian men and women, off-duty police officers, and retired firefighter Bill Koehler, formerly of Engine 41. These vol-

unteers helped lead hose to the fire from the AWSS hydrant at Divisadero and Bay Streets, two blocks south; volunteers then manned the hoses (fig. 19). Lt. Peter Cornyn, in his report to Chief Postel, wrote of “. . . [T]hirty civilians, whose names I did not get, . . . manned lines attempting to



Figure 17.—Fire in the Marina District. Photograph by Martin Klimek, *Marin Independent Journal*, taken shortly after sunset October 17, 1989; view southeastward.



Figure 18.—Volunteers assisted SFFD at fire. Note firefighter at right. Photograph by C.R. Scawthorn.

stop the Marina fire. Both men and women manned the lines with total disregard to their own safety and well-being."

Engine 36 employed volunteers relaying messages about charging the hoses, and keeping people out of the way. The crew of Engine 10, while closing street gas valves on Francisco Street, was assisted by civilians who formed a human barricade to close the street to all traffic. Perhaps most striking were the civilians who assisted Capt. Robert Jabs and firefighters Bailon and Reed of Truck 16 as they tried to rescue the two trapped occupants of 3701 Divisadero Street while the building burned overhead. In his report to Chief Postel, Chief Shannon wrote: "The citizens did everything possible to assist. I will not forget the acts or faces of our heroic citizens, but I do not know the names."

PARAMEDIC DIVISION RESPONSE

Paramedics responded to three Marina District locations. At 2 Cervantes Boulevard and 3701 Divisadero Street,



Figure 19.—Civilians helped to lead hoses and then man them at fire. Photograph by C.R. Scawthorn.

paramedics treated the injured and examined the dead. In addition, they set up an incident command post half a block from the fire, with an ambulance and a multicasualty unit standing by throughout the night.

CMED dispatched an ambulance to the Marina District shortly after the earthquake. Charles Saunders, medical director of the San Francisco Department of Public Health's Paramedic Division, indicated that the initial response occurred within 5 or 6 minutes of the earthquake; a second ambulance was dispatched shortly afterward. Firefighters had discovered four occupants trapped within the building at 2 Cervantes Boulevard by the time paramedics arrived: Carol Dickinson, Scott Dickinson, Diane Laufer, and Paul Harris.

Moments before the earthquake, Carol Dickinson waved goodbye to her husband Walter as he left for a bicycle ride. She returned to apartment 104, 2 Cervantes Boulevard, just as the earthquake occurred. Carol tried to escape from the building, carrying her 3½-month-old infant Scott in her arms, but they were caught when the stairway collapsed. She was trapped, and the baby was underneath her. She recalled that the baby was breathing at first, but then it became difficult for her to breathe, and she realized that the baby had stopped breathing. Despite the danger of further collapse, firefighters and paramedics successfully extracted the mother and child, and an ambulance transported them to Pacific Medical Center, with paramedic Eberle in attendance. Paramedic Eberle attempted to revive the baby but was unsuccessful. Scott Dickinson was pronounced dead on arrival at Pacific Medical Center at 8:15 p.m. Carol Dickinson survived (Medical Examiner/Coroner's Register 1303).

The other two victims, Diane Laufer and Paul Harris, were pronounced dead on arrival by a San Francisco Medical Examiner investigative team. The building had been pronounced structurally unsound, and the dead occupants were trapped beneath the debris; they were not extracted until the next day, after the building had been carefully disassembled. They were found lying amongst the rubble, partly pinned beneath a door jamb; Paul Harris appeared to be cradling Diane Laufer in his arms (Medical Examiner/Coroner's Registers 1306, 1307).

Paramedics were dispatched to treat William Ray when he was extracted from 3701 Divisadero Street, and, later, to treat Sherra Cox as she was removed from 2090 Beach Street. Both were taken to the hospital.

Throughout the night, paramedics manned the multicasualty unit and an ambulance standing by at the incident command post, half a block from the fire. The multicasualty unit was equipped with medical supplies, basic medical equipment, and communications equipment.

Injured Marina District residents generally were unable to communicate with the Paramedic Division because long delays getting a dial tone made it appear that telephone service within the district was inoperative. The Paramedic Division found that most earthquake victims near the dis-

district self-reported to nearby Letterman Army Medical Center and St. Francis Hospital. Of 70 who arrived at these two hospitals, only about 12 were brought by Emergency Medical Services.

CONCLUDING REMARKS

When examining the events related here, it is worthwhile contrasting San Francisco's experience in the 1989 earthquake with those in the 1906 earthquake. This section briefly summarizes observations and lessons learned, based on police, fire, and paramedic response in the Marina District, with reference to the record of the 1906 earthquake.

1. The city's fireboat *Phoenix* and the use of the PWSS proved crucial in stopping the blaze at 3701 Divisadero Street. The fire had burned out of control until PWSS equipment was deployed and supplied with water by the vast pumping capacity of the *Phoenix*. Without the fireboat *Phoenix* or the PWSS, the damage in the Marina District probably would have been substantially greater. Some firefighters also credit the limited damage to the unusual lack of wind. Estimates vary on the extent to which the fire might have burned, had winds been more typical of an October evening in the Marina District. One firefighter, in responding to a questionnaire by San Francisco Fire Fighters Local 798, noted, "Marina not in ashes because of (1) no wind, (2) fire boat, (3) portable hydrants and hose" (San Francisco Fire Fighter's Local 798, 1990).

In 1906, saltwater from the bay was the only source of water available to firefighters protecting buildings near the Embarcadero waterfront, the South Beach waterfront, and the channel. Pumping the saltwater were several military and private vessels, including the U.S. Navy destroyer U.S.S. *Preble*, the fireboat *Leslie*, the tugboats *Active* and *Fortune*, the U.S. Navy tugboat *Sotoyomo*, the two California fireboats *Governor Irwin* and *Governor Markham*, the Revenue cutter *Golden Gate*, and others (Hansen and Condon, 1989).

2. Planning and training in the use of the PWSS and the *Phoenix* worked. The strategies used with the PWSS had been carefully developed by SFFD staff, in anticipation of major events. When the time came to employ them, the plans proved well thought out and effective, and the time training PWSS crews proved well spent. We note that just 3 weeks before the earthquake, Chief Brophy had conducted a major training exercise at San Francisco's Pier 32, using the fireboat *Phoenix* to supply the PWSS. Firefighters interviewed after the earthquake remarked on how the use of the PWSS in the actual fire situation went just like the drill. This lesson demonstrates the effectiveness of thorough training and of tactics using high-pressure battery monitors to control large fires.

In 1906, SFFD leadership was centralized in Chief Dennis Sullivan. When he was incapacitated in the earthquake,

the absence of institutionalized preparedness planning is generally thought to have contributed to the inability of SFFD to contain the fire.

3. Inadequate communications capacity and procedures aggravated the SFFD's difficulty in identifying the number and location of fires, advising incident commanders of in-service-unit location and status, and employing the AWSS. From the start of the emergency response, radio traffic between SFFD units and the communications center far exceeded the capacity of allotted channels. Additional radio channels would likely have made a substantial difference in the SFFD's response in the Marina District.

As congested as radio traffic was in 1989, it represented a vast improvement over conditions in 1906, when the Central Fire Alarm Station at 15 Brenham Place was badly damaged, making the city's fire-alarm system inoperative (Hansen and Condon, 1989).

4. Significant numbers of volunteers emerged to assist in the Marina District response. This pattern of emergent volunteers assisting emergency-service personnel during crises has been observed in past earthquakes as well. After the September 19, 1985, Mexico City earthquake, volunteer rescue teams worked around the clock searching for trapped victims of building collapse (EQE Engineering, 1986). In the May 2, 1983, Coalinga, Calif., earthquake, citizen volunteers manned firefighting hose lines and shut off their own and neighbors' gas (Scawthorn and Donelan, 1984). Lechat (1989) reported, "In Japan, it was observed that within half an hour after an earthquake (Niigata, 1964), 75 percent of the non-affected survivors were engaged in some kind of rescue activity." Emergency-response planning for fire and search and rescue should consider how best to employ emergent response. At a minimum, substantial supplies of clothing and equipment for volunteers should be cached or prearranged.

5. The value of preevent planning and standard operating procedures (SOP's) was demonstrated by the success of the PWSS and by the short-term ineffectiveness of the AWSS. Faced with the loss of water pressure, the SFFD had three options to increase AWSS water supply to the Marina District:

(a) Start the pumps at Pump Stations 1 and 2. Each station has a pumping capacity of 10,000 gal/min at 300-lb/in² pressure. Pump Station 2 alone could supply enough water flow and pressure for the fire (M. Khater, oral commun., 1991). The extent of damage to the AWSS pipe network, and potential flooding and washout, made this option problematic in the first hours after the earthquake.

(b) Order the fireboat *Phoenix* to the fireboat manifold at Fort Mason's Pier 1. Once attached to the fireboat manifold, the *Phoenix* could pump 9,600 gal/min at 150-lb/in² pressure directly into AWSS mains near the fire, thereby supplying similar flows to those from Pump Station 2. We note that the fireboat was dispatched directly to the Marina District, rather than to a manifold. In hindsight, this deci-

sion can be seen as proper because AWSS damage was unknown at the time and the fire's proximity to the shoreline permitted the fireboat to supply the PWSS directly.

(c) Cut the Twin Peaks Reservoir into the lower pressure zone. This option would have briefly prevented the Jones Street Tank from draining, but it would also have resulted in drawing down the Twin Peaks Reservoir within several hours, leaving the upper pressure zone unprotected by the AWSS.

In the end, no decision was made. Lacking SOP's, operators at the Jones Street Tank waited for instructions that they never received, leading to a temporary loss of water within the AWSS' lower pressure zone.

6. The SFFD and the local geotechnical- and earthquake-engineering communities had long been aware of the potential for liquefaction in the Marina District. The earthquake vulnerability of structures on made ground had been evident as early as 1868, after the Hayward earthquake of that year and the San Francisco earthquake of 1865. Nonetheless, the old City Hall, completed in 1896, was built on filled land and subsequently destroyed in the 1906 earthquake (Hansen and Condon, 1989).

Despite this past experience, the area's seismic vulnerability was not well known by residents in 1989, nor was it reflected in the city's emergency planning for earthquakes. Since the earthquake, the city of San Francisco has sponsored studies of several areas where a high potential for liquefaction is known to exist, including the Marina District (Harding Lawson Associates and others, 1991a, b). This type of study represents a bridge of knowledge between the engineering community and city officials. The conclusions of these studies should be integrated into future emergency plans.

7. Immediately after the earthquake, although the building collapse at 2 Cervantes Boulevard was known, surrounding areas in the Marina District were not reconnoitered for similar damage, allowing precious time for the fire to grow. Indeed, personnel at the SFFD's communications center (the City's EOC) long lacked a clear picture of the damage in the Marina District. They did not realize the magnitude of the emergency until they saw it on television, broadcast nationwide by the blimp that was on hand for the World Series.

After an earthquake, television and radio helicopters should be employed immediately for rapid reconnaissance. Their reports could be integrated within a disaster-information-management system, to transmit this data rapidly, effectively, and without unnecessary repetition to emergency-response authorities at the EOC. With a clear picture of the situation, these authorities can maximize scarce resources and respond effectively to the emergency.

The foregoing observations and lessons can provide the basis for improved disaster mitigation. However, some of these observations have been made before and not acted upon (for example, those regarding construction on made

ground). Perhaps the most useful lesson is to observe a case in which recommendations based on "lessons learned" were implemented. Before 1906, SFFD officials and insurance underwriters had recognized that the city's water-supply system was inadequate to protect against conflagration. A design for the AWSS had been proposed but not implemented until after the 1906 disaster provided the final impetus. The AWSS has served San Francisco well, providing copious amounts of water for numerous large fires.

Earthquake losses were reduced only where responsible experts anticipated problems and communicated them effectively to appropriate authorities, who saw to it that solutions were promptly developed, implemented, and institutionalized with training and SOP's.

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