The Loma Prieta, California, Earthquake of October 17, 1989—Recovery, Mitigation, and Reconstruction

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SOCIETAL RESPONSE
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THE LOMA PRIETA, CALIFORNIA, EARTHQUAKE OF OCTOBER 17, 1989:
SOCIETAL RESPONSE

RECOVERY, MITIGATION, AND RECONSTRUCTION

INTRODUCTION

By Joanne M. Nigg,
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The papers in this chapter reflect the broad spectrum of issues that arise following a major damaging urban earthquake—the regional economic consequences, rehousing problems, reconstruction strategies and policies, and opportunities for mitigation before the next major seismic event. While some of these papers deal with structural or physical science topics, their significant social and policy implications make them relevant for improving our understanding of the processes and dynamics that take place during the recovery period.

Brady and Perkins provide a macro-level analysis of the economic consequences that the Loma Prieta earthquake had on the San Francisco Bay region. They conclude that effects of the quake on the regional economy were minimal, despite a large amount of structural losses, especially in Santa Cruz County. Although the quake did cause some economic disruption, the availability of redundant transportation systems and relief assistance greatly reduced its impact.

Two papers deal with the issue of sheltering and rehousing people displaced by the earthquake. Phillips looks at how socially vulnerable groups of victims in Santa Cruz County—the elderly, the already homeless, and low-income Latinos— were affected over a 2-year recovery period. She concludes that rehousing these groups was not approached in a comprehensive manner and that a variety of pre-existing social conditions actually added to the problems of sheltering and rehousing. In her assessment of housing problems that arose in San Francisco and Watsonville following the earthquake, Comerio investigates the linkage between pre-disaster mitigation efforts and reconstruction of the housing stock. She concludes that the rate of reconstruction varies greatly depending on several local factors.

The importance of mitigation during the post-earthquake recovery period is also addressed in three of the other papers in this chapter. Bolton and Oriens propose that the Loma Prieta earthquake provided a test of how well the National Earthquake Hazard Reduction Program's efforts have promoted local-level mitigation activities. They conclude that local officials believe that seismic elements of the State of California's building code were effective in limiting the extent of damage in their communities, but also that those officials were not likely to recognize the extreme importance of site characteristics as factors affecting structural damage. Bolton and Oriens' second conclusion is reinforced by Tyler and Mader in their investigation of how Santa Cruz County and some of its mountain residents became locked in a conflict over a land use issue. The County would not issue house rebuilding permits on sites with evidence of earthquake-caused ground failure, although residents claimed willingness to assume all risks and try to get their disrupted lives back to some state of normalcy. The paper by Thiel, Housner, and Tobin reviews the Board of Inquiry's recommendations to the Governor of California concerning design and policy needs to mitigate future earthquake damage to the State's transportation infrastructure systems (bridges and highways). They conclude that while much had been done in the two decades before the Loma Prieta earthquake, more aggressive efforts to mitigate future consequences are needed.

Brown and Mortensen, in the concluding paper, stress the importance of incorporating the Earth science community more fully into the organizations and agencies that manage earthquake hazard reduction activities. They maintain that response and mitigation decisions should be based on the best available scientific information and that this expertise must become institutionalized in order for it to be available in a timely manner to decisionmakers.

PUBLIC RESPONSE

MACROECONOMIC EFFECTS OF THE EARTHQUAKE

By Raymond J. Brady and Jeanne B. Perkins
Association of Bay Area Governments, Oakland, Calif.

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ABSTRACT

The Loma Prieta earthquake produced minimal disruption to the overall economy of the Bay Area and its environs. Our research indicates that approximately 7,100 workers were laid off as a result of the earthquake. The actual number could be higher because not all workers are eligible for unemployment claims. However, a statistical analysis of the employment data suggests that the actual number is close to that estimate. This disruption lasted a maximum of 4 months, with a direct potential loss of wages and salaries of about $54 million, resulting in a minimum potential loss in gross output (including wages and salaries) of about $110 million during this period. The total economic disruption resulted in an estimated maximum potential Gross Regional Product (GRP) loss ranging from $725 million in 1 month to $2.9 billion over a maximum of 2 months following the quake. However, at least 80 percent of that loss was recovered during the first and second quarters of 1990. This implies that the maximum GRP lost as a result of the Loma Prieta earthquake ranges from $181 million to $725 million.

These losses, when compared to the total size of the regional economy, can only be viewed as minor. For example, the potential short-term loss of approximately 7,100 jobs over an average duration of 4 months amounts to a loss of less than 0.25 percent of the jobs in an economy of more than 3 million jobs. The GRP loss is even smaller when compared to an economy with a GRP of $174 billion in 1989.

This economic loss is even small in comparison to the direct physical damage due to the earthquake of $5.9 billion. The economic loss was primarily concentrated in retail and selected manufacturing activity.

San Francisco experienced the greatest loss in retail activity for the fourth quarter. Data analysis indicates the

loss of approximately $73 million in taxable sales. This loss was, however, not regionally felt. Economic activity merely shifted to other parts of the region. Because the only direct damages which were disproportionately high in San Francisco were to transportation and power facilities, this suggests the critical role that transportation and infrastructure play in maintaining economic activity and gives a glimpse of the potential impact on the economy from a major failure of these systems in a future earthquake.

The job losses were most severe in Santa Cruz County, which experienced an 85 percent increase in unemployment insurance claims for the period from the third week of October to the second week of November over the same period in 1988. In 1988, the unemployment claims were 3,910; in 1989, they jumped to 7,246. Statistical analysis suggests that the actual total employment for November 1989 was, at a minimum, about 1,700 jobs less than would have been likely without an earthquake. The reduction for December was similar to that for November.

To perform these analyses, we used a methodology built around an input-output model of the San Francisco Bay Area previously developed by Association of Bay Area Governments (ABAG) staff. This work illustrates how secondary impacts of earthquakes can be measured in large urban areas. The methodology is designed as a quick-response mechanism to give policy makers estimates of macroeconomic loss based on sets of data and assumptions about duration of earthquake impacts on economic activity.

INTRODUCTION

The Loma Prieta earthquake was felt by millions of people over an area covering approximately 400,000 square miles (State/Federal Hazard Mitigation Survey Team, 1990). The earthquake caused more than $5.9 billion in direct property damage and disrupted transportation, communications, and utilities (State Office of Emergency Services, Region II, unpublished communication, Sept. 27, 1990). A breakdown of the damage patterns is provided in table 1. How did this damage and disruption translate into impacts on the region's economy?

Macroeconomic impacts are defined as recordable disruptions in business activity and employment. These impacts are viewed as short-term economic phenomena and are differentiated from property loss impacts. The objective of this report is to identify the macroeconomic impacts of the Loma Prieta earthquake.

METHODOLOGY

The macroeconomic impacts of the Loma Prieta earthquake are of three major types: (1) the employment impacts, (2) the impacts on regional sales, and (3) wage and output impacts.

TECHNIQUES FOR ASSESSING THE EMPLOYMENT IMPACTS

The most effective and simplest way to assess employment impacts is to view the data over time and to compare the data trends with those of other historical periods. Therefore, the initial step in this analysis was to plot month-by-month employment data for selected counties and Primary Statistical Metropolitan Areas (PMSA's) in the immediately affected region. The following areas were analyzed:

Santa Cruz County
San Benito County
Monterey County
Oakland PMSA (Alameda and Contra Costa Counties)
San Francisco PMSA (Marin, San Francisco, San Mateo Counties)
San Jose PMSA (Santa Clara County)
Santa Rosa-Petaluma PMSA (Sonoma County)
Vallejo-Fairfield-Napa PMSA (Napa and Solano Counties)

The monthly data for 1988 were compared against monthly data for 1989 to identify changes in trend that could be associated with the Loma Prieta earthquake. These trend data are identified in figure 1. Next, Auto Regressive Integrated Moving Average (ARIMA) and least squares time series models were developed for each county or PMSA. Data used in the ARIMA models covered the 12 months of 1988 and 10 months in 1989. For the least squares models, the data series covered the period from September 1988 to September 1989. The independent variable in the linear least squares models was California employment for the month. ARIMA and least squares models were used as a check against each other. An ARIMA is not likely to pick up macroeconomic "noise" in the data, since it calculates the forecast on the trend.

A macroeconomic downturn would show up in these data and could be differentiated from the rise in unemployment or slowdown in job growth that was specifically related to the earthquake. Both forecasting techniques were used to predict numbers for November and December 1989. If the forecast employment was greater than the actual employment, the difference was analyzed using both forecasting techniques to identify the Loma Prieta earthquake impact.

Unemployment Insurance (UI) claims data were collected from the California Employment Development Department (EDD) from the third week in October to the second week of November for both 1988 and 1989. The difference between the claims from these two periods was analyzed.

Two critical assumptions were made. First, it was assumed that 80 percent of the difference was associated with the earthquake. There was some concern that an assumption of 100 percent leaves little room for microeconomic disruptions that had nothing to do with the earthquake, such as a plant

Table 1.—*Estimated Loma Prieta earthquake damage in San Francisco and Monterey Bay Area counties*

[Source: California Governor's Office of Emergency Services (OES), Region II, Sept. 27, 1990, except as otherwise noted below]

Amount of Damage	Alameda County	Contra Costa Couny	Marin County	Monterey County	San Benito County	San Francisco County[1]	San Mateo County	Santa Clara County	Santa Cruz County	Solano County	Total
Total damage, in millions of dollars	1,472	25	6	118	102	2,759	294	728	433	4	5,940
Homes damaged	2,765	485	24	341	174	1,321	782	5,124	13,329	2	24,347
Uninhabitable housing units[2]	3,284	0	2	25	75	9,202	76	408	2,983	0	16,055
Businesses damaged	397	124	20	48	35	920	793	364	1,615	0	4,316
Businesses destroyed	16	0	0	11	22	16	1	6	310	0	382
Road damage, in millions of dollars[3]	559	0.6	3.6	0.6	0.3	212	9.2	5.3	40.3	0.5	833
Public utility damage, in millions of dollars	0.05	0.17	0.39	~ 0	0	37	0	0	5	0	43
PG&E losses, in millions of dollars[4]	— 4.1 —		0.5	(Combined with San Mateo and Santa Clara Counties)		— 33.1 —		— 25.5 —		0.1	74

[1]Data on homes damaged and businesses destroyed and damaged are taken from San Francisco City Planning Department, March 1991. The numbers are higher than those in the OES data. "Destroyed" numbers include those destroyed in the earthquake and those red-tagged and demolished. "Damaged" numbers include those secured or yellow-tagged. The number of dwelling units in residential buildings destroyed or secured was known, and all units are included in the totals. However, the numbers may be low for damaged homes due to an assumption of one unit per building for yellow-tagged buildings. Similarly, for commercial and industrial facilities, it was assumed that there was a single business per building, which underestimates the actual number of impacted businesses.

[2]Data from Perkins and others (1996).

[3]Data from the Region II OES Damage Assessment Surveys for local roads were added to data from a written communication from Caltrans District 4 Earthquake Damage Status Report as of September 14, 1990 and both written and oral communications from Districts 5 and 10 staff. San Francisco-Oakland Bay Bridge repairs are included in the values for Alameda County, not San Francisco. In addition, all Region II OES values were checked with the counties. This process resulted in an increase for Monterey County.

[4]Data from Pacific Gas and Electric Co. (PG&E), Insurance Dept. (written commun., Sept. 1991). Data supplied by PG&E multi-county region. Region boundaries follow, but are not identical to, county boundaries. Damage for the East Bay Region (Alameda and Contra Costa Counties) appears under those counties in this table. Damage for the Redwood Region (Marin, Sonoma, Napa, and a small portion of Solano County) appears under Marin County in this table. Damage for the Mission Trail Region (Monterey, San Benito, most of Santa Clara, and Santa Cruz Counties) appears under Santa Clara and Santa Cruz Counties. Damage for the Golden Gate Region (San Francisco, the headquarters offices, San Mateo, and a very small portion of Santa Clara County) appears under San Francisco and San Mateo Counties. Because much of Solano County is in the Sacramento Valley Region, the total damage for this large area is listed under this single county. The $0.6 million damage in the San Joaquin Valley Region and $10 million of indirect costs do not appear in this table except in the "Total" column.

closing, or for general macroeconomic disruptions, such as a general slowdown in growth. Therefore, the 80 percent value appears reasonable. Second, it was assumed that the economic disruption in employment and output lasted a maximum of four months. This conservative assumption was based upon an analysis by the California EDD, in which "claim loads returned to normal levels within four weeks" (California Employment Development Department, 1990a).

After estimating the number of UI claims, we compared these numbers against the employment estimates by the ARIMA or least squares for each PMSA or county.

TECHNIQUES FOR ASSESSING THE RETAIL SALES IMPACTS

Taxable sales data were collected from the California Board of Equalization for 12 quarters covering the period 1987-1989 for the 12 counties affected by the Loma Prieta earthquake. Data were plotted by quarter for the periods 1987-1988 and 1988-1989. The 1987-1988 data were used as a benchmark to identify quarterly trend data. The 1988-1989 series was plotted on the same graph to ascertain whether the quarterly patterns were similar. When it was clear that the slope change between the third and fourth quarters of 1988 differed from that between the same quarters in 1989, an ARIMA and least squares were used to predict the taxable sales for the fourth quarter based upon trend data for the 12 quarters.

TECHNIQUES FOR ASSESSING THE WAGE AND TOTAL OUTPUT LOSS ASSOCIATED WITH THE EARTHQUAKE

After the employment losses were calculated, wage and salary losses were calculated for each county affected by the earthquake. Using county business patterns data from the U.S. Commerce Department, average annual wages per employee were calculated for 1989. The average wage by county was multiplied by the employment loss.

Since, as explained in the section on "Techniques for Assessing the Employment Impacts," it was assumed that the duration of layoffs due to the earthquake was 4 months, the average annual wages were multiplied by 4/12 to obtain wage and salary loss for this shorter period. Next, using data on the ratio of wages to gross output gathered when updating the ABAG regional input-output table, an estimate of the gross output loss associated directly with the employment loss was calculated. The average duration of the loss was assumed to cover 4 months.

An estimate of the decline in potential gross output associated with economic disruption was calculated for the 12-county area. The disruption affected output where employment layoffs were associated with the earthquake. This potential decline in gross output reflects the minimum potential loss due to the earthquake.

Finally, an estimate of the range of regional gross output disrupted by or lost due to the earthquake was calculated. This estimate was based upon the gross output for the quarter for the 12-county area. Of this estimated value, most was recovered in the months following the earthquake. However, a conservative estimate was developed of the total loss in gross output that was not recovered.

Throughout this process, several assumptions have been made. The overriding rule, however, has been to make these assumptions maximize the impacts of the earthquake, to the extent practical. Thus, if the conclusion of this effort is that the impact on total regional output is small, this conclusion was reached in spite of the assumptions made during the analysis.

ANALYSIS OF THE MACROECONOMIC IMPACTS OF THE EARTHQUAKE

ANALYSIS OF COUNTY OR PMSA EMPLOYMENT IMPACTS

Monthly employment trends for 1988 and 1989 for the 12 counties within the study area are plotted in figure 1. For the 9-county Bay Area, the areas were delineated by PMSA. There are 5 PMSA's in the Bay Area, identified in the section "Methodology." Individual data exist for the counties of Monterey, San Benito, and Santa Cruz.

Table 2 identifies unemployment claims for the period from the third week in October through the second week in November for the years 1988 and 1989. The data give a relatively good picture of the direct job impacts of the Loma Prieta quake. As described in the previous section, it was assumed that between 70 and 90 percent of the increase in unemployment claims was associated with the earthquake. This varies by county or PMSA. It was assumed that 90 percent of the increase in claims in Santa Cruz County was associated with the quake and that 70 percent of the increase in the San Jose PMSA was so associated. The lower value of 70 percent was used for the San Jose PMSA because of an economic slowdown independent of the earthquake. The assumption for all other areas was 80 percent.

Using the above assumptions, we estimated that approximately 7,100 of the total 8,619 increase in claims during this period were associated with the earthquake. More than 42 percent of the estimated increase in claims due to the earthquake were located in Santa Cruz County. San Francisco PMSA (Marin, San Francisco, and San Mateo Counties) accounted for about another 20 percent of the increase. The Oakland PMSA accounted for about 15 percent, and the San Jose PMSA share was about 12 percent of the total. San Benito and Monterey Counties accounted for the remaining 11 percent of the claims.

SANTA CRUZ COUNTY

Figure 1*A* shows that the trend of employment growth in Santa Cruz County was disrupted in October 1989. Unemployment claims increased by 3,336 from the third week in October to the second week of November 1989. An ARIMA model was developed to predict nonagricultural employment for November and December 1989, based upon 20 months of time series covering 1988 and 1989. The predicted value using the ARIMA model for November 1989 was 84,800 jobs. The actual number of jobs was 83,100, or 1,700 jobs lower than the predicted value. The model has a range of 82,500 to 87,000, at a 95 percent confidence value. This analysis shows that the employment should have been higher than it was based upon monthly trends, the difference being assigned to the earthquake. The difference between the actual value (83,100) and the high end of the ARIMA predicted value (87,000) is

Table 2.—*Unemployment claims in Bay Area counties affected by the earthquake for the third week in October through the second week in November*

[Source: Effects of the October 17, 1989 Earthquake on Employment (California Employment Development Department, 1990a) p. 7-8.]

Area	1988	1989	Actual increase	Assumed percent of increase due to earthquake	Calculatd earthqua ke-related increase
Santa Cruz County	3,910	7,246	3,336	90	3,002
San Benito County	642	926	284	80	227
Monterey County	7,521	8,205	684	80	547
Oakland PMSA	9,410	10,778	1,368	80	1,094
San Francisco PMSA	7,541	9,270	1,729	80	1,383
San Jose PMSA	6,929	8,147	1,218	70	853
Total	35,953	44,572	8,619	- - -	7,106

greater than the calculated earthquake increase of 3,002. Therefore, our assumptions seem reasonable. For December, the predicted value is 84,100, which is 1,800 jobs higher than the actual employment; the upper limit of the ARIMA model's prediction is 87,700 with a 95 percent confidence value. Hence, the model tended to verify the observed increase in UI claims as shown in figure 2, and the decline in employment as identified in figure 1*A*.

SAN BENITO COUNTY

San Benito County was close to the earthquake's epicenter, but the economy was only marginally affected. Figure 1*B* shows the trend in employment in 1988 and 1989. No discernible shifts in growth could be identified. Unemployment claims increased by 284 during the period.

An ARIMA developed for nonagricultural jobs for 20 months covering 1988 and 1989 indicates a predicted level of jobs greater than the actual. For November the forecast suggests 8,263 jobs in the county. The actual number is 8,075. The difference is close to the number of claims filed. In December, 8,414 jobs were forecast for the County and the actual number was 8,100 jobs. This indicates continued weakness into December in the local economy.

MONTEREY COUNTY

Unemployment claims in Monterey County increased by 684 individuals for the period from the third week in October through the second week in November of 1989 over the same period in 1988. An ARIMA model was constructed to predict November and December 1989 nonagricultural employment. These predicted data were compared with the actual data (figure 1*C*) for the period. The actual employment in November 1989 was 112,200, and in December it was 111,800. The comparison tends to verify that the quake did have some impact on the county's employment growth. The ARIMA forecast for jobs in November 1989 was 600 higher than the employment reported by EDD. In December, the forecast was 400 jobs higher than the number reported by EDD. The difference in the forecast and actual numbers appears to be confirmed by the jump in unemployment claims. However, the increase clearly is minimal when compared to the total jobs in the county.

OAKLAND PMSA

The Oakland PMSA consists of Alameda and Contra Costa Counties. As shown in figure 1*D*, the quake had minimal impact on job growth during the affected period. In fact, the graph shows an acceleration of job growth for October-December 1989 over the same period in 1988. Although unemployment claims did jump by 1,368 during this period, when compared to the same period in 1988, the increase appears to have been limited to the Berkeley-Oakland area. The Hayward-Fremont areas farther south experienced a jump of about 392 claims during the week of October 28 over the same period in 1988. However, the number of claims dropped dramatically after this week. Kroll and others (1991) speculated that "employment trends in the East Bay (Oakland MSA) suggest that the earthquake may have induced a mini boom for the end of October and the month of November in some sectors, in portions of Alameda and Contra Costa Counties undamaged by the earthquake."

The increase in UI claims associated with the quake in an economy of 900,000 plus jobs can only be viewed as insignificant. To statistically verify that conclusion a least-squares model was constructed for the Oakland PMSA. The independent variable was nonagricultural employment in the state. The dependent variable was nonagricultural employment in the Oakland PMSA. The r^2 for the model was 0.92 and the DW statistic was 2.13, indicating little bias in the model. The results of the simulation indicated that the predicted growth was less than the actual. In short, economic conditions in the PMSA were not inhibited by the Loma Prieta earthquake.

SAN FRANCISCO PMSA

The San Francisco PMSA consists of Marin, San Francisco, and San Mateo Counties. Unemployment claims increased by 1,729 in the PMSA over the same period in 1988. Approximately 78 percent of this increase was in the County of San Francisco. Most of the job loss in San Francisco was in retail activity. This loss is verified by figure 3*H*, which shows a major slump in taxable sales in San Francisco, probably due to transportation disruption.

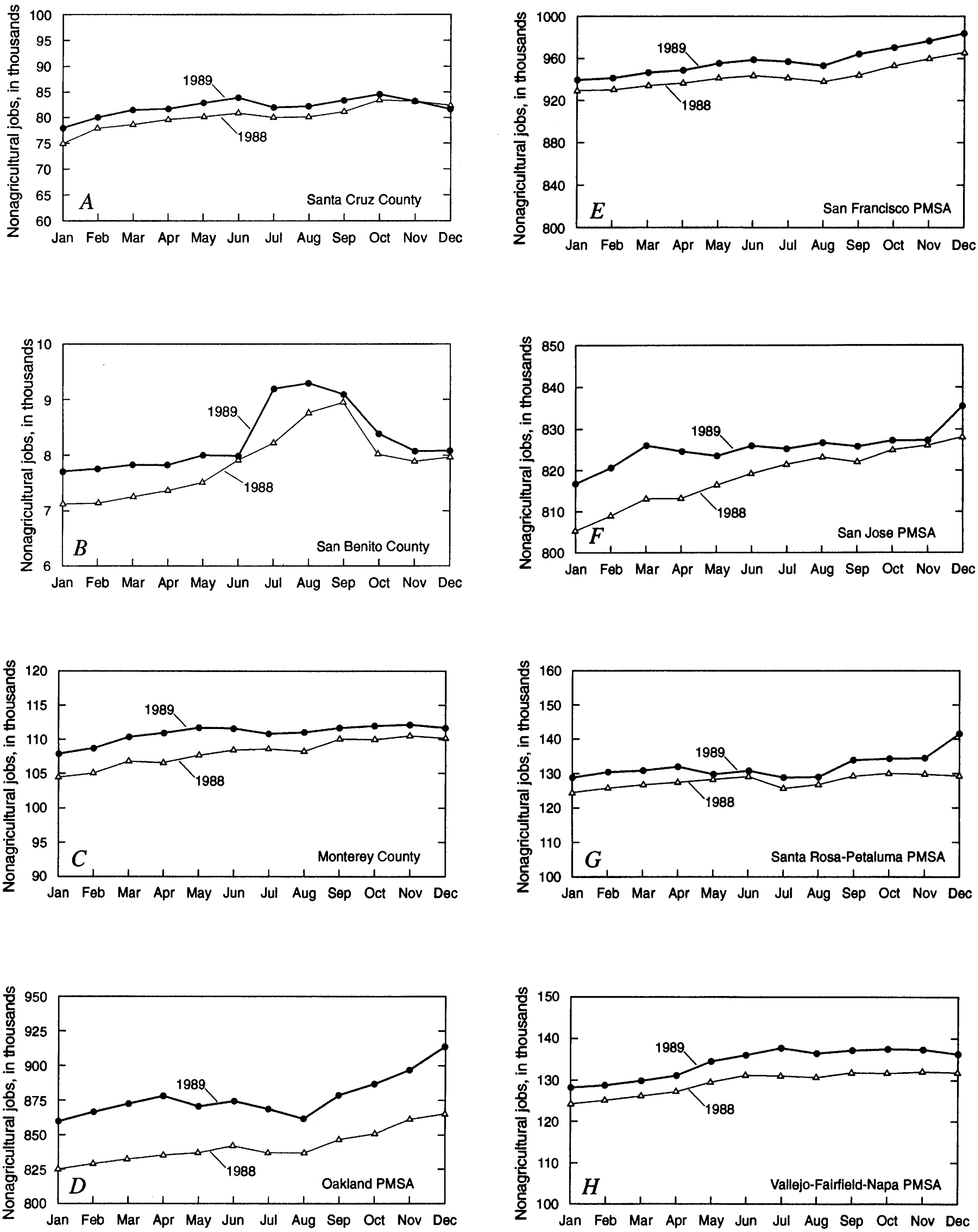

Figure 1. Monthy trends in total nonagricultural employment for San Francisco Bay Area counties during 1988 and 1989 (before and just after the Loma Prieta earthquake of October 17, 1989). Data from California EDD (1990) and ABAG files.

The overall employment impact in the PMSA was not significant. The job losses accounted for approximately 0.2 percent of total jobs in the PMSA during this period. Figure 1*E* shows that the trends of employment for the months of October-December 1989 were very similar to those for the same period in 1988.

SAN JOSE PMSA

The San Jose PMSA consists of Santa Clara County in the southern portion of the Bay Area. Unemployment claims jumped by 1,218 for the period from the third week in October through the second week in November 1989 over the same period in the previous year. Thirty-seven percent of the increase was in the Gilroy area, in southern Santa Clara County.

Approximately one-third of the increase was in the Sunnyvale area, in the northwestern corner of the county. A major fraction of this increase in claims is associated with high-tech layoffs unrelated to the quake. Figure 1*F* indicates a general weakening of employment growth through the year 1989, independent of the quake in October. The graph shows a jump in employment in December 1989 in sectors normally affected by an economic disruption such as an earthquake. More than 50 percent of the increase from November to December was associated with retail trade activity. An ARIMA model of monthly employment data from January 1988 to October 1989 was developed to predict November and December 1989 employment for the PMSA. The model predicted a November employment level about 2,000 jobs greater than the actual, but nearly 15,000 lower than the actual for December. The confidence band for the November forecast of 836,400 jobs was about ± 3.5 percent. The confidence band for the December forecast of 820,300 jobs deteriorates to about ± 5 percent. Therefore, the statistical model is not useful in this case, primarily because the trends illustrated in figure 1*F* show a general economic weakening throughout 1989. Therefore, it is argued that little or no evidence exists that Loma Prieta affected economic activity in Santa Clara County in a statistically measurable way.

SANTA ROSA-PETALUMA AND VALLEJO-FAIRFIELD-NAPA PMSA'S

The Santa Rosa-Petaluma PMSA consists of Sonoma County, and the Vallejo-Fairfield-Napa PMSA consists of Napa and Solano Counties.

These counties are in the northern Bay Area and farthest from the quake's epicenter. Figures 1*G* and 1*H* indicate little or no impact from the quake. Unemployment claims verify this statement. Although the Vallejo-Fairfield-Napa PMSA did see an increase in claims during this period and a slowing in job growth, these conditions are totally attributable to the early stages of the existing recession, since the losses were associated with residential construction activity.

ANALYSIS OF COUNTY TAXABLE SALES IMPACTS

In addition to examining the potential employment impacts of the earthquake, we analyzed the impact on retail sales to determine the effects of the earthquake on consumer behavior during this period.

SANTA CRUZ COUNTY

Given the employment impact of the earthquake in Santa Cruz, one would expect that a measurable impact on retail sales also would have been felt. However, as figure 3*A* illustrates, the trend for the affected quarter is quite similar to that of 1988. To verify this observation, an ARIMA model was used to predict taxable sales. Data covered the period from the first quarter of 1987 to the third quarter of 1989, or 11 quarters of data. The forecast for the fourth quarter 1989 was $460,930,000 in taxable sales. The actual amount was $456,900,000 in taxable sales. The difference is less than 1 percent and statistically insignificant. Therefore, it appears from these quarterly data that the quake had little or no impact on sales activity.

One factor minimizing the impact of such losses in Santa Cruz may have been the availability of relief funds for temporary tents to house those businesses displaced in the downtown area. Some businesses also were able to relocate to other areas of the county, minimizing the county-level impact (even though sales tax revenues in the city of Santa Cruz dropped). Another factor may have been the strong economic base of Santa Cruz as the site of an expanding University of California campus, and as a southern annex of Santa Clara County's "Silicon Valley." Finally, spending may have increased as people replaced or repaired those items damaged or destroyed.

SAN BENITO COUNTY

Figure 3*B* shows little or no impact from the earthquake in the fourth quarter 1989 retail sales patterns for San Benito

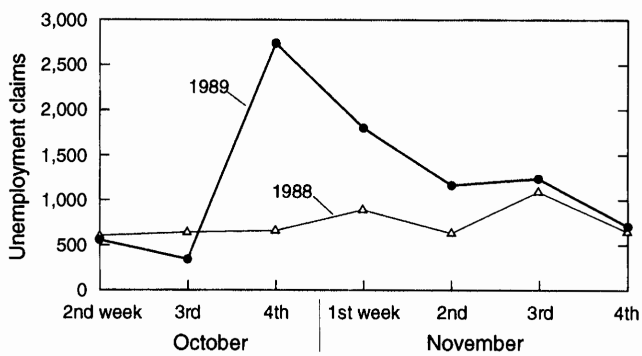

Figure 2. Number of unemployment claims filed in Santa Cruz County during October-November 1988 and October-November 1989 showing affect of Loma Prieta earthquake of October 17, 1989. Data from California EDD (1990).

County. In fact, sales in the quarter jumped substantially higher than the trend for the same period in 1988.

MONTEREY COUNTY

Figure 3*C* indicates that the earthquake had little or no impact on taxable sales in Monterey County in the fourth quarter of 1989. An ARIMA model for the same period forecast a taxable sales level 1.4 percent higher than the actual data. This difference is considered statistically insignificant. In short, it is not likely that the difference was the result of the quake.

ALAMEDA COUNTY

Alameda County is part of the Oakland PMSA. Figure 3*D* identifies the taxable sales data for the county.

The graph shows that the trends over the 1987-1988 and 1988-1989 periods are similar on a quarterly basis. The second and third quarters of 1989 actually were better than those in 1988. The fourth quarter appears to have flattened out. An ARIMA model, however, for the period forecast a lower fourth quarter than the actual taxable sales. Therefore, little or no evidence exists that the quake disrupted taxable sales in Alameda County in the fourth quarter of 1989.

CONTRA COSTA, MARIN, AND NAPA COUNTIES

Figures 3*E*, 3*F*, and 3*G* illustrate taxable sales activity for Contra Costa, Marin, and Napa Counties. The trend data show little or no disruption in taxable sales activity in these counties over this period.

SAN FRANCISCO COUNTY

Figure 3*H* identifies taxable sales activity in San Francisco County. The graph does suggest a shift in the retail sales activity trend for the fourth quarter of 1989. Various statistical techniques were used to measure the expected against the actual retail activity. An ARIMA model forecast sales $73 million above the actual. A statistical least squares, using California taxable sales as an independent variable, forecast taxable sales $31 million higher than the actual data. Some of this loss in potential retail activity can be associated with the drop in tourism, which is estimated to be a $3-billion annual business in San Francisco. Another source of the loss is associated with a shift of retail activity from San Francisco to other counties in the region. This shift may have been due, in part, to the damaged bridge access to San Francisco. A short-term power outage in the Financial and Marina districts may have exacerbated this problem. ARIMA models of retail activity for the fourth quarter 1989 for Alameda, Contra Costa, and San Mateo Counties indicated higher retail sales than

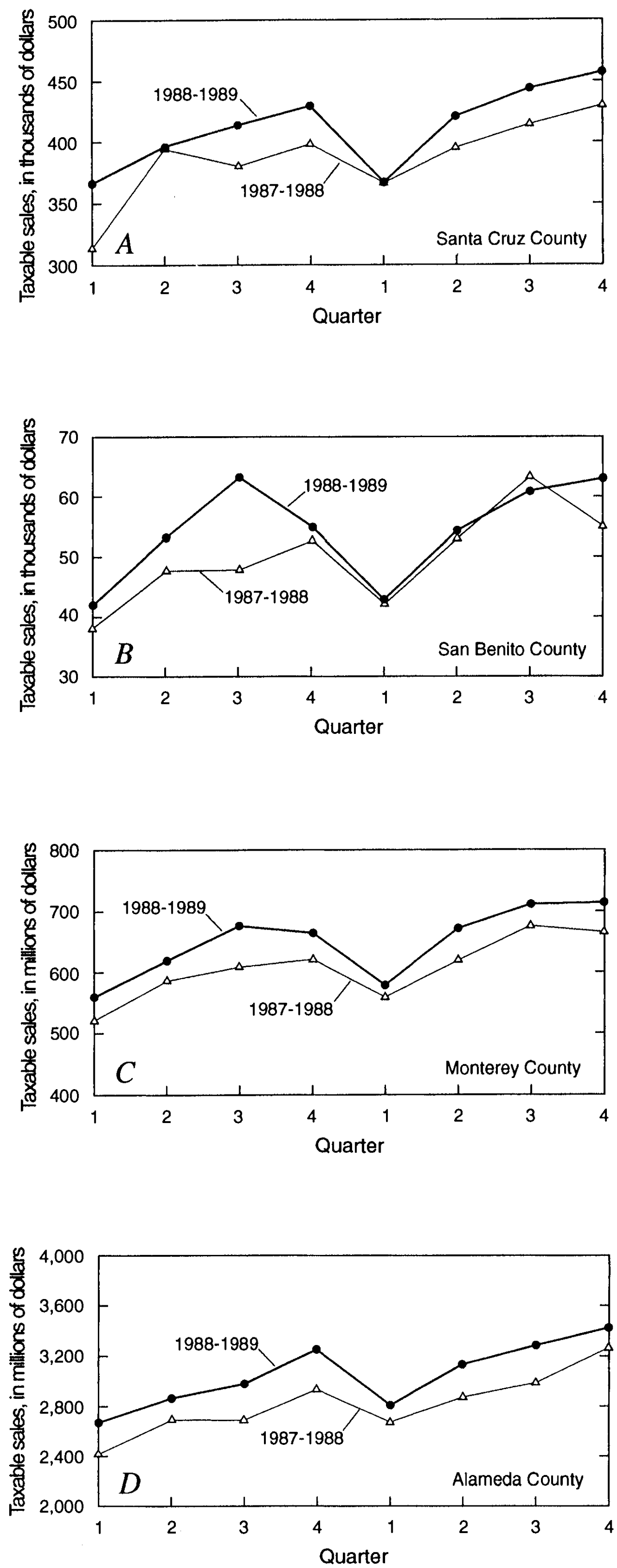

Figure 3. Trends in taxable retail sales in San Francisco Bay Area counties during 1987-1988 and 1988-1989 (before and just after the Loma Prieta earthquake of October 17, 1989). Data from California Board of Equalization (1989 and 1990) and ABAG files.

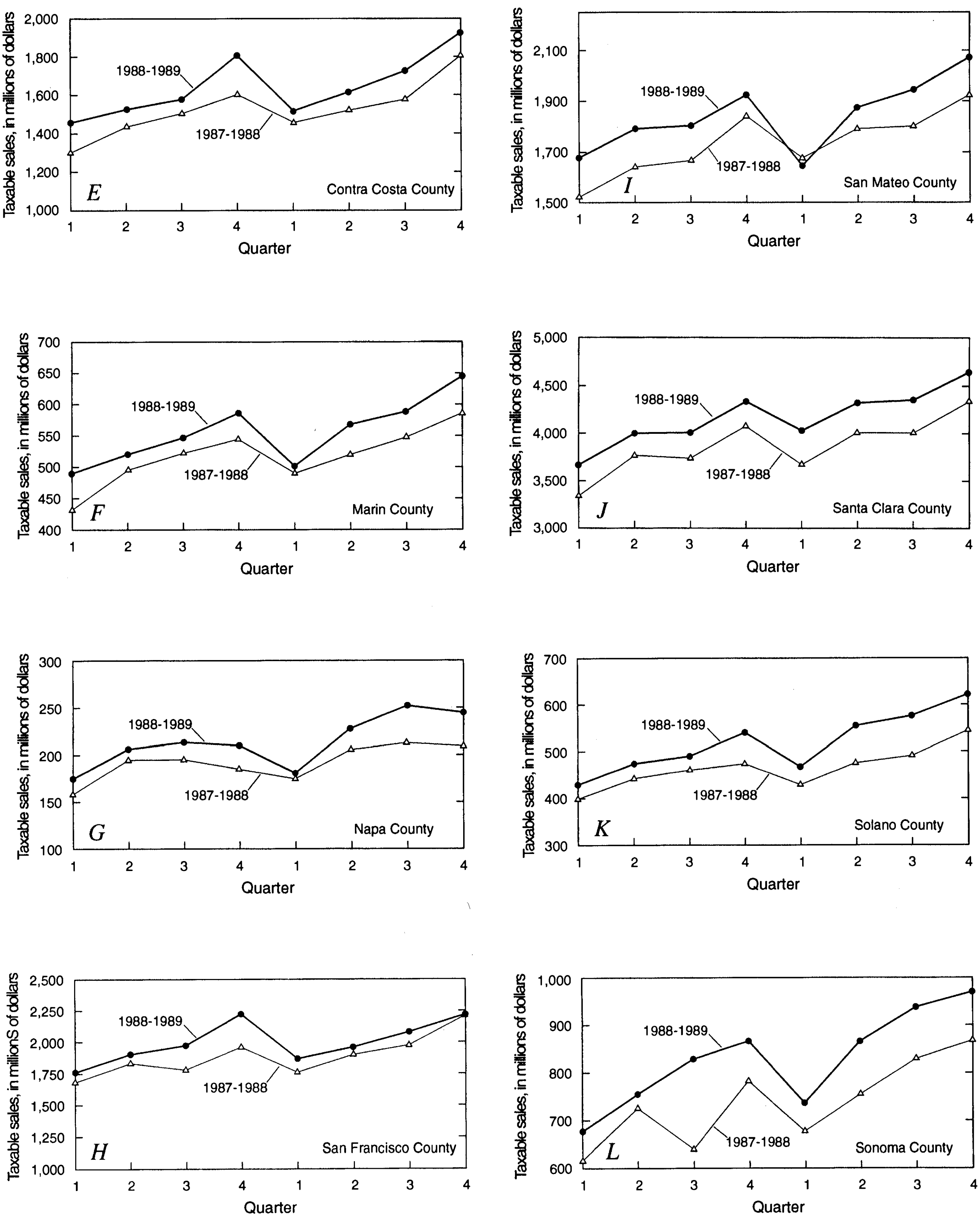

Figure 3. Continued.

expected for the quarter. A portion of this increase can be attributed to a shift in retail activity away from San Francisco County to other counties in the Bay Area.

This shift points to a potentially significant reason why the Bay Area's economy was not substantially affected by the quake. As noted earlier, a major portion of the loss in economic activity in San Francisco may have been due to a loss in transportation access. This suggests that lack of widespread infrastructure damage minimized the economic impact of the earthquake.

SAN MATEO COUNTY

Figure 3*I* shows retail activity in the fourth quarter of 1989 in San Mateo County. The graph suggests that the trend in this activity was not disrupted by the earthquake. This is verified by an ARIMA model of retail activity which forecast a lower level of growth than actually occurred.

SANTA CLARA COUNTY

Figure 3*J* identifies taxable sales activity in Santa Clara County over a period covering 1987-1989. Little or no identifiable quake impact can be observed from the trend data. An ARIMA model for taxable sales for the County covering the period from the first quarter 1987 through third quarter 1989 was developed. The model results confirmed that the actual sales exceeded expected sales for the fourth quarter of 1989.

SOLANO AND SONOMA COUNTIES

Figures 3*K* and 3*L* cover Solano and Sonoma Counties, located in the northern portion of the Bay Area. Both graphs show little or no impact from the quake on taxable sales in these counties.

ANALYSIS OF WAGE AND OUTPUT IMPACTS

As noted earlier, long- or short-term job disruption affected more than 7,100 individuals after the Loma Prieta earthquake. In order to estimate the impact of this disruption, the average wages of the affected individuals were estimated. It was beyond the scope of this project to develop a profile of the workers affected by the earthquake. Therefore, wage and salary losses reflect averages for the specific county or PMSA. Table 3 shows average wage and salary levels in 1989 for the affected counties.

After identifying the average wage and salary for 1989 for each affected area, we estimated the number of workers affected. The affected workers were defined as the difference (1989 versus 1988) in the claims for the period from the third week in October through the second week in November multiplied by a fraction. That is, it was assumed that the workers affected by the quake were not responsible for all of the increase. For Santa Cruz County, it was assumed that 90 percent of the increase was earthquake related. For Monterey and San Benito Counties, and for the Oakland and San Francisco PMSA's, the estimate was 80 percent. For the San Jose PMSA, the estimate was 70 percent. The 70 percent figure was chosen because an economic slowdown independent of the earthquake was already occurring in the San Jose PMSA.

Next, we estimated the lost income. Data on the actual duration of unemployment were not available, so we assumed that the average maximum duration of a layoff due to the earthquake was 4 months. This assumed maximum duration of unemployment represents one-third of the year without income. This value was multiplied by the annual wage and salary to obtain lost income. The resulting figure reflects maximum income lost, because unemployment benefits received during this period were not subtracted from the wage and salary lost. The wage and salary losses estimated in this way from reported unemployment due to the earthquake are shown for the affected areas in table 4.

After calculating wage and salary losses due to the increase in unemployment, we estimated the impact on output. In the Bay Area, employee compensation accounts for about 49 percent of the total value of output of industries. This average is found by calculating the employee compensation component of industry inputs developed by ABAG as part of its regional input-output model. The reciprocal of this employee compensation fraction multiplied by the wage and salary lost results in an estimate of the value of output affected directly by the employee reductions. This value is $110.2 million for the region.

ANALYSIS OF ECONOMIC DISRUPTION IMPACTS

The economic disruption of the earthquake was then calculated. For purposes of this analysis, a set of assumptions, based on professional judgment, were made to ensure that the impacts of the quake were not underestimated. We assumed that, at a minimum, 10 percent of the Bay Area's economy was affected for a period of one month, and, at a maximum, 20 percent of the region's economy was affected for two months. It was further assumed that, at a maximum, productivity fell by 50 percent over the affected period in affected industries. The resulting indirect economic disruption in the third quarter of 1989 cost the region's economy, in lost Gross Regional Product (GRP), about $725 million to $2.9 billion, depending upon the assumptions.

Finally, it was assumed that 75 percent of the lost productivity or production was recovered during the first and second quarters of 1990. Thus, the permanent loss from the earth-

Table 3.—*Average annual wage and salary by county or Primary Metropolitan Statistical Area (PMSA) in 1989*

[Source: U.S. Dept. of Commerce Bureau of Economic Analysis, Wage and Salary Data, 1990]

Santa Cruz County	$19,400
San Benito County	$18,800
Monterey County	$18,800
Oakland PMSA	$24,000
San Francisco PMSA	$26,800
San Jose PMSA	$30,000

quake in terms of potential GRP is between $181 million and $725 million. This amount is quite small compared to the ABAG estimate of the GRP for 1989 of $174 billion, in spite of the effort to ensure that the assumptions on which this analysis is based would tend to maximize, to the extent reasonable, the impacts of the quake.

Although it is difficult to attach definite numbers to these values, anecdotal conversations with businesses in the Oakland-Berkeley area, as well as in Silicon Valley, tended to confirm these assumptions. For example, a survey of seven major Silicon Valley firms determined that the vast majority of their operations were back on line on October 18 or 19. Dates for full operational recovery ranged from October 18 or 19 (two firms), November 1989 (one firm), first quarter 1990 (two firms), to second quarter 1990 (two firms).

EMPLOYMENT IMPACT INTO THE YEAR 1990

Figure 4 illustrates unemployment rates over the period July 1989-June 1990 for PMSA's and selected counties in the San Francisco and Monterey Bay regions. It shows a jump in unemployment rates in Monterey, San Benito, and Santa Cruz Counties and the San Jose PMSA starting in October 1989.

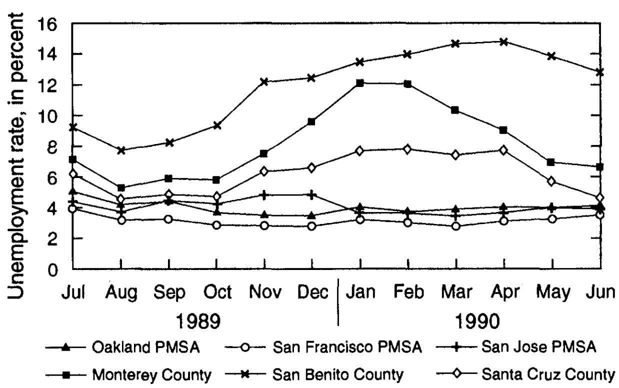

Figure 4. Trends in unemployment rates for selected San Francisco Bay Area counties and Primary Metropolitan Statistical Areas (PMSA's) between July 1989 and June 1990, showing effect of the Loma Prieta earthquake of October 17, 1989. Data from California EDD (1990b).

Table 4.—*Estimated income losses from the earthquake by county or Primary Metropolitan Statistical Area (PMSA)*

Santa Cruz County	$19,413,000
San Benito County	$1,423,000
Monterey County	$3,428,000
Oakland PMSA	$8,752,000
San Francisco PMSA	$12,355,000
San Jose PMSA	$8,530,000
Total	$53,900,000

In Monterey and San Benito Counties almost all of the continued increase is associated with seasonal agricultural employment. In Santa Cruz County, after an initial increase from October to November, the rate stabilized but then began to increase again in January 1990. The increase in January is associated primarily with seasonal employment. Overall, the unemployment statistics show no long-term lingering impact on employment from the Loma Prieta quake.

WHY THE MINIMAL ECONOMIC IMPACT ?

Given that the Loma Prieta earthquake caused more than $5.9 billion in property damage, why was the macroeconomic impact so small in comparison to the area's more than $170-billion GRP and more than 3 million jobs? This is a critical question because it gives us insight into both the flexibility and vulnerability of the region's economy.

Some might argue that luck played a key role in minimizing macroeconomic disruptions to the Bay Area's total economy. Economic impact was substantial only in isolated areas where the direct earthquake damage was concentrated (see table 1). Even in areas such as Santa Cruz County, the macroeconomic impacts were not "major" if viewed in the context of an entire county. Even if one assumes that the 3,300 jump in unemployment claims was minimal, and that the actual number of workers affected was 1,000 more, or 4,300, this number still represents only about 6 percent of the total jobs in the county.

One also could argue that the primary reason the earthquake had a minimal affect on the macroeconomic factors in the Bay Area was that the transportation and other forms of infrastructure were minimally damaged at the regional level. The damage and disruption to the Bay Bridge connecting San Francisco with the East Bay is a good indicator of how a major disruption of the transportation network could affect economic activity. It is hypothesized that the decline in taxable sales in San Francisco is directly related to the closure of the Bay Bridge for several weeks from October to November 1989. The damage to the Cypress freeway structure in Oakland minimally affected regional transportation activity because alternative routes were readily available. However, economic impacts of approximately $20 million annually were documented in a recent report (Bay Area Economic Forum and Metropolitan Transportation Commission, 1990). Had major freeways been disrupted throughout the Bay Area for any length of time, it is likely that economic activity would have been more substantially affected.

One can also argue that the complexity of the regional economy generates redundancies that serve to localize the impact of businesses displaced by building damage. A good example is the City of Santa Cruz, which, from an economic perspective, can be viewed as a southern annex to Santa Clara County's Silicon Valley. Localized impacts there were minimized because businesses were able to relocate to other areas of Santa Cruz County. Such redundancies found in an urban area are not present in a more rural area, such as Coalinga.

Finally, one must give credit to the high level of emergency preparedness among the major industrial leaders in Silicon Valley. In contrast to firms in some other Bay Area (and national) industrial areas, these industries are relatively young, and the structures in which they are located are relatively new. Some of these companies are also national leaders in the retrofit of nonductile concrete structures, or had abandoned such buildings (in part due to earthquake concerns) well before the earthquake. In addition, because of the rapidly changing technology in which these industries are engaged, the process equipment and contents of the buildings tend to be completely replaced about every five years. Thus, the companies have frequent opportunities to upgrade the quality and safety of their equipment and the means by which it is secured against earthquake damage.

ASSESSING ECONOMIC IMPACTS FROM POSSIBLE DAMAGE PATTERNS IN FUTURE EARTHQUAKES

The previous section focused on the direct macroeconomic disruptions in the San Francisco Bay Area that resulted from the Loma Prieta earthquake. Our analysis suggests that the economy was minimally affected because of (1) the location of the quake, and (2) minimal damage to the overall infrastructure of the region.

Developing a methodology to assess potential, as well as actual, impacts is an essential step to improve the way economic costs of earthquakes are evaluated. This section focuses on an existing model used at ABAG to assist in evaluating the potential economic costs of earthquakes. Kawashima and Kanoh (1990) used interindustry analysis (input-output analysis) to look at the indirect economic effects of an earthquake in Japan. Munroe and Ballard (1983) also developed a statistical modeling technique to assess the indirect economic effects of a natural disaster. The model used in the San Francisco Bay Area is structurally similar to that used by Kawashima and Kanoh since it is a regional input-output model (Brady and Yang, 1988). The model is part of a larger forecasting system that integrates economics and demographics to forecast growth and change (Brady and Yang, 1983).

ASSESSING MACROECONOMIC IMPACTS ON THE BASIS OF DAMAGE SCENARIOS

The system developed in the San Francisco Bay Area can be used to assess the macroeconomic impacts of an earthquake on the basis of various damage scenarios. This process is possible because input-output models allow one to view an economy in terms of linkages between sectors. In addition, the model structure makes assessing impacts relatively easy. The usefulness of the system lies in providing better and more timely information to formulate policy both on preparing for and on responding to crises.

It is useful to examine two possible damage scenarios to provide a better understanding of the possible impact of property damage on the region's economy. These scenarios use input-output analysis to illustrate that what is damaged is more important than how much is damaged.

Scenario 1: Damage from an earthquake is concentrated in the Silicon Valley and in southern Alameda County. The freeway network is heavily damaged, and preliminary assessment indicates that 10 percent of the high-technology business activity has been affected. Because of the extent of damage, business activity will be disrupted for a period of six months. What is the economic impact of this disruption to overall economic activity in the Bay Area?

In 1989, ABAG estimated that the output value of computers, electronics, and instruments produced in the Bay Area was $20.4 billion. Almost 85 percent of the output was located in the southern portion of the Bay Area. The impact of this damage scenario was to reduce output for these sectors to $19.5 billion for the year. This is a $900-million impact, with a potential loss of 7,500 jobs in these sectors. What is the region-wide impact of this potential disruption? The model suggests that the region-wide impact will be about 12.6 percent higher than that on the individually affected industries, or $113.5 million more, with the loss of an additional 4,500 jobs. Most of this loss is concentrated, by rank of affect, in four Bay Area industries: wholesale trade; finance, insurance, and real estate (FIRE); fabricated metals; and business and professional services. These combined industries account for about 3,700 jobs lost due to the secondary impacts. There are two main conclusions: (1) any disruption to high-technology manufacturing would be more costly to the economy for this scenario than that which actually occurred in the Loma Prieta earthquake, and (2) although a higher direct impact occurs for this scenario than for the following scenario, the secondary economic impacts are concentrated in a select number of industries.

Scenario 2: The Bay and Golden Gate Bridges are substantially damaged for a period of up to six months. Initial economic analysis using the Bay Area input-output model *indicates that this will affect the economic activity of finance, insurance, and real estate (FIRE); business and professional services; and retail activity. Analysis suggests that the disruption will reduce the supply of FIRE services by 5 percent, business services by 5 percent, and retail activity by 1 percent for up to six months. This reduction comes from having to shift office or retail operations, a fall-off in demand due to fear, and a general disruption of the productivity of these activities.*

The basic analysis of this scenario suggests that about $1 billion in output from the region's economy would be directly affected by the reductions identified above. However, the secondary impacts on the Bay Area economy are far more substantial than for the previous scenario. In scenario 1, overall regional output falls by about 0.4 percent as a result of the disruption of the identified industries. Under scenario 2, regional output falls by 1.1 percent, which is more than double the disruption associated with scenario 1. In particular, disruption of business services and FIRE is the principal cause for computer output to fall by 5 percent, electronics to have a decline in output of about 4 percent, and instruments to also decline in output by about 4 percent. The primary reason for the impact on manufacturing is that financial and business services contain both capital and labor resources that feed into these sectors. Any disruption in the flow of these services affects economic activity.

POLICY APPLICATIONS OF ANALYSIS OF THE ECONOMIC IMPACTS OF EARTHQUAKES

The above simple analysis helps identify those sectors that could disrupt overall economic activity, if affected by an earthquake. This approach allows one to develop profiles of earthquake impact on economic activity. These profiles, in turn, could enter into policy discussion on several types of issues. First, with regard to decisions about allocating financial and labor resources among repairing, maintaining, or strengthening highway networks and infrastructure, information provided by this process can assist in answering questions such as, "How can the choke points in the highway network be minimized in those locations that have sensitive industries?" Second, following an earthquake the process can help in identifying where to allocate scarce resources after initial damage information assesses the potential industries affected. Any allocation process should focus on getting the economy back on its feet as soon as possible. Such a process requires information about which industries can most disrupt the overall system.

CONCLUSIONS

The overall macroeconomic damage to the Bay Area's economy as a result of the Loma Prieta earthquake was minimal. One reason for this minimal disruption appears to rest in the fact that the highway and rail network was not substantially damaged. If both the Bay Area Rapid Transit (BART) system and highway network had been damaged, it is likely that the economic disruption would have been substantial. Maintaining the Bay Area's infrastructure as a functional system should be a top priority before and after future earthquakes.

Building property damage is not a good indicator of economic disruption. One factor minimizing the impact of property damage losses on the economy of Santa Cruz County may have been the ready availability of relief funds for temporary tents to house those businesses displaced in the downtown area. Some businesses in downtown Santa Cruz also were able to relocate to other areas of Santa Cruz County. Another factor may have been the strong economic base of Santa Cruz as the site of an expanding University of California campus, and as a southern extension of Santa Clara County's Silicon Valley.

Input-output analysis is a simple system to identify and evaluate those industries that might substantially affect the macroeconomy of the Bay Area. It will help both in doing preparatory work in this area and in assessing the dislocation impacts after an earthquake occurs.

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RECOVERY, MITIGATION, AND RECONSTRUCTION

SHELTERING AND HOUSING OF LOW-INCOME AND MINORITY GROUPS IN SANTA CRUZ COUNTY AFTER THE LOMA PRIETA EARTHQUAKE

By Brenda D. Phillips
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CONTENTS

ABSTRACT

An assessment was made of how the Loma Prieta earthquake of October 1989 displaced the elderly, the homeless, and low-income Latinos in Santa Cruz County. The longitudinal research design included 117 in-depth interviews with sheltering and housing-related organizations that responded to the needs of low-income and minority victims. The main conditions found to have affected displacement, besides the earthquake, were a lack of affordable housing, ethnic differences and traditions not fully anticipated by emergency preparedness officials, and heightened post-disaster interorganizational coordination and communication.

INTRODUCTION

After the Loma Prieta earthquake struck northern California in October 1989, fires and damaged freeways in San Francisco and Oakland caught the world's attention. In Santa Cruz County, farther south, the earthquake caused considerable damage to residential housing areas and nearly complete devastation of single-room-occupancy (SRO) hotels in downtown Santa Cruz. A long period of housing recovery loomed.

The cities of Santa Cruz and Watsonville contained specific population groups adversely affected by the earthquake. In Santa Cruz, elderly residents lost SRO hotel housing. Watsonville, a predominantly Latino community, witnessed extensive damage to low-income housing. In both these communities, the earthquake further reduced housing opportunities for those already homeless.

This paper assesses the impact of the earthquake on those who were already homeless or were made homeless among the elderly and Latino groups. It focuses on the problems of short-term sheltering and long-term housing. Given that recent census data indicate increasing minority populations in American society (Schwartz and Exter, 1989), such a study is timely.

LITERATURE REVIEW

DISASTERS, SOCIOECONOMIC STATUS, AND MINORITY GROUPS

Disasters affect low-income victims more negatively than middle- and upper-class victims (Bolin and Bolton, 1986; Bolin, 1982). For example, lower class homeowners and renters are more likely to live on or near flood plains and other hazards, are less likely to carry disaster-related insurance, and typically take longer to recover from a disaster. Discrimination against minority groups results in their concentration in lower socioeconomic levels. One result is that minority groups, such as Latinos, experience difficulty in obtaining adequate and affordable housing (Bolton and others, 1992). Minority groups therefore carry a higher risk in disasters.

Empirical support exists for the contention that disasters hit minority and majority groups differentially. Furthermore, communities generally are not adequately prepared to meet culturally diverse needs (Perry and Mushkatel, 1986; Phillips, 1993). For example, Aguirre (1988; see also National Research Council, 1991) found that a lack of appropriate bilingual warning systems probably contributed to the 26 deaths in a Saragosa, Texas, tornado.

DISASTERS AND THE ELDERLY

Elderly people typically lack affordable housing. One trend in elderly housing has been toward use of single-room-occupancy (SRO) hotels (Felton and others, 1981). SRO's are typically close to business sectors, are often deteriorating, and house tenants of low or fixed income.

Researchers describe SRO residents as socially marginal. Social engagement varies from isolation to participation through internal, informal support systems. Elderly SRO residents are usually geographically distant from family members (Rollinson, 1990). They also commonly experience strained familial relationships and mental health problems. SRO residents prefer to live alone. These elderly are at risk from earthquakes in part because of precarious and (or) inadequate housing (Tierney and others, 1988).

Kilijanek and Drabek (1979) describe early (1960's and 1970's) studies of the elderly in disasters as inconsistent and contradictory. Yet researchers have found "a clear differential impact of disasters on the elderly" (Kilijanek and Drabek, 1979, p. 565). For instance, the elderly keenly experience losses, such as of homes and possessions, on which they have labored (Bolin and Klenow, 1982). Poulshock and Cohen (1975) suggest that elderly who lose housing are more adversely affected thereby than younger victims. Other studies on disasters and the elderly look at how physical and mental health are affected (Melick and Logue, 1985; Norris and Murrel, 1988; Phifer and Norris, 1989; Phifer and others, 1988) and suggest that elderly victims tend to cope well with disasters (Huerta and Horton, 1978).

DISASTERS AND THE HOMELESS

We know next to nothing about how disasters affect the homeless. General literature indicates that people become homeless because of increasing poverty and decreasing affordable housing. We know that a disaster such as an earthquake damages low-income housing, which is more likely to be precarious or substandard. Thus, we can anticipate that a strong earthquake such as Loma Prieta would decrease affordable housing. Homeless persons would consequently endure a longer wait to return to affordable housing.

Wright (1988, 1989) describes a hidden group, the "marginally homeless" who live in doubled-up and tripled-up housing. An earthquake is likely to displace unforeseen numbers of these hidden homeless. The homeless are also a diverse group that range from families to individuals, from the physically disabled to the mentally ill (Wright, 1988). After a disaster, communities could face the problem of housing a heterogeneous group of previously and newly homeless who are difficult to relocate.

FOUR PHASES OF SHELTERING AND HOUSING

Quarantelli (1982a,b) identifies four phases of housing recovery: (1) emergency sheltering, (2) temporary sheltering, (3) temporary housing, and (4) permanent housing. Essentially, Quarantelli differentiates between these phases on the basis of their duration and the extent of established household routine. Sheltering phases are generally the shortest, ranging from a few hours of emergency sheltering to a few days of temporary sheltering. Housing phases involve establishing a household routine. The move from temporary sheltering to permanent housing can stretch from a few days to months or even years.

Emergency sheltering is the first phase of recovery. Usually covered under Congressional mandate by the American Red Cross (ARC), emergency sheltering can last from a few hours to a few days. Temporary sheltering involves a longer duration, lasting as long as a few weeks. During temporary sheltering, displaced residents are still unable to assume normal household tasks or routines.

Temporary housing involves the re-establishment of household routines. This phase is also indefinite, but can last from months to years. Families are able, however, to prepare meals and go about the regular business of family life. Temporary housing is a transitional stage in which the victims move from being provided for to providing for themselves. Finally, permanent housing is movement back into one's original, rebuilt domicile or into a new residence. This time, the move is of a lasting duration.

HOUSING IN CALIFORNIA

Two early 1980's studies of California housing focused on affordability and availability, yet reached different conclusions (Lowry and others, 1983; Rosen, 1984). In general, a state of flux characterized the 1970's California housing market. The average number of California households increased by a third, rents doubled, and home prices quadrupled. Nonetheless, housing production virtually stopped by 1980. Consequently, sales of existing homes declined dramatically.

Despite this alarming scenario, Lowry and others (1983) did not believe a housing shortage existed. Likewise, they did not anticipate potential problems with overcrowding and substandard rental units except for recent Latin American immigrants, the elderly, and the poor in marginal rentals. Lowry concluded that California had an "exceptionally good housing inventory."

Rosen (1984), on the other hand, came to a different conclusion. He predicted a crisis in housing availability by the mid-1980's. Rosen anticipated that low-income housing would be compromised because of strong demographic shifts, including immigration. A complicating factor would be the loss of housing units due to demolitions and natural disasters. Furthermore, Rosen found "in contrast to the Rand study [Lowry and others, 1983], that a significant number of California households face an affordability problem" (Rosen, 1984, p. 46). Additional constraints imposed by land-use controls (zoning, growth management systems, subdivision regulations, and environmental restrictions) would also hinder availability. Such constraints on the housing market would cause shortages and increased housing problems. "Thus, in contrast to the Rand report, the growth in housing demand will be at about the same level as in the 1970's. This represents an enormous demand for shelter in California in the 1980's" (Rosen, 1984, p. 29). It is quite likely, therefore, that low-income minority groups would face a dearth of affordable housing. A natural disaster would exacerbate the problem.

METHODOLOGY

This research was begun shortly after the Loma Prieta earthquake; field trips covered a 22-month period. Such longitudinal research is now a trend in the disaster research field (Drabek, 1986; Mileti, 1987).

A long-standing methodological tradition in the field of disaster research is the use of interviews, observations, and systematic documentation (Quarantelli and Wilson, no date). That tradition was followed in this study.

INTERVIEWS

Several student assistants and I conducted the field research. Overall, we completed a total of 117 face-to-face interviews. An additional 8 respondents served as informants; that is, they gave information but did not participate in the full interview. Of the total interviews, 39 were follow-up interviews. We talked with representatives of 16 organizations on 2 separate occasions, with 12 organizations on 3 occasions, and 2 of the original 16 organizations on 4 occasions.

We interviewed 72 separate individuals from 58 different organizations and offices. Our study ranged from local to external governmental units and from public organizations to private groups. Organizations ranged from local to regional to State to Federal entities. We included typical disaster response organizations such as the American Red Cross (ARC), Federal Emergency Management Agency (FEMA), local fire departments, and city and county emergency service departments. Our focus on housing meant that we also interviewed spokespersons of traditional housing organizations such as community housing coalitions, shelter services, and housing authorities.

OBSERVATION

To supplement our interviewing, we used a methodological triangulation strategy (Berg, 1989). That is, we used multiple methods to increase data richness and to improve validity and reliability. We conducted observations when opportunities became available, taking notes on the social structure and social processes involved in the events. As such, these observations are impressionistic and provide occasions for data checks, reflection, and the accumulation of anecdotal evidence. We made observations on 15 occasions, involving a variety of settings. For example, we observed public and private recovery meetings.

SYSTEMATIC DOCUMENTATION

Finally, we collected documents pertinent to this study. These documents included public disaster plans, internal reviews of the disaster plans, post-disaster plans for hazard mitigation, internally developed disaster plans for a variety of organizations, recovery plans, memos, reports, and so forth.

COMMUNITY CONTEXT

The cities of Santa Cruz and Watsonville, though related through county affiliation, are decidedly disparate entities. Furthermore, the communities differ demographically, providing opportunities to study different groups and different cultures.

SANTA CRUZ COUNTY AND CITY

Santa Cruz County is located approximately 90 miles south of San Francisco, 40 miles south of San Jose, and 350 miles north of Los Angeles. The city of Santa Cruz lies between the Pacific Ocean (Monterey Bay), the San Lorenzo River, and the redwood forests of the Santa Cruz Mountains. Because of the rolling topography, there are several high and low points in the city. An alluvial flood plain next to the San Lorenzo River contains the downtown Santa Cruz area. In addition to flooding, disaster risks and experiences for Santa Cruz include landslides, severe storms, and earthquakes.

In 1987, the population of the county was estimated at 220,364; that of the city of Santa Cruz, at 46,921. According to the 1990 census, 229,734 resided in the county, with 49,040 in Santa Cruz. Using either set of figures, the city of Santa Cruz constituted 21.3 percent of the county population.

The predominant housing type in the city of Santa Cruz (63 percent) is the single-family unit. Most of these units (68 percent) are owner occupied. Even though Santa Cruz employs 34 percent of the county work-force population, it only comprises 23 percent of the county's housing units. Because of the strong housing demand, vacancy rates remain very low (below 1.5 percent) in Santa Cruz, and housing costs are high.

Typical monthly rental rates range from $500 to $750 for one- and two- bedroom apartments. Exceptions to such high rates were the SRO hotels that existed before the earthquake. The Palomar, a downtown SRO hotel, typically rented a room with private bath for $300 a month. The average estimated purchase price for single-family homes is $216,000 for a two-bedroom home and $250,000 for a three-bedroom house.

WATSONVILLE

The city of Watsonville is an urban community that borders on rural farmlands. Its terrain is rolling to flat. Just inland from Monterey Bay and accessible off Highway 1, Watsonville is a small community close to several other communities, including the larger city of Santa Cruz.

Before the 1989 earthquake, Watsonville had a population of 25,377, with a larger census count of 55,000 for the business area. By 1990, Watsonville's population had risen to 31,099. Sixty-one percent of Watsonville's 1990 population was Latino. Watsonville's share of the county population was 13 percent in 1987 and 13.5 percent in 1990. Latinos, the largest ethnic group in Watsonville, have an average household size of 4.05, with 36 percent of the households including more than five persons.

Low-income families find it difficult to obtain housing, especially large rental units, in Watsonville. The price of homes, high rental prices, a high cost of living for the area, and a housing shortage all contributed to a pre-existing housing crisis in the area. This crisis appears to have worsened since the earthquake, with 3.12 percent of the rental market eliminated as of February 1990. The quake reduced overall housing by 8 percent.

Not only is there a lack of affordable housing, but existing units are expensive. Sale prices of homes in Watsonville during 1988 ranged from $115,000 to $350,000, with a mean of $156,254. Rental units began at about $600 for a one-bedroom dwelling.

Farmworkers have special problems finding affordable housing with enough space. Farmworkers make up 17 percent of the employed Watsonville population, and 26 percent of the area's Latinos are engaged in agricultural enterprises.[1] Today's farmworkers are less transient than 15-20 years ago, implying increased need for housing. Watsonville officials indicate that farmworkers have had to resort to severe overcrowding to obtain shelter. Use of converted chicken coops, garages, and the like also occurs. Half of Watsonville and almost all special-needs households (elderly, low-income Latinos, farmworkers, and the homeless) lack income to afford adequate housing.

EARTHQUAKE DAMAGE TO HOUSING

SANTA CRUZ

The earthquake created heavy damage to housing in downtown Santa Cruz; housing elsewhere in the area also suffered structural and fire damage. The most significant collective damage happened to the downtown SRO hotels. Each SRO hotel housed a mix of the elderly, transients, and low-income families and adults. Of the 4 SRO's hit by the earthquake, only the Palomar survived, and it did not reopen until summer 1991. Years after the earthquake, inspectors throughout the county still uncover structural damage to houses and buildings.

WATSONVILLE

A February 1990 study by the Watsonville Commission Housing Task Force found that the earthquake had affected the rental market. Of 1,633 rental units, at least 51 became

[1]This compares to 5 percent of the county population involved in farming.

unavailable because of the earthquake. These represent 3.12 percent of the rental market.[2] In December 1989, Watsonville residents encountered a 1.4 percent vacancy rate (98.6 percent occupancy rate) in the city. Normally, such a situation is not a problem from the landlord's point of view. Low vacancy rates do, however, create housing problems for low-income families. Building inspections also resulted in the loss of substandard housing such as converted garages and dilapidated buildings.

OVERVIEW OF SHELTERING AND HOUSING

This paper uses a framework identified by Quarantelli (1982a,b) to describe the process of sheltering and housing the earthquake victims. This section provides an overview of each phase: emergency and temporary sheltering, and temporary and permanent housing. Within each of the four phases, this paper looks at each community of Santa Cruz and Watsonville. The elderly and the already homeless are the focus in Santa Cruz, while low-income Latinos are described in Watsonville.

EMERGENCY SHELTERING

Emergency sheltering lasted from a few hours to a few weeks. Families and individuals camped out across the county for several nights after the earthquake. As expected, the American Red Cross (ARC) set up shelter facilities in numerous county locations.[3]

THE HOMELESS

In Santa Cruz, local citizens perceive that two types of homeless exist. First, those who use shelters and (or) sometimes live on the streets are called the "homeless." Generally, public sympathy exists for them, especially for homeless families. The other type, "street people," create community concern. Street people are perceived by some as being responsible for street crime, for panhandling, and for chasing away tourism and business from the downtown Pacific Garden Mall area. The street people were known to "hang out" downtown, and often engaged in panhandling.

The earthquake physically dislocated both the homeless and the street people from the familiar downtown (the city fenced it off for safety purposes) and from pre-quake shelters for the homeless. Both street people and the homeless made their way to the Civic Auditorium, located about two blocks away from the downtown mall. The street people used this ARC shelter instead of established homeless shelters because a wider variety of services was available there. ARC shelters stayed open 24 hours a day and provided three meals a day. Pre-quake homeless shelters operated on a limited time basis, usually just overnight. Sometimes homeless shelters would serve breakfast or dinner. For some of the street people and the homeless, sleeping facilities before the quake meant camping in a community with a no-camping ordinance. Thus, being homeless then meant evading police enforcing the ban (it was not enforced for a while after the quake).

ARC shelters, therefore, provided more comprehensive services to a pre-existing homeless population. Furthermore, the ARC made the decision to shelter everyone regardless of their pre-quake or post-quake homeless status.

At the Santa Cruz Civic Auditorium the ARC sheltered a diverse group ranging from the elderly to families to street people. The variety of their lifestyles led to conflict between sheltered groups. For example, some shelter residents and police accused the street people of stealing and using drugs. Police officers arrested street people in the Civic Auditorium shelter (for drug dealing). However, natural forces unexpectedly alleviated the situation. Four days after the quake, steady rains fell and the shelter roof began to leak, causing the ARC to move the shelter to a church several miles away, across a highway. Few street people followed the shelter to the church; most remained near the familiar downtown.

THE ELDERLY

Many of the elderly from SRO hotels went to the Civic Auditorium for emergency shelter. The earthquake damaged all four downtown hotels; the city ultimately razed three out of the four. Other low-income elderly resided in trailers. Throughout the County, about 500 trailers shifted from their foundations. According to local social workers, most trailer victims stayed put rather than seek ARC shelter.

Adult Protective Services, a program within the County's Human Resources Agency, became involved early with checking on elderly disaster victims and disabled adults. Overall, a high degree of concern and assistance for the elderly existed within and among elderly social services, and indeed throughout the community.

ARC officials reported that senior citizens responded well to shelter life. Although the elderly experienced the earthquake as confusing and stressful, the local ARC met their shelter needs.

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[2]This is based on a 53.6 percent response rate to a Watsonville Planning Department Vacancy Survey, with an N of 1633.

[3]County estimates, based on Red Cross figures, indicate that 549 people used shelters the night of October 17. When rain began on Saturday, October 21, shelter numbers rose to 2,545. The Red Cross opened 12 shelters in the south county (Watsonville area) and 9 in the northern part of the county (Santa Cruz). The Red Cross provided 38,295 shelter nights until December 22, 1989.

LOW-INCOME LATINOS[4]

Despite the availability of several indoor ARC shelters, two parks served as emergency shelters for many Latino families in Watsonville. Tent-city encampments emerged at Callaghan and Ramsey Parks within 24 hours after the earthquake. Displaced residents were able to camp in these parks because of donations of camping equipment and other resources by individuals, the city of Watsonville, and the Salvation Army. A local Latino health organization, Salud Para La Gente (Salud) rendered medical assistance, helped the damaged and beleaguered Watsonville hospital, distributed blankets, and served as advocate for the newly homeless, predominantly Latinos. Debate developed over the outdoor camping. The city and ARC tried to persuade campers to move to indoor shelters.

The ARC initially resisted declaring Ramsey Park, about five blocks from downtown Watsonville, an official "open air" shelter because the park lacked adequate sanitation, cooking, and refuse facilities. Local Latino leaders pressured the city and the ARC to open an official shelter. The county then asked the National Guard to erect tents in Ramsey Park. Four days after the earthquake, the Red Cross recognized Ramsey Park as an official shelter; however, rain soon transformed the campsite into a mudhole. Inadequate flooring, overcrowding, and lack of heat exacerbated the unpleasant shelter arrangements. Nevertheless, hundreds[5] stayed on in Ramsey Park, with the numbers gradually diminishing until the camp closed on November 16, 1989.

Callaghan Park, however, never became an official shelter, primarily because of a lack of appropriate amenities (restrooms, showers, and so forth). Between 100 and 300 victims continued to camp in Callaghan Park for several months. A few weeks after the quake, the ARC began to provide meals and nursing services in Callaghan Park. ARC personnel continued to urge Callaghan Park campers to move to an indoor facility or at least to Ramsey Park, but many refused. The site subsequently became a political focal point in the upcoming district elections for City Council. Local politicians seeking office in the district elections visited Callaghan Park to make speeches.[6]

A number of factors explain why so many Latinos camped out in Watsonville. First, our respondents indicate that residents feared the effects of aftershocks—falling debris and crumbling homes. In addition, some confusion existed about building inspection tags. The problem stemmed mainly from English-only tags that inspectors placed on homes. In addition, there was confusion about the meaning of the colors of tags. While most residents understood the use of red tags for "destroyed," and green tags for "safe to enter," they remained unsure about the meaning of yellow tags.

The use of National Guard tents and personnel created another problem. The military appearance of Ramsey Park apparently generated fear in some Latino families. Some Callaghan Park campers refused to move to Ramsey Park for fear of encountering the military. Immigrants from Central American countries especially feared the National Guard presence. Experience with the military government in some Latin American countries meant arrest, imprisonment, or encounters with death squads. Others feared being reported to the Immigration and Naturalization Service. Despite assurances to the contrary on these matters, Callaghan Park campers refused to move to the official shelter in Ramsey Park.

Finally, camping in parks or yards enabled victims to be close to their homes and to their children's schools. Thus, convenience, the presence of support networks, and fears about security kept people close to home and out of established shelters.

Critics asserted that the southern county government and the ARC responded to Latinos with cultural insensitivity, exemplified by discouraging outdoor camping, providing inappropriate food, and lacking bilingual information. Watsonville city officials believed the earthquake beset the city with overwhelming demands, but they believed they responded with every effort manageable. As a result of the accusations, the Justice Department launched an inquiry but did not find any evidence of deliberate discrimination. However, the Department of Justice did suggest increased inclusion of Latino representatives in the ensuing recovery. Watsonville responded by bringing Latino representatives into recovery meetings, which eased the conflict. The city also appointed a part-time ombudsperson to link the Latino community with the city. These efforts marked the beginning of more inclusionary disaster response and recovery efforts, which continue today. Former adversaries now work cooperatively and closely together.

TEMPORARY SHELTERING

Emergency and temporary sheltering periods blended one into the other. Generally, the merging point occurred about 1 or 2 weeks after the disaster. At that point, both official and unofficial shelters were fairly well established. However, the shelterees had not established household routines. The ARC and Salvation Army still met food, sanitation, and other basic needs. The temporary sheltering phase lasted from the end of October through December 1989.

The elderly, Latinos, and some homeless people used hotels and motels for temporary shelter. Shortly after the earthquake, an ad hoc Housing Recovery Task Force (HRTF) was formed at the county level. The HRTF recommended using hotels for temporary sheltering purposes, since the end of the county's tourist season provided vacancies.

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[4]"Latinos" is used here instead of the more general term Hispanics. Our respondents consistently indicated a preference for the term "Latinos."

[5]It is difficult to obtain accurate numbers of those who camped in the parks. The Watsonville Red Cross did keep official records for their shelters, but only for the first few days. Because Ramsey Park did not open as an official shelter until Saturday, October 21, estimates must suffice. Journalists, ARC officials, and city representatives suggest the number of Ramsey Park campers alone ranged up to more than 500 per night during the first week after the earthquake.

[6]The district elections had been ordered by the U.S. Supreme Court following a lawsuit for a more ethnically representative city council.

The ARC provided funds for some victims to seek such temporary shelter in hotels, which is a standard procedure. The local Community Action Board (CAB) created a Motel Voucher Program. Funded by donations, the Motel Voucher Program enabled displaced victims to seek temporary shelter. Finally, the local Lodging Association worked cooperatively with the HRTF and ARC Motel Voucher Programs, offering motel rooms at reduced rates, for example.

One final group assisting with both temporary shelter and temporary housing was an emergent, volunteer Housing Hotline, organized by community residents 2 weeks after the quake. People in need of housing or having housing with units available could call the hotline and be matched up. The hotline lasted until March 1990, when the CAB took over the hotline efforts.

THE HOMELESS

In Santa Cruz, a controversy arose early on as to whether people who were homeless before the earthquake deserved disaster-related sheltering and housing services. Although local officials felt sympathetic toward this homeless group, FEMA and the ARC chose to designate them as "pre-quake homeless" who were therefore not qualified for disaster aid.

Local social workers insisted, though, that the earthquake considerably worsened the plight of those who became known as the "pre-quake" homeless. The temblor decreased low-income housing stock, thus increasing the difficulty for the homeless to locate affordable homes. In an already tight market for affordable housing, this left the homeless worse off than before. Regardless, the mostly non-local disaster relief organizations effectively blocked the pre-quake homeless from housing. Additional funding to the Motel Voucher Program stipulated that monies could only be designated for disaster victims (that is, not for the pre-quake homeless).

THE ELDERLY

The Santa Cruz community responded quickly to the plight of displaced elderly victims. Multiple organizations, including Senior Shared Housing, Adult Protective Services, and Elderday, an adult day-care center, participated in identifying housing options and relocating victims displaced from SRO hotels. Community volunteers helped remove belongings from the damaged SRO buildings.[7]

Temporary sheltering for the elderly included ARC shelters; however, most elderly SRO-hotel victims moved on to temporary or permanent housing fairly quickly. This relatively rapid movement occurred because of numerous existing social service organizations for the elderly, which worked cooperatively to help the seniors.

LOW-INCOME LATINOS

The Santa Cruz County fairgrounds remained open until December 23, 1989, as an ARC shelter, providing aid to families and single men. ARC officials believe this shelter, open for 66 days, was one of the longest operating shelters in U.S. history. The majority of the victims came from low socioeconomic status. Some were pre-quake homeless, nearly all of whom were from Santa Cruz County (despite rumors to the contrary). Most of the remaining shelter victims were Latino families and Latino adult men displaced because of the earthquake. Many of the fairground shelterees were relocated campers from Ramsey and Callaghan Parks.

OVERVIEW OF EMERGENCY AND TEMPORARY SHELTERING PHASES

To summarize, the elderly, low-income Latinos, and the pre-quake homeless all experienced physical dislocations from the impact of the earthquake. Initially, the local communities sheltered all the homeless regardless of their pre-quake or post-quake status. However, externally based funding organizations cut the pre-quake homeless out of temporary sheltering and housing opportunities. At this point, I wish to focus on how organizations responded to the elderly and to low-income Latinos.

TEMPORARY HOUSING

In January 1990 the Housing Recovery Task Force (HRTF) split into two committees, dealing with temporary and permanent housing, respectively. The HRTF had envisioned this division of labor from the beginning. Because the HRTF was an ad hoc, county-based coalition and some of the members were county employees, the separate work of temporary and permanent housing was passed on to appropriate agencies. The Short Term Housing Coalition began to operate out of Community Action Board (CAB)[8] offices and the Permanent Housing Committee came under the auspices of the Housing Authority.

Movement into temporary housing began fairly quickly for some, mostly those from middle- and upper-income groups. These groups had more financial resources and insurance to provide for temporary housing. Movement was slower for the more numerous lower income victims. Housing officials

[7]The city allowed volunteers and elderly victims 15 minutes to remove their possessions. The 15-minute limit was implemented because of the possibility of dangerous aftershocks.

[8]CAB had experience in working with homelessness and housing issues not related to disasters.

indicated that the majority of those needing help with temporary housing came from lower socioeconomic levels. Also, the earthquake damaged low-income housing disproportionately.

Conflict over temporary housing developed between FEMA, the County, each city, and victims during this phase. Problems initially centered on the application process. FEMA had apparently used up most of its Spanish printed documents in Hurricane Hugo and had dispatched bilingual workers to affected Spanish-speaking islands, where they were still dealing with the hurricane's impact in September 1989. Therefore, FEMA responded to the quake with reduced supplies and personnel.

FEMA did expend considerable effort and funds assisting the county, but problems lingered over serving Latino clients. For example, FEMA initially sent out checks and explanatory letters in English. Confusion and misunderstanding resulted. When FEMA did identify a household as Spanish speaking, though, FEMA sent subsequent letters in Spanish.

As a result of problems like this, several northern California legal aid entities filed a lawsuit against FEMA in January 1990. The lawsuit dealt with three issues: first, the legal entities filed to guarantee a right to a 60-day appeal period on FEMA denials. Second, legal aid filed suit to guarantee that all individuals and families would receive benefits, not just the person whose name appeared on the lease or came to the FEMA Disaster Assistance Centers first. This was necessary because pre-quake overcrowding in Santa Cruz County had caused many households to contain multiple families or unrelated adults. Finally, the legal entities sued for replacement of destroyed housing stock. FEMA originally settled out of court, but then did not take the agreed actions. Legal Aid therefore returned to court, and the court ruled in favor of the plaintiffs in April 1990. In December 1990, FEMA agreed to give nearly $6 million to rehabilitate low-income housing lost in the earthquake in Santa Cruz County. The entire settlement committed $24 million to San Francisco, Santa Cruz, and Alameda Counties.

THE ELDERLY

Caseworkers within the ARC, FEMA, Adult Protective Services, and seniors organizations actively helped elderly victims locate interim housing. The earthquake displaced more than 250 elderly from downtown SRO hotels. Some seniors left the county to live in less expensive housing. Some moved in temporarily with family, although this arrangement usually failed. Most of the elderly in these SRO hotels, as has been typical elsewhere, preferred to live alone. Additional arrangements made by some included moving to congregate care facilities or to small apartments.

Some elderly held out for a return to the Palomar, the only remaining SRO hotel downtown. The loss of the other three downtown SRO hotels complicated the task of re-housing elderly victims. Elderly considered the downtown SRO hotels ideally located because they were close to grocery stores, a pharmacy, restaurants, shopping, and entertainment. Relocation threatened seniors' established links to needed services.

The Housing Recovery Task Force (HRTF) developed ideas for temporary housing, including a failed FEMA-funded trailer court. One of the most successful efforts came through a non-profit group, Elderday of Food and Nutrition, Inc. Elderday suggested using a closed nursing home facility, called the Garden. Experienced in adult day care, Elderday offered to oversee operations of the Garden. FEMA paid for the expenses, and Elderday opened the Garden in January 1990; however, meals were not included. About 25 seniors received temporary housing at the Garden.

Moving the elderly out of the Garden proved challenging. Caseworkers from FEMA, the ARC, and Adult Protective Services assisted with the relocation. Garden residents reportedly preferred to hold out for a return to the downtown. Some advocates for the elderly believed the victims felt pressured to leave the Garden. The Garden closed in February 1991.

LOW-INCOME LATINOS

The most open conflict between FEMA and local officials developed over the use of trailers as temporary housing. The HRTF believed trailers to be the best viable option for displaced Latino and elderly victims. FEMA disagreed, maintaining that adequate housing stock existed locally. The HRTF, local administrators, and politicians countered, citing a low vacancy rate and the lack of affordable housing. FEMA preferred not to use their mobile homes as temporary housing, given that the units were dated, not always up to code, and expensive to transport and set up.

After considerable disagreement and politicization of the issue, FEMA capitulated in November 1989. FEMA moved 122 trailers from Texas storage areas into Santa Cruz County, most of them onto temporary trailer park sites on public land in Watsonville (for example, at the county courthouse annex and the county fairgrounds). A few residents set up FEMA trailers on their private lots.

The first residents moved into the mobile homes in December 1989. Over time, some families moved on to permanent housing with the help of a variety of caseworkers from FEMA, the ARC, and a locally funded Human Resources Agency Earthquake Trailer Park Project. Residents of the mobile homes were almost exclusively Latino, many with large families. Family size complicated the process of moving into permanent housing because of a scarcity of affordable units of adequate size. Discrimination against Latinos allegedly further impeded movement into permanent housing. Again, language barriers proved formidable. The Earthquake Trailer Park Project served as a conduit for translation, representation, and advocacy.

Trailer families felt harassed by FEMA, who checked frequently on the status of the family's housing search. By the

1-year anniversary, though, FEMA slowly began to move trailers out of the county. FEMA allowed families to buy the trailers, with prices based on the family's income. This provided, for some, the first opportunity in their lifetimes to become homeowners. Most trailer families lived in Watsonville on a permanent basis and a purchase symbolized increased security and stability. The potential purchase of the trailers fueled family resistance to moving.

However, a lack of available trailer pads in Santa Cruz County increased the problems of purchasing trailers as a way of relocating into permanent housing. In addition to the cost of the trailer, purchasers had to pay for moving costs. Many families could not afford moving costs, which could be several thousand dollars.

An emergent citizen group, the 17 Octubre Comite, composed of trailer park residents, formed in fall 1990 to advocate for purchase and relocation of the trailers. FEMA responded by continually pressing for relocation of residents to existing housing, fearing the families would be left homeless because of the lack of trailer pad sites. Eventually local and Federal officials agreed that trailer families would be best served by encouraging movement into available rentals. Through cooperative efforts, FEMA, the Earthquake Trailer Park Project, the city of Watsonville, and the Housing Authority relocated families from trailers into rental units.

Buena Vista Migrant Camp, a summer residence for agricultural workers near Watsonville, also served as a temporary housing site from November 1989 through spring 1990. Operated by Housing and Community Development (HCD, a local organization), the camp usually closes in the winter because of sanitation problems. HCD, FEMA, and the city of Watsonville temporarily overcame these problems, but the location and facilities were not considered ideal.

FEMA contributed significantly to the Santa Cruz County recovery. At the 1-year anniversary (October 17, 1990), 95 coaches remained in Santa Cruz County as compared to 8 in Monterey County and 4 in San Benito County. Residents felt grateful for what they had received. Santa Cruz County received more aid for temporary housing than any other county, more than $11 million out of a total of $24.5 million, excluding mobile home costs.[9]

PERMANENT HOUSING

Permanent housing was obtained by some displaced residents fairly quickly after the earthquake. For others, especially low-income families, this phase took considerable time and effort on the part of multiple organizations. Permanent housing represented a return to normalcy, the continuation of household routines in a lasting residence.

THE ELDERLY

Once again, caseworkers played a major role in moving seniors toward permanent housing. FEMA, the ARC, and Adult Protective Services all contributed ongoing case-management services. Social service organizations for the elderly also participated in this process, making referrals and setting some seniors up with shared housing arrangements. Adult Protective Services created a Placement Planning Group composed of relevant seniors' and disaster-relief organizations. The Placement Planning Group followed displaced SRO-hotel victims and fostered cooperation and communication between responding organizations.

In addition to displacing residents of SRO hotels, the earthquake shook mobile homes owned by the elderly. An innovative program called Housing Assistance and Neighborhood Development (HAND), part of the county planning department, functioned to make damaged mobile homes usable. HAND served a clientele consisting mostly of elderly females. Part of the HAND program involved looking over contracts for reconstruction or repair in an attempt to reduce fraud against a vulnerable group. The HAND program, although limited in scope, served elderly women well.

The County Housing Authority, which coordinated the Permanent Housing Committee, issued Housing and Urban Development (HUD) vouchers to qualified elderly residents. The Housing Authority made referrals and served as an advocate for Santa Cruz disaster housing needs. The Housing Authority also linked Federal relief efforts to the local level.

Other efforts involved the transition into temporary housing. The Salvation Army exemplified a number of organizations that participated in helping victims to establish household routines, thus moving them into the latter recovery phases. SRO hotel residents, in particular, lost almost all household items. Non-profit groups, such as the Salvation Army, remained crucial in collecting and distributing household items ranging from appliances and furniture to household goods.

LOW-INCOME LATINOS

Similarly, traditional groups like FEMA and the ARC assisted low-income Latinos to relocate into permanent housing. Caseworkers from the Watsonville Red Cross and the Santa Cruz County Human Resource Agency's Earthquake Trailer Park Project helped with referrals, served as advocates, and eased the transition to permanency.

In both Watsonville and Santa Cruz, several Interfaith religious organizations worked for permanent housing, rendering aid with locating new premises, paying for deposits as well as first and last month's rent, financing small repairs, and rebuilding homes. Religious groups, like the Mennonite Disaster Service and the Christian World Relief Church Committee, worked with Watsonville Interfaith to completely rebuild homes. Habitat for Humanity also participated in the new construction.

[9]Data obtained from the Federal Emergency Management Agency, the Presidio of San Francisco Office, October 1, 1990.

AN OVERVIEW OF PERMANENT HOUSING

By mid-1991, a multitude of public and private efforts enabled victims to begin recovering and rebuilding. Most programs centered on affordable housing for low-income victims. Earthquake donations partially funded construction of the Neary Lagoon Housing Project in Santa Cruz.[10] Earthquake victims receive some priority in relocating to Neary Lagoon. As of two years after the quake, local planning efforts continued and it became difficult to distinguish between what was replacement housing and what was simply the normal, ongoing housing construction process.

SUMMARY

In Santa Cruz County following the Loma Prieta earthquake, those hardest hit for the longest time period came from low-income groups. Early on, relief organizations excluded the pre-quake homeless from assistance efforts. A variety of existing organizations worked to assist the displaced elderly toward permanent housing. A mixture of existing and emergent organizations helped low-income Latinos. More than 2 years after the earthquake, work continued to provide for affordable permanent housing for low-income earthquake victims.

CONCLUSION

The data from Santa Cruz County clearly show that several factors created the sheltering and housing problems. It is equally apparent that solutions to these problems must address the conditions in a comprehensive fashion. I believe that pre-existing conditions, including a lack of affordable housing, a lack of cultural inclusivity, and a lack of integrated interorganizational planning, led to many of the sheltering and housing problems.

AFFORDABLE HOUSING

The most significant condition creating sheltering and housing problems in Santa Cruz County was a lack of affordable housing. This is not a unique problem across the nation even without disaster situations. Affordable housing declined precipitously in the 1980's, when the Federal government significantly reduced its role in such construction. Studies of homelessness generally point to this dearth of affordable housing as hastening the rise of homelessness (McChesney, 1990). Concomitantly, an increase in the poverty rate foreshadowed the rise of homelessness (Giamo, 1992; Lam and Wright, 1987; Rossi and Wright, 1987; Wright, 1989).

[10]The Neary Lagoon Housing Project existed before the earthquake.

The experiences of the cities of Santa Cruz and Watsonville with housing low-income and minority victims are quite likely representative of the problems to be encountered in future disasters. Previous research on the Whittier Narrows earthquake of 1987 warned us of this possibility (Bolton and others, 1992). Efforts aimed at mitigating housing problems in future disasters should necessarily include addressing the more generic concern of affordable housing across the Nation. A catastrophic New Madrid (Mississippi Valley) earthquake could have enormous repercussions, given today's rates of homelessness, hidden homelessness, and poverty.

In summary, the solutions to potential housing problems in disasters lie in responding to existing problems of affordable housing, addressing the needs of a demographically diverse nation, and creating strong interorganizational communication and coordination.

INCLUSIVITY AND DIVERSITY

Demographic diversity also played a role in this disaster. First, disaster victims are heterogeneous. In addition, disaster effects do not strike randomly; socioeconomic status often determines who is affected most severely and who recovers most rapidly. In a society stratified on the bases of race, age, ethnicity, sex, and income, all aspects of sheltering and housing such a diverse group of people are affected. Community disaster response and recovery can be heightened by including diverse groups in the planning process and by anticipating both short-term and long-term sheltering and housing needs. Overlooking people and their problems is tantamount to increasing the effects of disaster (Haas and others, 1977).

Pre-quake conflicts and differences in community power affect sheltering and housing (Quarantelli 1982a,b; Bolin and Stanford, 1990). I found this to be true with the ethnic conflict in Watsonville and with the homeless controversy in Santa Cruz. Latino community representatives clearly felt excluded from the decisionmaking process. Since the earthquake, however, the city of Watsonville and Latino organizations have moved toward more cooperative disaster planning. This paradigm shift has healed some of the divisiveness, spurred recovery, and may serve as a mitigative factor in any future disasters. This is clearly an example of proactive, rather than reactive, mitigation policy (Drabek and others, 1983).

Clearly, organizations like FEMA and ARC did not anticipate the extent of minority groups' needs in such an earthquake. Given previous experience with disasters such as the Whittier Narrows earthquake (Bolton, and others, 1992), these traditional disaster responding groups should have been better prepared.

Our Nation continues to develop in demographically diverse ways. Addressing this demographic diversity in appropriate fashion, with involvement of members of the potentially affected groups, is essential. In the aftermath of the Loma Prieta earthquake, the ARC has taken a leadership role in responding to the needs of culturally diverse communities. The National ARC has created courses in cultural awareness and is looking closely at policy issues related to pre-existing homelessness.

INTERORGANIZATIONAL COORDINATION AND COMMUNICATION

Quarantelli (1982a,b) identified interorganizational coordination and communication as crucial to recovery. In Santa Cruz and Watsonville, local and nonlocal disaster relief organizations took a considerable time to develop a working rapport. Local groups and FEMA in particular experienced substantial conflict. This conflict affected organizations' abilities to respond to Loma Prieta quake victims.

However, despite rancorous relations in the first 6 months after the earthquake, conflict decreased as FEMA and local residents and organizational representatives came to know each other. FEMA officials and local government workers were able to work together best after the initial 6 months, while interactions between FEMA and more ad hoc groups could best be described as chafing. The main lesson learned here is not a new one: key organizations need to talk before disaster strikes.

Furthermore, it is useful to look beyond the emergency sheltering phase. Each community disaster plan studied in this research dealt only with the first phase following a disaster—emergency sheltering. Communities would be well advised to consider long-range plans for disaster housing recovery. Forging coalitions with existing nonprofit organizations may be a viable route toward such long-term planning. Studies of homelessness suggest that nonprofits are often well-suited to addressing the needs of temporary and permanent housing (Shinn and others, 1990). Additionally, homeless families typically need multiple services to be able to rise out of their predicament (Shinn and others, 1990). In Watsonville and Santa Cruz, caseworkers provided referrals, advocacy, translation, and other services. Multiple organizations gave out household items or funds for replacing goods. The process of arranging post-disaster housing involves more than the reconstruction or rehabilitation of dwelling units.

In summary, pre-existing conditions can greatly hinder or facilitate the return of low-income and minority groups to permanent housing after a disaster. This is not a new finding. However, given the national increase in homelessness, poverty, and demographic diversity, in combination with the decline of affordable housing, such post-disaster housing crises undoubtedly will be seen again. Clearly, viable solutions to post-disaster housing problems lie in addressing pre-existing social problems of housing, inclusiveness, and planning. Essentially, communities need to be prepared to reconstruct housing before disaster strikes (Haas and others, 1977). Disaster recovery can best be understood and facilitated through understanding the larger social context within which housing problems arise.

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RECOVERY, MITIGATION, AND RECONSTRUCTION

HAZARDS MITIGATION AND HOUSING RECOVERY—WATSONVILLE AND SAN FRANCISCO ONE YEAR LATER

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ABSTRACT

The City of Watsonville lost 642 housing units in the 1989 Loma Prieta earthquake. These were primarily small single-family dwellings that were knocked off their foundations. In less than one year, 75 percent were repaired or replaced. In San Francisco, 500 of the 1,482 red-tagged (severely damaged) units were demolished, and a total of 36,000 units were damaged. After one year none of the large brick buildings had been repaired, none of the units torn down had been replaced, and only 50 percent of the wood-frame buildings damaged had begun repair work. It is unfair and unrealistic to compare the housing recovery rate of single-family dwellings in a small-town setting to the replacement of multifamily units in a large city. However, it is valuable to examine what was and was not working in each locale as it pertains to housing issues and hazard mitigation. The factors that made the Watsonville and San Francisco experiences so different were the availability of financing, the incentive to rebuild, and the local construction capacity.

INTRODUCTION

The Loma Prieta earthquake in 1989 rocked the Bay Area for 15 seconds. In that brief period, a portion of the San Francisco-Oakland Bay Bridge and a three-quarter-mile section of the Nimitz Freeway collapsed and a large number of buildings sustained significant damage in the cities of Watsonville and Santa Cruz, in the Marina and South of Market Districts of San Francisco, and in downtown Oakland. Perhaps the most important lesson from the Loma Prieta earthquake was the vulnerability of structures built on fill and soft soils. As with any disaster, however, there are numerous lessons to be drawn on many topics, ranging from preparedness through mitigation, engineering, prediction, and response.

This paper will focus specific attention on housing, not only because so many people were directly affected by damage and loss, but also because the problems of recovery and reconstruction are related to the problems of pre-earthquake hazard mitigation. San Francisco and Watsonville represent the spectrum of housing issues affecting large metropolitan areas and small rural towns. The experience of these two communities suggests that the rate of reconstruction of the housing stock depends on several local factors—incentive, technology, financing, regulation, available space, self help, and luck.

BUILDING HAZARDS MITIGATION

Significant programs for hazards mitigation in existing buildings are relatively new in California. Since the early

1980's, local jurisdictions have begun the task of identifying potentially hazardous building types, and the engineering community has worked to develop techniques for improving building performance for life safety and damage control. During this period, engineers and emergency preparedness groups have also taken steps to develop a public consciousness regarding earthquake hazards and have lobbied for building codes that require retroactive repair of unreinforced masonry and tilt-up industrial buildings. In fact, very few cities had mitigation programs in place before October 1989.

Although the cities of Long Beach and Santa Rosa have had "active"[1] ordinances since the 1970's, it was the enactment of the Earthquake Hazards Reduction Ordinance (commonly known as "Division 88", its numerical section of the local building code) in Los Angeles in 1981 that helped focus statewide attention on the retrofit of existing unreinforced masonry buildings (known commonly as URM's). This ordinance established a set of priorities for retrofit of the city's 8,000 URM's. Emergency facilities, such as hospitals, police stations and fire stations, were the first to receive citations from the building department. Next in line were buildings defined as high risk, including churches, theaters, offices, and other public assembly buildings. Schools, which are regulated through State agencies, are not included in local building regulations. Buildings of medium and low risk (housing and industrial structures with relatively low occupancies) were to be cited last. The entire program was designed to be implemented over a period of 15 years.

In 1985, the severe damage in Mexico City from the Michoacan earthquake prompted Los Angeles City Council members to accelerate the program and require completion of all retrofit by 1991. This happened at the point when the city was just beginning the citation process for medium- and low-risk buildings, including 1,582 residential buildings containing 46,000 housing units. To meet the new schedule established by the Council, all citations were issued by December of 1986, all permits should have been secured in 18 months (by June of 1988), and all construction should have started within 2 years (by December of 1988). The fast-track mitigation program proved to be an unrealistic goal. As of October 1990, only 25 percent of the buildings cited in 1986 had actually completed construction, approximately 40 percent were in progress, 25 percent made no progress towards construction, and 10 percent were demolished. These figures on completion of seismic retrofits in Los Angeles were calculated by the Community Development Department (based on Building and Safety computer records) in October 1990 for a status report to the City Council. By 1991, more rehabilitations were in progress, but no more had been completed (Comerio, 1992).

While the implementation problems with the Los Angeles ordinance are the subject of other papers (Comerio, 1990, 1992), the completion rates for the housing are important to note here because most California cities look to the Los Angeles plan as a model both for engineering requirements and for implementation methods. In 1986, at the same time that Los Angeles was trying to speed up its compliance schedule, the State passed a law requiring all local jurisdictions to inventory their hazardous building stock and develop plans for mitigation. This law, Senate Bill 547, did not go so far as to provide funding, nor did it require cities to implement retrofit ordinances, but it did put cities on notice that they were responsible for thinking about how to handle this problem.

The 1987 Whittier Narrows earthquake provided the first small test of the Los Angeles retrofit program. Although it was only a moderate earthquake (magnitude 5.9), it did provide the opportunity to review strengthening procedures and renew the political pressure for State and local mitigation programs. Unfortunately, the 1989 Loma Prieta earthquake preceded the adoption of most such programs. On the positive side, this magnitude 7.1 quake did provide a good preview of the kind of damage the Bay Area might expect in future earthquakes of similar magnitude. "Preview" is the appropriate term because it is generally agreed that the earthquake's short duration (15 seconds) and the location of its epicenter (60 miles south of San Francisco in the Santa Cruz Mountains) spared Bay Area cities from more significant damage.

DAMAGE FROM THE LOMA PRIETA EARTHQUAKE

Although the media focused public attention on the collapsed portions of the Bay Bridge and the Nimitz Freeway and on the damage in San Francisco's Marina District, this was not the whole story. There was extensive damage to older buildings throughout San Francisco and Oakland. In San Francisco, 71 percent of all buildings damaged were residential. While this residential loss represents only a tiny portion (1.5 percent) of the city's total housing stock, 60 percent of the nearly 36,000 units damaged housed people of low and moderate income. Nearer to the epicenter, the cities of Santa Cruz and Watsonville each lost 60 percent of their downtown commercial districts. Furthermore, Watsonville lost 8 percent of its housing stock, while 76 percent of that city's total occupied housing was damaged (damage figures from Bureau of the Census, 1983, and internal reports by the cities of Watsonville and San Francisco).

For all the cities in the Bay Area affected by the Loma Prieta earthquake, recovery and mitigation are now two sides of the same coin. For San Francisco and Watsonville, housing (particularly affordable housing) is a critical issue, and the experience one year after the quake should help us to understand the opportunities and the stumbling blocks for both recovery and mitigation.

[1]Active ordinances target specific buildings, classes of buildings or elements of buildings and require specific action to be taken. By comparison passive abatement programs require hazard reduction only when a predefined action, such as a change of use or major renovation, is taken by the owner.

SAN FRANCISCO

San Francisco has a population of 720,000 in a 49-square-mile area. As a result, the city has a high proportion (75 percent) of its residential units in multifamily buildings—156,000 of 208,000 total units, not including 19,000 in single-room-occupancy hotels and 28,000 in tourist hotels (Comerio, 1987). San Francisco is also a city with large ethnic populations—90,000 Chinese, 30,000 Southeast Asians, 80,000 Hispanics, 80,000 blacks —and with a significant economic gap between low-income minorities and middle class whites.[2]

Who lost housing in the earthquake is therefore as important as how much was lost. The city reports that there was a total of 360 red-tagged (unsafe for entry) buildings, of which one-third were residential and contained 1,482 housing units. Within one month of the earthquake, more than 500 of these red-tagged housing units were demolished. Most of these were in multifamily buildings located in the Marina District. The remaining red-tagged units were mainly located in the South of Market and Tenderloin Districts. These buildings were left empty and fenced to prevent reoccupancy and protect from further damage. Similarly, the great majority of yellow-tagged (safe for limited entry, but unoccupiable) buildings outside the Marina were in downtown neighborhoods. Two-thirds of all the red- and yellow-tagged buildings contained low- and moderate-income housing units (City and County of San Francisco, 1989).

While many of the damaged wood-frame buildings in San Francisco had been repaired for habitability two years after the quake, not all the work was complete. In the Marina and Sunset Districts most of the demolished buildings were replaced. Fifty percent of those damaged were in the process of being repaired. By comparison, none of the red- and yellow-tagged single-room-occupancy hotels and multiunit brick buildings (more than 1,300 units) in the Tenderloin and South of Market Districts had begun repairs two years after the event. Further, it was not clear that the plaster cracks and other minor damage in about 9,000 units in these low-income neighborhoods had been addressed. The city reported that many landlords were simply ignoring the damage, and tenants were still calling the city about repairs and inspections.[3]

WATSONVILLE

Watsonville is a small city located 100 miles south of San Francisco at the center of one of the world's richest agricultural valleys. Watsonville has a population of 30,000, of which 61 percent are Hispanic, primarily farmworkers and cannery workers. During the Loma Prieta earthquake, Watsonville lost 642 of its 8,100 housing units. These were mainly older wood-frame single family houses in the downtown area that were literally knocked off their foundations. The occupants were primarily Hispanic and 40 percent of the houses were owner occupied. In less than one year, more than 75 percent have been repaired or replaced.[4]

This is an incredible recovery rate. In the news media, Watsonville was portrayed as a poor backwater, and reporters assumed that the loss of housing and of three downtown commercial blocks would devastate the city and that it would never recover. Immediately after the earthquake, Watsonville was compared to Coalinga, where the old downtown was never rebuilt after a magnitude 6.5 earthquake devastated it in 1983 and the economy languished. In fact, Watsonville had approved plans within a year for rebuilding two of the three commercial blocks, and city staff reported that the earthquake generated new construction in addition to the repair work, as people added second units or additions while they had contractors on site.

How did the housing repair in Watsonville happen so quickly? One critical factor was the Earthquake Relief Fund established by the city to assist with long term recovery. Watsonville received donations from individuals, corporations, foundations, and its sister city in Japan. These donations totaled $1 million. The city officials recognized that most emergency aid covered only the first 72 hours. They decided to use the donations to help people who could not qualify for loans from the Small Business Administration or commercial banks. Thus, the city gave away the money in small grants (the largest was $48,000) for housing repair or reconstruction.

THE COMPONENTS OF RECOVERY

In both San Francisco and Watsonville, there was very little business interruption or job loss. A survey of executives by the business-sponsored Bay Area Council found that businesses were negligibly affected by the quake. While many merchants in San Francisco's Chinatown have argued that the loss of the Embarcadero Freeway caused a drop in their business, others believe that this was part of a general economic downturn, only accentuated by the earthquake. The real damage was to public transportation systems and private housing.

The obvious question seems to be: How could the little town of Watsonville rebuild or replace the majority of lost housing so quickly, and why was San Francisco so slow? In

[2]Population data based on 1986 estimates from the San Francisco Department of Public Health, and more recent estimates from the Center for Southeast Asian Refugee Settlements in San Francisco.

[3]Information from Laurence Kornfield, Head of Earthquake Statistics, Bureau of Building Inspections, City of San Francisco.

[4]Information from interviews with Maureen Owens, Planning Director, and Dicksie Allen, Senior Planner, City of Watsonville, August 8, 1990.

part, it is unfair to compare single-family wood frame buildings of 1,000-2,000 square feet to large multistory, multiunit buildings. It is valuable, however, to examine what did and did not work in each locale and why. Specific local conditions significantly affected the rate of reconstruction.

INCENTIVE

In Watsonville, 40 percent of the houses were owner occupied and the remainder were owned either by an owner-occupant next door or by another town resident. In San Francisco, the great majority of the buildings were owned by absentee owners. There is a real difference in incentive, motivation, and energy between an owner anxious to replace his or her own home and an investor evaluating the financial merits of rebuilding a rental property in the current real estate market. The owners of single-family homes in Watsonville were clearly motivated to rebuild and restore their lives, whereas many owners of multifamily apartment houses in San Francisco faced high building renovation costs in neighborhoods where rents were low and housing was considered a bad investment.

TECHNOLOGY

As stated earlier, there is no comparison between small, single-family wood frame houses and multiunit apartment buildings. While appropriate building materials were generally available in both areas, the former type of structure requires minimal tools and skills while the latter requires engineering and architectural drawings as well as licensed, experienced professional contractors. The fact that single-family houses can be renovated by small contractors and owner builders with assistance from unskilled labor contributed to the speed of housing recovery in Watsonville. Large apartment buildings cannot be done in the same ad hoc fashion. Their reconstruction requires adherence to the standards set by design professionals, financial institutions, and city regulators.

FINANCING

In San Francisco, the Mayor's Office of Housing estimated a need for $118 million (at $80,000 per unit) to replace red-tagged units and $96 million (at $20,000 per unit) to repair yellow-tagged units. Remembering that 60 percent of the units lost or damaged were providing affordable housing to tenants of low and moderate income, the scale of the public subsidy necessary to retain some of those units for low- and moderate- income renters is daunting. Furthermore, it is unclear whether buildings in marginal areas such as the South of Market and Tenderloin Districts could obtain private financing for replacement housing.

In Watsonville, the city simply gave away $1 million in grants of $20,000 to $50,000 to individuals who wanted to repair their houses but could not qualify for conventional financing. Although the grants represented only 5 percent of the estimated $20 million repair bill, these funds clearly expedited the recovery process.

REGULATION

As in all large cities, construction projects in San Francisco must go through a myriad of planning and building reviews before permits can be issued. Even after an earthquake, there is a limited amount a large city can do to circumvent its own procedures once the immediate emergency has abated. In a smaller community like Watsonville, there is an opportunity for city staff to redefine the regulatory process. In the 1989 crisis Watsonville decided to be easy on permits and tough on inspections. In a city where the Planning Director knew most residents by name and the task of repair was relatively straightforward, the city was able to avoid time delays by placing the burden of control on the building inspectors in the field.

AVAILABLE SPACE

In San Francisco there were two very different kinds of tenants and two very different sets of choices. White middle class tenants who lost apartments in the Marina and other outlying districts simply moved to vacant units in other neighborhoods. Landlords offered them breaks on rent and deposits; department stores often offered furniture at cost. For non-English-speaking, low-income, elderly, and transient tenants in the South of Market, there were few opportunities outside the emergency shelters and city-sponsored homeless shelters. Community groups provided some assistance but could not rehouse those displaced in an already overcrowded and undersupplied market.

In Watsonville there was also a limited supply of vacant space to accommodate people and businesses on a temporary basis, and it was clear that even the strong extended family networks could not satisfy the need for temporary housing. Mobile homes were brought in by the Federal Emergency Management Agency, despite the agency's original reluctance, in order to keep people close to their jobs and the homes they hoped to rebuild.

SELF HELP

In San Francisco, middle class tenants generally accommodated the loss of housing and personal possessions while maintaining their jobs, but low-income people had a more difficult time. Displaced tenants in the South of Market District joined the ranks of the homeless, waiting for public assistance.

In Watsonville, cannery workers and farm laborers did not lose their jobs, because there was no damage to these industries. These families traditionally rely on themselves and their neighbors, and they simply worked with the local construction labor force to rebuild their homes. Retirees and church groups pitched in and organized volunteer labor and "house-raising" parties to assist individual families. Such efforts reduced the real costs of construction and built a strong community spirit.

LESSONS—ONE YEAR LATER

On all the points described above, San Francisco was a victim of scale. The loss of so many affordable units in a city with a housing vacancy rate of less than 1 percent is a significant blow, not only to the tenants, but to the city already struggling to maintain an adequate supply of affordable housing. Despite strong public leadership, neither the city nor private owners were able to fund the reconstruction, and State and Federal assistance would be too little and too late. Watsonville, by contrast, managed to overcome a potentially devastating loss of affordable housing units. The community exhibited very sensible leadership, targeted critical financing, and was blessed with a strong dose of luck, in that local jobs were not lost, and volunteers from charitable organizations supplied rebuilding assistance to local homeowners.

Other communities cannot guarantee the component of luck, but they can develop the leadership and the creativity to take advantage of local opportunities. In planning for future disasters, several lessons can be drawn from the experiences of Watsonville and San Francisco following the Loma Prieta earthquake.

LESSON 1: USE LOCAL RESOURCES, HUMAN AND FINANCIAL

The recovery program that worked for Watsonville took advantage of local people's vested interest in restoring their own houses. They took what was available and made the best of it. Had they decided to wait for larger loans or better deals, they might still be waiting. Although each individual house might not reach a level of finish that others would expect, shelter was more important than community architectural standards.

In San Francisco, the losses from the Loma Prieta earthquake have made the nonprofit community housing organizations recognize the importance of mitigation. These groups have asked the city for training from local engineers so that they could serve as technical inspectors and advisors on their own projects and in their neighborhoods. It was these same groups who began to include seismic upgrading in their low- and moderate-income renovation projects before it became a city requirement.

LESSON 2: BALANCE SAFETY AND SOCIAL NEEDS

San Francisco has been criticized for its slow process in developing a retrofit ordinance and criticized further for opposing a State model code. However, it is clear from the descriptions of conditions in only two cities that it would be impractical to impose a single technical standard on hazardous building types in all locations. This is not an argument for applying a lower standard to housing than to commercial buildings. Instead it is a recognition that the unique problems facing residents in the Chinatown, Tenderloin, and South of Market neighborhoods in San Francisco ought to be dealt with by San Franciscans who can shape a hazards abatement program to local circumstances.

Each community needs to analyze its own housing inventory and develop specific hazard-abatement strategies and methods that meet their own conditions. In some cases, a land-use decision to limit building on fill may be more useful than renovating a particular class of building.

LESSON 3: INTEGRATE TECHNICAL, SOCIAL, AND FINANCIAL ANALYSES IN LOCAL PROGRAMS

The main problem with locally based research is that most large-scale aid organizations do not want to accept local solutions. However, all good local solutions to specific problems, such as housing production or hazards mitigation, can be understood in terms of local application of general principles. Watsonville distributed funds quickly, made individuals responsible for their own construction, provided technical assistance, and stayed out of the way. How they did this was unique to Watsonville, but what they did could apply to any small-scale locale with extensive loss of housing and a minimal loss of jobs.

The arguments that favor local initiative and local control may appear to suggest that disaster assistance and hazard mitigation should be taken off the public agenda. That is not the intention. There is a very real need to maintain and improve our building stock over the long term. Natural hazards remind us of the need to renovate and extend the useful life of the existing housing stock through mitigation and recovery.

With some irony, Watsonville City officials express a certain thankfulness to the earthquake. It gave them the opportunity to rebuild and improve a large segment of very old and ill-maintained housing with donated funds, thus keeping it affordable to moderate income families who will be part of the community for a long time to come.

CONCLUSION

The final lesson from the experiences of both Watsonville and San Francisco is that housing is a precious commodity, and both mitigation and recovery are a matter of public choice. In Watsonville, the city chose to spend limited public funds on private property, while the community contributed expertise and labor to assist low-income families in rebuilding their homes. Because fully 75 percent of the housing stock sustained some damage, city inspectors used this opportunity to advise residents to ensure that houses were bolted to foundations, water heaters strapped, chimneys tied, and other obvious hazards mitigated to prevent similar losses in the next earthquake.

In San Francisco, the total cost of preventive strengthening for the undamaged housing stock could be twice that of the Loma Prieta earthquake's repair bill, even though the cost per unit for mitigation is only about 10 percent of the cost of a replacement housing unit (Rutherford and Chekene, 1990). No large city can depend on donations, self help, and good neighboring alone to preserve the existing building stock. Recovery and mitigation will be slow processes involving significant commitments of public funds and public will. Large cities, however, are similar to small towns in that there is a need to understand the physical conditions of their existing building stock and the social and economic conditions of their inhabitants to develop realistic and implementable programs. If there is any doubt about the importance of developing such programs, we have only to look at the numbers of housing units affected in the Loma Prieta earthquake and consider the potential for housing loss in the next earthquake in an urban area.

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RECOVERY, MITIGATION, AND RECONSTRUCTION

LOCAL EARTHQUAKE MITIGATION PROGRAMS—PERCEPTIONS OF THEIR EFFECTIVENESS FOLLOWING THE LOMA PRIETA EARTHQUAKE

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ABSTRACT

Federal, state, and regional programs promoting local-level mitigation activities to reduce losses and disruption from earthquakes have been carried out in past years. The Loma Prieta earthquake provided a test of these measures in many jurisdictions and offered an opportunity to examine if local agency staff now view their loss-reduction strategy as effective. Respondents from city and county agencies in the affected region were asked, through a combination of personal interviews and a mail-in questionnaire, if they believed their mitigation efforts had averted damage, what new mitigation measures or plans were being initiated in their jurisdiction since the earthquake, and what information sources and technical assistance they have found most useful. The responses suggest that (1) well-enforced local building codes are viewed as effective in reducing or eliminating damage and, in these California communities, are the primary means for mitigating damage; (2) programs aimed at promoting simpler, lower cost measures for strengthening existing buildings or minimizing nonstructural hazards should be more aggressively pursued; (3) sources of information and technical assistance that are easily accessible and locally relevant, and those provided by credible sources such as other members of their own profession, are viewed as most useful; and (4) Federal, state, and regional programs that provide assistance to local jurisdictions should be cognizant of the variety of organizational structures within governments, so that vital information reaches the appropriate offices or individuals.

INTRODUCTION

Since the passage of the National Earthquake Hazards Reduction Act in 1977 (Public Law 95-123), the Federal Government has taken the lead in developing earthquake safety policy and program goals. The National Earthquake Hazard Reduction Program (NEHRP) has supported a variety of efforts related to the promotion of earthquake loss reduction at the local level across the Nation (see, for example, Federal Emergency Management Agency, 1984, 1988). Federal policy focuses on state and local governments as the appropriate levels of implementation for earthquake preparedness programs. States may shape local policy by mandating that certain practices be consistent with state policy. However, for the most part, earthquake preparedness and loss reduction practices must be implemented at the local level. Local jurisdictions have been mandated, exhorted, and assisted in a variety of ways to develop programs designed to reduce the vulnerability of their residents, buildings, and lifelines to earthquake damage.

Technical studies that have been conducted to evaluate specific mitigation techniques include laboratory and field studies of specific techniques, systematic reviews of the performance of specific types of buildings, and post-earthquake investigations to identify factors that contributed to damage in specific buildings. Evaluations such as these address the theoretical effectiveness of techniques designed to reduce or prevent damage (May and Bolton, 1986). That is, they address the ability of specific measures to reduce damage, where correctly applied, or, conversely, the likelihood that observed damage could have been avoided had specific measures been implemented. Much of the available technical assistance on how to carry out specific mitigation measures is based on such studies. Each successive earthquake provides new insights into what does and does not work under certain circumstances. However, any given loss-reduction approach, no matter how theoretically effective, only works to the extent that it is applied.

A particular challenge is posed by structures constructed before advances in understanding of the seismic hazard and of effective means of mitigating or lessening their vulnerability to the hazard. Unfortunately, knowledge that has been gained is often not systematically applied because of formidable economic and political barriers (Alesch and Petak, 1986; Berke and Wilhite, 1988; Drabek and others, 1983). Of all the states with a recognized earthquake hazard, California has, despite such barriers, without question engaged in the greatest amount of earthquake mitigation planning at both the state and local levels (Berke and Wilhite, 1988).

The mainshock of the Loma Prieta earthquake was felt over much of central and northern California. Many jurisdictions in this region experienced ground shaking of a sufficient intensity (Modified Mercalli intensity VII to IX) to test the effectiveness of their building standards and other earthquake mitigation practices. Even though the Loma Prieta earthquake resulted in approximately $8 billion in damage to structures and other direct costs (California Seismic Safety Commission, 1991), most of the development in the San Francisco Bay region in fact survived the earthquake with little or no damage.

Although jurisdictions in the region that experienced lower ground shaking intensities (Modified Mercalli intensity VI or lower) may have escaped significant damage from the Loma Prieta earthquake, recent probabilistic forecasts along the same fault and along other active faults identified in the region indicate that many are at risk from future major earthquakes (Real, 1984; Working Group on California Earthquake Probabilities, 1990). These jurisdictions will benefit from reexamining their own actions in light of damage patterns in the harder hit areas. Similarly, the rest of the Nation at risk from major earthquakes should take note of the lessons of the Loma Prieta quake regarding the sources of seismic damage and seismic safety.

Even in California, few jurisdictions have anything that could be called an aggressive and comprehensive mitigation strategy (Berke and Wilhite, 1988, p. 33-35). However, the use of the Uniform Building Code (UBC) is mandated by the State, and many examples of local-level earthquake hazard mitigation programs can be found in the region (see, for example, Bay Area Earthquake Study, 1984; Beatley and Berke, 1990; Blair-Tyler and Gregory, 1988; Federal Emergency Management Agency, 1990, p.61-69; Mader, 1988). The Loma Prieta earthquake provided an opportunity to examine (1) how well some of these local efforts at earthquake hazard mitigation fared, (2) whether the consequences of the earthquake have led local jurisdictions in the region to reevaluate local efforts aimed at earthquake hazard mitigation, and (3) which of the various types of hazard information and mitigation program guidance have been useful to local building officials and planners. The study focused on county and city mitigation efforts in the seven counties that sustained the most damage as a result of the earthquake: Alameda, Contra Costa, Marin, San Mateo, Santa Clara, Santa Cruz, and San Francisco Counties.

The level of damage experienced in these counties varied considerably, from virtually no damage to structures, to severe localized damage of a specific structure, type of structure, or type of site. Data on mitigation activities were collected principally from interviews with agency officials and from a questionnaire sent to county and city departments most likely to be involved in hazard mitigation activities. Beginning approximately 18 months after the Loma Prieta earthquake, 30 personal interviews were conducted in 13 cities and counties with various county and city officials, and 4 similar interviews were conducted with Federal, California State, and regional program representatives. Based on these initial conversations, a questionnaire was mailed to each of two departments in 39 different jurisdictions. One or both departments from 24 of these jurisdictions provided information through the questionnaire. The observations reported here are derived mainly from these questionnaire responses.

EXAMINING MITIGATION

We postulated that the Loma Prieta earthquake should focus agencies' attention on whether or not the mitigation path they are pursuing is the most appropriate for their local hazard and development context. Assessment of mitigation effectiveness was addressed in two general ways: one was to have local agency staff describe ways in which they think their mitigation programs served to avert—or did not avert—disruption or damage as intended; the other was to examine their choice of new mitigation initiatives in the earthquake's aftermath.

In order to examine mitigation it was important to identify where in the governmental structure mitigation planning and program implementation are carried out, in hopes of obtaining a fairly complete picture of both programs and plans within the jurisdiction. We assumed that these Bay Area jurisdictions would have recognized their earthquake risk, that is, would not have been surprised to experience the Loma Prieta earthquake; it was important, however, to get some sense of what aspects of the community a particular jurisdiction believed were vulnerable to damage from such an earthquake.

INSTITUTIONAL LOCATION OF LOCAL RESPONSIBILITY FOR MITIGATION

The question of who is charged with planning or implementing mitigation efforts was not intended to be part of this study. However, initial interviews clearly indicated that the distribution of efforts among specific agencies varies between communities, and also that one agency is not necessarily aware of what another agency has done or is planning with respect to earthquake mitigation. This is in part because city organization differs between communities; in part it is the result of situational factors within agencies, such as the presence of a staff member with a particular commitment to mitigation, or traditional locations for types of activities.

In the absence of information as to which agency was responsible for mitigation programs, the questionnaires were directed to specific agency heads. As anticipated, in many instances completion of the questionnaire was delegated to some other person or persons considered most knowledgeable about the jurisdiction's earthquake mitigation activities. Often only one questionnaire was returned from a jurisdiction, with different agency representatives contributing to its completion. It is likely that the most complete responses were obtained on those questionnaires where several departments collaborated. At the same time, responses provided some evidence that departments do not necessarily confer with each other and will not necessarily be aware of activities or similar goals in other departments.

Among the agencies that contributed to the completion of the questionnaires (as noted on the front page of each questionnaire received), there are 13 building officials or building departments. Someone in public works, which in many communities is the location of the building inspection department, is listed on 7 of the returned questionnaires; 11 respondents identified themselves as representatives of planning or community development departments; and 5 as representatives of emergency services, such as the local office of emergency services or fire or police departments. In a few instances, someone representing a redevelopment agency or special program for unreinforced masonry (URM) structures participated in the response, or someone from administration.

These observations imply that efforts to disseminate technical information to appropriate agencies or divisions must carefully consider general assumptions about where certain functions are carried out in local government. These observations further imply that comprehensive community strategies for earthquake hazard mitigation are not likely to be developed unless this separation of objectives and tasks within a jurisdiction is overcome.

LOCAL UNDERSTANDING OF VULNERABILITY

The belief that some specific area or type of construction is particularly vulnerable to damage can be a major factor in deciding which mitigation measures to adopt. Contrary to initial media portrayals of strong earthquakes, major portions of the development within even the higher intensity zones associated with recent earthquakes in the western United States have suffered mainly minor damage. Major damage has been concentrated in specific locations, in specific building types, or in combinations of location and building type. Some of the absence of damage can be attributed to the mechanics of the particular earthquake. The rest is attributable to the application of geotechnical, seismic, and engineering information and technology. Misconceptions on the part of decisionmakers about what is and is not vulnerable to the more probable types of earthquakes in their region (or what part of the nondamage is due to the fortuitous character of a particular earthquake) can lead to complacency about the need to address the hazard.

We examined local agency understanding of the damage—and nondamage—related to the Loma Prieta earthquake in two ways. First, the questionnaire asked for a description, in very general terms, of the damage level experienced in their community or county. We asked for the typical level of damage (on a scale of none to extensive) across several categories of structures, including unreinforced masonry (URM) buildings, nonductile concrete buildings, simple buildings (typically for warehouse use) constructed of prefabricated slabs tilted into place at the site, bridges and roads, and other residential or commercial buildings. The responses indicated variations between categories and between communities and also provided examples of other factors respondents thought contributed to some of the damage in their jurisdictions. For example, one respondent noted that some of the damage was in an area built up under the 1960-70 building code; another indicated that many houses on stilts or in areas of fill were damaged. Chimney damage was mentioned by several.

The questionnaire next asked if any of the damage was unexpected for an earthquake of this magnitude. The most common response to this question was no, they were not surprised by the damage in their area. Several, most typically from communities that had only minor damage or no damage, offered that they were surprised they didn't have more damage. This suggests (1) an awareness on the part of many of the jurisdictions before the earthquake of the lack of seismic resistance for some aspects of their built environment and (2) an awareness that part of the built environment might still be considered vulnerable, even if not affected by this particular earthquake.

A few respondents mentioned examples of unexpected damage in their communities, including: equipment dislodged by the strong vertical acceleration associated with this particular earthquake, even where devices to resist the more typical lateral movement had been installed; greater ground movement in bay muds than expected, leading to damage to some types of structures in those areas; disruptions to an auxiliary water supply system; unexpectedly great variation in damage related to soil-type microzones; the exacerbation of long-term sliding on sloping ground; unexpectedly great chimney damage in a particular community; and damage, albeit minor, to a specific newly constructed neighborhood. Both expected and unexpected damage could be viewed as sources of insight into what should be priorities for future mitigation measures.

We also asked these agency representatives if they were surprised by damage elsewhere in the region, whether or not there had been damage in their area. Again, most responded that, for the most part, they had not been surprised. Observations about unexpected damage elsewhere included the Bay Bridge damage, the Hyatt Hotel near the San Francisco airport, and the severity of damage at large distances from the earthquake source. Again, there were a few mentions of the lack of damage in some specified places where it would have been expected.

EXPLANATIONS OF DAMAGE AVERTED

There are a variety of sources of information on the specific damage that the Loma Prieta earthquake caused in these Bay Area communities (see, for example, Association of Bay Area Governments, 1991; California Seismic Safety Commission, 1991, p. 33-48; Earthquake Engineering Research Institute, 1990). In particular, eligibility for the Federal and State assistance programs requires extensive documentation of the damage and of repair costs. Descriptions of damage also are provided by teams of engineers and other specialists interested in documenting certain phenomena. In our questionnaire we approached damage from another angle by focusing on the damage that did not occur, and the reasons for this, by asking about damage averted. The question read, "... do you think that some types of damage from the earthquake were less in your community/county than they might have been because of specific measures taken to reduce damage...?"

This question was designed to elicit examples of measures that were perceived to have made a difference, even if small, in reducing the consequences of the earthquake in that community or county. Respondents from communities that had experienced little or no damage generally did not answer the question. This is unfortunate, but may be due to a correct perception on their part that the lack of damage was more related to the characteristics of the earthquake than to actions taken by the community.

Table 1 lists all responses to this question and the respondents' description of the program or requirement to which they attributed the damage reduction. Some communities gave several examples. The types of damage averted fall into three familiar categories: the reduction or elimination of structural damage to recent (since about 1960) construction; the reduction of damage to nonstructural aspects of buildings, such as fittings and contents; and the reduction of damage to existing older, hazardous buildings.

Good engineering design and appropriate codes are given the credit for having protected the newer buildings in many communities. Most of the answers referred specifically to the application of the Uniform Building Code, thus implying the importance of requirements that have to be met for various types of structures. A few of the responses explicitly recognized enforcement of the Code as the key. For the reduction of losses in nonstructural elements, the responses contained more of a mix of required practices and measures left to the discretion of the building owner. When measures depend on voluntary application, it has to be assumed that a much smaller proportion of the hazards will have been affected than for required measures. Nonetheless, as awareness grows that certain types of measures work, it becomes more likely that greater numbers of building owners will implement those measures voluntarily. Evidence of effectiveness, and in particular cost-effectiveness, may increase the likelihood that such measures will eventually be required, at least for new construction and maybe for certain existing buildings. However, most communities lack any effort to track and evaluate the success of these voluntary efforts, or to engage in cost-effectiveness analyses.

The examples given of damage averted in potentially hazardous existing buildings were heartening but have affected a fairly limited number of buildings. Two examples are important in that they indicate a community's willingness to address one or more of its own government buildings that had been assessed as lacking in seismic resistance. The enforcement of seismic requirements when buildings are altered was mentioned by one community. While this sounds like a fairly simple approach, it has raised complex issues about what standards to use, the effects on owners' willingness to upgrade older buildings, and cost-effectiveness. Two communities believed information provided to building owners had prompted at least some amount of voluntary strengthening of buildings susceptible to earthquake damage.

Experience in the initial personal interviews indicated that the question on "damage averted" was puzzling to many at first. It is much more difficult, and a more subjective task, to think in terms of damage averted rather than damage observed. Of the respondents who addressed this question, some only indicated one or two examples, while others provided several. The variation in the ability to provide examples from one jurisdiction to the next is not readily explainable. The difference could be the result of any of the following: little attention to mitigation in some communities; uncertainty about whether measures had been effective; or a tendency to lose awareness of the implications of mitigation activities once they are routinized. For example, the fact that more respondents did not mention their local building code, at a minimum, in response to this question could indicate a failure to understand the question but may mean that the implications of the codes for seismic safety are taken for granted.

To the extent that the latter explanation holds true, for purposes of promoting additional loss reduction efforts it may be important to raise awareness of the significance of the use

Table 1.—*Examples of damage believed averted by local mitigation activities undertaken before the Loma Prieta earthquake*

[From questionnaire responses to the question, "Do you think that some types of damage from the earthquake were less in your community/county than they might have been because of specific measures taken to reduce damage or prepare for an earthquake? Please list the type of damage that was averted and describe the activity that was responsible for the reduction."]

Type of damage believed averted	Local measure(s) credited with averting damage
Structural damage reduction in recent construction	
Failure of any modern buildings	Building code that requires all buildings to be designed for seismic/lateral forces
Major or extensive damage to new structures	New structures were engineered at higher standards
Residential and commercial building damage	Enforcement of most current building, mechanical, plumbing and electrical codes
Separation of structure from foundation/ footing	Application of provisions of the Uniform Building Code, Chapter 23
Racking due to reduced wall area or wall damage	Application of Uniform Building Code, Chapter 23 since 1955, with 1973 update
Cripple wall failure or damage	Application of Uniform Building Code, Chapter 23 since 1955, with 1973 update
Damage to buildings in general	Buildings were constructed to model code requirements
Damage to buildings in areas of bay mud	Local code for identified bay mud area more restrictive than Uniform Building Code since 1972
Damage to all structures	Local emphasis on quality design and details, and plan review and inspection by the city

TABLE 1.—*Examples of damage believed averted by local mitigation activities undertaken before the Loma Prieta earthquake*—Continued

Damage reduction related to nonstructural aspects	
Contents damage at [specific] construction company	Contents tie-down requirement
Ammonia vessel rupture	Vessel was secured to a concrete pad and was properly strapped
Tipping or breakage of hot water heaters	Voluntary efforts of individuals to strap hot water heaters
Personal injury in workplaces	Voluntary programs of some businesses to develop earthquake safety and evacuation plans
Nonstructural failure in the emergency operations center	Facility survey had been done and mitigation measures applied in 1988-89
Broken windows and flying glass	Voluntary increase in use of plastic film to cover window glass as encouraged through ongoing public education by county and city emergency services organizations since 1970's
Chimney separation or damage	Application of Uniform Building Code, Chapter 37 since 1984
Damage to equipment and buildings	Local code and strong enforcement of Uniform Mechanical Code/Uniform Building Code requirements for water heaters and other equipment tie-downs since 1972
Damage to underground piping systems in specified bay mud area	Local code requirement for nonmetallic piping in specified area to reduce corrosion since 1972 with 1981 modifications
Damage to utility connections at buildings	Local construction community emphasis on good practice of using flexible utility connections to buildings in bay mud areas since 1970's
Collapse of ceiling systems	Uniform Building Code lateral-force criteria for supports of ceilings as per latest model codes from State Building Standards Commission

TABLE 1.—*Examples of damage believed averted by local mitigation activities undertaken before the Loma Prieta earthquake*—Continued

Damage reduction in existing hazardous buildings	
Parapet and ornamentation failure	Long-term continuing program to reinforce parapets and related hazards
Failure of Candlestick Park Stadium structure	Seismic upgrade project completed
Failure of building upgrades	Long-term enforcement of special seismic upgrade requirements
Damage to older wood frame homes	Increased number of homes voluntarily applying foundation bolts as retrofit, encouraged through ongoing public education by county and city emergency services organizations since 1970's
Damage to some unreinforced masonry structures	Voluntary retrofit stimulated by information available and emphasis of 1986 California Unreinforced Masonry Building Law (Senate Bill 547)
Damage to masonry fire station, library	City decision to reinforce during conversion and construction

of updated building codes as part of the mitigation process. There may be considerable political value in being able to remind the public that the survival of buildings and services in the community was not necessarily accidental, but a result of intelligent decisions on the part of building and planning officials and private citizens, followed by the reminder that more of these types of decisions remain to be made. This is particularly true for extending lessons learned to other seismically vulnerable areas of the United States that have not recently experienced a strong earthquake but are lacking in something as basic and significant as building codes relating to seismic resistance.

The perception of current building codes as an effective mitigation strategy was revealed in the questionnaires and interviews in other ways besides responses to this question. For example, several jurisdictions characterized their development as too new to be concerned about the seismic hazard because their growth had occurred in the years since more stringent building standards were adopted. This assumption may or may not be totally correct, because the short duration of the ground shaking associated with the Loma Prieta earthquake (about 8 seconds for the greatest intensity) did not provide a particularly severe test for many buildings. Nonetheless, the widespread enforcement of recently revised building codes with seismic provisions has to be viewed as a major cause of earthquake loss reduction in the San Francisco Bay Area.

The list in table 1 presents an array of examples of both required and voluntary efforts that the respondents said they believed had been effective in reducing the overall impact of the earthquake. During the initial personal interviews, two different building officials pointed out a reverse approach for making judgments about damage that was averted. They observed that a quick analysis of their post-earthquake damage inspections provided insights about certain fairly simple measures, such as chimney reinforcement or foundation bolting and bracing, that would have prevented damage. For example, the examination of inspection results in one community revealed that well over half of the inspections performed after the quake were for chimney damage; in another, inspections of older homes that had been displaced from their foundations had placed major demands on the damage inspection process.

These officials noted that, had requirements been in place to address these weaknesses, not only would the post-earthquake demand for inspections have been far less, but hundreds of homeowners would have been spared the costs and the disruptions to their lives which this damage caused. Another interview respondent suspected that cost-effectiveness studies of some of the less complicated measures, in particular those related to dwelling damage, would prove favorable, and therefore could be very valuable for promoting programs. If it were possible to factor in the nonmonetary aspects of the disruption and stress, the ratio of prequake strengthening costs to post-quake repair costs would be even more favorable.

THE LOMA PRIETA EARTHQUAKE AS A CATALYST FOR SUBSEQUENT MITIGATION EFFORTS

Various analyses have suggested that the occurrence of an earthquake (local or otherwise) helps to promote local reevaluation of acceptable risk and briefly widens the constituency for earthquake mitigation so that local priorities can be rearranged to provide for the implementation of new preparedness or mitigation measures. Observations about the factors contributing to damage in the Loma Prieta earthquake might well prompt jurisdictions to change what they had previously considered a reasonable and feasible level of effort directed at earthquake mitigation. The experience also may have provided direct evidence of what effectively reduces damage, or perhaps changed the local definition of acceptable risk with respect to some type of vulnerability.

Besides being asked what earthquake mitigation programs and plans they had before the Loma Prieta earthquake, respondents were asked about plans and programs initiated since the earthquake. So that respondents would think about a wide variety of measures, the questionnaire asked them to describe their post-earthquake activities in the following seven categories:

- Planned or actual revisions in land-use ordinances
- Revisions in procedures for implementing existing rules or regulations
- Proposed or adopted changes in standard construction practices
- Proposed or adopted changes in the seismic safety element of the general plan
- New programs or regulations aimed at reducing the potential seismic hazard from existing buildings (including programs in response to the 1986 Unreinforced Masonry Building Law)
- Development or provision of outreach or training programs for employees, businesses, residents, or other special population groups on earthquake safety measures
- Involvement in community redevelopment efforts that specify seismic safety as an element of the program

EXISTING BUILDINGS

Attention to existing buildings is the most frequently mentioned post-earthquake mitigation activity. Virtually all activity described in relation to existing buildings focused specifically on unreinforced masonry (URM) buildings. Generally, the programs were developed in response to the California URM law (the 1986 Unreinforced Masonry Building law, often referred to as Senate Bill 547). This law requires cities and counties to inventory all unreinforced masonry buildings and establish a local program to mitigate the hazards in these buildings. These programs must include, at a minimum, notifying building owners about the potential hazards of their building and developing a plan to address the building hazard. To comply with the URM law, communities were to have completed their inventory of URM buildings by January 1990. Many communities were well along in the process or had already completed this task by the time of the Loma Prieta earthquake in October 1989. Thus momentum already existed for developing mitigation programs related to the URM buildings (California Seismic Safety Commission, 1990). Certainly the URM Law (SB 547) has been the central driver for the progress made in addressing the URM building hazard at the local level, and some respondents stated explicitly that the law was probably more important than the Loma Prieta earthquake in prompting their actions related to URM buildings. However, other respondents noted that because of the Loma Prieta earthquake, they had decided to switch from a voluntary to a mandatory program, or that they had speeded up the process from what was originally planned. For communities like Watsonville and Santa Cruz, the earthquake eliminated much of the URM building hazard, providing a graphic illustration of what URM strengthening is intended to prevent. Both these communities also had examples of URM buildings that had been reinforced and that fared considerably better than the unreinforced buildings.

The initial personal interviews also revealed a need to establish programs for strengthening other types of existing buildings, such as the prefabricated tilt-up buildings, in widespread use as production and warehouse facilities; older concrete frame structures, especially those housing schools and critical facilities; mobile homes not tied to footings; and wood frame houses built before codes required adequate tie-ins with the foundation. The Loma Prieta earthquake provided examples of hazards associated with these building types, as well as with URM buildings. Older concrete frame buildings in California, older wood frame houses, and tilt-up buildings constructed before code changes will have to be treated through measures focused on existing buildings; future tilt-up and similar-style buildings can be addressed with new construction standards.

The interviews and questionnaires clearly indicate that far less attention has been paid to these other types of hazardous buildings than to URM buildings. This illustrates the important effect of the state-level policy for attending to the URM hazard. Even though many local governments resent state initiatives that affect local discretion on issues, others will acknowledge that it can be very helpful to have important requirements emanate from the state, thereby making local action an implementation issue rather than a political issue. The California policy, at a minimum, provides building owners with necessary information and goals to address hazards in their buildings. This permits the local jurisdiction discretion about the schedule for mitigation and whether to make strengthening mandatory, thereby leaving the definition of acceptable risk to local policy makers.

Both Federal and California State policies reflect the belief that URM strengthening, at least theoretically, is an effective approach to reducing one type of loss and should be promoted. Implementation of URM strengthening programs has not been considered very feasible at the local level because owners often cannot afford to do what is necessary and the jurisdiction cannot afford to provide adequate financial incentives to make it cost effective for owners. Nonetheless, some jurisdictions have decided that the risk represented by these buildings is not acceptable. They have therefore established objectives for the amount of damage that is acceptable (that is, life safety only, or preservation of functionality) and required that these buildings meet standards that keep damage at or below that level in future typical earthquakes. Because strengthening programs can be such major social and economic issues for communities, these programs will be most feasible, as one interview respondent noted, in those communities with the fewest URM buildings. In other parts of the United States, vulnerable existing buildings constitute a larger portion of the building stock than in California. In those areas URM strengthening may not be economically feasible at the local level unless some sort of financial assistance or subsidy is provided. However, when the costs of losing these buildings from the building stock, providing disaster recovery assistance, and grappling with the provision of replacement housing is compared to the cost of subsidizing their strengthening, such programs may nonetheless prove desirable.

Evidence that URM programs are being adopted following the Loma Prieta earthquake does not necessarily mean that communities have, on their own, decided the measure is too effective to ignore. State policy is a major factor in the development of URM strengthening programs. Progress to date is therefore not necessarily related to the Loma Prieta earthquake, although that event probably has helped make implementation of the program less difficult to justify within some communities.

SEISMIC SAFETY ELEMENTS AND LAND-USE ORDINANCES

One of the more sobering lessons learned from the Loma Prieta earthquake was an appreciation of the amount of damage to the built environment caused by local soil and ground conditions and by unrecognized geophysical hazards (Earthquake Engineering Research Institute, 1990, chap. 4; Federal Emergency Management Agency, 1990). The earthquake also reactivated landslide areas and led to a renewed awareness of the extent of the liquefaction hazard, particularly on the margins of San Francisco Bay. Respondents in the Santa Cruz area during the initial in-depth interviews pointed out that damage patterns proved the effectiveness of the combined use of building codes and geologic-hazard review requirements. Much of the damage there was to older structures built before such measures were in place, to structures built without a permit, or in areas where the hazard from soil conditions had not heretofore been recognized.

Since 1971, the California State Planning law has required cities and counties to include in their general plan the identification and appraisal of seismic hazards. In 1984, this seismic safety element of general plans was combined with other elements into a single safety element under which jurisdictions must address ways to protect the community from unreasonable risks, including seismic risks. This and other laws that require attention to seismic risks have helped to ensure that seismic matters are included in local planning programs and have served to heighten the awareness of city officials and the public regarding seismic hazards and options for dealing with them (California Seismic Safety Commission, 1985). These laws have not necessarily resulted, however, in specific actions being taken to mitigate the hazards described.

Some respondents to the questionnaire indicated that they were preparing to review or had reviewed the information in their seismic safety element, and revised it if necessary, since the 1989 earthquake. However, few examples were provided of changes in land-use or other ordinances that would indicate these jurisdictions believed they needed to take a different approach to better identify or mitigate their existing seismic hazards. If such reviews were done in light of what was experienced in the Loma Prieta earthquake only, they may not adequately address the consequences of movement on other faults in the area or of larger earthquakes. Communities that claimed to be working on revisions to land-use ordinances included two of the communities that sustained the greatest damage in the Loma Prieta earthquake.

In 1990, the State adopted the Seismic Hazard Mapping Act (1990 Statutes, Chapter 1168 [AB 3897]). The Act calls for the California Division of Mines and Geology to prepare maps that will be used to identify seismic hazard zones. The establishment of these zones will facilitate the use of seismic hazard information in land-use regulation and for establishing construction requirements or other regulations for specific types of areas, should communities choose such approaches to deal with their particular hazards. As before, the feasibility of implementing such ordinances will be a major consideration in deciding whether or not to enact them. For most of the State, the designation of seismic hazard zones will not occur immediately after the Act was passed, as the program did take several years to complete. Once it is completed, the existence of well-defined zones may also affect other policies, such as those applied to financing or insurance for development in hazard zones.

OUTREACH, EDUCATION, AND OTHER ACTIVITIES

Training and outreach typically are not particularly controversial programs to implement, and their costs are fairly low compared to other measures. To the extent that the techniques promoted are theoretically effective, they can make a major contribution to the reduction of losses if correctly applied by a significant proportion of building owners. Many respondents to the questionnaire expressed a belief that citizens or businesses do voluntarily apply measures they learn through these educational outreach efforts, though none cited any evidence of the actual extent of such applications. Many stated that they had provided post-earthquake education of some kind to either city employees or the public, but most indicated that this was basically a continuation of what they had been doing before. The in-depth interviews revealed that jurisdictions commonly create their own informational materials for education of the general public, even on generic procedures, despite the existence of many already prepared materials available through Federal, State, and regional programs.

Virtually no other examples were provided of post-earthquake measures these jurisdictions consider effective and thus worth implementing. An oversight in the questionnaire was the omission of the development of repair or reconstruction standards from the list of potential post-earthquake activities. Damaged buildings presented a major challenge to the jurisdictions. The standards applied to repair are important to the reduction of losses in future earthquakes, but in many jurisdictions this issue had not been addressed before the earthquake. In those areas, repair standards needed to be developed quickly after the earthquake to be of most use. This called for tough policy decisions and demanding compromises to craft standards lenient enough to permit recovery but tough enough to achieve acceptable seismic safety levels. This dilemma was identified in the personal interviews as being particularly difficult for historical buildings, and also in areas where the earthquake revealed geologic hazards not previously recognized there and thus not addressed in geologic hazard reviews of those sites.

SIGNIFICANT CHANGES RELATED TO THE LOMA PRIETA EARTHQUAKE

Although examples of measures initiated following the Loma Prieta earthquake are provided above, the overriding impression from reviewing the responses to the questionnaire is that the earthquake prompted very few communities to initiate additional mitigation measures in the years immediately following the quake. Besides having respondents list the pre-quake and post-quake mitigation activities in their community, the questionnaire also asked for a subjective assessment of the effects of the earthquake on local concerns or activities. This question read, "In your view, do you think that the approach your community is taking to prepare for and reduce the potential for damage from an earthquake has changed in some significant way because of the Loma Prieta earthquake?"

In answer to this question, several respondents mentioned that there was now a greater awareness of what an earthquake could do, or of the potential vulnerability of their community to future earthquakes. This is a somewhat disappointing answer, because it does not address whether this awareness was leading to more aggressive efforts to reduce future losses. More than a third of the respondents indicated increased attention to emergency response preparedness, but did not mention loss reduction measures. Other types of answers included (1) a greater sense of urgency, (2) greater awareness and action on the part of top administrators, (3) more aggressive approach to URM buildings, and (4) increased attention to geotechnical review in areas now recognized as particularly hazardous. Some mentioned their impression that more individual citizens were voluntarily taking measures such as strapping their hot water heaters, anchoring their houses better, and reinforcing chimneys, or at least they were asking for information on how to do these things. One person stated frankly that the earthquake raised awareness, "but not enough to fund some key programs."

Both the initial interviews and the more concise responses to the questionnaire imparted the same impression: despite the evidence from the Loma Prieta earthquake that mitigation efforts both can help and are lacking in many places, the actual adoption and implementation of loss reduction measures is still an uphill battle. In the interviews a few of the respondents acknowledged that they assumed there was a "window of opportunity" for taking advantage of heightened awareness and concern about earthquake damage, but they knew that it would not be open long, and perhaps not open very wide. By the end of the first year, this window was perceived as closing rapidly in conjunction with the worsening fiscal condition of the State and of most local jurisdictions.

Even during times of fiscal stability, virtually all communities face tradeoffs between directing resources to immediate threats to the community's well being, such as crime, deteriorating education, or traffic congestion, and directing them to more indeterminate threats such as earthquakes and other highly disruptive events. Earthquake mitigation programs, in particular, typically cannot compete on the local political agenda with more pressing everyday problems. Even an event such as the Loma Prieta earthquake may not provide an impetus beyond those communities most directly affected. Under these circumstances, earthquakes themselves remain the most effective, even if the least desirable, means of removing development vulnerable to earthquake damage.

USEFULNESS OF TECHNICAL ASSISTANCE SOURCES

A central element in both the National Earthquake Hazard Reduction Program (NEHRP) and in California State efforts to promote earthquake preparedness and hazard mitigation is the provision of information to inform and guide local programs. Several types of hazard information and mitigation program guidance have been provided for the earthquake hazard in general, and others for use in California and the Bay Area specifically. For example, types of technical assistance available to California officials include the following:

- Information emanating from the Federal level, fairly generic in nature and typically designed to be widely applicable.
- Sources provided by the State of California, typically focused on California seismic issues and policies.
- Regional technical assistance and information from education agencies focused on regional issues and accessible to the jurisdictions in the region.
- Sources particularly relevant to a specific profession, focused on solutions to the problems typically addressed by members of that profession.
- The availability of persons with special knowledge, including in-house expertise or private consultants, that can extend agency expertise regarding a specific problem.

The questionnaire listed 14 sources of information and technical assistance and instructed respondents to indicate those they were familiar with, had used, and had found most helpful. Certainly not all sources of technical assistance are captured in the questionnaire list, but the selection represented a variety of major sources of information available in recent years to California agencies involved in planning or implementing earthquake hazard mitigation programs. These sources all have the objective, to a greater or lesser degree, of enabling practitioners to use the information to reduce risk. Responses to this question were received from 30 different respondents in 24 jurisdictions.

The information sources the respondents were asked about are shown in table 2, along with agency responses. High numbers in the table suggest that a source has been visible and valuable to these local agencies; small numbers suggest that a source has not been particularly visible or valuable. However, a small number of mentions should not automatically be assumed to mean that the source of assistance has little to offer. It is more appropriate to say that these findings indicate which sources were or were not particularly applicable to the needs of these local building and planning officials. Some may be well suited and useful to other audiences, such as consulting engineers, practicing architects, or teaching professionals, and thus the path of their effects at the level of local agencies is more circuitous. The value of any specific source of technical assistance must be assessed against its own intended objectives.

MOST FAMILIAR SOURCES

Agency representatives responding to the questionnaire were familiar, on average, with about half of the 14 assistance sources listed. Five of the sources were recognized by more than half the respondents. The single source that the most respondents (24 out of 30) indicated as familiar was the Bay Area Regional Earthquake Preparedness Project (BAREPP)—more recently renamed as the Earthquake Program of the California Office of Emergency Services Coastal Region. It should be recognized that the breadth of BAREPP's activities probably gives it the greatest number of paths to people's desks. BAREPP not only provides direct, personal technical assistance for planning, and presentations to provide preparedness or mitigation information, but also produces and distributes a large number of documents related to mitigation planning and programs that vary in focus and level of technical detail. BAREPP has been associated with many widely publicized education and preparedness activities such as the annual Earthquake Week and a large conference held one year after the Loma Prieta earthquake. BAREPP also serves as a means for delivering guidance developed by others, including sources on the list such as the Applied Technology Council, the Federal Emergency Management Agency, the United States Geological Survey, and other experts.

A similar number of respondents (24) indicated that they were familiar with information provided by their professional associations. This type of dissemination represents many different sources, but refers most typically to professionals providing information to others in the same profession (for example, engineers) or the same agency function (for example, building officials) through association journals, local chapter meetings, and conferences. Organizations such as these can be very instrumental in informing members of the implications of research findings and issues for their profession. These associations also can advocate for attention to earthquake hazard mitigation as good practice. Since they must attend to a wide array of concerns of the particular profession, however, the amount of attention given to earthquake mitigation will necessarily be limited.

Table 2.—*Number of agency respondents indicating familiarity with and helpfulness of sources of information and technical assistance*

[From questionnaire responses in regard to list of 14 sources given below. Respondents were asked to indicate all sources with which they were familiar, the 3 they found most useful before the Loma Prieta earthquake, and the 3 they found most useful after the earthquake. Not all respondents completed all questions. N, number of responses to a question. Some respondents indicated fewer or more than 3 sources as most useful.]

Source and type of information or technical assistance	Familiar sources (N = 30)	Most helpful, pre-quake (N = 21)	Most helpful, post-quake (N = 17)
Federal Emergency Management Agency, Earthquake Hazard Reduction Series (also known as "the yellow books" because of their covers)	14	3	3
U.S. Geological Survey hazard assessments and information dissemination from these assessments	15	1	0
Building Seismic Safety Council workshops or publications	6	0	0
Applied Technology Council workshops or publications	16	7	5
California Seismic Safety Commission documents, program priority statements, contacts with staff	20	4	5
Bay Area Regional Earthquake Preparedness Project multijurisdictional earthquake planning assistance; staff contacts, consultation, meetings; handbooks and planning guides; public education materials; workshops and conferences	24	13	8
Association of Bay Area Governments earthquake hazard data or maps; planning information; workshops and conferences	21	4	1

Table 2.—*Number of agency respondents indicating familiarity with and helpfulness of sources of information and technical assistance*—Continued.

California Division of Mines and Geology hazard information, maps; scenario document for earthquake in Bay Area	16	4	0
American Institute of Architects workshops and conference; publications	7	1	0
Professional associations (engineers, city managers, and others) conferences and workshops with special focus on hazards or earthquakes	24	10	9
Specialized training sessions (such as California Specialized Training Institute or Federal Emergency Management Agency's Emmitsberg Training Center)	15	8	4
In-house expertise (tap what is available)	14	3	4
Outside consultants, hired for special projects	15	5	5
Postearthquake briefing sessions (following major earthquakes in Mexico City; Whittier, California; Armenia)	12	4	3

Two other sources of information and assistance also were cited as familiar by at least two-thirds of those who answered this question. These are the Association of Bay Area Governments (ABAG) and the California Seismic Safety Commission (CSSC). The initial interviews and comments on the questionnaires indicate that when respondents mentioned CSSC, they were often thinking about assistance with complying with the California URM Law (SB 547). There were no specific comments about ABAG activities, but ABAG's more notable efforts in recent years related to earthquakes include providing information on earthquake risks and hazardous areas in the San Francisco Bay Area and sponsoring conferences on important issues such as liability in the area of earthquake preparedness and mitigation.

Many of the other sources on the list were noted as familiar by about half the respondents. The two sources with the lowest recognition were the Building Seismic Safety Council (BSSC) and the American Institute of Architects (AIA). The lack of familiarity with the work of the BSSC on the part of planners and building officials at the working level is probably not surprising. Its contributions to the development of consensus on building standards and approaches to seismically resistant design are directed at a much more limited audience, and the fruits of its work are probably most likely to reach practitioners through their professional associations, or as effects on codes. The AIA was included as a source separately from other professional associations because of special projects directed at providing education on approaches to seismic safety among the design professions. Because its efforts were national in focus, there would have been less opportunity for any particular agency professional to have had exposure to its workshops.

MOST HELPFUL SOURCES

The respondents were asked which sources they had actually used for their mitigation activities before the Loma Prieta earthquake and which three had been the most useful to them. Compared to the question on familiarity, where respondents listed on average seven sources, the average number respondents said they used before the Loma Prieta earthquake was between three and four. About 70 percent (21) of the respondents addressed the question of which three sources were the most useful to them for mitigation planning and program development before the earthquake. Some respondents listed fewer than three, and a few, perhaps because of the combined efforts of multiple individuals in completing some of the questionnaires, indicated more than three as particularly useful.

BAREPP, which had been the source most familiar to the agency representatives, also was identified as among the three sources most useful before the earthquake by about 60 percent of the respondents. About half of the respondents included the category "professional associations" among the most useful sources of technical assistance. Third in number of mentions as most useful came the specialized training sessions, such as those provided by the California Specialized Training Institute (CSTI), and information from the California Seismic Safety Commission (CSSC).

Respondents also were asked which sources were most useful to them after the Loma Prieta earthquake. Only 17 of the 30 respondents were willing to persist in this exercise of describing their use of these information sources through the set of five questions. Professional associations and BAREPP were mentioned by about half of these respondents (9 and 8, respectively) as most useful to them following the earthquake. The next three highest, each with 5 mentions, were the Applied Technology Council, the California Seismic Safety Commission, and outside consultants.

Besides obtaining some idea of whether or not agencies charged with earthquake hazard mitigation knew and used these resources, we also had hoped to see if their use varied by type of planning and program activity (such as land-use planning, building standards, and education). However, as noted above, many jurisdictions prepared a combined response, with appropriate separate agencies filling in those items most relevant to them. Therefore, it was not always possible to distinguish the responses of one agency from those of another in the same community.

To get a better idea of the potential effects of these information sources, additional details would be desirable to have, such as the extent to which the assistance reaches the audience for which it is intended; assessments of the effectiveness and accessibility of the various media (for example, one-on-one exchange, workshops, and documents) for providing information; who uses the information; and exactly what the information is used for. Detailed data on the effectiveness of an organization's information programs are best obtained through systematic evaluations of the individual programs, conducted in light of their particular objectives.

IMPLICATIONS FOR THE ENHANCEMENT OF TECHNICAL ASSISTANCE

The two sources of information and technical assistance that were reported to be most useful to the staff of local agencies—both before and after the Loma Prieta earthquake—were BAREPP and professional associations. This immediately suggests a general recommendation to provide support for these organizations, or ones like them, to carry out their functions related to earthquake hazard mitigation. At the same time, it is obvious that these two types of sources perform these functions quite differently and raise different questions about where the greatest leverage can be achieved in providing technical assistance. In addition, both of these sources are multifaceted; further detail about which aspects of their programs are the most valued by these agency practitioners would be important to have when formulating strategies for enhancing the provision of technical assistance.

BAREPP is funded jointly by Federal NEHRP money and State funds and has the central objective of fostering earthquake preparedness and mitigation in the San Francisco Bay region. Its efforts are almost totally dedicated to enhancing local understanding of the regional earthquake hazard and of educating a wide range of different audiences in both the public and private sectors about appropriate preparedness and mitigation measures. Its services vary from mailing informational brochures to private citizens to making available its planning and hazards experts to meet with staff of local agencies. It distributes a large array of technical assistance brochures and handbooks, most of which have been developed with public funds, either by itself or by others. Although our questionnaire information does not provide details on what aspects of BAREPP's services are most valued by the agency people, some potentially important characteristics can be suggested: as a source of assistance, BAREPP is centralized, accessible, knowledgeable about local hazards and issues, and has off-the-shelf products applicable to many aspects of preparedness and mitigation.

Professional associations, on the other hand, focus on providing information that is useful to their members in their professional lives. Some associations exist for professions in general, such as engineers or architects. Others are dedicated to the concerns of specific types of functionaries, such as city managers, fire chiefs, emergency managers, or building officials. Association activities typically are funded by dues and fees paid by the members themselves, and their agendas are set by the concerns and information needs voiced by members of the profession. It is through these organizations, and through interactions with other members of the same profession provided by association-sponsored journals, newsletters, and functions, that practicing professionals share new information relevant to their activities. Professional associations develop and promote the use of standards of good practice for what individual professionals do. Although only a small part of what an association does may be directly related to earthquakes, certain characteristics of these associations may make them valuable for helping agency professionals deal with earthquake risks. For example, they have the ability to screen and funnel information specific to the needs of a particular agency professional (who may be one of a kind in his agency or community, as for example a city manager or city engineer). This can be particularly important because the source of the information will be others who share similar concerns and problems, making it a truly credible source of information and guidance. Professional associations also serve to provide legitimacy for the adoption of land-use or building standards and perhaps some degree of political currency in the struggle to have mitigation programs implemented.

The development of more specific recommendations about how to enhance technical assistance efforts demands further systematic analyses and critical evaluation of existing approaches. It is important to examine in greater detail those information sources deemed as particularly valuable to local agency people and to try to understand more about the specific functions those sources perform for them. Attention can then be paid to enhancing the performance of these functions, whoever is performing them, and to developing the necessary linkages among assistance providers and information producers. For example, in the San Francisco Bay region, BAREPP performs the function of being a distributor of documents describing how to develop plans and how to reduce earthquake damage in a variety of settings. Much of what they distribute has been developed by others (for example, the Applied Technology Council or independent experts), who can focus on the function of developing sound advice, while BAREPP focuses on the function of identifying appropriate audiences and developing campaigns to see they that receive this information. At a future time, or in other places in the U.S. with an earthquake hazard, other organizational models may be identified or created to carry out these functions as, or even more, effectively than does the BAREPP model.

Another way to select sources of technical assistance for special attention is to think in terms of what a particular community wants or needs to accomplish. For example, different sources might be best for assisting with the political process of getting a long-term mitigation strategy adopted in a community, for helping a community determine the need for special codes to address specific and less common hazards, or for helping a department design and implement a specific mitigation program such as enhancing the seismic resistance of existing tilt-up buildings. The responses of the agencies reported in this study suggest that an important objective to pursue would be that of getting relevant building codes instituted or enforced in areas where this has not yet been done. Another is to promote the widespread application of lower cost measures for strengthening existing buildings and minimizing nonstructural hazards, in order both to reduce losses and disruption to building owners and to permit responsible agencies to focus on more serious post-earthquake problems. The source of critical assistance may be different in different places, depending on the central focus of a community's mitigation strategy.

SUMMARY AND CONCLUSIONS

This study examined the effectiveness of loss-reduction activities at the local government level by asking agency representatives to reflect upon potential damage that did not occur during the Loma Prieta earthquake and to think about which activities may have averted damage that otherwise would have been expected. It also asked agency representatives to describe their mitigation plans and efforts both before and after the earthquake and to reflect upon the changes and what they are now doing to move forward with mitigation efforts.

Our findings suggest that (1) well-enforced local building codes are viewed as effective in reducing or eliminating damage and, in these California communities, are the primary means for mitigating damage; (2) programs aimed at promoting simpler, lower cost measures for strengthening existing buildings or reducing nonstructural hazards should be more aggressively pursued; (3) sources of information and technical assistance that are easily accessible and locally relevant, and those provided by credible sources such as other members of the same profession are viewed as most useful; and (4) Federal, state, and regional programs that provide assistance to local jurisdictions should be cognizant of the variety of organizational structures within governments, so that vital information reaches the appropriate offices or individuals.

The perceived effectiveness of building codes in mitigating the damaging effects of an earthquake was illustrated in several ways. Many participants in the study explicitly mentioned building codes, either in a general sense or with reference to specific portions of the Uniform Building Code, in response to the question about damage averted. Some officials in cities where little damage occurred remarked that it was the young age of their building stock that was to be credited, indirectly showing their belief in the efficacy of modern building standards, which are required for new construction in California communities. Many respondents made specific mention of the small number of unreinforced masonry buildings within their jurisdiction. This caused them to feel less vulnerable to a damaging quake. In some other areas of the United States where earthquakes are less frequent than in California, building codes are less attentive to seismic safety. Officials there should be encouraged to adopt more stringent standards and to enforce such codes locally. The cost is relatively low when only new construction is targeted. Every year that passes without relevant standards being applied to new construction increases the number of existing buildings that may eventually demand special attention by state legislators, city leaders, or insurers and lenders; or that may contribute to the loss of life, injury, and relief and recovery costs when an earthquake does strike.

The disruption and damage caused by building hazards that are relatively simple and inexpensive to address is another noteworthy observation. Many measures can be implemented for private dwellings by the owners if appropriate information is provided on what can be done, how to do it, and the estimated costs and benefits of the actions. These simple measures include chimney reinforcement, attachment of older homes to their foundations, strengthening of cripple walls, and strapping of water heaters to prevent tipping. Bracing or tying down of equipment, building fixtures, and storage vessels are measures typically taken by businesses or government facilities. Some respondents believed that damage had been less in areas where such measures were popular or required; others said they wished they had done more to promote these measures. Some of those we interviewed noted the widespread damage to chimneys or problems with house anchoring and cripple-wall failure that was evident in postearthquake inspection records and commented that considerable damage could have been avoided if these measures had been implemented.

The lesson learned here is particularly important to areas in the eastern United States where a greater proportion of the building stock is old and vulnerable to earthquake damage. Reinforcing an extensive stock of existing buildings susceptible to earthquake damage in a particular city may simply not be feasible in view of the enormous costs associated with it, whereas relatively simple measures may be very feasible and practical and still help considerably to reduce injuries and industrial disruption. Such measures also can serve to lessen the post-earthquake demands put on officials charged with disaster relief, building inspection, and repair requirements.

Many communities in the San Francisco Bay Area that were spared damage in the Loma Prieta earthquake face the temptation of thinking that they are not vulnerable and therefore need take no further action. Are they really not vulnerable, or was the lack of damage related to specific characteristics of the earthquake which may not hold true next time? If the shaking from the Loma Prieta earthquake had lasted longer, would structures in areas subject to liquefaction have been damaged that were not damaged in that event? It is important for communities to critically assess the reasons why so little damage occurred and not be lulled into inactivity. Similarly, communities that were hard hit may feel that the problem has been solved for them. While to some extent this may be a valid conclusion, an earthquake on one of the other major faults, on an as yet unidentified fault, or with different attributes, may strike next time, leaving behind a new pattern of damage.

Though a major lesson from the Loma Prieta earthquake concerned the influence of site characteristics on the type and extent of structural damage, the respondents did not emphasize the need to identify and address newly recognized hazardous areas. Some areas already required geotechnical review, but few respondents mentioned new efforts to establish such programs. As better maps become available that can delineate areas susceptible to such secondary consequences of earthquakes as liquefaction or landsliding, it will be easier to establish appropriate zones in which to regulate construction activity. Land-use regulation has traditionally been even more difficult to adopt than building codes, but more precise maps now provide for a wider variety of strategies to guide development in hazardous areas through nongovernmental institutions such as the banking and insurance industries. At the same time, this does not address the vulnerability of existing development already in these zones and the need for policies to deal with these potential problems.

As shown by the pattern of response we received to the mail-out questionnaire, individuals responsible for various aspects of earthquake mitigation in local governments can be found in a wide variety of positions within a range of offices and agencies. Building officials, for example, are found in planning, public works, or fire departments, or in an independent department. Similarly, some agencies charged with disaster preparedness include mitigation activities within their scope of responsibilities while others do not. This has important implications for the provision of technical assistance by Federal, state, and regional programs, and for the assumptions they make about how to reach the appropriate audiences for particular types of information. The functions for which local agencies most need assistance in the implementation of mitigation programs must be identified so that technical assistance can be as useful as possible.

The Loma Prieta earthquake was only a moderately strong earthquake that occurred in the most prepared state in the nation, yet it caused more than $8 billion in damage, most of which did not surprise persons knowledgeable about the hazard and the built environment in the region. At the same time, much of the region's development was relatively unscathed both because of the brevity of the shaking and because of actions taken by governments or individuals to prevent or lessen damage. Other parts of the Nation have done far less than the average California jurisdiction, for which the typical mitigation strategy has been to enforce its building codes and engage in some degree of public education about simple mitigation measures. The challenge is to find those measures best suited to individual communities and their pattern of vulnerability, based on the likely ability of the measures to reduce some significant portion of the local risk, and to devise strategies for supporting their implementation.

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RECOVERY, MITIGATION, AND RECONSTRUCTION

REBUILDING AFTER THE EARTHQUAKE IN AREAS OF GROUND FAILURE, SANTA CRUZ MOUNTAINS SUMMIT AREA

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CONTENTS

ABSTRACT

The Loma Prieta earthquake was centered in a sparsely developed residential area near the summit of the Santa Cruz Mountains in Santa Cruz County. Ground shaking and disturbance in this epicentral area were severe, damaging many houses. At the time of this study, two years after the earthquake, summit area homeowners were still locked in a battle with County officials for permits to repair or rebuild their homes. The County insisted that without geologic studies that conclude the sites are safe places to rebuild, no permits could be issued in areas with evidence of earthquake-caused ground failure. The owners claimed willingness to assume all risks and pressed to get on with their disrupted lives. In the meantime, the Army Corps of Engineers was in charge of FEMA-funded geologic studies of the summit area to determine the causes of ground cracking and the potential for future movement.

Immediately after the earthquake, Santa Cruz County began very general mapping and applied strict rules for repair and rebuilding permits in the most hazardous areas. Over the following two years, the sizes of the hazardous areas were reduced as new information was generated and the rules gradually liberalized in response to both political pressure and new information. Preliminary conclusions from the Army Corps study then indicated that the earthquake had reactivated a large and deep ancient landslide in the summit area, but that it had little potential for rapid movement. The risk did not appear to be life threatening. Accordingly, the County moved toward applying geologic study requirements in effect before the earthquake to applications for repairs, rebuilding, and new development in the summit area.

INTRODUCTION

The most difficult questions about recovery and rebuilding after an earthquake arise when damage has been caused by ground failures—landslides, debris flows, surface fault ruptures, and other surface failures from liquefaction, lateral spreading, settlement, and related phenomena. The questions are similar whether the ground failures are caused by an earthquake or by some other cause. Geologic investigations are usually required to determine if it is safe to repair or rebuild. These investigations are often extensive, expensive, time-consuming, and controversial, and sometimes they are inconclusive. Under current disaster relief procedures, responsibility for the cost of such studies is not clear. The stakes are high: if studies show that future failures are likely, local governments may have little choice but to prohibit all repair and rebuilding in the area. This is not a decision that can or should be made without the best available information. No local political body wishes to add to the losses its constituents have already suffered in an earthquake.

In the Loma Prieta earthquake, ground failures of uncertain origin and significance occurred in the Santa Cruz Mountains near the epicenter. The authors believe that by recording the sequence of decisions about repairs and rebuilding in this case, much may be learned that would help other jurisdictions having to deal with ground failures in the future. We also offer suggestions to help Federal and state disaster-response systems deal more effectively with this aspect of recovery after earthquakes.

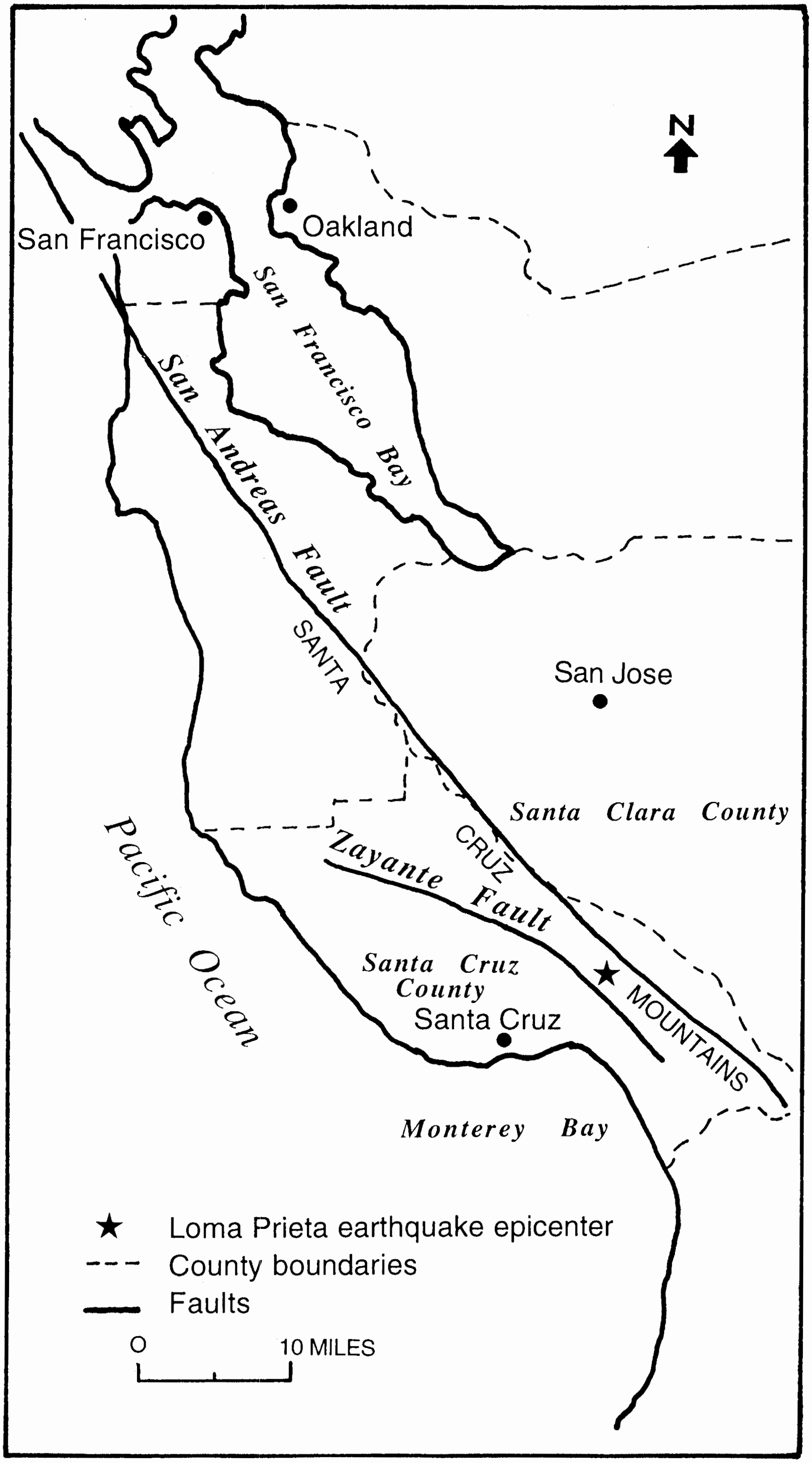

Figure 1.—San Francisco Bay region, showing the location of the epicenter of the Loma Prieta earthquake in the Santa Cruz Mountains of Santa Cruz County.

SETTING

The epicenter of the Loma Prieta earthquake is in Santa Cruz County, and the County suffered widespread damage in that earthquake. Sandwiched between the north shore of Monterey Bay and the crest of the Santa Cruz Mountains (see fig. 1), the County includes the rugged western slopes of the mountains, which are forested and incised with deep, narrow valleys dropping down to the coastal terrace and ocean cliffs. Most of Santa Cruz County's population live and work on the coastal terrace. Broad beaches, sunny weather, and good accessibility attract vacationers, retirees, tourist-serving businesses, and an increasing number of electronics firms. The fertile coastal terraces support a significant agricultural industry and the redwood forests in the Santa Cruz Mountains sustain declining, but still important, lumbering operations. Since the 1960's, a large student population has been added with the opening of a campus of the University of California.

Development in the rugged mountains has been sparse and for many years consisted mainly of small settlements and cabins used as second homes. However, the pressure to build in the mountains has increased in recent decades. Santa Cruz County is just over the hill from Santa Clara County's bustling "silicon valley," center of the San Francisco Bay region's high-technology industry. With the chronic and growing shortage of reasonably priced housing near the high-technology jobs, commutes have lengthened and Santa Cruz County now faces increasing pressure to house people who work elsewhere.

From 1980 to 1990, the County's population grew from 186,100 to 228,700—an increase of 23 percent—in spite of a system of planning procedures and regulations designed to control growth (State of California, 1980, 1990). Less than half the County's population (43 percent) is concentrated in the four incorporated cities of Santa Cruz, Watsonville, Capitola, and Scotts Valley; the majority (57 percent) is scattered throughout its unincorporated areas including the Santa Cruz Mountains.

GEOLOGIC REVIEW

Santa Cruz County adopted a geologic hazards ordinance in 1975 to implement policies in the seismic safety element of its general plan (see County of Santa Cruz, 1985) and to meet the requirements of the Alquist-Priolo Special Studies Zones Act (State of California, 1972). The ordinance requires an assessment of geologic hazards before approval of any application for new development in areas mapped as hazardous. In Santa Cruz County mapped hazard areas include floodplains, coastal bluffs, landslide areas, and fault zones. If the assessment indicates hazards potentially affecting the proposed development, County staff can require additional geotechnical studies. The requirement pertains to fault zones designated by the California Division of Mines and Geology under the Special Studies Zones Act and also to county-designated fault zones. Potential landslide areas are designated on a map of landslide deposits at a scale of about 1:20,000 prepared in 1975 for the seismic safety element (Cooper, Clark and Associates, 1975).

REBUILDING AFTER THE LOMA PRIETA EARTHQUAKE

In the aftermath of the earthquake, Santa Cruz County found itself in a very difficult situation. Ground near the summit of the mountains in the vicinity of the epicenter was obviously disturbed. Open fissures, buckling, and cracks were evident at many locations in the area. The cause of the cracks and their significance were not obvious. A massive landslide on Highway 17 in the mountains temporarily cut off access to the coast from the Santa Clara Valley. Houses, many seriously damaged and some beyond repair, were scattered throughout the area of ground disturbance (see figs. 2, 3). The sequence of actions taken by the County in addressing the repair and rebuilding of homes in this area is outlined in table 1 and described in the following sections.

HAZARD MAPPING

Santa Cruz County's response to the earthquake was immediate. County and consulting geologists were in the summit area right away, mapping the cracks and other evidence of disturbance. By October 23, six days after the earthquake, geologists from the U.S. Geological Survey (USGS), California Division of Mines and Geology (CDMG), and Santa Cruz County, together with local private geologists, had prepared a map delineating an area that had heavy damage and evidence of ground failure. Called the "red zone," this area formed a broad band between the San Andreas and Zayante Faults (see fig. 1). Areas within the "red zone" having the greatest indications of ground failure were also delineated on the map and labeled "areas of critical concern" (fig. 4).

Early policy decisions about repairs and rebuilding were based on this initial map and subsequent refinements. Geologists were, however, uncertain about the cause and significance of the ground cracks. Some could be surficial and of little importance; others could be expressions of an unusual pattern of fault rupture associated with movement on the San Andreas fault; still others seemed more like evidence of deep landsliding. Some geologists feared that the earthquake had reactivated a huge ancient landslide that might continue to move.

The County was in a dilemma about whether to permit rebuilding in the area affected by ground deformation without additional information. In November 1989, the Federal Emergency Management Agency (FEMA) allocated $600,000 to the U.S. Army Corps of Engineers for comprehensive geologic studies of the epicentral area. The Corps in turn contracted with consultants familiar with the geology of the Santa Cruz Mountains to study the causes of the ground failures and the potential for renewed movement (see fig. 5). In December 1989, a Technical Advisory Group (TAG) was formed to oversee the geologic studies. The TAG included representatives from the Corps of Engineers, USGS, and CDMG, as well as the Santa Cruz County geologist and two local geologists—one a professor at the University of California at Santa Cruz and the other a consultant. The latter two had been retained over the years by the County to review geologic reports submitted with development applications and were familiar with the local geology.

Two years after the earthquake, the studies were still underway and the process had been very controversial. In effect, many residents in the area were prevented from repairing or rebuilding damaged homes until studies were completed. Their desire to rebuild and begin to normalize their shattered lives was far stronger than their concern about uncertain, future ground failures. They filled in ground cracks, refused geologists access to their properties and water wells for data, and fought on every possible level any geologic interpretation that would define their properties as unsafe. They impugned the impartiality of the TAG and the study process and insisted on having a representative attend the closed meetings. An engineering geologist representing the homeowners was eventually added to the TAG—a decision that led to the resignation of its chairman and another member, who believed that good science could not result from what was becoming essentially a political process.

After almost two years and the expenditure of $1.45 million in FEMA funds (article in Santa Cruz Sentinel, June 4, 1991), the studies began to clarify a very complex geologic situation. In February 1991, two draft reports were released with tentative conclusions. Summit area residents, however, questioned the data, the process, and the conclusions. In June 1991, TAG released a preliminary map of surface cracks believed to be related to ground movement and held a public hearing to give residents a chance to correct any misinformation. In August, summit area homeowners presented their own study to the County Board of Supervisors. This study, prepared by engineers, geologists, and scientists in their group, disagreed with the hypothesis of the ancient landslide, instead attributing the surface cracks to tectonic movements.

The Corps of Engineers studies were being reviewed by independent specialists who had not been involved in the studies up to that time. The preliminary conclusion of the Corps studies was that the earthquake had reactivated an ancient and deep landslide, causing many of the arc-shaped cracks in the summit area. However, the landslide, if it moves again, is expected to move slowly and is not considered life threatening. After the independent review and public comment, a final report was to be released in December 1991 at the earliest. The Santa Cruz Sentinel (May 5, 1991) commented: "Until the findings of the investigation are released, hundreds

Figure 2.—Structure damaged by vertical movement on ground crack, Summit Road area, Santa Cruz Mountains, October 1989.

of Summit homeowners remain in limbo, unable or unwilling to rebuild until the County receives conclusive data evaluating geologic risks in the mountains."

REBUILDING POLICY

Within a week of the earthquake, the Board of Supervisors passed an emergency ordinance amending the County's 1975 Geologic Hazards Ordinance, which originally pertained only to new development in areas designated as potentially hazardous, to make it applicable to repair and rebuilding of houses and accessory structures in areas of ground failure (County of Santa Cruz, 1989). The amendment gave the Planning Department the authority to require geologic investigations before issuing permits to repair or rebuild structures in the "areas of critical concern." The initial policy was to prohibit repairs to structures in these areas if damage exceeded 50 percent of the value of the structure. Buildings in the areas of critical concern with damage less than 50 percent could be repaired, provided studies showed no significant geologic hazards.

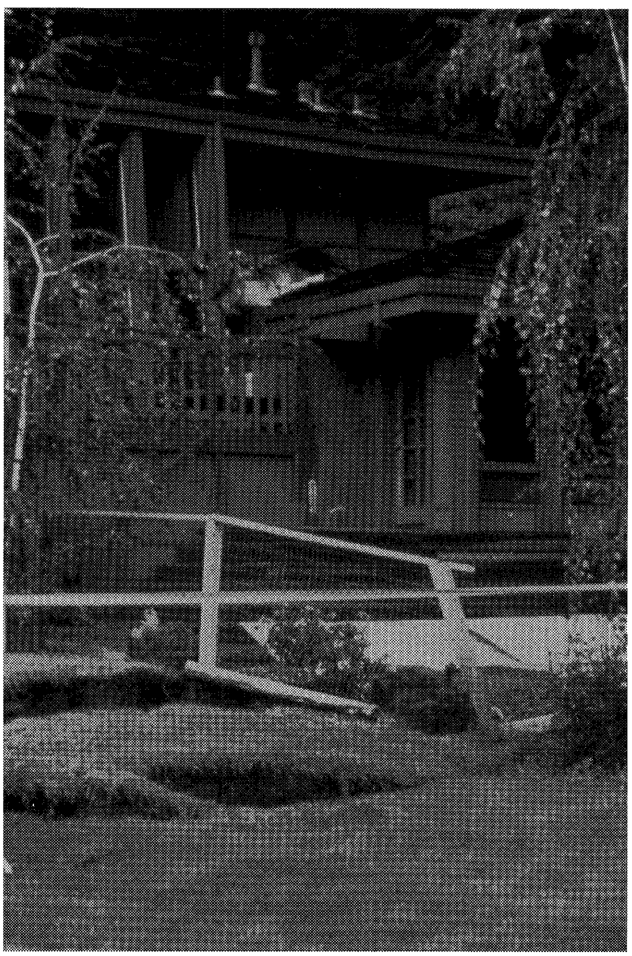

Figure 3.—Damaged house with ground cracking and deformation in foreground, Santa Cruz Mountains, October 1989.

One month after the earthquake, the 50-percent limitation was removed. Reconnaissance mapping completed by the USGS and the CDMG had by then allowed better delineation of areas likely to suffer further ground failure. With the removal of the 50-percent restriction, permits could be issued for repair or rebuilding of any structure in the areas of critical concern if geologic studies indicated favorable conditions at the local site.

However, engineering geologists retained by home-owners to conduct site investigations in the areas of critical concern found it very difficult to conclude that hazards were not significant, because the regional studies undertaken under the Army Corps of Engineers were not yet completed. The site reports were therefore often inconclusive, citing the need to wait through at least one real rainy season to determine the potential for further ground failures. With the area in the midst of its fourth consecutive drought year, nobody knew when enough rain would fall to provide a test. Owners of damaged houses thus found themselves stymied. With inconclusive geology reports, they were unable to obtain permits and often found it impossible to get financing to make repairs. They began to pressure the Board of Supervisors for relief.

The Board responded by adopting Ordinance 4048 in January 1990 (County of Santa Cruz, 1990). This ordinance permanently amended the geologic hazards ordinance to cover repair and reconstruction of damaged houses and accessory structures in areas of earthquake-induced ground failure. It also established that permits for repairs and rebuilding could be issued under the following conditions:

a. The Planning Director determines on the basis of a geologic assessment or report of the dwelling site that any significant geologic hazard can be mitigated to an acceptable level of risk. For the purposes of this section, a potential risk associated with ground failure resulting from the October 17, 1989 earthquake shall be regarded as an acceptable risk if it can only be evaluated by monitoring over time, and it does not present an immediate threat to life or of significant personal injury to persons residing on the subject property.

b. The Board of Supervisors has not determined that the area in which the dwelling is located is unsafe to occupy.

c. The owner records a Declaration of Geologic Hazards with the County Recorder which describes the potential geologic hazards from any on-site or off-site geologic conditions, the level of prior geologic investigation conducted, and any geoglogic investigation in progress, and which includes an agreement by the owner to assume all risks, waive all claims against the County, and indemnify and hold the County harmless from any claims arising from the issuance of the permit or from any alleged inadequacy of geologic investigation or geologic monitoring of the area in which the property

Table 1.—*Chronology of the rebuilding process in Santa Cruz County after the Loma Prieta earthquake, 1989-1991*

Year	Month	Event that occurred or action that was taken
1989	October	*Loma Prieta Earthquake*
		Initial map of "red zone" and "areas of critical concern" completed.
		County offices opened to issue building permits for repair of earthquake damage.
		Geologic Hazards Ordinance amended to cover repairs and reconstruction in addition to new construction.
		Planning Department prohibited repair and reconstruction of buildings damaged more than 50 percent of value in "areas of critical concern."
	November	FEMA provides $600,000 to the Army Corps of Engineers for studies of the ground failures.
		Board of Supervisors allows building permits in "areas of critical concern" if damage over 50 percent.
		Board of Supervisors adopts 45-day moratorium on new construction in "areas of critical concern."
	December	Technical Advisory Group (TAG) established to oversee regional geologic studies of summit area.
		Moratorium on new construction in "areas of critical concern" extended to November 1990.
1990	January	Summit homeowners "angrily demand that they be allowed to make necessary repairs at their own risk." (Santa Cruz Sentinel, January 9, 1990)
		FEMA-funded Earthquake Recovery Division opens.
		Geologic hazards ordinance amended to permit repairs and rebuilding pending geologic studies, if owners sign waivers.
	August	Board of Supervisors orders review of procedures. Supervisor Keely states, "The abundance of caution has instead become an impediment. There is this obsession with the geology that does not seem to be borne out by the facts." (Santa Cruz Sentinel, August 29, 1990)
	September	Geologic Hazards Ordinance amended to exempt repair applications from geologic study requirements when the repairs cost less than 50 percent of the value of the structure.
	December	Summit homeowners file class action lawsuit protesting waivers.
1991	January	County staff resumes issuing building permits for earthquake repairs and rebuilding. Fees reinstated.
	February	Draft TAG report released with tentative conclusions.
	June	Public hearing held on a preliminary map of cracks in the summit area.
	July	Earthquake Recovery Division disbanded after processing more than 7,600 permits.
		Moratorium on new construction in "areas of critical concern" expires.
	August	Preliminary geologic study report indicates no significant hazard to life from geologic instability in summit area.
	September	Waiver requirements and procedures for rebuilding in "areas of critical concern" eased.

is located by the U.S. Army Corps of Engineers or the County. By such declaration the permittee shall expressly agree that the issuance of said permit shall not preclude the County of Santa Cruz or any other agency from determining in the future that the property which is the subject of said permit, or any structure or improvement thereon, is unsafe to occupy and requires repair, vacation, demolition, or abatement. The permittee shall further agree by said Declaration to waive any claim against the County for any losses to any improvements authorized by said permit which are later duly ordered demolished or abated.

These new provisions opened the door for repairs and rebuilding in the most hazardous areas, but owners were still required to submit geologic or geotechnical reports evaluating site-specific conditions not requiring long-term monitoring. The January 1990 ordinance did not affect new construction, and the approximately 500 vacant parcels in the areas of critical concern remained under the building moratorium established the previous November (County of Santa Cruz, 1989).

The County planning staff had recommended against the new waiver provisions, arguing that they would expose people and property to significant risks. The staff felt that the waiver

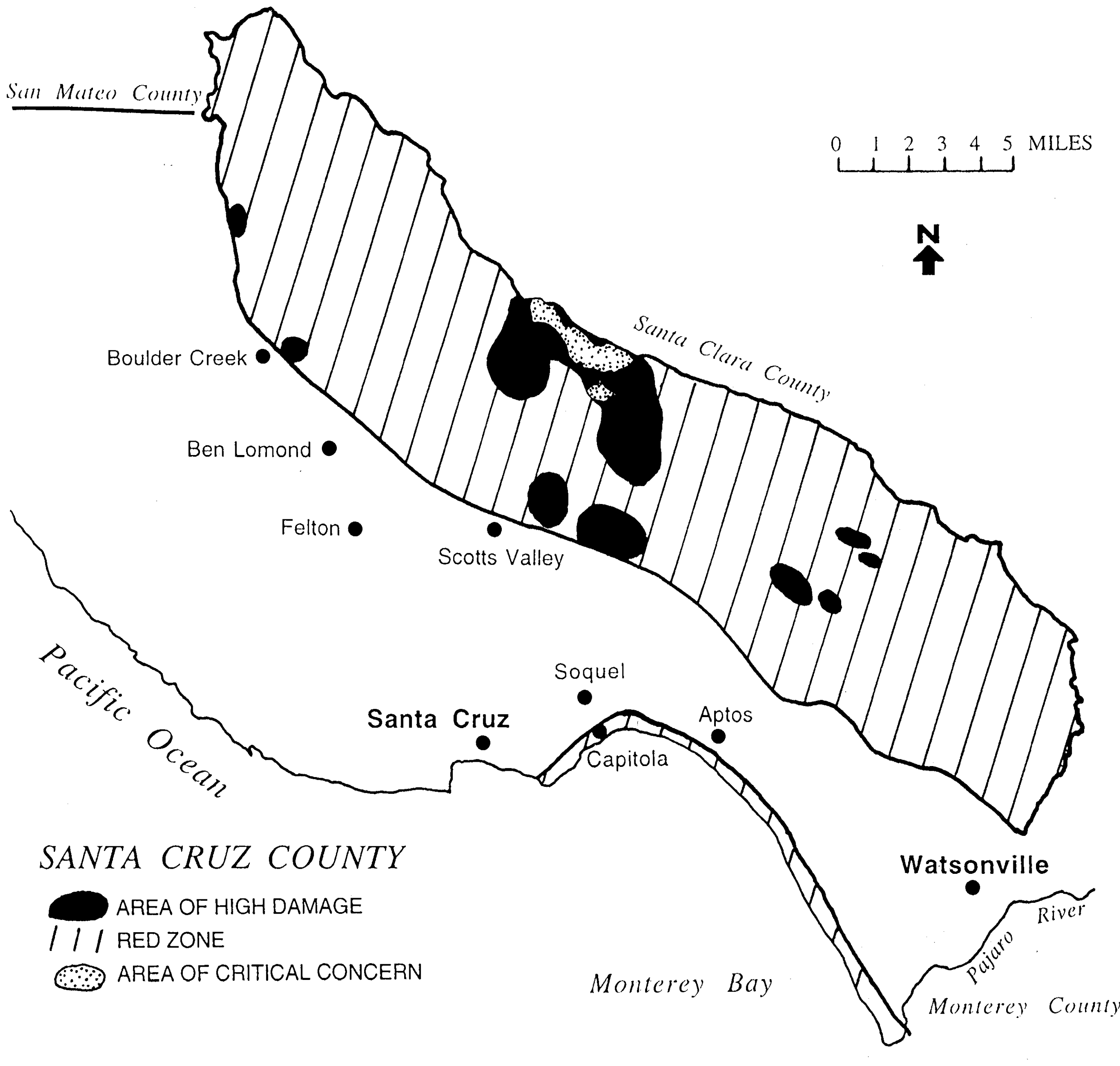

Figure 4.—Map prepared by informal consortium of Federal, State, County, and private geologists in the first week after the Loma Prieta earthquake, showing the "red zone" (encompassing the areas of considerable damage and ground failure), areas of high damage, and the "areas of critical concern" (where the greatest indications of ground failure were found).

procedure required making judgments about geologic safety without full geologic information. However, the Board was under strong pressure from owners of damaged property and considered the waiver provisions a responsible compromise.

These changes did not, however, satisfy property owners in the summit area, who continued to press for more relief from the the geologic report requirements. In September 1990, the Board once again amended the Geologic Hazards Ordinance. This time, the definition of a project subject to the geologic study requirements was changed to exempt repairs and improvements costing less than 50 percent of the value of the structure. This change allowed many repair projects in the area of critical concern to proceed without any geologic review. Property owners were still required to sign waivers holding the County harmless in the event of future damage or of County decisions affecting the use of the property.

The system of requiring geologic reports for major projects and waivers for almost all projects continued until the fall of 1991. Because the regional geologic studies were still ongoing and a rainy season passed without significant rainfall, property owners continued to find it almost impossible to obtain conclusive geologic reports and get financing for major repairs and rebuilding. Financial institutions did not like the waivers, particularly the one permitting the Planning Department to later order demolition of buildings found to be unsafe without compensation to owners. More than 100 summit area property owners joined in a class action lawsuit to overturn this waiver requirement.

In September 1991, after preliminary results from the regional studies indicated that there was little threat to life from geologic hazards in the summit area, the Board of Supervisors further relaxed the rebuilding requirements and took steps to streamline the procedures for obtaining permits. The provision of the January 1990 Ordinance (Ordinance 4048) giving the County unrestricted power to order demolitions was rescinded, responding to a major objection by property owners. Time limits were set for the official review of permit applications and for responding to geologic reports. Channels of communications, particularly with applicants' geologists, were simplified.

During all this time, little actual rebuilding had taken place in the summit area. Ordinance 4031, which the Board of Supervisors had adopted in November 1989, established a 45-day moratorium on new development in the areas of critical concern (County of Santa Cruz, 1989). This moratorium was periodically renewed until July 31, 1991, when it was allowed to expire. At that time, Planning Director Dianne Guzman noted that "existing procedures for geologic review and in-

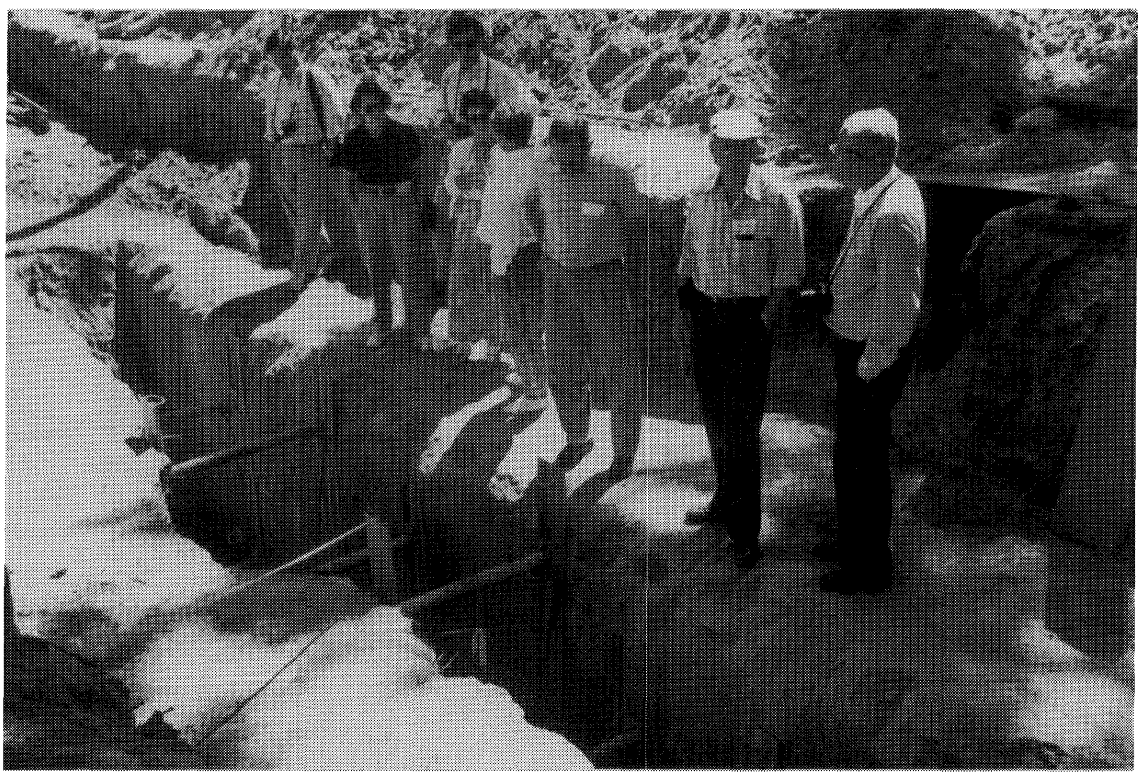

Figure 5.—Geologic trenching in area of ground cracking, near Summit Road, Santa Cruz Mountains, viewed here by participants at the International Symposium on Rebuilding After Earthquakes, Stanford University, August 1990.

formation from the upcoming TAG report provide sufficient assurance that new building will be appropriately regu-lated to avoid the consequences of geologic hazards" (quoted in the Santa Cruz Sentinel, July 31, 1991).

ADMINISTRATION OF REBUILDING

After the earthquake, very complex policy issues regarding rebuilding demanded time and attention from both County staff and the Board of Supervisors. These demands occurred at a time when the normal administrative demands also increased dramatically.

Less than a week after the earthquake, County planning and building offices reopened. However, they accepted applications for building permits only for repair of earthquake damage; no other permit applications were accepted. The staff estimated that earthquake damage would lead to 4,000 permit applications requiring about 48,000 hours of staff time to process. The County therefore proposed, and FEMA agreed to fund, the hiring of a private consultant, Wildan Associates, to handle all building permit applications for repairing earthquake damage (oral communications from Pete Parkinson, Santa Cruz County Planning Department, June 1990).

The Earthquake Recovery Division (ERD), staffed by Wildan and funded by FEMA, opened in January 1990 in a separate building across the street from the County building. It operated with a staff of 22, including 7 inspectors, 4 code enforcement officers, 4 plan checkers, 4 plan intake persons, and 3 clerks (oral communication from Glen Parrot, head of ERD, June 1990). Wildan assembled the staff from around the State and also contracted with a geotechnical firm to review permit applications and geologic reports. County staff familiar with building inspection, demolitions, environmental planning, and planning were assigned to the ERD to ensure coordination with regular County operations. The County staff then resumed processing applications for permits not related to earthquake damage.

In March 1990, five months after the earthquake, the ERD was still processing more than 100 building permits and conducting more than 300 inspections per week (Glen Parrot, oral communication, June 1990). Because ERD staff expenses were covered by FEMA, the normal building permit fees were waived. In January 1991, regular County staff took over the processing of permit applications for earthquake repairs and rebuilding, and the building permit fees were reinstated, but with a six-month grace period of free inspections on projects already in the system. The ERD continued conducting inspections until July 1991, when it was disbanded altogether. At that time, about 3,000 repair applications were still in the process. During the 18 months of its operation, the ERD had processed more than 7,600 permits and made thousands of inspections. Federal reimbursements for the effort exceeded $7 million.

Wildan personnel contend that geologic review was the most difficult and time-consuming part of the permitting process. They established an objective of processing all permits within 4 to 5 days, but they were not able to do so in cases requiring geologic review. Most of the complaints about the process from applicants centered on the time and expense needed to meet the geologic requirements (oral communications from Kevin Powers of Wildan Associates and Glen Parrot, head of ERD, June 1990).

CONCLUSIONS

Role of County Planning Staff.—The Santa Cruz County planning staff consistently held to the position that repairs and rebuilding in the areas of critical concern should not occur until geologic studies were completed. When studies showed less risk than originally feared, staff recommended easing restrictions. Although opponents of the staff position suggested that "no growth" politics influenced the position, we found no confirming evidence. Nor did concerns about either liability or "taking" of property by the County without compensation appear to have been major factors. As far as could be judged from various articles and discussions published in the Santa Cruz Sentinel during the period 1989-1991, the position seems to have stemmed almost entirely from the staff's concept of their role in protecting public safety.

Role of the Board of Supervisors.—The Board of Supervisors, more subject to pressure from constituents, compromised by permitting some repair and rebuilding on the condition that homeowners signed waivers. This was ultimately ineffective, because lending institutions were reluctant to lend money with the waivers in place. Eventually the waivers, created originally to give an additional option to homeowners, became the focus of opposition.

The Role of FEMA.—After the earthquake, FEMA quickly authorized funds for a regional geologic study to evaluate potential ground failure problems. When such problems clearly transcend individual property boundaries, there is strong need for area-wide studies to establish the conditions for safe rebuilding. Not since the Alaska earthquake in 1964 has the Federal Government been involved in hazard evaluations after a disaster as extensive and complex as those following the Loma Prieta earthquake. FEMA procedures for dealing with ground failures, however, are ad hoc. There is a need for a consistent policy that supports the local government in upholding public safety.

Role of Owners of Damaged Homes.—At the political level, the summit-area homeowners maintained a single, consistent position. They wanted to repair and rebuild their houses and restore normalcy to their lives. For most homeowners, their home is their largest investment. They stand to lose everything if their property is declared unsafe. In Santa Cruz County, summit-area residents brought anger and deep emotion to the political process. Arguments for safety did not seem relevant to them. Staff and political decisionmakers, charged with protecting public safety, were placed in an adversarial position to those they were trying to help. In fact, planners and geologists, not the geologic hazards, were seen by many property owners as the problem.

Mapping Ground Failures.—The experience in the Santa Cruz Mountains and in Anchorage after the 1964 Alaska earthquake demonstrates the value of rapid delineation of areas encompassing ground failures and potential ground failures, coupled with imposition of tight rebuilding restrictions in those areas. These measures allow rebuilding to proceed unimpeded in areas without potential hazards while pinpointing areas where additional studies are needed. As new information is developed, the areas of concern tend to be reduced and rebuilding restrictions can be eased. Given typical postdisaster politics, it is almost impossible to tighten restrictions as time passes after the disaster.

Geologic Studies.—No earthquake victim wishes to wait a year or two for geologic studies to be completed before knowing if a home or other structure can be rebuilt. In reality, however, such studies may take a long time. Also, the results of even the most exhaustive studies are often not as conclusive as many would like. Qualified professionals can often differ on interpretations of geologic phenomena. It is very important to protect the integrity of the study process, while at the same time keeping it open enough that affected property owners and jurisdictions know what is being done. Professionals need more guidance in how to work out scientific and technical differences successfully in highly charged political contexts.

Acceptable Risk.—Acceptable risk is not an abstraction. It is readily discerned from the pattern of public decisions. Santa Cruz County appears to be willing to accept the risk of property damage from slow-moving ground failure, but not risk to human life. Additionally, owners are more likely to be allowed to assume risks if their structures have minor damage than if they have major damage. People with existing houses in the summit area are generally permitted to accept more risk than those planning to build new houses in the area. Thus, although the general nature of acceptable risk is discernible, it is not necessarily a rational pattern.

Waivers.—Waivers do not solve the problem of rebuilding in potentially unsafe areas. Although property owners may volunteer to assume liability so that their projects can move ahead, elected officials must look at public health and safety, potential liability for damage, and possible loss of public improvements serving private uses in unsafe locations. Financial institutions seem increasingly wary of making loans secured by property encumbered with waivers. In the end, a waiver does nothing to address the potential for future ground failures. In Santa Cruz County, the waiver provisions originally sought by the owners were soon considered to be as onerous as the geologic study requirements.

Building Permits.—Practically all cities and counties are hard pressed to keep current with the normal processing of building permits. After an earthquake, when emergency repairs, major repairs, and reconstruction must be handled, the load can be more than doubled. This puts a stress on staff and requires difficult decisions in setting priorities and obtaining outside assistance. Santa Cruz County, with Federal assistance, engaged a private firm to take over processing of building permits related to the earthquake. This action separated the permit process for earthquake repairs and rebuilding from the normal permit process. Controversy centered on the relatively few cases in which uncertainty about geologic stability held up the granting of permits. Otherwise, the process was efficient, paving the way for the repair and rebuilding of earthquake-damaged structures throughout most of the County.

Suggestions for Responding to Future Earthquakes.—The key to improving response to ground-failure hazards after an earthquake seems to lie in preplanning for the comprehensive geologic studies that will be required. This would involve clearly defining the responsibilities of Federal, State, and local agencies, as well as those of the property owners. Procedures for handling the increased load of building permit applications can also be worked out in advance.

ACKNOWLEDGMENTS

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RECOVERY, MITIGATION, AND RECONSTRUCTION

THE RESPONSE OF THE STATE OF CALIFORNIA TO THE LOMA PRIETA EARTHQUAKE

By Charles C. Thiel Jr., Stanford University
George W. Housner, California Institute of Technology, *and*
L. Thomas Tobin, California Seismic Safety Commission

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ABSTRACT

A Board of Inquiry was appointed by the Governor of California to investigate the damage caused by the 1989 Loma Prieta earthquake, particularly to bridges and freeway structures. The Governor wanted to know not only what happened, but how to prevent such destruction in the future. The Board identified three essential challenges that must be met by the citizens of California, if they expect a future adequately safe from earthquakes: (1) ensure that earthquake risks posed by new construction are acceptable; (2) identify and correct unacceptable seismic safety conditions in existing structures; and (3) develop and implement programs that will foster rapid, effective, and economic response to and recovery from future damaging earthquakes. The Governor issued an Executive Order to implement the principal Board recommendations that all State-owned and State-operated structures are to be seismically safe and that important structures are to maintain their function after earthquakes. The California Seismic Safety Commission was directed to evaluate the response of State agencies to the Order. They found performance to be generally good, though variable. Inadequate funding is the most serious and most difficult problem for the agencies to address internally; also difficult are legislative capital budgeting processes that are cumbersome. Agencies were encouraged to make individual administrators responsible for seismic safety to ensure management accountability, in place of the generally diffuse responsibility now found in most agen-

cies. The Board, Governor, and Commission all concluded that while much progress had been made during the previous two decades in reducing earthquake risks, much more awaits doing. More aggressive efforts to mitigate the consequences of inevitable future earthquakes are needed if one of the most fundamental of responsibilities of government is to be fulfilled—to provide for the public safety. The Loma Prieta earthquake should be considered a clear and powerful warning to the people of California. Earthquakes respect our actions, not our intentions.

INTRODUCTION

The Governor of California signed an Executive Order on June 2, 1990, that may prove to be the most significant step to improve seismic safety taken by the State in the last several decades. Executive Order 86-90 for the first time sets the policy that all State-owned and State-operated structures are to be seismically safe and that important structures are to maintain their function after earthquakes. This is a marked departure from responses to past earthquakes, where actions tended to focus on the type of facility that failed. The full text of the Executive Order is reproduced in the appendix. The Order was a direct consequence of the recommendations and findings contained in the report of the Board of Inquiry on the Loma Prieta Earthquake of 1989 (Housner and others, 1990).

The language of the Executive Order is simple and direct. The Governor required the Department of Transportation in particular, and all other California State agencies in general, to use generally accepted earthquake resistant codes and to seek external evaluations of compliance. The effect of external scrutiny should not be underestimated as a tool to obtain better seismic design and construction. Early indications were that implementation of this Executive Order would substantially improve the seismic resistance of transportation structures and State buildings. The Order also directed the Seismic Safety Commission to review actions by State agencies in response to the directions of the Order and to report to the Governor on their actions. The Commission issued its report to the Governor on agency response on November 30, 1990. The Commission found agency actions to be generally positive, but with substantial differences in approach among them (Seismic Safety Commission, 1990).

This paper is divided into two parts. The first part reviews the findings and recommendations of the Board of Inquiry; the second presents the Seismic Safety Commission's review of the actions taken by the State agencies in response to the Governor's Executive Order 86-90. This paper integrates materials presented in Housner and Thiel (1990) and Thiel and others (1991). It represents actions that had been taken through 1990. In the intervening period much has been done. Caltrans has undertaken a massive, publicly financed program to retrofit many bridges. The more substantial of these investments, particularly for the San Francisco-Oakland (Bay Bridge) and Golden Gate toll bridges, is currently being debated (1996).

THE BOARD OF INQUIRY ON THE LOMA PRIETA EARTHQUAKE

In November 1989 Governor George Deukmejian of California appointed an independent Board of Inquiry to report on the October 17, 1989, Loma Prieta earthquake. The Board consisted of George W. Housner, Chairman, Joseph Penzien, Vice Chairman, Mihran S. Agbabian, Christopher Arnold, Lemoine V. Dickerson, Jr., Eric Elsesser, I. M. Idriss, Paul C. Jennings, Walter Podolney, Jr., Alexander C. Scordelis, and Robert E. Wallace. John F. Hall served as Technical Secretary, and Ben Williams served as administrative officer in support of the Board; Charles C. Thiel, Jr., served as the technical writer and editor of the Board's report. The formation of the Board of Inquiry was prompted by earthquake damage to bridges and freeway structures and by the desire to know not only what happened, but how to prevent such destruction in future earthquakes. The Governor charged the Board with reporting on the causes of damage and what implications these findings might have on the California highway system (Deukmejian, 1989).

The Board gathered its information from presentations by State Department of Transportation (Caltrans) employees and independent experts in seismology, structural engineering, geotechnical engineering, and other disciplines. Most of the information was presented at public hearings held in Sacramento, the San Francisco Bay Area, and Southern California. Testimony was also invited from the public. Reports and written information were sent directly to Board members for their review. The Board held seven public meetings between November 1989 and March 1990 at which 70 individuals provided testimony. Board members also toured the collapsed Cypress Viaduct structure in Oakland and several of the damaged San Francisco viaduct structures.

EARTHQUAKE-CAUSED DAMAGE TO TRANSPORTATION STRUCTURES

The Loma Prieta earthquake in October 1989 occurred near three large modern cities in central California—San Jose, San Francisco and Oakland. Thirteen State-owned and five locally-owned bridges were closed to traffic following the earthquake, very small numbers considering that there are over 4,000 bridges in the area. Forty-one people died in the collapsed Cypress structure, and one died on the San Francisco-Oakland Bay Bridge in an automobile accident moments after the earthquake. The cost of the earthquake to the transportation system was estimated at $1.8 billion, of which damage to State-owned viaducts totaled about $200 million and damage to other State-owned bridges was about $100 million.

The impacts of the earthquake were much more, however, than the loss of life and direct damage. The Bay Bridge is the principal transportation link between San Francisco and the East Bay (see fig. 1). It was out of service for a month, and use of alternative routes caused substantial hardship to individuals and businesses.

Only a small percentage of the bridges in the area sustained any earthquake damage at all. Most of the bridges damaged in this earthquake were built before construction standards were stiffened in the 1970's to reflect lessons learned in the 1971 San Fernando earthquake. The greatest damage during the Loma Prieta earthquake occurred to older bridge structures sited on soft ground.

Throughout California, Caltrans currently maintains 11,287 highway and pedestrian bridges with spans greater than 20 ft, a number almost identical to the 11,229 bridges maintained by California local governments in the State. Caltrans District 4, whose jurisdiction approximates the area of greatest earthquake damage, is responsible for 1,896 State bridges, of which 91 (4.8 percent) incurred some degree of damage (mostly minor) during the earthquake. At only 13 bridges was structural damage or the potential threat to public safety sufficiently serious that they were closed to traffic for some period of time.

The most tragic impact of the earthquake was the loss of life caused by the collapse of the Cypress Viaduct. The greatest disruption was caused by the closure of the Bay Bridge for a month while it was repaired, leading to costly commuting alternatives and significant economic losses. In addition, some of the steel rocker bearings supporting the navigator spans of the San Mateo-Hayward Bridge failed, but the bridge remained open. This could have led to catastrophic damage if earthquake shaking had been longer or more intense.

On the other hand, only minor damage was incurred by the Golden Gate Bridge, which is founded on rock, and by the BART trans-Bay tube, which was specially engineered in the late 1960's to withstand earthquakes. A post-earthquake inspection of the Dumbarton Bridge, built during the 1980's

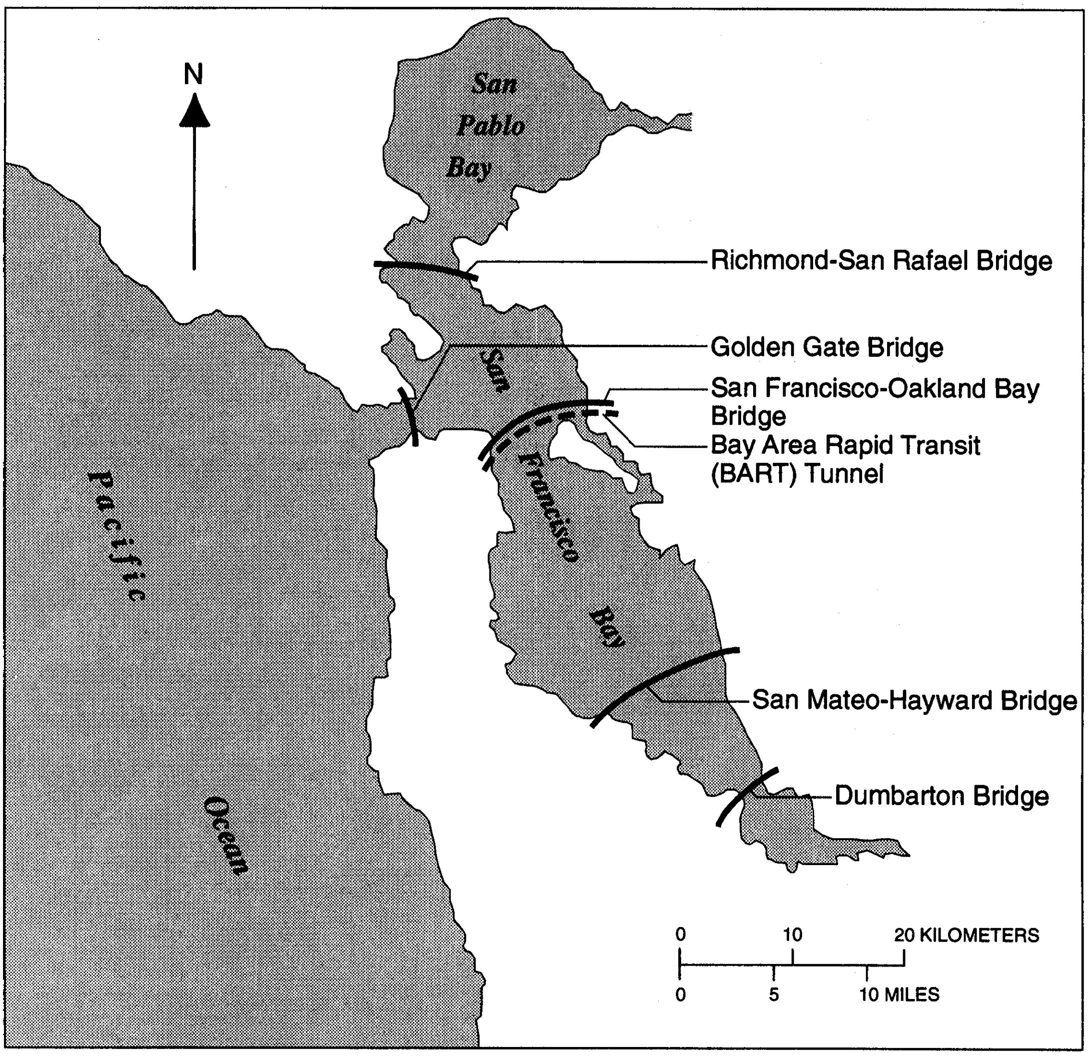

Figure 1.—Principal transportation links across San Francisco Bay.

with earthquake design criteria in mind, revealed no structural damage.

Bridges maintained by local governments also incurred damage, though for none was it as catastrophic as for some of the Caltrans structures. A partial survey by Board of Inquiry staff found that at least 43 locally maintained structures in the area were damaged, of which at least 5 were closed to traffic for some period of time, but none collapsed. Reports from post-earthquake reconnaissance teams indicated that most local bridges performed remarkably well.

DAMAGE TO THE BAY BRIDGE

Design of the San Francisco-Oakland Bay Bridge was completed in 1933, and construction was finished in 1936. It consists of two sections—a West Bay crossing from San Francisco to Yerba Buena Island and an East Bay crossing from Yerba Buena Island to Oakland. The total distance along the alignment from the San Francisco anchor of the West Bay crossing to the easternmost Pier E39 of the East Bay crossing is 4.35 mi. The bridge is of double-decker design, with the upper deck carrying five lanes of traffic in the westerly direction and the lower deck carrying five lanes of traffic in the easterly direction. The lower deck had been originally designed for trains.

The West Bay crossing consists of two suspension structures. Its total length is 1.95 mi. Both anchorages and the main supporting piers are founded on rock. The East Bay crossing consists of 4 shallow simple-span trusses on Yerba Buena Island, 1 long cantilever truss structure, 5 deep simple-span trusses, 14 shallow simple-span trusses, and a number of simple-span deck systems that use steel and concrete stringers supported on concrete bents (transverse supporting frames). The total length of the East Bay crossing is 2.14 mi. The Bay Bridge was designed for earthquake accelerations of $0.1g$ (g is the acceleration due to gravity), comparable to the levels specified in the 1930 Uniform Building Code for buildings. Knowledge of actual ground motions in damaging earthquakes was very limited at that time; the first few measurements of strong ground motions were not made until the 1933 Long Beach earthquake. In the 1970's some seismic strengthening of the Bay Bridge had been done through the installation of cable restrainers.

The principal earthquake damage to the Bay Bridge was the failure of the upper and lower closure spans at Pier E9 of the east Bay crossing. These 50-foot-long upper and lower closure spans fell when the bolts failed that connected the pier to the 290-ft truss to the east (fig. 2). Bolts at connections of Piers E18-E23 also failed. The span at Pier E23, close to the eastern edge of the bridge, was near failure of a comparable type to that of E9. The concrete pedestal bases of Pier E17 cracked when the pier rocked back and forth and incurred some damage at the corners. The Bridge was closed for one month for repair.

The closure spans linking the two long-span trusses on either side of Pier E9 were supported on 5 in of bearing on seat-type expansion joints 6 in wide at the west end and by bolted connections at the east end. When the truss to the east broke free from its support, the closure spans were pulled with it, and the motions were large enough to slide them off the 5-in seats at the west end. As a result, the spans hinged down under gravity load, with the upper span coming down on the lower one, which hit an electrical housing before coming to rest on the west truss connection to the pier.

The level of ground shaking at the bridge site in the Loma Prieta earthquake was both of smaller intensity and shorter duration than that which can be expected in larger and closer earthquakes. Moreover, the duration was not sufficient to excite all the different modes of the Bay Bridge's response that are likely in a longer duration event, nor was the level of shaking sufficiently close to that expected in major earthquakes to test the strength of bridge elements.

THE CYPRESS VIADUCT COLLAPSE

The Cypress Viaduct was California's first continuous double-decker freeway structure, a design used again for several freeway viaducts in San Francisco, but not used anywhere else in the State. Each deck of the Viaduct carried four lanes of traffic. During the magnitude 7.0 Loma Prieta earthquake, a large portion of the Cypress Viaduct collapsed (fig. 3). This collapse, which took the lives of 41 people, was the most tragic consequence of the earthquake. Search and rescue operations continued for a week. Fortunately, traffic at the time of the earthquake was very light compared to the normal density for the middle of rush hour, because the televised third game of the World Series at Candlestick Park between the two local baseball teams had just started. Caltrans demolished and removed the standing portions of the structure and resurfaced the frontage roads within three months.

Preliminary design of the Cypress Viaduct was began in 1949 by Caltrans, and construction was undertaken between 1954 and 1957, during a period when little was known about

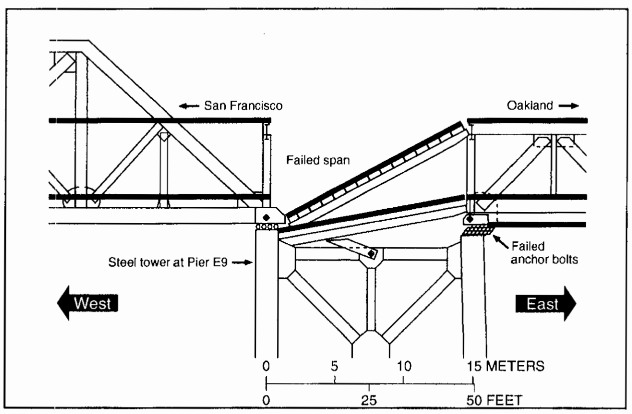

Figure 2.—Failure of the San Francisco-Oakland Bay Bridge in the Loma Prieta earthquake. The upper and lower closure spans at Pier E9 fell when the bolts attaching the east truss-span were severed and it moved to the east, pulling the link spans off their western supports.

seismic design of reinforced concrete structures. It was one of the earliest uses of prestressed concrete in U.S. bridges. More significantly, the Cypress Viaduct was designed before research had developed procedures for achieving ductility in overstressed structural members; the columns and joints therefore failed in a brittle manner when overloaded. The Caltrans seismic design criteria in effect during 1949 to 1954, which had been introduced in 1943, stipulated only a seismic strength coefficient of 0.06*g*.

The Cypress Viaduct was a reinforced concrete structure with some prestressing and two levels of elevated roadway. The box-girder roadway was supported by a series of 83 two-story bents. Forty-eight of these bents collapsed in the Loma Prieta earthquake—bents number 63 through 112, with the exception of Bents 96 and 97, which remained standing (the middle portion of fig. 3). A number of the bents had post-tensioned concrete transverse girders at the top level. The Cypress design did not incorporate ductility, since this was not common until the 1970's. Longitudinal cable restrainers were installed in 1977 at all transverse joints in the box-girder bridge superstructure to provide continuity. The northern two-thirds of the Cypress Viaduct, the major portion that collapsed, was founded on about 7 ft of dense to stiff artificial fill overlying a preexisting triangular tidal marsh composed of soft bay mud and old slough channels that parallel the west side of the viaduct structure.

Failure occurred in the lower girder-to-column joints on both sides of a bent; the initial failure was in the short column stub above the top of the lower deck and below the shear key (fig. 4). The upper girder-to-column joint sometimes failed completely or was severely cracked. Almost all the damage in this upper joint, however, seems to have been produced as a result of the collapse of the upper deck onto the lower deck.

Static and dynamic analyses and experiments performed on standing portions of the Cypress structure indicate that the calculated seismic demands on the structure during the Loma Prieta earthquake exceeded the level required to initiate failure in this nonductile structure.

SAN FRANCISCO FREEWAY VIADUCTS

The Loma Prieta earthquake caused only minor to moderate shaking at the San Francisco freeway viaduct sites. These viaducts (Embarcadero Freeway, Terminal Separation Viaduct, Central Viaduct, China Basin Viaduct, Southern Freeway Viaduct, and Alemany Viaduct; see fig. 5) were all built with the same technology used for the Cypress Viaduct and these were the only structures in the State of this design. With the exception of the Alemany Viaduct, all the San Francisco viaducts were damaged during the earthquake and subsequently closed to traffic. A contributing fact to their earthquake performance for some may be their location on filled ground or at the transition between natural and filled ground.

The San Francisco freeway viaducts are composed of single-column and multicolumn bents, typically with two tiers of framing (rarely three) supporting two levels of roadway. The transverse lateral-load-resisting system in the multicolumn bents typically consists of pinned-base single-story portal frames with one or more columns cantilevering to the upper level bent cap (girder). The reinforcement in the columns and girders of the bents was generally poorly detailed by current standards and reflects the engineering profession's lack of understanding regarding the inelastic response of reinforced concrete members at the time when these structures were designed. None of the six freeway structures had a planar lateral-load-resisting system in the longitudinal direction. A lack of redundancy and the inadequate reinforcement detailing are two of the major seismic deficiencies in these freeway structures.

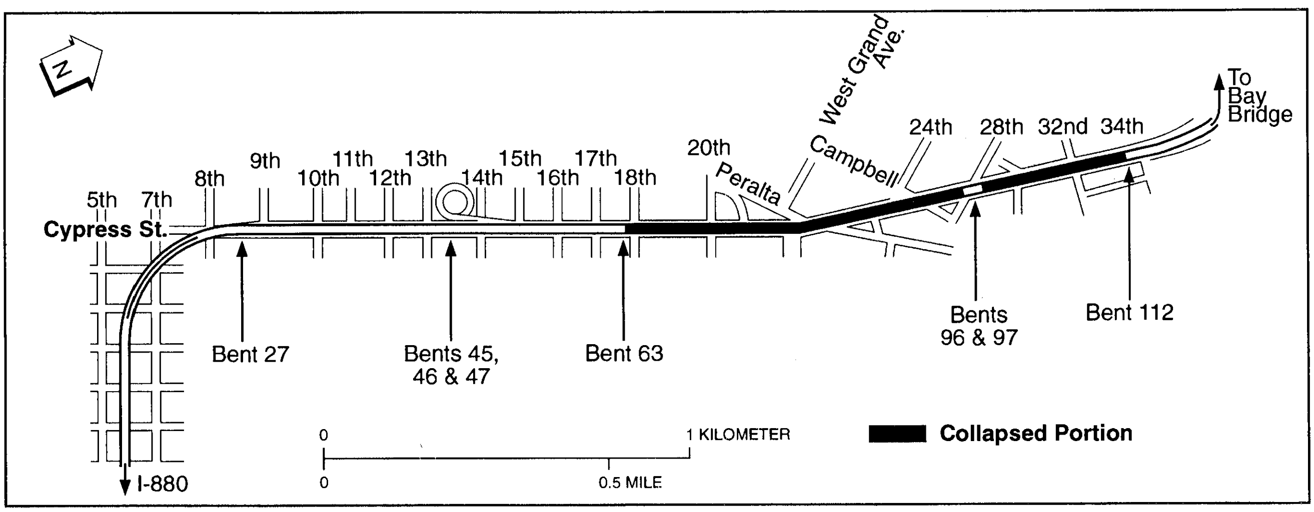

Figure 3.—The Cypress Viaduct double-decker freeway on Interstate 880 in Oakland, California, showing the extent of the collapse in the Loma Prieta earthquake. Location of selected bents (transverse frame elements) in the structure are shown for reference. Also identified are some of the roads and numbered streets in the part of Oakland traversed by the structure.

Damage to the individual viaducts in San Francisco varied and included shear cracking in columns, girders, and joints; torsional cracking in outrigger bents; anchorage failure of the girder reinforcement; and shear key failure, among others. Many of the crack patterns are similar to those observed in the collapsed and damaged portions of the Cypress Viaduct in Oakland.

After the Loma Prieta earthquake, Caltrans retained six consultants to prepare contract documents for the upgrading of the six San Francisco viaducts. The criteria set by Caltrans for the development of the upgrading schemes included requirements for the analysis of the freeway structures' design and detailing requirements. The damage criterion accepted serious damage, but not collapse, during severe earthquake shaking. These designs were later reviewed by a Caltrans-appointed independent review panel, at the suggestion of the Board of Inquiry.

COLLAPSE OF THE STRUVE SLOUGH BRIDGE

The Struve Slough Bridge is located on California Highway 1 along the Pacific Coast between Watsonville and Santa Cruz. It consists of side-by-side structures constructed in 1964; one structure carried northbound and the other southbound traffic. These structures are about 800 ft long and 34 ft wide and have spans of 37 ft. As was typical for structures at this time, they were built of a reinforced concrete T-beam construction supported on pile bents. There were three expansion joints in the deck of each structure, effectively dividing the length of each into four segments. Seismic retrofitting, completed in 1984, consisted of the addition of cable restrainers at each expansion joint.

These structures were supported by 22 pile bents along their length and by monolithic diaphragm abutments at the ends. Each bent consisted of four driven piles, approximately 80 ft long, which were driven to full length. Each pile was then extended by reinforced concrete columns to the underside of the superstructure into transverse cap beams. The pile extensions were lightly confined with wire.

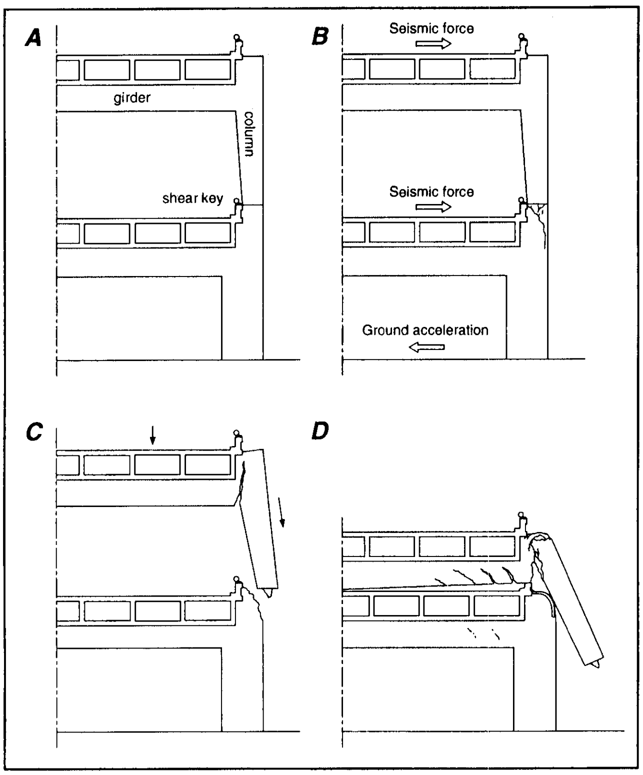

Figure 4.—Typical failure sequence of the common style of bent (B1) in the Cypress Viaduct in the Loma Prieta earthquake (see fig. 3). *A*, Bent before failure. *B*, Failure was initiated along a crack forming a plane of weakness in the joint region. Gravity and seismic forces then pushed the upper column down and away from the joint (*C*), resulting in the collapse of the upper deck (*D*), After Nims and others (1989). Of the 48 collapsed bents, 41 failed in this way.

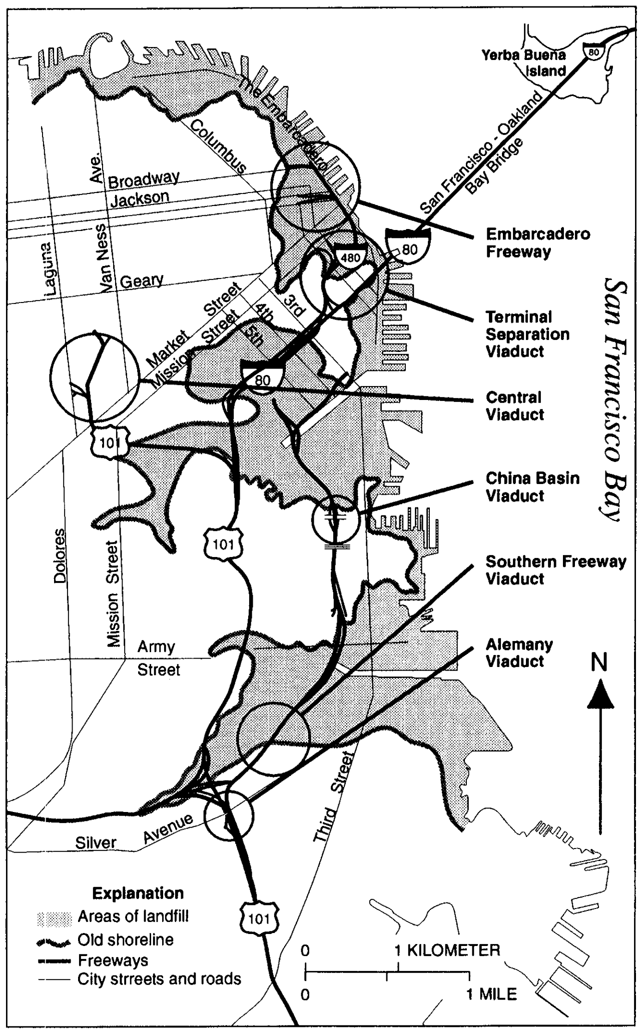

Figure 5.—Location of the freeway viaducts in San Francisco. All but the Alemany Viaduct were damaged in the Loma Prieta earthquake.

During the earthquake, extremely strong shaking led to the collapse of the center two segments of each structure. Pile extension columns within these segments suffered severe cracking, buckling of longitudinal reinforcing, and fracture of the lateral confining reinforcement. Most of the columns sheared off at the interface with the underside of the transverse cap beams, immediately beneath the road deck. Seven spans of the northbound structure collapsed and dropped approximately 5 ft onto the damaged pile extension columns. Ten spans of the southbound structure collapsed and dropped 8 to 10 ft to the ground surface. A few pile extension columns, sheared at the transverse cap beams, displaced and punched through the deck slab as the structure fell to the ground. Although the collapse was generally in the downward direction, the southbound structure displaced approximately 2 ft to the side. Apparently, some piles also failed below the ground surface. Soil displacements at the ground surface around the piles in several directions reached a maximum of 18 in at several piles. The approach fills settled approximately 3 in.

The Struve Slough Bridge showed little evidence of significant seismic forces reaching the superstructure above the abutments. There was no indication of horizontal movement at the abutments or of hammering at the expansion joints. Despite the significant displacements experienced by the road deck from the failure of the supporting piles, the cable restrainers performed well and held the deck together during these displacements.

The primary cause of collapse is attributed to a lack of adequate concrete confinement and shear reinforcing at the top of the columns. Current practice and standards would require ductile detailing of these members, which would have led to substantially better seismic performance.

IMPACTS ON CROSS-BAY TRANSPORTATION

San Francisco Bay stretches about 65 mi from Alviso in the south to its northern boundary at the Richmond-San Rafael bridge. The stretch of water beyond this bridge is San Pablo Bay, ending at the Carquinez Bridge near Vallejo. Besides the Richmond-San Rafael Bridge, San Francisco Bay is crossed by three other bridges: the San Francisco-Oakland Bay Bridge, the San Mateo Bridge, and the Dumbarton Bridge (see figure 1). The Bay exits to the Pacific Ocean under a fifth bridge, the Golden Gate Bridge. In addition, the Bay is traversed by the Bay Area Rapid Transit (BART) trans-Bay tube between Oakland and San Francisco (fig. 1). The Carquinez Bridge crosses San Pablo Bay, and the Antioch and Benicia-Martinez Bridges cross the Sacramento River, which empties into San Pablo Bay to the east of the Carquenez Bridge. These Sacramento crossings provide alternative routes across to the north side of San Pablo Bay.

The importance of integrating the Bay Area by bridging the water barrier between San Francisco and its neighbors was recognized early in the century. In 1912 the engineer John Freeman predicted that the population of the Bay counties would reach 2 million within 40 years, and that towards the end of the century a population of 3 million might be reached, depending upon "the wisdom and vigor with which San Franciscans seize their opportunity" (Scott 1985). By 1980 the San Francisco Bay counties had a population of 4.29 million, and their population is expected to increase to 5.24 million by the year 2005 (Diridon, 1988.)

The San Francisco Bay crossings form a crucial part of the entire Bay Area transportation network. In the Bay Area counties, about 20 percent of the workers are employed outside their county of residence. It is estimated that this percentage will grow to almost 25 percent by the year 2005. At the same time, automobile ownership in the area is expected to rise from 3.3 million autos in 1990 to 5.1 million in the year 2005 (Diridon, 1988). Hence the Bay Area highway network will continue to be crucial to the economy, but its maintenance as a swift and convenient means of travel will become increasingly difficult.

Before the Loma Prieta earthquake, the five San Francisco Bay bridges together carried an average of 517,000 vehicles per weekday, and an average of 108,000 passengers rode on the BART trans-Bay tube and the ferries per weekday. The distribution of this traffic flow before and after the quake are given in table 1. Two facts stand out from these figures: the importance of the Oakland-San Francisco link; and the volume of traffic normally borne by the San Francisco-Oakland Bay Bridge (approximately equal to the combined traffic carried by all four other bridges). For automobile traffic, the Golden Gate and Bay Bridges are essentially non-redundant systems; alternative routes via the other bridges are extremely time consuming. In contrast to freeways, which are typically superimposed over an existing (if inadequate) road pattern, which is still available if a section of freeway is closed, the cross-Bay bridges have no satisfactory alternative.

When the Loma Prieta earthquake damaged the Bay Bridge, causing immediate closure of the most widely used cross-Bay route for an indeterminate period, Bay Area traffic patterns were forced to change. Although there is an apparent change in cross-Bay total traffic, this is mostly a result of the fact that BART and the ferries count individual fares while the bridges count vehicles.

The critical role played by the BART trans-Bay tube in cross-Bay transportation is clear from the figures in table 1, as is the fact that the South Bay bridges (San Mateo and Dumbarton) accommodated much of the redistribution of vehicular traffic. While ferry service more than tripled, from 6,250 to 21,057 passengers, the number of people carried was still well below that of automobiles and the BART system. Total vehicles over the available bridges dropped from 517,370 to 407,080 during the closure period. Many people apparently used BART or simply curtailed their travel. The effect of this pattern was noticeable in San Francisco; for example, many restaurants in the city had markedly fewer customers during this period.

Table 1.—*Volume of traffic using transportation links across San Francisco Bay before and after the Loma Prieta earthquake*

Transportation link	Daily use (weekday, both ways)		Change	
	Before Earthquake	After Earthquake	Number	Difference
	Counted by vehicles			
Richmond-San Rafael Bridge	44,000	79,173	+35,173	+79.9%
Golden Gate Bridge	123,754	150,927	+27,173	+21.9%
San Francisco-Oakland-Bay Bridge	243,116	0	-243,116	-100.0%
San Mateo Bridge	65,000	109,791	+44,791	+68.9%
Dumbarton Bridge	41,500	67,189	+25,689	+61.9%
Total	517,370	407,080	-110,290	-21.3%
	Counted by passengers			
Bay Area Rapid Transit (BART) tube	102,152	226,876	+124,724	+122.1%
All ferries	6,250	21,057	+14,807	+236.9%
Total	108,402	247,933	139,531	+128.7%

That the economic and personal losses from the Bay Bridge closure were considerable is not in doubt, although much detailed study would be necessary to define them fully. If the Bay Bridge had not reopened within a month—a much shorter time interval than initially projected immediately after the collapse—the operational and economic consequences could have been much more severe. The equipment and maintenance facilities of BART, for example, were severely strained, and the post-earthquake increase in BART ridership could not have been sustained indefinitely. If the BART trans-Bay tube or the Golden Gate Bridge had simultaneously been closed for a comparable time, the economic and social consequences could have been dramatic.

The closure of the Bay Bridge, though fortunately short, gave some indication of the disruption that could be caused by the long-term loss of one of the essential cross-Bay links. The Loma Prieta experience can be seen as a "live" exercise demonstrating the short-term closure of a single cross-Bay link. A previous accident—the fire in the trans-Bay tube in April 1979—resulted in closure of the tube for two and one-half months. That experience also showed that failure of a single trans-Bay crossing can be accommodated, with some loss of convenience.

The societal consequences from earthquake damage to the Bay Area highway system were considered in two earthquake planning scenarios developed and published by the California Division of Mines and Geology for the Office of Emergency Services. The first sketched the possible effects of a magnitude 8.3 earthquake on the San Andreas Fault (Davis and others, 1982). The second considered the effects of a magnitude 7.5 earthquake on the Hayward Fault (Steinbrugge and others, 1987). These studies considered what might happen if the scenario earthquakes occurred, and had the primary objective of making emergency response and recovery authorities aware of the types of situations that they might have to face. While they were carefully prepared and appropriate for planning purposes, they were not the result of engineering analyses of the expected performance of the physical structures they considered.

The Loma Prieta earthquake demonstrated the vulnerability of Bay-crossing structures to even a relatively distant event. Future planning must recognize the likelihood and potential consequences of closer, more powerful events caused by earthquakes on the San Andreas and Hayward Faults. In particular, the possibility of the simultaneous failure of two or three Bay crossings would result in a situation for which there has been no precedent. Moreover, even if additional retrofits are implemented for the Bay Bridge and if the trans-Bay tube and the Golden Gate Bridge are deemed safe, the possibility of post-earthquake closure is always present. No engineering measures can guarantee a damage-free response of these structures to earthquake shaking.

The Bay crossings represent one component, though perhaps that with the least redundancy, of the Bay Area highway transportation system. This, in turn, forms part of a Statewide, indeed national, system—rail, air, ship—that is critical for the economic transportation of people, materials, and products. The transportation network itself forms one subsystem of the entire urban and regional structure of the State. In preparing for future earthquakes, it is necessary to identify and strengthen the weak links in these systems.

Only aggressive programs of identification and strengthening can prevent the possibility of perhaps scores of tragic collapses similar to the collapse of the Cypress Viaduct in the event of a future, closer earthquake of longer shaking duration. In addition, the economic and administrative effects of such a quake could be deep and long-enduring, perhaps even threatening the viability of California as an attractive environment in which to live and work.

FINDINGS AND RECOMMENDATIONS OF THE BOARD OF INQUIRY

Central to the Board of Inquiry's process was the determination of what actually occurred during the earthquake and why. These findings formed the basis for the recommendations made by the Board. A large volume of information was considered, part provided through public presentations to the Board, part through study of documents and files. The 52 findings of the Board were organized under the following general headings:

1. Findings on seismology and ground motion
2. General findings on transportation structures
3. Findings on Caltrans seismic design practices
4. Findings on the Bay Bridge failure
5. Findings on the Cypress Viaduct collapse
6. Findings on San Francisco freeway viaducts
7. Findings on the Caltrans retrofit program
8. Findings for other types of structures

The full report of the Board (Housner and others, 1990) presents the specific findings, the rationale for each finding, and technical information on which each was based (see also Housner and Thiel, 1990).

On the basis of these findings, the Board of Inquiry identified three essential challenges that must be met by the citizens of California, if they expect a future adequately safe from earthquakes:

- Ensure that earthquake risks posed by new construction are acceptable.
- Identify and correct unacceptable seismic safety conditions in existing structures.
- Develop and implement actions that foster the rapid, effective, and economic response to and recovery from damaging earthquakes.

These challenges concern the problems not only of bridges, whose failure prompted the Board's formation, but also of all other constructed facilities upon which our modern economy and well-being depend. Although the Board could have limited its recommended actions to those it believed necessary to correct problems with State-owned bridges, to do so would have been to abdicate a fundamental responsibility of government—to provide for the public safety. The Board interpreted its Charter in a broad sense and made recommendations that are directed both at seismic issues for bridges and at some of the larger issues of seismic safety facing the State.

The Board made the following eight recommendations for implementation (Housner and others, 1990, p 76-87).

FOR ACTION BY THE GOVERNOR

1. Affirm the policy that seismic safety shall be a paramount concern in the design and construction of transportation structures. Specific goals of this policy shall be that all transportation structures be seismically safe and that important transportation structures maintain their function after earthquakes.
2. Establish that earthquake safety is a priority for all public and private buildings and facilities within the State by taking the following actions:
   A. Propose legislation to ensure that every new facility in the State not otherwise subject to adequate seismic regulation and having the potential to cause substantial life loss during an earthquake be subject to compliance with adequate seismic safety standards for construction.
   B. Require that seismic safety be a paramount concern in the design and construction of all State-owned structures. Specific goals of this policy shall be that all State-owned structures be seismically safe and that important State-owned structures maintain their function after earthquakes.
   C. Initiate and fund a vigorous, comprehensive program of research to improve the capability in engineering and the physical and social sciences necessary to mitigate earthquake hazards and to implement the technology transfer and professional development necessary to hasten practical use of research results.
3. Direct the Seismic Safety Commission to review and advise the Governor and Legislature periodically on State agencies' actions in response to the Recommendations of this Board of Inquiry.

FOR ACTION BY THE DIRECTOR OF THE DEPARTMENT OF TRANSPORTATION

4. Prepare a plan, including schedule and resource requirements, to meet the transportation seismic performance policy and goals established by the Governor. The plan shall include the timely seismic retrofitting of existing transportation structures.

5. Form a permanent Earthquake Advisory Board of external experts to advise Caltrans on seismic safety policies, standards, and technical practices.
6. Ensure that Caltrans seismic design policies and construction practices meet the seismic safety policy and goals established by the Governor:
   A. Review and revise standards, performance criteria, specifications, and practices to ensure that they meet the seismic safety goal established by the Governor and apply them to the design of new structures and rehabilitation of existing transportation structures. These standards, criteria, and specifications are to be updated and periodically revised with the assistance of external technical expertise.
   B. Institute independent seismic safety reviews for important structures.
   C. Conduct a vigorous program of professional development in earthquake engineering disciplines at all levels of the organization.
   D. Fund a continuing program of basic and problem-focused research on earthquake engineering issues pertinent to Caltrans responsibilities.
7. Take the following actions for specific structures:
   A. Continue to sponsor and utilize the Independent Review Committee's technical reviews of the engineering design and construction proposed for the short-term repair and strengthening of the San Francisco freeway viaducts.
   B. Develop a long-term strategy and program for the seismic strengthening of existing substandard structures, including the San Francisco freeway viaducts, that considers their overall behavior, the degree of seismic risk, and the importance of the structure to the transportation system and community.
   C. Perform comprehensive earthquake vulnerability analyses and evaluation of important transportation structures throughout the State, including bridges, viaducts, and interchanges, using state-of-the-art methods in earthquake engineering.
   D. Implement a comprehensive program of seismic instrumentation to provide measurements of the excitation and response of transportation structures during earthquakes.

FOR ACTION BY TRANSPORTATION AGENCIES AND DISTRICTS

8. Agencies and independent districts that are responsible for transportation systems—rail systems, highway structures, airports, ports and harbors—should:
   A. Adopt the same seismic policy and goals established by the Governor for State transportation structures and implement seismic practices to meet them.
   B. Perform comprehensive earthquake vulnerability analyses and evaluations of important transportation structures—for example, the BART trans-Bay tube and Golden Gate Bridge—using state-of-the-art methods in earthquake engineering, and install seismic instrumentation.
   C. Institute independent seismic safety reviews for important structures.
   D. Conduct a vigorous program of professional development in earthquake engineering disciplines at all levels of their organizations.

GOVERNOR'S QUESTIONS

The Governor directed the Board of Inquiry to study and reach conclusions on five specific issues arising from the Loma Prieta earthquake (Deukmejian, 1989):

1. To determine why the Cypress Viaduct of Interstate 880 and the Bay Bridge span failed in the earthquake.
2. To determine whether these failures were or could have been foreseen.
3. To advise on how to accurately predict possible future bridge and structure failures.
4. To determine if the schedule for and manner of retrofitting these structures properly used the seismic and structural information that has been developed following other earthquakes in California.
5. To make recommendations as to whether the State should modify the existing construction or retrofit programs for freeway structures and bridges in light of new information gained from this earthquake.

To this group of directives the Board itself added the question:

6. Are California's freeways safe in earthquakes?

Summary responses to these six issues, recast as questions, are given below. Background information and more detailed discussion of these responses are to be found in the Board's Report (Housner and others, 1990).

1. WHY DID THE CYPRESS VIADUCT OF INTERSTATE 880 AND THE BAY BRIDGE SPAN FAIL IN THE EARTHQUAKE?

The Cypress Viaduct and the Bay Bridge appear to have had no design or construction deficiencies, as measured by bridge design practices in effect at the time they were built, nor is there evidence of subsequent maintenance deficiencies that could have contributed to their failure. However, the practice of earthquake engineering has improved substantially since the periods during which the Cypress Viaduct (1950's) and San Francisco-Oakland Bay Bridge (1930's) were designed and constructed.

2. WERE THESE FAILURES FORESEEN OR COULD THEY HAVE BEEN FORESEEN?

No evidence was presented to the Board suggesting that Caltrans was specifically aware of the earthquake hazards that caused the failures of the Cypress Viaduct or the San Francisco-Oakland Bay Bridge. Although there had been some seismic strengthening of both structures by the installation of cable restrainers, there is no evidence that Caltrans had identified either structure as being especially vulnerable in earthquakes.

The issue of whether these failures could have been foreseen in the Loma Prieta earthquake is a difficult one because of the uncertainties and lack of previous studies. The fiscal environment in the preceding two decades seems to have inhibited Caltrans from giving necessary attention to seismic problems. Many items, ranging from research on earthquake engineering to seismic retrofitting, were given low priorities because of budget constraints.

The Board of Inquiry concluded that had an engineering seismic assessment of the Cypress Viaduct been performed before the earthquake, but after 1971, by a professional engineering organization in a manner consistent with the care and expertise usually exercised in evaluating such important structures, it would have concluded that a collapse could be expected during a nearby major earthquake on the San Andreas Fault or Hayward Fault. Damage, but not extensive collapse, would have been expected for an earthquake similar to the Loma Prieta earthquake in magnitude and location. Collapse would have been anticipated for the intensity of ground motion actually observed in the Loma Prieta earthquake; however, the extent of the collapse that actually occurred would probably not have been anticipated.

The Cypress Viaduct was a nonductile concrete structure. It has been common knowledge within the structural engineering community since the 1960's that nonductile reinforced concrete structures are particularly vulnerable in earthquakes. Most Caltrans concrete bridges constructed before 1971 use nonductile details of reinforcing placement. Caltrans instituted design changes in 1971, following that year's San Fernando earthquake, that required new construction to utilize ductile details. However, for the Cypress Viaduct retrofit of 1977 a prior decision in the retrofit program dictated that the limited available funds should be used to install longitudinal restraints at the transverse expansion joints in the box-girder spans. This was done to prevent failures of the type experienced in the San Fernando earthquake. Unfortunately, no detailed comprehensive analysis of the entire structure-soil system, to determine if other weaknesses existed, was made before the failure of the Viaduct on October 17, 1989. Had such an analysis been made, the Board believes the failure would have been predicted.

The Bay Bridge is a very large and complicated structure made of steel and concrete and has foundations extending to rock or stiff soils through very soft, water-saturated soils. The assessment of seismic performance and possible damage to such a complex structure requires an unusually thorough and detailed investigation. Had such a study been made, it probably would have identified the possibility of collapse of the link span in addition to other hazards.

3. HOW MAY POSSIBLE FUTURE BRIDGE AND STRUCTURE FAILURES BE ACCURATELY PREDICTED?

Predicting the possibility of failures is confined to determining whether the bridge or structure could fail when subjected to a given level of ground shaking. This requires, first, that the level of ground shaking be determined for the site and, second, that an engineering assessment of expected performance be made for this level of ground shaking. The ground shaking used in such a failure analysis should be determined from a probabilistic risk assessment for the site, with an acceptable (small, consistent with the structure's importance) probability of exceedance during the projected lifetime of the structure.

Because there are more than 11,000 State-owned bridges and a comparable number of locally owned bridges, it is not expected that all of these can or should be assessed with such rigor. Design standards used by Caltrans after 1971 were better than those used before, and it is reasonable to expect that the older structures pose a greater risk. Application of risk analysis procedures that consider the frequency of occurrence of different levels of ground motion and the characteristics of each structure (configuration, materials, foundations, soils, age, and condition) could reduce the inventory of older bridges to a manageable list of potentially hazardous structures. Locations with a potential for ground failure (such as liquefaction or lateral spreading) deserve special attention.

4. DID THE SCHEDULE FOR AND MANNER OF RETROFITTING THESE STRUCTURES PROPERLY UTILIZE THE SEISMIC AND STRUCTURAL INFORMATION DEVELOPED FOLLOWING OTHER EARTHQUAKES IN CALIFORNIA?

Several freeway bridges collapsed in the 1971 San Fernando earthquake when decks were pulled off their supports at expansion joints. The decks fell, causing failure of the bridges. This happened even though no significant direct damage was necessarily done to the bridge elements themselves by the ground shaking. In response, Caltrans adopted a statewide "cable restrainer" seismic retrofit program to prevent such failures by tying each deck section to adjacent sections and abutments. It took 17 years and expenditures of $54 million to complete this program. The Board concluded that this program significantly increased the seismic resistance of many structures, and its only major criticism was that 17 years was too long for completion of such an important program.

During this post-1971 Caltrans retrofit program, the Cypress Viaduct and the San Francisco-Oakland Bay Bridge had been fitted with cable restrainers to limit the relative motion between adjacent decks at expansion joints. No special seismic analyses, however, were made of these structures. Following the 1971 earthquake, seismic design procedures for new structures were modified to include ductile detailing for concrete elements, but no special efforts were made to retrofit existing nonductile concrete bridge elements.

The near collapse in the 1987 Whittier Narrows earthquake of the overpass at the intersection of highways I-5 and I-605 emphasized the need for strengthening nonductile concrete bridge columns. An ongoing Caltrans research project was accelerated, and an inventory was made of single-column bridges having high hazard potential . The Cypress Viaduct, being a multiple column bridge, was not given high priority for attention.

Early in the post-1971 retrofit program, Caltrans considered the performance of individual elements (restraining motion at expansion joints). Caltrans did not consider the response of the whole structure or the soil/structure system. This focus on elements, in hindsight, may have inhibited the identification of problems in overall seismic behavior such as those uncovered in the failure of the Cypress Viaduct and the Bay Bridge.

The repair of the Bay Bridge appears to be appropriate for the short term. However, the fact that damage to this bridge during the Loma Prieta earthquake was only slight and has been completely repaired does not mean that the bridge may now be assumed to be adequately resistant to earthquake damage. The expected performance of the Bay Bridge during major earthquake loadings should be assessed by comprehensive state-of-the-art methods in earthquake engineering analysis. The results of this analysis should be used to determine what seismic upgrading is required to ensure adequate performance.

The San Francisco freeway viaducts are substantially comparable to the Cypress Viaduct in their design and construction. These viaducts can be expected to suffer severe damage and possibly collapse if subjected to more intense or longer duration ground motions than those experienced in the Loma Prieta earthquake. The installation of cable restraints during the Caltrans seismic retrofit program appears to have improved their behavior, possibly saving some spans from collapse in 1989 by limiting the relative displacements of the decks at the expansion joints.

The repair of some of the San Francisco Freeway Viaducts was begun in 1990. The retrofitting is expected to strengthen the columns substantially, but the precise degree of improvement in seismic resistance of the structures requires detailed studies and analyses, which were not completed by the Board. The Board of Inquiry was unable to evaluate the specific details of the retrofit designs and programs for the individual viaducts. It considers this retrofit to be only a short-term approach to their repair. Substantially more engineering analysis and evaluation will be required to determine if additional seismic retrofitting may be necessary in order for the Bay Bridge and San Francisco freeway viaducts to be appropriately safe in the long-term.

5. SHOULD THE STATE MODIFY THE EXISTING CONSTRUCTION OR RETROFIT PROGRAMS FOR FREEWAY STRUCTURES AND BRIDGES IN LIGHT OF NEW INFORMATION GAINED FROM THIS EARTHQUAKE?

The answer to this question is an unequivocal yes. The Loma Prieta earthquake demonstrated that nonductile structures designed before 1971 can fail in a brittle manner with consequent collapse. It also showed that the intensity of ground shaking on soft soils can be greater than is anticipated by current seismic codes. This evidence requires modifications both to the retrofit program and to new design standards (see Housner and others, 1990.) In response, Caltrans appears to be vigorously modifying their technical approaches and standards for both.

The existing Statewide Caltrans seismic retrofit program should continue to consider the overall behavior of transportation structures and foundations and not focus principally on the behavior of structural elements instead of systems. The retrofit program should be enhanced by the assignment of greater personnel and budgetary resources so that it can be implemented and completed by the year 2000.

Most of California's reinforced concrete bridges were designed and built before the 1970's, and many are deficient in their earthquake resistance. New knowledge in earthquake engineering for bridge design has been developed slowly through research, and there is always a lag in putting research results into practice. The quality, effectiveness, and economy of new construction and seismic upgrading will be enhanced substantially if a vigorous research program is undertaken on earthquake engineering, in contrast to the limited and occasional efforts of the past.

6. ARE CALIFORNIA'S FREEWAYS SAFE IN EARTHQUAKES?

Most of California's freeway structures are adequately resistant to earthquakes, but some are not. Among the more than 11,000 structures in the State highway system, there are some that have the potential for severe damage and collapse in the event of the strongest expectable earthquake ground motions. These deficiencies warrant prompt, systematic correction; however, the Board of Inquiry did not deem that closure of any structure was warranted, based on the Board's understanding of past Caltrans seismic design and construction practices. The occasional earthquake risks to life and safety posed by highway structures in earthquakes are different from those continuously posed by traffic conditions. Earthquakes with ground motions large enough to pose a threat to a specific bridge have relatively low probability in any year.

The Board thought that existing structures of high hazard can and should be corrected in a planned and accelerated program. With the implementation of the Board's recommendations, Caltrans could complete the identification of these structures and carry out the required seismic retrofitting. Then the State's freeway structures will be appropriately safe.

STATE AGENCY ACTIONS

Governor George Deukmejian issued Executive Order D-86-90 in June 1990 in response to the Board of Inquiry's report (Housner and other, 1990). It provided the direction to

State agencies in how to implement many of the Board's recommendations. It established a State policy that seismic safety shall be given priority consideration in the design and construction of all State structures and in the allocation of resources for transportation construction projects. Priority consideration may be defined as assigning a specific factor—in this case, seismic safety—precedence when making a decision. The Executive Order also gave specific directives to State agencies. The Department of Transportation (Caltrans) was directed to: (1) prepare an action plan to ensure that all transportation structures maintained by the State are safe from collapse and vital transportation links maintain their function following an earthquake; (2) establish a formal process for obtaining external expert advice in seismic policies, standards, and technical practices and in the reviewing plans for retrofit or construction; (3) assign a high priority to the development of a program for research on earthquake engineering issues. The Department of General Services (DGS) was directed to prepare an action plan to ensure that all facilities maintained or operated by the State (other than those for which Caltrans is responsible) are safe from significant failure and that important structures maintain their function following an earthquake. The University of California (UC) and State University of California (CSU) systems were directed to prepare plans for increasing seismic safety of their facilities. All of these agencies were given only three months to submit the requested plans to the governor. Finally the California Seismic Safety Commission was directed to review the responses of the agencies and report to the Governor on the adequacy and status of their plans and actions.

The Commission reviewed and analyzed the responses that each agency submitted to the Governor, using the criterion of priority consideration as given above as the benchmark in evaluating the adequacy and status of the efforts made. The Commission's staff discussed the problems identified during their review and analysis with representatives of the agencies. The Commission also conducted a public hearing on October 12, 1990, at which representatives of the four agencies were invited to discuss the concerns the Commission had expressed regarding their responses to the Executive Order. Agencies were asked to comment on the draft of the Commission's report, and their comments were considered when the final report was adopted by unanimous vote on November 8, 1990 (Seismic Safety Commission, 1990).

The Seismic Safety Commission determined that an effective seismic safety program in response to the Governor's directives must include adequate consideration of the following (Seismic Safety Commission, 1990, p. 2.):

1. *Policy Statement.* A statement of policy that states goals, expectations, deadlines and that explains the ranking of seismic safety in the agency's responsibilities must be developed.
2. *Seismic Safety Program.* A seismic safety program must be formulated that includes a plan and process to identify earthquake hazards to people and to organizations' functions, and recommendations to abate the unacceptable hazards or to prudently manage the risks that cannot be eliminated.
3. *Responsible Staff.* A management-level agency official should be designated as having clear responsibility for meeting the goals in the policy statement, aided by an appropriately sized staff that has the administrative and technical knowledge and experience needed to carry out the program.
4. *Adequate Funds.* Funds adequate to carry out the program or a plan to raise the needed funds must be identified.
5. *Accountability.* A way to measure and report progress to the designated official, as well as to the Governor and the Legislature should be developed, as should a way to ensure technical performance in carrying out the program.

The Commission found that, although great strides had been made during the previous few years to lessen the State's exposure to earthquake risks, there was still a long way to go. Table 2 summarizes the Commission's evaluation of the adequacy of each of the four agencies' responses to these five elements. Only Caltrans was evaluated as responding to the Executive Order with an adequate program. Although DGS made considerable progress in giving seismic safety priority consideration, it still had to find a solution to its fiscal resources problem. UC had begun to address seismic safety long before the Loma Prieta earthquake, but it did not reexamine or accelerate its existing program after the issuance of the Executive Order. Because of the lack of funding and the absence of a process of accountability, UC's program was evaluated as not adequate to meet immediate, existing seismic safety needs. Although CSU had responded to the Executive Order in good faith, it was far behind UC. Its response did not adequately address any of the five concerns essential for an effective seismic safety program. It seemed doubtful that either UC or CSU would be able to perform the planned seismic retrofits indicated in their responses; neither had the fiscal resources necessary to make seismic safety a priority consideration.

The responsiveness of the agencies was in general inversely related to their experiences in the Loma Prieta earthquake. Caltrans, being heavily affected, moved quickly and forcefully to change its practices. It established a Seismic Advisory Board, reporting to the Director of Caltrans, to review its programs. Caltrans committed substantial additional resources to research and established a Research Program Committee to review research proposals and recommend future directions. It also established a standing Project Review Committee made up of outside experts in earthquake engineering to review individual projects. Combined with the commitment of substantial new resources to seismically retrofit existing hazardous bridges, these steps provided positive expectations of substantially improved seismic safety of highway structures in the near future.

Table 2.—*Seismic Safety Commission's evaluation of the responses of four California State agencies to Executive Order D-86-90*

Element of response	Department of Transportation (Caltrans)	Department of General Services	University of California	California State University
Policy Statement	Excellent	Good	Excellent	Poor
Seismic Safety Program	Very Good	Good	Good	Very Poor
Responsible Staff	Excellent	Good	Good	Fair
Adequate Funds	Good	Poor	Poor	Very Poor
Accountability	Good	Fair	Fair	Very Poor

COMMON PROBLEMS IN AGENCY RESPONSE

The Commission found that action on seismic safety programs in the State agencies named in the Executive Order was being delayed by problems common to all four agencies. Inadequate funding is the most serious of these problems, and the most difficult for the agencies to address internally. Competing priorities cannot be used as an excuse to compromise seismic safety in public buildings any more than they would be allowed to lessen fire code compliance in the private sector. The cooperation of the Governor and Legislature is essential to provide the financial support for timely elimination of seismic hazards in State buildings and structures.

Other common problems and concerns identified by the Seismic Safety Commission (1990) include:

- The capital outlay budgeting process is too slow and inflexible.
- Potential liability exposure for failing to correct known dangerous conditions may be significant.
- Independent peer review, which could optimize design and program solutions, prevent errors, and improve accountability, is generally lacking.
- Independent plan checking and construction inspection are needed for all projects.
- Proposed strengthening standards are not consistent among agencies.
- Seismic safety does not have statutory support as a priority.
- Recovery planning has not been considered, so there is high potential for lengthy disruption of operations.

The Commission recognized seismic safety as a long-term endeavor that, to be achieved, must be institutionalized as a priority by governmental agencies (Seismic Safety Commission, 1990, p. 19-20):

> Even after today's problems are corrected, there must still be an ongoing effort and clearly defined accountability. California's government cannot let the lessons of the Loma Prieta earthquake fade as did those of the 1971 San Fernando Valley earthquake. Making certain that seismic safety programs are consistently pursued over the long term will require legislation establishing the official public policy that seismic safety is an important, priority factor in the governmental decision making and resource-allocation process.

Agreeing with a recommendation of the Board of Inquiry, the Commission found that a meaningful oversight process is needed to ensure accountability for progress on seismic safety. The Commission's report drew attention to the Governor's executive authority to present, or to establish a mechanism to prepare, an annual report to the people of California on the progress that each State agency had made in seismic safety. Backed by the power and prestige of the Governor's Office, an annual report to Californians should motivate appointed agency heads to act quickly and effectively to mitigate seismic safety hazards. It could also encourage local governments to take appropriate action concerning their hazardous buildings and move on other earthquake planning items.

Another aspect of accountability is introduced by the practice of "value engineering" as practiced by several State agencies. Value engineering is a process whereby outside experts in engineering and construction review project concepts and plans to eliminate problems and find ways of doing the work more cheaply. Value engineering experts rarely are experts in or even knowledgeable of seismic safety. They may assume that mere code compliance is sufficient to provide an adequate level of safety and recommend that structural systems or materials be changed to facilitate faster or less expensive construction. Although this is an important process to limit construction expenses to those absolutely necessary, economy must not be at the expense of seismic safety. Value engineering efforts that focus too heavily on reducing initial construction costs and deemphasize seismic safety through strict interpretation of the letter and not the intent of the seismic provisions of the building code can result in recommendations for construction techniques that leave buildings and structures far more vulnerable to earthquake damage than they should be. The value engineering review should always include the earthquake design engineer as part of the process and make every effort to assure a fair hearing to concepts introduced into the project to provide an adequate level of seismic safety and to maintain building functions after earthquakes.

The Commission emphasized the critical problem of assuring funding for seismic safety (Seismic Safety Commission, 1990, p. 16):

> While the agencies targeted by the Executive Order each have some discretion in redirecting funds, most of their capital outlay funds have been approved by the Legislature and the Governor for specific purposes and cannot be readily diverted to other projects, no matter how worthy. The agency may propose, but it is the Governor and the Legislature who now must ensure that the wherewithal for seismic retrofitting, safe new structures, and ongoing emergency response and recovery plans is provided. General obligation bonds, revenue bonds, fees, and even tax increases must all be explored. Seismic safety is too important, and ignoring it will be too expensive, to drop because of lack of money. The existing level of earthquake risk is unacceptable.

One impediment to priority funding of seismic safety is the State's capital outlay process. This process, which is project-based, requires departments to submit individual projects to prescriptive reviews at several different stages. Each review has the potential for creating delay and adding cost, increasing the risk that the project may be abandoned, suspended, or significantly changed. This project-based process tends to be slow and unnecessarily inflexible, particularly for State agencies with large ongoing capital outlay needs. Specific funding decisions have to be made so far in advance that there may be insufficient information on which to base those decisions. This is particularly true for seismic safety projects, in which the full scope of work to be done is seldom known until after the project is started. The result is the frequent need either to adjust the scale of the project to match the budget or to ask the Legislature for more money. Either path is time consuming, costly, and inefficient. Project-based budgeting is too slow to meet the need for increasing the seismic safety of State buildings.

The Commission suggested that the program-based budgeting procedure used by Caltrans might be more appropriate for seismic-safety projects. Caltrans' procedures use careful planning, thorough programming, scheduling, and independent review of capital outlay needs to ensure accurate budgeting and yet provide flexibility within the budget allocated by the Legislature. While this approach may not be appropriate for agencies that have only periodic capital outlay needs, it could improve the effectiveness of seismic safety programs pursued by DGS, UC, and CSU. Like Caltrans, each of these agencies is confronted with the necessity of strengthening hundreds of structures. A flexible, program-based budget process is more conducive to meeting the complex needs of seismic retrofitting in a timely manner than a building-by-building (project-based) process.

The Commission found that another important consideration for the State in providing funding and setting priorities to abate earthquake hazards is the potential for liability. Although fear of liability should not be the driving force, the State must recognize its potential exposure to liability if seismic safety remains just another competing need in resource allocation. The State didn't know that the Cypress Viaduct was a collapse hazard, but it is paying millions of dollars in damages to the victims of that collapse. This amount may be minuscule compared to the claims that might occur after the failure of State buildings that are known to be potential collapse hazards in an earthquake. It is also important to note that, although Chapter 2 of the Tort Claims Act (Sections 810-840.6 of the California Government Code) confers limited immunity upon the Regents of the University of California and the Trustees of the California State University system, under that law these individuals can still be held personally liable, along with the State of California, for failure to mitigate known dangerous conditions such as earthquake hazards (a precedent was the 1986 decision in Peterson vs. San Francisco Community College District). In determining whether an administrator, regent, or trustee is personally liable for an act or omission, the courts apply the "reasonable person" standard, which excuses honest errors in judgment but not the intentional ignoring of significant problems.

Finally, the Commission recommended that the concept of seismic safety be extended and institutionalized beyond the four State agencies mentioned in Executive Order 86-90. It is perhaps particularly important for the Department of Corrections and the Department of Water Resources, whose buildings and construction programs are exempt from oversight by the Office of the State Architect, but all State agencies that build or maintain their own buildings should make seismic safety a priority.

CONCLUSIONS

The Loma Prieta earthquake was a clear and powerful warning to the people of California. Fortunately it was centered in a sparsely populated region outside a major urban area; had its center been within an urban area, the consequences would have been much greater. Although progress had been made during the previous two decades in reducing earthquake risks, much more could have been done. More aggressive efforts are needed to mitigate the consequences of earthquakes.

An important lesson to be learned from this earthquake is that independent technical review is essential to achieve consistent excellence in civil engineering design and construction. The design of structures entails the making of many decisions and technical compromises. A peer review should be conducted if the owner or client wants assurance that a project design will be of acceptable quality.

The Loma Prieta earthquake also serves as a reminder that over the years improvements will continue to be made in seismic design. These result from research, the study of earthquake damage, and improvements in materials, among other things. As a consequence, structures that were designed within the understanding of a previous time, or even of the present, may not meet future standards of seismic safety. Such potentially hazardous structures should be identified and strengthened. It is especially important that this be done for major structures whose collapse would threaten many lives or would have a severe impact on the functioning of a community.

There are lessons from this earthquake for those institutions, both public and private, that do not want to be confronted by problems like those faced by Caltrans after October 17, 1989. Technical excellence is not enough— Caltrans was evaluated by the Board of Inquiry as a management and engineering organization of great skill and dedication. The conditions that led to the observed unacceptable performance of bridges resulted from the lack of a specific seismic safety policy within the organization and from an insular attitude of looking almost solely within for technical content and guidance. In addition, there were critical gaps in the knowledge required to effectively mitigate earthquake hazards, and there were delays in incorporating such knowledge into practice.

Before the Loma Prieta earthquake, Caltrans did not have a management-directed seismic safety performance goal that all its structures had to meet. The requirements for accommodating earthquakes were contained only in design documents for use by engineers on individual projects. It is common for construction projects to have many criteria and goals, not all of which can be met simultaneously within budgetary and time constraints. It is understandable that seismic requirements, when not specifically stated as part of policy, can become the subject of compromises as management makes allocations among competing uses for limited funds. During the decades before 1989, the pressure to relieve traffic congestion and the limitations on funds led to severe budgetary problems for Caltrans. The fact that it took 17 years to implement the modest-cost cable restrainer program after the 1971 San Fernando earthquake suggests that seismic safety was not as pressing as other issues. Internal design guidance, especially without independent review, can not provide the same level of assurance of good seismic policies and practices as does a clear statement of minimum seismic safety goals for an organization.

The Seismic Safety Commission reviewed the response to the Board of Inquiry's report and the Governor's Executive Order 86-90. On the basis of that review, the Commission recommended a number of actions that can and should be taken to improve the seismic safety in State-owned buildings and transportation structures (Seismic Safety Commission, 1990, p. 22-24). These actions would cure deficiencies in the detailed action plans submitted by the agencies to the Governor, extend the same requirements to other agencies, and create a clear system of responsibility and accountability. Most of these actions could be effected through an executive order; others should be adopted independently by Caltrans, DGS, UC, and CSU to improve their programs; and a few should be enacted by the Legislature to ensure a firm and lasting commitment to seismic safety policy and funding. The following is a brief summary of these recommendations:

- The Governor should issue an Executive Order that directs each State agency to designate a policy-level person to be accountable to the agency head for taking all reasonable steps to ensure the protection of employees and clients against the effects of earthquakes. The order should also: (1) direct agencies to adopt policies regarding the seismic safety of the buildings they use and to create and manage hazard abatement programs; (2) require independent peer review of all major projects; (3) require all agencies that own and operate large numbers of buildings, especially those exempt from Office of the State Architect (OSA) oversight, to prepare detailed action plans and to use the plan-checking services of OSA; (4) create an ad hoc Seismic Safety Construction Coordinating Council charged with resolving existing differences in seismic safety methodology and standards; (5) direct agencies to post warning signs on buildings determined to be hazardous in earthquakes and to retrofit or vacate those buildings as soon as possible, but certainly by the end of the century; and (6) require the Department of Finance to audit the agencies' compliance with the Executive Order.
- The Department of General Services, the University of California, and the California State University should provide for independent peer review of seismic safety methods, standards, and priorities and of project design criteria and concepts; the director of DGS and chancellor of CSU should adopt and implement an official seismic safety policy; and Caltrans should modify the make-up, reporting relationships, and responsibilities of its independent boards and resolve any disagreements with the Board of Inquiry's recommendations by discussing them with the Seismic Design Advisory Board.
- The Legislature should enact legislation making seismic safety a priority consideration in capital outlay programs; streamlining the capital outlay process; giving OSA authority over plan checking and construction inspection for all State-owned buildings; and placing a seismic safety bond measure on the next statewide ballot that would require the retrofit or abandonment of all State-owned buildings determined to be hazardous in earthquakes as soon as possible, but certainly no later than the end of the century.

Although most of the Commission's recommendations for action were based on the Board of Inquiry's report and the Governor's Executive Order 86-90, some expanded the scope into other issues of seismic safety. The recommendation that hazardous buildings be posted with warning signs follows a recent trend of making the user of products and services aware of the hazard posed in their use. The Board had called for the retrofitting of hazardous bridges by a certain date, but the

Commission extended this recommendation to governmental buildings. This augmentation, if acted upon by the Governor, should go a long way toward achieving the goals proposed by the Board for all structures.

Initial observation of the response of State agencies to the Loma Prieta earthquake is encouraging, but continued scrutiny is required to ensure that promises are fulfilled. Substantial efforts will be required to find the appropriate compromise between current seismic safety expenditures compared to other demands for scarce resources and the future consequences of these actions when an earthquake occurs. The Loma Prieta earthquake, like California's other recent earthquakes, had surprises that upon reflection should have been not only expected but anticipatable. The only thing lacking was the resolve and commitment to ask and answer the appropriate questions.

Future earthquakes are inevitable—in California and elsewhere in the Nation. They represent a continuing danger to our population and economy. The consequences of severe earthquakes in urban areas will be extensive—too large to allow "business as usual" to continue. It is time to set priorities for seismic safety. Research and development must be supported to meet our needs for effective, economic strategies for earthquake hazard mitigation, and determined actions must be taken to reduce seismic risks. Earthquakes respect our actions, not our intentions.

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APPENDIX—EXECUTIVE DEPARTMENT, STATE OF CALIFORNIA, EXECUTIVE ORDER D-86-90

This executive order to improve State seismic safety was signed by the Governor on June 2, 1990, in response to the report and recommendations of the Board of Inquiry on the Loma Prieta Earthquake of 1989.

Whereas, on October 17, 1989 a major earthquake occurred in Northern California, causing deaths, injuries, and widespread damage to transportation facilities and other structures; and

Whereas, an independent Board of Inquiry was formed in November 1989 to investigate the reasons for the collapse of transportation structures and to recommend actions to reduce the danger of tragic structural failures in future earthquakes; and

Whereas, the Board of Inquiry found that there is a high probability that one or more major earthquakes will strike heavily populated areas in Northern and Southern California in the future; and

Whereas, California's state of earthquake readiness needs improvement to better protect the public safety and our economy from potentially serious impacts of future earthquakes;

Now, therefore, I, George Deukmejian, Governor of the State of California, by virtue of the power and authority vested in me by the Constitution and Statues of the State of California, do hereby issue this Order, to become effective immediately:

1. It is the policy of the State of California that seismic safety shall be given priority consideration in the allocation of resources for transportation construction projects, and in the design and construction of all state structures, including transportation structures and public buildings.
2. The Director of the Department of Transportation shall prepare a detailed action plan to ensure that all transportation structures maintained by the State are safe from collapse in the event of an earthquake and that vital transportation links are designed to maintain their function following an earthquake. The plan should include a priority listing of transportation structures which will be scheduled for seismic retrofit. The Director shall transmit this action plan to the Governor by August 31, 1990.
3. The Director of the Department of Transportation shall establish a formal process whereby the Department seeks and obtains the advise of external experts in establishing seismic safety policies, standards, and technical practices; and for seismic safety reviews of plans for construction or retrofit of complex structures. The Director shall transmit a summary of this process to the Governor by August 31, 1990.
4. The Director of the Department of Transportation shall assign a high priority to development of a program of basic and prob-

lem-focused research on earthquake engineering issues, to include comprehensive earthquake vulnerability evaluations of important transportation structures and a program for placing seismic activity monitoring instruments on transportation structures. The Director shall transmit a description of the research program to the Governor by August 31, 1990.

5. Local transportation agencies and districts are encouraged to review the findings and recommendations of the Board of Inquiry on the 1989 Loma Prieta Earthquake and to adopt policies, goals, and actions similar to those proposed for Caltrans.
6. The Director of the Department of General Services shall prepare a detailed action plan to ensure that all facilities maintained or operated by the State are safe from significant failure in the event of an earthquake and that important structures are designed to maintain their function following an earthquake. The plan should include a priority listing of facilities which will be scheduled for seismic retrofit. The plan shall further propose measures by which state agencies constructing new facilities or retrofitting existing facilities would:
   a. be governed by the provisions of a generally accepted earthquake resistant code for new construction;
   b. secure structural safety review and approval from the Office of the State Architect;
   c. seek independent review of structural and engineering plans and details for those projects which employ new or unique construction technologies; and
   d. have independent inspections of construction to insure compliance with plans and specifications.

   The Director shall transmit the plan to the Governor by August 31, 1990.
7. The Department of General Services shall, when negotiating leases of facilities for use by state employees or the public, consider the seismic condition of the facilities and shall initiate leases only for those facilities which demonstrate adequate seismic safety.
8. The Seismic Safety Commission shall review state agencies' actions in response to this executive order and the recommendations of the final report of the Board of Inquiry and provide a report to the Governor on the adequacy and status of actions taken by December 1, 1990.
9. The University of California and the California State University shall give priority consideration to seismic safety in the allocation of resources available for construction projects. The University of California and the California State University shall prepare and transmit to the Governor by August 31, 1990 a description of their plans to increase seismic safety at facilities which they maintain or operate.

THE LOMA PRIETA, CALIFORNIA, EARTHQUAKE OF OCTOBER 17, 1989: SOCIETAL RESPONSE

RECOVERY, MITIGATION, AND RECONSTRUCTION

EARTH SCIENCE, EARTHQUAKE RESPONSE, AND HAZARD MITIGATION: LESSONS FROM THE LOMA PRIETA EARTHQUAKE

By William M. Brown III *and* Carl E. Mortensen

CONTENTS

ABSTRACT

The Loma Prieta earthquake and its aftermath offered an opportunity to examine the interrelations between the earth-science research community and those agencies and institutions charged with managing hazard reduction activities, including long-term mitigation, preparedness, response, recovery, and reconstruction. We describe the actions undertaken by the U.S. Geological Survey (USGS) after that earthquake and examine them in the larger context of the earth-science community's response to catastrophic earthquakes. Federal legislation governing disaster response and earthquake hazard mitigation provides a basis for defining a role for that community. This role includes providing information, essential for informed decision-making at all levels, to policy makers, response and recovery officials, and the general public. We recommend that this role be formally recognized and facilitated through deliberate advance planning. We also recommend that the USGS participate in regularly scheduled earthquake response exercises; execute formal agreements and prearrangements with primary response agencies; participate on hazard mitigation teams to formulate mitigation recommendations; and develop disaster-resistant communications links to disseminate information to response officials. These and other actions will help ensure that response to catastrophic earthquakes is coherent and coordinated and is based on the best available scientific information.

INTRODUCTION

During the response to and recovery from the Loma Prieta earthquake, the earth-science community interacted with operating agencies in a variety of ways. These interactions warrant examination to determine how effective they were and whether organizational changes or additional arrangements could provide an improved response to future severe earthquakes. Historically, there has been little direct connection between emergency response planning and earth-science research conducted under the National Earthquake Hazard Reduction Program (NEHRP). Research was seen as purely a long-term endeavor whose results sometimes take years to be translated and applied to hazard reduction. Response and recovery were seen as immediate necessities to which earth-science researchers had little to contribute. As monitoring and assessment capabilities have improved, however, this situation has gradually changed. By using powerful techniques for evaluating hazards in near real-time, the earth-science community is now able to provide rapid solutions to urgent problems posed during response and recovery operations.

This paper describes two avenues for the immediate translation and transfer of earth-science research results. The report of the joint State/Federal Hazard Mitigation Survey Team (HMST), which is mandated under Federal law in any declared disaster, and the Plan for Federal Response to a Catastrophic Earthquake (currently undergoing revision to encompass all types of natural disasters) offer opportunities to affect long-term mitigation activities and response actions, respectively, through direct participation and through deliberate planning. We briefly summarize the role of earth science in earthquake response, illustrated by the investigations carried out in the wake of the Loma Prieta earthquake, in order to place into context the opportunities that are available to affect earthquake response and hazard-mitigation policy following any severe earthquake.

This paper focuses on certain contributions to hazard mitigation by the earth-science community following a severe earthquake. The response of the engineering community is widely recognized and substantial, but a discussion of those activities is outside the scope of this paper and beyond the expertise of the authors. We review the coordinating role assumed by the U.S. Geological Survey (USGS) for earth-science investigations and activities in the aftermath of the Loma Prieta earthquake, recognizing that the Earthquake Engineering Research Institute (EERI) played a similar role in coordinating activities of the many agencies and entities contributing to engineering aspects of the Loma Prieta response.

THE ROLE OF EARTH SCIENCE IN EARTHQUAKE RESPONSE

When a damaging earthquake occurs, the earth-science community has three principal obligations: (1) to gather and analyze basic data; (2) to provide hazard evaluations and advice to responding authorities; and (3) to provide information and advice to the general public. The activities undertaken to fulfill these objectives can be made more effective through preplanning and coordination with the operational response agencies.

The data that must be gathered and analyzed by earth scientists in order to fulfill their role of providing advice and information, and to further the understanding of earthquake processes, include observations to achieve the following objectives. Some examples from the Loma Prieta earthquake are given.

1. *Determine source parameters, mechanism, and characteristics of the earthquake.*—These data may help to determine whether the event is a main shock or perhaps a foreshock to another, possibly larger event. These data also may be used to place the earthquake in a time sequence of other earthquakes for the region and can aid in estimating the probabilities of future earthquakes (Working Group on California Earthquake Probabilities, 1990).
2. *Characterize the distribution and parameters of strong ground shaking.*—Rapid processing of broadband strong-motion recordings from in-place arrays (Brady and Mork, 1990) and aftershock recordings from portable instruments can provide valuable data to authorities concerned with reconstruction and zoning decisions, as in the Marina District of San Francisco (Holzer and others, 1990).
3. *Map the distribution of ground effects.*—These data lead to estimates of ground displacements, shaking intensities, extent of landsliding, occurrence of liquefaction, and other effects of the earthquake (U.S. Geological Survey Staff, 1990). Such information is vital for response agencies to best deploy their resources to areas of need and to assess the possibilities of latent effects of the earthquake. This information is also essential to decisionmakers planning long-term recovery and reconstruction in order to mitigate effects of future earthquakes as required by law (see later section titled "Planning for earthquake response").
4. *Map the extent of surface rupture, if any.*—For both primary and secondary breaks, the length and width of the rupture are measured, as well as the vertical and horizontal offsets of the ground. This work defines the fault segment that has broken and has implications about which segments are likely to break in future events. It also helps in estimating how large a volume of the Earth's crust was affected by the movement and in gauging the potential limits of different levels of damage.
5. *Measure afterslip.*—Afterslip is postseismic creep in the rupture zone that can increase stress on the margins of the zone. This activity has the potential to produce new ground rupture for several days to weeks following the main event and to cause movement on nearby fault zones.

These data must be gathered promptly after an earthquake because (1) most of the indicators, such as ground cracks, are perishable and must be observed and measured before they are obliterated by grading, reconstruction, rainfall, or other processes and activities; (2) the data constitute the primary information for further mitigation of effects of future earthquakes, both specifically for repeated characteristic earthquakes on the same fault and for earthquakes in general; and (3) some of the data are prerequisite for the mandated warnings and advisories concerning aftershocks and other hazards that derive from analysis of the data.

Warnings and advisories to authorities and to the public depend on rapid, preliminary analysis of the basic data collected. These advisories include estimates of aftershock probabilities and timing, landslide risk, risks of other continued or progressive ground-failure effects, especially those that can be induced by aftershocks, and projections of afterslip and the risks of earthquakes induced on adjacent fault segments. After the Loma Prieta earthquake, the USGS routinely issued advisories about aftershock activity and probabilities and cooperated extensively with the news media in relaying this information to the general public. No post-earthquake information is of greater interest to the general public than aftershock forecasts because of the concern and anxiety aftershocks cause. Aftershock information therefore needs to be realistic and accurate, but presented in a dispassionate, calming fashion so that people can fully understand what they will have to live with over the next several months to years.

Earth scientists can help to determine the risks faced by rescuers and others working in or around particular damaged structures, such as partially collapsed buildings or bridges. They may also be asked for advice on the redevelopment of specific damaged areas, including the types of development feasible considering both short-term and long-term seismic hazards. Earth scientists may be called to testify before commissions and special hearings on such matters as why a particular facility failed or how effective particular codes were in ensuring safe development (see, for example, U.S. Congress, 1989). They may be asked to give information to insurance companies on matters such as the conditions of a failed site before an earthquake or the location of a site with respect to various mapped seismic hazards.

Finally, information and advice to the general public is required in order to (1) satisfy the immediate, large, and continuing demand for explanations of what happened; (2) direct inquiries to the proper information source; and (3) counsel people about what is likely to happen next. Knowledge itself has a salutary effect and goes a long way toward minimizing irrational, counterproductive personal responses. People want knowledge to help them evaluate their own risks, and making the best information available encourages rational, productive responses by individuals regarding their particular circumstances. People need to be advised about whether to rebuild, to buy earthquake insurance, to return to work, to send their children back to school, and whom to contact for additional information. Many such questions are asked of earth scientists, and they should be prepared to answer them or refer people to specific sources of information. In addition, there is an obligation for earth scientists to make the public aware of earthquake hazard mitigation opportunities.

EARTH-SCIENCE RESPONSE TO THE LOMA PRIETA EARTHQUAKE

After the Loma Prieta earthquake struck, earth scientists and technicians from numerous institutions and agencies immediately undertook reconnaissance investigations of the effected areas, primarily by aircraft and automobile (Plafker and Galloway, 1989). The various reconnaissance teams had different objectives, which included determining the character and extent of surface faulting, mapping the distribution of ground failures caused by liquefaction and landslides, and estimating the distribution of shaking intensities from observations of damage and other factors. Post-earthquake investigations by groups within the USGS were coordinated, following prearranged plans based on experience gained in responding to other earthquakes worldwide; most USGS activities were under the general guidance of the Branch of Engineering Seismology and Geology (now part of the Earthquake Hazards Team). For the reconnaissance and investigation effort of the wider earth-science community however, there was little in the way of centralized coordination in the early stages, though this rapidly began to develop as a result of the common needs of investigators.

Some post-earthquake investigations involved the execution of prearranged plans, but many contingencies had to be dealt with through ad hoc arrangements. One such unplanned aspect was volunteered efforts. Scientists and engineers who happened to be in the San Francisco Bay region on other business when the earthquake struck immediately came to offer assistance, and soon other people with experience and interests in earthquakes began to pour into the region from throughout the world. Many (perhaps most) of the earth scientists who joined the response in these ways contacted the USGS for the information they would need to embark upon their investigations.

As the response developed, USGS activities were coordinated through meetings held every evening at the USGS Western Region Center in Menlo Park, California. Presided over by the Chief of the Branch of Engineering Seismology and Geology, these meetings were attended by scientists and technicians from the USGS, universities, and other agencies, plus representatives of the news media. The meetings served to consolidate the observations and data gathered during the day in an effort to form a coherent picture of the earthquake mechanism, processes, and effects; to identify critical gaps in information; and to coordinate plans for further efforts. At each meeting, the day's activities and findings were presented and discussed, and information was posted on maps or in other forms of data displays on the walls of a large room, where it remained for further inspection by all investigators. Open access and direct media attention to the accumulating results helped to focus the response on the most critical issues and areas.

In the remainder of this paper we attempt to evaluate the successes and shortcomings of the earth-science response to the Loma Prieta earthquake and the interrelations of agencies, institutions, and individuals involved in the response. Studies conducted after the earthquake revealed that the next large San Francisco Bay area earthquake is probably not far in the future, and the lessons we learned in 1989 must be well considered in preparing us for that next event.

PLANNING FOR EARTHQUAKE RESPONSE

THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM AND THE PLAN FOR FEDERAL RESPONSE TO A CATASTROPHIC EARTHQUAKE

The Plan for Federal Response to a Catastrophic Earthquake, hereafter referred to as the Plan (Federal Emergency Management Agency, 1986, 1987, 1989), was developed by the Federal Emergency Management Agency (FEMA), which assumes the lead coordinating function for earthquake response by all participating Federal agencies. The Plan was authorized under the National Earthquake Hazards Reduction Program (NEHRP), enacted by the Congress in 1977 and amended in 1990; authorities that accrue to various agencies under the Plan derive from the Robert T. Stafford Disaster Relief and Emergency Assistance Act, PL 93-288, as amended, hereafter referred to as the Stafford Act. In the terminology of disaster planning, "response" refers to actions taken to save or protect lives and property immediately after an earthquake or other disaster; "recovery" includes measures to satisfy vital human needs with interim measures that may last for several months; and "reconstruction" refers to efforts that may extend over many years to rebuild and renew public and private buildings, roads, utilities, and other facilities. The Plan covers only response. Federal recovery and reconstruction measures are covered under a variety of other legislation and programs. The Plan is currently undergoing revision to cover Federal response to all natural disasters. Some organizational details will be changed in the new draft, but the basic structure and concept of operations will remain the same.

The Federal response to disasters is managed at the national level by the Catastrophic Disaster Response Group, headed by FEMA and comprising representatives of the various Federal disaster-response agencies. This group oversees the allocation of Federal resources in a disaster and responds to Congressional attention. In this paper, we concentrate on response at the regional level, where input from the earth-science community can have its greatest and most immediate impact. The regional structure for Federal response under the Plan at the time of the Loma Prieta earthquake is diagrammed in figure 1. The regional effort is directed by the Federal Coordinating Officer (FCO), a FEMA official, assisted by an Emergency Support Team (EST) comprising key aides and advisors. Included among the technical advisors is the Science Advisor. Since the Loma Prieta earthquake, the Science Advisor function has been placed within Emergency Support Function 5 (now called Information and Planning).

Once the President declares a disaster in accordance with the Stafford Act, the Plan may be activated. Because the Loma Prieta earthquake was not considered "catastrophic" in the sense that local and State response resources were not completely overwhelmed, the Plan was not fully implemented. Under the partial implementation, however, the Federal response structure was staffed, missions were assigned, and funds were provided to various Emergency Support Function (ESF) agencies to carry out response activities.

The Stafford Act has evolved over time, with the experience from past disasters being used to call for new specific and useful activities. Many of these activities rely on applications of scientific research. The Stafford Act specifies that the President ensure that all appropriate Federal agencies are prepared to issue warnings of disasters to State and local officials. This means that, where feasible, earthquake forecasts and predictions, including aftershock warnings and other advisories following earthquakes, are required by law. Such warnings are therefore not simply a freely offered public service, but a duty of those agencies with the scientific capability to devise and issue them. The Stafford Act also requires that emergency support teams of Federal personnel come to the assistance of the President's appointed Federal Coordinating Officer (FCO). The Act mandates the presence of Federal earthquake specialists on the emergency support teams in the aftermath of an earthquake and hence offers a significant opportunity for scientists to help direct the Federal response.

The Stafford Act is unambiguous on the responsibility of certain agencies to issue warnings and advisories. However, care must be exercised in the entire warning procedure. The wording of warnings needs to follow specific formats concerning time, location, actions to be taken, and duration of the warning period. Response agencies and the general public will take official warnings as authority to act, and therefore careful consideration must be given to questions of liability and service to the community. Generally, issuing warnings requires significant preplanning, particularly in writing sample warning statements that can be rapidly modified to suit particular situations when real warnings need to be issued. The mechanisms for issuing warnings also need to be preplanned, particularly in determining who is to be contacted regarding the warning and how the warning is to be distributed through the media. Procedures for issuing natural-hazards warnings are discussed in a report by Gori and Hays (1987), and a case study is available in the Parkfield Prediction Experiment of the USGS (Bakun and others, 1987).

The earth-science research community is not generally integrated into the Plan, except in a fairly circumscribed way, and their response to the Loma Prieta earthquake was mostly not formally preplanned, but generally ad hoc. This is not to say that the earth-science response in general, and that of the USGS in particular, was not effective. Rather, the valuable lessons of the Loma Prieta experience should form the basis for a deliberately planned response to future, more severe earthquakes that will heavily tax organizations, coordination measures, and material and personnel resources. A considerable body of experience in responding to disasters has evolved within the USGS as a result of previous responses to significant earthquakes and volcanic eruptions. Substantial response efforts were mobilized after the Armenian earthquake of 1989 (in the former USSR) and the eruptions of Mt. St. Helens in 1980 (U.S.A.) and Nevado de Ruiz in 1985 (Colombia). Planning in advance of such events serves to create a more efficient and effective response and to identify potential resource shortfalls. In order for such planning to take place, it is necessary to understand the basic elements of the Plan, its concept of operations, and how the resources and capabilities of the research community can best be integrated into the response operations and enhance their overall effectiveness.

RESPONSE-89 EXERCISE

To ensure effective implementation of emergency response plans, these plans must be tested and refined through appropriate exercises. A major earthquake response exercise, titled RESPONSE-89, was held during August 9-11, 1989, just two months before the Loma Prieta earthquake. Conducted jointly by FEMA and the Governor's Office of Emergency Services (OES) of the State of California, the exercise brought together State and Federal agencies from throughout Califor-

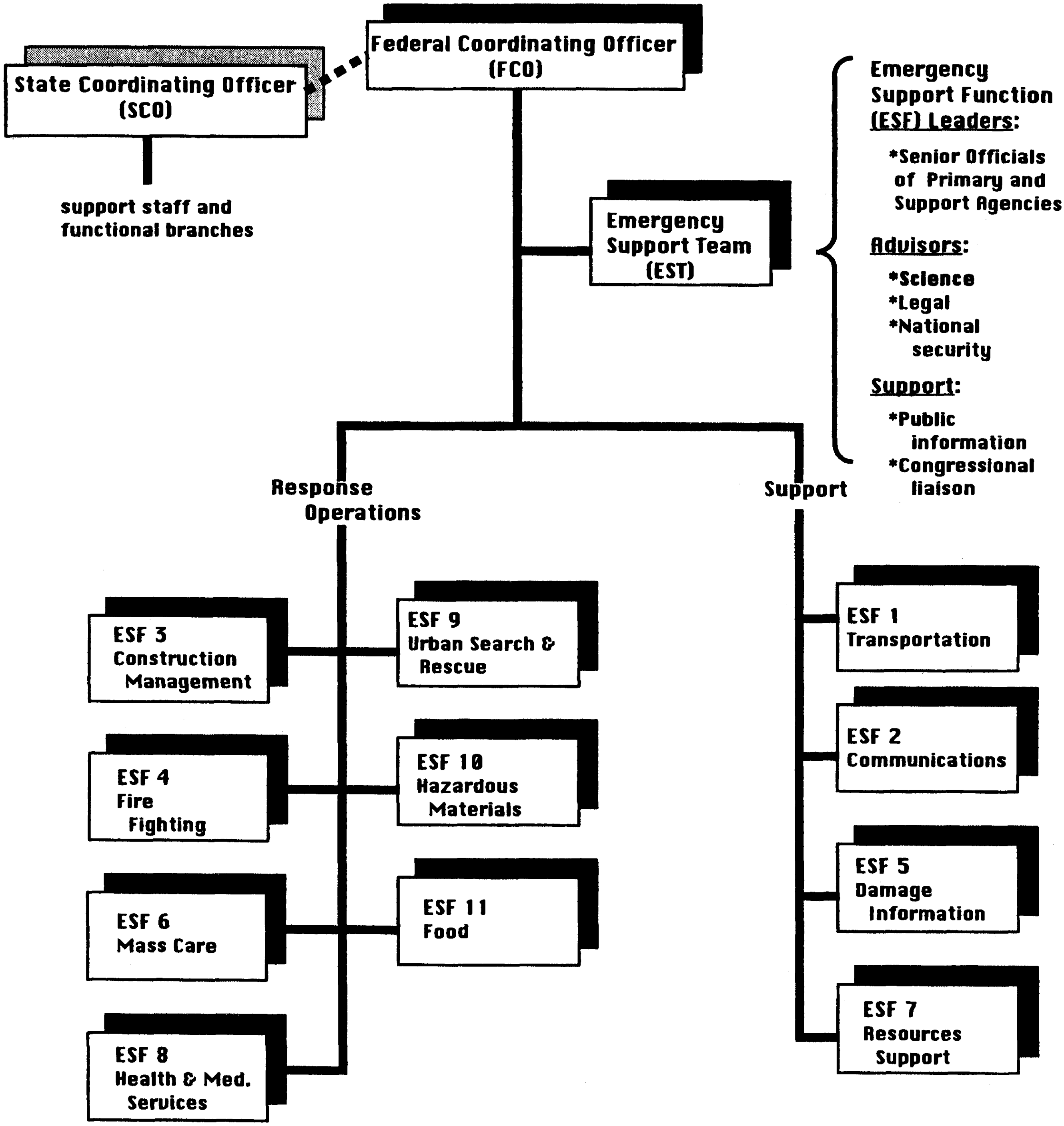

Figure 1.—Functional organization of a regional Disaster Field Office (DFO) from the Plan for Federal Response to a Catastrophic Earthquake (at the time of the Loma Prieta earthquake). The various Emergency Support Functions (ESF's) are conducted by staff of the different Federal agencies involved in the response under the direction of the Federal Coordinating Officer (FCO).

nia in a simulated response to an earthquake scenario for the Hayward Fault Zone in the San Francisco Bay region.

During the RESPONSE-89 exercise, the designated Science Advisor provided information on aftershocks to the Federal Coordinating Officer (FCO) and to the various Emergency Support Functions (ESF's), particularly those concerned with the safety of unstable structures. The primary agency for one such ESF (ESF-3, Construction Management), the U.S. Army Corps of Engineers (USACOE), found aftershock probabilities computed by the method of Reasenberg and Jones (1989) to be useful in organizing their response activities during the exercise.

Participation in the RESPONSE-89 exercise by the U.S. Geological Survey served to introduce key USGS personnel to the local FEMA Region IX organization and officials, greatly facilitating subsequent interactions during the actual response to the Loma Prieta earthquake.

USGS ACTIONS AND INTERACTION WITH THE EARTH-SCIENCE COMMUNITY FOLLOWING THE LOMA PRIETA EARTHQUAKE

For 8 days after the Loma Prieta earthquake, aftershock probabilities were calculated twice a day and widely disseminated to responding agencies and to the news media (Reasenberg, 1990). Later, the frequency of these aftershock forecasts gradually diminished. Initial distribution included the California OES, the USACOE, and FEMA. Other agencies were added to the list as they requested information.

Another USGS response action following the Loma Prieta earthquake was to establish a direct radio link to the site of rescue operations at the collapsed Cypress Street freeway structure (Interstate Highway 880 in Oakland). This link allowed the USGS to give rescue workers about 27 seconds of advance warning before the beginning of ground shaking from larger aftershocks occurring in the epicentral area (Bakun and others, 1994). Such warnings could also be useful in future rescue operations in partially collapsed, unreinforced masonry buildings or in other badly damaged structures at sufficient distance from the epicenter. This is an example of a new capability that could be formalized in the plans of ESF-9, Urban Search and Rescue.

In such ways, the USGS and other research institutions may contribute directly to the response operations of a particular ESF. The Science Advisor to the FCO, however, must avoid becoming engrossed in ESF staff functions in order to fulfill the role of observing response operations overall and advising the FCO of opportunities for scientific capabilities to be applied to important problems. The Science Advisor must advise the FCO of the risk of progressive ground-failure processes and the expectation of damaging aftershocks. During the response to the Loma Prieta earthquake, the Science Advisor found it useful to attend the nightly briefings by field personnel at the USGS and to interpret, condense, and report the important facts from these meetings to the FCO and to ESF 3 (Construction Management).

A valuable contribution that could be made by the USGS after a damaging earthquake would be to provide response agencies with a quick estimate of likely damage intensity and distribution. Such estimates could be based on the magnitude and location of the earthquake and on the local geological factors. This contribution was not available following the Loma Prieta earthquake, but the analytical techniques that could be applied to produce such estimates were verified in that earthquake (Borcherdt and others, 1991). Possible application of these techniques is suggested by the following recent experiences. Both the RESPONSE-89 exercise and the Loma Prieta earthquake demonstrated that, particularly for critical life-saving tasks, the method of allocating resources by waiting for resource requests to arrive from local responders was unworkable. The very areas most in need may be least able to formulate and communicate requests for help. In more severe earthquakes in the future, it is expected that local government itself will be a victim—overtaxed before it can respond. Response planners therefore have determined to implement what is referred to as a "push system," under which critical life-saving functions are preassigned ("pretasked") to respond to the event without waiting for formal tasking or mission assignment (Federal Emergency Management Agency, 1990, p. 44). Indeed, some of the most effective Federal response efforts after the Loma Prieta earthquake resulted from ad hoc "push" efforts by units acting without prior formal authorization. The push system offers an opportunity for the USGS to contribute immediately by providing real-time notifications of earthquake facts and predicted earthquake effects. This information could then be the basis for the initial governmental response under the push system and could greatly enhance the effectiveness of that response. Current technology, particularly that based on geographic information systems (GIS), would easily support such an application (Wentworth and others, 1991).

In addition to helping integrate the research community into the response under the Plan, deliberate advance planning can support the needs of the earth-science community itself. Given a necessary research program of observation, evaluation, and analysis after a major earthquake, preplanning is useful to: (1) assign people to field investigation teams, (2) assign a Scientist-in-Charge of USGS operations and liaison staff to coordinate operations with other research institutions and groups, (3) assign a Science Advisor, (4) allocate resources, (5) identify and organize equipment, procedures, and facilities for rapidly compiling, correlating, evaluating, and interpreting observations, (6) assign priorities to missions and tasks, (7) organize response to the media, and (8) avoid duplication of effort while ensuring that all important aspects of the problem are covered.

Following the Loma Prieta earthquake, it became necessary for the USGS to coordinate field operations with numerous people from other research institutions and disciplines, including geologists and engineers making field observations of ground-failure effects, engineering seismologists deploying arrays of strong-motion recorders, and geodesists and geologists conducting major, cooperative surveying efforts to help evaluate the situation and assess the further risks from incipient fault conditions in the region. Arrangements were made quickly for commercial air reconnaissance services using funds previously allocated for other research projects. Had such missions been identified under the Plan (perhaps as an integral part of ESF-5, Damage Information), it is possible that these services could have been funded under the Stafford Act.

A curious feature of the Loma Prieta earthquake was its failure to produce surface rupture along the San Andreas Fault (U.S. Geological Survey Staff, 1990). The surface cracks and crevasses that formed throughout the epicentral region were found to be only secondary expressions of the primary fault-plane rupture at depth, many of them landslide features and secondary breaks in near-surface rocks. Such features have different implications for the nature of the earthquake and its associated potential hazards. From a policy standpoint, the locations and distribution of secondary breaks in near-surface rocks may have implications for evaluating California's Alquist-Priolo Special Studies Zones (California, 1972) in the region: Should the secondary breaks be considered active faults in the context of land-use zoning? Is the pattern of these breaks recurrent? Can the Special Studies Zones Act effectively deal with the style of ground fracturing observed following the Loma Prieta earthquake?

The Loma Prieta earthquake reactivated many large landslide deposits and caused other slope failures. Many of these, particularly along highways and coastal bluffs, continued to move and collapse after the earthquake. Because of these observations and the imminent onset of California's rainy season, which could exacerbate the landslide problem, the USGS issued warnings and advisories about landslides in the days and weeks following the earthquake. Many of the warnings were adapted from standardized warning messages developed during the mid-1980's by the USGS for rainfall-induced landslides. The concern about slope instability after the Loma Prieta earthquake led to longer term monitoring of hillslopes and coastal bluffs throughout Santa Cruz County. The County was rezoned with respect to requirements for new construction and for rebuilding and repair of damaged structures (County of Santa Cruz, written commun., 1989). A landslide project for Santa Cruz County was developed from recommendations of the Hazard Mitigation Survey Team (Federal Emergency Management Agency, 1990, p. 30-31) and became a cooperative venture among FEMA, USACOE, USGS, Santa Cruz County, the California Division of Mines and Geology, the University of California at Santa Cruz, and private contractors (Technical Advisory Group on the Santa Cruz Geologic Hazard Investigation, 1991). Later, the State of California mandated long-term, statewide mapping of hazards for liquefaction, ground shaking, and landslides (California, 1990).

The USGS and the earth-science community in general have an important role to play with regard to informing the public. This role includes the obligation to translate and transfer research results and scientific observations about particular earthquakes and associated risks to the public in a clear and understandable way. Plans for responding to public inquiries following earthquakes can build upon past efforts. A popular brochure issued soon after the Loma Prieta earthquake (Ward and Page, 1989) and a subsequent, widely distributed newspaper insert (U.S. Geological Survey, 1990) contained excellent information on responding to earthquake hazards and evaluating personal risks. To accomplish such information transfer effectively, it is important in time of disaster that the earth-science community quickly agree on the fundamental facts about the earthquake and speak with one voice, particularly on the basics regarding risks to the public. Vigorous scientific debate should, of course, be carried out at the appropriate times and places, with the arguments and conclusions summarized by a public affairs team. The public may readily accept the notion of a healthy, informed dialogue but may be uneasy with acrimonious disputes, perhaps overemphasized by media predisposed to reporting conflicts. Fortunately, cooperation was more prevalent than controversy among earth scientists following the Loma Prieta earthquake.

It is noteworthy that about 10 percent of the USGS employees involved in response to the Loma Prieta earthquake were formally engaged in public outreach activities for the agency, and most others engaged in some ad hoc form of outreach activity. Much of this activity stemmed from impromptu press contacts in the field and telephone contacts while in the office. Although formal press conferences were set up on a regular basis by the USGS Public Affairs Office, these satisfied only part of the continuous demand for information.

In the response to future, more severe earthquakes, all the activities discussed above, plus others, will likely have to take place, and shortcomings of earth-science response implied in the preceding text are likely to be greatly magnified unless we are better prepared. An organized scientific response plan could greatly facilitate rapid transition to a disaster-response footing. Such a plan should be flexible but comprehensive, outlining general guidelines, missions, and assignments and identifying resources and personnel. The plan should provide managers with the flexibility to make decisions and accommodate particular circumstances. Internal planning for the USGS should coordinate with the Federal Plan and with State plans to the extent possible.

THE STATE/FEDERAL HAZARD MITIGATION SURVEY TEAM

After the President officially declares a disaster, the Federal and State governments jointly form a Hazard Mitigation Survey Team (HMST). This team is composed of Federal, State, and local government officials, and is charged with evaluating all aspects of response and recovery and recommending mitigation measures. The recommendations are then turned over to State and local governments and must be considered in Federally mandated disaster plans as a condition for receiving Federal disaster relief funds. The authors served on the HMST for the Loma Prieta earthquake and were able to draft recommendations and overall content for the team report (Federal Emergency Management Agency, 1990). That report is a blueprint for reducing earthquake hazards in California and is a good example to show the value of having scientific input from the outset. The authors were able to monitor information about the causes and effects of the earthquake through activities and reports of USGS scientific staff and to condense this information into advice on immediate and long-term needs for disaster reduction. These needs were translated into written statements of work elements, including scientific background, assignment of entities to do the work, designation of possible sources of funding, and work schedules. Such recommendations generally require significant scientific input on issues such as landslide hazards, site-specific shaking hazards, coastal bluff hazards, liquefaction hazards, and seismic criteria for building codes.

The overall influence of the HMST recommendations on new legislation would probably be very difficult to determine. Nonetheless, the continuing work for seismic safety by the diverse partnership of professional communities reflected in the HMST report illustrates the persistence required to effect new legislation on hazard reduction.

COMMUNICATIONS

The most important requirement for interacting among various agencies and institutions during the response to a disaster situation is the capability to communicate. Communications systems must be rapid, reliable, and sufficiently robust to remain operational through the earthquake. As demonstrated during the Loma Prieta earthquake response, the commercial telephone system does not meet these requirements. It is susceptible to saturation by overuse, damage to lines and equipment, and, for some systems internal to an institution, to power failures. Connectivity of communications links to other organizations should be specified in agency response plans and coordinated with the Federal Plan through deliberate planning.

Communications systems used during disaster response must provide for information flow between field locations, from field sites to regional headquarters and thence to national headquarters, from those headquarters to other agencies conducting response operations, and to the general public through the media. Because large amounts of data may need to be transmitted rapidly, provision must be made for systems to handle data flow as well as voice reports. Systems must employ equipment that is in place and used on a regular basis to ensure operability when needed during an actual emergency. Personnel should be trained in the operation of this equipment and should practice using it during local and regional earthquake response exercises. The only outside communications link with the USGS that is presently provided for under the Plan is between the National Earthquake Information Center in Golden, Colorado, and FEMA headquarters in Washington, D.C. This link serves for the primary notification from the USGS that a major earthquake has occurred and for providing additional information on that earthquake. Other links of this type are being developed.

An agency or institution can ordinarily establish communications for field operations using its existing assets. Communications to the general public through the news media are usually effected using those media's facilities. However, communications with other responding agencies, other than by commercial telephone, are not part of the normal course of affairs for a research institution. Thus, in order to mount an effective response, communications between responding agencies must be prepared through advance planning. A communication link should be established as soon as possible to connect the Science Advisor at the Disaster Field Office (DFO) to USGS field headquarters. The DFO can then distribute messages from the USGS to the various Emergency Support Functions (ESF's) as necessary. For this to be effective, message routing must be understood and the authority to release messages must be in place. At the DFO, FEMA normally sets up the Mobile Air Transportable Telecommunications System (MATTS). Among other features, MATTS continuously displays on a large television monitor a running account of significant response actions, status reports, and other information valuable to managing the ESF operations. Another monitor may display a regional map in a Geographic Information System (GIS), keyed to a variety of demographic data, that can be altered and viewed at different scales. ESF's can enter data directly into the text stream of the first display using systems on personal computers. This can be an effective method of disseminating up-to-the-minute scientific information, such as aftershock probabilities, locations and conditions at ground-failure sites, and risk estimates, to responding agencies.

These communications links in a disaster response are best established using satellite-based systems for maximum flexibility and survivability.

CONCLUSIONS AND RECOMMENDATIONS

The response of the earth-science community to the Loma Prieta earthquake was helped by several favorable factors: the proximity of many scientists and their resources to the affected area; significant, rapid volunteerism; excellent weather conditions; continuous media coverage; the relatively minor damage from such a large earthquake; and the extensive knowledge about regional geological conditions derived from decades of intensive investigations. In future earthquakes in this same region and in other regions, many of these favorable conditions might not be met. Therefore, any insufficiencies of the earth-science response identified from the Loma Prieta earthquake experience could be greatly magnified in another large earthquake unless careful advance planning is done.

The U.S. Geological Survey became the primary coordinating agency for earth-science response to the Loma Prieta earthquake because of its well-known presence in the affected region, not because of any official policy. It is likely that the USGS will assume a similar role in future large earthquakes in the San Francisco Bay area. The agency should therefore investigate the responsibilities of that role, both internally and in consultation with potential cooperators in disaster response, so as to be fully prepared. The USGS needs to initiate or participate strongly in earthquake-response exercises like RESPONSE-89, both to teach and to learn the roles of scientific investigators as responders in the aftermath of a large earthquake.

The primary governmental agencies charged with disaster response should clarify the nature of their charges and their responsibilities to each other and set these out explicitly through formal agreements and plans. Such agreements will help reduce misunderstandings about responsibilities and jurisdictions and provide both the public and the agencies with clearer and more complete information. The USGS (and other scientific research organizations) have not generally seen themselves in primary disaster-response roles. They should now recognize that they do have such roles and should involve themselves more directly with the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and the California Governor's Office of Emergency Services. After a major earthquake, these agencies need frequent scientific briefings, and they can in turn provide funding, equipment, people, geotechnical data, and other benefits to the earth-science research community. One major contribution that the earth science community could provide is immediate notification of the parameters and expected effects of an earthquake. This information can then form a basis for initial response using preassigned missions (the "push system"), without waiting for direct reports of damage and casualties.

Scientific agencies like the USGS should make formal organizational connections between their research capabilities and the needs of disaster response. To do this they should develop internal response plans; participate through the National Earthquake Hazards Reduction Program in the Plan for Federal Response to a Catastrophic Earthquake (now the Federal Response Plan); identify selected scientists for participation on Hazard Mitigation Survey Teams and public affairs teams; prepare warning statements and practice issuing warnings; and draw from recent experiences during responses to disasters to undertake formal advance planning.

The U.S. Geological Survey should ensure that its communications facilities are disaster resistant and should participate in systems like the Mobile Air Transportable Telecommunications System of FEMA through the Disaster Field Office during active disaster response. The interchange of real-time information that this will allow with governmental Emergency Support Functions and people who must make the immediate decisions about what to do next in critical situations would have many advantages to the earth-science community and to society.

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