# REAL-TIME EARTHQUAKE HAZARD ASSESSMENT IN CALIFORNIA: THE EARLY POST-EARTHQUAKE DAMAGE ASSESSMENT TOOL AND THE CALTECH-USGS BROADCAST OF EARTHQUAKES

Ronald T. Eguchi[1], James D. Goltz[2], Hope A. Seligson[3] and Thomas H. Heaton[4]

## ABSTRACT

A real-time earthquake monitoring system which provides source parameters to user groups through a commercial paging service is now in place in California. A GIS-based system to predict and display near real-time damage and casualty estimates is currently being developed by EQE International under contract with the State of California. These new technologies offer immediate tangible benefits to state and local governments, utilities, lifelines and corporations with facilities or operations at risk. This paper will outline the development of these new technologies, identify the contributions they will make to emergency management and explore some directions these innovative systems may take in the future.

## Introduction

In the immediate aftermath of a major damaging earthquake, local governments face the difficult task of rapidly allocating life safety services and identifying severely damaged structures, particularly damage to critical facilities. In the past, this task has often been characterized by a lengthy period of reconnaissance during which inaccurate reports, distortions and rumors must be separated from factual disaster intelligence painstakingly gathered from multiple sources. State government, responsible for assisting impacted cities and counties through the mutual aid system, also relies on this chaotic information gathering process.

During the days immediately following the October 17, 1989 Loma Prieta earthquake, several relatively isolated incidents received a lion's share of attention. Much of this attention was media-driven due to the concentration of local and national news organizations in the area to cover the World Series. The extent of structural damage in the region, beyond the collapse of the Cypress structure, the Marina District fire and the fallen span of the Bay

1 Vice President, EQE International, 18101 Von Karman Ave., Suite 400, Irvine, CA 92715-1032
2 Senior Planner, EQE International, Irvine, CA
3 Senior Project Engineer, EQE International, Irvine, CA
4 Research Geophysicist, United States Geological Survey, 525 S. Wilson Ave., Pasadena, CA 91101

Bridge, was not well understood for several days. Even several weeks after the earthquake, there remained considerable uncertainty regarding the number of buildings moderately or severely damaged. The Cities of San Francisco and Oakland initially estimated that 1400 and 500 buildings were severely impacted, respectively. The actual number of buildings requiring structural repair due to the earthquake was significantly higher for each city.

An automated rapid damage assessment capability would alleviate much of the uncertainty, delays and inaccurate information which characterize traditional approaches to post-earthquake intelligence gathering. While methods for estimating regional damage have been available for several years, they are generally time consuming efforts and have not been implemented in the real-time post-earthquake environment. In the remainder of this paper, we will discuss the development of two new technologies, one of which is currently available and a second which will be available within the next year. The Caltech-U.S. Geological Survey Broadcast of Earthquakes (CUBE) system provides earthquake magnitude and location information to participating organizations through a commercial paging system within minutes of an earthquake. Currently under development for the California Office of Emergency Services and the United States Geological Survey, the Early Post-Earthquake Damage Assessment Tool (EPEDAT), rapidly estimates damage and casualties based on the source parameters of an actual or scenario earthquake.

## New Technologies for Real-Time Earthquake Hazard Assessment

### The Caltech-USGS Broadcast of Earthquakes (CUBE)

The information on earthquake events provided through CUBE is the product of a cooperative effort between the California Institute of Technology and the United States Geological Survey (California Institute of Technology, 1992). The two organizations jointly operate the Caltech-USGS Southern California Seismic Network consisting of over 200 seismic stations which locate an average of 10,000 earthquakes every year. In 1992, due to the Landers and Big Bear events and their aftershocks, that number approached 45,000. The area covered by the network includes the major cities of Los Angeles and San Diego and a population at risk of more than 20 million.

Currently, the Southern California Seismic Network consists of 220 conventional short-period stations positioned approximately 15 to 30 kilometers apart over an area of 150,000 square kilometers. The data provided by these stations is augmented by additional sensors. Ten stations have three-component seismometers and an additional vertical seismometer running at a lower magnification. Fourteen stations have three-component force balance accelerometers to measure ground motions generated by large earthquakes. Signals recorded by these stations are sent via analog telemetry, telephone lines, and microwave links to the seismological laboratory at Caltech in Pasadena.

Data received at the seismological laboratory are automatically digitized and analyzed to determine earthquake locations and magnitudes for CUBE. This information is then disseminated to CUBE subscribers via commercial radio pager service. CUBE participants receive the time of occurrence, preliminary magnitude and location of earthquakes in two forms: as a digital readout on a belt pager (location is expressed in both longitude/latitude and as an alpha-numeric description) for earthquakes of magnitude 3 or greater, and through the

CUBE Automatic Display System which utilizes a pager-personal computer link to plot the locations of all earthquakes on a map. Still under development is the software to display preliminary ground motion estimates for large earthquakes.

Caltech and the Pasadena office of the USGS are also collaborating on the development of an advanced new seismic network called TERRAscope. These are three-component stations with 200dB dynamic ranges that measure the complete spectrum of ground motions encountered in the earth, including strong motions. Fourteen of these stations are currently operating and an additional ten should become operational within a year. It is thus anticipated that at least 40 strong motion stations with real-time telemetry will be available in the near future. CUBE software is now being modified so peak ground motions from these strong motion stations will be transmitted and displayed on CUBE personal computers. These ground motions can be used to prepare preliminary contour maps of the spatial distribution of shaking intensity.

Participation in the CUBE program is available through membership in the Earthquake Research Affiliates of Caltech (ERA). The governing body of the CUBE system, called the quorum, is made up of earth scientists and engineers from the U.S. Geological Survey and Caltech. "Level III" members of ERA are eligible to participate in CUBE and financial contributions from all ERA members support the costs of improvements to CUBE. Participants in the CUBE program include water, power, gas and telephone utilities, railroads and state and local offices of emergency services.

**Early Post-Earthquake Damage Assessment Tool (EPEDAT)**

Currently under development by EQE International is a GIS-based system capable of modeling building and lifeline damage and estimating casualties in near real-time given the source parameters of an earthquake. To date, no system for rapid damage assessment of structures has been available due at least partially to a lack of adequate building inventory information. The EPEDAT system will use computerized data files obtained from county assessor building inventories including the latest information on seismically vulnerable buildings.

EPEDAT will utilize fault and seismicity data to locate the most likely source of an earthquake. Applicable ground motion and soil amplification models will be employed to estimate the expected intensity patterns in the affected area. These intensities will then be overlain onto the computerized data files containing an aggregate listing of buildings and lifelines in the region. Based on damage and casualty models already developed under contract with the State of California, and the intensity patterns computed, building and lifeline damage as well as casualty statistics will be estimated for the impacted area.

In addition to providing near real-time damage and casualty estimates, EPEDAT will allow the user to update early estimates with actual reconnaissance data. Thus, as more accurate and specific data becomes available, it can be incorporated to refine or correct initial predictions. Such a system will have obvious value to state and local government, utilities and lifelines, major corporations and others. EPEDAT will assist first responders in allocating fire, medical, search and rescue and other emergency services in the immediate aftermath of a locally damaging earthquake. The system will assist government agencies to maintain better records of earthquake-induced damage, information that will be used in requesting federal disaster assistance during the recovery period.

Development of EPEDAT will require the integration of several systems, models and databases. In general, the EPEDAT system requirements (Dames and Moore, 1992) are as follows:

- Computerized data files on active fault systems, regional soil information, building inventories, and population distributions must be assembled and made easily accessible.

- Damage and casualty estimation models must allow for rapid calculations based on limited structural, building use and population exposure data.

- Damage estimation routines must allow for updating of initial damage estimates in order to incorporate field and reconnaissance information after the event.

- The computer system must be user-friendly to permit easy access by emergency response personnel. This system would be PC-based to allow for independent usage as well as transferability.

- The system should facilitate the construction of various "what if" scenarios to investigate the range of impacts that may occur given actual or hypothesized earthquake events.

- The system should incorporate effective graphic displays to allow the user to view projected damage scenarios. Separate screens should be developed to characterize the following risks on a regional scale:

  Number of partially collapsed buildings
  Number of totally collapsed buildings
  Number of uninhabitable residential buildings
  Number of critical facilities damaged
  Number of seriously injured
  Number of deaths
  Number of displaced individuals
  Areas of potential utility system outage
  Potentially damaged highway structures
  Areas potentially affected by hazardous materials release

- The system should be modularized so that all computer models and data bases can be easily updated.

One of the main modules of the EPEDAT system is the "rupture locator" which utilizes available fault data to determine a likely fault rupture location. This module uses recurrence data and fault geometry information to project the epicenter onto a likely causative fault and applies a deterministic rupture length relationship to estimate an appropriate rupture length. Available estimates of peak ground acceleration, telemetered in and broadcast over the CUBE system, will then be used to optimize the placement of the rupture along the fault as defined within the digitized fault database. The result translates a simple epicentral location into a likely fault rupture trace for use in predicting regional patterns of strong ground shaking.

**Combining Real-Time Hazard Assessment Technologies**

Both the current use of CUBE and the eventual capabilities envisioned for EPEDAT represent significant benefits to the emergency management community, and ultimately, to public safety. The utility of EPEDAT as a "real-time" damage assessment system is critically dependent upon the rapid availability of earthquake source parameters in order to initiate the calculation of damage and casualty estimates. The most expeditious method of initiating these calculations would be to link EPEDAT to the CUBE system in such a way that data from CUBE would trigger EPEDAT operation, even in the absence of a human operator. Upon the arrival of emergency response personnel, real-time data on magnitude and location would already have been used to develop a damage and casualty scenario which could then be used to guide emergency response.

Consider the example of CUBE and EPEDAT operation presented in Figures 1-3. Figure 1 represents five simplified EPEDAT screens, the first contains only the preliminary magnitude (M8) and the latitude/longitude of the event plotted on a map of southern California divided into counties. This data could have been broadcast over a special CUBE pager with a direct data link to a personal computer operating the EPEDAT system. Screen 2 overlays the mapped faults in the area indicating that the causative fault is probably the San Andreas with involvement of the San Bernardino Mountains and adjacent segments. The third screen depicts the calculation of fault rupture length and shaking intensities based on available source data from CUBE. Screen 4 reveals the distribution system for a water utility's pipeline system with location, fault rupture and ground shaking intensities overlain. Finally, the last screen indicates the number of pipeline repairs likely at specific MMI intensity levels.

Figure 2 provides a more detailed view of EPEDAT capability to identify those segments of pipeline likely to have been damaged in the earthquake. Figure 3 provides a detailed report of predicted breaks for each pipeline segment. A segment is selected by pointing to it with the computer mouse and clicking on it. The point-and-click operation activates a pop-up window detailing segment characteristics for the scenario. Different segments may be inspected by using the "next segment" buttons to access an adjacent segment of the pipeline. This type of selection/display option will be developed for each damage and casualty measure. Recall that computer routines will allow new information to be entered to modify or correct initial predictions.

## The Future of Real-time Earthquake Hazard Assessment

In 1990, the California Office of Emergency Services initiated a study to assess earthquake hazards on the southern San Andreas fault. As this study progressed and new dimensions were added to the original scope of work, discussions led to the conceptualization of a GIS-based system to estimate damage and casualties in near real-time. The basic dimensions of the EPEDAT system have been described in this paper and EQE International, under contract with California OES, will soon begin work to develop EPEDAT. State emergency response officials plan to integrate this new technology into current plans and

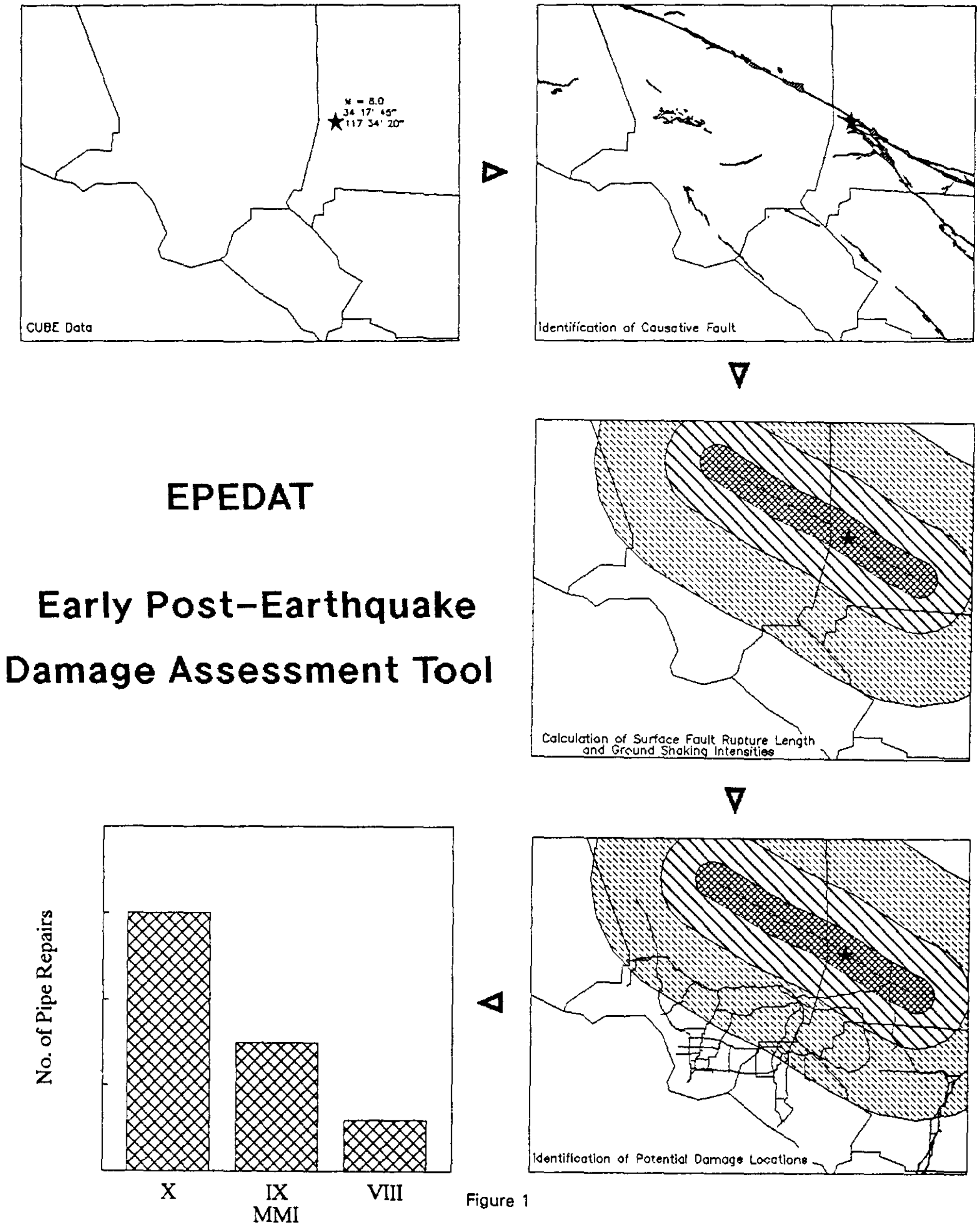
M = 8.0
34 17' 45"
117 34' 20"
CUBE Data
Identification of Causative Fault
EPEDAT
Early Post-Earthquake
Damage Assessment Tool
Calculation of Surface Fault Rupture Length and Ground Shaking Intensities
Identification of Potential Damage Locations
No. of Pipe Repairs
X
IX
VIII
MMI

Figure 1

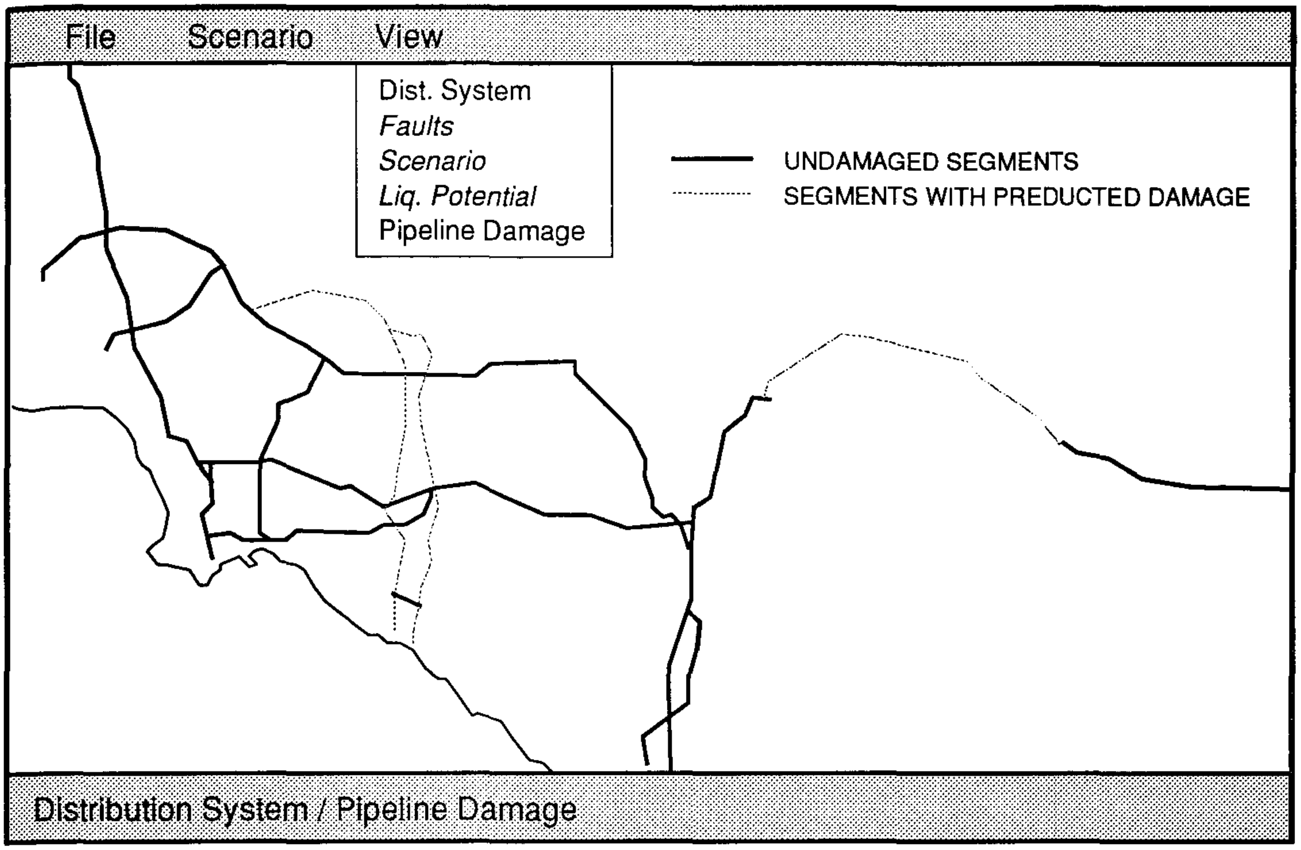


Figure 2: Sample EPEDAT Screen - Pipeline Damage

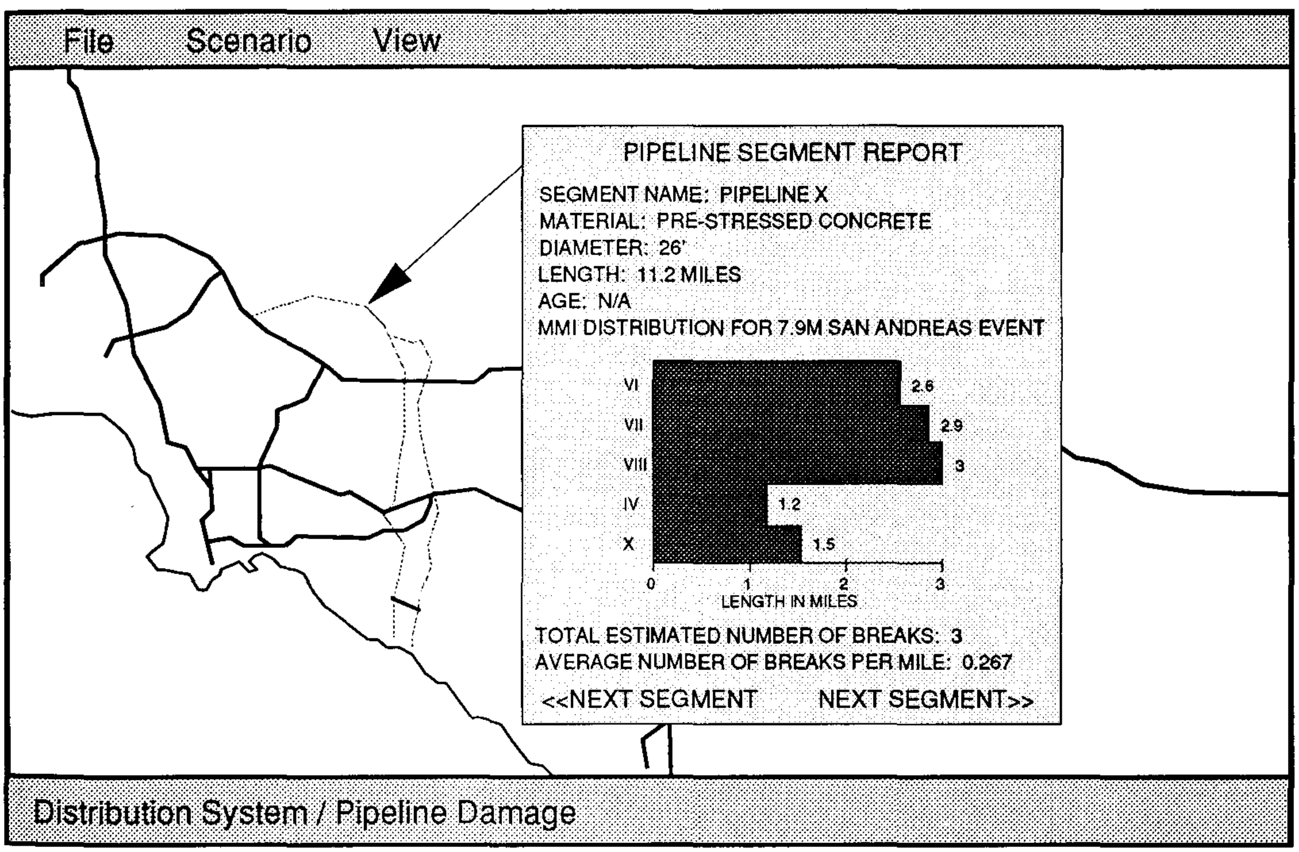


Figure 3: Sample EPEDAT Screen - Pipeline Segment Report

procedures including sharing damage and casualty projections from EPEDAT with earthquake impacted local "operational areas" through the state's Operational Area Satellite Communications System (OASIS) and use these projections to direct state operations in an earthquake disaster.

In addition to improved emergency response and recovery capabilities, EPEDAT will assist in preparedness and mitigation efforts by facilitating the detailed development of numerous hypothetical earthquake scenarios which could be used in planning, local and regional training exercises and the identification of vulnerable structures to prioritize structural mitigation. If linked with CUBE, EPEDAT may also play a significant role in the evaluation of short-term future seismic potential. New methodologies have been developed for assessing the probabilities of large earthquakes based on the characteristics of events which may be foreshocks (Jones, 1985; Reasenberg and Jones, 1989). The calculation of these probabilities could be integrated into the EPEDAT system such that the occurrence of an earthquake with a significant likelihood of being a foreshock would initiate damage and casualty projections for a "predicted" earthquake. Based on these projections, state officials would have a sound basis for determining whether to issue an earthquake warning as well as assess to whom the warning should be directed.

Early warning of ground shaking is a long-term goal of CUBE. Extremely rapid analysis (within several seconds) of telemetered strong motion data will allow the transmission of earthquake shaking projections to many sites, including utilities and critical facilities, before the actual seismic waves arrive. In large earthquakes, these warning times could be several tens of seconds in length depending on the distance of the site from the earthquake epicenter and could be used to trigger automated responses to decrease earthquake losses (Heaton, 1985; National Research Council, 1991). An earthquake early warning system using data from CUBE could provide sufficient time to shut down some utility and manufacturing processes and initiate personal safety precautions in schools, offices and factories.

The integration of these new technologies, their pilot testing and transfer to seismically vulnerable regions of the United States is possible and desirable. Real-time earthquake hazard analysis, as a comprehensive scientific and emergency management system, will produce dramatic improvements in all phases of an earthquake emergency--in early warning and the evaluation of short-term seismic potential, in response, through improvements in the speed and accuracy of situation assessment and the capability to rapidly allocate life-saving emergency services, and in recovery, where the accuracy of damage and loss data will expedite the disaster assistance process and hasten the rebuilding of an impacted community.

## Acknowledgements

The authors wish to thank the State of California, Office of Emergency Services, the United States Geological Survey and the California Institute of Technology for assistance in providing documents and verbal information used in preparation of this paper.

## References


California Institute of Technology. "CUBE Handbook", Pasadena, 1992

Dames and Moore. "Seismic Vulnerability Assessment of Southern California: Draft Report". Los Angeles, 1992.

Heaton, Thomas H. "A Model for a Seismic Computerized Alert Network" Science 228 (May, 1985): 987-990.

Jones, L. M. "Foreshocks and Time Dependent Earthquake Hazard Assessment in Southern California" Bulletin of the Seismological Society of America 75 (December, 1985): 1669-1679.

National Research Council "Real-Time Earthquake Monitoring: Early Warning and Rapid Response" Washington, D.C., 1991

Reasenberg, P.A. and Jones, L.M. "Earthquake Hazard After a Mainshock in California". Science 243 (March, 1989): 1173-1176.