

Major Improvements in Progress for Southern California Earthquake Monitoring

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Major improvements in seismic and strong-motion monitoring networks are being implemented in southern California to better meet the needs of emergency response personnel, structural engineers, and the research community in promoting earthquake hazard reduction. Known as the TriNet project, the improvements are being coordinated by the California Institute of Technology (Caltech), the U.S. Geological Survey (USGS), and the California Division of Mines and Geology (CDMG) of the state's Department of Conservation. Already the ambitious instrument and system development project has started to record and disseminate ground motions from a spatially dense and robust network of high quality seismographs.

Deficiencies in the southern California seismic monitoring network and in other networks became apparent with the 1994 Northridge, California, earthquake and the 1995 Kobe, Japan, earthquake. Both earthquakes occurred in relatively well-monitored regions but certain vital information was lacking in the instrument data. In the Northridge event, in which there was about \$30 billion in losses, there was extensive damage to a large number of structures including the well-publicized problem of cracks in the welds of large steel frame buildings [Krawinkler *et al.*, 1995]. There were, however, relatively few strong-motion recordings to document the actual ground shaking that caused the damage. In Kobe, where over 6,000 people were killed and some \$200 billion in damage was caused, there was a lack of real-time information that might have facilitated emergency response, as well as a lack of strong-motion data.

Main Objectives

The TriNet project has three main objectives.

The first is to provide ground shaking data within just several minutes of a damaging earthquake so that the effectiveness of emergency response can be increased. Point

measurements at the critical locations and contour maps of the affected areas will be distributed quickly to local emergency response groups so that appropriate measures can be taken in heavily impacted areas.

The second objective is to record ground motion data in order to improve seismic provisions in building codes and in research. Regulatory decisions on building and retrofit practices are in need of this better information on expected ground motions. The array of wide-dynamic range and broadband instrumentation will also provide some of the best data on local, regional, and teleseismic waveforms for seismological research.

The third objective is to develop a prototype early warning system. Ground motion information will be rapidly recorded, analyzed, and communicated to test user sites. Seismic waves travel at the speed of a few kilometers per second, so rapid interpretation of earthquake information is essential for an early warning to distant locations (over 100 km) that large seismic waves from an earthquake are on the way. This is the situation for Los Angeles with respect to the San Andreas fault where a 10-40 second warning could be given before the intense shaking from a large San Andreas earthquake arrives in Los Angeles.

The Caltech/USGS segment of the project involves upgrading the regional seismic network into a modern system with broadband and high dynamic-range recording combined with new digital telemetry technologies. The CDMG segment is closely tied in with Caltech and USGS to integrate extensive strong motion recording into the system. This instrumentation will make possible the production of several new products for distribution through the Internet and other electronic communication channels. These include

- Quick maps of potentially damaging ground shaking (ShakeMap) following significant earthquakes. Up to 670 instruments in southern California will be reporting information.

- An easily accessible database of all parametric and waveform data. This earthquake information from local and teleseismic events will provide one of the best collec-

tions of seismic data for utilization by engineers and seismologists.

- Frequency-dependent amplification maps for the Los Angeles region. These maps will quantify the geology-dependent site effects that locally amplify or attenuate shaking.

- A prototype early warning system. A system will be developed to test the feasibility of providing very rapid warnings of expected seismic waves. This will include a data utilization component which will examine the problems of implementing a system and educating users about this technology.

Evolution of the Project

Following the Northridge earthquake in 1994, the USGS received funds appropriated by Congress to the National Earthquake Hazard Reduction Program (NEHRP) to improve seismic recording in southern California. The allocation was originally split into two parts, real-time system improvements to the regional network, the other for the upgrade of strong-motion recording. Early in the planning, the USGS decided it was more appropriate to combine the two and begin to build a single system that integrated the functions of the regional seismic network with the engineering strong-motion network. Seismologists and engineers of USGS (in Pasadena and from the National Strong Motion Program) and Caltech worked together to design a system that took advantage of modern instrumentation which could record both weak motions from small events and the strong shaking from larger earthquakes.

During the 3 years before TriNet formally began, experimental systems were designed and hardware was installed. For example, 60 state-of-the-art digital seismic stations were installed with continuous communication to Caltech/USGS. New technology telemetry on frame-relay telephone lines and spread-spectrum radios were tested. Also, the USGS National Strong-Motion Program installed 30 free-field strong-motion sites, with many near critical structures. Some 40 more sites will be completed in the next year. In addition, 5 high-rise buildings were outfitted with instruments. Other monitoring installations (in a nonductile concrete building and in connection with a building drift experiment) will be completed in the next year. Software that combines and broadcasts information from the new digital signals and the existing analog system also has been designed and implemented. Experimental maps of contoured ground shaking are available on the Web (<http://www.socal.wr.usgs.gov>) within a few minutes after felt and damaging earthquakes [Wald *et al.*, 1997].

Leading up to its participation in TriNet, CDMG's California Strong Motion Instrumentation Program (CSMIP) developed a system for near real-time data recovery from strong-

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motion stations in its network [Shakal et al., 1996]. The CSMIP strong-motion monitoring system uses standard digital accelerographs at field stations throughout California which automatically transmit data via high-speed dial-out communication links to Sacramento computers using conventional phone lines. While in a pilot mode, the system automatically and rapidly transmitted and processed data from stations after several events. In contrast to the classical strong-motion network, the near real-time system creates a new type of strong-motion network with the ability to quickly recover and process data. Although not truly real-time like traditional seismic telemetry, the economy of the approach is a valuable asset given a large number of strong-motion stations. The concept of reference stations, developed by CDMG and its advisory committees, also led to the development of objectives of the TriNet project. Reference stations are ground response stations that provide recordings of the input motion in the built environment. This is key to providing information for shaking maps in the urban area and complements the traditional recordings from regional seismic stations. In the period leading up to TriNet, CDMG also installed instruments at many structures (buildings, bridges, and downhole arrays) and other stations in California.

Implementation of TriNet

With major support from the Federal Emergency Management Agency (FEMA) hazard mitigation program through the California Office of Emergency Services, the implementation of TriNet began in 1997. The project is divided into two elements with the real-time information emphasis centered at Caltech and USGS in Pasadena and the extensive collection of strong-motion data for engineering purposes centered at CDMG in Sacramento. By 2002, there will be 670 stations in southern California. Caltech and USGS will install broadband and strong-motion sensors with continuous telemetry, expanding the efforts

started by the USGS to a total of 200 high dynamic-range sites. CDMG will install new sites and upgrade existing instrumentation to provide digital strong-motion recording at 400 stations. Many of the strong-motion instruments will be part of the CDMG plan for establishing engineering reference sites throughout the region. Also included are the 70 digital strong-motion sites being installed by USGS from the NEHRP Northridge funds.

Connecting the real-time telemetry from the Caltech/USGS stations to the central processing site in Pasadena is a major challenge for the project. One of the tasks is to provide fast and reliable communications that will be robust even during the strong shaking of an earthquake. A variety of telemetry paths will be utilized to minimize any single points of failure. New technologies such as frame-relay telephone lines, spread-spectrum radios, and digital microwave links will also be utilized in the system. The 400 CDMG sites (plus the 70 USGS strong-motions sites) will be connected by dial-up telephone telemetry. These instruments will provide significant contributions to the database of strong motions recorded in southern California and provide the basis for improvements to the seismic provisions of building codes. The near real-time communication from these sites will provide additional information (on the order of tens of minutes to an hour) to the initial estimates of shaking distributions that will be provided by the real-time system. Extensive software development will be needed to handle the large volume of digital data. Central processing will be designed to handle data very quickly for the early warning applications, as well as to produce rapid estimates of earthquake source parameters and shaking distributions. The system will also provide organized databases of parametric and waveform data with accessible user interfaces.

Acknowledgements

The TriNet project is being built using existing infrastructure and with collaboration

between federal and state government, university, and private sectors. Southern California's first digital network began with the installation of seismographs known as TER-RAScope, made possible by a grant from the Whittier Foundation and the ARCO Foundation. Pacific Bell, through its CalREN Program, has provided new frame-relay digital communications technology for telemetry. The CUBE (Caltech-USGS Broadcast of Earthquakes) project, started in 1991, has formed a consortium of government agencies and private industry concerned with earthquake hazards in southern California. This group has built support for the project and provided valuable user input into the design of the earthquake information systems. In addition to the initial support from USGS and the current support from FEMA, numerous government and private organizations have made significant contributions to the funding. These include the National Science Foundation, California Trade and Commerce Agency, and Pacific Bell through the CalREN project. Cost-sharing of the FEMA funding is also provided by Caltech and CDMG. The Southern California Earthquake Center Data Center continues to provide facilities for data storage and distribution.

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