Real-Time Seismology at UC Berkeley: The Rapid Earthquake Data Integration Project
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Abstract  The Rapid Earthquake Data Integration project is a system for the fast determination of earthquake parameters in northern and central California based on data from the Berkeley Digital Seismic Network and the USGS Northern California Seismic Network. Program development started in 1993, and a prototype system began providing automatic information on earthquake location and magnitude in November of 1993 via commercial pagers and the Internet. Recent enhancements include the exchange of phase data with neighboring networks and the inauguration of processing for the determination of strong-motion parameters and seismic moment tensors.

Introduction  Interest in rapid access to earthquake information has grown enormously in the last few years. In addition to satisfying inquiries from the public and the media, rapid notification programs provide valuable information for earthquake disaster response. Recognizing the importance of this information for seismic hazard mitigation, efforts to design and implement systems to provide earthquake parameters in a timely manner have expanded over the last 5 yr at both the regional and national level (Heaton, 1985; National Research Council, 1991; Kanamori et al., 1991; Buland and Person, 1992; Romanowicz et al., 1992; Ekström, 1992; Ammon et al., 1993; Bakun et al., 1994; Malone, 1994) as well as abroad (Nakamura and Tucker, 1988; Espinosa Aranda et al., 1995).

In southern California, these efforts have produced the Caltech/USGS Broadcast of Earthquakes (CUBE) system (Hauksson et al., 1992). In its fifth year of operation, the collaborative Caltech and USGS project utilizes data from the Southern California Seismic Network (SCSN) and TERRAscope network to provide automatic earthquake information. Originally designed using Real-Time Picker (RTP) technology (Allen, 1978, 1982), CUBE currently utilizes the ISAIAH (Information on Seismic Activity in a Hurry) system (Given et al., 1994). In northern California, the USGS developed a notification project based on the Northern California Seismic Network (NCSN) in the mid-1980s, using three RTP systems (Oppenheimer et al., 1992). These hardware boxes process the short-period waveform data for P-wave arrival time and coda decay, releasing event information 144 sec later. In 1996, the aging RTP boxes were replaced by the Earthworm system, which is designed to decrease the processing time associated with event notification (Johnson et al., 1995).

The UC Berkeley Seismographic Station (BSS) has also been active in the development of methods and procedures for the rapid determination of earthquake parameters. Over the last 5 yr, the BSS has upgraded and expanded its instrumentation in northern and central California to a high-dynamic range network of three-component broadband seismometers and strong-motion sensors, with 24-bit digital data recording and continuous telemetry. In parallel with the deployment of Berkeley Digital Seismic Network (BDSN), the BSS has developed a number of analysis methods to expedite the determination of earthquake parameters. The Rapid Earthquake Data Integration (REDI) project has three major objectives: to provide near real-time locations and magnitudes of northern and central California earthquakes; to provide estimates of the rupture characteristics and the distribution of ground shaking following significant earthquakes; and to develop better tools for the rapid assessment of damage and estimation of loss. A long-term goal of the project is the development of a system to warn of imminent ground shaking in the seconds after an earthquake has initiated but before strong motions begin at sites that may be damaged.

Collaborators in the REDI project include the USGS and Caltech. This pooling of scientific expertise, technical resources, and seismic data leads to more complete and comprehensive earthquake monitoring in California. The BSS is coordinating with Caltech to provide REDI and CUBE information on a single pager and with the USGS/Menlo Park to form a single earthquake notification system for northern and central California.

System Design  The REDI project combines the BDSN and NCSN and spans a region extending south to San Luis Obispo and
Mammoth Lakes and north to Crescent City and Alturas (Fig. 1). The NCSN is an array of over 350 high-gain, short-period, vertical-component seismometers, with an additional 20 strong-motion sensors. The BDSN consists of 13 sites with three-component broadband sensors and strong-motion accelerometers and an additional five stations with downhole accelerometers. The instrumentation of the NCSN and BDSN is quite complementary, as the relatively dense spacing of the NCSN contributes to the rapid detection and location of events, particularly for smaller earthquakes, while the on-scale recordings of the BDSN provide critical information on the size and rupture characteristics of larger events.

REDI event analysis is comprised of five major elements: detection, selection, scheduling, processing, and notification (Fig. 2). While this design is compatible with a distributed computing environment, the present operation is conducted on a single SUN Sparc20 workstation.

Event Detection

The primary input to the REDI system is arrival-time information, such as P- and S-phase picks, from the BDSN and the NCSN. Phase information from TERRAscope network and the SCSN is also incorporated in order to improve the location of events on the fringes of the networks as well as to provide redundant information on southern California earthquakes. The BDSN event detections are transmitted to UC Berkeley through continuous telemetry with an average delay of 5 to 10 sec, while the parametric information from the NCSN, the SCSN, and the TERRAscope network are transferred through an IPC socket over the Internet with typical delays ranging from 10 to 240 sec.

Phase detections may be generated by a variety of mechanisms besides seismic sources. Sifting through picks generated by cultural, meteorological, and telemetry noise to find earthquakes is a difficult task, which may be further complicated by energetic aftershock sequences and swarms. An association program is used to identify and locate earthquakes, based on a phase stacking algorithm (Johnson et al., 1994), which was developed as a component of the Earthworm system at the USGS Menlo Park. The stacking algorithm is conceptually analogous to the early methods of earthquake location using S-P times from three or more stations (Richter, 1958). In this modern variant, the program forms a cone of compatible hypocenters in location—time space for a given arrival. When a sufficient number of these cones intersect, the associator forms an event and determines

Figure 1. Map of northern and central California, showing the location of the BDSN stations (squares) and NCSN stations (circles). Each of the BDSN sites is equipped with a high-gain instrument (STS-1, STS-2, or Guralp CMG-T30) as well as a strong-motion accelerometer (FBA-23). The five sites on the northern Hayward fault (inset) are borehole installations with Wilcoxon accelerometers and 4.5-Hz geophones. All BDSN sites are recorded on a SUN Sparc20 workstation at UC Berkeley using 24-bit digital data logging with continuous telemetry. The dedicated telemetry provides near real-time data acquisition, an essential component of any rapid response program.
its location. Subsequent arrivals are compared with a catalog of known events and are added to the list of associated phases if they satisfy the residual criteria. Arrivals that remain unassociated are stacked to test for the formation of new events.

Event Selection

The main task of the associator is to analyze phase picks as they are received and combine them into probable events. Because phase information is acquired continuously, the associator's "view" of an event is never static, and event information is constantly updated as additional arrivals are analyzed. A separate program uses spatial and temporal criteria to decide when an event is ready to be processed.

The spatial criteria are defined using regional polygons (Fig. 3). Each polygon is defined by a series of coordinates with associated parameters, such as the minimum number of picks and minimum magnitude, which determine whether an event is eligible for processing. For example, the REDI system will process all events with at least 10 picks in northern California regardless of magnitude, while the more stringent criteria of either a minimum of 30 picks or a preliminary magnitude greater than 4.0 are required for events in the southern California polygon. Two polygons are currently configured, and the structure can be expanded to additional regions. Events that do not meet the regional criteria are saved in an "ignore" directory and may be scheduled manually for processing.

The temporal criteria attempt to maintain a balance between the reliability of the solution and the rapidity of notification. Although the associator may locate an event within seconds based on only five picks (fewer than 2% of the northern California stations), the quality of the location may be improved by waiting for additional phase information. The selection program provides two measures of delay. The first assesses the total time from the initial association, while the second marks the time since the last change in the event. These temporal criteria can be overridden by a third parameter, which measures the number of phases associated with the event.

Event Scheduling

Once an event is selected, it is queued for analysis by the event scheduler. The scheduler oversees event processing from initiation to notification and decides which stages of analysis are required. REDI currently supports four levels of processing (Fig. 2): (1) computation of revised location; (2) computation of local magnitude; (3) estimation of peak ground acceleration, velocity, and displacement; and (4) determination of seismic moment, centroid depth, and faulting mechanism. The scheduler utilizes information about an earthquake's size and location to decide which stages are appropriate. For example, a magnitude 4 earthquake is not scheduled for stage 3 (the determination of strong-motion parameters) but is scheduled for stage 4 (the estimation of seismic moment).

The primary purpose of the scheduler is to prevent the processing computer from being overwhelmed during an earthquake sequence. To avoid this situation, the scheduler configuration limits the total number of analysis processes that may run at any time. The scheduler also reserves slots for certain critical stages and prioritizes analysis based on event magnitude and processing stage, rather than origin time. For example, REDI normally allows two processes to run. One of these two slots is reserved for stages 1 and 2, while the second may be utilized for all levels of processing. The scheduler is also charged with deleting an event, if more recent information received by the associator has destroyed the phase grouping.

Event Processing

The phase associator program determines a preliminary location and magnitude for each group of associated phases. The magnitude estimate is based on the first few seconds of the P-wave arrival (Hirshorn et al., 1993) and may be in-
accurate, while the preliminary location is generally quite good. Event processing stages improve the accuracy of the location and magnitude as well as provide additional earthquake parameters of interest. The multi-stage processing is designed to utilize the waveforms generated by the BDSN for the characterization of large earthquakes.

Revised Location and Magnitude The first stage generates a revised location using the standard 1D location program with station corrections of the BSS. Once relocated, the magnitude of the event is recomputed based on the first few cycles of the $P$-wave amplitude. If the resulting magnitude is greater than 3.0 or if no magnitude estimate is obtained, the processing software selects waveforms from the BDSN 20 samples-per-second data stream. The resulting broadband records are convolved with the Wood-Anderson instrument response to estimate local magnitude (Uhrhammer et al., 1996). In addition to the estimation of $M_L$, we have implemented an energy magnitude algorithm (Kanamori et al., 1993) to provide a more robust estimation of event size for larger earthquakes. Once the revised location and magnitude are determined, the appropriate event notification messages are constructed.

Ground Motion Parameters For events with magnitude greater than 5.5, the next stage of REDI processing generates estimates of peak ground motion and the duration of shaking from the BDSN accelerometers, providing a more direct measure of earthquake damage. At this stage, three-component waveforms from FBA-23 and Wilcoxon accelerometers are extracted for processing. After deconvolving the instrument response and filtering the data above a 10-sec period, peak ground acceleration, peak ground velocity, and peak ground displacement are estimated from the records. In addition, the duration of strong shaking above the levels of 5%, 10%, 20%, and 50% $g$ are determined. Currently, only values of peak ground acceleration which exceed 2% $g$ are queued for notification to avoid saturation of the broadcast system. This processing stage includes the estimation of the strong-motion centroid, using the amplitude location procedure of Kanamori (1993), and the construction of contour maps of peak ground motion.

Moment Tensor The fourth stage of processing is invoked for events with magnitude greater than 3.5 and provides robust estimates of event size, depth, and source mechanism. Two methodologies of moment tensor estimation are being tested. The first set is based on the complete waveform modeling within the frequency range 0.01 to 0.1 Hz (Dreger and Romanowicz, 1994), while the second methodology utilizes fundamental-mode surface waves with periods between 15 and 45 sec for events with magnitude less than 5.5 and between 25 and 70 sec for larger events (Romanowicz et al., 1993). While this effort is still in the development stages (the results from these procedures are reviewed before release), the preliminary results are encouraging. For example, the moment tensor estimation codes were manually operated at the time of the 01/17/94 Northridge earthquake ($M_w$ 6.7).
and E-mail notification of the focal mechanism was released 3.6 hr after the event. When the 08/28/94 Tres Pinos earthquake ($M_c$, 3.8) occurred, the automated codes were operational. A solution was obtained approximately 14 min after the event, and the revised solution was released 34 min after the earthquake occurred. Recent efforts have reduced the moment tensor computation time to 3 to 8 min (Pasyanos et al., 1996). In the short term, we anticipate incorporating both methodologies for the robust determination of $M_w$, since the moment and moment magnitude are better descriptors of the energy released by an earthquake than conventional magnitude estimates. This implementation will provide revised magnitude estimates using an “update notification” mechanism if $M_w$ differs from the estimate of $M_l$ by more than 0.25 units. In the longer term, the moment tensor information is valuable for identification of the likely fault plane, particularly when complemented by directivity estimates (Dreger, 1994).

Event Notification

At the completion of each processing stage, the appropriate notification is dispatched using a series of regional polygons to determine suitability for broadcast (Fig. 3). For example, earthquake location and magnitude are broadcast as soon as the computation of those parameters is complete—before the next stage of processing is initiated. This structure makes it simple to control notification for different stages and regions. For example, if a major earthquake should prevent Caltech from distributing the CUBE information, the notification configuration file could be edited to “turn on” the broadcast flag for the southern California polygon. This change would permit the REDI system to distribute information about southern California earthquakes to CUBE recipients. Current policy allows this change to be made only in response to a request from Caltech; we hope to establish policies and procedures that allow this modification to be made automatically in the future.

Notification levels are based on magnitude, with cutoffs of 1.8, 3.0, and 4.5. The first category is designed for users who wish to view background seismicity. Software developed by Caltech (Kanamori et al., 1991) runs on a personal computer and receives earthquake information over a serial line from either a pager or some other data source. The earthquakes are plotted on a map of California, with roads, faults, and other features of interest. The higher levels are designed for users who are interested in larger events, such as BSS personnel who receive the second level of broadcast.

REDI uses both commercial paging systems and electronic mail to notify participants of earthquake occurrence. The communication with the primary paging company is via a dedicated leased telephone line, with a dial-up telephone link as a backup. The list of events is also available through the Internet via the “finger quake” command (Malone, 1994) as well as on the WWW server for the Northern California Earthquake Data Center (http://quake.geo.berkeley.edu). We have collaborated with Caltech to format messages identical to those generated by the CUBE system and coordinated broadcasts such that a single pager may receive information from both the REDI and the CUBE systems.

A number of agencies, including the California Office of Emergency Services, the California Division of Mines and Geology, the California Department of Transportation, Pacific Bell, Southern Pacific Transportation, Peninsula Commute Service, and EQE International receive earthquake information from the REDI system to enhance their emergency response operations. In addition to the emergency operations application, educational displays are also installed at a number of universities, such as Cal State Fresno, Humboldt State University, UC Berkeley, UC Davis, and UC San Diego, and museums, such as the Lawrence Hall of Science.

System Performance and Reliability

While most events processed by the automatic system have been small earthquakes, a number of magnitude 4 and larger earthquakes have been analyzed. REDI solutions are reviewed each day by BSS analysts, who revise the information as necessary. In the case of larger events ($M \geq 4.0$), the seismologist on duty will evaluate the automatic information within 10 to 20 min and provide updated solutions if needed.

On a day-to-day basis, REDI has performed quite well, although both telemetry glitches and teleseisms pose problems for any automatic system. Telemetry glitches, such as microwave noise, are not screened out in the current system and can create spurious events. Fortunately, the use of the BDSN waveforms to determine magnitude generally prevents these glitches from being mistaken for large earthquakes. On the other hand, teleseisms with significant high-frequency energy (for example, the 9 June 1994 Bolivia earthquake) can trigger the NCSN and BDSN instruments and generate false regional events. In this case, the estimated magnitude can be quite large due to large-amplitude arrivals. We are testing procedures for detecting telemetry glitches and teleseisms, based on the pattern of arrival times.

To demonstrate aspects of REDI processing, we present examples from three recent northern California earthquakes (Fig. 4). Figures 5 and 6 show chronologies for stages 1 and 2 processing that display the epicentral location error between the REDI solution and the final UCB catalog epicenter as a function of time after the earthquake initiation ($t_0$). Each “dot” represents the REDI solution at that particular time; vertical lines indicate various REDI stages, including the arrival of the first BDSN pick, the first event association, the arrival of the first NCSN pick, the event selection, and the event notification. In Figure 5, the 03/15/95 Berkeley event illustrates the typical time delays associated with smaller earthquakes, when BDSN waveforms are not used, while the 12/07/94 Alum Rock earthquake displays time delays associated with processing those waveforms. For both events, the first pick received by REDI originated from the BDSN event detectors, and a preliminary location was estimated.
within 30 sec, based only on BDSN arrivals (the 30-sec delay is due the sparse distribution of the BDSN and represents the travel time required for five stations to have triggered). Approximately 220 sec after the events initiated, the first picks from the NCSN RTP systems were received, and the events were selected for processing between 60 and 90 sec later. The preliminary magnitude estimate of the Berkeley earthquake was 2.8, which is below the cutoff for ML determination, and stages 1 and 2 were completed without processing BDSN waveforms 340 sec after the earthquake originated. This P-wave magnitude slightly underestimated the UCB catalog \( M_L \) of 3.0. In the case of the Alum Rock event, the preliminary magnitude estimate was 3.7, prompting the extraction of BDSN waveforms for \( M_L \) estimation. The processing of stages 1 and 2 was completed within 372 sec, and the REDI magnitude of 3.8 was identical to the final UCB catalog \( M_L \).

Since these earthquakes were located within the network, the BDSN-only locations are reasonably good, and this preliminary information could have been distributed within 60 sec. In general, however, the locations based on BDSN event detections may be less accurate, and the selection program is currently configured to wait some number of seconds after the preliminary association before selecting an event for processing. The delays associated with the NCSN picks are primarily due to the coda estimation procedure of the RTP systems, and in these examples, the first picks from the NCSN were received between 210 and 225 sec after the event initiated. These chronologies indicate that the delayed triggering of the NCSN RTP systems accounts for approximately half of REDI processing time. Replacement of the RTP hardware with the Earthworm system should reduce processing times to less than 3 min from the current 6 to 9 min.

A glimpse of this future is offered by the chronology of the 04/23/95 San Benito earthquake. Figure 6 compares the timing of the REDI system with a test configuration that was operating at the same time on a different computer. During this comparison, the REDI system was receiving picks from the NCSN and the BDSN, while the test system received picks...
from TERRAscope and SCSN in addition to the northern California networks. The contrast in processing time is striking—over 9 min were required to complete stages 1 and 2 on the production system compared with 3 min on the test system. This difference is due to the speed with which the ISAIAH system in southern California can generate phase picks. This event triggered a significant number of SCSN stations, and the first event association contained BDSN and SCSN arrivals. The event was selected within a minute of initiation; waveform extraction and manipulation required an additional 2 min. This example gives us confidence that the time delays associated with event notification in the REDI system will be significantly reduced with the replacement of the NCSN RTP hardware.

The San Benito event also provides an example of the automated moment tensor procedures. Although the multi-stage processing was not completely implemented at the time of this event, the automatic moment tensor codes were running, triggered by E-mail from the REDI system. These codes completed processing 7 min after the E-mail was received, and a hand-checked, revised solution was available within 60 min of the earthquake (Fig. 7). The comparison between the automatic and reviewed solution is quite good, with only slight variations in the dip and rake of the fault plane and the seismic moment.

More important than the day-to-day operation of REDI, however, is its performance for large earthquakes. On 1 September 1994, a magnitude 6.9 event struck northern California off the coast of Cape Mendocino and was broadcast by REDI within 9 min. Although REDI performed well in determining the location and magnitude for this event, the system created three additional “ghost” events. Ghost earthquakes are not real events; they represent the failure of the automatic system to interpret the input data correctly. In this case, two problems in REDI contributed to the ghost earthquakes—event “splitting” in the phase associator and event “echoing” of the BDSN event detectors.

Event splitting is caused primarily by inadequacies in
the velocity model and residual tapers used for phase association. Larger earthquakes will trigger most of the stations in northern and central California, creating a blizzard of phase picks. The 1D velocity model in the associator has difficulty predicting the travel times for distant arrivals and may fail to associate them correctly. These arrivals, which have been "split" from the correct earthquake, may stack to form a ghost event. Event echoing is caused by retriggering of the event detectors, which creates an "echo" of the earthquake. Once triggered, the detectors (Murdock and Hutt, 1983) turn off for some time period before returning to detection mode. The BDSN implementation will retrigger 55 sec after the preliminary detection if the event is ongoing, which generates a duplicate or echoed event 55 sec after the origin time of the earthquake. These problems have been reduced since the installation of a new version of the association algorithm that utilizes pick "weights" in the phase stack.

System Robustness

The Northridge earthquake demonstrated the fragility of rapid notification systems to disruption by earthquakes. While we have studied the various points of failure experienced by the CUBE system and have attempted to alleviate potential problems, a number of weak links remain. We see the question of increasing the reliability of these automatic systems as comprised of two elements: (1) improving the robustness of the individual systems through efforts to provide uninterrupted power and communications and (2) establishing redundant capability at other institutions. Redundant capability is a particularly important issue, as the facilities of UC Berkeley and the USGS Menlo Park are at risk from earthquakes in the San Francisco Bay area, and the facilities of Caltech and the USGS Pasadena are threatened by events in the Los Angeles basin.

As part of the effort to create a robust system, each BDSN site is provided with an uninterruptible power supply (UPS) and 72 hr of backup battery power. The central facilities of the BSS have a UPS and an oil generator with a 4-day supply of fuel. At present, the BDSN employs a combination of telephone, microwave, and radio links for the continuous telemetry with the goals of both providing rapid access and maintaining a permanent archive. These dual goals require significantly higher bandwidth than either goal individually, and we are exploring alternative solutions to the problem of reliable and cost-effective telemetry for the BDSN. One direction is frame relay telecommunications, which establishes a 56 Kbps virtual circuit between the BDSN stations and UC Berkeley. This approach, which is being tested by Caltech and UC Berkeley with support from Pacific Bell through the CalREN foundation, provides exceptional bandwidth at costs that are commensurate with current telemetry (Maechling et al., 1994; Neuhouser et al., 1995). However, it is unclear what type of disruptions will be experienced by frame relay service during a large earthquake.

One advantage of the frame relay technology is the ability to establish multiple "permanent virtual circuits." This capability will allow the BSS to establish a remote emergency operations facility that will receive and process an identical data stream from a subset of our seismic stations, providing redundancy for REDI earthquake notification.

On the other hand, satellite telemetry is an attractive way to eliminate vulnerable land lines and is extensively used by the U.S. National Seismic System (USNSN). Three stations of the BDSN contribute to the USNSN, and the BSS receives a "loopback" link from the USNSN of these three sites as well as from the TERRAscope station ISA via satellite. The REDI system utilizes these data in case of the failure of the normal BDSN data acquisition, and these four stations provide limited, but sufficient, coverage of northern and central California for the determination of local magnitude and focal mechanism of larger \(M > 4.0\) events.

As part of the plan to establish redundant capability, the current Internet-based data exchange between UC Berkeley, USGS Menlo Park, and Caltech will be replaced with a satellite-based system. Although the Internet is a relatively inexpensive medium for transmitting parametric data between institutions, it is not particularly robust and is subject to disruption due to the failure of routers and other critical hardware devices. The California Office of Emergency Services has provided these three groups with very small aperture telecommunications units and has agreed to dedicate three 56 Kbps circuits connecting UC Berkeley, Caltech, and the USGS Menlo Park for the rapid and robust exchange of phase and amplitude information. This connection is one step toward establishing redundant capability between northern and southern California, although it does not solve the essential problem of data transmission from remote seismometers to a central processing facility.

Future Directions

In early 1996, the BSS and the USGS Menlo Park formed a joint earthquake notification system for northern and central California. This system merges Earthworm and REDI in a collaborative project. Under this plan, REDI processing is driven by earthquake detections from the Earthworm system, rather than the event detection/event selection scheme of the original operation. Earthworm processing produces reliable estimates of location within 20 sec, with final locations and coda magnitudes available within 2 to 4 min. REDI will utilize the preliminary location to accelerate processing of the BDSN data, producing estimates of local magnitude and peak ground motions within 3 min and moment magnitude in under 5 min. As part of this collaborative project, the BSS and the USGS Menlo Park are utilizing a T1 frame relay connection between their sites to exchange parametric and waveform data.

The UC Berkeley-USGS joint notification system builds on the complementary nature of their networks, providing more robust and comprehensive earthquake information. We
hope to extend this partnership to Strong Motion Instrumentation Program of the California Division of Mines and Geology in order to provide a more complete view of the strong shaking produced by major earthquakes. We also intend to participate in exchange of near real-time phase information to the neighboring networks operated by the University of Washington and the University of Nevada at Reno.

Other plans for the development of REDI focus on the capabilities of the broadband network. A natural extension of decreasing the processing time is the development of an early warning system, and a near-field ramp detector is under development to provide rapid assessments of event size (Uhrhammer, 1993). Beginning at the P-wave onset, this algorithm calculates the rate of growth of the velocity vector magnitude squared and can be used to estimate the scalar seismic moment of the source before the arrival of the S waves. We are also developing new picking algorithms to improve the quality of arrival-time information available from the BDSN and provide more accurate preliminary locations.

We are incorporating a strong-motion centroid estimation procedure (Kanamori, 1993) to provide information relevant to extended ruptures. In the long term, we plan to implement the automatic determination of parameters from finite fault calculations, such as directivity, duration, and slip heterogeneity as well as estimates of displacements from GPS observations, as part of REDI processing. We are also exploring the use of geotechnical databases to predict strong ground motions, based on the seismological observations and local site conditions.

Conclusions

In 1993, the REDI project initiated the broadcast of automatic earthquake information for events in northern and central California. This information was initially limited to earthquake location and magnitude; recent developments include the broadcast of peak ground acceleration, velocity, and displacement and the automatic estimation of seismic moment and mechanism. Future goals include increasing system reliability and adaptation of REDI products to specific needs of users.

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