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THE CALIFORNIA INTEGRATED SEISMIC NETWORK: STATUS AND APPLICATION IN EARTHQUAKE ENGINEERING

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SUMMARY

A collaborative effort of federal, state and academic institutions engaged in earthquake monitoring in California, called the California Integrated Seismic Network (CISN), has been established. It is a major step forward in integrating the efforts of the seismic networks operating in California, of both the traditional strong motion and weak motion type, and supported by federal government, state government and universities. The institutions that currently comprise the CISN are the California Geological Survey, the United States Geological Survey, the UC Berkeley, the California Institute of Technology, and the California Office of Emergency Services.

A major goal of the CISN is integration of instrumental data so that recordings from both small and large earthquakes can be combined from all member networks. A goal is for data from all stations to be dually usable, for seismological monitoring and research, and for strong ground motion analysis. The CISN has three data centers, a joint USGS/Caltech Seismic Data Center in Pasadena, a joint USGS/UC Berkeley Seismic Data Center in the San Francisco area, and a joint CGS/USGS Engineering Data Center in Sacramento. The engineering center will rapidly gather and distribute statewide strong-motion data for post earthquake response and engineering damage assessment. The CISN integrated system, while still in ongoing development, came on line during 2003, and the key aspects of the consortium, infrastructure, and potential for earthquake engineering applications are discussed.

The CISN is governed by a Steering Committee representing institutions actively involved in earthquake monitoring in California and a Program Management Group, comprised of the authors, which performs project management and coordination. The CISN is a designated region of the U.S. Advanced National Seismic System.

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A goal of the CISN is to develop a uniform system for earthquake monitoring across the State through improvement of the seismic system in northern California and continued operation of the earlier TriNet system in southern California. Another goal is the integration of earthquake notification and reporting statewide, utilizing compatible software and creating a single seismicity catalog. The CISN is also endeavoring to improve robustness in earthquake monitoring and notification, working with the California OES and other emergency responders to maximize the use and benefit of real- and near-time seismic information.

INTRODUCTION

Seismic networks and strong motion networks have traditionally been separate. The traditional focus of seismic, or weak-motion, networks is to record earthquakes and determine locations and magnitudes of the events. The purpose of strong motion networks has been to record the earthquake shaking, on scale, during the infrequent earthquakes with motion strong enough to damage structures and other facilities. Because of the different times scale and nature of these two problems (frequent vs. infrequent, low amplitude vs. high amplitude), these have traditionally been separate functions.

Technology that has become available in recent years has opened up new possibilities. Some modern seismic instrumentation is able to perform the role of the traditional strong motion accelerograph and the role of the traditional weak motion seismic recorder at the same time. These instruments require a wide dynamic range recording capability and sensors that do not clip in strong shaking, while also able to sense small amplitude motion from local events. After the 1994 Northridge earthquake in southern California, it become clear that, first, there were not enough stations in the area to adequately record the shaking, and second, that the necessary expansion would be most effective if the networks with the most stations in the area began to coordinate and collaborate. The California Strong Motion Instrumentation Program of the California Geological Survey (formerly the California Division of Mines and Geology, CDMG) began to work cooperatively with the Southern California Seismic Network, already a joint effort of Caltech and the USGS/Pasadena. Out of this effort the TriNet project was born, with support of the U.S. Federal Emergency Management Agency (FEMA) and the California state Office of Emergency Services (OES). After several years, the pressing need to extend the collaboration California-wide was clear. From that start the California Integrated Seismic Network (or CISN) began, in which the original three institutions were joined by USGS center at Menlo Park (both weak motion and strong motion networks) and the Univ. of California Berkeley’s Seismological Laboratory. The California Office of Emergency Services participates as a key supporter as well as a customer of the network products.

KEY ELEMENTS OF THE CISN CONSORTIUM

Organization

A collaborative effort like an integrated seismic network requires certain key aspects to be in place in order to operate and evolve. The consortium needs to provide products and services, while at the same time the individual identity of each member agency must be preserved. Individual agencies may have missions and functions they fill which need to be preserved. An early step was the development of a Memorandum of Agreement (MOA), signed by each agency. Although an MOA cannot foresee all potential issues, it provides a consensus framework for approaching them. The CISN MOA established a Steering Committee, which considers overall direction, and a Program Management Group, which manages day-to-day operations; both are comprised of key members of the individual agencies. In addition, an Advisory Committee is established, comprised of public members, to provide user perspectives.

Besides these governing, operational and advisory structures, there was an early recognized need for the establishment of common standards among the member networks. Several working groups were established, with the greatest ongoing effort being devoted to standards for communication and exchange of data between the networks. Although standard methods and parameters had been developed through the years at each network, these were in general quite different from network to network. This was especially true when comparing the methods and approaches of the strong motion groups relative to the weak motion groups, which had developed distinctly because of their traditionally distinct missions and goals. Even among weak motion networks, standard procedures were needed for functions such as locating earthquakes and determining magnitudes. A continuing standards development effort has been important to address issues that develop as the collaboration progresses. The CISN web site, shown in Figure 1, provides links to CISN products and other information and to the member institutions and networks.

Centers

The CISN is organized into three management centers, the Northern and Southern California Earthquake Processing Centers and the Engineering Data Center. The two earthquake processing centers perform routine automated earthquake monitoring, focused on earthquake locations and magnitude determination. The Northern California Center is comprised of the seismological network operations of UC Berkeley and USGS Menlo Park. The Southern California Center is comprised of the Caltech and USGS Pasadena operations. These centers have responsibility for the rapid and reliable determination of earthquake location and magnitude.

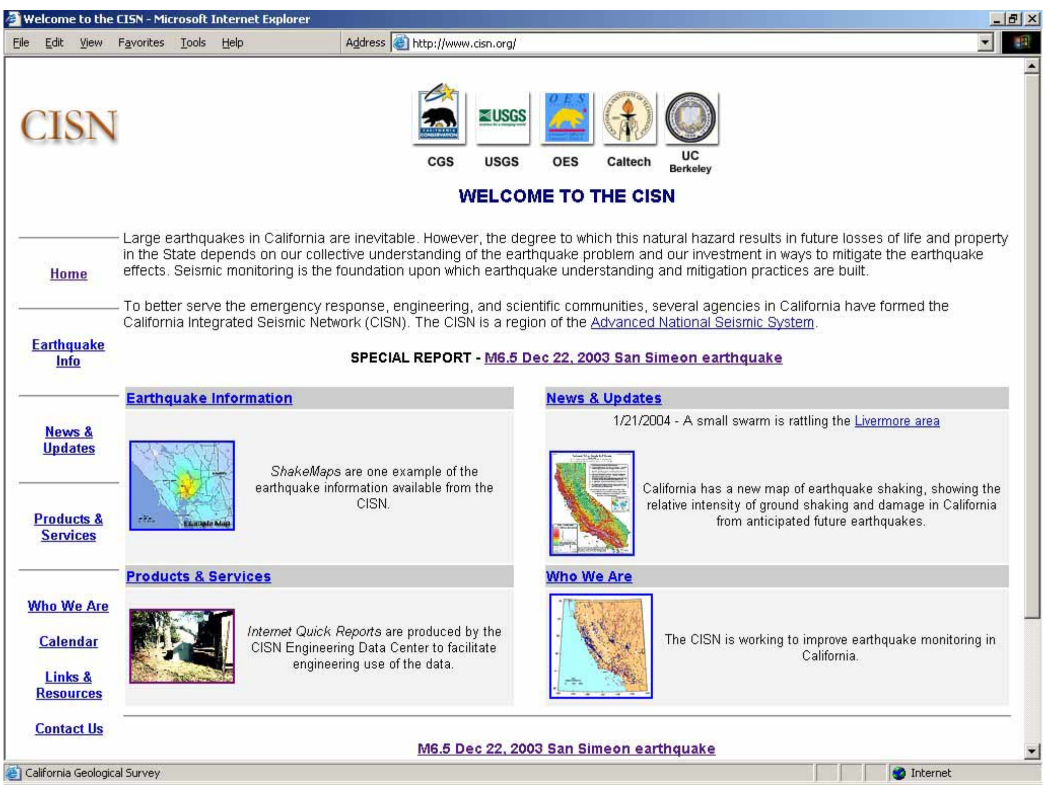


Figure 1. Earthquake data and information products discussed here, such as ShakeMaps and Internet Quick Reports of strong motion data are available through the **http://www.cisn.org** web page**.**

The Engineering Data Center provides strong motion data products focused on emergency response, in the short term, and improving building codes, structure design and construction practices in the longer term. The California Strong Motion Instrumentation Program in the California Geological Survey and the

National Strong Motion Program of the USGS at Menlo Park have responsibility for the Engineering Data Center.

All three data centers are responsible for the determination of shaking distribution after significant events in the State.

Goals

One of the most important goals of CISN is operational robustness for earthquake response. Large earthquakes are infrequent, and when they occur they test communication infrastructures and other aspects. Achieving robustness requires careful attention to many details. Information communication, both between networks and between the networks and the emergency management agencies, was recognized as an early aspect to be addressed. Prior communication between networks occurred by means of conventional Internet and dedicated phone circuits. In the event of a major earthquake these may be unavailable or compromised. Also, construction accidents and acts of nature had previously taken out main communication trunk lines in California. This led to the usage of a ring structure discussed below.

Another goal is to provide single estimates of earthquake parameters to the public. Emergency response agencies and public media have found unsatisfactory the not infrequent occurrence that differing magnitudes estimates are released by different agencies. Under the CISN organization and agreements, only a single best magnitude and location is distributed immediately after an event, preventing confusion.

A key concept of the CISN effort is the dual data use principle. That is, a given record of ground motion is to made be available for use in both seismological applications and engineering applications, as appropriate, in formats customary for their usage. Thus, large amplitude records can be used for engineering analysis, whether recorded by conventional strong motion stations or a seismic network stations with collocated accelerometers. Similarly, low amplitude records obtained at strong motion stations, which are not ordinarily important for engineering studies, and therefore often not used, will be available for use in seismic studies, in order, for example, to better locate an event or for source modeling or wave propagation studies. This dual use principle is the real benefit of utilizing the new instrument and communication technology that has become recently available.

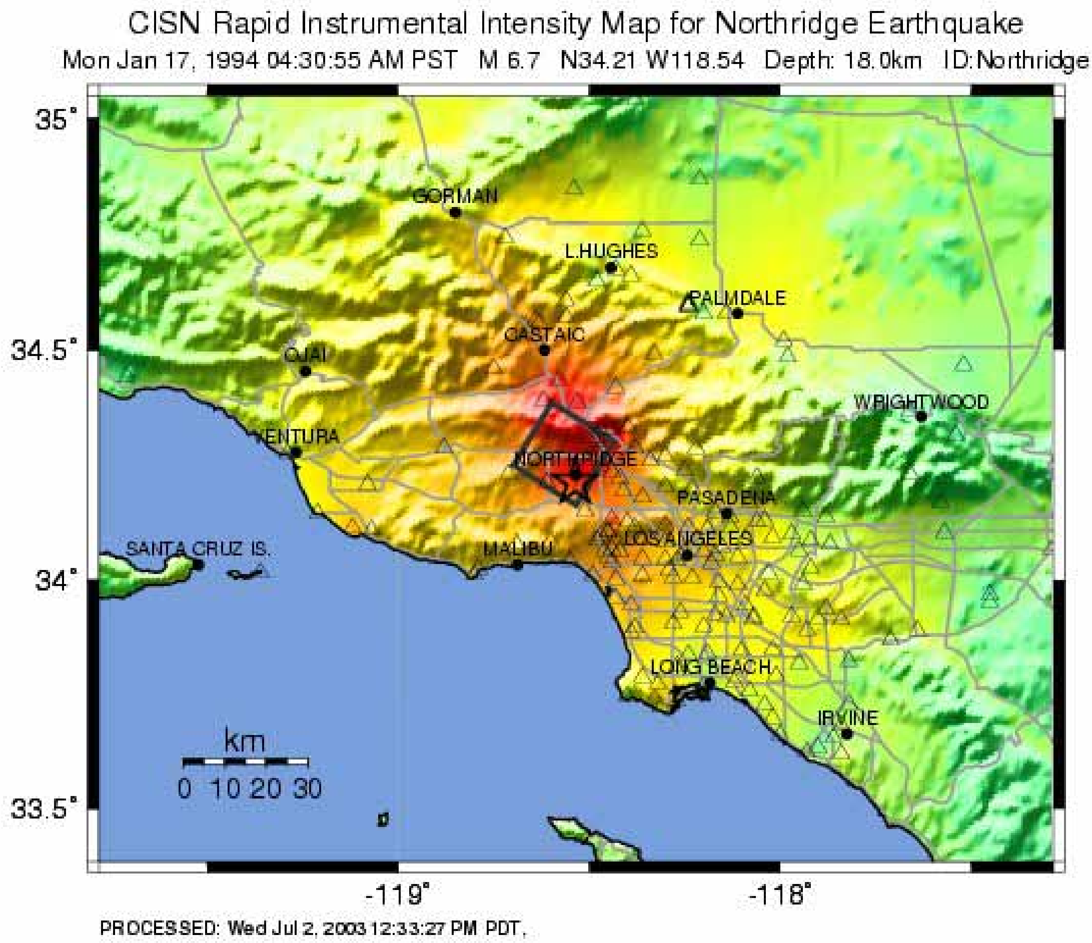
CISN PRODUCTS

Several products of value in earthquake engineering were planned during the initial TriNet project and the effort continues under the CISN project. These products are aimed at improving the information available to guide emergency response agencies, and at improving the ability of earthquake engineers to determine if structures in earthquake affected areas may be compromised, or on the other hand, have been shaken at less than design levels.

ShakeMap

Mapping the distribution of shaking immediately after an earthquake is a critical component of executing an effective emergency response operation for the event. The first ShakeMaps were developed as part of the TriNet project (Wald et al. [1]). An example ShakeMap for the Northridge earthquake of 1994, generated from the recorded data after the fact, is shown in Figure 2. Figure 2 is a map of the computed Modified Mercalli Intensity. Additional maps are produced of contoured values of peak acceleration, peak velocity, and response spectral values. With ShakeMaps, emergency response can be guided by actual measured shaking levels, rather than by media reports or anecdotal reports of individuals.

The generation of accurate and reliable ShakeMaps is a goal of CISN. It is also challenging because it requires all the components of the consortium to be in place – common software, robust communications, and fully shared station metadata. Accurate ShakeMaps also require an adequate number of stations, well distributed. An adequate distribution of stations is a serious outstanding problem for CISN, except in southern California. Future efforts will be focused on increasing the station distribution in central and northern California, and also on improving methods for interpolating the motion between measured sites, until an adequate number of stations exist.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 2. ShakeMap computed for the 1994 Northridge earthquake (see **http://www.trinet.org/shake** for this and other archived events); the square indicates the estimated location and surface projection of the fault in this case. ShakeMaps, maps of estimated Intensity computed from instrumental measurements, are a key CISN product, and require combining all data from the participating networks.

Several important applications of ShakeMap are underway. One use of ShakeMap is by engineers in assessing structural performance and structural safety after a damaging earthquake. The strong motion record itself, available through the IQR discussed below, is also valuable in this application. Rojahn et al.

[2] have developed an Applied Technology Council report (ATC-54) on the engineering application of ShakeMap and other data products in more effective post-earthquake response.

Estimation of damage is the next important application of measured shaking data after an event. With the introduction of ShakeMap, it becomes possible to do loss estimation based on recorded ground motion in near real time. HAZUS, a loss estimation package developed with FEMA support (NIBS [3]) is now able to use the ShakeMap output files as input to its loss estimation computations. Kircher [4] addressed the calibration of HAZUS using the 1994 Northridge data to increase its accuracy in near-real-time loss estimation.

Direct applications can be made to utilities and other lifeline systems with wide geographic extent. For example, Wald et al. [5] report on the usage of ShakeMap within the California Department of Transportation (Caltrans) to develop a response-prioritization system for categorizing the inventory of bridges in an earthquake area according to the likelihood of damage to the structure, based on the time of construction and the shaking at the site. More advanced methods of estimating the damage level will be developed in further efforts like this, but it's a clear direction of applications that can be made to distributed systems or utilities, such as pipeline networks, schools, hospitals, and so forth.

Internet Quick Report

The CISN Engineering Data Center uses the Internet Quick Report (IQR) to rapidly disseminate strong-motion data for engineering applications after significant earthquakes. The IQR is based on the concept of the traditional hard copy Quick Report of strong motion data distributed after earthquakes, but updated

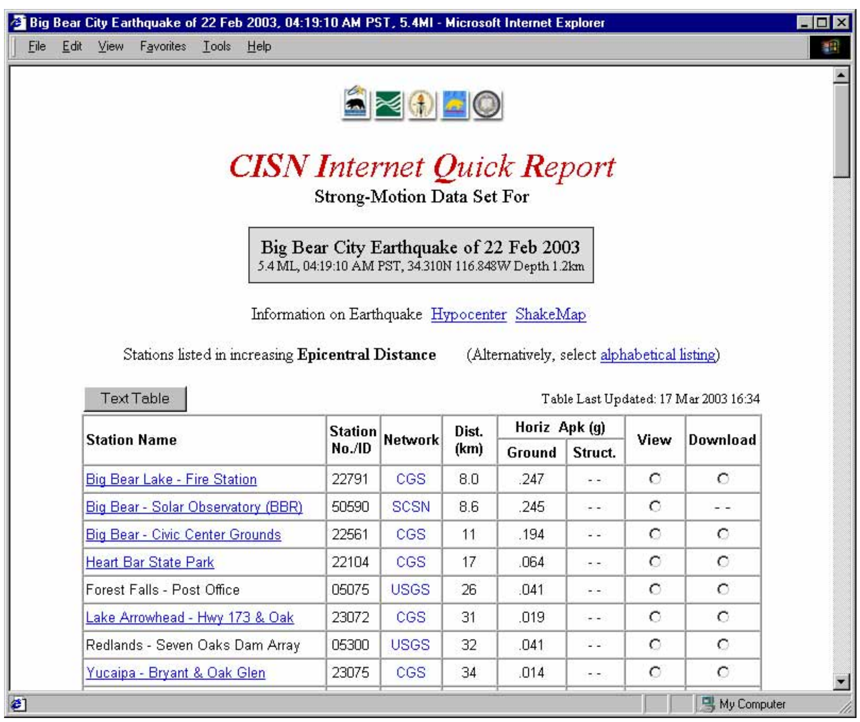


Figure 3. Example of an Internet Quick Report page for the M5.4 Big Bear City, CA earthquake in February 2003. The stations can be listed in epicentral distance or alphabetical order, and the table can be downloaded for analysis. Stations with strong-motion data available for viewing and/or downloading are indicated by buttons in the right columns. For underlined stations, a linked page contains station photographs and station information. The Network column indicates that data from the CGS, the USGS, and the SCSN (Caltech/USGS Pasadena) is included for this earthquake.

for electronic distribution and automated generation. An Internet Quick Report is generally prepared for earthquakes over magnitude 4.0, for events for which a ShakeMap is also released by CISN. The IQR table lists peak acceleration values and station distances for all strong-motion records recovered. For each record, the peak horizontal accelerations on the ground and in the structure (if applicable) are listed with the station name and epicenter distance. The data can be viewed or downloaded, and information regarding the station or instrumented structure is also easily accessible via Internet links created for that station. As an example, a portion of an IQR table is shown in Figure 3. An accompanying paper (Huang et al. [6]) provides a full discussion of the Internet Quick report, available at **http://www.cisn-edc.org**.

CISN Display

The CISN is developing an Internet application, CISN Display, to provide statewide real-time earthquake information. The original development efforts were concentrated at the Caltech/USGS Pasadena Center. The CISN Display is an integrated Web-enabled earthquake notification client-server application that is continuously updated on the user's PC. The application provides users with real-time seismicity information, and following a large earthquake it will automatically provide links to the earthquake information products such as ShakeMap and the Internet Quick Report.

A sample screen is shown in Figure 4. After a significant earthquake, the link to products, including the ShakeMap and Internet Quick Report for that event, will appear in the lower right. The key benefit is that engineering users and others with event response responsibilities can have CISN Display running as one of the processes on their PC. They will have updated information which until recently was only possible for network operators and others with specialized communication systems in place. The product is in use at test sites, and the Pasadena Center expects it to be generally available to CISN customers later in 2004.

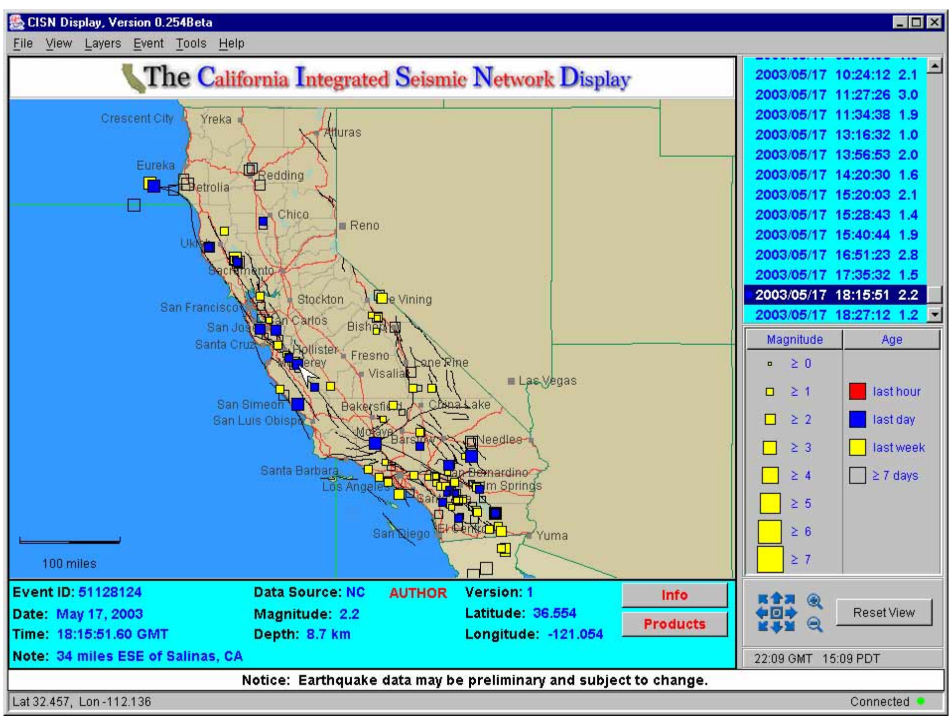


Figure 4. CISN Display is a seismicity-monitoring product developed at the Caltech/USGS Pasadena Center as a powerful, convenient way for engineering and other users to keep abreast of seismic activity in California. In the event of earthquakes large enough to be of engineering significance, the ShakeMap and Internet Quick Report generated by CISN can be accessed from this screen through the 'Products' link.

PROGRESS

The CISN is a multi-year effort and will require several years to become fully functional at the planned level. Initial efforts are focused on statewide robustness, including the improvement of communication links between the participating networks. Another effort is the calibration of software to ensure product standardization and the exchange of station and network parameters to develop statewide processing capabilities.

Robustness

Because of the geographic locations of the major earthquake faults in California, the seismic centers in both northern and southern California are vulnerable to earthquakes. The CISN has undertaken major steps to improve the robustness of earthquake monitoring with this in mind. The first component is a dedicated communications ring connecting the CISN partners (Figure 4), brought on line in early 2003. This communication ring is used to exchange data parameters and waveforms themselves between the data centers.

The T1 ring consists of dedicated T1 connections between centers, and includes features to allow communication to continue if one or more of the dedicated links fail. With a ring approach, data can go in either direction, which is important in case one of the links is severed. The lines are dedicated (i.e., not part of the commercial Internet), so the ring should be unaffected by commercial traffic after an earthquake. Further, the initial user of the data products, the California Office of Emergency Services, is also on this ring, and is directly served the products. They in turn pass the data products, via other secure communication pathways, to city and county emergency offices throughout the state.

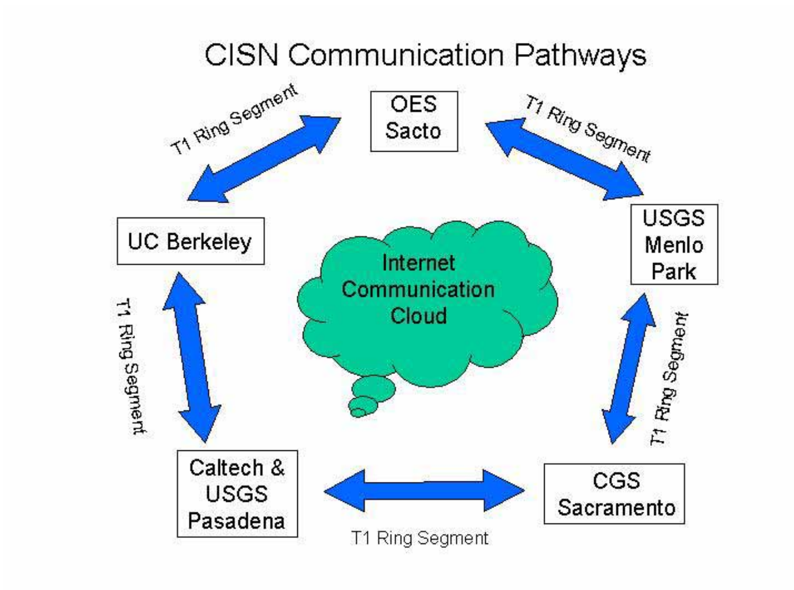


Figure 5. Communication pathways between seismic centers within the CISN system. The dedicated T1 segments form a robust ring, with communication allowed in both directions in the event a given segment is damaged. Normal communication tunnels through the Internet cloud are also used, but as backup to each link of the robust system.

Another robustness step is the establishment of seismic stations with data transmission to two separate centers. The Southern Data Center and CGS have established dual data feeds to several stations in the Los Angeles area. Another set of stations transmits to both Caltech and USC Berkeley/Menlo Park.

There are approximately 25 dual-feed stations in CISN, and another 25 are planned. Although these will never be a large percentage of the total number of stations because of costs involved, they will be carefully located for maximum benefit to statewide robustness.

Product Standardization

A key component of an integrated network is that the same estimates of parameters (magnitude, location, or strong motion amplitudes) be produced at the centers, since if one center is offline for some reason the other center must produce the needed results. This requires shared seismic data, accomplished through the communications ring, but also requires standardized software and procedures at the centers. A significant part of the effort needed to make CISN operations robust is the continued discussions and adjustments at each of the centers to accomplish this. The Program Management Group and the Standards Committee have worked together to accomplish this goal. The development of software to assess and monitor the state of health of the distributed system is also being addressed.

Seismic Instrumentation

As part of the TriNet project, the instrumentation in southern California was significantly upgraded and expanded during 1997-2001. Today over 150 sites have co-located broadband and strong motion sensors, and over 480 stations have strong motion sensors with modern digital recording and communications. In northern California, progress has been slower, but over 30 sites have co-located broadband and strong motion sensors and approximately 200 sites have modern strong motion instrumentation and communication.

Standard stations installed under CISN have instruments with 18 bits resolution, minimum, and many have 24 bits. The stations and instruments meet or exceed the guidelines for urban strong motion reference stations developed under COSMOS (see **http://www.cosmos-eq.org**, under Urban Guidelines).

The overall goal of the strong motion effort within CISN is at least one station within each zip code in the state. There are over 2000 zip codes in the state, and approximately 700 now have a CISN strong motion capable instrument. Even when this goal is achieved there will be a lower station density than, for example Japan or Taiwan, but this is an important goal, and additional efforts could be planned in the future.

ACKNOWLEDGEMENTS

An effort as large as the California Integrated Seismic Network could not be accomplished without the involvement of a large number of people at each of the seismic networks. Some of the working groups, especially the Standards Committee, chaired by Doug Neuhauser, have worked diligently to resolve the large number of issues necessary for the planned effort to be an operational reality. In addition, the California Office of Emergency Services has provided continued support and user focus as the CISN project was being developed.

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