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Paper No. 2135. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

AN EARTHQUAKE RAPID RESPONSE SYSTEM OPERATING IN SOUTH-EAST AUSTRALIA

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ABSTRACT

Seismograph systems can use centralised or distributed recording systems, each having distinct advantages and disadvantages. Alarm systems must have telemetered data to a central recording site. However a hybrid system with advantages of each may be the optimum solution for some applications.

Following a major earthquake, the location and magnitude are of limited value to the emergency authorities and owners of large structures such as dams or power stations. Their questions are more concerned with the likely effects of the earthquake, and what needs to be done about it. To be useful, this information must be provided as soon as possible, preferably within minutes of the earthquake.

Hazard data provided by the seismologist (earthquake location and magnitude, attenuation) is combined with vulnerability information provided by the authority (asset locations, vulnerability and importance, tasks and priorities) to determine estimated effects of an earthquake using intensities, and a prioritised task list.
The system can also be used to train users about possible earthquake effects.

KEY WORDS

Earthquake rapid response, Earthquake alarm, Lifelines, Risk management, Emergency simulation, Australia, Seismograph networks.

INTRODUCTION

The past two decades have seen significant developments in seismological instrumentation, and in the speed and efficiency of earthquake data processing (Gibson, 1992). This has extended the range of applications in which these instruments are applied. Much seismological data is now processed in near real-time, and remotely recorded data are available much more quickly than was possible in the past. Many organisations now require information about an earthquake very soon after it occurs, preferably within minutes.

Digital recording has replaced analogue recording, providing many opportunities for extending the bounds of seismograph systems. Modern transducers, both seismometers and accelerometers, have wider dynamic range and frequency bandwidth than could be used in the past.

The availability of precise timing from Global Positioning System (GPS) satellites means that high precision timing can now be maintained for a moderate cost, simplifying the operation of distributed recording systems. Other recent developments in digital telemetry, including radio telemetry, the internet, and high-speed modems, are reducing the costs of both continuous and dial-up data acquisition.

Characteristics of Australian Earthquakes

Intraplate areas such as Australia experience a low level of earthquake activity compared with interplate regions. However, as the Newcastle, Australia, ML 5.6 earthquake of 1989 December 28 demonstrated, even moderate magnitude intraplate earthquakes may produce significant damage (McCue *et al*, 1990). That event killed 13 people, injured over 120, and produced over A$1,500 million in insurance claims.

Australia, in common with many other intraplate areas, experiences earthquakes due to horizontal compression on reverse faults. These usually occur at shallow depths, rarely greater than 20 km in eastern Australia. Earthquakes smaller than magnitude ML 1.0 can be felt when they occur within one or two km of the surface. Moderate magnitude earthquakes, such as that at Newcastle, can cause an unusual amount of damage. Events larger than magnitude MW 6.5 will normally produce a surface rupture.

Because most people in Australia will only feel an earthquake every five or ten years, when they are felt they are often considered newsworthy and receive more attention from the press than would be expected in more active areas. Under these circumstances some people tend to over-react. An earthquake alarm system in Australia will be set more sensitively than for many other places. It will not trigger often, but there will be minor damage in the epicentral area of a large proportion of those earthquakes that do trigger the system

Network Instrumentation

The scale of operation may vary continuously from tens or hundreds of metres in mines, through kilometres to tens of kilometres for aftershock or reservoir induced seismicity studies. Regional networks cover hundreds of km, national networks thousands of km, and the global network covers up to 20,000 km.

Smaller scales involve recording of higher frequency motion, with higher timing precision and accuracy, and result in higher precision for earthquake locations. The uncertainty in an earthquake depth depends mainly on the distance from the epicentre to the nearest seismograph. This should not be further than about twice the earthquake depth, so a fairly dense network is often required.

Table 1: Characteristics of seismograph networks operating at different scales

	Network diameter km	Lower Frequency Hz	Higher Frequency Hz	Typical Sample Rate per sec	Location Precision km
Global network	20,000	0.0003 - 0.05	2	10 - 20	20 - 40
National network	1000 - 5000	0.03	5	20, (10 to 40)	15 - 30
Regional network	200 - 2000	0.2	10	50, (20 to 100)	10 - 20
Local network	50 - 400	0.5	25	100, (50 to 200)	2 - 10
Near field studies	2 - 80	2	50, (25 - 100)	200, (100 to 500)	0.1 - 2
Mining seismology	0.1 - 5	5 - 10	100 - 10,000	400 to 40,000	0.001 - 0.1

Given the shallow earthquakes that occur in Australia, it is desirable that preliminary locations should have an uncertainty of ±10 kilometres or less. A reasonable depth estimate requires that the nearest seismograph should be not further than about 20 kilometres from the epicentre. Computation of magnitudes requires sufficient recording dynamic range so that even the largest events will produce some on-scale recordings.

CENTRALISED, DISTRIBUTED AND HYBRID SEISMOGRAPH NETWORKS

Seismograph data may be detected by remote transducers then telemetered to a central location for recording. Provided the telemetry delay is known, the seismograph network timing can be performed by a single central master clock. Central recording systems are almost essential for alarm systems, and they facilitate rapid processing of data. However, the cost of telemetry may be high, especially if the distances involved are beyond the range of direct cabling or line-of-sight radio. Centralised triggered recording systems require continuous transmission of data from all remote transducers.

The central recording system itself may be a weak link in the seismograph system, and relatively minor failures of critical elements may lead to total loss of data. A particular example of this may be loss of data due to earthquake damage. It may be difficult to ensure that every element in the system is independent of mains power, by use of either solar power or trickle charged batteries.

Distributed recording of seismograph data occurs when data is stored in the remote recorders, then later returned to the laboratory for processing. This requires precise timing in each recorder, but this is now available at reasonable cost using GPS satellite systems. Data may be retrieved from distributed triggered recording systems manually or automatically, regularly or infrequently.

Distributed seismograph networks are inherently more reliable than centralised networks because each of the field seismographs operates independently, so a degree of redundancy is usually built into the network. Loss of any system element will not cause loss of data from more than one site. Because field seismographs usually do not use mains power, this level of reliability will not change following a major earthquake.

The flexibility provided by modern digital seismographs means that there are now hybrid options that include elements of centralised recording and of distributed recording.

The work of the RMIT Seismology Research Centre concentrates on seismology at a microearthquake to local scale, particularly for engineering and geological applications. The configuration adopted for its seismograph network is a hybrid system. It consists of about 85 seismographs and accelerographs covering an area of about 1000 x 1000 km in south-east Australia. All sites have triggered digital recorders with local (distributed) recording. Data from a small proportion of these are telemetered continuously by telephone or radio to a central recording system in the laboratory. To minimise costs, telemetered signals from each recorder usually consist of only a single channel (the vertical seismometer), run at a limited sample rate (50 or 100 per second), with limited dynamic range (70 dB).

The triggered digital data being recorded on the field seismograph usually has 3 or 6 channels (a triaxial seismometer and at some sites a triaxial strong-motion accelerometer). It runs at 100 or 200 samples per second, has a high dynamic range (90 to 130 dB), and has more precise timing than is possible with the telemetered signal. This triggered data replaces the telemetered data from the site when it becomes available later in the processing cycle. After a preliminary location has been determined, higher-quality multi-channel triggered data from other non-telemetered stations about the epicentre may be obtained using dial-up telephone. The more recordings used, the more precise the location.

The hybrid system provides an alarm function and a reasonably accurate preliminary earthquake location using telemetered data, while not suffering a high telemetry cost, or risk of total system failure.

THE EARTHQUAKE PREPARATION, ALARM AND RESPONSE SYSTEM

After an earthquake the first task for a seismologist is usually to determine the longitude, latitude, depth and magnitude of the earthquake. This is not necessarily the most useful information for people responsible for managing large assets or emergency services. Of more value to such authorities would be answers to the questions: "What are the likely effects of this earthquake?" and "What course of action should be undertaken?".

Over the past two years a system has been developed which is designed to provide alarm, damage scenario and response information after moderate or large earthquakes within a few minutes after they occur. Based on a rapid determination of the earthquake location and magnitude, preliminary reports are generated based on estimated intensities, and provided to authorities by phone, fax or other means.

Hazard information provided by the seismologist (earthquake location and magnitude, attenuation) is combined with vulnerability information provided by the authority (asset locations, vulnerability and importance, tasks and priorities). The earthquake data is provided by the telemetered seismograph network, while the vulnerability information from the authority is stored on a data base.

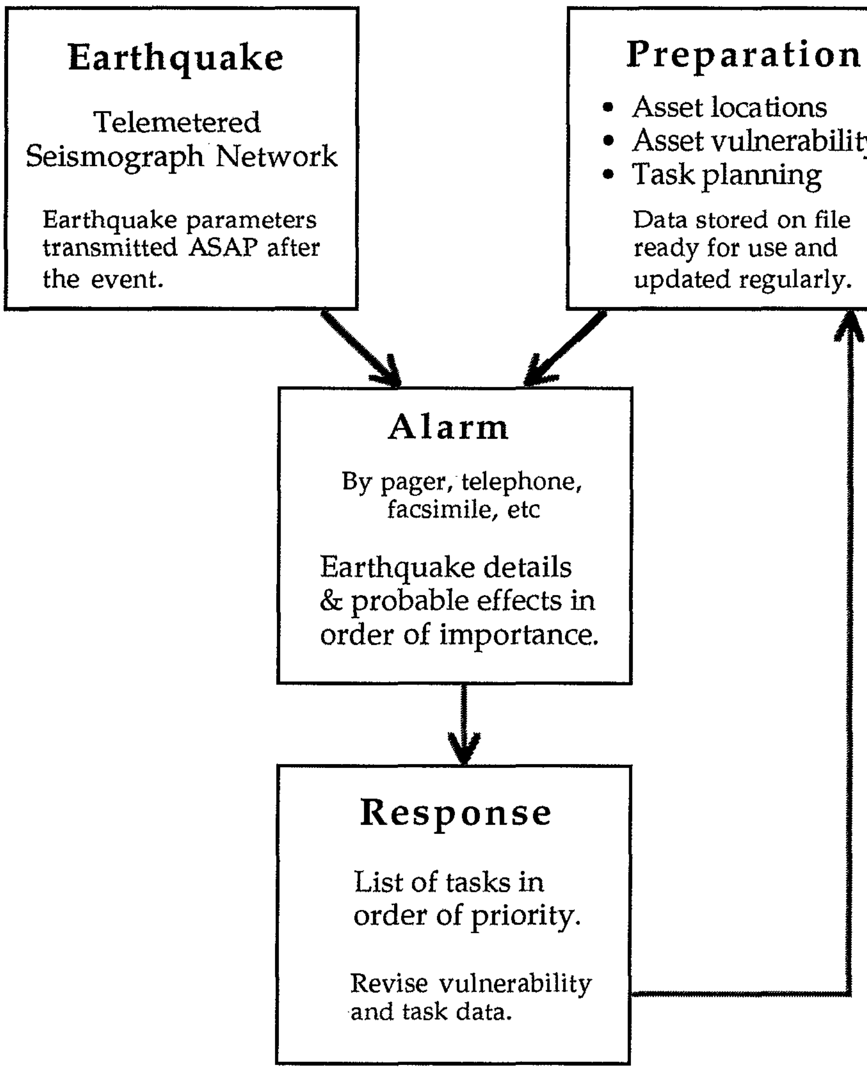

Fig. 1. Earthquake Preparation, Alarm and Response system overview. The system uses earthquake details provided from a telemetered seismograph network, and a feed-back loop containing a data base of asset locations, vulnerabilities and tasks.

The sole purpose of this report is to assist the authority in its response to the earthquake, including allocation of resources and communication of information.

The report contains three sections:

The first section gives general information about the earthquake, including location and magnitude. This includes the intensities expected to be observed at the epicentre and at nearby cities and towns. This section also contains the latest information on known damage, an estimate of the return period for an earthquake of this magnitude in this area, and information about the last major earthquake in the region.

The second section is specific to the authority for whom the report is being prepared. It contains descriptions, listed in order of importance, of the expected effects of the earthquake on a pre-determined list of assets, such as dams and pumping stations, or power stations for which the authority is responsible. The order of importance is related to, but is not necessarily the same as, the decreasing order of expected intensity.

The final section comprises a list of tasks that should be undertaken by the authority, listed in priority order. The task list contains inspection and mitigation measures to be carried out by staff on site, as well as communication tasks such as informing management, public relations or emergency services.

The report may be revised as improved earthquake location and magnitude estimates become available, and as information is received in the hours after the earthquake, revisions will contain actual reported intensity information rather than estimates based on earthquake distance and magnitude.

Reports may be computed by the seismological observatory and sent to each relevant authority, or the earthquake parameters may be sent to the authority who will then compute the report for themselves. In practice it has been found that most authorities prefer the former, although the latter would be more reliable if there have been communications failures. Computing the reports at the observatory will facilitate incorporation of actual rather than estimated earthquake effects.

For the majority of earthquakes in Australia, the system will be used to confirm that although the event may have caused some alarm amongst members of the public and is being widely reported in the media, serious damage to major structures is most unlikely.

To reduce the time lag between the origin time of an earthquake and the calculation of a reliable location for that event, a number of steps have been taken to speed the data retrieval and analysis processes. Data from the seismic recorders that make up the telemetered system are transmitted continuously by radio, dedicated telephone line, or a combination of the two.

This stream of incoming data is fed to a dedicated earthquake detecting computer that digitally records any event that occurs, and alerts SRC staff of larger events using an automatic paging system at any time of the day or night. A rough preliminary location can be calculated by staff members from the information provided by the pager system. In addition the stream of incoming data is recorded at the centre on continuous analogue recorders so that a constant real-time visual record of seismic activity within the network is always on hand.

For calculation of a reliable location and magnitude it is necessary for staff members to either travel into the observatory to locate the event, or for a staff member with a portable computer and modem to download event data and perform the location on their portable computer. The earthquake alarm reports can also be produced and sent from the portable computer.

The total time delay between the occurrence of an earthquake and the notification of the authority at present ranges between a few minutes and an hour, depending on the time of day of the event. It is planned that this delay will be reduced with increased automation.

In the future it is planned to have a real-time earthquake location system automated so that the pager system will transmit a preliminary earthquake location and magnitude directly. It is not expected that an earthquake alarm will ever be sent without verification by a seismologist, although some users may be interested in receiving a message to say that the alarm system has triggered on a major event, and more details will be coming soon.

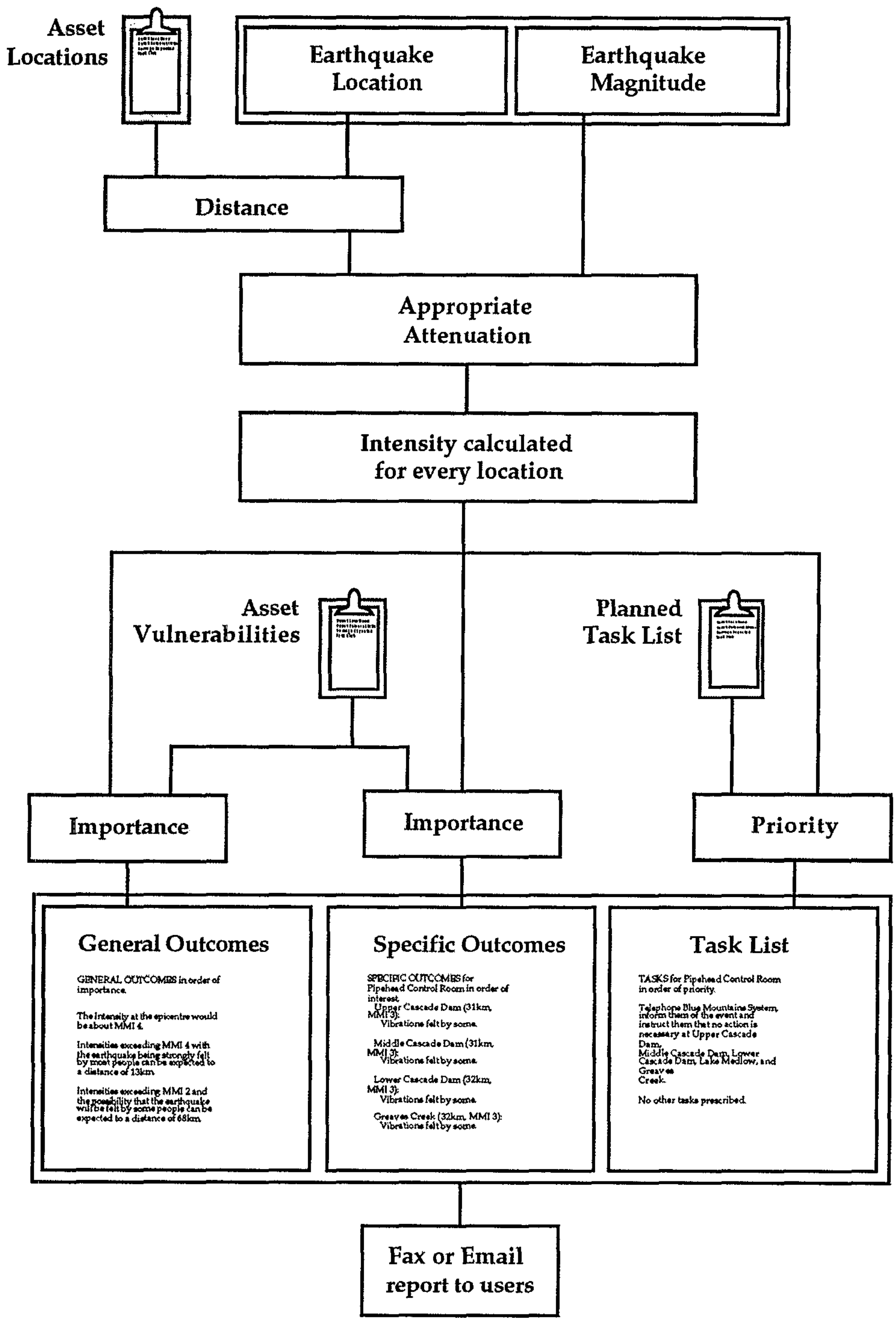

Fig. 2. Production of the three-part report uses the earthquake location and magnitude, and the three part data base of locations, vulnerabilities and prescribed tasks. Importance and priority are used to order the items listed in the report.

Preparation

A data base listing the following is required for each report recipient:

- Asset locations (points, lines or areas)
- Asset vulnerabilities, including the importance of expected earthquake effects
- Planned task list, including priorities

This data base is developed by each authority, possibly after consultation with earthquake engineers and with assistance from seismologists.

The importance for earthquake effects depends on intensity for each asset individually, and is used to order the list of earthquake effects. It is also used to determine whether significant effects will always be listed (rather than just a specified number of effects), or whether they may be disregarded. For example, relatively weak motion may be reported for training purposes for earthquakes that occur during the day, but not if they occur on a public holiday or at night. The priority of tasks is used only to determine the order of the tasks listed.

Once the system has been implemented, the data base must be kept up to date and regularly reviewed, particularly the emergency contact details and procedures.

Preparation of the data base provides good training for staff from the authority. Test runs with large hypothetical events, or with real earthquakes that would normally be considered too small to cause any damage, can be useful for training purposes both for seismologists and the authority staff. Weak points in the data base for asset locations, vulnerability and tasks, or for changes in contact details or procedures can be identified and then improved.

Reliability

The reliability and time delays within the system are critical factors for the usefulness of the system in an emergency. Since the alarm system is centralised, its reliability may depend on individual components which may fail due to one of any number of normal factors, or more importantly due to earthquake effects.

In the event of a large, damaging earthquake the most likely sources of failure within the system are currently the telemetry links between the remote recorders and the laboratory, and the communication links between the laboratory and the seismologist and between the seismologist and the authority's control centre.

Telemetry failure of seismic data can be minimised by using a combination of telephone links and radio links, or by duplication of critical sections of the system. Radio links are more reliable in large nearby earthquakes.

At present the communications links include electronic pager systems, and relies on the continuous operation of the pager computer. To minimise communication failures, a range of alternative communication channels can be provided, including the digital mobile telephone message services. Satellite based mobile telephone systems will significantly improve reliability following large nearby earthquakes.

Another way of improving reliability is by using a network of alarm systems. The seismograph network can be sub-divided into a number of clusters, each with an alarm system. If any one should fail then the others could still provide an alarm. Data may be shared between clusters, so that loss of this data will alert a cluster to a possible system failure, and it may then broadcast a warning signal. The Seismology Research Centre has connected alarm clusters in Melbourne and Sydney. If neighbouring seismograph observatories actively cooperate, then reduced precision preliminary information can still be supplied in case of communications failure by using information from the neighbouring network.

EXPERIENCE TO DATE

Since the system was developed there have been several earthquakes in south-eastern Australia of sufficient magnitude to warrant operating the alarm system. Most of these have been small magnitude earthquakes that were unlikely to cause any damage, so the lists of earthquake effects and tasks were small. However implementation of the system after small earthquakes has provided useful training for all involved.

On August 6 at a little after 9 pm an earthquake of magnitude ML 5.1 occurred a few kilometres south of the small town of Ellalong, near Cessnock. The earthquake was strongly felt in Cessnock, Newcastle and surrounding areas and caused structural damage to buildings in Wallaby Gully, Ellalong, Paxton and Bellbird. Maximum intensity in the epicentral region was MM 7. The earthquake was felt throughout the eastern suburbs of Sydney with a maximum intensity of MM 3. Insurance claims for damage caused by the earthquake currently stand at about A$32 million. Fortunately there were no reports of injuries. This was the largest earthquake within south east Australia since the 1989 Newcastle earthquake.

On May 20 at 1129 UT (09:29 pm EST) an earthquake of magnitude ML 3.6 occurred 7 kilometres south-east of Jenolan Caves at a depth of about 14 kilometres. This event was felt throughout much of the Blue Mountains area west of Sydney, and was widely reported in the media.

In both the above cases the earthquake preparation, alarm and response system was implemented soon after the event. In both cases the preliminary earthquake location was within 5 kilometres of the ultimate location, and it was found that the intensities reported from these earthquakes almost exactly matched the results computed by the system.

Initial versions of the Preparation, Alarm and Response program have been written for Macintosh and DOS computers, and most of the development is being done on the Macintosh version. It is planned that this will include maps on versions developed during 1996.

CONCLUSION

A hybrid seismograph network with both distributed and centralised recording is an economical way to provide a reliable alarm system. Using a preliminary earthquake location, and having prepared a data base of asset locations, vulnerabilities and tasks, it is possible to provide useful information to owners of infrastructure and to emergency services within 10 to 30 minutes of a major event.

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