# MANAGING SEISMIC RISK FOR HYDRO TASMANIA'S DAMS

ANDREW PATTLE
HYDRO TASMANIA

**INVITED SPEAKER**

*Andrew Pattle has held the position of Dam Safety Manager with Hydro Tasmania for the last 4 years and is responsible for managing the safety of 54 dams.*

*Prior to his current position, Andrew had 10 years experience as a civil engineer in the hydro-electric power industry in New Zealand. Dam owners devote considerable resources to managing seismic risks in New Zealand's dynamic landscape, and Andrew has been involved in a large number of earthquake engineering projects, ranging from seismotectonic studies to post-earthquake inspections of damaged facilities.*

*(Full paper not available at time of printing)*

Experience from a number of large earthquakes worldwide has shown that dams have a very good seismic resistance, and have caused essentially nil loss of life during the last two decades. In the same period, there have been several hundred thousand fatalities due to earthquake effects such as building collapses, tsunamis, landslides and post-earthquake fires. The excellent seismic performance record of dams, together with the low level of seismic activity in Tasmania, indicates that Hydro Tasmania's dams pose an infinitesimal risk to the population of Tasmania. However, seismic risks cannot be completely ignored and responsible dam ownership requires that they still need to be considered as part of risk management activities.

This paper describes Hydro Tasmania's approach to managing seismic risk for their 54 dams. The primary activities are:

- determining regional and site specific seismic hazard
- re-assessing the seismic resistance of dams, using analysis techniques and knowledge of precedent behaviour of dams during earthquakes
- ensuring emergency preparedness includes post-earthquake response procedures.

To date, these activities have shown that upgrading the seismic resistance of dams will not be needed.

# SEISMIC HAZARD ASSESSMENT OF METRO MANILA, PHILIPPINES

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## INVITED SPEAKER

*Dr. Bartolome C. Bautista is the Chief Seismologist, Philippine Institute of Volcanology and Seismology (PHIVOLCS). He obtained his PhD from Kyoto University based on assembly analysis of a large database of focal mechanisms throughout the Philippines. PHIVOLCS is a government agency within the Department of Science and Technology with its Head Office on the campus of the University of the Philippines, Quezon City, Metro Manila. PHIVOLCS has responsibility for monitoring and research of earthquakes and volcanoes throughout the Philippines. Its thirtyfour seismic station network has recently been upgraded with digital recording equipment from Australia as a Japanese Government funded aid program.*

*The Philippine Islands are in one of the most active seismic and volcanic areas of the world. On average there is a magnitude 7 event every twelve months and an eruption every fourteen months. The are numerous smaller events that also pose an ongoing risk to the 70 million population. In the Philippines news media the name PHIVOLCS and its Director Dr. Raymondo Punongbayan are frequently quoted and PHIVOLCS staff are highly regarded as a source of geohazard information.*

*Manila is one of the "megacities" taking part in the Earthquake and Megacities Initiative (EMI) of the International Lithosphere Program (ILP) that operates under the International Council of Scientific Unions (ICSU). "The rapid growth of large cities, their increasing vulnerability to disasters and the urgent need to concentrate the attention of city authorities on risk reduction is in the interest of social and economic stability." Other cities in the EMI include Beijing, Cairo, Izmir, Kobe, Los Angeles, Mexico City, Naples, and Tehran.*

*Bart Bautista is presently engaged in a risk management program for the city of Metro Manila with its 10 million population at risk from earthquake damage.*

*(Full paper not available at time of printing)*

Metro Manila is one of the most densely populated areas of the world and its population continues to rise at a high and alarming rate. The seat of the Philippine government as well as the other government departments including the country's financial district are found on this small area.

The metropolis had been affected by destructive earthquakes throughout its 400-year history. Parts of the metropolis are built on deltaic and floodplain deposits of the meandering Pasig-Marikina River. Past damages had been along areas underlain by such kinds of soft deposits. Recently, a 100-km long active fault has been identified to cross the metropolis. Future movement along this structure or from any of the other nearby earthquake source regions could have devastating effects on the population, structures and economy.

A ground shaking hazard mapping was done for the area using deterministic and probabilistic approaches. The effects to ground shaking of different types of geologic conditions were also considered. Results show high ground acceleration in areas close to the identified fault and in areas underlain by soft sediments. To have an idea on the amount of risks, the locations of lifelines and other infrastructures are also plotted on the resulting hazard maps.

# CURRENT EARTHQUAKE ENGINEERING ISSUES IN AUSTRALASIA

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**Andrew King** is the Immediate Past President of the New Zealand Society for Earthquake Engineering. He is Manager of the Structural Engineering Section of the Building Research Association of New Zealand (BRANZ). He is also convenor of the seismic loadings sub-committee of the Joint Australian and New Zealand Loadings Standard.

## ABSTRACT:

The New Zealand Society for Earthquake Engineering has recently undertaken a strategic planning review in order to establish a conscious forward planning process. This paper outlines the issues arising, some of which are thought to be of interest to the Australian Earthquake Engineering Society as it enters its second decade of existence.

This paper also touches on the other current NZSEE Working Group activities. These include the development of operational frameworks through which members would be deployed following a major earthquake in New Zealand – or Australia!

The draft joint Australian and New Zealand earthquake loadings standard provides a platform for a more unified approach to earthquake design in the lower seismicity regions of Australia and New Zealand. While a simpler approach for structures in some parts of New Zealand will result, a more conscious and structured seismic design process will be required for parts of Australia. Some of the process issues and implications are outlined.

# Current Earthquake Engineering Issues in Australasia

*David Brunsdon and Andrew King*

## 1. INTRODUCTION

Following on from the highly successful 12th World Conference on Earthquake Engineering in Auckland in February 2000, the NZSEE Management Committee has focused on the future direction of the Society. Many of the Society's activities have historically evolved in response to issues of the day, and so it is considered essential that a conscious forward planning process be established.

This paper outlines the issues arising from the strategic planning process, some of which are thought to be of interest to the Australian Earthquake Engineering Society as it enters its second decade of existence.

A number of interesting questions have also emerged from the current joint seismic loadings standard process. One of the most challenging is the extent to which common design procedures should be encouraged in those parts of Australia and New Zealand with comparable seismicities.

## 2. NZSEE STRATEGIC PLANNING

The New Zealand Society for Earthquake Engineering (NZSEE) was formed in April 1968. The Society has approximately 640 members at present, with about 160 of these members being based overseas. A further 40 are student members. The total budget for the 2000/ 01 financial year is $125,000.

A Strategic Planning Workshop involving current and past Management Committee members and invited guests from other organisations involved with the Society was held at the end of March 2000. All aspects of the Society's activities were reviewed, and a wide range of ideas and options discussed. Four key themes emerged, highlighting where the Society needs to place emphasis in terms of its future activities:

- ***Communications*** - the Society needs to upgrade its communications, both internally with its members and externally with other agencies and the wider community
- ***Broadening our Involvement*** – the Society should make better use of its strong reputation as a knowledgeable and independent body in helping shape public perceptions of seismic risk and in promoting and supporting research
- ***Technical Development*** - the Society needs to be more active in producing technical publications for the benefit of its members, and in participating internationally to keep NZ's earthquake engineering at the forefront
- ***Involvement of Others*** – the Society needs to actively seek the involvement of people from related fields in its activities, especially from the social sciences

The common issue from these themes is the need to increase the level of outputs across many of the Society's activity areas. This desire is however set against the backdrop of reduced technical production by the Society in recent years due to increasing workplace demands upon key personnel. The resulting lower level of voluntary inputs is a common problem for professional societies of this nature. The Management Committee has responded by making funds available from reserves to promote 'output growth' – to encourage the production of a wider range of technical tools for the use by members, and to upgrade communications mechanisms to promote and convey information.

A series of specific communications initiatives are being implemented during the current year. These include the establishment of a new and more interactive website (by December 2000) and the launch of a regular electronic newsletter (by June 2001).

A draft Strategic Plan has been produced by the Society, drawing together the issues raised at the workshop. This plan will be discussed at the feature session of the Society's next Annual Conference to be held in Wairakei in March 2001. The theme of this conference is *Future Directions: A Vision for Earthquake Engineering in New Zealand.*

## 3. CURRENT AND PROPOSED NZSEE WORKING GROUP ACTIVITIES

The traditional mechanism for the production of technical information and tools for members is via Working Groups (or Study Groups). The Society currently has Groups underway in the following areas:

***Earthquake Risk Buildings*** – technical guidelines to assist practitioners in assessing and strengthening buildings constructed prior to modern codes (mid-1970's)

***Storage Tanks*** – guidelines for determining design loadings for the seismic design of storage tanks, with particular emphasis on large steel tanks for the storage of bulk fuels

***Industrial Plant*** – seismic loadings and typical details for the restraint of items of major industrial plant and equipment

***Integrated Planning for Earthquake Response*** – the development of a framework for co-ordinating the post-earthquake response of technical personnel, including clarification of the roles and responsibilities of various agencies

Some of the possible topics for future Study Groups identified at the recent strategic planning workshop included *performance based design, displacement based design, torsion in buildings, dynamic analysis methods* and *public perception of risk.*

Whereas traditionally most of the work carried out by these groups has been undertaken on a voluntary basis, there is now a recognition that at least partial payment for key group members is necessary to ensure focus is maintained and progress made.

The Earthquake Risk Buildings Study Group is being supported financially by the Building Industry Authority, which is essentially NZ's equivalent of the Australian Building Codes Board. Funding is currently being sought from industry sources for the Storage Tanks and Industrial Plant groups.

The reality however is that while some of the Study Groups will be able to attract funding due to the appeal of their subjects to broader industry sectors, others from the above list will not. It is cases in this latter category to which the Society's reserves funding will be targeted.

## 4. EARTHQUAKE RESPONSE PREPAREDNESS

Despite the generally high awareness of the threat posed by earthquake in many parts of New Zealand, there are distinct weaknesses in many of the country's arrangements for responding to a significant event. The scarce resource that experienced earthquake engineers represent was highlighted by the Society in 1995 as one such weakness. This led to the creation of the Working Party on Integrated Response Planning as outlined above.

A NZSEE project funded by the Ministry of Civil Defence in 1997 developed the framework for the establishment of a national register of engineers. Such a register could enable local emergency managers to have first priority on senior engineers in the hours and days following a major earthquake. Due to the limited number of engineers in NZ with experience of actual earthquake situations (eg. from the Society's Reconnaissance Teams to international events), engineers from other Pacific countries with comparable experience will be sought for this register.

While this register has yet to be formally established, work over the subsequent years has focused on encouraging the managers of key facilities such as hospitals to set up *priority response agreements* with engineers.

## 5. SUMMARY OF THE PROPOSED SEISMIC DESIGN PROCEDURES FOR AUSTRALASIA

This section summarises the essential aspects of the seismic design provisions of the new draft joint Australian and New Zealand earthquake loadings standard, which is currently available for public comment.

The minimum acceptable verification method (refer Table 1 following) is determined by reference to:

a) *the site hazard spectra*, $C_h(0.5)$, from tabulated period-dependent data for each of 4 soil types normalised to 0.5 seconds (Note: for NZ conditions these range from 1.0 for rock sites to 1.35 for soft soils, and for Australia from 0.78 for stiff rock to 2.4 for soft sites).
b) *the seismic zone factor*, Z, by reference to isoseismal zonation maps (Note: for NZ, Z ranges from 0.15 in Northland to 1.1 in the Alpine fault region (but currently has a minimum set at 0.3); for Australia Z ranges from 0.0 to 0.2)

c) *the return period factor*, R, by reference to the building classification table given in Part 0 of the loadings standard and a magnification factor which adjusts the base spectra (Note: for Ultimate Limit State considerations, R ranges from 0.5 to 1.8 for NZ buildings and 0.3 to 1.9 for Australian buildings)

**Table 1 Earthquake Design Verification Methods**

| Base Parameter $C_h(0.5)ZR$ | Verification Method | Implications |
|---|---|---|
| ≤0.1 | No earthquake provisions | |
| ≤0.15 | VM I | • A primary lateral load resisting system capable of resisting 1% of the seismic mass.<br>• Connections capable of resisting 5% of the vertical self weight and imposed actions. |
| <0.35 | VM II | • Earthquake action from equivalent static or multi-modal analysis.<br>• Strength and detailing from material standards but with structural ductility ≤ 3.0 |
| ≥0.35 | VM III | • Earthquake action from equivalent static or multi-modal analysis.<br>• Yielding and non-yielding primary structural elements differentiated (ie capacity design approach implied)<br>• Detail in yielding zones according to material standards |

Verification Methods II and III require either a equivalent static analysis or a multi-modal analysis to be undertaken to determine the base shear and/or modal shape upon which the base shear is to be distributed up the structure.

Drift limits for both serviceability and ultimate limit states are to be checked to ensure interstorey drift does not impair functionality (at SLS), and that overall lateral deformation is maintained within acceptable limits to avoid either significant P-Δ effects or pounding with adjacent properties.

The effect of earthquakes on parts and components has been tiered to permit either a simplified (conservative) approach or a more complex detailed approach as necessary.

## 6. ISSUES RELATING TO LOW SEISMICITY REGIONS IN AUSTRALIA AND NEW ZEALAND

The joint loadings standard provides a platform for a more unified approach to earthquake design in the lower seismicity regions of Australia and New Zealand. This will enable a simpler approach for structures in some parts of New Zealand, but will require a more conscious and structured seismic design process for parts of Australia.

The commentary relating to the earthquake provisions identifies that while damage under design intensity events is considered acceptable, collapse is to be avoided in extreme events. These provisions have implications for designs which do not use capacity design to eliminate the potential for rupture of key support elements. Such buildings are expected to be prevalent in low seismicity regions. In New Zealand, avoidance of collapse under extreme events is addressed by limiting the Zone factor to be not less than 0.3. In Australia, this additional provision is not considered to be necessary.

Within low and moderate seismicity regions (ie where the base coefficient < 0.35, which for New Zealand includes Auckland, North Auckland, coastal South Canterbury and Dunedin and in most of Australia on all but soft or very soft soil sites, capacity design provisions can be waived provided the ductility level is not greater than 3). In such cases compliance is required with the limited ductility provisions within the various materials standards. In such cases, concurrent actions (100% plus 30% orthogonal) is required for elements that are common to two orthogonal primary load resisting systems. This is in recognition that without a rational capacity design, elements cannot be relied upon to maintain their load-carrying capacity under overload conditions. Conversely, the additional detailing required within plastic hinge zones (for structural ductility of $\mu>3$) can reasonably be expected to limit the consequences of concurrent actions.

## 7. SUMMARY

This paper has outlined a number of areas where NZSEE is placing emphasis in terms of its future development. These include:

- Improving communications with members by taking full advantage of information technology
- Improving international connectivity, with particular emphasis on technical issues and code development
- Encouraging greater production of technical output for the benefit of members
- Establishing and maintaining appropriate response arrangements for engineers and scientists for a major earthquake event in our region

It is hoped that progress in a number of these areas will be explored further in papers presented at the Pacific Conference on Earthquake Engineering to be held in Christchurch in March 2003.

The key elements of the draft joint Australian and New Zealand earthquake loadings standard, currently available for public comment, are also summarised. This standard provides a platform for a more unified approach to earthquake design in the lower seismicity regions of Australia and New Zealand, and has important implications for structural designers and others.

# THE SEISMICITY OF TASMANIA – A REVIEW

GARY GIBSON, VAGN JENSEN, AND KEVIN MCCUE

## AUTHORS:

**Gary Gibson** is a co-founder of the Seismology Research Centre in 1976, and a rersearcher/teacher at Phillip Institute of Technology and RMIT University since 1968. His interests lie in observational seismology and its practical applications. He is Vice President of the Asian Seismological Commission and Chairs the IASPEI sub-committee on Seismology in Developing Countries.

**Vagn Henrik Jensen** is the Manager of 'JENSONICS' Seismological and Electronic Services and Former Director and Manager of the Tasmania Seismic Net with 32 years experience in seismic net management. He is an Honorary Research Associate at the School of Earth Sciences, University of Tasmania, Secretary of the Australian IGCP 383 Working Group and a Member of the Geological Society of Australia and the Australian Earthquake Engineering Society

**Kevin McCue** is an engineering seismologist at AGSO with a strong interest in the Neotectonic history of Australia. He has worked in a range of seismo-tectonic environments in Europe, Antarctica, Papua New Guinea and Australia and investigated Recent faults in Mongolia and Turkey.

**Paper No. 4**

# THE SEISMICITY OF TASMANIA – A REVIEW


## *Abstract*

This paper summarises the known seismicity from 1850 to 2000 and discusses the implications for risk assessment and need for re-assessment.


## *Introduction*

Extensional faulting was active around Tasmania in the Late Cretaceous – Eocene Period (90 to 35 Ma) associated with the opening of the Tasman Sea, Bass Strait and the rifting of Antarctica from the Southern margin of Australia. Since then there has been minor intra-continental tectonism and a number of glaciation cycles.

Written history commenced in 1803 following European settlement and documents a most extraordinary sequence of earthquakes in north-eastern Tasmania east of Flinders Is (Fig 1) during the last two decades of the 19$^{th}$ century. Many of these events have been investigated to determine an approximate epicentre and magnitude.
During the investigative stage of the Gordon Hydro scheme in the 1950's, Carey (1960) discovered a large Recent fault scarp intersecting one of the abutments of the proposed Lake Edgar Saddle Dam. As a result the world's first telemetered digital seismographic network was installed in Tasmania to monitor local seismicity resulting in a comprehensive earthquake database for Tasmania.

## *Dams and Earthquakes in Tasmania*

**Paleo-seismological data** During the investigation stage of the Gordon Hydro scheme in the 1950's, Carey (1960) discovered a large Recent fault scarp intersecting one of the abutments of the proposed Lake Edgar Saddle Dam. He assigned a student to map the fault but this project was never completed (pers comm). Subsequently the late Dr Robert Underwood of the HEC took one of the authors (KMc) to view the scarp in 1977 which ultimately led to a field investigation and mapping program supported by HEC (McCue and others, 1996; Van Dissen and others, 1997). This field work enabled the investigators to propose a history of the causative earthquakes though absolute dating of the most recent event did not eventuate. Their work indicated that there have been at least 2 large earthquakes on the Lake Edgar Fault Scarp of magnitude 7.0 ± 0.2 in the last 2M years, the most recent perhaps just a few hundred years or so ago.

The scarp is the most spectacular of known Recent scarps in Australia with a vertical displacement of up to 5m and a traceable length of about 30 km. It dammed local streams and was no doubt felt strongly throughout Tasmania and in southern Victoria. The fault dips to the west under the uplifted block as observed in a surface trench and a HEC investigation borehole which classifies its mechanism as reverse faulting (the only known Tasmanian earthquake mechanism).

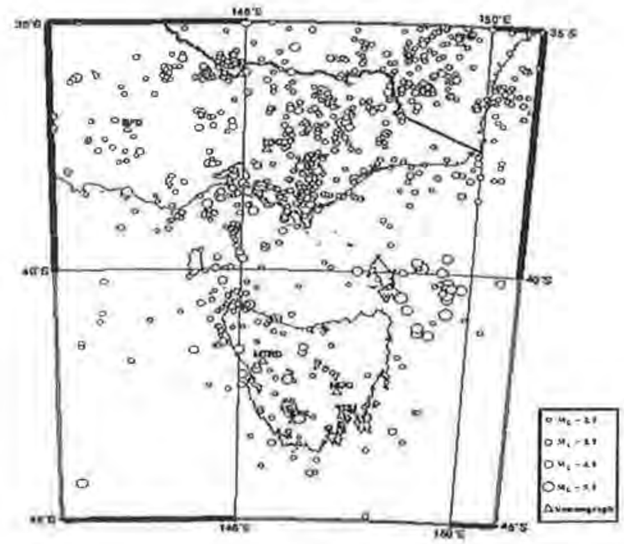
Hale and Roberts (pers comm) identified an apparently older co-linear fault scarp, the Gell River fault to the north of the Lake Edgar Fault scarp and about a fault dimension away so there was at least a third large Recent earthquake in central western Tasmania. A recurrence of any one of these earthquakes today would undoubtedly be most destructive in Tasmania.

**Pre-instrumental/Historical Data** The building of the Tasmanian Hydro scheme was the impetus for the installation of the first seismographs of a local area network there in 1957 (Jensen this volume). For the previous period information on damaging or felt earthquakes reported in the local newspapers and other sources was assessed to draw up isoseismal maps so that the location and approximate size of the earthquake could be assessed. Michael-Leiba (1989) and Michael-Leiba and Jensen (1993) have drawn up isoseismal maps for nine earthquakes, five of which were in the 19$^{th}$ century. Ripper, Pongratz and McCue (McCue, 1995) drew up another 11 isoseismal maps for Tasmanian earthquakes between 1958 and 1986.

Ripper (1963) compiled a list of reported earthquakes, which begins with an event in 1824 and includes an amazing sequence of some 2540 earthquakes that rocked the northeast of Tasmania in the 1880's and 1890's. The largest of them were felt in Melbourne and as far north as Kiama, south of Sydney (Hogben, 1898, Ripper, 1963; Michael-Leiba, loc. cit., McCue, 1995). Magnitudes of the three largest events were estimated by Michael-Leiba to be in the range 6.4 to 6.9 making the sequence a slow version of the Tennant Creek NT sequence of 1988 which badly buckled and crimped a buried natural gas pipeline (Dykes and McDonald, 1994) and damaged the Tennant Creek Hospital, the only engineered structure within 100 km of the epicentral region.

In the 20$^{th}$ century a single Tasmanian earthquake with a magnitude near 6 occurred east of Flinders Island in the Tasman Sea in 1946 (Everingham and others 1987, Michael-Leiba and Jensen 1993). It did no damage apart from breaking windows and cracking plaster in Launceston but was felt throughout Tasmania and in southeastern Victoria. A recurrence of any one of these earthquakes onshore today would undoubtedly be most destructive in Tasmania.

**Instrumental data** On its own, forty three years of instrumental data is too short a baseline to make a confident assessments of earthquake hazard. A map of known Tasmanian earthquakes 1850 to 1997 has been compiled from University of Tasmania and AGSO earthquake databases (Fig 1 below). Most of the plotted events are post 1958. Since the incredible sequence of mainshocks and aftershocks in the 19th century, seismic activity has been modest. The largest earthquake in the post- instrumental period, a magnitude 5.3 earthquake on 1 January 1958 near Port Davey in the Southwest, occurred within months of the establishment of the first seismograph (FNT) near Hobart.



Earthquake epicentres around Tasmania (1803-2000), magnitude $M_L \geq 2.5$

Another highlight was an earthquake swarm at Bream Creek east of Hobart in 1986/87 (Jones and others, 1988) which caused some minor non-structural damage to local houses and outbuildings. This swarm numbered in the hundreds of microearthquakes in a very small and shallow crustal volume, the largest event magnitude ML2.7. Had they not been felt so strongly and caused such anxiety amongst the Bream Creek population most of the earthquakes would have gone unrecorded. They occurred beneath thin basalt flows of Paleocene age (55 to 65 Ma) and Jurassic dolerites which are underlain by the East Tasmania terrane, composed of granite and metasediments, extending through Flinders Island and possibly into Wilson's Promontory (Gunn and others, 1996)

Previous authors have discussed the earlier seismicity (Ripper, loc cit; McCue, 1978; Shirley, 1980; Richardson, 1989). The latter two authors addressed the questions of whether the seismicity correlated with geological structure and with reservoir filling.

**Recurrence Relation** Using the database compiled by AGSO and the University of Tasmania, a recurrence relation has been drawn using the completeness intervals M≥5 from 1900, M ≥ 3.5 from 1958 and M≥2 from 1977. The equation is shown in Fig 2 below

$$\text{Log Nc/yr} = 2.46 - 0.75M \qquad 2 \leq M \leq 5.8$$

where Nc/yr is the cumulative number of events per year of magnitude M or more.

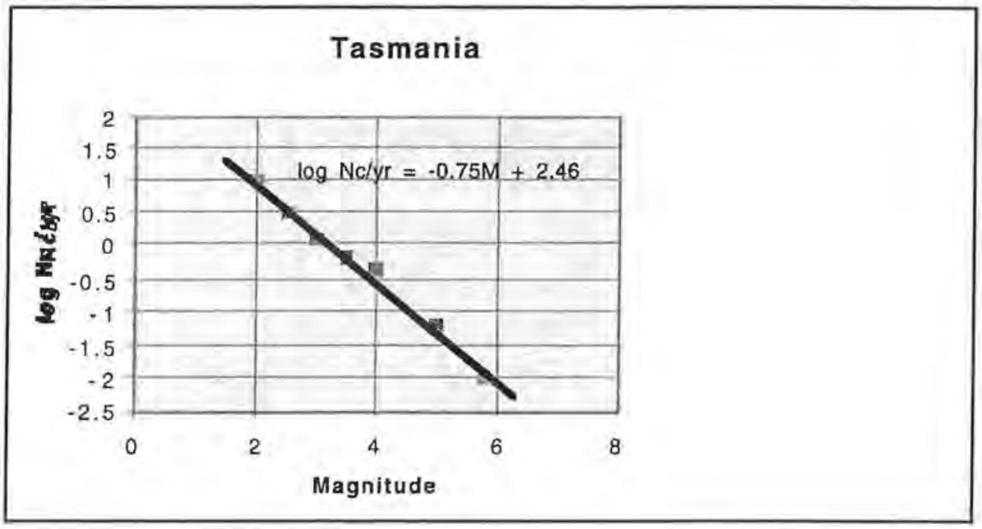



**Figure 2** Recurrence relation, Tasmanian seismicity, 39.5 – 45.0°S, 142 – 151°E

## Correlation with Geological Structure

The Tasmanian crust west of about 146.5°E is thought to be underlain by rock of Precambrian age (>545Ma) where most, including all the magnitude 5 or greater, on shore earthquakes have occurred. This pattern is repeated in the smaller post-instrumental data. Any correlation of the epicentres with mapped faults, gravity lineaments or crustal elements mapped by Gunn and others (1996) is not obvious. Much of this high hazard region of Tasmania is a designated World Heritage area but its water-rich resources have been dammed by some of Australia's most interesting and innovative dams.

**Reservoir induced seismicity** A small percentage of dams worldwide in all tectonic environments have been associated with reservoir-induced seismicity. Shirley noted that Tasmania was no exception, he documented a correlation between the filling of lake Gordon with an apparent increase in the local seismicity, by a factor of 3.5. A few years after filling the seismicity reverted to the pre-lake level. Monitoring of these induced earthquakes can be beneficial since it will reveal the ground shaking associated with local earthquakes and also the response of the structure at risk. The records of these small earthquakes can be scaled to more realistic magnitudes representative of the 1000 or 5000 year local event for enhanced risk assessment.

### *Discussion*

Risks cannot be eliminated but can be reduced by sensible planning and design. Earthquakes are high impact low frequency hazards in Australia generally and in Tasmania in particular. The probability of a 500 year event, close enough to cause structural damage to infrastructures, is low but not negligible. For the design of dams and other structures a longer return period design earthquake should be used with a significantly lower probability of its being exceeded. But what is the acceptable risk level and hence the size of the design earthquake? The return period of the design flood and earthquake should be similar. Balancing risk is a tricky business which is guaranteed to not please everyone and as more data and information become available, the risk should be re-evaluated.

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# EMERGENCY SERVICES RESPONSE TO NATURAL DISASTERS

WARWICK KIDD
NEW SOUTH WALES FIRE BRIGADES

## AUTHOR:

Warwick Kidd is a Station Officer with the NSW Fire Brigades, he is a twenty one year veteran of the fire service occupying the position of Senior Rescue Instructor for the past ten years.

His present brief is as the Urban Search & Rescue Coordinator for NSW Taskforce One....... a response team of emergency services workers including Firefighters, Ambulance Paramedics, Doctors and Engineers, capable of deployment anywhere within Australia and as a smaller team, overseas, with the ability to conduct Search & Rescue from major structural collapse.

He worked as the Brigades Operations Officer during the Thredbo Landslide and the Glenbrook Train accident. Most recently he worked as a Field Assessment Officer for the United Nations during the Turkish Earthquake, travelling to the most devastated areas working with other international Search & Rescue teams.

**Paper No. 5**

The emergence of rescue training based strategically around structural collapse has produced a blending of other rescue areas, such as confined space, trench and vertical, combined with firefighting techniques of entry and salvage, to evolve as a single discipline called Urban Search & Rescue ( US&R ).

The concept of US&R produces a multi-agency, taskforce style response group with the ability to combat almost all natural and man-made disasters maintaining self sufficiency for up to 72 hours, together with an identified resupply capability.

NSW Taskforce One provides the incident with rescuers, canine search, hazardous materials experts, engineers and specialist medical assistance, along with a support infrastructure and extensive equipment cache. (Appendices 1 & 2).

The Australian Fire Services, in partnership with their Ambulance and Police Service counterparts, have the ability to provide large numbers of highly trained and suitably equipped personnel, integrate them into a US&R taskforce and deploy them to any emergency that requires a response of this proportion. Incidents such as the Okalahoma bomb blast, Kobe and Turkey earthquakes and within our own shores, the Newcastle earthquake and Thredbo landslide, have provided the catalyst to produce a US&R taskforce.

Although we refer to US&R as a discipline, it must be seen as more of a capability than a discipline, it embraces a style of fluid management with parameters that could easily be adjusted to deal with the varying conditions that the taskforces will encounter. It must be emphasised that within Australia no one agency could be capable of forming a comparable Taskforce, with the various internal disciplines and infrastructure.

The training involved with US&R work is categorised into three areas, which caters for all emergency services workers across Australia and gives us the ability to deploy competently trained personnel to any incident.

- **Category 1 .....** is directed at everybody involved with emergency work and is purely an addendum to disaster rescue training. It is aimed at the ground troops that would be in position at the outset of the incident as the first responder. It highlights the best way to approach the site and gives the first rescuers some insight as to what the responding Taskforce may require.

- **Category 2 .....** deals with the training of taskforce personnel, focussing on the necessary skills for long duration rescue operations, including technical search, shoring and concrete breaching, coupled with the ability to operate remotely for extended periods as was highlighted through our experiences at the Thredbo landslide, Turkey and Taiwan earthquakes. The brigades have identified specialists from such areas as general land based rescue, SCAT ambulance paramedics, Police K9 Search, Hazmat and communications, as the appropriate people for admission into the Taskforce structure. These people make up the nucleus of the State's US&R Taskforce. Outside advisers are attached to the Taskforce structure and are seen as a necessary part of the response team. These advisers would include doctors, heavy rigging and lifting experts and engineers familiar with the problems associated with a major structural collapse.

- **Category 3 .....** is directed at the command, control and management of the taskforce (not the incident). It follows closely the structure of the Incident Command System - the disaster management training that has been adopted by fire services Australia-wide.

All categories compliment each other blending to form the response requirements for almost any major incident.

Within most States the fire service has been identified as the coordinating and management authority for the US&R Taskforce, and as such is responsible for all deployments of that group. In partnership with Emergency Management Australia, which is the Commonwealth arm of disaster management, the Taskforce style response group is the leading edge in the combat against major structural collapse.

The New South Wales Fire Brigades have sent trained rescue workers to international disasters as United Nations Field Assessment Officers, on several occasions, the first being the August 1999 Turkey earthquake and afterward to the Taiwan earthquake. On both occasions our Firefighters came back with an even greater understanding of exactly how we, as rescue workers, can best combat these events. The training that has been undertaken around Australia over the past 3 –4 years has built a solid base of personnel and response arrangements able to quickly deploy and combat both man-made and natural disasters.

This training and its multi-disciplined approach, bring together a unique paramilitary style, cohesive group. This is not the first time that a group of highly specialised individuals has been placed in an emergency environment. The Thredbo landslide saw rescuers and engineers working side by side in a fairly dangerous environment. The problems that surfaced were more to do with a poor understanding of each other's work-related ideology than anything else. Bringing these two groups together prior to the event and working out these problems will ensure a far speedier conclusion and also provide a safer environment for the rescuers to work in.

The beauty of the Taskforce structure is that it can integrate whatever specialist capability is required for the task at hand and support it logistically for an extended period of time. The key to this successful merging of so many disciplines is simple ...train them together on the same course so that each can experience the problems the other faces.

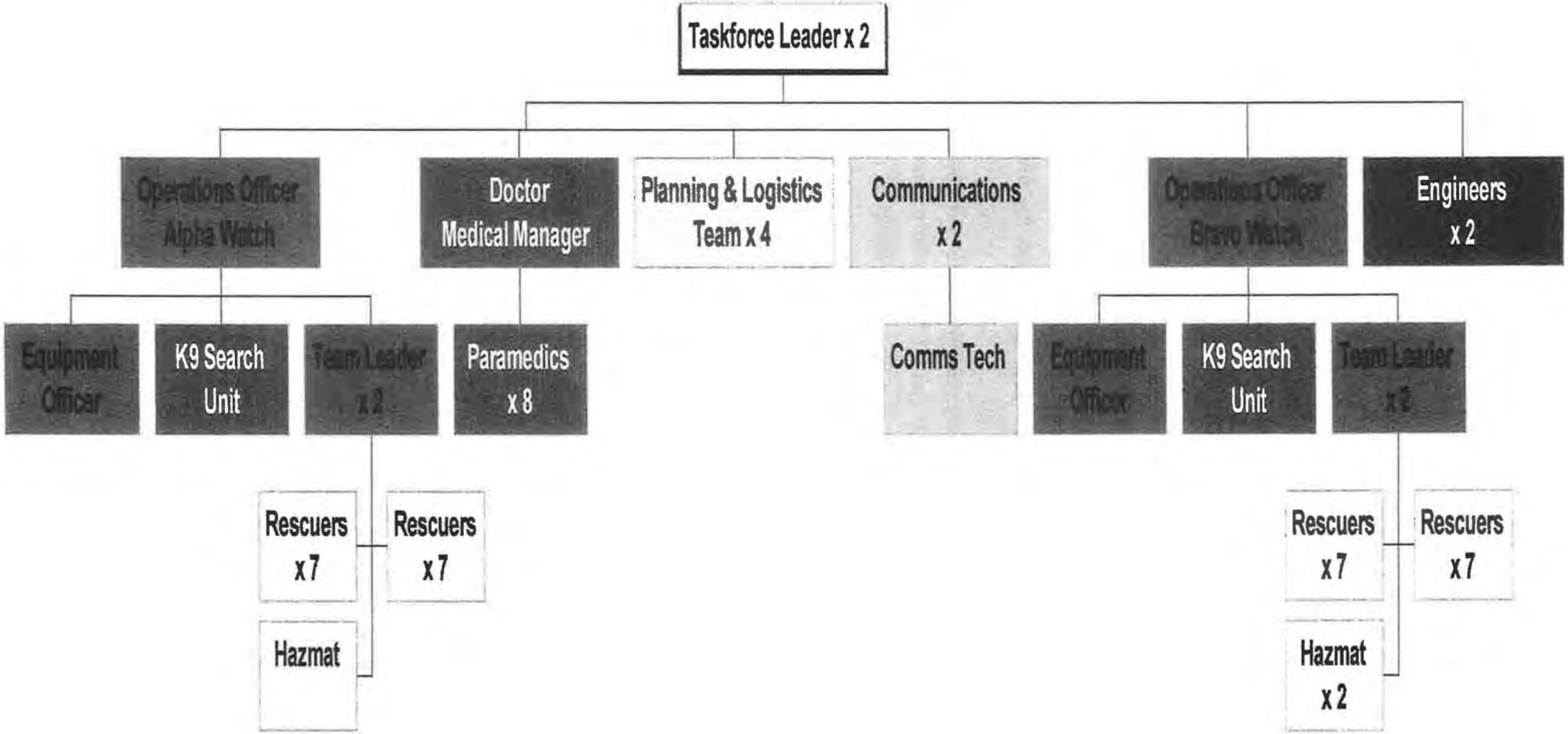
The future for emergency response is certainly focusing on the larger style teams with a broad base capability that will be deployable to major incidents. This cannot happen at the decay of the first response local rescue teams who don't carry the extensive and expensive cache of equipment the Taskforce does. With this in mind the Fire Service has produced a training CD Rom that targets the first responder to a major structural collapse. It offer this group a clear and manageable way to provide support and commence rescue operations commensurate with their level of capability. The course was produced by the NSW and ACT Fire Brigades and has been widely distributed around Australia and the Asian Pacific countries. It isn't the future of rescue training; it's what's happening now and can only further enhance our Emergency Services ability to respond to natural disasters.

# Addendum 1

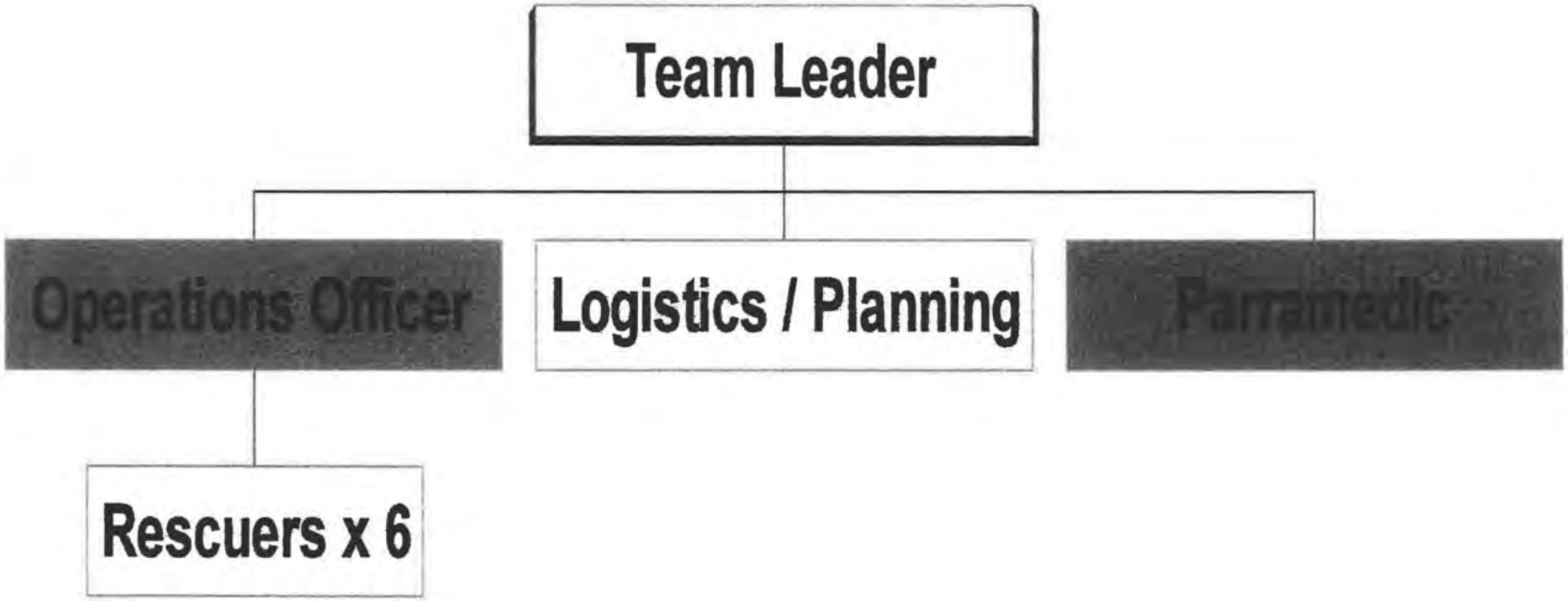
# NSWTF/1

# State & National Deployment Taskforce

**URBAN SEARCH & RESCUE**



# NSWTF/1
# INTERNATIONAL RESPONSE TEAM



# SEISMICITY IN THE APPIN AREA OF NSW AND ITS ASSOCIATION WITH MINING ACTIVITIES

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**Dr Peter Hatherly** is Senior Principal Research Scientist and Program Leader for Geological Sensing in the Cooperative Research Centre for Mining Technology and Equipment. He has extensive experience with the development of geophysical techniques for use in mining. His current interests include microseismic monitoring of longwall operations, high resolution seismic reflection imaging and in-situ geotechnical classification using geophysical logs.

**Greg Poole** is Manager, Exploration and responsible for the exploration activities required for BHP's 5 collieries in the Illawarra region,. Mr Poole has had widespread experience in the development and application of geophysical techniques for use in coal mining, This has included seismics, electromagnetics, potential field methods and well logging, He manages the use of a 200 channel telemetric seismic system built by BHP to Mr Poole's specifications.

**Dr Xun Luo** is Senior research scientist and responsible for research and operations for CSIRO's microseismic monitoring group. To date there has been monitoring at 12 sites. This work received ACARP's 1998 award for research excellence and the Hawkins prize at the 1998 ASEG Conference. Dr Luo is an earthquake seismologist with a strong interest in the application of geophysics to mining.

## ABSTRACT:

In the Appin area of NSW there is mounting evidence for seismic activity outside of that associated with the direct collapse of the ground as a result of longwall coal mining, Between August 1999 and June 2000 BHP maintained a seismic monitoring network in the area and numerous seismic events were observed. It is thought that the events are largely due to the significant tectonic stress field present. The changes in this field caused by mining are sufficient to trigger the seismic events. Similar seismic activity has been reported from many mining districts around the world. A preliminary assessment of the ground vibrations due to the seismic events at Appin suggests that they are within the acceptable levels set by Australian standards.

## 1. INTRODUCTION:

In 1992, CSIRO Exploration and Mining began researching the microseismic emissions associated with the ground response due to underground longwall coal mining. In the first instance the possibility of identifying precursors to high gas emissions and coal outbursts as identified by Davies et al (1987) in the UK was studied (Dixon and Hatherly, 1994). Subsequent work has concentrated on the failure and collapse of the strata surrounding the coal seams being extracted. The first of these studies was at the Gordonstone Mine in Central Queensland (Hatherly et al, 1995). This mapped a regular pattern of microseismic activity around the longwall face consistent with continuous caving. Other studies at mines such as North Goonyella and Appin (Kelly and Gale, 1999) and more recently at South Blackwater (Luo et al, 2000) indicate that faults and other discontinuities are also activated when they are within or close to the longwall panel under extraction. The movement on the structures also influences the overall response. Movement is sometimes observed hundreds of metres ahead of the longwall face but it maintains an association with the mining activity. As an example, Figure 1 shows the microseismic event locations at Appin Colliery due to ground failure (dark circles) and movement on a system of shears (light circles).

On July 7, 1998, a chance occurrence introduced a new dimension to our work. During the shooting of a 3D seismic survey by BHP at Tower Colliery near Appin, a seismic event unrelated to the firing of the shots was recorded on a seismic record (Figure 2). Given the extensive spread of geophones that was deployed in the survey, the location of this event could be determined and was found by B. Zhou of CSIRO to be south of the geophone array and within the first few hundred metres of the surface. Significantly, this event was outside the 3D survey area (ie. it was not due to the detonation of some other shot) and it was located on a dyke over 2 km from the nearest longwall face. Its location is shown in Figure 3 along with the location of the Tower, Appin and West Cliff collieries which are all operated by BHP. These mines extract coal from the Bulli seam at depths of 400 to 500 m. Appin township is about 80 km southwest of Sydney.

This incident had been preceded by reports of ground vibrations from residents. For example in April 1998 a resident in the Appin area reported 'explosions' to BHP. Some property damage was reported but it was not possible to identify the cause.

BHP exploration staff themselves experienced an event on 23 November 1998 near Elouera Colliery, about 20 km to the south. The seismic exploration crew experienced strong ground vibrations on the ground surface which were reported as follows (B. Anderson, BHP memo, 8 December 1998):

"The crew reported 5 to 8 seconds of rumbling vibrations through their feet, and associated sound ... with a variable timing of discrete shocks ... it sounded like something being dropped down a flight of stairs."

On 17 March 1999 a magnitude 4.4 event occurred near Appin. The location provided by the Australian Seismological Centre (www.seis.com.au) is about 4 km SW of the region (Figure 3) and its depth is given as 3 km.

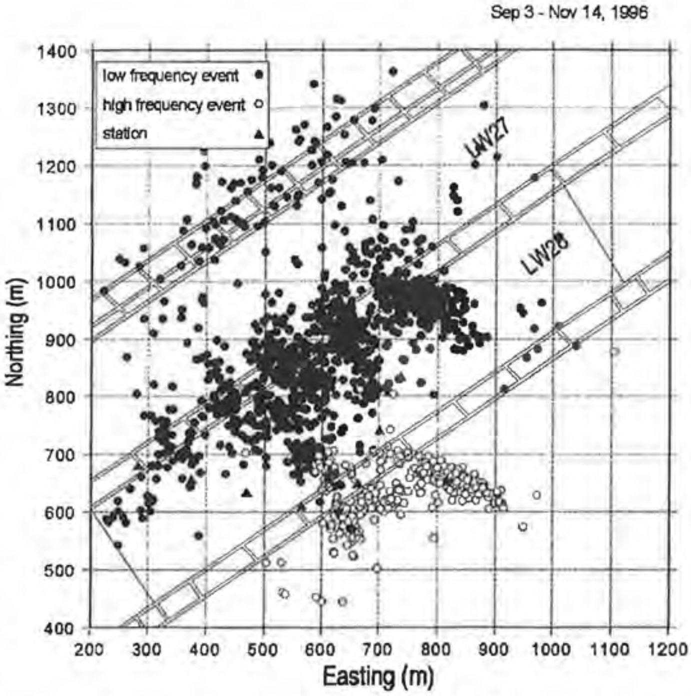


Figure 1. Locations of microseismic events recorded during longwall mining of Panel 28 at Appin Colliery, NSW. The dark circles indicate the locations of events which were associated with failure within the roof and floor sequence. There was also renewed failure in the floor under the pillars between panels 26 and 27. The light circles indicate the locations of events which occurred on a system of shears. These were first observed when the longwall face was 300 m distant.

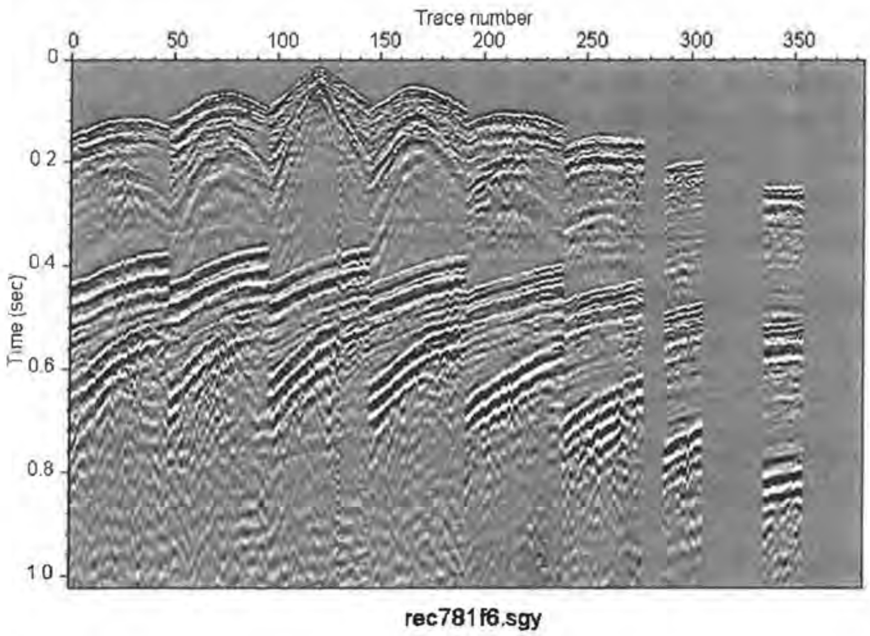


Figure 2. A seismic field record showing recordings from 484 geophones arranged in 8 parallel arrays of 48 geophones (not all geophones in the last three arrays were connected). Reflections can be seen from the target Bulli seam at about 0.32 seconds two-way travel time. Soon after the reflected arrivals, an unrelated seismic event occurred with clear P- and S-wave motions. This event was located just to the south of the geophone arrays.

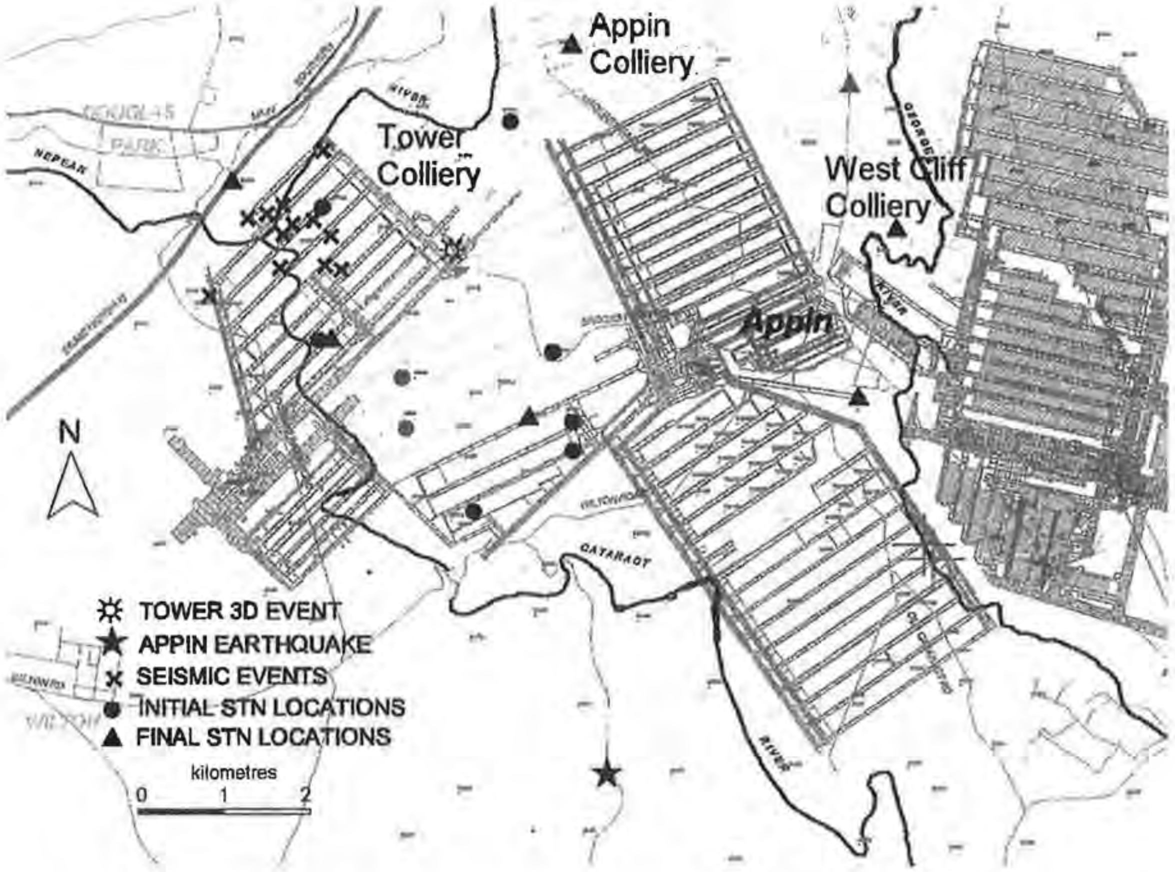


Figure 3. Location map showing mined areas, areas to be mined in the future (light grey), major cultural features and the positions of the various seismic events. At the time of these events, Tower Colliery was mining the longwall panels to the northwest of the mine and Appin and West Cliff Collieries were both mining panels to their central west. Appin's panel 28 (Figure 1) is in the southeastern corner.

In response to these various occurrences, the decision was made by BHP to further investigate these seismic events and a successful application was made to the Australian National Seismic Imaging Resource (ANSIR) to deploy a network of seismometers at Appin. This was operational between August 1999 and June 2000 with more or less continuous recordings made during this period.

## 2. INSTRUMENTS AND MONITORING SET UP:

ANSIR's short period recorders are solid-state units with 80 Mbyte flash-card memory and timing provided via GPS. 15 units were available and connected to 4.5 Hz three-component geophones. Through 1999, just the vertical components were recorded (to allow longer intervals between data downloading). During 2000, three of the units recorded all three components and as well, recordings were made from two geophones (28 Hz) previously cemented in two exploration boreholes by BHP. The locations of the seismometers are shown in Figure 3.

Data were downloaded at regular intervals by BHP and archived on compact discs. With the assistance of CSIRO, a program was written to search for triggers within the data set on the basis of short-term versus long-term averaging.

## 3. RESULTS:

To date, our efforts have been directed mainly towards obtaining the data and only limited analysis has been undertaken. However it is not uncommon for there to be tens of events per day and for the larger of these to be detectable 6 km or more from their source. Other events can occur as weaker multiple events without clear P- and S-phases.

Given the distances over which the larger events are detected it is likely that they have Richter magnitudes between 1 and 2 (B. Kennett, 1999, pers comm). Certainly they are considerably larger than the microseismic events recorded as part of the longwall caving process or any explosive shot fired during seismic exploration. Close to the source, the events are strong enough to be felt and some of the events do coincide with reports of ground vibration from local residents. On the basis of seismometer calibration data provided by Professor Kennett, the ground vibrations due to the events appear to be within acceptable levels defined by Australian Standard AS2187.2-1993.

Locations for some of the larger events recorded in September and October 1999 and January 2000 are shown in Figure 3. They lie beneath the Cataract and Nepean river gorges in an area where residents have reported events. Possibly they are associated with a geological fault which limits the western extension of Tower Colliery.

The locations were determined by a grid search which minimises the differences between the observed P- and S-wave arrival times and those calculated using P- and S-wave velocities of 3,700 m/s and 2,200 m/s respectively. These velocities are typical of those used in this area for seismic reflection surveying and microseismic monitoring. The depth of the events is uncertain but they appear to be within one kilometre of the surface. A review of the amplitudes of other events confirms that most of the seismicity is occurring in this zone. Small events have also been located along the NNW trending dyke zone associated with the event observed during the recording of the Tower Colliery 3D seismic survey.

## 4. DISCUSSION:

McGarr and Simpson (1997) provide a review of the occurrence of seismicity due to engineering activities such as mining and hydrocarbon extraction. They distinguish between induced and triggered seismicity. With induced seismicity, most of the energy required to produce a seismic event is due to the engineering activity whereas for triggered seismicity, the causative activity only accounts for a small amount of the required energy. Examples of induced seismicity include the events associated with rock bursts in deep mining and fracture propagation through hydrofraccing. Events associated with water impoundment and hydrocarbon extraction represent triggered seismicity. Central to the concept of triggered seismicity is the notion that the tectonic stress levels in much of the earth's crust are within one stress drop of failure.

In considering the prime cause of the seismic events in the Appin area, it is necessary to decide whether the events are induced or triggered. In the case of the microseismic events associated with longwall mining shown in Figure 1, the events with locations shown by the dark circles are closely associated with the caving of strata around the mine opening. These represent induced seismicity. The events shown by the light circles lie on shears and represent triggered seismicity. The larger regional events in the Appin area also appear to be triggered events because of their lack of association with direct longwall caving.

Overseas, seismicity of this type is observed in many mining districts. For example Mutke and Stec (1997) identify the unbalancing of the tectonic stress field by 200 years of coal mining in the Upper Silesian Coal Basin of Poland as the cause for regional events with magnitudes between 2.5 and 4.5 occurring in faulted areas of the basin. In Britain, Professor P. Styles (2000, pers. comm.) suggests that perhaps 50% of the seismicity in Britain is mining related and has occurred in the coal fields of South Wales, Yorkshire, Nottinghamshire and southern Scotland. In some districts this activity has continued well past the cessation of mining. Wong (1997) reviews the major role of the tectonic stress field in earthquakes triggered by mining in many parts of the world including the Coeur d'Alene and Wasatch Plateau regions in the USA.

In the Appin area, the horizontal stress is known to be up to three times the vertical (Hebblewhite et al, 2000). Tower Colliery was mining in the vicinity of the seismic events and in Hebblewhite et al (2000), regional horizontal movements affecting a nearby bridge on the Hume Highway across the Nepean River are detailed. The movements were monitored during the mining of two longwall panels at Tower Colliery and covered the period of the seismic monitoring. The total horizontal movement at the bridge was 135 mm.

The mining was at horizontal distances greater than 450 m from the bridge. These horizontal movements which were towards the longwall panels provide further indications of a significant regional response. While Hebblewhite et al (2000) mention mechanisms which are linked to the presence of the abrupt 70 m deep river gorges in this area, the seismic evidence suggests that there is a larger picture linked to the tectonic stress field. Possibly the lateral movements are occurring within substantial volumes of rock and the seismic events are defining the point of failure. It is also interesting to speculate on whether the 1999 Appin earthquake was an associated event.

In a sense, the seismic activity on the shears at Appin Colliery shown in Figure 1 is a version at the scale of a mine panel, of the regional seismic activity being observed at the mine/mine district scale. If triggered regional activity is occurring and the overseas experience is taken as further evidence for it, then it is quite likely that similar regional activity is occurring in other established mining districts of Australia. The Newcastle/Lake Macquarie region is one such area and while we do not have first hand experience with the seismicity of that region, there was a magnitude 5.1 event near Ellalong Colliery on 6 August 1994. The NSW Mine Subsidence Board is also maintaining a network of vibration monitors to check for large mining related seismic events which have been the subject of damage claims in the Newcastle area. The origins of these events, as do those at Appin, require much closer scrutiny.

## 5. CONCLUSIONS:

Seismic activity of greater magnitude than that caused by longwall caving has been recorded in the Appin area. It is mainly concentrated in the north-western corner of Tower Colliery in an area where significant lateral ground movement has occurred. Here the horizontal (tectonic) stresses can be three times the vertical stress. The conclusion drawn from these observations is that triggered seismicity of the type described by McGrath and Simpson (1997) is occurring. Similar activity could well be occurring in other Australian mining districts.


## ACKNOWLEDGEMENTS:

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# MANAGING THE EARTHQUAKE RISK IN DAMS

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**Tariq Anzar** is currently enrolled as a final year student in the Honours program of the Bachelor of Applied Science (Computer Technology) at Curtin University of Technology. His project for the Honours program is to perform the risk assessment in dam and use artificial intelligence as a tool.

## ABSTRACT:

The failure of a dam and the release of the dam's reservoir without adequate warning to those affected can result in catastrophic losses of life and property. By planning in advance for quick and prudent action and by devising an effective, timely method for warning downstream residents, the disastrous result of a dam failure may be mitigated. This paper describes the integration of such activities and use of artificial intelligence as a tool in risk management of earthquakes and its application in Dam Engineering.

**Paper No. 7**

## 1.0 INTRODUCTION:

Risk management is a process that assists in decision-making by using systematic and rational methods of dealing with risk and uncertainty (ANCOLD, 1987). A risk profile identifies the probability of failure due to different events, which can give an indication of the total risk of failure and allows comparison of the probabilities of various events leading to its failure.

In water storage structures, the effect of earthquakes is unavoidable. However, it may be possible to reduce the effect caused by earthquake damage to water storage structure. The purpose of this paper is to introduce project risk management in order to identify the earthquake activities that have the greatest risk of damage. The risks identified will be evaluated and then responded to.

The meaning of "risk" must be clearly understood before a risk management programme is started, otherwise risk analysis may be inappropriate and unclear. "Risk" is the likelihood that an event or outcome with adverse consequences will occur. The risk management process is a rational approach to evaluating and responding to the risks involved in various activities. Risk management is important in analysing decisions in equipment selection, operation, repairs and maintenance, and replacement. Potentially there is a great opportunity to improve long-term profits by using risk management, particularly in power generation, water distribution and irrigation supplies.

This paper will describe the risk management process, which consists of four main elements. They are risk identification and assessment; risk quantification; risk response development; and risk response control. It is very difficult to response and control the risk in earthquake situation. The focus of this paper is to minimise the impact of possible identified risks by using artificial intelligence.

In detail the factors to consider are population density, age of population, their readiness to evacuate, evacuation routes, warning time. A number of US based case studies have yielded the following results;

- For a warning time greater than 1hr 30 minutes, the number of victims, V, is 2 per 10000 persons at risk R: [Ref: 4]
- For a warning time of between 15 minutes and 1hr 30 minutes, the relationship V=R^0.6 applies ( for example, for R=1000 persons, V=63 victims) this applies for a population up to about 25000. [Ref: 4]
- If warning time is less than 15 minutes, the average number of victims is about 50% of those at risk [Ref: 4].

## 2.0 RISK IDENTIFICATION AND ASSESSMENT:

Risk identification involves defining the process being assessed, its objectives and its stakeholders. The process being assessed here is the effect of an earthquake on a dam structure.

The failure of a dam and the releases of the dam's reservoir without adequate warning to those affected can result in catastrophic losses of life and property. By planning in advance for quick and prudent action and by devising an effective, timely method for warning downstream residents, the disastrous result of a dam failure may be mitigated.

Examination of the external surfaces cracks of a Concrete dam may produce evidence of weak zones for earthquakes. (see pictures 1, 2 and 3). No major structural changes can be made to a dam after it has been constructed.

**Figure 1, 2 & 3: Showing evident of developing cracks**

## 3.0 RISK QUANTIFICATION:

Dam surveillance is an activity or group of activities carried out to determine whether a dam, its appurtenant works and its reservoir are behaving safely and in a manner consistent with previous behaviour. Safety surveillance is usually carried out at regular intervals (normally once a day) by a trained Operator. They are typically required to complete checklists concerning the behaviour of the dam. These checklists are then forwarded to the dam owner, where they are examined by the engineers, who have experience in the monitoring of the dam behaviour.

Monitoring the dam is very important in the evaluation of risk. The most important feature in improving risk analysis is not the refinement of theoretical risk analysis concepts, but the understanding of the behaviour of the dam itself. The loss of human life as a result of dam failure is a function of the magnitude of the earthquake as well as the distance of the dam from the epicentre.

Given that this project is not based on a particular case study dam, it is difficult to fully perform this step. Also, quantifying a risk is not free of controversy. The primary problem inherit in the process is range of uncertainties involved in assessing risks and assigning probabilities to events.

But it is clear that the risk posed by dam failure is very high. At worst, that risk is loss of lives. In order to recognise the risk posed to life without actually quantifying, the concept of "socially acceptable risk", to life is used. This could be, for example, that the risk is "extremely unlikely to occur". The level of socially acceptable risk will vary depending on a number of factors, such as the number of people at risk, whether the risk is faced voluntarily or is imposed, and whether those at risk are workers or employees in the enterprise or members of the public (ANCOLD, 1994). As noted above, when a dam fails, there is potentially a large number of people at risk, and it is the risk that is imposed. Those at risk are public and downstream commodities. Given these factors, it is likely that community will be willing to accept only a very small risk of the dam failure.

Table 1: Risk identification, assessment and its Impact

| *Risk Identification* | *Risk Assessment* | *Impact* |
|---|---|---|
| ***Internal risks*** *Incorrect data collection* | High: Likelihood of risk is level C and the consequence of risk is level 4. | It can cause panic and fear in public. |
| *Equipment failure* | Low: Likelihood of risk is level B and the consequence of risk is level 1. | The chance to be occurred is minor but it would be better to provide additional equipment |
| *Equipment vandalism* | Low: Likelihood of risk is level C and the consequence of risk is level 1. | It gives minimum impact on the project but there is a possibility to be happened. |
| *Software (loosing data)* | Low: Likelihood of risk is level B and the consequence of risk is level 1 | The chance of loosing data is unlikely. It will provide minimal or no impact. |
| ***External risks:*** *Earthquake* | High: Likelihood of risk is level B and the consequence of risk is level 5. | The consequence is Sunny Day Dam failure and the chance to be happened is unlikely. |
| *Reservoir induced seismic effect* | High: Likelihood of risk is level D and the consequence of risk is level 4 | The consequence is that Public will require more warning time |

Explanation to Risk assessment levels A,B,C,D,E and 1,2,3,4,5 is given on page 5.

## 4.0 RISK RESPONSE DEVELOPMENT:

Surveillance and monitoring of the dam, together with warning procedures, is very important in dealing with the ongoing risk of cracking or dam movement. The manual monitoring system currently being used at many Water Resource Structures should be replaced by artificial intelligence system. The cracks and the dam movements have to be monitored 24 hours through out the year so as to raise the alarm at the appropriate time. It is simply not feasible to do this manually – and this is where an artificial intelligence system can help.

On the basis of the risks identified, this paper has drawn a broader picture of response. Work is in progress to develop an artificial intelligence system, which is expected to be completed later this year. The system will monitor any development of new cracks, existing cracks and movement of the dam. Development in any new cracks or widening of existing cracks results in increase in length. In the case of downstream or upstream movements of dam wall will result in the movement of target points. These changes in dam wall would be monitored by using laser technique. A software program would further analysis the recent changes and their affect on risk management.

## 5.0 RISK RESPONSE CONTROL:

The only way to control risk is by keeping a close watch on the dam to ascertain the earliest possible indication of adverse effects on the dam from an earthquake, in order to alert nearby residents and evacuate them if necessary. The adverse effects of an earthquake on a dam may be the formation of new cracks in the dam, deterioration of existing cracks or a downstream movement of the dam itself. Therefore, the only one way to address all of these risks is through **dam surveillance**. Another factor that is critical is whether there is a warning system in place or not.

After the project risks have been identified, assessed and responded to, the final stage in the risk management plan is to control the potential risks. Crucially, the planned risk response should be controlled when installing the system and during the collection of physical data. The system should have its own back-up power supply during situations such as power failure caused by an earthquake impact. The controlled output from artificial intelligence should be updated regularly to response the change in risk control.

## 6.0 CONCLUSION:

Risk management is the identification, evaluation and control of all risks that threaten the assets, earnings, finances and essential operations of an organisation or system. Risk Engineering is one type of analysis, which can be applied to all water storage structures. The traditional approach to such studies is a process of hazard identification, probability assessment, consequence assessment and formation of risk results together with an evaluation against suitable criteria. Included in such approaches are events tree and fault tree modelling. The use artificial intelligence as a tool will improve the risk management process and reduce the communication time between respective authorities. (Example: Cawndilla Outlet Regulator failed due to single man surveillance and delayed in arriving emergency services) [Ref: 7]


## 7.0 ACKNOWLEDGMENT:

The authors gratefully acknowledge the support from Curtin University of Technology.


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**Likelihood**

| Level | What is the likelihood the risk will happen? |
|---|---|
| A | Remote |
| B | Unlikely |
| C | Likely |
| D | Highly Likely |
| E | Near Certainty |

**Consequence**

| Level | Technical Performance | and/or | Schedule | and/or | Cost | and/or | Impact on Other teams |
|---|---|---|---|---|---|---|---|
| 1 | Minimal or no impact | | Minimal or no impact | | Minimal/no impact | | None |
| 2 | Acceptable with some reduction in margin | | Additional resources required; able to meet need dates. | | <5% | | Some impact |
| 3 | Acceptable with significant reduction in margin | | Minor slip in key milestone;not able to meet need dates | | 5-7% | | Moderate impact |
| 4 | Acceptable, no remaining margin | | Major slip in key milestone or critical path impacted | | >7-10% | | Major impact |
| 5 | Unacceptable | | Can not achieve key team or major program milestone | | >10% | | Unacceptable |

Source: Baccarini, D. 1999, Risk Management 641 course notes, Curtin University