PERSONAL AND PROFESSIONAL EXPERIENCE IN THE HOURS FOLLOWING THE NEWCASTLE EARTHQUAKE

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Robert Sirasch, aged 51 qualified as a Civil Engineer at the University of Newcastle in 1972. Employed by the Newcastle City Council as a Cadet Engineer he worked as an Engineer in the Drawing Office , then as a Structural Designer with Curtin & Ptrs - Architects & Engineers, and prior to establishing his own practice in Newcastle in 1974 worked with Smith Dekanzo Wholohan and Grill. The work with all these was structurally orientated involving residences through to oilrig support structures in Bass Strait.

He has had construction and manufacturing experience as well through the design and manufacture of timber laminated beams and the design and construction of "pole homes"

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

Within an hour after the event the author presented himself to the Sergeant coordinating rescue operations on the site of the collapsed Workers Club in King Street, Newcastle.

This attendance was in response to a public plea for assistance broadcast on Radio NewFm Being in the proximity of the site inspecting his own clients' building made such a response convenient to make.

He approached Sgt Whitley with the words do "you need an Engineer? " to which Whitely replied "Are you an Engineer?" Sirasch replied "yes", Whitely then said "that I needed to know that the collapsed building was safe for my people to be working in". Sirasch said "ok" and went about viewing and reporting to Whitely all he saw that was considered to be relevant.

It is the circumstances over the next 4 to 5 hours experienced by myself - having accepted a role that was described by others later on as having "difficulties" that I intend to describe in this paper.

LEARNING FROM THE NEWCASTLE EXPERIENCE: INFORMATION RESOURCES FOR EARTHQUAKE AWARENESS

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ABSTRACT:

The Newcastle Earthquake CD-ROM is a multimedia, full text database of information resources pertaining to the 1989 Newcastle Earthquake. Its primary objective is to serve the information, research and educational needs of present and future generations. The earthquake experience is reproduced in image, textual, audio and video formats across a range of subjects. It is hoped that the resources will assist in the understanding of Australia's vulnerability to earthquakes and its resulting impact and thus improve in the Australian community an awareness of risk, preparedness and response to the earthquake hazard. Users of the information have to date come from a variety of backgrounds but the largest group have been schools. There is a need to develop other collections of earthquake related resources and link them so that there is available a national network of resources.

LEARNING FROM THE NEWCASTLE EXPERIENCE: INFORMATION RESOURCES FOR EARTHQUAKE AWARENESS

1. Background

The Newcastle Earthquake devastated the city and the people of Newcastle when it took place ten years ago. It seemed that no member of the community was spared from its impact in some way. When 13 lives are lost, hundreds injured, and more than 10,000 buildings damaged, the entire community is affected in some way. If homes were spared, then vital services, places of work and just access to normal facilities were affected.

Whilst our earthquake in Newcastle seems a relatively minor disaster in comparison to the one in Turkey last month, we are reminded yet again that the deaths of the thousands in Izmit and Istanbul were caused by buildings. With death and destruction, there is the economic, social and psychological trauma that follows. In Newcastle today, everyone has a story to tell - in Turkey it will be an even more tragic story, but with time, memories will fade and complacence will again take over.

Ten years later, the people of Newcastle have moved on after carefully orchestrated steps by various agencies towards recovery and renewal. What steps towards earthquake mitigation has the community taken to reduce the impact of another disaster? What procedures in emergency services response are in place and are they being regularly reviewed? How many new buildings are being designed that implement the new building codes? My enquiries indicate that the building standards are not being fully implemented by practitioners. How many residents have taken out insurance policies to the full value of their properties? Conferences and papers have discussed these issues but have these messages been put into force? We hope that the compilation of resources on the database will serve as a reminder of the disaster in Newcastle and the research and studies that followed that event and continue today.

2. Rationale for the Earthquake Library and Database

In the aftermath of the 1989 Earthquake, the Newcastle Region Library was approached to trace records of earlier earthquakes that were known to have been recorded in the region and the buildings that were previously affected. The only accounts that were located were from newspaper reports. Minutes of council meetings and archival records made no mention of these earlier earthquakes. Although there were references to Leo Cotton, a geologist at Sydney University who was supposed to have conducted a survey in 1868, there were no records of his research or any documentation of his findings. There was in fact very little information to draw upon, and Newcastle City Council decided that the experience of the 1989 earthquake would be collected in all formats and be made available for the education and research community now and for the future. This objective led to the development of the Newcastle Earthquake Library and Database in the Newcastle Region Library.

Another reason for the development of the Earthquake Library and Database were the enormous number of requests for information that the Library received in the aftermath of the earthquake. Library staff were called upon to obtain information to assist the disaster managers and other library clients. In the early months this became a focal point of activity. Later the requests for information came from information seekers across the country and beyond for information on the Newcastle experience for their own mitigation efforts. To date the Library has probably received over 25,000 enquiries over the last 9 years specifically about the Newcastle earthquake.

As this demand for information increased from users outside Newcastle, the Library decided to convert the library and database into an electronic format suitable for dissemination. This involved the retrospective scanning and editing of records with copyright issues to resolve. The technology was basic 6 years ago and the task was time consuming and expensive. The information resources were also in a variety of mediums - photographs, maps, audio and video recordings and all this information had to be digitised. With grant assistance from IDNDR (International Decade for Natural Disaster Reduction) Australia, this project was funded for two years.

3. THE NEWCASTLE EARTHQUAKE CD-ROM

The Earthquake CD-ROM is a library of resources on the 1989 Newcastle Earthquake and related information. Our goal was to make the available resources in the library accessible to users wherever they were, in a format that would be easy to retrieve and manipulate. It is not a bibliographical listing of resources but the actual materials available in the library in an electronic format. At present 70% of the textual resources, 20% of the images available and 90% of the digitised audio and video information is available on the CD-ROM. There are about 4,000 entries and about 3200 are available as complete records.

As no further funding is available for the project it has been decided to release the CD-ROM in its current state for the 10th Anniversary of the earthquake. If we are able to raise funds from the sales of this CD-ROM, we will complete the scanning of the remaining materials. The existing collection and resources have successfully generated research and publications but the Newcastle Region Library does not have the funding or resources to continue updating and maintaining such a specialised database indefinitely. We are continually locating more and more materials for inclusion but we have to draw a line at some stage.

4. TYPE OF INFORMATION IN THE EARTHQUAKE CD-ROM

The information in the collection includes:

- earthquake engineering
- insurance issues
- seismology
- emergency management and response
- social and economic impact
- health and psychological impact
- heritage issues
- recovery and renewal

The Library's CD-ROM includes not just textual information but images, oral interviews and video clips. The oral interviews with victims of the earthquake, disaster managers, engineers, conservationists and other.s are a valuable information source as these interviewees' experience would never have been documented otherwise. We have also included excerpts from radio and television broadcasts that report the earthquake's impact as it unfolded. As many of these recordings are lengthy it was not possible to reproduce the entire recordings on the CD-ROM and we have reproduced 2-3 minute excerpts of each. Access to the full recording may be negotiated with the Newcastle Region Library.

The emotional impact and the extent of destruction of the earthquake are conveyed in the photographs and images that we have drawn from a variety of sources. There were thousands of images available from the Newcastle Herald, insurance companies, and various organisations and individuals. A sample of hundred images has been scanned and included in the CD-ROM. In addition to these photographs, many of the full text documents also included images and illustrations, which are accessible on the database.

The CD-ROM includes conference papers, reports, dissertations, newspaper and journal articles. The impact of the earthquake on people's lives is illustrated in musical renditions, poems, letters, cartoons, anecdotes, a play and in artistic works which are also included in the collection.

Primary materials often provide the basis for research. These have been indexed in the database as a collection. Following are some examples of the primary collections:

1. A survey of felt reports of homes in the Hunter after the 1989 earthquake was undertaken by a seismologist and has been deposited in the library. (There are about 4,000 surveys in the collection).
2. The NRMA has 15,000 files of damaged property and an analysis of these is available as an EXCEL file, which is indexed in the database.
3. The applications for financial assistance from the Lord Mayor's Earthquake Appeal funds are a restricted collection.
4. Historical records of previous earthquakes from newspaper clippings in the Hunter region are also indexed. (These are also comprehensively covered in Cynthia Hunter's book.) [1]

5. USERS OF THE EARTHQUAKE LIBRARY AND DATABASE

Over the past seven years, users of the information resources in the library have come from a variety of backgrounds. They include:

- Building and Construction personnel
- Emergency workers
- Engineers
- Geologists
- Heritage experts
- Historians
- Insurance Companies
- Legal researchers
- Librarians
- Local government planners
- Radio and Television Producers
- School students
- Seismologists
- Teachers
- University researchers
- Writers & Journalists

[1] Hunter, Cynthia. (1991)The earth was raised up like waves in the sea...earthquake tremors felt in the Hunter Valley since white settlement.

However the largest group of users have been schools. We have an average of 20 enquiries a week during term time for earthquake related information from students aged 8 to 18 years. This is an encouraging trend as education on earthquakes and natural disasters is surely the best way of instilling community awareness and preparedness. We would have liked to develop, for the school community, a more state-of-the-art product and interface, to make the learning experience an exciting one with games and exercises. However, our limited resources prevented this. We hope however that schools may still be able to use this CD-ROM as a resource.

6. A National Network of Information Resources

The Newcastle Earthquake Database is the most comprehensive record of information resources on the 1989 Earthquake and possibly the most extensive collection on any Australian earthquake. I believe that records such as these are important for learning, understanding and taking steps towards mitigation. We all need to bring together the existing collections on earthquake related literature in Australia.

There must be amongst many participants here, a wealth of information resources on other earthquakes and related information. The National Hazards Research Centre at Macquarie University has a database of earthquake resources. There must be similar literature collections in the other earthquake research centres, libraries and local government offices. There is a need to draw these resources together into a national database or to develop a national network of resources for research and study on the behaviour and impact of earthquakes in Australia. These multidisciplinary resources will enable study not just for geologists, engineers, the insurance industry and emergency services, but for all other related agencies such as the health profession, the welfare and social services and the business and industrial communities.

7. Conclusion

I hope that this gathering will seek to reinforce and remind the Australian community that damaging earthquakes can occur in Australia, as it did so unexpectedly in Newcastle 10 years ago. Perhaps we need the co-operation of the media. We need to emphasise preparedness at every level - in relation to the design and construction of buildings, in insurance coverage and in lifeline and emergency service management and response. There is no place for complacence. We hope that the Earthquake CD-ROM will serve to provide some lessons from the Newcastle experience 10 years ago.

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NEWCASTLE AND BOTANY EARTHQUAKE RISK ASSESSMENT PROJECT

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ABSTRACT:

The work reported in this paper examines geohazards for the Newcastle/Lake Macquarie and Botany regions in NSW. A difficulty faced by communities and facility owners is obtaining and analysing the information needed to determine what is an acceptable level of risk. The paper proposes the hypothesis that the frequency of occurrence and the impact of major geohazard events in Australia now exceed levels of community acceptability for adverse consequences to urban communities, to both individual facilities and the wider urban infrastructure. The paper describes the technique developed by AGSO for examining macro risks to urban communities and the approach being adopted for reviewing the impact of earthquake events to specific buildings and lifeline infrastructure.

The majority of data and the relationships linking them in the geohazard risk function are spatial in nature and the analysis process proposed for this project, building on that developed by AGSO in Queensland, will use a GIS platform on which to construct a model of urban infrastructure and communities and to analyse geohazard risk. Work will also be done at the individual facility level to review damage assessment based on the 1989 event in Newcastle.

1 INTRODUCTION

The Cities Project was established within AGSO in 1996 to develop a better understanding of geohazards and their impact on urban communities, and to apply risk management techniques to the geohazard urban environment. A series of case studies is being undertaken to develop the science, the techniques and tools, and the information needed to analyse complex problems of cities within their natural world. The first of these case studies was undertaken for Cairns and has been the test bed for development of this approach to risk analysis. Further city studies are being undertaken in Queensland and for the ACT. The work reported in this paper examines geohazards for two regions in NSW comprising the municipalities of Newcastle and Lake Macquarie as one, and the municipalities in South Sydney around Botany as the second. It is being undertaken jointly by AGSO, Newcastle and Lake Macquarie City Councils, Hunter Water Corporation, Department of Public Works and Services and other groups and agencies.

These two regions were first established well over 100 years ago and still contain much of their early building and utility infrastructure which predates modern science in risk assessment and building technology. That is not to say that this infrastructure is at high risk but it does mean that the extent of risk is less certain than more recently constructed facilities.

The aims of the Newcastle and Botany project are to provide: a comprehensive analysis of the Newcastle 1989 earthquake event and its consequences; an assessment of geohazard risk for the region on which to base future risk mitigation and emergency response plans; decision support tools for local emergency managers; and to design material to maintain and enhance community awareness of earthquakes and other geohazards.

This paper describes aspects of some of the work proposed under the project, covering the technique for examining macro risks to urban communities and the approach being adopted for reviewing the impact of earthquake events to specific buildings and lifeline infrastructure. Although the whole project will examine a range of geohazards this paper focuses on earthquake hazard.

2 RISK

Risk has a specific definition in the science of geohazards. At the micro level specific risk has been managed for individual facilities, buildings and infrastructure through best practise (engineering, building, local government) with concern for immediate impacts of a hazard on the facility but without considering the aggregate effect on the whole neighbourhood of damage to each individual facility. At this local level resistance against some hazard events is mandatory and is specified in building codes and local government building regulations, whilst provision for other hazards is at the discretion of the owner. Events which can be excluded from resistance capability are those which can be managed around (eg. live loads beyond the code limits which are managed by the facility owner), those whose consequences affect use of the facility for short periods but not its structural integrity (eg. inundation or severance of access), and those whose probability of occurrence is deemed to be so rare as to be acceptable by the owner and community. However, one of the difficulties faced by individual facility owners, a difficulty which is usually passed on by them to approving agencies and the professions, is obtaining and analysing the information needed to determine what is an acceptable level of risk.

At the macro scale infrastructure in Australian urban communities is expanding in amount (physical and monetary value) and technical complexity. Management of the wider risk of the breakdown of function of this infrastructure has to a considerable degree been ignored. Rather, very efficient professional and community based emergency response organisations have been established, with coordination structures and training regimes instituted to respond to a wide range of catastrophic events across the urban (and rural) infrastructure. Have we readied ourselves to respond to but not to mitigate the effects of geohazard disasters?

This question postulates the hypothesis that the frequency of occurrence and the impact of major geohazard events in Australia now exceed levels of community acceptability for adverse consequences to urban communities, for both individual facilities and the wider urban extent. The perceived increase in risk contained in this hypothesis may result from either a reduced tolerance to adverse consequences (a change in acceptability) or a scientific reappraisal of an increase in the hazard, or both. As Australian urban communities have grown in their density and their quantum the losses from geohazards have increased - there is more to be damaged and there are fewer places to escape to! As our immigrant civilisation learns more of this land, after 200 years, we find that presumed limits to catastrophic events can be exceeded, as has happened with predicted maximum flood events and the consequential changes needed to strengthen dams throughout Australia. In these circumstances we need to find a new approach to geohazard risk for urban communities.

3 THE MACRO RISK MODEL

The model proposed expresses risk as the outcome of a relationship between a hazard phenomenon, the elements exposed to risk, their fragility or vulnerability, and the level of acceptability of adverse consequences.

Risk = f (*Natural Hazard, Elements, Vulnerability, Acceptability*)

The definitions of The Office of the United Nations Disaster Relief Organisation (UNDRO) in 1979, cited by Fournier d'Albe[1], are:

> *Risk (ie. 'total risk')* means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.
>
> *Natural hazard* means the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon;

Elements at risk means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area;

Vulnerability means the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude; a measure of fragility to the hazard;

Acceptability is either the return period of risk being assessed for the hazard or the sensitivity of the vulnerability measure, its form being determined by the context of the risk function.

The Australian/New Zealand Standard on Risk Management[2] provides a methodology for the assessment and management of risk. It uses the term "Evaluation" of risk and a methodology to calculate risk and then compare it against (pre-)determined standards of acceptability. However, acceptability is often politically or emotionally based, rather than based on logic and in any case may change according to prevailing circumstances in response or recovery from disaster. Consequent evaluation of risk against a poorly defined benchmark presents difficulties to be examined further into the project.

To apply this model for an urban area all four elements (H,E,V and A) in the above function require specifying data and the form of the function requires definition. The following sections comment on the process for collecting and manipulating data for built elements and on the vulnerability variable.

4 INFORMATION SOURCES FOR ELEMENT DATA

The majority of data and the relationships linking them in the geohazard risk function are spatial in nature. The analysis process to be used in this project, building on that developed in the Cairns study[3] will use a GIS (Geographical Information System) platform on which to construct a model of urban infrastructure and communities. This model will include, for the two areas being examined - Newcastle/Lake Macquarie and Botany - detail on infrastructure from the following sets:

- topography
- cadastre
- land parcel details and street addresses
- building type, materials of construction and age
- administrative, Census Collector District and suburb boundaries
- road centrelines and levels
- lifeline spatial location, structural form and construction materials
- public space boundaries
- geology
- flooding profiles

and, for the Newcastle region, from Councils and NSW Department of Mineral Resources;

- earthquake damage incurred in 1989
- mapping of underground mineworkings

Information to be obtained in electronic form ABS will include:

- demography and employment.

Information available from other agencies will include:

- geology – from 1:100,000 mapping in electronic format for the Newcastle Coalfield from NSW Department of Mineral Resources Geological Survey of NSW.
- Mine workings, now being mapped in GIS form by NSW Department of Mineral Resources.

Experience from the Cairns project and from the Sydney 1999 hailstorm has shown the need to report at Census Collector District level in order to provide sufficient detail for further operations, both as response by emergency managers and for planning remediation and upgrade programs. The CCD has a grain size which can allow recognition of local variations at the street and facility level.

Much of this information is available on databases held by the participating agencies, though some will require re-configuration to the GIS format. It is expected that considerable field survey work will also be needed to complete data on building type and construction, to smooth edges across data-set boundaries and to bridge missing pockets. Local Governments and other agencies have a range of electronic mapping and data systems though they do not generally hold data on building type and construction, nor is information on land parcels usually collated with street address. The GIS platform is able to bring these data sets together and this will also provide a tool for local government to use in the future for other management functions.

An example of the ability to extract data using the GIS platform is illustrated in the work now in hand by AGSO on cyclone hazards for Mackay, Queensland. A new building code requiring strengthening for strong winds was instituted in Queensland in 1982. Aerial photography was available for most of the town for 1983/1985 and for 1995. The photos were scanned and registered onto the GIS and overlain for the two time periods. Dwellings constructed after 1983 were identified and even their roofing material could be defined, thus providing the data needed to categorise these buildings for cyclone resistance. Buildings existing in 1983 were assumed to be non-compliant and were deemed to carry a residual cyclone risk.

Work has commenced in Newcastle collating data onto the GIS platform. The success of the Cairns and Mackay work provides confidence that the technique will be workable.

5 INFRASTRUCTURE VULNERABILITY

Vulnerability, the resistance of infrastructure to shock waves, requires assigning vulnerability parameters to all elements in the study area; this is a major task. Two specific aspects of infrastructure vulnerability are considered in this paper; a review of the damage to selected buildings resulting from the Newcastle 1989 Earthquake in the light of the earthquake loading standard, microtremor studies and high resolution seismic testing; and an appraisal of major lifeline infrastructure in the Botany region.

This review has two objectives; to contribute to an improved understanding of the 1989 earthquake event and to examine the Site Factor approach used in the earthquake loading standard[4].

Information on selected buildings and ground conditions in Newcastle is being gathered from the following sources:

- Reports of damage from Newcastle City Council records of building inspections and post-earthquake engineering reports,
- Photographs and descriptions of damage from first hand observers,
- Geotechnical reports from sites at or adjacent to the damaged building; these have been prepared following the earthquake for new building works.

A microtremor study for Newcastle was conducted by Miliauskas[5] in 1996 and further microtremor investigations will be carried out as part of this project. The planned high-resolution seismic tests will measure the ground response from a broad frequency range vibration applied to a plate anchored on the soil. These investigations will assist in developing a detailed understanding of surface response to earthquake waves in selected areas most affected by the 1989 event.

The procedure proposed for examining the selected buildings is:

- Examine and quantify the recorded damage.
- estimate the earthquake shear force required to cause this damage and using known geological information calculate the ground motion which would generate this shear force.
- using results of high-resolution seismic investigations, waveform modelling and/or other sources estimate the ground motions at the site from information known of the 1989 event.
- Compare the ground motions calculated from the building damage and the 1989 event.

The two approaches , literally top-down and bottom-up, will allow this comparison of ground motion in order to build on work earlier in this decade by Sommerville et al[6] and others and to provide a review of parameters in the earthquake loading code.

The Botany region was selected because its geotechnical setting has similarities to the areas of Newcastle which suffered most damage in 1989 and because it contains major and some very old lifeline infrastructure. Burg[7] provides an excellent introduction and a starting point for this analysis. Main elements are:

- freight rail lines and arterial roads which cross on structures,
- airport runways on reclamation,
- massive airport terminal structures,
- wharves with deep retaining structures and massive crane structures,
- electricity substations and switching yards,
- high pressure gas mains,
- chemical and petroleum pipelines,
- water mains
- sewer gravity mains,
- telecommunication exchanges.

The behaviour of these elements under earthquake shock is not as well defined as for building structures and techniques for analysing risk using a GIS platform have yet to be developed.

6 CONCLUDING COMMENTS

Work has commenced on the Newcastle and Botany Project as part of AGSO's comprehensive study of geohazard risk to Australian urban communities. The three aspects discussed in this paper, the GIS approach to examining macro risk, the review of damage to buildings incurred in 1989 and the examination of effects on lifelines, are aimed at improving the knowledge of earthquake impacts on built infrastructure.

The conclusions we draw at this early stage are that, although there is a need to address the specification of the acceptability variable in the risk function, the application of science and the adoption of an engineering approach to providing increased surety to urban communities faced with risk of geohazards can be productive. There is still a way forward.

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NATURAL FREQUENCIES OF DOMESTIC AUSTRALIAN BUILDINGS: HIGHER THAN THE CODE SUGGESTS?

BEN MILIAUSKAS, VIC DENT AND TREVOR JONES

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Ben Miliauskas' honours thesis studied the relationship between Microtremor recordings and insurance losses caused by the Newcastle earthquake of 1989. Ben currently works for Guy Carpenter and Co., investigating the potential and realised impacts of Natural Catastrophes on the insurance industry.

Vic Dent has had several decades' experience with AGSO in many aspects of earthquake seismology including instrumental networks, strong motion recording, crustal modelling, and earthquake hazard analysis. He has worked variously from Canberra, Perth, Rabaul, Antarctica and sub-Antarctica.

Trevor Jones is Manager of the Australian Geological Survey Organisation's Cities Project. He leads the earthquake risk activities of the Cities Project and advocates community-centred earthquake risk treatment activated by spatial analysis. Trevor holds BSc., MSc. and Dip. Tch qualifications and has worked extensively in earthquake hazard and risk assessment at AGSO and the Mineral Resources Department, Fiji, since 1982.

ABSTRACT:

A survey of ambient vibration frequencies was carried out on a range of building types in the Newcastle region in March 1999. The objective was to measure the range of frequencies that might be expected amongst domestic structures in the region. It was expected that a correlation would exist between the observed frequency and local characteristics such as type of construction, foundations etc., with a maximum structural frequency around 10 Hz. Whilst the data set needs to be expanded, preliminary results do not support such an assumption, with a general trend indicating natural frequencies almost double those expected.

Paper No. 10

NATURAL FREQUENCIES OF DOMESTIC AUSTRALIAN BUILDINGS: HIGHER THAN THE CODE SUGGESTS?

by Ben Miliauskas[1], Vic Dent[2] and Trevor Jones[3]

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1.0 INTRODUCTION

Earthquakes most severely impact structures when incoming seismic motions have similar frequencies to the natural frequencies of the overlying structures. Accordingly, earthquake loss estimates must account for this observation to improve the comprehensiveness of loss calculations.

The general vibrational behaviour of engineered structures may be known to some extent, but the vast majority of Australia's buildings, residential structures, are not engineered. As such, the in-situ behaviour of Australian residential buildings is probably less well-known.

We have recorded the motion of various residential structures within the Newcastle region in a first attempt to typify the natural frequencies of residential structures, and compare their behaviour to current expectations. The results are of particular interest to participants in the Newcastle Earthquake Risk Project (see Stewart, these Proceedings), however they will also be important for future earthquake loss assessments in Australia.

We present the results of this preliminary investigation at the Symposium less to present answers but more to stimulate interest in developing further knowledge on this subject.

2.0 METHODOLOGY

Recordings were made in 17 buildings across the Newcastle region, 15 being residential structures and two engineered structures (the Newcastle City Council headquarters and the Gibson St car park owned by Newcastle City Council). It is hoped that the two engineered structures will allow a check of the methodologies adopted.

Building response characteristics have been measured by placing a triaxial 1 Hz seismometer in the ceiling cavity of the building concerned and recording motion caused by ambient vibrations over a four minute period. Where possible, recordings were also made on the floor, and microtremor recordings were taken outdoors.

The interpretation has involved reviewing the Fourier spectra generated by the recordings from each ceiling, and qualitatively adjusting the response by using the floor and outdoor recordings as indications of input motion.

It must be stated that the recording and interpretation methodologies are not fully developed at this stage, with no account taken of important structural characteristics such as directional frequency variations or the proximity of internal support walls. Whilst some of the methodologies are subjective, this paper is not aimed at reviewing individual building behaviour, but rather establishing a preliminary overview of residential structure responses.

3.0 CHECK AGAINST AS1170.4-1993

Before reviewing the response generated by residential structures, it is important to look at the responses of the two engineered structures as a means of checking the adopted methodologies.

The Newcastle City Council headquarters is a circular building eight storeys high. The construction is reinforced concrete frame, with precast concrete curtain wall in-fills. Based on AS1170.4-1993(1) , Page 39, the expected building frequency would be around 2 Hz. Adopting the current methodology, the results generated for the council building show frequencies in the range of around 1.25 - 1.8 Hz.

The second engineered structure is a split level car park, with 11 levels. The construction is again reinforced concrete, this time with brick in-fill between the columns to about chest height. The response frequencies forecast by AS1170.4-1993 are around 2.5 to 4 Hz. The recorded responses were in the range 1.25 Hz and 2 Hz.

These results indicate that the methodologies adopted appear to define natural frequencies that are lower than the responses predicted by AS1170.4-1993.

4.0 RESULTS

The responses display some interesting trends, and offer a starting point from which to launch further investigations.

Figure 1 shows the range of natural frequencies generated by the 15 domestic structures, with each point representing a building. The most striking outcome from Figure 1 is the uniformly high natural frequencies. Based on AS1170.4-1993, frequencies of around 4 Hz – 13.5

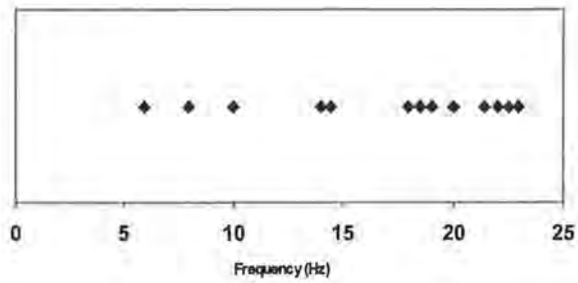

Figure 1 : Distribution of recorded residential structure frequencies.

Hz are expected for structures of 1 – 3 storeys (the common height of residential structures). However, the measured results suggest a higher natural frequency, ranging between 6 Hz and 23 Hz.

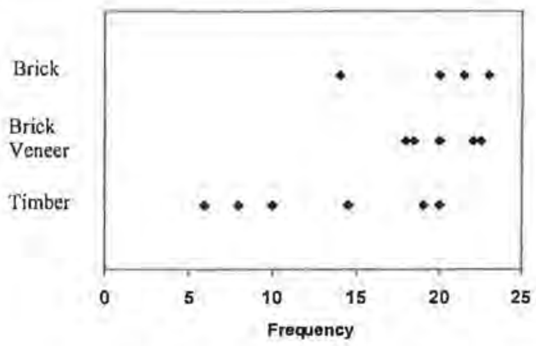

Figure 2 : Wall Type vs Frequency.

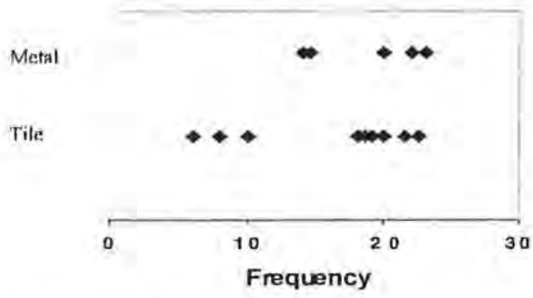

Figure 3 : Roof Type vs Frequency.

The second observation from Figure 1 is the large variation in observed frequencies. The wide distribution means that the characterisation of residential buildings may be difficult, with the potential natural frequency highly variable.

In an attempt to characterise the building responses, we have divided the recorded frequencies based on, basic construction characteristics: wall type, roof type, and structure height (number of storeys). The results are shown in Figures 2, 3 and 4 respectively.

Figure 2 shows that Brick and Brick Veneer structures generally generated higher natural frequencies, with less scatter, than Timber* buildings, which show a wide range of natural frequencies from around 6 Hz up to 20 Hz.

Figure 3 indicates that some clustering of natural frequencies may occur based on roof type, however to be of practical use, the groups would have to be further divided using secondary characteristics such as wall type (e.g. tile roof with brick walls etc.). A brief analysis of classifications based on secondary characteristics did not illustrate any clear associations.

Finally, Figure 4 shows building responses plotted against building height. The results suggest that Buildings of two storeys show a wide range of natural frequencies, while most of the single-storey buildings surveyed have natural frequencies in the range of 17 Hz to 22 Hz. The variation amongst these groups would once again suggest that further sub-division is

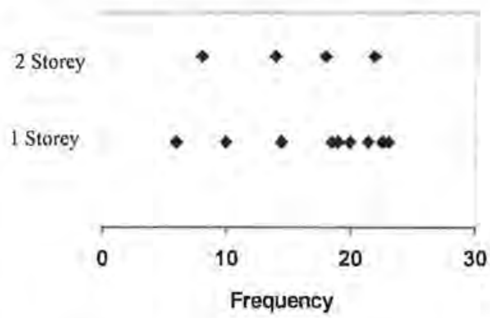

Figure 4: Building Height vs Frequency

* Note should be made that in the above discussion, the title 'Timber' refers to buildings of timber frame with light cladding, as such, these include, 100% Timber buildings and Fibro buildings.

necessary. Again, a brief analysis of classifications based on secondary characteristics did not illustrate any clear associations.

Given that building height is generally taken as the defining characteristic of structure frequency, the wide range of recorded frequencies, and the large commonality of frequency range with building heights is somewhat surprising. A larger sample may bring out a correlation between the structure height and the building's natural frequency.

5.0 CONCLUSION

Based on the results, there are three main points worthy of consideration :

1. The observed natural frequencies of residential structures are generally higher, and cover a wider range, than the frequencies commonly attributed to domestic (i.e. low rise) structures. Accordingly, a re-examination of urban earthquake hazard maps in Australian cities may be necessary, particularly those based on microtremor surveys, where a general practice of mapping the ground's natural frequencies to a maximum of around 15 Hz[2,3,4] has been adopted.
2. With our limited data, only loose associations are evident between the natural frequency of domestic structures and their basic construction characteristics such as wall type, roof type or height.
3. The findings highlight the complexities involved with modelling the earthquake behaviour of the majority of Australia's building stock.

Finally, the large variation in the results, and their divergence from expectations, indicate that much work is needed to identify the true behaviour of residential structures in Australia.

6.0 ACKNOWLEDGEMENTS

We thank the Newcastle City council and Lake Macquarie City Council for providing us with test properties. In particular, we thank the householders of all the residences for their cooperation and hospitality.

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SEISMIC QUALIFICATION TESTS FOR SYSTEM ENCLOSURE

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ABSTRACT:

During an earthquake, telecommunication equipment are subjected to motions that can overstress equipment framework, circuit boards and connectors. In order to ensure the integrity and functionality of the equipment, seismic qualification tests are often required for the equipment installed in seismic regions. This paper describes seismic qualification tests of a series of network system enclosures, designed for installation in seismic regions. Test specimens failing to meet the qualification criteria, were structurally modified and strengthened. The modification was guided by results of modal analysis and modal prediction. The modified enclosures were then subjected to the same qualification tests. The test results show that all enclosures can successfully pass the qualification tests.

1. INTRODUCTION:

The seismic qualification tests for equipment demonstrate equipment's ability to perform a set of required functions during and/or after being subjected to the forces resulting from specified earthquakes. Focusing on Experimental Seismic Qualifications (ESQ), the seismic qualification tests reported in this paper are based on the Bellcore Standard (GR-63-CORE) with reference to other international standards. These tests were aimed at assessing the adequacy of a series of telecommunication enclosures to protect their sensitive contents during major earthquakes.

2. QUALIFICATION TESTS:

2.1 Bellcore requirements

Table 1: Summary of Bellcore requirements

Static Pull Test	Maximum deflections at the top of the system enclosures < 75 mm Maximum residual deflection upon release of the load < 6 mm No observable structural/mechanical damage during tests
Sweep Sine Test	First natural frequency of the test specimens identified by sweep sine tests > 2.0 Hz
Waveform Test	TRS (Test Response Spectrum) envelops RRS (Required Response Spectrum) Maximum relative deflection at the top of the enclosures < 75 mm No observable structural/mechanical damage during tests

2.2 Test facility Seismic Qualification Tests were conducted at the National Facility of Dynamic Testing and Research at the University of Technology, Sydney, featuring an advanced uni-axial shake table. UTS shake table, utilising advanced technology, provides a high capacity/high fidelity signal reproduction means for Experimental Seismic Qualification. Figure 1 shows the comparison of desired earthquake signal and the table reproduced signal for the standard earthquake specified by Bellcore.

2.3 Static tests Prior to the waveform testing, horizontal static pull tests on test specimens were performed. Static pull tests provided information on enclosures' strength and stiffness characteristics. Static pull tests applied a pulling load in each of the four horizontal directions through a load frame at the top of each enclosure. The loads and top deflections of enclosures were recorded using a load cell and two displacement transducers. The applied loads were functions of the simulated content mass and self-weight of enclosures. Figure 2 shows a typical static test result.

2.4 Waveform Tests

Earthquake risk zone : In accordance with Bellcore standard (GR-63-CORE, Clause 4.4.1.1), the entire United States is divided into five Earthquake Risk Zones (Zone 0 to 4) depending on geological conditions. Zone 4 corresponds to areas with highest risk, Zone 3 is the next highest and so on. Areas designated as Zone 0 present no seismic risk. Equipment to be used in earthquake risk Zone 1 to Zone 4 shall be tested to determine the equipment's ability to withstand corresponding earthquakes.

Waveform test: The severity of the test is determined by the designated seismic zone where the equipment is to be installed. In this instance, the equipment is designed for installation in earthquake risk Zone 4 of the United States. This means that the equipment will be tested at the highest acceleration levels. The acceleration-time history waveform (Fig. 1), VERTEQII, supplied by Bellcore for earthquake risk zone 4 has been synthesised using several typical earthquakes and different building and site conditions. The test procedure subjects the equipment to the prescribed motion of the synthesised waveform by means of a shake table. Shaking is applied to equipment in each of its two principal directions. This simulates conditions that would be encountered in service.

Required Response Spectrum (RRS) and Test Response Spectrum (TRS): When reproducing the Bellcore waveform, the shake table's acceleration response spectrum known as the Test Response Spectrum (TRS), must envelop the Required Response Spectrum (RRS) which is specified by the standard. However, the maximum value of TRS should not exceed specified RRS by more than 30%. Figure 3 shows the RRS for Zone 4 and TRS achieved by UTS shake table. Figure 3 also confirms that the stated requirements are met.

Tests and instrumentation: Five typical network system enclosures manufactured by Rack technologies Pty. Ltd, have been tested, representing a wide range of their products. Two displacement transducers were installed at the top of the enclosures to record top displacements. Five PBC tri-axial accelerometers were installed at various locations to obtain detailed information on accelerations. Each enclosure was tested in two orthogonal directions. Sweep-sine tests were carried out before waveform tests to determine the natural frequencies of the enclosures.

3. MODIFICATIONS AND PREDICTIONS:

If specimens failed the waveform tests, modal analysis of that particular specimen was then carried out to identify possible modification options. Modifications also considered factors such as accessibility, serviceability, simplicity and cost. The modal tests and modal analyses were carried out using the state-of-the-art 32-channel high speed HP Vxi analyser which is equipped with one of the best and most powerful software for data acquisition, modal analysis and modal prediction. A proposed structural change was evaluated through a modal design program, enabling authors to quickly gain insight into how to improve the vibration performance of the structure. The effects of proposed modifications on the dynamic response of system enclosures were determined in terms of new resonant frequencies, modal parameters, and mode shape deformation patterns. Guided by these results, the necessary modifications of the structure proceeded. Modified specimens were then put back on the shake table to undergo another round of seismic qualification tests. Figure 4 shows the mode changes before and after modification.

4. RESULTS:

All system enclosures passed seismic qualification tests, including those failed the first test and re-tested after modification. Tables 3 and 4 show typical results for the static and dynamic tests, respectively. Figure 5 shows the relative deflections at top of an enclosure during a waveform test. Figure 6 illustrates the acceleration at top of an enclosure whose maximum acceleration is more than twice the table acceleration.

Table 2 Typical Static test results (side 1)

Enclosure ID	A1	A4	A2	A3	A5
Max top deflection (mm)	41.3	68.6	40.3	40.1	26.4
Max residual deflection (mm)	4.1	5.2	0.7	0.5	4.1
Structural/Mechanical failure	None	None	None	None	None

Table 3 Typical Dynamic test results (side-to-side axis)

Enclosure ID	A1	A4	A2	A3	A5
Lowest nature frequency > 2.0Hz	Yes	Yes	Yes	Yes	Yes
Max relative top deflection (mm)	32	47	26	49	9
Structure failure during the test	No	No	No	No	No
TRS envelops RRS	Yes	Yes	Yes	Yes	Yes

5. CONCLUSIONS:

- A series of seismic qualification tests of network system enclosure were successfully completed.
- National Facility for Dynamic Testing and Research, featuring UTS modern shake table provided the required platform for high standard dynamic testing.
- Modal analysis and modal prediction provided effective tools for modification and re-design of qualification-failed specimens.
- Modified specimens successfully passed the required seismic qualification tests.

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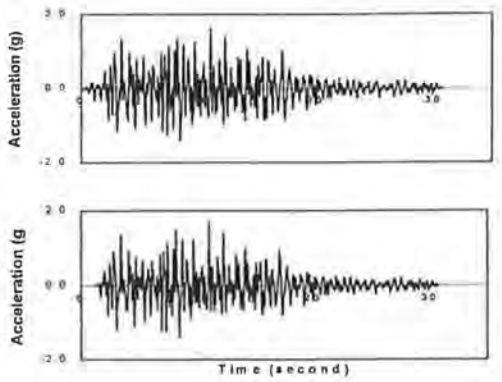

Fig. 1: Desired (top) and achieved (bottom) synthetic earthquake design for risk zone 4

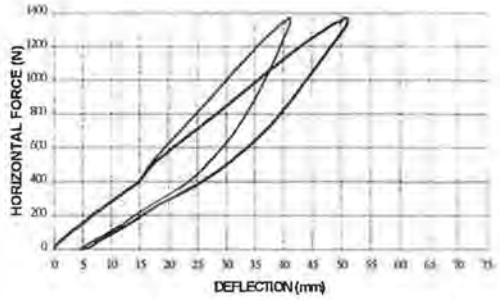

Fig. 2: Typical results of static pull test

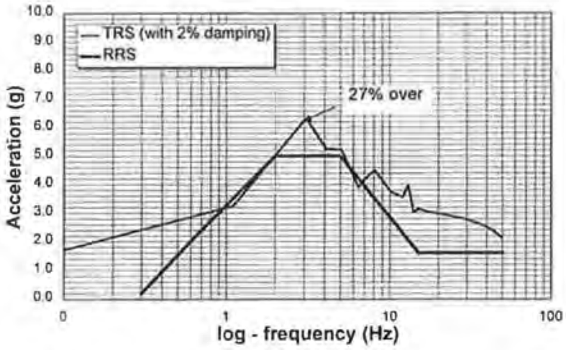

Fig. 3: RRS and TRS for earthquake of risk zone 4

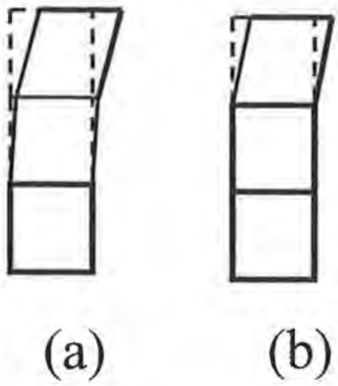

Fig. 4: Typical mode changes: (a) before and (b) after modifications (fundamental mode)

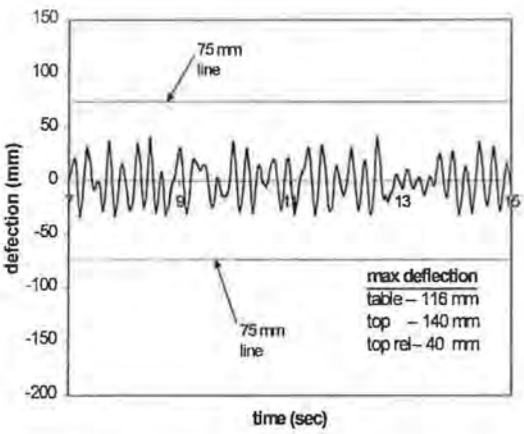

Fig. 5: Recorded relative deflections at top of a specimen during a waveform test

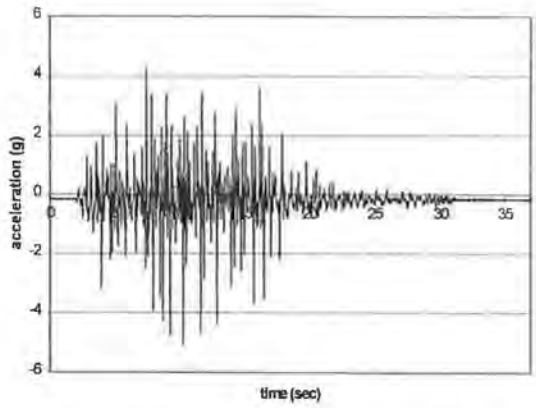

Fig. 6: Recorded accelerations at the top of an enclosure during a waveform test

IMPACT OF MINE BLAST VIBRATION ON RESIDENTIAL CONSTRUCTION OF SOFT FOUNDATIONS: CASE STUDY

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ABSTRACT:

This paper reviews the impact of ground vibration from open cut mining on a rural residential community struggling to come to terms with the physical and psychological disturbance to their homes and life styles.

Coal mining has been active in the Upper Hunter Valley NSW since the early 1900's with underground and open cut mines operated by Muswellbrook Coal Company on the eastern side of the township of Muswellbrook. In 1981 large portions of Muswellbrook Shire were identified as having either open cut or underground longwall mining potential resulting in these areas being proclaimed as being subject to mine subsidence.

The shallow depth of some of these coal reserves and their close proximity to established residential areas has lead to inevitable conflict between mining and urban development, with open cut mining creeping closer and closer to existing development.

While the current Australian standard AS 2187.2 Part 2: Use of Explosives attempts to set guidelines on the level of maximum peak particle velocity of the mine blast induced ground vibration, it is capable of significant variation in interpretation and does not fully account for variations in subsurface soil conditions affecting building performance. It is therefore difficult for Authorities responsible for setting environmental limits governing rnine operations to select appropriate criteria.

The case study represented in this paper reviews the response of a number of typical Australian brick veneer structures to blast produced ground vibration from a new open cut mine. It confirms the results of Australian and Overseas research, which indicates that the safe level of ground vibration for residential structures is extremely variable with the damage threshold values being functions of the frequencies of the the vibration transmitted into the residences and the types of construction. Particularly serious are the low frequency vibrations that existing in soft foundation materials and/or result from long blast to residence distances. These vibrations have been shown not only to cause structure resonances, but also excessive levels of displacement and strain.

Threshold damage is defined as the occurrence of cosmetic damage, that is the most superficial interior cracking of the type that develops in all homes over a period of time. The difficulty of separating the apparent vibration damage from soil related movement is also examined, together with structural amplification factors based on actual measurements at different levels within the residences. Comments are also made regarding human and animal response to the blast vibration.

Paper No. 12

IMPACT OF MINE BLAST VIBRATION ON RESIDENTIAL CONSTRUCTION ON SOFT FOUNDATIONS CASE STUDY BY JOHN F BERTHON

Background 1.

Many New South Wales towns and cities were founded on Coal. After the discovery of coal in Newcastle in 1797, the first regular callers were ships collecting coal. The port's first commercial export was in 1799, when a cargo was loaded for India [(1)]. Coal has therefore continued to be a valuable export from the Hunter Valley for the last 200 years. As coal mining was the reason for establishment of numerous settlements in New South Wales, urban development inevitably has taken place over the coal reserves.

Underground coal mining leads to deliberate or accidental subsidence or lowering of the surface of land, leading to the inevitable conflict with surface features such as buildings, road and services. The first evidence of subsidence damage was discovered in Newcastle in 1906, with further damage being recorded in residential areas surrounding Newcastle up to 1925. These events led to the passing of the Mine Subsidence Act in 1928 and the formation of the Mine Subsidence Board, with the Mine Subsidence Compensation Act being passed in 1961.

While the Mine Subsidence Board is responsible for the investigation of subsidence damage, including prediction of planned subsidence from longwall mining and damage compensation from underground coal mines, the Board has no control or responsibility for open cut coal mines.

Under the NSW Planning Laws, open cut cut mines are designated developments approved by the Minister and administered by the Department of Urban Affairs and Planning. The operation of each mine is subject to conditions of consent, covering such environmental issues as noise, dust control and blast vibration. The Department generally relies on environmental data generated by the individual mine to confirm compliance with the conditions of consent.

While underground mines have operated under and in close proximity to urban areas for a significant period of time and are subject to a defined complaint procedure for affected residences via the Mine Subsidence Board, no similar provisions exist for open cut coal mines. Residents' complaints must be addressed to the individual mine, with appeal to the consent authority in the event that an issue cannot be resolved by negotiation. The main legal avenue available to complainants is the Mine Warden's Court.

Blast Vibration 2.

The environmental impacts of concern in this paper are blast vibration and airblast. The energy released in blasting to break and move rock can result in ground vibration and airblast which may cause discomfort and damage to neighbours, adjacent structures and underground services.

Blast generated ground vibration or seismic energy is usually described as a time varying displacement, velocity or acceleration of a particular point (particle) in the ground. Limits for damage and human discomfort are set by regulators based on AS 2187.2-1993, Explosives Code with reference to "Peak Particle Velocity" (PPV) for ground vibration and pressure shock waves or airblast in terms of decibels (dB).

It has been suggested by a number of sources that this approach ignores the complex interaction between the vibration wave and the propagating medium and the variable response of structures and people to vibration.

Studies carried out in Newcastle by the CSIRO during the deepening of the harbour in 1982 concluded ; "In all buildings examined there was an overlap of the frequencies of ground vibration with the natural frequencies of the building modes leading to the building response magnifying the ground motion. This factor, together with the statistical variation of the ground vibration velocity for a given explosive charge, should be taken into account in order to reduce probability of damage to buildings and disturbance to occupants". (2)

The SAA Explosive Code recommends a Peak Particle Velocity of 5 mm/sec in residential areas "in the absence of a particular site specific study", this limit appears to be regarded as absolute by regulators, although there are additional factors affecting blast vibration limits, such as soft ground, which can be considered. Similarly the SAA Explosives Code sets a limit of 120 dB for human discomfort and 133 dB to avoid structural damage from airblast.

Australian and overseas research confirms there is a need to consider not only the peak particle velocity of the blast induced ground vibration, but also the frequency of the wave train. Open cut coal mine blasts have been shown to produce a high proportion of low frequency energy. The damage thresholds are a function of the vibration transmitted into the residences and types of construction.

Particularly serious are the low frequency vibrations which exist in soft foundations and/or result from long blast-to-residence distances. These vibrations produce not only structure resonances (4 to 12 Hz for whole structures and 10 to 25 Hz for midwalls) but also excessive levels of displacement and strain.(3)

Case Study 3.

A rural residential community south west of Muswellbrook, involved in horse training associated with Muswellbrook Racecourse has become unwilling neighbours to an open cut coal mine. The mine is located on the opposite side of the Hunter River at a distance of 1.5 km from the residences. Coal outcrops on the surface beyond the western escarpment of the Hunter River and the mine plan involves mounding, to reinforce this barrier to enable open cut mining of the coal bearing strata which dip in a westerly direction.

Unlike the remainder of most of the residential development of Muswellbrook, the one and two storey rural residential residences are founded on a lens of Hunter River alluvium with a high ground water table. The underlying strata slopes upward from west to east directing mine blast energy upwards into the alluvium.

Trial blasting at the mine took place between May and November 1997 and production blasting commenced in August 1998. Inspections were made of two of the affected two storey brick veneer residences in September and November 1997 by the Mine's consultants, who observed that "there has been a considerable increase in the number of observed cracks since our previous survey of the residence on 3rd September 1997. A conclusion that may be drawn from this is that the majority of cracks that have appeared since the initial inspection were related to the blasting that occurred on 11th November 1997." The report goes on to record that this conclusion is inconsistent with published information such as the 10 mm/sec damage limit shown in TABLE J1 of AS 2187.2-1993. Other reasons such as soil related movement and human activity eg slamming of doors by occupants were also suggested to explain the cosmetic damage apparently caused by blast vibration.

Production blasting commenced in August 1998 and to date the residences have been subjected to vibration from over 72 main or presplit blasts varying in intensity from 0.5 to 3.97 mm/second together with 16 trial blasts as shown in Figure 1.

Limited data obtained from 1st floor test results, such as Blast 13, implies an amplification up the two storey building of 4.19 when compared to the base monitor, external to the building. The impact of this multiplied on the results recorded to date can be seen in Figure 2

A number of meetings were held between the affected residents, representatives of the mine and the regulator or consent authority, the Department of Urban Affairs and Planning. A meeting in September 1998, produced a protocol or procedure to attempt to differentiate the cause of apparent damage between blast vibration and soil related movement. Unfortunately this protocol was never completed. It involved detailed inspection and monitoring of each of two residences, soil testing to determine the reactivity of the alluvial soil supporting each structure and vibration monitoring at two or three levels in each structure.

Subsequently after the mine had significantly reduced the intensity of blast vibration, another study is about to proceed (August 1999) to determine;

1. Frequency and magnitude characteristics of the blast waves ie overall magnitude and narrow band frequency characteristics of the radial, transverse and vertical components.
2. Amplification factors present in the buildings concerned.
3. Local dynamic characteristics of individual structural elements.

It is hoped that this study will confirm or dismiss residents' claims of cosmetic damage from the initial higher intensity blasts which when coupled with the multiplication factors caused by resonance of the structures could have caused the cracking of brick and plasterboard finishes, loosening of wall tiles etc.

Conclusion 4.

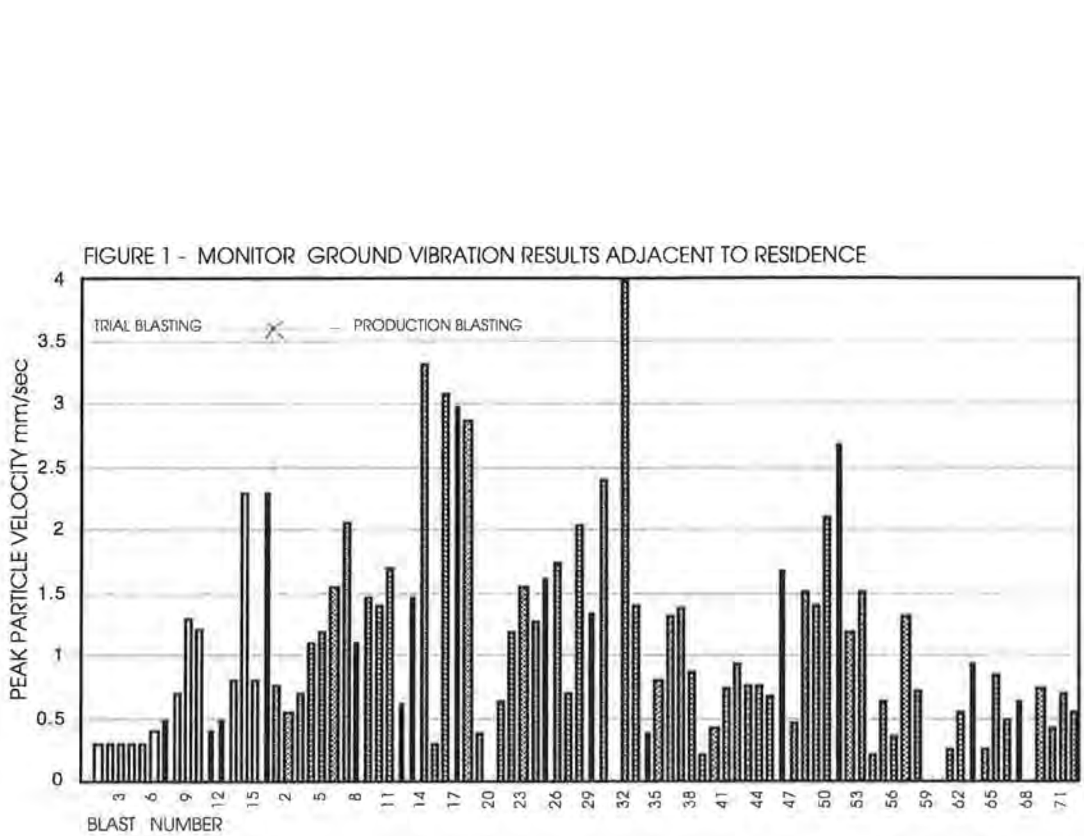
This case study shows the impact of open cut mining on an existing rural residential subdivision development close to Muswellbrook. It highlights the conflict between the Government Regulator's roll in promoting development of an economic resource and the need to set adequate environmental guidelines for blast vibration limits, including the measurement of frequency.

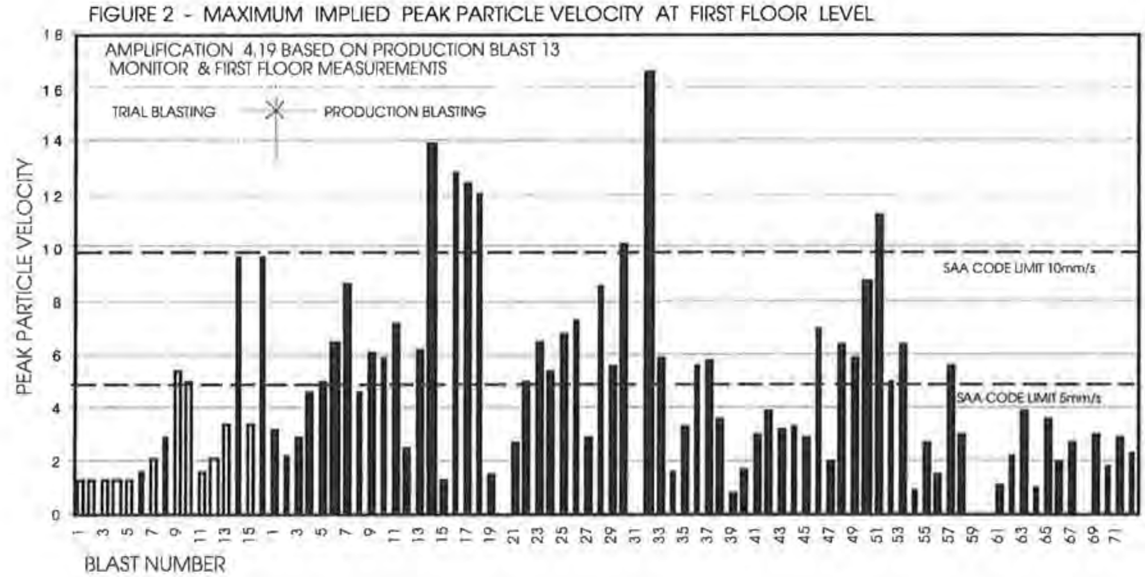
While the SAA Explosives Code recognises the need to examine particular blast related damage in unusual circumstances, such as soft foundations, there is no mention of the need to consider either the frequency of the blast or the amplification factors applying to a particular building.

In addition, as the human body is an effective and sensitive detector of vibration, the residents are not likely to readily accept the explanation of blast vibration experts who claim that blasting is not affecting their houses, particularly when there have been long delays in implementing tests or protocols aimed at measuring building performance.

Thoroughbred racehorses are highly strung sensitive animals and their response to ground transmitted blast vibration must also be a factor when considering the impact of mine activity on this rural residential subdivision.

All parties involved in this conflict need to communicate to relieve the paranoia created by having a peaceful environment disturbed by mining.





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EVOLUTION OF EARTHQUAKE STATISTICS AND FORECASTING EARTHQUAKE HAZARD

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ABSTRACT:

The occurrence of the Tennant Creek and Newcastle earthquakes in areas not identified as higher hazard regions on the earthquake hazard map of the time demonstrates the limitations of probabilistic hazard analysis. An understanding of earthquake phenomena is required for quantifications and forecasts of the reliability needed to ensure mitigation efforts are well directed. A physically based numerical model for elastic stress build-up and dynamic rupture in a 2D fractured zone is used to generate seismicity data. Sequences are observed in the synthetic data where the rate of seismic energy release accelerates and earthquake statistics evolve prior to large events. Accelerating energy release is observed before several Australian earthquakes including the 1997 Burra earthquake. Combined, the simulation and observational results suggest seismic energy release and earthquake statistics evolve in a predictable way under certain conditions. The simulation model provides a tool to probe this phenomenon and develop improved hazard quantifications and forecasts in Australia.

Paper No. 13

Introduction and overview

Australia has a substantial earthquake hazard for an intraplate region with events with Richter magnitudes of up to around 6.5-7 having been recorded within mainland Australia. According to recent US and Australian earthquake hazard maps[1], the higher hazard parts of Australia have roughly similar hazard levels as higher hazard parts of the USA (excluding California) such as the New Madrid seismic zone and the Utah-Idaho region. The substantial hazard in Australia coupled with the common perception that earthquakes are not a major problem makes Australia highly vulnerable to earthquakes. While predicted ground motions and probabilities of earthquakes can provide a basis for mitigation and earthquake engineering design, the paucity of earthquake data in Australia renders the widely applied probabilistic approaches for earthquake hazard analysis unreliable. This problem is illustrated by the occurrences of the 1989 M=5.6 Newcastle earthquake and 1988 M=6.7 Tennant Creek earthquake in areas previously assessed as having a low earthquake potential according to the hazard map of the day. The relatively modest in size Newcastle earthquake caused damage in the $ billions and fatalities. An earthquake the size of the Tennant Creek event near an urban centre would cause a major disaster.

An improved understanding of space-time seismicity patterns and the physics of earthquakes would help allow such problems to be overcome and hence, provide the basis for more reliable earthquake hazard quantifications and forecasts.

We use the physically based lattice-solid numerical model[2,5] to simulate the dynamics of earthquakes in a fractured zone and to generate a synthetic earthquake catalog. We then study the time-evolution of the simulated earthquake sequences contained in the catalog. We observe that simulated earthquake sequences within the catalog often have a strong time evolution effect consistent with observations of accelerating seismic energy release prior to several recent Australian earthquakes, and in agreement with the Critical Point hypothesis for earthquakes.[1,6] Namely, cumulative Benioff strain (square root of seismic energy) release calculated using the synthetic earthquake catalog is often observed to accelerate according to a power law time-to-failure function in the period prior to large simulated earthquakes, and during such periods, the b-value typically evolves from a higher to lower value. For both the observed and simulated earthquake sequences studied, the power law time-to-failure function fits the cumulative Benioff strain and predicts a time just prior to the occurrence of the large earthquake.

Standard probabilistic hazard analysis does not take evolution in b-value into consideration and may therefore yield incorrect forecasts of the earthquake hazard even when extensive data is available to render the statistics reliable.

The combined simulation and observational data suggest that earthquake patterns evolve and that there is an underlying physical basis that controls these patterns. The simulation based approach provides a means to gain an understanding of these patterns and their origin. Such an understanding would allow for the development of more reliable long and intermediate term earthquake hazard forecasts[2], and hence, enable the earthquake risk in Australia to be better managed.

[1]Maps of horizontal ground acceleration with a 10% probability of being exceeded in 50 years.

[2]By long term here, we mean a long term estimate of the earthquake hazard useful for engineering purposes (c.f. probablistic hazard analysis), and intermediate term is used to imply a forecast of order months to years in advance of a potentially dangerous period when a large earthquake may occur. Intermediate term predictions would allow for focussed mitigation and planning.

The lattice solid model for earthquake dynamics

The lattice solid model was developed to simulate the physics and dynamics underlying the complete earthquake process.[2,5] It consists of a system of interacting particles representing indivisible units in the system being modelled. Particles representing solid rock are bonded by elastic-brittle bonds and pieces of model rock interact through frictional forces and elastic repulsion between surface particles. Solid bonded pieces of model material behave as isotropic elastic solid material with a Poisson's ratio of 0.25 which is similar to that of most rocks. Hence, seismic compressional and shear waves as well as elastic stress transfer is accurately modelled in complex models using the lattice solid approach (e.g. in models containing complex distributions of faults and fractures). The model in its present form is capable of simulating rock fracture, granular dynamics and friction between model rock surfaces. It has been used to study the breakdown and evolution of granular fault zones and can simulate dynamic rupture processes on complex faults.[3,4]

In the following, we have specified a 2D lattice solid model consisting of two elastic blocks separated by a highly fractured zone representing a simplified fault system. The two elastic blocks are driven from their outer edges at a constant rate representing gradual loading of the system by tectonic movements, while being subjected to a normal stress of 150 MPa which is similar to stresses in the brittle crust. As the system loads, the elastic stresses build up. Eventually, a rupture will nucleate somewhere in the fractured zone and a synthetic earthquake will occur radiating seismic waves in the process. These are gradually attenuated by an artificial viscosity as they propagate through the elastic blocks. This attenuation is introduced to ensure seismic waves that are radiated away from the fracture zone disappear from the system after being radiated from the fault zone as would seismic waves radiated away from real fault zones. The seismic (i.e. kinetic) energy release is measured for each synthetic earthquake, and is used to create a catalog of model earthquakes (time and magnitude of the synthetic earthquake events).

The Critical Point hypothesis for earthquakes

The observed power law frequency-size distributions for earthquakes are widely used as a basis for probablistic hazard analysis (i.e. the assumption of a linear fit of the log of the number of events versus magnitude is used to make a prediction of the rate of large earthquakes). The power law observation has led some researchers to propose that the earth's crust is in a critical state when a large earthquake can occur at any time. If so, then the Poisson process assumption underlying traditional hazard analysis would be appropriate (i.e. that the probability of an earthquake in time does not change). The Poisson process or random hypothesis contradicts expectations based on simple physics principles that stress would need to build up on a fault after a large earthquake before another can occur.

An increasing number of observations worldwide suggests a more evolutionary behaviour. A power law time-to-failure function has been found to fit well the cumulative Benioff strain release in the lead-up to large events, and during such periods, the statistics of earthquakes evolves.[1] This led various researchers to propose at least some parts of the crust may behave in the same way as a critical point. Under this hypothesis, long-range correlations in stress (or closeness to failure) in the crust gradually build up as earthquakes occur within a given region. Once a large earthquake occurs, these long range correlations are destroyed. This hypothesis explains the observed power law time-to-failure fits and provides a possible physical basis for earthquake forecasting (i.e. intermediate term earthquake prediction). Renormalisation group theory was subsequently shown to yield complex exponents which implies the power law time-to-failure function should have log-periodic fluctuations.[6]

Results

We fit a power law time-to-failure function with log-period fluctuations using least-squares to sequences preceding large simulated earthquakes in the synthetic earthquake catalog. The power law time-to-failure function[6] is given by

$$\epsilon(t) = A + B(t_f - t)^c \left[1 + C\cos\left(2\pi\frac{\log(t_f - t)}{\log\lambda} + \psi\right)\right] \quad , \tag{1}$$

where ϵ is the cumulative Benioff strain release, t_f is the predicted time of the critical point, c is the power law exponent, and A, B, C, λ and ψ are parameters.

All parameters of the power law function including t_f were obtained by least squares fitting of the cumulative Benioff strain release calculated from the synthetic earthquake catalog. The model data was found to contain numerous sequences that match well with the power law time-to-failure function (i.e. to have a low E-value where E is defined as the RMS error of the power law fit divided by the RMS error of a linear fit). Fig. 1 shows one such sequence. The predicted critical point time is slightly prior to the large earthquakes and aftershocks occurring at the end of the sequence. This is consistent with the critical point hypothesis that the largest earthquakes can only occur after the system has reached the critical point (i.e. after the largest scale stress correlations have been built up within the system). To confirm whether the good fits can be ascribed to chance, we studied a random catalog with the same event-size statistics. We found that the random data could not reproduce the good power law fits observed using the lattice solid generated data.

For comparison, we analyze the 1997 M=5 Burra SA earthquake data in the same way (see Fig. 2). The results are very similar to the synthetic data with the cumulative Benioff strain being well fit by a power law time-to-failure function. The predicted critical point in this case is only about a month prior to the Burra earthquake. We note that in all cases analyzed, a power law with log periodic fluctuations fits substantially better to the data than a power law with no fluctuations.

The statistics of earthquakes in synthetic earthquake sequences were observed to evolve, typically from a higher b-value of around 0.9 early in the sequence, to a lower b-value of around 0.65 in the latter part of the sequence (see Fig. 3).

Conclusions

Combined, the simulation and observational results suggest seismic energy release and earthquake statistics evolve in a predictable way under certain conditions. The simulation model provides a tool to probe this phenomenon and develop improved hazard quantifications and forecasts in Australia, and thus overcome the inherent problems with standard probabilistic hazard analysis.

Acknowledgement

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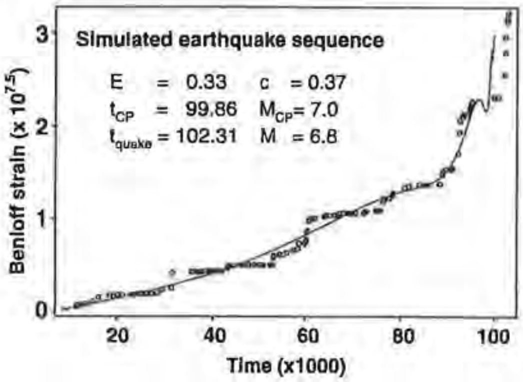

Figure 1: Cumulative Benioff strain release for simulated earthquakes generated using the lattice solid model (open circles) and a power law time-to-failure fit (solid line). The predicted time and magnitude of the critical point is compared to the synthetic mainshock time and magnitude. Only simulated earthquakes within 2 magnitude units of the main shock are plotted.

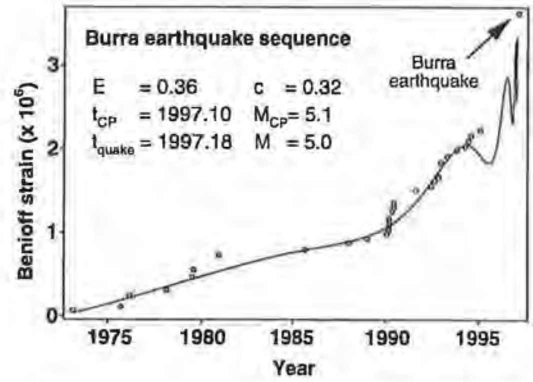

Figure 2: Cumulative Benioff strain release for M $\geq$ 3.0 earthquakes within 100 km of the M=5 1997 Burra earthquake (open circles) and a power law time-to-failure fit (solid line). The predicted time and magnitude of the critical point is compared to the Burra earthquake time and magnitude.

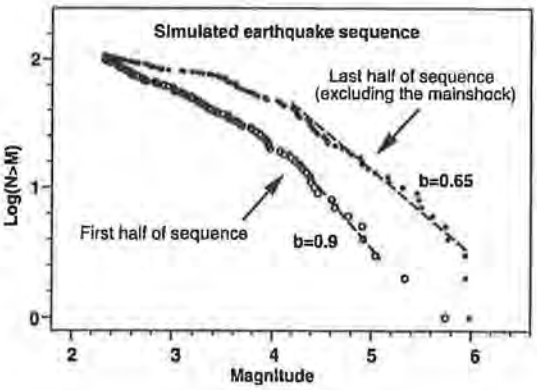

Figure 3: Cumulative frequency versus magnitude plots for simulation data generated using the lattice solid model shown in Fig. 1. Open circles are for the data taken in the first half of the sequence and stars are for the last half of the sequence excluding the mainshock and aftershocks. The b-values (negative slope) of the two broken line segments are indicated for reference.