Welcome

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Ladies and gentlemen, welcome to our third Annual Seminar on Earthquake Engineering and welcome to Canberra.

Our first and second seminars were held in Sydney and Melbourne respectively and in those we concentrated on Codes and Standards, mainly for buildings and structures and damage to buildings and structures in earthquakes, especially in Australia. This time we want to broaden our outlook and look more at the lifelines, the infrastructure and the community.

Our speakers will cover water supply, the electric power industry, bridges, the telephone system, pipelines and the availability of infrastructure after an earthquake.

As we consider and think about these matters based on our past experience and expectations I want to ask you to take the time also to consider changes that might be taking place both in the real world and in attitudes and expectations in the community, and in litigation.

For example, a real world change - *Rising salinity now threatens country towns* says a recent Sydney Morning Herald headline. Dry land salinity is causing house foundations to crumble, waterpipes to corrode, roads to breakup. Will this exacerbate future earthquake damage? as corrosion did in Newcastle?

Another example - litigation following the Newcastle earthquake may have as big an effect on the building professions as did the earthquake itself. Just recently the personal damage claims of 13 people injured or whose relatives died when the Newcastle Workers Club collapsed in 1989 were settled on terms not to be disclosed.

However this is not the end of the matter and the Club's claim for costs and for the loss of the building associated costs and loss of profit against the Council, the engineer, architect and the builder has been listed for hearing in March 1995.

One more instance of a ruling on warnings of possible risks. A patient succeeded in an action because the surgeon did not warn her of the possible loss of sight even though the odds against it happening were very small, 14 000 to 1 or even less. If given that advice she may have decided not to proceed with the operation.

It occurred to me that we probably do not warn our clients of all such possibilities . We know that our Codes and indeed our best efforts in earthquake resistant design are directed to prevent loss of life and not to limit damage. We know that damage will probably occur in an earthquake, but do our clients know?

It would appear that we must warn them of all risks they are taking, however small, when they undertake a course of action based upon our advice. So please keep these things in mind as we proceed with our seminar.

Earthquakes and the Community: Response and Responsibility

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Introduction

August 6, the anniversary of the day allied planes dropped the atomic bomb on Hiroshima, also marked the day when Cessnock, NSW entered the record books as being host city to an earthquake.

The earthquake

We joined a select few cities in the nation this year, our saving grace being that despite the magnitude of the seismic event, not one bandaid, not one bottle of dettol needed to be opened.

Our luck was undoubtedly due to the fact that the epicentre was in a country area at Ellalong, one of the smallest of the 23 villages in our local government area. There were a number of lucky escapes, 30 people including babies were in the Ellalong Hotel as the quake struck. As it turns out, the entire top floor of the hotel needs to be demolished and had the quake lasted a couple of more seconds, we were close to losing those 30 lives.

Other lucky stories involve residents stepping outside of their homes just prior to walls collapsing and furniture being flung across rooms.

Our luck on that night was astounding.

Like every other Australian city the host venue of a victimless earthquake, the event will soon be forgotten by the outside world. Certainly at the moment home prices are not sky high in Ellalong, but we will retreat back to our safe world within a couple of years. All will be forgotten - except maybe by insurance companies.

As a nation, those of us who are not experts do not like to dwell on earthquakes. They occur in third world countries, perhaps in Los Angeles now and then. But as a nation, we regard ourselves as relatively earthquake proof - no need to worry.

Cities like Newcastle, Lake Macquarie, Cessnock and a relative handful of others have embraced new building codes designed to co-exist with earthquakes. But Sydney Councils, the areas of massive population growth, see not the need. This is Australia, it won't happen here.

Those more savvy including some insurance companies pinpointed the potential for massive losses and have begun to spread their risk by entering new fields or new states. But outside of that and the few odd consultants, the remainder of Australia have buried their collective heads in the sand.

The Emergency

The event itself and the ensuing days and weeks after remain etched in my mind. Perhaps I am a trifle passionate but I am stunned at the nonchalant attitude adopted by most authorities.

As chair of the local recovery committee, I remain confused as to why an emergency was not called as the shaking halted. I am amazed that my State apparently does not possess a striker team to enter natural disaster areas immediately they become apparent.

There was no State or Federal or outside assistance on hand, not only that night... But, little also in the weeks or months which have followed. When I questioned why.... I was told that earthquakes are a Local Government responsibility.

I see a need for striker teams to be available to enter all such areas and to respond to possible people needs as quickly as did the Australian Geological Survey Organisation respond to a measurement on a scale.

Our earthquake occurred at nine on a Saturday night. My house shook and appeared to roll. But having been away for the Newcastle earthquake, I had not experienced one before and had no idea what had happened.

Finding my phone out of order, and as there was no indication on the radio nor TV that an event of any type had occurred, I was as confused as anyone. I tried another phone fax line and it worked, so rang neighbours and friends along with local police. No one knew anything.

I then tried local radio station newsrooms to be told almost one hour later that it appeared that an earthquake had occurred at Ettalong on the central coast... Not Ellalong only 10 kms away from my home.

The lack of information was absurd. The mayor of the city had no idea of what was happening.

By midnight it was established on radio that an earthquake had occurred in or near Cessnock but that virtually no damage was reported. In the eventual count, one leading insurance company estimates that every home in the Cessnock region suffered some form of damage, though most of it minor. The insurance council of Australia estimates that $32 million will be spent on repairs to 8000 Hunter homes - thus far.

At the Ellalong hotel, after the shaking halted, adults and children re-entered the bar and kept drinking using candles for power. At the local registered clubs, the drinkers stayed playing the poker machines before driving home.

No authority was out checking the safety of bridges, highways, roads or power lines. The SES was repairing a few chimneys but that was all that occurred in Cessnock on the night of our earthquake.

Those seeking help phoned overloaded police lines or else the media.

Nothing else was in place.

The evening passed with no thought being given to the safety of bridges, roads, public buildings etc., We all just went on with our life, we all drove home in the dark country roads and over bridges with no thought being given to the safety of those structures.

A Warning System

We simply must institute a system that when AGSO becomes aware of a significant event, that the police commander or mayor or emergency controller of the area in question is immediately notified. As the beep goes off for seismologists to prepare to leave, so too must a call be instituted to the affected area personnel. We must institute another system also where areas with similar names like Ettalong and Ellalong are not confused.

In retrospect, perhaps a general warning over TV and radio stations could have automatically cautioned residents not to leave their premises before light. In particular calls could be scheduled asking residents to check the welfare of their neighbours.

I am speaking of preventative and proactive action, as against the reactive type which seems to be the NSW response... Again, so lost in the belief are we that earthquakes cannot occur in this nation, that in our ignorance we have failed to institute due care.

You see, my field as mayor is worrying about people. Your role is seismic events, the role of power authorities is providing communications or energy, council is concerned about health and safety, but in an elected role, my position is to advocate for the people and concern myself with what is in their heads and their hearts.

And what the people were concerned about was that no one was out there reassuring them that another earthquake else aftershocks would not descend on them. They were aware that the media was everywhere, that council was doing what it could, but there was simply no one else.

Cessnock Council had been left on its own to cope. This, a country council for heaven's sake. Some insurance companies had assessors on the ground in Ellalong on the early morning after the earthquake... If the private sector could display such efficiency and care about welfare, and mount teams to assist less than 12 hours after the event, how come no one else could.

What Price Public Welfare?

Cessnock Council has limited resources in the form of one structural engineer and a handful of building inspectors to handle 2000 sq km and 23 village centres of population. We have quite obviously a number of central business districts with two storey brick commercial buildings as well as a road network of 2000 kms.

Thank heavens Newcastle Council offered health workers and builders. The State and Federal Governments offered virtually nothing.

My concern, and one I hope that this venue will take up, is the fact that country areas lack the human infrastructure to ensure the safety of both buildings and its people in times of natural disasters. It took us five days to check the central business district area buildings alone, even with experienced help from Newcastle Council.

As a point of interest 300 claims have been made for commercial/industrial buildings to date.

Some weeks were taken up in checking bridges and roads and community facilities along with the private homes of our residents. But during that time, buildings had the potential to collapse.

The NSW Public Works Department, following my media cry, offered us on August 11 the use of their services to check buildings in our council jurisdiction - at commercially competitive rates!

Many country councils are short of funds and would not be able to afford to pay for such services. As there is no automatic natural disaster registered after earthquakes, no assistance funds or grants are available to local government.

So the potential for greater disaster and loss of lives continued longer than it should. Am I to assume that public welfare therefor only comes at a price?

I seek an experienced striker team to be set up by State Governments to enter a city following a natural disaster. Such a team would assess the local council's ability to cope and be able to swiftly co-opt outside staff to supplement experts in all fields.

Let us bear in mind that in NSW, there are 177 councils, but that 136 of those councils are rural councils outside of the metropolitan area... As such, some have one engineer, one health and building inspector. They have Buckley's chance of coping.

Nowadays in NSW, following the January bushfires, an emergency controller in Sydney monitors fires and wind conditions across the State. When he deems it appropriate he can call an emergency or 41f situation from Sydney and then phone the local controller telling him what has been effected. He sometimes appoints the 41f designated person as well. But, along with his emergency declaration, comes a team of experienced firefighters from across the State and free resources such as helicopters. In this way, we of Cessnock have been able to control three 41f situations since September. This system has bypassed any inefficiencies of errors of judgement or indeed incapable local controllers. It has also ensured that fires are controlled before too much damage has occurred.

Perhaps Sydney needs a major tremor for such measures to include earthquakes.

The Government Response

No government representative, no politician cared to visit the city nor the shaken residents of Ellalong.

My people were unable to sleep, children in particular. Women were afraid to leave their homes and go shopping, just in case.

Sociologists tell me that after every Australian natural disaster, a second and worse wave hits within three months... A wave of human quakes. The frustration, the grief which does occur, the anger building up from a lack of sufficient insurance, the time it takes to secure repairs, to fight insurance companies... Spills over. But again, there is little state or federal disaster welfare assistance to cover this well-known phenomena.

My council initiated a series of public meetings near the epicentre, the Department of Community Services brought in counsellors... Certainly, there was to be a long waiting list, but nevertheless counsellors would eventually come. We organised public meetings with the Insurance Council of Australia, the Building Services Corporation, Mines Subsidence Board and the like. We continue to monitor the anger we believe could eventually erupt.

With our limited resources, we are endeavouring to manage the human tremors ahead.

Some good has come from the earthquake... It has brought a disparate community together... We have encouraged many who held little community spirit to form tidy towns committees to beautify what has never been an attractive village.

We have a long way to go... I still see two or three people per week with problems with their insurance. Insurance companies cannot convince clients that the drought is the major cause of what people see as earthquake damage... Else the damage is allegedly caused by the foundations on which their homes were built... I find that difficult to accept myself. There are big problems ahead and as my council was the only government body to be there at the earthquake; people see us as being in charge or responsible for earthquake problems.

Little knowledge is readily available... I have doubts that all insurance companies have thoroughly researched overseas trends and patterns in regard to claims. I know that information and studies on the breakdown of essentials like water pipes have been undertaken, but that information is not offered... We have to chase studies or information ourself as a council. Which is why I am here today.

Seismologists seem to have varying theories as to why our quake occurred... We have heard all manner of stories... Some locals believe that it was pre-empted by longwall mining in a noted but undeclared mine subsidence area.

We hope that any strategic planning process includes official reports from the AGSO on its theories... I am unaware if areas subject to earthquakes are automatically given such reports. If we were, we could better plan for the future safety of our people... Small councils would know the need to institute an earthquake building code, else to institute as we have recently done, areas in which residential subdivisions are not permitted.

Insurance companies could better plan their risk where there is doubt that further seismic events could occur. Mining or old mining lease areas which have undeclared problems with subsidence, could or would be required to be declared, permitting councils to insist on specific building codes... Thus reducing the risk of injury, reducing the cost of insurance claims and the risk of damage to homes.

Forward or strategic planning is a proactive approach as against the current reactivity after tremors. Preventative planning will save lives.

We must get back to the fact that when earthquakes occur in country areas, the same type of backup and facilities that are available in major metropolitan areas, simply do not exist.

The local leocon, or local emergency operations controller, this is the designated person in charge of emergencies in each region, may not be up to scratch or have the personal attributes to be able to determine or handle an emergency situation. Then again, he or she may be away when the disaster occurs, the deputy may be new to the job and the area anyway. The leocon in a country area may have no qualifications to fill the role, holding the position because no one else wanted it.

The leocon may not assess the situation accurately and so additional fatalities could occur which may have been preventable, or may not take the role seriously.

We cannot program earthquakes for 9-5 Monday - Friday, our leocon may be out partying - may not be able to be found.

In proposing a government unit which moves immediately to an area when a natural disaster such as an earthquake over a given point on the Richter scale occurs, we are ensuring the safety of our community.

I checked my council's local area disaster manual before I came here... Every local government area has such a manual and disaster plan. In that plan are listed a number of emergencies with a scale given to the likelihood in each area... ie., Industrial areas see a different range of emergencies such as plants exploding than do rural areas where bushfires are rated higher on probability. In cities, fires in multi-storey buildings are more likely to occur.

My city's manual shows earthquakes as having the lowest possible risk of occurring of any disaster, this despite the Newcastle earthquake of only a few years ago.

Because the risk is low, the focus on preparation or studying how to handle such an emergency is the lowest priority.

Our manual was prioritised in April of this year.

I am suggesting that the AGSO notify a council area upon monitoring a particular number of seismic events. The council could then ensure that any earthquake monitoring equipment is maintained, that personnel are alerted and educated as to handling earthquakes.

The particular council may choose also to establish new earthquake building codes, so we are mitigating the possibility of disaster before it strikes.

I am an amateur with no knowledge of earthquakes. I enrolled at this seminar to learn. I hope that over the next twenty four hours I can ascertain if a given number of seismic events eventually precipitates a major earthquake.

I do know that many locals look to the mine subsidence problems caused by longwall mining in the Ellalong region, and now believe that what they thought earlier were mining explosions, were earth tremors precipitating the major earthquake.

On this basis, coupled with the fact that mining has moved up the Hunter and away from Newcastle and Cessnock and towards Singleton and Muswellbrook, perhaps we should install earthquake monitors there. I know not if the Hunter with two quakes in five years can now be thought earthquake prone but if this be so, we must monitor other parts of the region, and notify local councils to raise the risk of earthquake higher on their emergency priority list.

You the experts need to reach, teach and communicate with representatives of the people like me about earthquakes. Together we can pursue the additional research funding so sorely needed.

I urge you to extend your knowledge and your hand to local authorities... And I promise that we will grasp it!!

The earthquake risk to lifelines in Australia and in Canberra in particular

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Introduction

London in England may seem a strange starting point for a discussion on earthquakes in Australia but there are significant parallels. On a recent visit to the European Strong Motion Data Centre at Imperial College London, I came across a new publication documenting earthquakes that have affected that city. To my surprise, significant damage was occasioned by a local earthquake in the 18th century and falling masonry caused one death and several injuries in the city.

This was by no means an isolated event; in Canterbury Cathedral I came across a plaque describing the effects of an earthquake in the 13th century. It was strongly felt in London where the Bishop of Canterbury was attending a church synod meeting. He quickly returned to his See on learning that the earthquake had caused the partial collapse of a bell tower on the cathedral then under construction.

British seismologists have compiled a database of earthquakes spanning the last 1000 years which shows that there is a low but non-negligible earthquake hazard in Britain. And the parallels with Australia are that there is neither total consensus on an earthquake hazard map nor widespread public knowledge of the risk.

In Australia the earthquake hazard is higher than in Britain and most parts of non-plate-boundary Europe, and also higher than that in intraplate Southern Africa, northwestern America and southeastern China. The record shows that few areas of Australia have escaped perceptible shaking from earthquakes in the last two hundred years. In that time the largest known earthquake was that offshore from Geraldton WA in 1906, which was felt over most of the State. It had a magnitude of 7.2.

That there are differing views amongst Australian seismologists as to the location of zone boundaries, the form of an attenuation relationship or the precise estimate of hazard, must not paralyse the engineering community into doing nothing to mitigate damage. Rather, seismologists should be encouraged to spend more effort to understand the nature of Australia's earthquakes; their mechanisms, depth distribution, limiting size and cause. Engineers should contribute to the debate by ensuring that their important structures are instrumented and that more free field strong motion instruments are installed so that appropriate attenuation relationships can be developed and the critical response spectra computed.

Seismicity and earthquake hazard in Australia

Spatial distribution AGSO, with input from State and university collaborators, has compiled a database of Australian earthquakes extending back to 1788. The catalogue is of course incomplete for the early period but should be complete for all magnitude 6 or greater earthquakes since 1890 and for all magnitude 4 or greater earthquakes since 1969. More than 90% of the earthquakes in the database happened in the last 25 years; they are the majority of the epicentres shown in Figure 1 which depicts all magnitude 4 or greater earthquakes.

At a continental scale it is obvious that some parts of Australia are more active than others, large blank areas without seismicity are surrounded by active zones. In addition there have been more large earthquakes in the western part of the continent than in the centre and more large earthquakes in the centre than in eastern Australia. This correlates roughly with both the age of the crust, (age increasing from east to west), and the outward heat flow from the mantle through the crust (high in the east, low in the west).

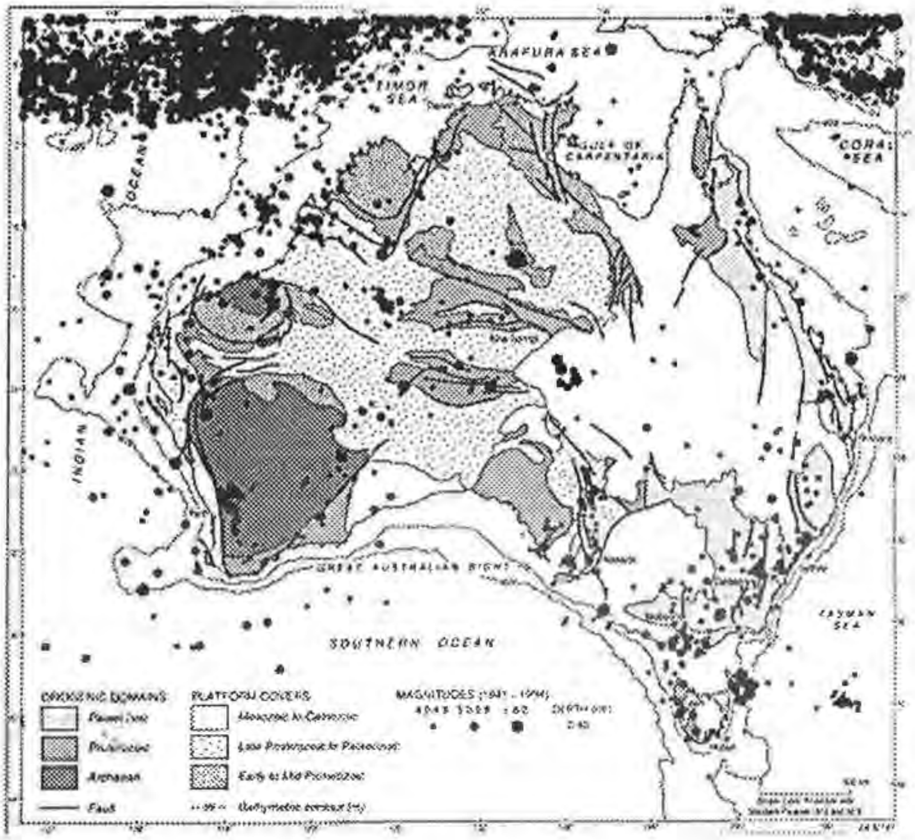

Figure 1 Epicentres of known Australian earthquakes to 1994

At a State scale this pattern is repeated, the epicentres are clustered in zones surrounding inactive areas. The Eastcoast Seismic Zone is a good example, it forms an active eastern boundary to the relatively inactive Murray and Darling Basins. But within that zone there are areas of above average activity or *hotspots*, Newcastle is a good example with 6 earthquakes of magnitude 5.0 or more within 50 km since 1840, compared with Sydney where there were none of this magnitude within 50 km. Both cities are built on sediments of the Sydney Basin, the same broad geological province. Sixty kilometres north of Canberra near the town of Dalton is another of the active hotspots where there have been 4 earthquakes of magnitude 5 or more in the last 100 years, but in the same time there were none of this size within 50 km of Canberra. Unlike Sydney, small earthquakes are relatively common within the Canberra region as will be discussed later.

Temporal distribution In Australia there have been 16 independent earthquakes (not aftershocks or multiple events) of magnitude 6.0 or more in the last 100 years (Table 1). The time between events has been anything but periodic, varying from months to nearly 3 decades but the average inter-occurrence time or return period is about 6 years. The last earthquake of this size was at Tennant Creek NT on 22 January 1988, more than 6 years ago at the time of this seminar.

In eastern Australia only the 1918 earthquake offshore from Rockhampton and a series of earthquakes off northeastern Tasmania in the 1883 - 1892 period were of magnitude 6 or more. Geologically Recent fault scarps (postdating the last ice age at about 10 000 years) near Lake Edgar Tasmania, Echuca on the NSW/Victoria border, Bendigo Victoria and Snowy Mountains NSW show that large earthquakes have occurred recently in a geological sense but before written records were kept.

On the assumption that earthquakes are random and independent and the activity stationary in time, it is a simple matter to compute the probability of a magnitude 6^{+} earthquake occurring within say 50 km of any site within this Eastcoast Seismic Zone.

Canberra at risk?

The first assessment of earthquake hazard in Canberra was undertaken by Bubb (1976) during design of the Telecom Tower on Black Mountain by the then Commonwealth Department of Works (CDW). This study considered earthquakes on the Lake George fault, in the Dalton region, and a distant magnitude 7.0 earthquake, but not earthquakes closer than 32 km. The structural analysis assumed a lumped mass model of the tower and used modal superposition to compute the maximum response. Results indicated that, shaken by the modelled earthquakes, the steel mast atop the tower would yield but the tower structure would survive intact.

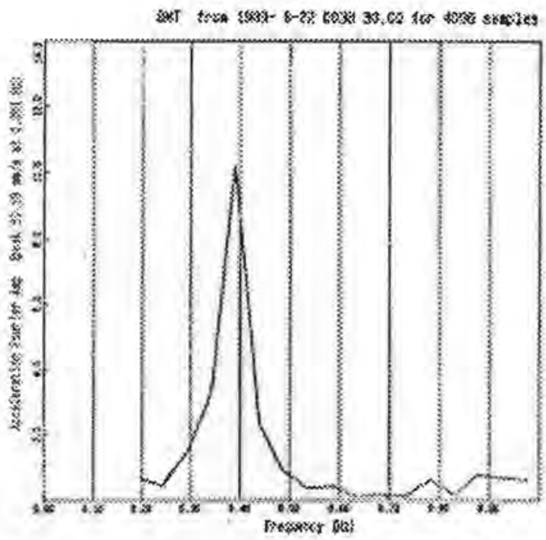

Figure 2 Vibration analysis of Telecom Tower Canberra

Gaull, Michael-Leiba and Rynn (1990) also used a Cornell analysis to estimate the hazard in Canberra and they did assume some background seismicity. Isolated cases of damage were reported in Canberra suburbs after the 1973 Picton NSW earthquake and earthquakes down to magnitude 4 in the Dalton seismic zone are felt in Canberra. Several microearthquakes have caused localised alarm in Canberra suburbs over recent years, the most interesting was a small ML 2.4 earthquake right under Black Mountain in the centre of Canberra in November 1985 (prior to the installation of the accelerographs of course). Too small to cause damage, it was widely felt (Leiba, 1993). AGSO now monitors the city with seismographs and accelerographs and utilities such as Telecom and ACTEW monitor some of their critical facilities in and near the ACT.

Damage to lifelines in the past

Most large damaging Australian earthquakes have occurred in isolated areas and caused little damage. The Meckering earthquake on 14 October 1968 shook the general complacency in the engineering sector and gave rise eventually to AS2121 - the first Australian earthquake code. This code introduced an importance factor *I* in recognition of the need for certain structures housing critical services to remain operational for post-earthquake recovery.'

Prior to that time, when <u>lighthouses</u> were so important for shipping navigation, the Troubridge Lighthouse in South Australia and the Seal Rocks Lighthouse in NSW suffered damage during earthquakes in 1902 and 1912 respectively that rendered them inoperable. The lighthouses are designed to withstand 210 km/h gale force winds and suffered little structural damage but lost mercury from the lens flotation and rotation system.

A similar fate struck the Norah Head lighthouse at Port Nelson NSW during the 1989 Newcastle earthquake. It was reported that the 20 m high cylindrical stone tower vibrated and the optic shook violently for 12 to 15 seconds. Sixty kilograms of mercury splashed out of the bath but the light continued to rotate. The tower was undamaged though the station buildings, toilets garages and workshops, were cracked. To my knowledge there was no resultant loss of shipping in any of these cases.

Bridge performance is the topic of a later address by Bill Boyce at this Seminar. The only bridges suffering damage in Australia as far as I am aware are one over the Merri River at Warrnambool Victoria which was destroyed in the 1903 earthquake there - a footbridge, and the Stockton Bridge NSW which suffered minor abutment damage in the 1989 Newcastle earthquake.

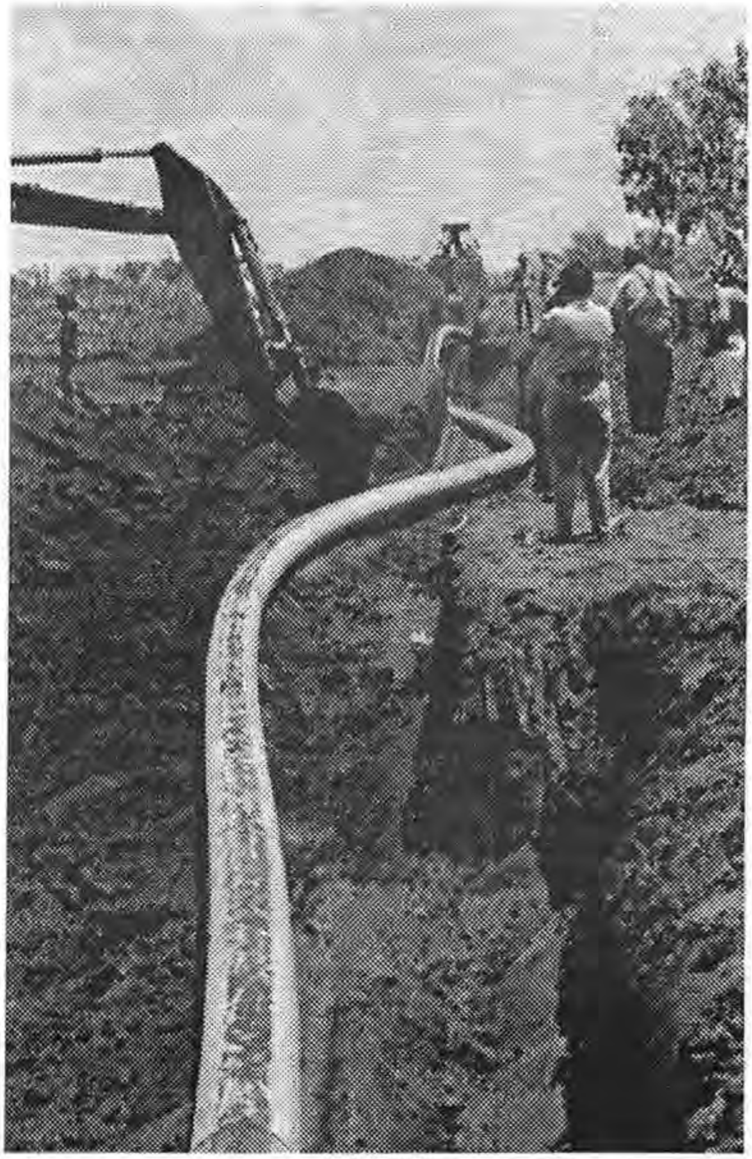

Figure 3 Damage to the natural gas pipeline near Tennant Creek NT, January 1988

Buried structures normally fare very well in earthquakes unless they cross the earthquake fault break (see picture above). Long pipelines and fibre-optic communications cables however are particularly vulnerable because of their great exposure and rigidity, as are surface utilities such as roads and power lines. In less than 30 years, 7 Australian earthquakes have ruptured the ground surface, seven of only 10 worldwide in intraplate regions. Classic pipeline failures near Meckering WA in 1968 and Tennant Creek NT in 1988 are well documented. The first was a brittle failure in a cast iron water pipe, the second a ductile failure in a mild-steel gas pipeline (Figures 3). The long gas pipeline servicing the Sydney, Woolongong, Newcastle and Canberra regions from the Cooper Basin on the SA/Qld border region crosses the Dalton Seismic Zone and proposed gas pipelines in WA also traverse earthquake prone areas.

Critical emergency facilities such as hospitals, ambulance and police stations and communications buildings have also suffered under earthquake loading in Australia. The Children's hospital in Adelaide suffered minor damage in the 1902 Warooka SA earthquake as did a police station at Darlington in the 1954 Adelaide SA earthquake. Both the old masonry Royal Newcastle and still unopened reinforced concrete John Hunter hospitals in Newcastle suffered badly in the Newcastle earthquake. The Newcastle telephone system was apparently not damaged but was severely overloaded immediately after the earthquake rendering communications impossible for several hours.

The 1902 earthquake in South Australia caused severe damage in a small stone country school at Warooka SA, fortunately at night when students and teachers were at home. Large stone blocks fell onto unoccupied desks. Authorities were also lucky in the Newcastle earthquake in that it was Christmas break time for schools and colleges. Many Newcastle schools and the TAFE college were badly damaged, some not repaired in time for the new school term in late January.

Water storage facilities Several dams have been strongly shaken by earthquakes in Australia: Warragamba and Eucumbene dams in NSW, the Canning and Serpentine dams in WA and the Chichester dam NSW twice. They all performed well. A large water tank near Cadoux WA is the only real earthquake casualty to date, it moved substantially on its foundation during the large Ms 6.2 Cadoux earthquake on 2 June 1979.

Like pipelines, railways and roads are vulnerable because of their extent. They may be damaged by either foundation failure (landslide or settlement) or faulting. Faulting associated with the 1968 Meckering earthquake cut the main highway east, and spectacularly buckled both the standard gauge and narrow gauge railways linking Perth and Kalgoorlie and eastern States. Faulting during the 1979 Cadoux earthquake also buckled a railway. The 1986 Marryat Creek earthquake in northern SA caused faulting with a 0.5 m scarp across a local road. The damaged road and rail links were restored within 24 hours.

An electrical transformer station near Newcastle suffered considerable damage during the 1989 earthquake (see Rod Caldwell's talk at this seminar). This caused a loss of power for several hours threatening furnaces at the BHP steelworks and pots at an Aluminium refinery. Fortunately power was restored in a short time. There were no reports of damage to the large coal-fired power generators locat ed between Sydney and Newcastle.

New submarine cables laid for TELSTRA between Australia and New Zealand, and Australia and Guam are particularly vulnerable because they cross plate boundaries, the latter twice, and in the Marianas trench it is on the sea floor 8 km deep. Both faulting and submarine slides cause great damage to these cables as shown by the experience of the OTC whose cables into the Madang cable station on the north coast of Papua New Guinea were regularly broken by large earthquakes under the Finisterre and Adelbert Ranges.

Recent intraplate earthquakes worldwide

On January 15, 1994 small earthquakes of magnitude 4.0 and 4.6 struck the US east coast city of Reading. They damaged more than 200 houses and lifelines, including a sewerage treatment plant, a bridge and a water main causing an estimated loss of $US3.5M. They were preceded by an earthquake swarm in the spring of 1993.

Amongst other notable intraplate earthquakes was the magnitude 6.2 earthquake near Killari India where almost 10 000 people were killed in September 1993. This earthquake, like that at Tennant Creek NT, was preceded by a year-long foreshock swarm. A magnitude ML 5.8 earthquake near Liege on the Dutch side of the Netherlands/German border on 13 April 1992 caused significant damage costed at 150M ECU (0.8 ECU @ 1.0 US$). One person died of a heart attack in Bonn. A magnitude Mb 5.7 earthquake was recorded in South Africa on 31 October 1994 but no damage wa reported.

Discussion on the future

Earthquakes do occur in Australia, which is now recognised to be one of the World's more active intraplate regions. The ground motion close to a magnitude 6 earthquake in Australia can be expected to be as strong as the ground shaking from a shallow magnitude 6 earthquake anywhere on earth, be it California or New Zealand, and the duration will be similar to for earthquakes with similar mechanism.

On a number of occasions in the past, the Australian community has been lucky to escape serious damage and lifeloss; because of the sparsity of population, the time of day or school holidays. The urban areas are expanding rapidly, infrastructure growing at great speed and the complexity and size of vulnerable structures increasing daily. We cannot continue to rely on that luck.

Schools and hospitals should be treated separately to other structures as was done in California after the 1933 Long Beach earthquake. The Field Act ensured that schools were strengthened long before general building codes were introduced there. In Australia retrospective strengthening for pre-code buildings should be considered and all schools and hospitals strengthened to resist horizontal shaking to an agreed minimum level, regardless of the acceleration coefficient.

Where pipelines, particularly gas or oil filled ones, cross known seismic zones or faults, provision should be made for deformation similar to that at Tennant Creek. This is not a difficult engineering problem. AGSO is addressing some of these issues by: (a) upgrading the National Seismographic Network (b) providing representation on the Standards Loading Code Committee (c) responding to a Commonwealth Government initiative with the States to monitor the urban areas where the vulnerability is high, and (d) participating in microzonation studies to identify and map foundations liable to cause ground motion amplification in urban areas.

The Commonwealth and State Governments or instrumentalities are the only ones participating in the strong motion recording program which will ultimately benefit everyone. It is time the engineering profession convinced some of their clients to take an active role in long-term monitoring; perhaps by collectively instrumenting a few special or even typical Australian structures and nearby free field locations. There is no doubt these activities are reaping unexpectedly quick rewards as you will see (McCue et al. this volume).

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Table 1. Large or damaging Australian earthquakes, 1788 - 1990

Date UTC	Time	Lat °S	Long °E	ML	Ms	$AUS loss (1994$)	Location
1873 12 15	0400	26.25	127.5		6.0		SE WA
1884 07 13	0355	40.5	148.5		6.2		NE Tasmania
1885 01 05	1220	29.0	114.0		6.5		Geraldton WA
1885 05 12	2337	39.8	148.8		6.5		NE Tasmania
1892 01 26	1648	40.3	149.5		6.6		NE Tasmania
1897 05 10	0526	37.33	139.75		6.5		Kingston SA
1902 09 19	1035	35.0	137.4		6.0		Warooka SA
1903 04 06	2352	38.43	142.53	4.6			Warrnambool Vic
1903 07 14	1029	38.43	142.53	5.3			Warrnambool Vic
1906 11 19	0718	21.5	104.5		7.3		Offshore WA
1918 06 06	1814 24	23.5	152.5	6.0	5.7		Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0		Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6		Broome WA
1935 04 12	0132 24	26.0	151.1	5.2	5.4		Gayndah Qld
1941 04 29	0135 39	26.92	115.80	7.0	6.8		Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5		Simpson Desert
1946 09 14	1948 49	40.07	149.30	6.0	5.4		West Tasman Sea
1954 02 28	1809 52	34.93	138.69	5.4	4.9	107M	Adelaide SA
1961 05 21	2140 03	34.55	150.50	5.6		3M	Bowral NSW
1968 10 14	0258 50	31.62	116.98	6.9	6.8	31M	Meckering WA
1970 03 10	1715 11	31.11	116.47	5.1	5.1		Calingiri WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9		L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2		Simpson Desert
1973 03 09	1909 15	34.17	150.32	5.6	5.3	2M	Picton NSW
1975 10 03	1151 01	22.21	126.58		6.2		L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2		L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7		Broome WA
1979 04 25	2213 57	16.94	120.48		6.1		Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	10M	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8		Tasman Sea
1985 02 13	0801 23	33.49	150.18	4.3		.09M	Lithgow NSW
1986 03 30	0853 48	26.33	132.52		5.8		Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	1.3M	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4		Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7		Tennant Ck NT
1989 12 27	2326 58	32.95	151.61	5.6	4.6	1 270M	Newcastle NSW
1994 08 06	1103 52	32.92	151.29	5.3		50M	Ellalong NSW

A Review of the Electricity Commission's Experiences Following the Newcastle Earthquake

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Introduction

For the first time in Australia an earthquake caused major electrical plant damage. In this paper the impact on the Commission's system is described, and a review is made from the system planner's perspective of the ability of the local transmission system to withstand the damage and allow rapid restoration of supply.

The earthquake

At 10:27 am on Thursday, 28th December, 1989 an earthquake registering 5.6 on the Richter scale struck Newcastle, with its epicentre about 15 km WSW of Newcastle city, near Boolaroo. Twelve lives were lost and over 100 people were seriously injured. Widespread damage was caused to buildings in the area, the cost of repairs and losses being estimated to total perhaps $1000 million.

The severe shaking caused transient operations of mercury contacts on the Buchholz protection of almost all large transformers in both Commission and Council systems in the vicinity, affecting 16 Commission transformers and in total about 70 transformers in Shortland, Prospect and Sydney County districts.

The tripping of these transformers blacked out the whole of the Newcastle area and portions of the north coast, central coast, Sydney coastal suburbs and some city areas, as well as scattered localities in the Prospect area. Commission transformers tripping occurred generally within a 20 km radius. Transformers fitted with reed type contacts did not trip.

The load dropped was about 900m MW or about 16% of the State load at the time. The Tomago aluminium smelter was unaffected, but both the Alcan smelter and BHP works were without supply.

The severe ground shaking also resulted in the fracture of numerous porcelain support insulators on 330 kV and 132 kV circuit breakers at Newcastle 330 kV and Waratah 132 kV substations, the majority at Newcastle. Nine circuit breakers at Newcastle at Newcastle (1-330 kV and 8-132 kV) and two (132 kV) at Waratah were partly destroyed in the initial event and others damaged. The resulting collapse of heavy interrupter mechanisms and air cylinders caused consequential damage to auxiliary high voltage plant. There was some non-critical building structural damage. Photographs 1 to 4 show examples of the damage to 330 kV and 132 kV circuit breakers.

One generator at Munmorah, 28 km from the epicentre, tripped but in general there were few problems affecting power production and no significant damage as resistance to seismic disturbances is a requirement of the design of Commission power stations.

Shortland County Council staff were forced to evacuate their building and control for a short period due to some structural damage. Their control computer storage became overloaded by the huge information flow.

Photographs 1 & 2 Damage to circuit breakers

The Commission's Data Acquisition and Control (DAC) computers and private communications networks performed extremely well, although the Telecom network was badly overloaded and the latter delayed some supply restoration to smaller load areas and collieries. The DAC system recorded some 1600 events over a period of six hours, half of these in the first hour and 250 in the first minute!

Restoration of supply

Fortunately, some Commission operating staff were on the site at Newcastle and Waratah and they immediately started assessing damage and reporting to the Operations Centre on the state of the switchyard. This allowed some confusing indications on the DAC system to be corrected and compressed air to be preserved from the many broken circuit breaker air lines. Isolation of damaged plant and progressive return switching then commenced. The first priority was to restore auxiliary supplies for air compressor operation, battery charging and other auxiliaries.

A number of overhead circuits had tripped and there was no clear picture as to their state, so ground and helicopter patrols were instituted and these later reported no signs of damage.

In the meantime, customer contact was made to advise of the state of the system and to reassure them that it was not a Statewide shutdown as some thought. Clearly with so many events to consider, operators had an extremely busy time coping with the many localities at once. Priority was given to the restoration of supplies to the smelter, to BHP and to the City.

Restoration of supply by Councils was begun in the outlying areas soon as it was clear there was no damage locally and the majority of areas other than close to Newcastle were restored within one hour.

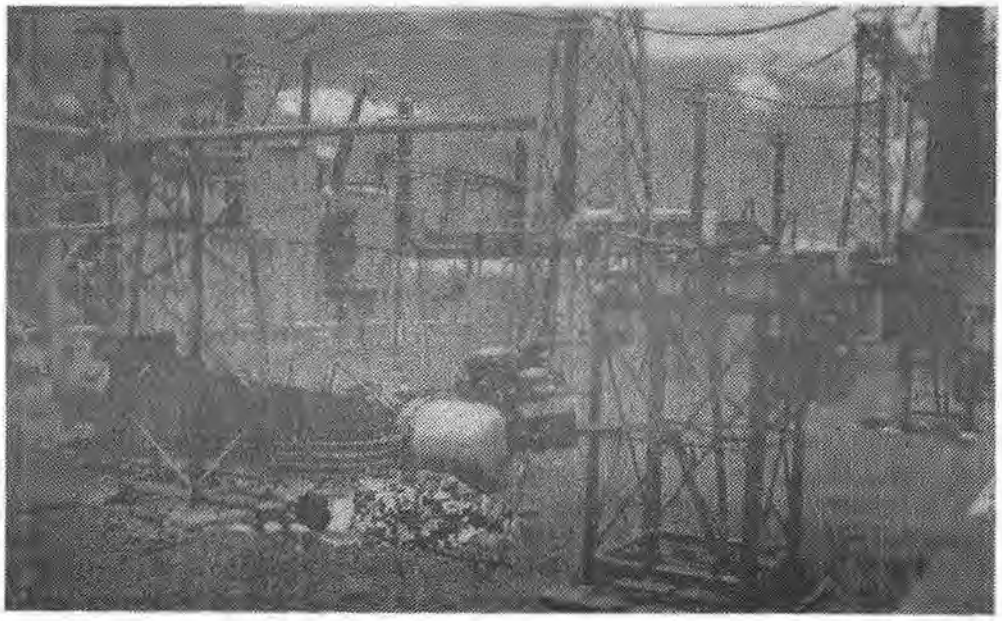
Areas affected by the damage at Newcastle were ready for Council restoration commencing with near city areas after one hour 50 minutes and progressively the load was restored to about 80% of normal within 3 hours. Shortland County Council was able to enter some CBD areas for checking damage to their plant although access was restricted for safety reasons. For this reason supply was not restored for a considerable period to the CBD as a whole.

The three Alcan smelter potlines were all restored within two hours 40 minutes and BHP within two hours 12 minutes. In both cases, the companies were pleased with the Commission's speed of response and reported no major plant damage. There was no precaution while awaiting restoration of power supply and confirmation that there had been no damage sustained.

Repairs

Within 30 minutes maintenance staff arrived at Newcastle Substation and assisted in identifying plant in a hazardous state and in the physical disconnection of plant. It was a feature of most of the damage that may failed circuit breaker poles fell clear and pulled off the associated high voltage connections from current transformers or broke away one leg of the associated disconnectors. Damage to current transformers proved to be such that they could be repaired readily.

Repair teams were immediately set up, and staff began the major task of identifying all faulty plant. It was not initially clear how much plant had suffered electrical damage, and so high voltage testing staff were sent to site. Fortunately it became evident that there had been virtually no damage to auxiliary wiring or controls. There was however concern for staff safety, when breaker switching became necessary as the risk of injury seemed very real when considering the high pressure air in conjunction with the possibility of cracked insulators.



Photographs 3 & 4 Damage to circuit breakers

There has also been warnings of possible aftershocks within the first 24 hours, although in the event, these were of very minor magnitude.

Much of the more severely damaged plant was replaced or repaired at Newcastle and Waratah within four days, allowing near normal operation of the system to be restored although with some loss of security. Almost all the remaining failed plant was repaired or replaced within 14 days, with much voluntary and selfless working by the many staff involved. Careful inspection and checking for incipient damage subsequently revealed many cracked insulators on other circuit breakers. The overall cost of repairs is estimated at about $1.5 million.

The nature and extent of damage to the system was entirely outside previous Australian experience, although earthquakes of magnitude 5.5 occur on average at about 15 year intervals in the State. However, this is the first instance where a large built up area has been impacted.

As in overseas countries prone to earthquakes, the highest voltage switchyard equipment appear to be the most vulnerable because of the length and brittleness of the porcelain insulators. Councils have not reported any plant damage of any consequence to their lower voltage plant except in the vicinity of damaged buildings plus some cracked transformers bushings. Overhead lines and cables performed creditably. In the case of overhead lines, the normal requirement for severe wind gust loading renders the support structures resistant to earthquake shocks.

One of the major difficulties experienced was the availability of sufficient spares. Cannibalising some failed circuit breakers helped, as well as diverting some new breakers bought for other sites. Consequently a lot of adapting and improvising proved necessary to foundation anchorages and support structures. It would appear that a standardised support anchorage would allow rapid replacement by a breaker of another make or model in the event of major overhaul or uprating or for a situation such as this.

Review

A formal Committee of Review was established to look into the performance of the system in the earthquake and to make recommendations, if appropriate, for improved performance of plant, design standards, controls, communications, staff response, emergency planning and the like.

The Committee made 35 recommendations on the terms of reference for further investigations, and for specific action. These matters are now in process of implementation or investigation.

It was the Committee's view that any such future event could be withstood with fewer problems and with less damage and disruption if certain key actions were taken, based on American and New Zealand experience, whereby cost effective improvements are possible which reduce the extent and severity of disruption and damage in the event of a similar incident elsewhere on the system. This refers in particular to minimisation of circuit breaker failures.

Resilience

It is significant that the provision of the degree of duplication of supply elements within substations and in the number of circuits, which has been Commission normal planning practice, allowed supply to be restored as soon as faulty plant could be safely cut away and isolated. Without this provision, restoration would have taken many hours or even days and could have had system wide repercussions with major economic consequences for the State and energy intensive industries.

Furthermore, New Zealand and overseas experience confirms that resilient mounting, avoidance of resonance and attention to damping together with care with the selection of sites and the design of foundations will ensure damage can be avoided or at least minimised.

Commission design staff suspect ground conditions to be one of the most likely primary causes of the extensive damage at both Newcastle and Waratah, as there appears to be good correlation between damage and location of plant on filled ground. Considerable care is needed in building on alluvial soil and fill which can cause force amplification of five or even more times.

Response

Commission staff directly involved in the operations and repairs responded well to the crisis, with a high degree of co-operation displayed at all levels. Much assistance with staff and spares, etc. was provided by other Regions and Power Stations.

Many Commission off duty staff offered assistance to their supervisors or to emergency services co-ordinators to assist in rescue and restoration work either in their specialist roles or as general volunteers. Five civil engineers were made available to assist Newcastle City Council staff by providing advice and assistance with assessment of building damage, particularly residences. In addition, Eraring Power Station sent some staff with rescue equipment on 28th December to assist in clearing up. The Commission's helicopter was sent to the area to survey the condition of transmission lines and although not used was offered to the Police for their assistance.

The experiences gained in this event highlighted the value of planning for emergencies and having human and physical resources to add to local knowledge and capacity. Adequate availability of spares is critical as is ready addition to local communications by use of FAX and radio systems which are independent of the public network.

"The Electricity Commission of NSW and industry emergency crews have received praise for their swift response to the power failures caused by the Newcastle earthquake last month" - Engineers Australia, 26th January, 1990.

Reservations

It was fortunate that the earthquake occurred during daylight in normal working hours. Had it occurred in darkness, it is likely that restoration of supply to Newcastle could have been delayed by a number of hours. This would have caused major smelter damage and greatly increased inconvenience and loss to consumers.

Recommendations

The Committee of Review's 35 recommendations cover seismic, design, planning and operating criteria, secondary systems, staff resources and emergency planning. Many of these recommendations at this stage cover proposals for further detailed investigations and reviews. However by the end of the year the majority of these should be completed. The two principal improvements which should lead to improved immunity to seismic events are:

- completion of the programme of fitting anti-seismic Buchholz relays to main transformers; and
- improvements to support, bracing and damping of high voltage plant.

Other authorities have shown interest in our experiences in the event and the related studies and it is expected there will be more detailed engineering reports and papers published over coming months. ESAA members may contact the author for a copy of the Report.

A Planners Perspective of the Earthquake

As this is the first such experience for Australian supply authorities where major damage was caused, it is a salutory lesson that improbable events do happen, even if almost inconceivable or where the probability is exceedingly remote.

Consider the poor system planner. He has to try to develop a system which the community can afford, yet it has also to be able to survive 'anything' that nature or man can throw at it.

This dilemma is one which constantly recurs in the literature of planner and they are constantly seeking the holy grail of the affordable 'perfect' solution. Accountants might tell you that the risk of an earthquake may be 1 in a million, while the loss os supply may be valued at $15 million. So, you can only justify spending $15 to fix the risk!

What Price Reliability?

You will all recall the disastrous blackouts in New York some years ago when the second and major shutdown persisted for about a day. The investigations into the cost of the disruption to the community threw up total costs of the order of $350 million by including social costs such as policing, emergency services and losses from looting as well as direct costs of loss of production, spoilage, etc.

In the Newcastle case the lost energy was about 2 Gigawatthours and using an average value used in planning studies for the worth of unsupplied energy of $5 per kilowatthour, the value is $10 million. However it is highly unlikely that a system average value such as this would be appropriate for the circumstances of an earthquake when most people would hardly be thinking of being prevented from productive work or pleasure. They would however be distressed if the lights went out while they were in buildings or lifts or trains.

It is always necessary to use considerable discretion in applying average values of unsupplied energy in arriving at the total benefits of any scheme for system augmentation because of circumstances of the loss of supply can and do vary so widely, and so affect the perceived value of secure supply. However that is not to say that some effort should not be made to try to assess community benefits. In a paper in 1988 the author gave some details of the varying influences on the Community's views of the value of unsupplied energy.(1).

Review of Newcastle 330 kV Substation Configuration

The configuration of the 330 kV busbar at Newcastle is shown in Figure 1. Notice that there are four sections of busbar, with two bus-sections and two incoming circuits equipped with double breakered bays which act as bus-couplers. The four transformers each connect to separate bus-sections.

In the earthquake, one of the breakers on the Liddell line bay failed, but this caused very little local or system disruption as it did not cut off any vital line or load. The flexibility of the planned arrangement proved equal to the event and while it is expensive to provide such flexibility, this substation is almost the sole source of supply to the whole of the Newcastle area and the importance of the aluminium, steel, coal and metal industries as well as the city itself fully justifies the arrangement.

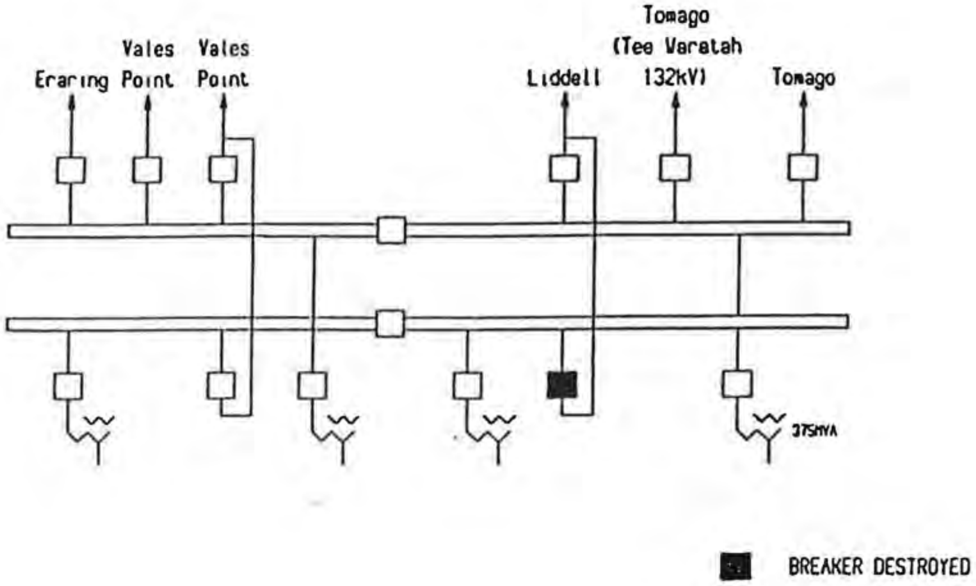


Figure 1 : NEWCASTLE 330kV BUSBAR CONFIGURATION

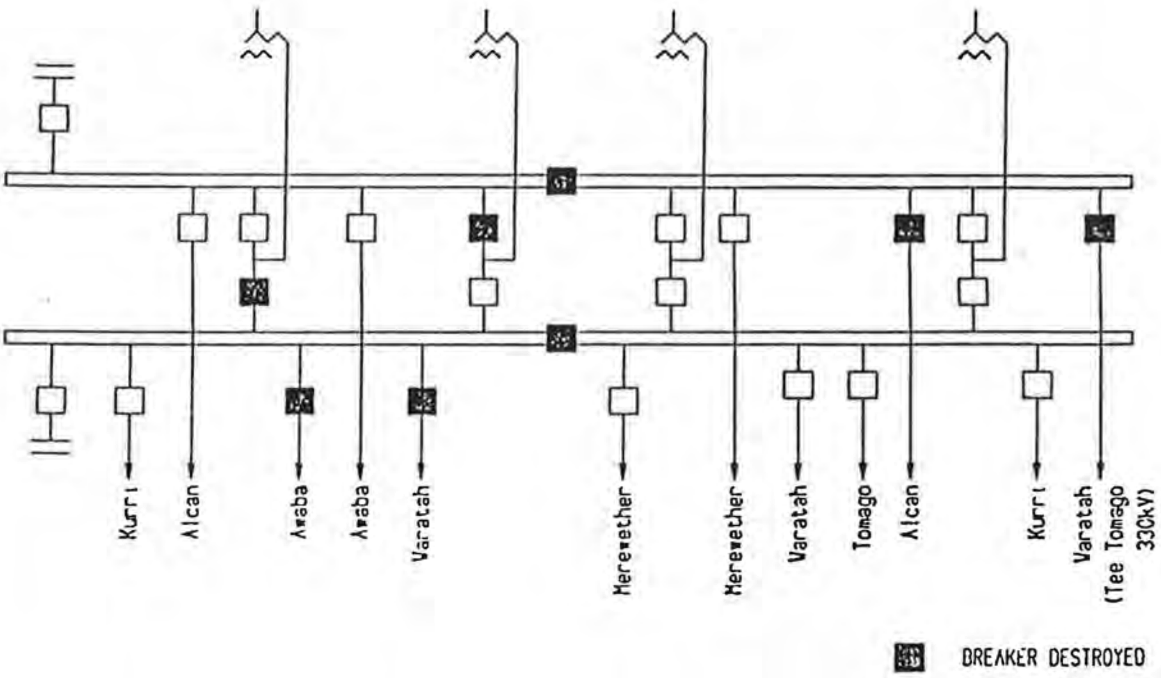


Figure 2 : NEWCASTLE 132kV BUSBAR CONFIGURATION

TP610164

The 330 kV configuration also gives high priority to the maintenance of the main grid through circuits, minimising the potential for major disruption to the interconnected system.

Newcastle 132 kV Busbar Arrangement

The 132 kV arrangement, as shown in Figure 2. is somewhat similar in that there are four bus-sections, with all four transformers being double switched for high security. These circuit breakers can thus serve as bus couplers as well as their normal role. Notice that the lines to the same destination substations are fed from different busbar sections.

This part of the substation suffered the major damage, but due to the very flexible configuration, the disruption to security of supply was not too great.

However, because both of the bus-section breakers suffered damage and in turn caused damage to their associated disconnectors, the restoration of supplies was delayed while the safety of the still standing apparatus was confirmed or disconnected. This may have delayed restoration by about 30 minutes. Because of concern about aftershocks, and the possibility of incipient but invisible damage, great caution was necessary when any switching was required. With the damage spread over much of the length of the switchyard, operations, isolation switching and repair work needed very careful co-ordination.

Waratah 132 kV Substation

At Waratah, the major damage was much more localised to two transformer bays, but again the flexibility of the configuration of the substation allowed the restoration of supply to proceed without excessive delay, the delay mainly being in restoration of supplies from Newcastle Substation. Subsequent switching showed up further faults, and later careful inspection found many main breaker support insulators cracked at their bases.

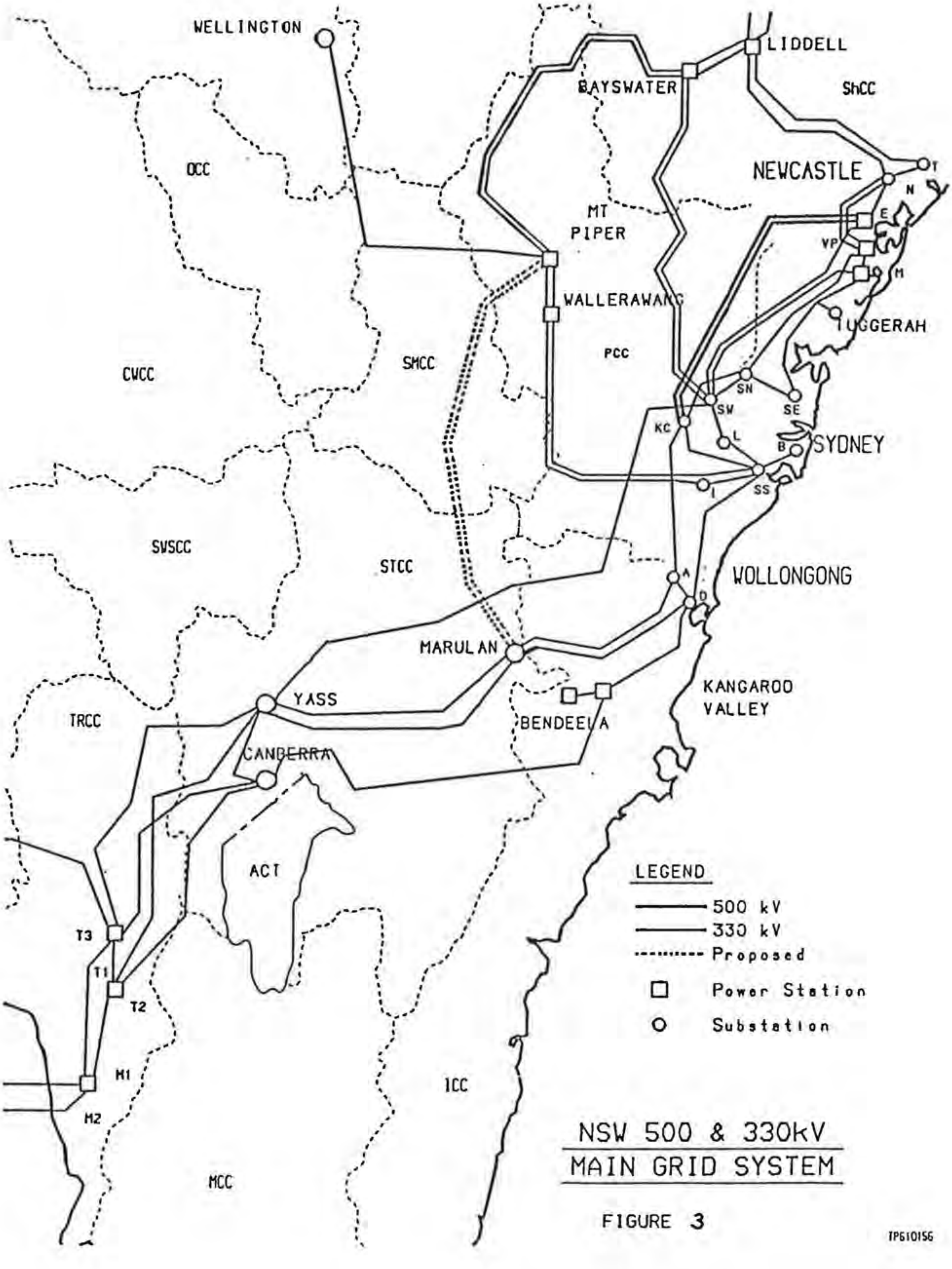
Review of Main System, Risks

After such an event as this there is inevitably cause for reflection on the consequences and the potential for other, similar events which could cause system disturbance or major disruption. Because the new three State interconnected system has an overall length between main generating stations of some 2000 kilometres, the operation of the system is dominated by the need to retain transient stability. This requirement imposes limits on the power transfer south of Sydney, with particular load and generation levels.

With the progressive load increase in the south of the State over the 15 years since the southern system was last reinforced and with generation development in the Hunter Valley and Central Coast areas, the transfer capacity has been gradually decreasing. One of the major system wide benefits to be gained from the completion of the proposed Mount Piper to Marulan 500 kV line will be to strengthen the system interconnection.

The main system diagram Figure 3, shows how this line will provide a vital strategic alternative route for power flows which bypass the congested Sydney basin. At present, faults on any of the three lines to south of Sydney can cause system instability, and so planned outages for maintenance are difficult to arrange. The impact of faults on the major lines converging on Sydney from the north or west must also be considered in planning.

While the probability of such events is quite low, planners cannot ignore the possibility of plane crashes, bushfires affecting at the same time all of the lines in a power line corridor, and earthquakes. The S.E.C.V. recently experienced a serious incident of a plane crash affecting more than one major line. The Commission has experienced several instances where bushfires have caused outage of all lines in a corridor.



NSW 500 & 330kV MAIN GRID SYSTEM

FIGURE 3

TP610156

If the consequences of a major but rare event are to cause collapse of the main grid system due to instability or voltage collapse, then the "cost" to the community can be immense if it is of statewide extent. The onerous task of operators is to restore supply as quickly as possible in spite of the comparatively narrow stable operating range of voltages. It is for this reason that full restoration can extend over many hours, and can result in huge cost impacts.

Conclusions

The Commission's experiences in the Newcastle earthquake are that a localised extreme event can occur without disastrous widespread consequences, but it is a severe reminder that such rare events cannot be ignored.

Acknowledgements

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