weakened crust have ancient faults, buried under a blanket of sedimentary material, which may lie dormant for many millions of years (Reference 1). There is a passive margin all along the eastern seaboard of Australia, where Newcastle is located. In the United States, New Madrid, Missouri is located over a failed rift and Charleston, South Carolina is located along a passive coastal margin.

The first reported earthquake in Australia was at Port Jackson, Sydney in 1778. Although there have been numerous earthquakes since then, the Newcastle Earthquake in 1989 was the first Australian earthquake to cause fatalities and significant structural damage. Earthquakes having Richter magnitudes ML greater than 4.0 during the period 1873-1983 are shown in Figure 1. Two previous earthquakes in the Newcastle area, one in December 1925, the other in 1868, had magnitudes ML of 5.2 and roughly 5.3, respectively (Reference 2).

**REGIONAL GEOLOGY**

The city of Newcastle is located at the mouth of the Hunter River, near the boundary of two geological regions - the Sydney Basin and the New England Fold Belt. Newcastle lies at the northern edge of the Sydney Basin, characterized by Permian sediments which include alternate marine and continental sequences bearing numerous coal seams. The New England Fold Belt, to the north, contains rocks of various ages which are all moderately to heavily folded. These two regions are separated by the Hunter Thrust System, including several small faults which lie to the northwest of Newcastle near Maitland.

Coal mining is an important feature of the economic geology

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**Newcastle Earthquake**

**NEWCASTLE EARTHQUAKE, 27 DECEMBER 1989 (GMT)**

--Cynthia Perry, Dames & Moore, San Francisco

**SEISMOLOGY**

Earthquakes on the Australian continent are caused by compressive stresses which have built up in the crust as a result of the northerly movement of the Australasian Plate under the Indonesian Plate. Although intraplate seismicity is still not well understood, it appears that most stable-continent earthquakes occur within crust that has undergone extension at some time in the past, producing failed rifts and passive margins. Rifts are formed when the brittle upper crust breaks into blocks under the influence of extensional forces. If the extension stops, what remains is a failed rift within the interior of a continent. If the extension continues, the rift will eventually rupture, leaving weakened crust along the edges of the resultant continents. These areas with
of the Newcastle area. Coal was first discovered in situ at the mouth of the Hunter River in September, 1797 and was being exported from the area by 1799. The Newcastle Coalfield has dominated the coal-mining industry of New South Wales ever since.

**STRATIGRAPHY OF THE NEWCASTLE/MAITLAND AREA**

The stratigraphy in the Newcastle area is well known due to the presence of numerous coal bores which extend to depths of 3,000 feet beneath the city.

The city of Newcastle, and several of the surrounding communities, are located on Quaternary Alluvium which ranges in depth from 36 feet to 195 feet. These alluvial deposits consist of gravels, sands, silts, and clays of both marine and freshwater origins. There are apparently no significant areas with artificial fill around Newcastle but there are numerous mine shafts, from both active and inactive mines, located beneath metropolitan Newcastle. Due to the controversy regarding possible ground settlement (described below), some additional information is given here to describe the stratigraphy of the area. The alluvium is underlain by layers of Permian deposits known as the Newcastle Coal Measures, the Tomago Coal Measures and the Maitland Group. At a bore hole (No. 16) located just west of the Central Business District, the alluvium extends to a depth of 69 feet, the Newcastle Coal Measures range from 69 to roughly 265 feet and the Tomago Coal Measures extend from 265 to 3002 feet below the surface. The Newcastle Coal Measures consist of coal seams, massive conglomerates, sandstone, tuff and shale. The Tomago Coal Measures consist of shale, mudstone, sandstone, tuff, clay and thin coal seams. The Maitland Group, which underlies the Tomago Coal Measures, consists of siltstone, sandstone and conglomerate.

**GEOLOGIC EFFECTS**

There was no evidence of surface faulting, ground breakage, slope failure or soil liquefaction as a result of the December 28th earthquake. No damage to coal mines was reported, although miners were apparently trapped underground for several hours as a result of power failures in the area. One unusual instance was reported where a home, built on top of a 6" concrete cap over an abandoned mine shaft which had filled with water, imploded due to an apparent drop in the water table which left a vacuum beneath the concrete cap. The doors and windows of the house caved in and the owner's grand piano got stuck in the hole (Reference 3).

An unusual aspect of the Newcastle Earthquake was that some residents of the city, including personnel in the City Council offices, perceived that the alluvial soils which underlie the city were continuing to settle and shift for weeks following the earthquake, causing progressive collapse of some structures. The Newcastle City Council hired a surveyor to monitor the alleged settlement with highly sensitive stereoscopic camera equipment. Plaster was placed over diagonal cracks in masonry walls in order to detect any continuing movement. Efforts were made to investigate a possible correlation between the locations of underground mines and areas with extensive structural damage or continuing movement.

This issue was apparently the source of considerable controversy at a post-earthquake conference held at The University of Newcastle on February 14-16, 1990. Evidence, arguments and counter-arguments were presented regarding the possibility of post-earthquake
ground subsidence. According to Dr. Kevin McCue with the Australian Bureau of Mineral Resources, there has not been any convincing evidence of long term settlement resulting from the earthquake. In addition, he found no correlation between underground mine locations and heavily damaged areas, or any evidence of earthquake-induced mine subsidence. Dr. McCue opined that a possible explanation for localized soil movement may be that Newcastle experienced record rainfall during the weeks following the December earthquake, the heaviest rain in the 100 years since they began recording rainfall. The soils in the area include many reactive clays which are highly expansive when wet and may be the cause of the perceived ground movement (Reference 4).

EARTHQUAKE INTENSITY

The Australian Seismological Centre maintains a network of seismographic stations throughout parts of Australia, although there were no recording stations within 100 kilometers of Newcastle. Thus, there are no instrumental recordings of the main shock of the December 28th earthquake taken in the epicentral area.

Figure 2 shows the isoseismal map prepared by the Bureau of Mineral Resources, showing Modified Mercalli Intensity contours in the affected area. The map indicates a maximum MMI VI in the epicentral area with a radius of 80 kilometers; an MMI V contour extending 130 kilometers to Sydney; and an MMI III contour extending 350 kilometers, nearly to Canberra. The motion was reportedly felt in highrise buildings in Melbourne, nearly 800 kilometers from Newcastle.

BUILDING DESIGN/BUILDING DAMAGE

The seismic zone map for Australia, shown in Figure 3, was first adopted by the Standards Association of Australia in 1979. Although this map was apparently under revision at the time of the earthquake, it shows that Newcastle is a zone 0. A revised map, presently under consideration, will upgrade Newcastle and much of the eastern coast of New South Wales, to either Zone A or Zone 1.

One of the earthquake fatalities which occurred along Beaumont Street in Hamilton was caused by the collapse of an awning above a commercial storefront onto an adjacent sidewalk. Most of the masonry construction in the damaged commercial areas dates back to the late 19th century or early 20th century. It is ironic to note that many of these storefront awnings were originally supported by timber posts located along the curb. During the 1950’s, these posts were all removed in an effort to enhance the public safety. The posts were considered hazardous since a vehicular accident might remove one or more posts, causing an awning or posted-veranda to collapse. The posts were generally replaced by steel tie-backs, anchored to the inside face of an existing masonry cavity wall with steel plates (Reference 5). There was no evidence that any special details were used to reinforce the masonry facade or parapets to carry this additional load. In numerous cases throughout the area, there was evidence that these awnings contributed to the failure or collapse of masonry.
facades and parapet walls along the commercial street fronts. In the weeks following the earthquake, the sidewalks along commercial streets were lined with temporary shoring to support these heavy awnings and prevent any additional collapse.

Property insurance policies in the Newcastle area did not contain any exclusion for earthquake damage, since this risk was perceived to be very low. As a result, many of the earthquake losses will be covered by insurance, although the insurance companies are requesting government assistance. Even so, 30% of the cities' homeowners were uninsured and 50% were underinsured. Many of these are older people whose homes were paid for and thus did not have a mortgagor requiring insurance.

EMERGENCY RESPONSE

Immediately following the earthquake, police and emergency response personnel from throughout NSW were mobilized to help with the rescue and clean-up operations as well as crowd control. The entire Central Business District, roughly five blocks by twenty-five blocks, was cordoned off from the public until January 9th. Beaumont Street in Hamilton was also cordoned off.

The Newcastle City Council (NCC) developed damage assessment forms, one of which is quite similar to the ATC-20 Rapid Evaluation Safety Assessment, with some notable additions for information pertaining to awnings. Many buildings in the Central Business District are considered to have historic value, so there was some public reaction when buildings such as the George Hotel were demolished.

FIGURE 3. Seismic Zone Map

REFERENCES


3. Robert E. Melchers, Professor of Civil Engineering, Newcastle University, personal conversations.


ADDITIONAL BIBLIOGRAPHY


EQE Reports on Newcastle

EQE, San Francisco, has published an 8-page report on their investigation: THE DECEMBER 28, 1989 NEWCASTLE EARTHQUAKE.

Excerpts (somewhat edited):

At 10:27 A.M. on Thursday, December 28, 1989 local time
the first fatal earthquake, ML5.5, in Australia's history struck the city of Newcastle and the surrounding Hunter Valley Region of New South Wales (NSW). The epicenter was estimated to be only 5 km west of the city center. Combined with the lack of seismic design in the local building stock, the proximity of this earthquake resulted in far greater damage than usual, say, in California, for such a moderate magnitude. The Newcastle Earthquake killed 12 people, damaged over 3,000 buildings, and resulted in total losses estimated at over (US) $900 million.

While tragic, the lack of seismic design in the Hunter Valley region is understandable because earthquakes are so rare in the area. The damage caused by the Newcastle Earthquake was a shock not only to residents, but to most seismologists.

Australia's seismic design requirements, adopted in 1979, were modeled after the U.S. 1976 Uniform Building Code. Newcastle is in an area designated as Zone 0, requiring no seismic design, although some
concrete-frame structures. Among the latter was the Newcastle Workers’ Club, where a section built in 1972 collapsed.

Much of the residential construction in Newcastle is unreinforced masonry dating from the turn of the century to the present. Roofs are generally wood frames with either corrugated metal or clay tile. Walls are typically of cavity wall construction (i.e., two independent wythes of brick separated by a one-inch cavity). There are usually ties between the two wythes in new buildings, but not in the older ones. These walls are very weak when bending out-of-plane since the two wythes move independently. In addition, the older buildings have very poor-quality mortar of lime and plain beach sand. Newer buildings are generally built with much stronger portland cement mortar.

About 3,000 homes were damaged to some degree over a wide area.

The Newcastle Earthquake demonstrated the consequence of ignoring even a limited seismic history. Though all earthquakes in this area have been moderate, the unreinforced masonry construction that predominates was inadequate to the task of resisting even a short moderate earthquake, albeit with a close epicenter. Even some modern structures proved unable to resist this moderate earthquake because seismic concerns had not been considered in their design.

Industrial facilities performed well, as expected for a moderate event, but also due to the extensive use of steel for construction. Earthquake effects to lifelines were limited to the power system, where somewhat more damage than expected occurred to high voltage switchyard components.

There are several areas in the United States, and, indeed, the rest of the world, that are similar to Newcastle in that they have a history of seismic activity, limited building code requirements to accommodate seismic forces, and an extensive stock of unreinforced masonry buildings.

The lesson of this earthquake once again is that loss of life and economic disruption can be avoided by taking measured action in areas of greatest vulnerability. Hazardous buildings with high occupancy need to be identified and strengthened. Design and review of new buildings should be done with an understanding of the lateral forces that may impact the structure. Eventually, a systematic inventory of hazardous buildings should be undertaken and a long range plan developed for their continued use or demolition. Emergency planning to cope with the possibilities of a seismic event should take place in private industry and government agencies.

All of these steps are in fact what has been going on in California and Japan for years, where there are regular reminders of the potential for disaster. The risk that exists elsewhere, but is not as obvious, is slowly being recognized. It is important that the decision makers in private industry and government not be overwhelmed and paralyzed by the enormity of the task. Earthquake hazard mitigation needs can be addressed over time, but programs to establish priorities should be started immediately. Cost-effective solutions to priority items can then be taken to avoid the level of losses suffered in New South Wales.