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AEES Newsletter

The Society David Rossiter (Treasurer)

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President's Column Charles Bubb

This newsletter has three reports on the Kobe earthquake. This marks the first time the Australian Earthquake Engineering Society has had its own representatives on site following a major earthquake in another country.

Our thanks to Dr George Walker and to his employer for funding, to Dr Mike Griffith and Prof Bruce Boreham, and to the NZNSEE for their cooperation and support.

Once again the result is that most lives lost comes from crushing due to the total collapse of buildings. The Sakhalin earthquake in Russia just a few days ago is another terrible demonstration of the same effect.

That is, maximum life protection results from the prevention of total collapse of buildings and the greatest danger is posed to the occupants of weak, heavy, brittle buildings shaken beyond their capacity.

There are puzzling references to the perception of a low risk of earthquakes in the region. Puzzling because there was a magnitude 6 earthquake in virtually the same area in 1916, and four earthquakes in excess of magnitude 7 within 100 km in the last 400 years.

All things are relative and the magnitude of the disaster was less than that still expected to hit Tokyo one day. Do we see here evidence of a 'Tokyo or the bush' viewpoint?

At first sight it might seem unlikely that there could be direct lessons for Australia from such a massive disaster but both our reporters clearly demonstrate that there are. Read the reports! One lesson is that working stress design plus extreme events equals disaster.

IEAust has adopted a policy of sustainability and is looking to every engineering society, group and discipline to contribute to this policy. It is obvious that communities cannot be sustainable if they cannot survive natural disasters. The NZ team (see below) suggested that it is unlikely the Kobe Port will regain its previous high world status for some time, if ever.

It is clear with hindsight that no one had an adequate emergency plan for Kobe for the event nor flexibility to adjust for the circumstances as they arose.

But we should not be complacent - are you sure that there is an adequate emergency plan for the community you live in? How do you know? Does the plan encompass all infrastructure, including power, water, gas, waste disposal, transport and communications?

If there is one now, will it continue to survive in the face of the rapid changes now taking place in the Public Sector? Although our main concern is earthquake hazard resistance it may not be the main threat to your community. What is? - do you know?

It has been conventional in the past to ignore earthquakes in Australia, less so since Newcastle. Still the memory of Newcastle is fading fast. The new earthquake code should help but it still does not require any positive additional action for many small buildings in many situations.

The NZNSEE has just published a 100 page report on Kobe which covers virtually every aspect. It is a 'must read' for those needing the fullest available detail for the moment along with the EERI report. At this time let me quote just a few items from the NZ report:

• there were no failures of western style houses
• several dedicated emergency communication circuits failed including the Prefectural Government's emergency satellite communications network.
• Japan does not operate national emergency service structures.

Finally, they say beware there are traps in planning; one is not to recognise the need, another is to plan unrealistically. If you plan just one scenario, how prepared are you if the situation is significantly worse or significantly different?

Ref: - NZNSEE Bulletin 28 (1), March 1995.

The recent Japanese earthquake discussed below has been given different names by different investigators and these have been deliberately retained here.

THE 1995 HYOGO-KEN NANBU (KOBE) EARTHQUAKE - A SEISMOLOGICAL PERSPECTIVE

Kevin McCue
Australian Geological Survey Organisation

Some of the seismological background on the earthquake has been compiled as a foreword to the reports by Dr Walker and Dr Griffith. They visited the Kobe area to study engineering aspects of the earthquake and advise on implications for Australia.

The Japan Meteorological Agency computed the following earthquake parameters:

origin time	05:46:53.9 am , 17 January 1995
epicentre	34.60°N, 135.00°E
focal depth	10 to 20 km
magnitude	7.2 (JMA scale), Mw 6.9

The epicentre is about 20 km southwest of down-town Kobe between Awaji Island and Honshu Island. Tectonically the epicentre is 200 km north of the Nankai trough which is the boundary between the Philippine and Eurasian Plates, and about 100 km south of a zone of major earthquakes along the Japan Sea coastline of Honshu (Fig 6).

The epicentral area is in the highest hazard area defined in the Japanese earthquake code (Earthquake Resistant Regulations A World List 1992, IAEE), and was in 1978 designated an *Intensified Observation Area* by the Japanese Coordination Committee for Earthquake Prediction.

Hundreds of aftershocks located by the Abuyama Observatory, Disaster Prevention Research Institute, Kyoto University in the first 3 days outline a 50 km long faultplane extending southwest through Awaji Island and northeast under Kobe. The rupture extended bilaterally from the epicentre, both to the southwest and the northeast under the city.

A 9 km long surface rupture with a slip of up to 1.5m has been mapped by geologists through Awaji Island along the Nojima Fault but the surface faulting did not extend into Kobe.

Various agencies have computed the focal mechanism both from first motions and body-wave inversion; the result a right lateral strike-slip fault striking north-east. The moment magnitude was Mw 6.9, identical to that of the January 1994 Northridge earthquake in California and not much larger than the 1968 Meckering and 1988 Tennant Creek events. Different magnitude scales yield different estimates of magnitude because they are a measure of seismic wave amplitudes in different parts of the frequency spectrum. The best estimate of relative size is given by Mw.

Extensive strong motion data was recorded, the 3 near fault peak accelerations on soil in Kobe were between 0.80 and 0.83 g and strong shaking lasted about 10 sec. The ground velocity on rock was 55 cm/sec but on soft soils the ground velocity exceeded 100 cm/sec. A large long period velocity pulse in the records has been interpreted by Somerville and others as evidence of directivity or rupture focussing - a phenomenon which may account for the surprisingly high damage in Newcastle.

This brief report was distilled from preliminary reports on the earthquake by Kanamori (Seismological Research Letters, 66 (2), 1995), Somerville (EERI Bulletin, 1995), DPRI staff, NCEER and others.

BRIEF REPORT ON THE HANSHIN EARTHQUAKE - 1995

Dr. George R. Walker FIEAust
Research Director
Alexander Howden Reinsurance Brokers (Aust) Ltd

Background Following the occurrence of what the Japanese are calling the Great Hanshin Earthquake the New Zealand National Society for Earthquake Engineering organised a reconnaissance team to inspect the damage. The author was included in the team as a representative of the Australian Earthquake Engineering Society. The 13 strong team arrived in Japan 6 days after the earthquake, and spent 10 days there, most of it inspecting damage in Kobe and adjacent areas. The team was led by Professor Robert Park from the University of Canterbury.

Kobe Kobe (pop. 1.5 million) is a modern city forming the northern end of a crescent of continuous development around Osaka Bay that includes Osaka (pop. 2.6 million). The whole area is known as Hanshin, and it is the second most important industrial and commercial area in Japan after the Tokyo - Yokohama area.

Kobe and the adjacent heavily hit communities of Ashiya and Nishiomiya are located on a narrow strip of alluvial and colluvial flat land and the adjoining lower slopes of Mount Rokko in a setting reminiscent of the location of Wollongong. Kobe includes two of the largest artificial islands, Port Island and Rokko Island, each of which is of the order of 3-4 sq km in area. The extensive port facilities around the edge of these islands made Kobe the sixth largest port in the world in terms of tonnage throughput in 1994 and the largest container port in Japan.

The Earthquake The earthquake occurred at 5.46 am local time on Tuesday 17 January 1995 (2046 GMT 16 January). It was estimated to have had a Richter Magnitude of 7.2 with an origin 20 km beneath the northwestern tip of Awaji Island about 30 km southeast of Kobe. The earthquake caused extensive damage, mainly in a narrow strip of the order of 1-2 km wide and 30-40 km extending through Kobe and the adjacent communities. Over 5000 people were killed, about 27,000 injured, and over 250,000 made homeless. Over 100,000 buildings were reported destroyed and the total damage cost has been estimated as being of the order of 150 billion Australian dollars. It was the worst earthquake disaster in Japan since the 1923 Great Kanto Earthquake which devastated Tokyo and Yokohama, and resulted in 140,000 deaths, mostly from the resulting fires.

Ground Motion The maximum ground motion intensities are estimated to have been of the order of MM9-MM10 with a maximum recorded ground acceleration of 0.83g. They occurred in a narrow strip of land about 1 km wide and 30 km long extending from a few hundred metres from the edge of the sea to the beginning of the lower slopes of Mount Rokko. This area was marked by considerable soil damage but no liquefaction. Extensive liquefaction with considerable settlement occurred in the land adjacent to the sea and on the artificial islands, but the ground surface vibration intensity appears to have been not greater than MM8 in these areas, suggesting that liquefaction has a vibration isolation effect. The ground motion appears to have reduced dramatically on the lower slopes of Mount Rokko with estimated intensities of MM6 occurring within a few hundred metres of the strip of maximum ground motion.

The pattern of ground motion appears to be the result of a combination of the direction of the earthquake fault, with which it aligns, the characteristics of the soft soils on the plain, and the close proximity of rock on the lower slopes of Mount Rokko.

Building Damage The most striking feature of the building damage was the contrast between old and new buildings. Commercial and apartment buildings less than ten years old appeared to have suffered little or no damage, whether small or large, even when located in areas of maximum ground motion intensity. Kobe has a significant number of recent high rise glass clad buildings. Apart from the occasional broken window they appear to have survived unscathed. No general failure of a modern glass curtain wall facade was observed. Modern lightweight frame housing also appeared to have survived undamaged in the areas of most intense shaking. That was the good news.

The bad news was that almost all other classes of buildings performed poorly in the areas of most intense ground shaking.

The worst was traditional houses which because of their heavy brittle construction, suffered significant damage at MM7, general lower storey collapse at MM8 and general complete collapse at MM9. Not far behind were traditional small 3-4 storey commercial buildings despite the steel portal frames which generally provided the main structural support. A significant factor in the collapse of these buildings was welded and bolted connections much weaker than the framing members which became the weak links and resulted in the framing systems having brittle characteristics under overload. These suffered significant damage at MM8, general bottom storey collapse at MM9 and general collapse at MM10. The collapse of these two types of structure, the first non-engineered and the second probably marginally engineered, were the primary causes of the devastating fires and loss of life.

Older larger commercial buildings up to 4 or 5 storeys high were typically of reinforced concrete frame construction. They performed reasonably well up to MM8 but behaved poorly above this level with many examples of bottom storey collapse as a result of brittle failure of columns under combined bending, axial load and shear. Insufficient ties to support the main reinforcing after spalling of the concrete appeared to be the major cause of this brittle behaviour. Higher older commercial buildings and the many older apartment buildings which were typically 10-20 stories high behaved in a similar manner, except that a significant number of intermediate storey collapses occurred. It is believed that in many of these composite construction was used in the lower stories, with reinforced concrete being used in the upper stories where failure occurred. In some cases the intermediate storey collapse was associated with changes in building plan with height.

In areas of liquefaction and soft soils some rotation of these buildings occurred, particularly the long narrow apartment buildings, but this did not appear to be a major feature of the damage, and the tilting was generally small.

The reason for the excellent performance of the more recent construction appears to be a new earthquake code introduced in 1981 which reflects modern earthquake engineering knowledge. Prior to that design was based on a combination of working stress design and static analysis. The earthquake has demonstrated that the expenditure on earthquake engineering research underlying modern earthquake engineering knowledge and the additional design and construction costs required for its implementation are justified.

Infrastructure Physical infrastructure such as rail and road elevated structures, port facilities, and water and gas supply networks performed poorly. Next to the poor performance of traditional houses and small commercial buildings these were the main contributors to the scale of the disaster.

Kobe is a linear city dependent on a number of parallel rail and road systems for transportation. All the major road and rail systems were rendered inoperable, most for several months, as a result of major damage to bridge structures forming the elevated sections of the expressways and railways. Brittle failure of reinforced concrete columns similar to that observed in the older buildings appeared to be the primary contributing factor, but some steel failures were also observed. Most of the structures predated the 1981 design code, and their failure highlighted the weaknesses inherent in the old methods of earthquake design. The failure of these systems has severely affected access to Kobe, and is seriously hampering relief and restoration activities.

The reasons for the extensive disruption of gas and water supplies was not ascertained but is believed to be associated with extensive ground damage in the soft soil areas. The sewerage system is also believed to be out of action. Their failure has had a major impact on the resumption of commercial and industrial activities. A number of very modern undamaged hotels in Kobe are closed because of this and one major international company with its Japanese headquarters in Kobe has estimated its business interruption costs at US$50-100M despite its modern high rise building being undamaged.
In contrast the electricity and telephone systems performed well with 95% of services restored within a week.

The damage to the port facilities, largely as a result of damage to the sea walls and cranes resulting from the liquefaction, has paralysed the extensive Kobe port facilities.

Implications for Australian Construction The Kobe earthquake reaffirmed the incompatibility of earthquakes, soft soils and brittle construction, and demonstrated again the fallacy of putting too much emphasis on perceived risk based on recent history.

Kobe was perceived by the Japanese as an area of lower risk, and design loads reflected this, but again as in Newcastle the earthquake demonstrated that soft soil amplification is far more important than differences in perceived risk, particularly for small buildings, with large differences in performance being observed over very short distances as a result of different ground characteristics. The myth, embodied in the current Australian earthquake code, that short period buildings are relatively insensitive to soft soil effects should have been completely dispelled by the Kobe earthquake.

The Kobe experience should also have dispelled the myth than liquefaction is the major problem of soft soils. While it had a major effect on earth retaining structures such as sea walls, and on water, gas and sewerage lines, it appears to have had a mitigating effect on building damage.

Kobe has clearly demonstrated the importance of ensuring all construction in soft soil areas at risk from earthquakes is ductile, small buildings as well as large. The failure of small buildings due to brittle failure was a major contribution to the scale of the disaster - so much so that the excellent performance of the modern construction has gone entirely unnoticed by the media. As Cyclone Tracy did 20 years ago in Australia, the earthquake highlighted again that in large scale extreme events like earthquakes and tropical cyclones small buildings are as important as large buildings, and need to be structurally designed with the same attention to detail and to the same criteria as large buildings.

Kobe should also be the death knell of working stress design in earthquake prone areas. Just as Cyclone Tracy did 20 years ago it has demonstrated that working stress design plus extreme events equals disaster. The older steel and concrete buildings were designed by working stress design without consideration being given to the ultimate limit state. Working stress design without recognition of the need to ensure that brittle failure of the system does not occur at ultimate loads led to the insufficient ties in the reinforced concrete and the weak connections in the steel. These weaknesses are very prevalent in Australian construction which to date has largely reflected this approach. They were not shown up by the Newcastle earthquake with its maximum estimated ground intensities of MM7-MM8, but the Kobe earthquake has shown that much of this construction will be at risk at higher levels of ground motion.

The Australian construction industry has much to learn from Kobe's experience with an earthquake code that places too much emphasis on perceived risk and the behaviour of large buildings, and insufficient emphasis on the importance of soft soils and small buildings, and a design profession and building products manufacturing industry that has been very resistant to the change from working stress design philosophy to limit state design philosophy.

Author The author obtained his PhD in earthquake engineering at the University of Auckland in 1966. He spent 21 years at James Cook University in Townsville, 13 as an Associate Professor in Civil Engineering where he became noted for his work on design for tropical cyclones. He led the investigation of damage to Darwin from tropical cyclones undertaken by the Commonwealth Government. In 1989 he moved to Sydney to become Assistant Chief of the CSIRO Division of Building, Construction & Engineering. Shortly after he participated in the investigation of the Newcastle earthquake undertaken by The Institution of Engineers Australia for the New South Wales Government. He recently became Research Director for Alexander Howden Reinsurance Brokers (Australia) Limited. The author was Chairman of The Institution's National Committee on Structural Engineering during 1986-87 and is currently Chairman of the Joint Australia-New Zealand Structural Standards Advisory Committee. He has been a member of the New Zealand National Society for Earthquake Engineering since its inception and is a member of the Australian Earthquake Engineering Society.

The Pacific Conference on Earthquake Engineering *PCEE'95* will be held in Melbourne, 14 - 16 November 1995. It will be hosted jointly by AEES and the NZNSEE for the first time. Hope to see you there!

REPORT ON THE JANUARY 17 1995 GREAT HANSHIN (KOBE) EARTHQUAKE

Dr. Mike Griffith
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Introduction Following the occurrence of the Kobe earthquake, Dr. Lam Pham from the CSIRO in Melbourne and Dr. Griffith from the University of Adelaide travelled to Kobe, Japan on February 2 and spent 8 days inspecting the earthquake damage. Many research teams have travelled to Kobe to conduct earthquake reconnaissance in an effort to learn from the lessons of Kobe. The findings of these groups will become available throughout the next 12 months and will cover all aspects of the earthquake, including seismic and geotechnical aspects, earthquake response and recovery issues as well as structural aspects. The comments here are confined to observations of the structural damage and the implications for structural design in Australia.

Kobe and the adjacent heavily hit communities combine to form a large, modern city (population 1.5 million). It is located at the Northern end of Osaka Bay (Figure 6) and includes two man-made islands, Port Island and Rokko Island. The economic importance of Kobe to Japan is reflected in the fact that the extensive port facilities on the islands make

Kobe one of the most significant container ports in the world.

The earthquake occurred at 5:46 am local time on Tuesday 17 January 1995 and was estimated to have had a moment magnitude of $M_W = 6.9$, maximum ground motion intensities of MM9-MM10, and a maximum recorded ground acceleration of 0.83g. Over 5000 people were killed, approximately 27,000 injured, and over 250,000 made homeless. Over 100,000 buildings, including houses, were destroyed and the total damage cost has been estimated as being of the order of 9.5 trillion yen ($150 billion Australian dollars). The total economic loss will, of course, be significantly higher.

Building Damage There are many important aspects of the earthquake damage to buildings in the Kobe area, however, the 3 most significant are probably:

- the degree and extent of structural damage;
- the large number of weak-storey collapses, notably even at upper levels of buildings; and
- the contrast between damage in old and new buildings.

The earthquake damage was extremely heavy and widespread although concentrated over a fairly well defined area stretching some 20 to 30 km long and several km wide between the waterfront and Rokko mountains centred near Kobe. From this it was apparent that soft soils played an important part in the pattern and extent of damage. Furthermore, within this area, most buildings suffered some damage and it was not uncommon to find city blocks where well over 50% of the buildings were damaged beyond repair. This was evidenced by the large percentage (approximately 1/6th) of the population which was rendered homeless.

There were also a very large number of soft storey collapses at the ground-floor level in detached, single family dwellings, as well as apartment and small commercial buildings up to 3 or 4 storeys. This type of damage was not confined to a single material; concrete, steel and timber all fared badly. The large number of upper storey collapses was also generally unprecedented. At least 6 buildings in the Kobe central business district alone suffered complete collapse at upper levels while many others suffered partial upper level collapses.

Thirdly, commercial and apartment buildings less than ten years old appeared to have suffered little visible damage. However, as steel structures are frequently hidden behind fire protection and cladding it will be some time before the damage to newer steel buildings has been fully investigated. Unfortunately, most older buildings (pre 1981) performed poorly in the areas of most intense ground shaking.

Traditional houses, because of their heavy brittle construction, suffered significant damage including many lower storey and complete collapses (Figure 1). These buildings typically consisted of "post and beam" construction and heavy clay tile roofs. Their lateral resistance was provided by a brittle cladding system consisting of a timber lath and paper backing with plaster cladding. Many examples of plaster peeling off timber backing were observed (Fig 2).

photo Mike Griffith

Fig 1 Collapsed housing around Nishinomiya

Small 3-4 storey steel commercial and apartment buildings fared little better despite the use of cross-bracing and/or portal frame action to provide the main seismic resistance. Many of the cross-braced frames

photo Mike Griffith

Fig 2 Cladding failure reducing lateral stiffness

had grossly under strength braces which must have yielded repeatedly during the earthquake permitting large lateral drifts, often resulting in collapse or significant permanent offset in the structure (Fig 4). In the case of portal frames, the welded and bolted connections were much weaker than the framing members which became the weak links and resulted in the framing systems having brittle characteristics under overload (Figure 5). It should be noted here that while there were approximately 500 fires in the Kobe region which resulted in the complete destruction of over 7000 buildings, most loss of life was due to crushing due to building collapse.

Reinforced concrete commercial buildings up to 4 or 5 storeys high were typically of moment frame construction. As for the steel buildings, the concrete buildings performed poorly in the areas of strong ground motion where there were many bottom storey collapses. Insufficient confinement steel (250 to 300mm spacing of ties) in the columns appeared to be the major cause of this brittle behaviour (Figure 8).

Interestingly, taller commercial and apartment buildings in the range of 5-20 storeys high behaved in a similar manner, except that a significant number of intermediate storey collapses occurred (Figure 9). In many of these buildings, composite construction (SRC) was used in the lower storeys and reinforced concrete (RC) was used in the upper storeys. SRC is a form of construction commonly used in Japan which consists of steel members encased in concrete. The cause of most of the upper level storey collapses is suspected to be associated with either a change from SRC to RC construction or changes in building geometry such as set-backs. However, this has yet to be confirmed.

Lifelines Most of the physical infrastructure such as elevated rail and road structures, port facilities, and water and gas supply networks performed poorly. While these failures resulted in comparatively few deaths, the loss of most of the area's lifelines may end up contributing more to the total scale of the disaster than anything else. For example, Kobe is a linear city dependent on a number of parallel rail and road systems for transportation. The port facilities and all major road and rail systems were rendered inoperable, most for at least several months, as a result of lateral spreading on Port and Rokko Islands (Figure 3) and major damage to bridges and elevated sections of the expressways and railways (Figure 4). Brittle failure of reinforced concrete columns similar to that observed in the older concrete buildings discussed previously appeared to be the primary contributing factor. For example, ligature spacings of 300 mm were observed in many of these columns, regardless of size, whereas more recent structural details use 100 mm ligature spacings as a maximum. The failure of the transportation lifelines has severely affected access to Kobe, and continues to seriously hamper the relief and restoration activities.

Extensive ground movement in the soft soil areas was also probably responsible for the extensive disruption of the gas, water and sewerage systems. The failure of these lifelines has had a major impact on the resumption of commercial and industrial activities. Ironically, many of the undamaged buildings in Kobe were closed because of the disruption to these services.

Implications for Australian Construction
The Kobe earthquake appears to be another dramatic example of the disastrous effects of soft soil amplification on brittle structures. The failure of so many domestic structures (small brittle buildings) highlights the need for seismic design input into all buildings, not just large building structures. Although domestic construction in Australia is of a generally high standard, the popularity of unreinforced brick masonry construction still offers structural engineers some interesting seismic design problems. It was also interesting to hear the Japanese talk about how they had believed Kobe was an area of lower risk, and not in danger of earthquakes. These factors are reminiscent of the Newcastle experience.

The excellent performance of the more recent construction in Kobe appears to be due to the introduction of a new earthquake code in 1981. Prior to 1981, seismic design was essentially based on static analysis and the working stress design philosophy for strength. Apparently, no consideration was given for the need to ensure that a structure behaves in a ductile manner under conditions of extreme overload. This resulted in insufficient ties in reinforced concrete structures and weak beam/column connections in steel structures. These weaknesses are also prevalent in Australian construction which to date has largely reflected a similar approach. Thus, while the Newcastle earthquake did not cause widespread collapse of reinforced concrete and steel buildings, the Kobe earthquake has shown that much of this construction could be at risk at higher levels of ground motion.

IMPRESSIONS OF KOBE 100 DAYS LATER

Professor Bruce Boreham
Department of Applied Physics, CQU

On Friday 28 April 1995 exactly 100 days after Kobe was flattened, I made a quick visit from Osaka where I was attending a conference. I travelled by overground Japan Rail Train and subsequently spent about 3 or 4 hours walking around central Kobe immediately adjacent to the central Sannomiyu railway station. I covered an area of approximately 1 to 2 km radius, which included much of the port facilities plus what I could see from the train. My main observations were:

1. Domestic housing was severely damaged. Many of the houses, as seen from the train, had been reduced to a pile of rubble topped by a relatively intact heavy tile roof.

2. Extensive surface ground movement was apparent, especially in roads, footpaths and in the port area. Large numbers of cobblestones, paving stones and concrete blocks had been strongly displaced along roads, footpaths and the port, retaining the shape of the waves that had displaced them and providing a snapshot of the wave motion frozen in time.

3. The port forecourts suffered severe damage, fragmented into many blocks of concrete and soil of several square meters in area. The vertical ground movement in many cases was as much as a metre or more. The concrete seawall had been broken-up and displaced into the sea along with much of the foreshore lighting and railings, which now protruded sadly from the sea.

4. There are in Kobe many very tall modern buildings which appeared to have suffered no damage.

5. Many older high-rise buildings (up to about 10 storeys or so) had sustained some damage (although a number of buildings had already been demolished and demolition was continuing, so it was not possible to obtain an accurate impression of the amount of damage suffered by these buildings, but merely the type of damage). Damage was from two main sources:

(i) Subsidence due to foundation failure (eg liquefaction) of which there were many examples, and

(ii) Building structure failure. Many buildings had supporting columns buckled in one place, resulting in one floor partially collapsing onto the one below it. This effect appeared to be almost random and not consistently associated with a change in building stiffness at any particular height.

The Author Professor Boreham is from the Department of Applied Physics, University of Central Queensland.

Photos Mike Griffith

Fig 3 Lateral spreading - Rokko Is in port area

Fig 4 Damage to elevated section of railway

Sakhalin Earthquake
Eastern Russia - 27 May 1995

Kevin McCue

The earthquake occurred at 1:04 am EST on Sunday morning 28 May. It is feared that the deathtoll may exceed 2000 in the rubble of reinforced concrete apartment buildings which collapsed during the shallow magnitude Ms 7.5 earthquake.

The magnitude of this earthquake has been variously assessed as Ms 7.5 from the amplitude of seismic surface waves, or Mw 6.9 the moment magnitude computed from the area and average slip on the fault plane. The latter is about the same as the January Kobe earthquake discussed above.

Sakhalin island is about 1000 km west of the Pacific Plate boundary, further than Darwin is from the northern margin of the Australian Plate through the Sunda Arc so this earthquake was an intraplate earthquake. Previous earthquakes extracted from the AGSO database include; a magnitude Ms 6.0 earthquake on 10 July 1932 and more recently a magnitude Mb 5.6 earthquake on 17 March 1993. The focal mechanism or Centroid Moment Tensor Solution is that of a strike-slip fault with a north-east striking principal stress direction.

Authorities have announced that they may not rebuild Neftegorsk (literally oil-town) but move activities elsewhere.

The figures opposite belong with Mike Griffith's report - the order dictated by available space and limited computer RAM. Some of the figures could not be reproduced here and will hopefully be printed next newsletter (Ed.)

Fig from Newsweek via Somerville

Fig 5 Part of the fault scarp on Awaji Is showing there was both vertical and lateral movement.

from Newsweek via Somerville

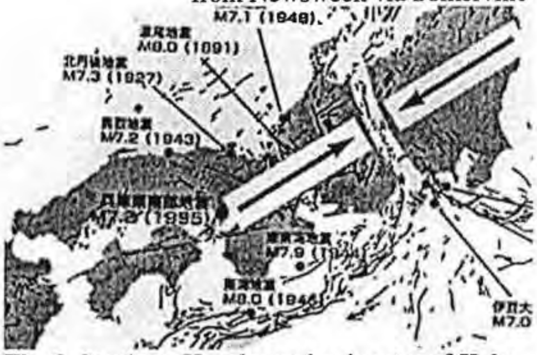

Fig 6 Southern Honshu and epicentre of Kobe earthquake. The plate boundary is shown as well as the epicentres of onshore large earthquakes this century.

photo Mike Griffith

Fig 7 cross-braced steel frame with failed cladding

photo Mike Griffith

Fig 8 Large tie spacing led to many failures

Photo Mike Griffith

Fig 9 Collapsed upper storey of old Kobe City Hall building