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# A Summary of Earthquakes in 1998

David Galloway and Alice Walker present a summary of seismic activity during 1998

## Overseas

This year was not exceptional in terms of worldwide earthquakes (Figure 1). There was one 'great' earthquake (magnitude over 8.0), five 'major' earthquakes (magnitudes between 7.0 and 7.9) and 59 'strong' earthquakes (magnitudes between 6.0 and 6.9). These numbers are less than the long-term averages for these magnitude ranges, which are 1, 18 and 120, respectively. The number of people killed by earthquakes during 1998 was 8,930 (Table 1), which is consistent with the long-term average of 8,700.

The two most disastrous earthquakes during the year occurred on 4 February and 30 May, with magnitudes of 6.1 and 6.9 Ms, respectively, in the Hindu Kush region near the Afghanistan and Tajikistan border. Between them they caused the deaths of at least 6,323 people (approximately 70% of the death total for 1998), injured many thousands more, destroyed or damaged over 9,000 homes leaving many thousands homeless in the Badakhshan and Takhar Provinces. In this same region, on 20 February and 11 December, earthquakes with magnitudes of 5.8 and 5.1 Mb, respectively resulted in the deaths of 6 more people, and the February

**Table 1 Earthquakes causing deaths in 1998**

| DATE | LATITUDE | LONGITUDE | MAGNITUDE | LOCATION | DEATHS |
|---|---|---|---|---|---|
| 10 January | 41.08 N | 114.50 E | 5.8 Mb | Northeast China | 70 |
| 30 January | 23.91 S | 70.21 W | 6.5 Ms | Northern Chile | 1 |
| 04 February | 37.08 N | 70.09 E | 6.1 Ms | Afghanistan/Tajikistan | 2,323 |
| 20 February | 36.48 N | 71.09 E | 5.8 Mb | Afghanistan/Tajikistan | 1 |
| 14 March | 30.15 N | 57.61 E | 6.9 Ms | Northern Iran | 5 |
| 26 March | 43.26 N | 12.97 E | 5.4 Mb | Central Italy | 1 |
| 10 April | 32.46 N | 59.98 E | 5.7 Ms | Northern Iran | 12 |
| 12 April | 46.25 N | 13.65 E | 5.7 Ms | Austria | 1 |
| 22 May | 17.73 S | 65.43 W | 6.6 Ms | Central Bolivia | 105 |
| 30 May | 37.11 N | 70.11 E | 6.9 Ms | Afghanistan/Tajikistan | 4,000 |
| 27 June | 36.88 N | 35.31 E | 6.2 Ms | Turkey | 145 |
| 09 July | 38.65 N | 28.63 W | 6.0 Ms | Azores Islands | 10 |
| 17 July | 23.41 N | 120.74 E | 5.5 Mb | Taiwan | 5 |
| 17 July | 2.96 S | 141.93 E | 7.1 Ms | Papua New Guinea | 2,183 |
| 29 July | 32.31 S | 71.29 W | 6.3 Mb | Central Chile | 2 |
| 04 August | 0.59 S | 80.39 W | 7.1 Ms | Ecuador | 3 |
| 27 August | 39.66 N | 77.34 E | 6.4 Ms | Southern Xinjiang | 3 |
| 09 September | 40.04 N | 15.98 E | 5.2 Mb | Southern Italy | 2 |
| 28 September | 8.18 S | 112.47 E | 6.3 Mb | Jawa, Indonesia | 1 |
| 29 September | 44.19 N | 20.04 E | 5.3 Ms | Northwest Balkan | 1 |
| 13 November | 27.77 N | 53.61 E | 5.3 Mb | Southern Iran | 5 |
| 19 November | 27.27 N | 100.97 E | 5.6 Ms | Yunnan, China | 5 |
| 29 November | 2.05 S | 124.93 E | 7.7 Ms | Ceram Sea, Indonesia | 41 |
| 11 December | 36.52 N | 71.02 E | 5.1 Mb | Afghanistan/Tajikistan | 5 |

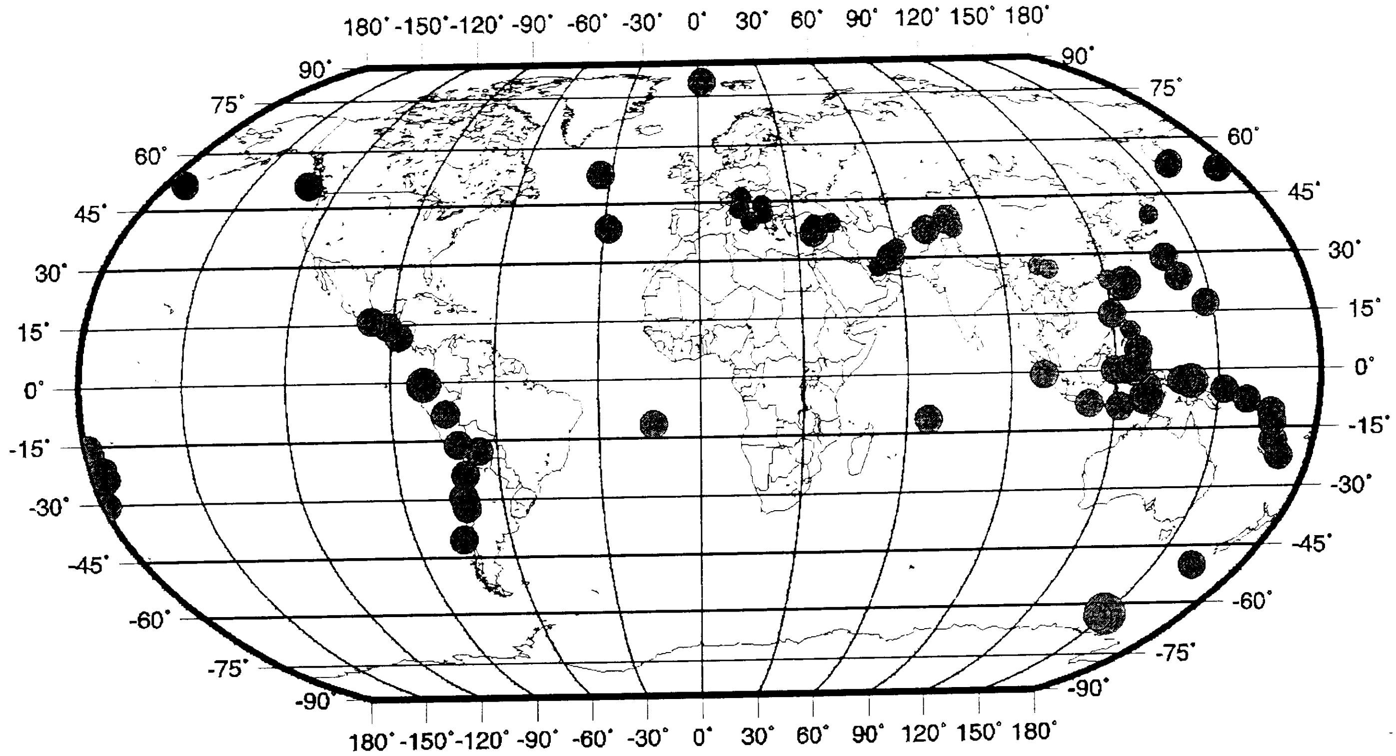


**Figure 1 Notable world earthquakes of 1998**

***Magnitude Key***

| | |
|---|---|
| ● | **8.0 and above** |
| ● | **7.0 to 7.9** |
| ● | **6.0 to 6.9** |
| • | **4.0 to 5.9** |

event induced an avalanche which destroyed 35 homes and left 300 people homeless.

The one 'great' earthquake of the year, with a magnitude of 8.0 Ms, occurred on 25 March in the Balleny Islands region in the Southern Ocean, Antarctica. No damage or casualties were reported due to the earthquake occurring in a remote, sparsely populated area.

The year started off with a destructive earthquake in the Shangyi and Zhangbei area of NE China on 10 January. It had a magnitude of 5.8 Mb and killed 70 people, injured 11,500 more and damaged over 70,000 homes leaving 44,000 families homeless. Damage to parts of the Great Wall of China in NW Hebei Province was also reported. The same day, a magnitude 6.2 Ms earthquake occurred in Guatemala and injured 24 people in Guatemala City and in the Quezaltenango and San Marcos Departments.

In Austria, on 12 April, one person was killed (as a result of a heart attack) at Bovec, Slovenia during a magnitude 5.7 Ms earthquake in the region. Over 700 people were left homeless in the Bovec-Kobarid area, Slovenia, after damage to buildings and landslides occurred. Minor damage also occurred at Arnoldstein, Austria. The earthquake was felt strongly throughout Austria, Slovenia and NE Italy as well as in parts of Croatia, Germany and Hungary.

On 14 March, an earthquake with a magnitude of 6.9 Ms, killed 5 people and caused injury to 50 others in Golbaf, northern Iran. Over 2,000 houses were destroyed, 10,000 people were left homeless and 1,200 livestock were killed. Water, electricity and communications were also severely damaged or disrupted in the area.

In Perugia, Central Italy, on 26 March, one person died of a heart attack during a magnitude 5.4 Mb earthquake in the area. Additional minor damage to buildings, already weakened by the earthquakes of 26 September 1997, and their aftershocks, was reported. A week later, on 3 April, a magnitude 5.1 Mb earthquake occurred in the same region and caused injury to five people and damaged or destroyed over 300 homes.

In northern Iran, an earthquake, with a magnitude of 5.7 Ms, killed 12 people, caused injury to 20 more and severely damaged 600 homes in the area between Birjand and Gonabad on 10 April.

On 22 May, in the Aiquile-Totora area of central Bolivia, an earthquake with a magnitude of 6.6 Ms caused extensive damage to approximately 80% of the buildings at Aiquile and 70% at Totora. At least 105 people were killed and over 150 were injured. This was, in fact, a complex earthquake set with at least two larger events occurring about 8 and 12 seconds after the first.

In the Adana and Ceyhan area of Turkey, on 27 June, an earthquake with a magnitude of 6.2 Ms killed at least 145 people and injured 1,500 more. Over 17,000 homes were destroyed and 6 major buildings collapsed in the Adana Province. This earthquake was also felt in Cyprus, Israel and Syria. A week later, on 4 July, over 500 people were injured in the same area during a magnitude 5.0 Mb earthquake. Another two damaging earthquakes occurred in Turkey during the year. The first, on 13 April, with a relatively small magnitude of 4.8 Ms, injured 11 people and damaged or destroyed several buildings at Karliova. The second, on 14 December, with a magnitude of 4.5 Mb, injured 2 people, collapsed 20 houses and damaged 118 more at Kayseri.

On 9 July, 10 people were killed, more than 100 were injured and over 1,000 were left homeless on Faial as a result of a magnitude 6.0 Ms earthquake in the Azores Islands. Some minor damage also occurred on Pico and Terceira.

On 17 July, an earthquake with a magnitude of 5.5 Mb, occurred in Taiwan. It killed 5 people, injured 27 more, caused damage to several buildings and induced landslides in Chia-i County.

A damaging earthquake, near the coast of Papua New Guinea, on 17 July, with a magnitude of 7.1 Ms, resulted in the deaths of at least 2,183 people. Thousands more were injured, approximately 10,000 were made homeless and hundreds are still missing as a result of a tsunami (one of the most devastating this century) generated in the Sissano area. Maximum wave heights were estimated at 10 metres. Several villages were completely destroyed and others were extensively damaged. Further afield, in Japan, wave heights of up to 15 cm were observed, and in New Zealand, up to 6 cm.

On 29 July, near the coast of central Chile, an earthquake with a magnitude of 6.3 Mb, killed 2 people and injured many more. Four miners were also injured when trapped underground at the Boton de Oro gold mine.

In Ecuador, on 4 August, 3 people were killed and forty injured in the Bahia de Caraquez-Canoa area. Approximately 60% of the buildings at Canoa were severely damaged. Electricity, telephone and water services were widely disrupted and the majority of buildings, with three or more stories, were damaged at Bahia de Caraquez. Considerable damage was reported from many other parts of western Manabi Province and landslides blocked the roads between Bahia de Caraquez and Canoa.

Several fatal and damaging earthquakes occurred in Southern Xinjiang, China during 1998. The largest, on 27 August, with a magnitude of 6.4 Ms, killed 3 people, injured 7 others and destroyed or damaged over 21,000 houses in Jiashi County. The others occurred on 19 March, 28 May, 28 July and 2 August, with magnitudes of 5.6 Ms, 5.6 Ms, 5.3 Mb and 5.6 Mb, respectively. A further 30 people were injured, thousands of buildings were destroyed leaving thousands homeless and over 5,000 livestock were killed as a result of these earthquakes.

In southern Italy, approximately 430 km SE of the damaging earthquakes of 26 September 1997, an earthquake, with a magnitude of 5.2 Mb, killed 2 people, injured 12 more and damaged several buildings in the Castelluccio-Lauria area on 9 September.

In Indonesia, on 28 September, one person was killed, many more were injured and over 200 were made homeless as 38 buildings collapsed and 62 were damaged in the Malang area, Jawa during a magnitude 6.3 Mb earthquake.

In the NW Balkan region, one person died from a heart attack, 17 people were injured and some damage occurred in the Valjevo-Belgrade area, Yugoslavia as a result of a magnitude 5.3 Ms earthquake on 29 September.

On 18 October, near the coast of Nicaragua, an earthquake with a magnitude of 4.4 Ms, injured 3 people, destroyed 2 houses and severely damaged 45 others in the Ticuantepe area. This was the largest in a swarm of over 200 events which occurred in the area on 18 and 19 October.

In southern Iran, on 13 November, an earthquake, with a magnitude of 5.3 Mb, killed 5 people, injured 105 more, damaged about 850 houses and caused several landslides in the Bigherd-Khonj area.

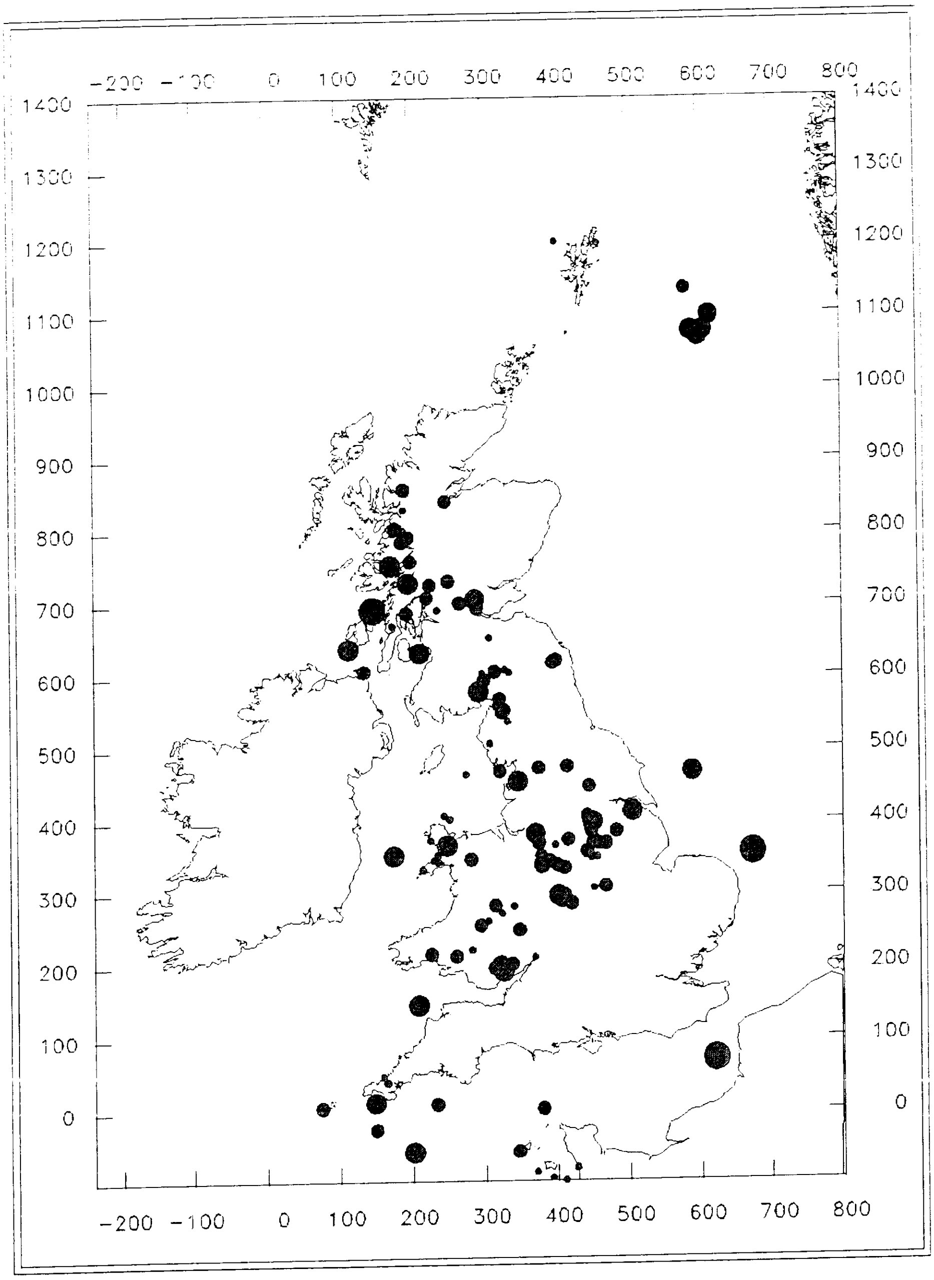
On 19 November, 5 people were killed and at least 1,543 others were injured in the Huaping, Ninglang and Yongsheng Counties of Yunnan, China. Extensive damage to roads and houses occurred in the epicentral area and landslides blocked a river in the region. Prior to this event, on 26 October, an earthquake with a magnitude of 5.6 Ms, injured 28 people and damaged over 700 buildings in the Lijiang area of Yunnan, China.

On 29 November, an earthquake with a magnitude of 7.7 Ms, occurred in the Ceram Sea, Indonesia, killing 34 people and injuring 153 others on Mangole and Taliabu, and killing another 7 and injuring 8 more on Manado, Sulawesi. A timber factory sustained extensive damage, dozens of houses were destroyed and landslides and rockslides were also reported on Mangole. The earthquake was felt throughout many islands of Indonesia.

## UK Earthquakes

The British Geological Survey detected and located some 201 earthquakes in the British Isles and surrounding continental shelf areas during 1998 (Figure 2). Of these, 31 had magnitudes of 2.0 ML and greater; 8 in this category were felt together with a further 22 smaller ones, bringing the total to 30 felt earthquakes during the year. Twenty-one of the earthquakes, with magnitudes of 2.0 ML or greater, occurred onshore or near shore. The remaining 10 were located in the North Sea and Norwegian Sea areas. No earthquakes were reported felt in the North Sea or Norwegian Sea areas during the year.

The largest offshore earthquake occurred in the southern North Sea on 16 May. It had a magnitude of 3.8 ML and was located approximately 60 km NE of Great



KEY

MAGNITUDE (ML)

- ● ≥ 5.0
- ● 4.0 – 4.9
- ● 3.0 – 3.9
- ● 2.0 – 2.9
- • 1.0 – 1.9
- · < 1.0

**Figure 2 Epicentres of all UK earthquakes located in 1998 (from the BGS Bulletin of British Earthquakes for 1998)**

Yarmouth. The Coastguard, Police, local gas and oil rig operators were contacted but no felt reports were received. A further six events occurred in the North Sea area during the year, with magnitudes ranging between 1.8 and 2.8 ML, and were located using both the BGS and Norwegian networks.

During 1998, there were two earthquakes, onshore, in the magnitude 3.0 to 3.9 ML range, which is comparable to the long-term average of 2 or 3 per annum. The total number of events with magnitudes 2.0 ML or greater was below the average; 21 against 26 per annum.

The largest onshore earthquake occurred on 3 May, with a magnitude of 3.5 ML; and was located near Jura. A macroseismic survey was carried out and 240 responses were received. The earthquake was felt over an area of 12,000 km$^2$. The highest intensities were reached on the Islands of Colonsay and Jura, where an intensity of 4 EMS was assigned from reports describing "the whole house shaking", "loud bangs and rumbles", and "objects rattling and falling down". The earthquake was felt throughout most of Argyll and Bute, as far north as the Glencoe area, towards the Isle of Arran in the east and Southend, Kintyre in the south. This is the first event that has been felt in the area, since the magnitude 3.0 ML Colonsay earthquake, on 26 January 1990, which was felt with intensities of at least 4 EMS in the epicentral area.

Near Onich, Highland, an earthquake, with a magnitude of 1.5 ML, occurred on 8 January. It was felt in the village of Onich, where local residents described "a large rumble like thunder", "the house trembled" and "we thought it was a landslide" indicating an intensity of at least 3 EMS.

On 27 January, an earthquake, with a magnitude of 3.1 ML, occurred in the Strait of Dover. The Dover Coastguard and LDG in France were contacted, but both confirmed that no felt reports were received.

On 8 February, an earthquake, with a magnitude of 2.4 ML, occurred 15 km south of Penzance, Cornwall. Felt reports were received from Penzance, Land's End and St. Ives, which described "sounded like a train under the house" and "light fittings rattled", indicating an intensity of at least 4 EMS.

On 11 February, an earthquake with a magnitude of 2.3 ML, occurred in the Cwmbran area of Gwent. It was felt throughout Cwmbran and Newport with intensities of at least 3 EMS. Felt reports described "windows and doors rattling" and "felt like the wall was moving". In 1974, the same area was affected by two felt events, the largest with magnitude 4.1 ML, which caused damage to chimneys and roofs.

On 5 March, two earthquakes, with magnitudes of 1.9 and 1.7 ML, occurred in the Killin area of the Central region of Scotland. Felt reports were received from Killin, Balquhidder and Glen Lochay which described "loud rumble like an airplane flying past" and "loud rumbling sound", indicating intensities of at least 3 EMS.

Near Oban, Strathclyde, an earthquake, with a magnitude of 2.7 ML, occurred on 7 March. It was felt throughout the Oban area, where many people described "we were woken up from sleep" and "we heard a loud bang", indicating intensities of at least 4 EMS in the epicentral area.

On 3 April, an earthquake, with a magnitude of 1.1 ML, occurred in the Annan area of the Dumfries and Galloway region of Scotland. It was recorded on the strong motion instrument, some 3 km away, where accelerations of 3.7, 8.2 and 8.4 $mm/s^2$ for the vertical, NS and EW components, respectively, were measured.

On 31 May, two earthquakes, with magnitudes of 2.6 and 1.7 ML, occurred 8 minutes apart, in the Bristol Channel; no felt reports were received. These are the largest events in the area since the magnitude 2.8 ML Bristol Channel earthquake, on 1 January 1994, which was felt with intensities of at least 4 EMS in the epicentral area.

On 23 June, an earthquake, with a magnitude of 3.5 ML, occurred in the north Atlantic near Hatton Bank, some 540 km west of the Outer Hebrides. It was located using stations from northern Scotland and Iceland and represents the first seismicity to be detected in the area.

Two felt earthquakes with magnitudes of 2.0 and 1.4 ML, occurred in the Locharbriggs area of Dumfries and Galloway, with intensities of at least 3 EMS on 21 and 23 July, respectively. Felt reports described "a rumble lasted 5-10 seconds and neighbours rushed into the streets" and "the whole house shook". A fault plane solution of the largest event showed dominant strike slip motion on planes striking north-south or east-west.

Near Beauly, Highland, two earthquakes, with magnitudes of 0.9 and 1.1 ML, occurred on 28 September. They locate in an area which historically has been active (two earthquakes with magnitudes of 5.1 ML on 13 August, 1816 and 18 September, 1901) but which has remained quiet since then.

On 16 October, an earthquake, with a magnitude of 2.7 ML, occurred in the Menai Straits, Gwynedd. A macroseismic survey was carried out and questionnaires were placed in a local weekly newspaper, resulting in 41 replies which indicated a maximum intensity of 4 EMS. The earthquake was felt in Port Dinorwic, Caernarvon, Bangor and Llangefni where residents described "heard a loud rumble", "the ground shook" and "the house shook".

Near Doune, Central Scotland, one earthquake was detected during 1998 with a magnitude of 1.2 ML. It was not felt but located in the same area as the swarm of events which occurred in 1997, with magnitudes ranging between 0.9 and 2.7 ML, of which six were felt by local residents.

A swarm of ten earthquakes, two felt by local residents, were detected in the Blackford area of Tayside during 1998, with magnitudes ranging between 0.4 and 2.2 ML. The largest, occurred on 26 March and was felt in Blackford, Alva, Gleneagles and Glendevon. The felt reports described "the whole house and furniture shook" and "felt like an underground explosion", indicating intensities of at least 3 EMS. This is an area that has continued to be active; 49 events in 1997, of which five were felt by local residents. In 1979, the magnitude 3.2 ML Ochil Hills earthquake was felt with a maximum intensity of 5 EMS.

In North Wales, seven events, with magnitudes ranging from 0.1 to 0.8 ML, were located on the Lleyn Peninsula, in the same area and at similar depths as the magnitude 5.4 ML Lleyn earthquake of 19 July 1984, which was felt throughout England and Wales and into Scotland and Ireland.

The coalfield areas of central Scotland, Yorkshire, Staffordshire, West Midlands and Nottinghamshire continued to experience earthquake activity of a shallow nature which is believed to be mining induced. Some 54 coalfield events, with magnitudes ranging between 0.6 and 2.0 ML, were detected in the year. Sixteen of these were reported felt by local residents. Near Newcastle-under-Lyme, Staffordshire, 24 shallow events occurred with magnitudes ranging between 0.9 and 1.6 ML. Seven of these events were felt by local residents in the Keele, Whitmore and Newcastle-under-Lyme areas of Staffordshire. Seven events, with magnitudes ranging between 0.8 and 1.8 ML, were located near Clackmannan in the central region of Scotland. Four of these were felt by local residents in Clackmannan, Coalsnaughton, Dollar and Shannockhill. This is an area which has experienced many such mining induced events in the past.

Other notable UK earthquakes in 1998, include the magnitude 2.2 ML Lochaline, Highland event (6 July), the magnitude 2.4 ML Islay, Strathclyde event (20 July), the magnitude 2.3 ML Altrincham, Greater Manchester event (31 July), the magnitude 2.3 ML Galgate, Lancashire event (8 August) and the magnitude 2.8 ML Grimsby, Humberside event (7 October); none were reported felt.

***D Galloway** and **A Walker** are both members of the Global Seismology and Geomagnetism Group of the British Geological Survey.*

The "**Bulletin of British Earthquakes 1998**" edited by A B Walker will be published in March 1999. Copies of this and previous years' bulletins can be obtained from the Global Seismology and Geomagnetism Group secretaries and from BGS bookshops. For further details contact: A B Walker, Global Seismology and Geomagnetism Group, British Geological Survey, Murchison House, West Mains Road, EDINBURGH EH9 3LA, Scotland, UK.

# EARTHQUAKE PREDICTION COMPETITION

## Taking place at the SECED AGM on the 28th April

At the SECED AGM on 28th April, the earthquake competition will take place once again asking:

**Where will the next earthquake with a magnitude of at least 2.5 be located by BGS onshore UK?**

The answer will be available and the winner will be notified as soon as the earthquake occurs.

# DYNAMICS: AN INTRODUCTION FOR CIVIL AND STRUCTURAL ENGINEERS

The launch of this Design and Practice Guide will take place at the Institution of Civil Engineers in London at 5.30 pm on 14 April 1999.

Dynamics is a far more important subject to civil and structural engineers than it used to be, because structures have become lighter, members more slender and for buildings especially, cladding has changed from thin brick wall to thick curtain walling in much of modern architecture. This change has increased amplitudes of vibration and moved frequencies of structures into bands which are both more awkward to deal with as well as being more easily perceived by users.

A new ICE design and practice guide on structural dynamics has therefore been prepared by the Wind Engineering Society (WES) and SECED. It covers wind, earthquake, blast, impact, ground transmitted vibrations, waves and human induced vibrations.

The guide is intended to provide an introduction to practising civil and structural engineers seeking to find out more about the subject of dynamics. It is aimed primarily at those approaching chartered status, whatever their age, and will educate practising engineers in the main principles and important aspects of the subject. It provides, through the references, guidance on authoritative, relevant and up-to-date published documents which practising engineers should refer to for more detailed and reliable guidance.

It is important to stress that dynamics is a complex and evolving field. The is guide is intended as an introductory reference document and should not be expected to provide detailed information, or solutions to, all dynamics problems. If in doubt, it is advised that the reader seek the assistance of a recognised dynamics specialist. These points are emphasised at appropriate locations in the text.

The guide will be published by Thomas Telford (publication date April 1999) and will be launched at a meeting at the Institution of Civil Engineers at 5.30pm on Wednesday 14th April 1999. At the meeting the editors of the guide, Professor Tom Wyatt and Dr John Maguire, together with the other contributors to the guide from SECED and WES, will "walk through" the guide and highlight particular points of interest to civil and structural engineers. The Agenda for the meeting will be as follows:

1. Introduction, Basic Dynamics Theory and Design for Dynamic Loading
2. Wind loading and Earthquake loading
3. Vibrations induced by people, blast loading, machinery, ground transmitted vibration, impact effects, wave and current loading
4. Illustrative examples
5. References, Codes and Standards
6. Questions

The formal close of the meeting will be at 7pm but informal questions will be welcomed thereafter.

Further details of this meeting can be found on the Internet at http://www.ice.org.uk

A one day course also based on the guide is being held at the Institution of Structural Engineers on Thursday 27th May 1999. It will finish at 5.00pm, in good time for those wishing to attend the Mallet Milne lecture on the same evening. The cost of the course is £145 + VAT (total £167.75), which includes refreshments, lunch and a copy of the guide. Further details can be obtained from the Conference Office, Institution of Structural Engineers, 11 Upper Belgrave Street, London SW1X 8BH, tel 0181 201 9108, fax 0171 235 4294.

# ARE ATTENUATION SIGMA VALUES TOO HIGH?

One of the core components of a probabilistic seismic hazard analysis is the modelling of the attenuation of seismic ground motion from a seismic source to a site of engineering interest. The standard practice is to invoke a statistical relation derived from regression analysis of a set of strong-motion records. The uncertainty in estimating the ground motion at a specific distance from an event of a specific magnitude is gauged by the standard deviation (sigma value) calculated from this regression. Typical regression sigma values are around 0.5 to 0.6 for peak ground acceleration. Assuming a lognormal distribution for the scatter, this implies that, at two standard deviations above the median, the modelled acceleration is as much as three times higher than the median value.

Ideally, from an engineering seismologist's perspective, an attenuation model should be site-specific, and be founded on actual observations of ground motion at the site resulting from earthquakes occurring on regional seismic sources. In the absence of sufficient direct data of this kind, synthetic stochastic models of the fault rupture and wave propagation processes have sometimes been developed, with artificial sigma values grafted on to the attenuation relations. Inevitably, the size of the artificial sigma value is queried: why should it be as high as 0.5, when modelling studies might perhaps suggest a much lower figure, e.g. 0.2?

A recent challenge to orthodoxy has been made by Anderson and Brune (Seism. Res. Lett., 1999), who suggest that attenuation sigma values may be exaggerated. The basis for this challenge is essentially conceptual: why should the spatial variability in ground motion, as represented by empirical attenuation relations, be a good guide to the temporal variability in ground motion at a specific site? Borrowing the terminology of statistical mechanics, Anderson and Brune refer to this as the ergodic hypothesis.

There is no clear-cut seismological evidence to decide this issue, but Anderson and Brune have been musing over a number of precariously balanced stones in the Mojave desert. Some of these stones may well have survived a hundred great earthquakes on the San Andeas Fault, without as yet toppling over - rather unlikely, perhaps, if the attenuation sigma value were higher than about 0.3. The survival of these stones might indicate that seismic ground motion has some characteristic elements, rather in the way that faults can give rise to earthquakes of a characteristic size.

Has a philosopher's stone been discovered, which would reduce conservatism in seismic hazard analysis? How much of the uncertainty in ground motion estimation is attributable to random (aleatory) factors, and how much is epistemic, i.e. due to lack of knowledge? At least the seismic source differences between events of a given magnitude should be designated as aleatory, but what about path and site differences? We really need much more single-site strong-motion data recorded from repeat earthquakes to answer these important seismological questions. In the meantime, a reduction may be warranted in the upper range of sigma values elicited for probabilistic seismic hazard analysis.

**Dr Gordon Woo**
EQE International

# RECONCILIATION OF R AND Q VALUES

Possibly more than in other branches of structural engineering, earthquake engineers have had to come to terms with inconsistencies so large as to undermine both ones confidence in those who devised the methods and ones confidence in ones interpretation. The situation was so bad in the early 1970's that, using the static equivalent force method of the Uniform Building Code, one obtained lateral forces which were a tiny fraction of those obtained using the New Zealand code, which was the more theoretical approach.

Only some years later was one able to reconcile the discrepancies on realising that the UBC grossly overestimated the effects of inelasticity, whereas they were totally disregarded in the New Zealand code. It was then concluded that the approach originally adopted, of using the New Zealand method but with what was later released to be a considerable underestimation of the ground acceleration, gave a sensible result.

Successive editions of the UBC have used calibration with existing editions as the main yardstick in determining the R or $R_w$ values. This was especially true when the UBC first introduced the $R_w$ value in the 1987 version of the code, and there has been no revision of the basic values since. In the 1997 version of the UBC the R values are the earlier $R_w$ values divided by 1.4, reflecting the omission of the 1.4 factor in the seismic load combination. As a result the allowance for inelastically is still much as it was in the 1980's, with the main difference being the measures in the more recent editions to ensure better ductility, though with an increase on many soils of the excitation.

With the millennium approaching and with end of the UBC it would be a suitable time to try and reconcile the large difference between the R values of the UBC and the q values of Eurocode 8, which are much lower. Possible reasons for the high R values in the UBC code are:

1. In the UBC method the spectral design is anchored to the static equivalent force procedures. As a result
    - for the longer period structures (above T2 in the EC8 spectrum) the use of nominal stiffnesses using simplified expressions to determine the period of the structure was the method used in the design of most of the older buildings and is therefore effectively the 'basic' method (that is Method A in the 1997 UBC). This method is normally used with the static force procedure as those capable of using Method B are also capable of using Dynamic Analysis. The use of the Dynamic Method anchored to Method B is rare because of the excessive

engineering input with this approach.

- The use in pre-1997 editions of the UBC of a greater maximum spectral response for the static force procedure.

  It is noted that in the NEHRP version of the UBC method the anchorage of the dynamic to the static method has been removed, and, as a result, so too has the inherent conservatism for the longer period (and generally more important structures) been lost.

2. In the UBC it is reasonable to suppose that for sway frames the R and $R_w$ values are associated with the ductility of beams, as the design method discourages ductility in columns. Eurocode 8 however uses the ductilities of the columns, despite also discouraging ductility in them.

3. It is possible that the R and $R_w$ values of the UBC represent displacement ductility factors, though we cannot find the derivation of the values used and would be interested in any information readers have access to. The values in the UBC would therefore strictly only be applicable in the long period range. In contrast in Eurocode 8 it is clear from the published background documents that the q values have been derived from the displacement ductility factors appropriate for periods within the range of the site period.

4. For the UBC, overstrength is claimed to be present in most structures, which means that the plastic load factor, resulting from the non-uniform distribution of load effect/resistance characteristics, is taken into account. Indeed this is now included within the definition of R, which in the 1997 UBC is defined as the "numerical coefficient representative of the inherent overstrength and global ductility of lateral-force resisting systems." As a result, in structures which are economically designed such that widespread inelasticity occurs simultaneously, the method is unsafe.

5. The UBC method has been tested against numerous earthquakes, but these have all been of the typical medium intensity Californian type earthquake, with a single strong pulse of the ground shaking and relatively few pulses within 20% of this intensity. In such earthquakes the effects of non-structural features, and the initial undamaged state, generally protects the structure from the full effects of the large pulse. The absence of large subsequent pulses means that the structure is not fully tested in its degraded state. The UBC values can therefore be regarded as justified only for such conditions.

There is a problem for the static and spectral methods in that, in using spectral methods, the benefits of inelasticity in reducing the force varies significantly between structures of the same construction and of the same period and the problem is most acute for long period structures. This is because a long period structure may derive its long period from being:

- a number of stiff sub-frames in series (as in a multi-storey building) or
- a single very flexible member.

Strictly the R, $R_w$ and q values for these structures should be different, but this is not taken into account in either the UBC or Eurocode 8.

In summary, R and q values need to be studied in greater depth and in order to reconcile them it may be necessary to replace both by simple calculated expressions taking into account:

- the plastic load factor (already in EC8, but only for steel sheds, and with a much smaller correction factor than justification for the R values would require)
- the variation in inelastic effects with the ratio between the period of vibration and the site period
- variation in the value to take account of the individual member flexibility
- variation to take account of the nature of the earthquake, in particular, the number of peaks in the ground motion close to the maximum peak.

**DGE Smith**

# ECONOMIC ANALYSIS PROCEDURES FOR EARTHQUAKE HAZARD MITIGATION

**DGE Smith** of Scott Wilson Kirkpatrick reviews Technical Report TR-2055-5HR written by JM Ferritto and published by the Naval Facilities Engineering Services Centre, Port Hueneme, California, February 1997

The US Navy seismic economic analysis procedure for structures, recently released on the Internet, provides a means for selecting the most cost-effective structural solution for structures required to remain functional after earthquakes. It is suitable for both design and retrofitting. It has already been used to retrofit hospitals and is shortly to be used in the retrofitting of United States federal buildings.

From site specific information the probabilities of the structure experiencing earthquakes in ten bands of horizontal ground acceleration up to 1.0g are assessed. For the mean acceleration in each band three non-linear time history analyses are undertaken and the distribution of maximum storey drifts and floor accelerations determined.

The preferred software is DRAIN2DX/DRAIN3DX with the damping increasing with the level of the ground acceleration.

The damage ratio to the structure is assessed for the type of construction and the storey sway.

The advantage of the procedure over alternatives is that in the assessment of the non structural damage it takes into account both floor acceleration and storey drift in assessing the damage to glazing, partitions, ceilings, mechanical equipment, electrical equipment and the contents. For each of these it gives, in graphical form, the damage in terms of the proportion needing to be replaced (the "damage ratio") for the likely range of interstorey drifts and floor accelerations, and the greater damage for these two situations is adopted.

Knowing
- i) the original costs of the building and its contents,
- ii) the increase in the unit costs for repair above those in initial construction,
- iii) the damage ratios for each band of ground acceleration,
- iv) the probability of occurrence of each band of ground acceleration within the design life,

the cost of the damage in each acceleration band is multiplied by the probability of occurrence within the design life. The products for all the bands are then summed.

A final adjustment is made for the present cost of future damage, which assumes the risk is uniformly spread over the design life, taken for federal buildings as 50 years. This results in the present value of the losses due to the earthquake being only 28% of the actual cost. Our view on this is that such a reduction may be appropriate when considering federal property, as it effectively assumes funds are set aside for repair. However, the application of such values to other properties is more complicated, as considerations which are difficult to quantify apply.

The economic position is so confused where insurance is concerned that the procedures defined are strictly only relevant to corporate organisations well distributed geographically and which do not usually carry insurance. The principles are relevant to other organisations however when account is taken of the effect of major disasters on their survivability.

Further the calculations are dependent on:
- the accuracy of the structural representation in the analysis and the accuracy with which structural damping and degradation is taken into account.
- the accuracy of the information on the damage ratios assumed for the various structural and non-structural components, and
- the strict applicability of the numerical evaluation of both the above outside the United States.

The methods presented for assessing the damage to the equipment are an interesting alternative to procedures using secondary spectra and power spectra, which may be considered more appropriate when the performance of particular equipment is essential. The methods used are more appropriate to buildings in which the equipment is ancillary to the main function of the building. It is unlikely that without modification they could be used for buildings designed principally to house mechanical or electrical equipment.

# DESIGN CRITERIA FOR EARTHQUAKE HAZARD MITIGATION OF NAVY PIERS AND WHARVES

**DGE Smith** of Scott Wilson Kirkpatrick reviews Technical Report TR-2069-5HR written by JM Ferritto and published by the Naval Facilities Enquiry Services Centre, Port Hueneme, California, February 1997

Both wharves and piers are decks supported by piles and the difference structurally is that wharves generally have beneath them a sloping dike, such that the piles on the landward side, which being the shortest are usually designed to carry the lateral loading. Piles supporting piers are longer, typically 50ft (15m) in the United States, and typically they are of prestressed concrete. This report refers particularly to this form of construction.

The representation of the behaviour of such structures in earthquakes requires the appropriate representation of soil-structure interaction, a non-linear behaviour of the soil, and of the structural ductility.

The new methodology would appear to be more onerous than that it replaces and the return period of the design earthquake has been reduced from 950 to 474 years to minimise the effect on design. The approach is to assume limited deformation capacities and settlements as opposed to the safety margin approach adopted previously.

Since piers and wharves support few personnel the design is not safety critical and is influenced mainly by economic considerations, but as they are deemed to be "essential" structures significant down-time is unacceptable.

The design criteria are as follows:
- to design elastically for the earthquake expected to occur in the design life in order to avoid structural damage (in this review called the 'SLS' condition).
- to design against collapse against the earthquake with a 10% chance of occurrence in the

design life (here called the 'ULS' condition).
- to design against release of hazardous and polluting materials under the earthquake with a 10% chance of occurrence in twice the design life, though this may be provided by a containment system.

In the above the design life for wharves and piers is taken as 50 years.

The structural performance factors (called 'ductility factors') for design against collapse are set to attract inelastic effects to the underside of the pile cap where it is practical to design for appreciable rotation and away from the more inaccessible parts lower down (which are designed more conservatively). At the top ductility factors are similar to those assumed by AASHTO in the design of piers, but lower down they are restricted to 1.5 for piers and 2.0 for wharves, the difference reflecting the better inelastic performance of shorter piles and typically about half of the values allowed at the top.

Dikes, sheet piles, bulkheads and retaining structures must be designed for complete liquefaction in the backfill and for the consequential settlement and lateral spread.

Maximum movements due to liquefaction at ULS are specified as 100mm vertically and 300mm horizontally, but at SLS liquefaction is discouraged. Additionally, at SLS the movement of the dikes in wharves is restricted to (a generous) 100mm.

Because they are essential facilities site specific seismicity studies are required, and because the soils generally have the worst possible characteristics, simple but reliable methods are required to assess local site amplification.

3-dimensional non-linear time-history analysis is recommended, including orthogonal effects based on AASHTO, but the use of the vertical component is optional. The piers are to be repairable at ULS.

The bulk of the report lies in the supporting information provided, much of it based on Japanese experience. Points to note are:

- liquefaction effects predominate over normal seismic excitation.
- piles should be designed to move with the soil and not prevent soil movement, so the use of battered piles is discouraged.
- more rigorous consideration is needed in the design of anchors to retaining walls as many have suffered excessive movement when the soil liquefies.
- piles are slender and during liquefaction buckling is possible, particularly where liquefaction occurs at the surface. Buckling is avoidable by ensuring the load is less than 25 - 33% of the ultimate bearing capacity of the soil.

There is an interesting discussion on the structural aspects of pile design, accounting for actual pile damage during earthquakes. For example away from the ends of piles damage is concentrated near the interface between soils of different stiffness. In past design the positions of the points of contraflexure in piles have been incorrectly assessed and the reinforcement discontinued too near the top. The anchorage length of pile reinforcement within the pile cap is often far too short. Sometimes the optimum solution is to ensure high ductilities. Capping beams have been poorly designed, with the top bars curtailed too early and with inadequate anchorage lengths. Even the anchorage of column bars has been found insufficient, and is poorest when bars are bent at 90° away from the column.

The piers should be isolated from the abutment.

All crane rails should be supported on piles and should be interconnected (by a continuous deck or beams) to prevent spreading.

Underestimation of the strains in prestressed piles results in the loss of prestress.

Loss of concrete cover begins at displacement ductility levels of about 2.0, so there is general concern for the durability of piles which have been subject to significant seismic loading.

Generally there is insufficient transverse reinforcement in piles to affect either the ductility or the shear strength. The use of spiral reinforcement improves both and is recommended, and an expression is given for calculating the amount required for prestressed concrete piles.

The problem of the poor flexural strength of prestressed concrete piles over the transmission length is mentioned. If it cannot be resolved by the designer a capacity reduction factor has to be applied.

The approximate non-linear behaviour and pile size is first determined by a simple pushover analysis. The pile is then analysed non-linearly taking into account degradation using DRAIN2DX/DRAIN3DX and the soil modelled by bi-linear spring stiffnesses.

The rest of the report appears to be a reasonably concise and quantified résumé of the performance of soils under seismic loading and how to combine this information with a proper knowledge of the structural performance of piles. Structural engineers now have fully codified their best understanding of the performance of structures subject to earthquakes. This would appear to be a good attempt to present the geotechnical aspects on the same basis, though it is noted that liquefaction is considered in a companion report. For a structural engineer prepared to represent both the structure and the foundation in his structural analysis, but who does not have "unlimited" computing power, the approach in the report would appear to indicate the way forward. However it is for others to assess whether the presentation of the geotechnical information is as sufficient as the structural aspects.

# "PASSIVE ENERGY DISSIPATION" AND "ELECTRICAL LIFELINES"

The use of passive energy dissipation systems in earthquake design and retrofit, and the socioeconomic impact of electrical lifeline disruption from earthquakes are the topics of two monographs recently released by the Multidisciplinary Center for Earthquake Engineering Research (MCEER), headquartered at the University at Buffalo.

The new publications are the first two in a series of monographs to be published by MCEER. They are intended to offer practical information to engineers, emergency planners, policymakers and others interested in technologies and strategies to reduce earthquake damage and losses.

The first of the monographs, *Passive Energy Dissipation Systems for Structural Design and Retrofit*, provides both a basic and detailed look at the development and practical application of various dampers used to reduce earthquake and other vibrations in buildings and engineered structures. Authors Michael C Constantinou, TT Soong and Gary F Dargush offer basic definitions for passive energy dissipation systems and review fundamental design principles governing their use.

The 300-page volume includes information on mathematical modelling, as well as recent developments and modern applications of these systems. Devices covered in depth include: metallic dampers, viscoelastic dampers, tuned mass dampers, friction dampers, viscous fluid dampers, and tuned liquid dampers.

A chapter devoted to semi-active mass dampers and semi-active fluid dampers details the application of these devices in Japan, and reviews current research.

The second monograph, *Engineering and Socioeconomic Impacts of Earthquakes: An Analysis of Electricity Lifeline Disruptions in the New Madrid Area*, unveils a methodology to examine the potential societal and economic upheaval caused by damage to electrical power systems. Edited by Masanobu Shinozuka, Adam Rose and Ronald T Eguchi, the 190-page publication includes contributions from a dozen recognized authorities in engineering and social science disciplines.

The volume reveals a first-of-a-kind case study of the socioeconomic impact of a repeat of the 1811 New Madrid earthquake on the electrical power system of metropolitan Memphis, Tennessee. Chapters detail the modelling of the economy, seismic performance of electrical power systems, the linking of physical damage to economic functions, emergency preparedness among businesses, direct, regional and interregional economic impacts, and effective lifeline risk reduction policy formulation.

Both monographs are available from MCEER at a cost of $25 each. Through a special promotion with John Wiley & Sons Ltd., MCEER is offering a 50 percent discount on Wiley's, *Passive Energy Dissipation Systems in Structural Engineering*, by TT Soong and GF Dargush, when purchased with the MCEER monograph on passive energy dissipation. The cost of the two-publication set is $75.

For more information or to place an order, contact the MCEER publications office at: Publications, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Red Jacket Quadrangle, Buffalo, New York 14261-0025,
Tel.: 716/645-3391, ext. 4;
Fax: 716/645-3399;
Email: mceer@acsu.buffalo.edu.
Orders may also be placed through the MCEER Web site at http://mceer.buffalo.edu.

# SEISMIC ZONATION: A FRAMEWORK FOR LINKING EARTHQUAKE RISK ASSESSMENT AND EARTHQUAKE RISK MANAGEMENT

This 160 page monograph with colour maps, exists within in the framework of the closing activities of the International Decade for Natural Disaster Reduction (IDNDR). It is designed to provide scientists, engineers, planners, emergency managers, and policy makers from earthquake-prone communities from throughout the world with the basic information they need to reduce unacceptable risk from ground shaking, ground failure, surface fault rupture, regional tectonic deformation, tsunami wave run-up and aftershocks. It contains contributions from over 30 American, French, British, and other European authors that have been integrated into six chapters dealing with policy for risk management, opportunities for worldwide collaboration, advances in understanding risk assessment, and the programmatic resources that are now available. Six appendices provide contact information for individuals and organizations throughout the world who can help. The monograph is the culmination of nine years of work sponsored by the United States Geological Survey, UNESCO, and other organizations. Dr. Walter W Hays, USGS, the Principal Editor, can be contacted by Email at whays@usgs.gov, Dr. Bagher Mohammadioun, Associate Editor, can be contacted by Email at WilloWay@wanadoo.fr
This monograph is available from OUEST EDITIONS, Presses Academique, 1, rue de La Noe, BP 52106, 44321 Nantes Cedex 3, France Tel: 02 40 14 34 34 Fax: 02 40 14 36 36 The price is 250 FF plus 20 FF for postage.

## Seismic design of reinforced concrete buildings

**Indian Institute of Technology, Kanpur, May 24 - 28, 1999**

This 5 day course is intended for practising civil and structural engineers, and has been run successfully on a number of occasions since 1992. Further details can be obtained from Professor Sudhir Jain at IIT Kanpur (skjain@iitk.ac.in).

## NOTABLE EARTHQUAKES OCTOBER - DECEMBER 1998

Reported by British Geological Survey

| YEAR | DAY | MON | TIME UTC | LAT | LON | DEP KM | MAGNITUDES ML | MB | MS | LOCATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 07 | OCT | 18:39 | 53.60N | 0.29W | 31 | 2.8 | | | GRIMSBY, HUMBERSIDE |
| 1998 | 08 | OCT | 04:51 | 15.96S | 71.47W | 136 | | 6.1 | | SOUTHERN PERU |
| 1998 | 16 | OCT | 13:04 | 53.18N | 4.23W | 12 | 2.7 | | | PORT DINORWIC, GWYNEDD |
| | | | | Felt throughout Gwynedd with intensities of at least 3 EMS. | | | | | | |
| 1998 | 28 | OCT | 16:25 | 0.80N | 125.93E | 33 | | 6.2 | | NORTHERN MOLUCCA SEA |
| 1998 | 09 | NOV | 05:30 | 7.01S | 128.98N | 33 | | 6.1 | | BANDA SEA |
| 1998 | 09 | NOV | 05:38 | 6.89S | 128.98E | 33 | | 6.4 | 7.0 | BANDA SEA |
| 1998 | 13 | NOV | 13:01 | 27.77N | 53.61E | 33 | | 5.3 | 5.1 | SOUTHERN IRAN |
| | | | | At least five people were killed, 105 people injured and approximately 850 houses were damaged throughout the epicentral region. | | | | | | |
| 1998 | 19 | NOV | 11:38 | 27.27N | 100.97E | 33 | | 5.2 | 5.6 | YUNNAN, CHINA |
| | | | | Three people were killed, at least 1500 people were injured and extensive damage occurred throughout the epicentral region. | | | | | | |
| 1998 | 29 | NOV | 14:10 | 2.05S | 124.93 | 33 | | 6.5 | 7.7 | CERAM SEA |
| | | | | At least 34 people were killed on Mangole and approximately 150 people were injured on Mangole and Taliabu. | | | | | | |
| 1998 | 01 | DEC | 07:37 | 26.44N | 104.03E | 10 | | 4.5 | | SE CHINA |
| | | | | At least 84 people were injured and approximately 21,000 houses were damaged throughout Xuanwei. | | | | | | |
| 1998 | 06 | DEC | 00:47 | 1.30N | 126.25E | 33 | | 6.3 | 6.2 | NORTHERN MOLUCCA SEA |
| 1998 | 16 | DEC | 17:45 | 1.18N | 126.16E | 33 | | 6.1 | 5.8 | NORTHERN MOLUCCA SEA |
| 1998 | 27 | DEC | 00:38 | 21.50S | 176.41W | 144 | | 6.1 | | FIJI ISLANDS REGION |

*Issued by Bennett Simpson, British Geological Survey, January 1999*

## Forthcoming Events

**31 March 1999**
Remote sensing.
*ICE 5.30pm*

**14 April 1999**
Dynamics: An introduction for civil and structural engineers
*ICE 5.30pm*

**28 April 1999**
AGM followed by "Strong motion parameters for seismic design"
*ICE 5.30pm*

**27 May 1999**
Dynamics: An introduction for civil and structural engineers
*IStructE. Full day course*

**27 May 1999**
The Road to Total Earthquake Safety.
The 7th Mallet Milne Lecture
*ICE 5.30pm.*

**22-24 September 1999**
Practical seismic design for new and existing structures
*Imperial College. Three day course*

**29 September 1999**
Remedial measures at the Basilica of St. Francis in Assisi

## Contents

Selected extracts from previous SECED Newsletters can now be found on the World Wide Web at the Institution of Civil Engineers:

http://www.ice.org.uk/public/seced.html

Comments are welcomed and should be sent to: A.J.Crewe@bristol.ac.uk

## SECED Newsletter

The SECED Newsletter is published quarterly. Contributions are welcome and manuscripts should be sent on a PC compatible disk or directly by Email. Copy typed on one side of the paper only is also acceptable.

Diagrams should be sharply defined and prepared in a form suitable for direct reproduction. Photographs should be high quality (black and white prints are preferred). Diagrams and photographs are only returned to the authors on request. Diagrams and pictures may also be sent by Email (GIF format is preferred).

Articles should be sent to:

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## SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics, is the UK national section of the International and European Associations for Earthquake Engineering and is an affiliated society of the Institution of Civil Engineers.

It is also sponsored by the Institution of Mechanical Engineers, the Institution of Structural Engineers, and the Geophysical Society. The Society is also closely associated with the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics including blast, impact and other vibration problems.

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