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Contents

A Summary of Earthquakes in 2004

David Galloway and Bennett Simpson present a summary of seismic activity in 2004

Overseas

The occurrence of two 'great earthquakes' in 2004, in the Macquarie Islands region and in Northern Sumatra, Indonesia, indicates a higher than normal annual average (usually there is only one per year). Lower down the scale, there were thirteen 'major earthquakes', with magnitudes between 7.0 and 7.9, which is slightly lower than the long-term average of seventeen per annum. Seven of them resulted in casualties and damage to buildings. There were 139 'strong earthquakes', with magnitudes between 6.0 and 6.9, which is slightly higher than the annual average of 134 per annum (Figure 1). The number of people reported killed by earthquakes during 2004 was 284,007 (Table 1), which is significantly greater than the long-term average of around 10,000 per year. The vast majority of the fatalities (over 99%) occurred as a result of the magnitude 9.3 Mw earthquake and associated tsunami in Northern Sumatra, Indonesia on December 26, 2004.

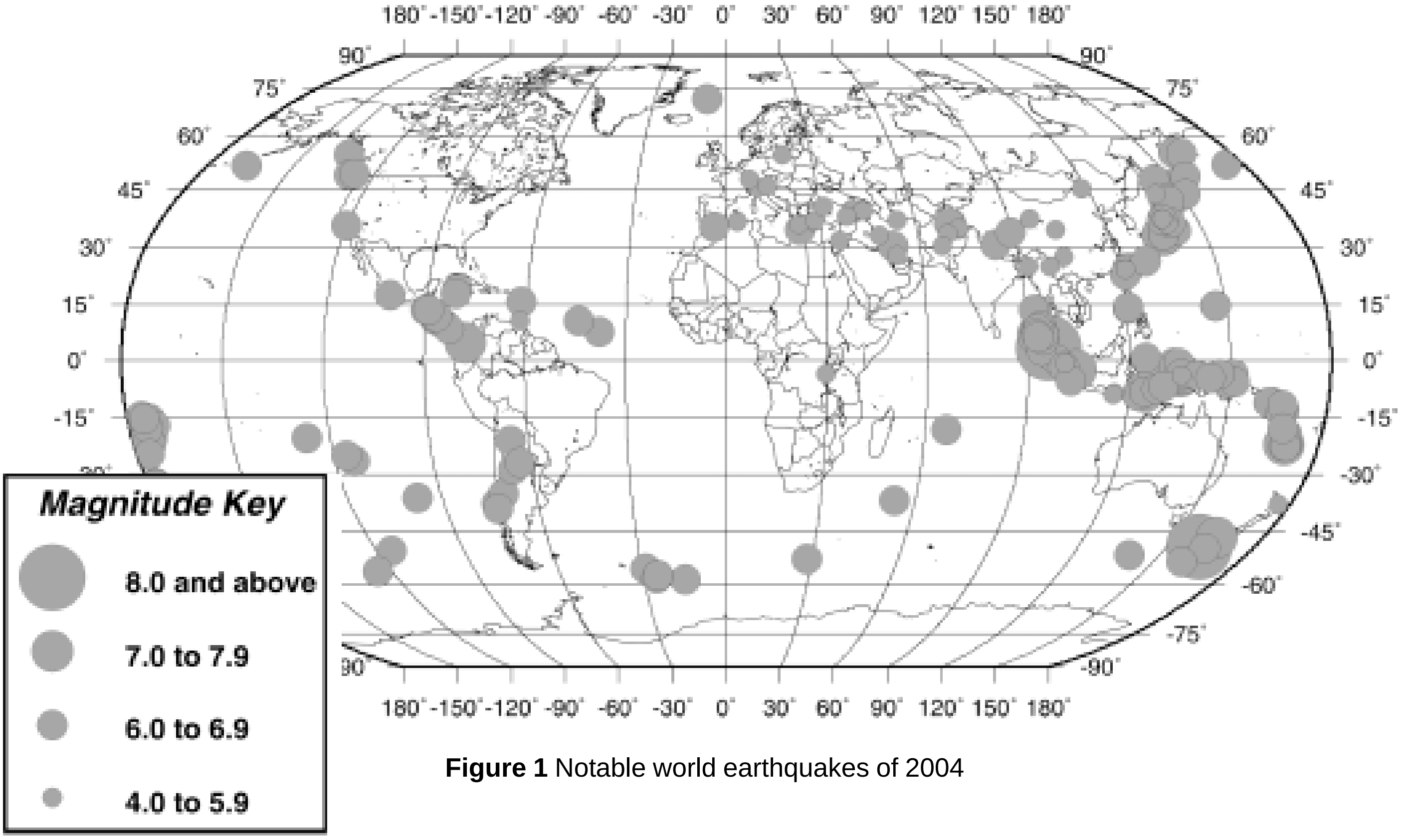


Figure 1 Notable world earthquakes of 2004

DATE	LAT	LON	MAG	LOCATION	DEATHS
1 January	8.31 S	115.79 E	5.8 Mw	Bali Region, Indonesia	1
5 February	3.62 S	135.54 E	7.0 Mw	Papua Region, Indonesia	37
14 February	34.77 N	73.22 E	5.5 Mw	Pakistan	24
16 February	0.47 S	100.66 E	5.1 Mw	Southern Sumatra, Indonesia	5
24 February	35.14 N	4.00 W	6.4 Mw	Strait of Gibraltar	628
24 February	3.39 S	29.59 E	4.7 Mb	Burundi	3
1 March	38.06 N	38.28 E	3.8 Md	Eastern Turkey	6
25 March	39.93 N	40.81 E	5.6 Mw	Eastern Turkey	10
5 April	36.51 N	71.03 E	6.6 Mw	Hindu Kush Region, Afghanistan	3
1 May	24.08 N	121.61 E	5.2 Mb	Taiwan	2
8 May	30.13 N	67.12 E	4.4 Mb	Pakistan	1
28 May	30.25 N	51.62 E	6.3 Mw	Northern Iran	35
1 July	39.77 N	43.98 E	5.4 Mb	Eastern Turkey	18
12 July	46.30 N	13.64 E	5.0 Mw	Slovenia	1
18 July	38.00 S	176.51 E	5.6 Mw	North Island, New Zealand	1
18 July	33.43 N	69.52 E	5.1 Mb	Central Afghanistan	2
30 July	39.63 N	43.97 E	4.8 Mb	Eastern Turkey	1
10 August	27.27 N	103.87 E	5.1 Mb	Sichuan/Yunnan Region, China	4
11 August	38.38 N	39.26 E	5.7 Mw	Eastern Turkey	1
7 September	28.57 S	65.84 W	6.4 Mw	Catamarca, Argentina	1
15 September	8.77 S	115.36 E	5.2 Mb	Bali Region, Indonesia	1
23 October	37.23 N	138.78 E	6.6 Mw	Coast of Honshu, Japan	40
11 November	8.15 S	124.87 E	7.5 Mw	Kepulauan Region, Indonesia	34
20 November	9.60 N	84.17 W	6.4 Mw	Costa Rica	8
21 November	15.58 N	61.71 W	6.3 Mw	Leeward Islands	1
26 November	3.61 S	135.40 E	7.1 Mw	Papua Region, Indonesia	32
1 December	3.67 S	135.53 E	5.5 Mw	Papua Region, Indonesia	1
26 December	3.30 N	95.98 E	9.3 Mw	Northern Sumatra, Indonesia	283,106
					284,007

Table 1 Earthquakes causing deaths in 2004.

Without doubt, the magnitude 9.3 Mw Northern Sumatra earthquake on 26 December at 00:58 UTC was the most disastrous during 2004, accounting for over 99% of the fatalities. This was the second largest earthquake in the world since 1900 and the largest since the magnitude 9.5 Mw Chile event on 22 May, 1960. The earthquake together with the associated tsunami caused the deaths of at least 283,106 people (with over 14,000 still reported missing) and injured thousands more in ten different countries in South Asia and East Africa. At least 108,100 people were killed and 127,700 are presumed dead in Indonesia, 30,900 were killed and 5,400 are missing in Sri Lanka, 10,700 were killed and 5,600 are missing in the Andaman and Nicobar Islands and 5,300 were killed and 3,100 are missing in Thailand. The other deaths occurred in Somalia where 150 people were killed, the Maldives where 82 people were killed, Malaysia where 68 people were killed, Myanmar where 90 people were killed, Tanzania where ten people were killed, the Seychelles where three people were killed, Bangladesh where two people were killed and Kenya where one person was killed. Landslides and approximately two metres of subsidence were observed in Sumatra, a mud volcano became active near Baratang in the Andaman Island and water level changes were seen in wells as far away as Florida, Nebraska and Virginia in the Unites States.

The earthquake occurred along a thrust zone as the Indian plate is subducted beneath the over-riding Burma plate along the line of the Sunda Trench. The Indian plate is moving approximately northeast at a rate of around 6 cm per year at an oblique angle to the Sunda Trench. Stress had accumulated along this thrust zone for hundreds of years until it finally reached a critical point and failed. The distribution of aftershocks suggests that the rupture that caused the earthquake extended from the north west coast of Sumatra to the Andaman Islands, over 1200 km away. The width of the fault rupture is estimated at about 100 km and the maximum displacement on the fault plane was about 20 metres, most of this concentrated in the southern 400 km of the rupture. The rupture took several minutes to propagate from the epicentre to the northern end of the fault. The devastating tsunami was a direct consequence of the earthquake, which caused movement of the seafloor all along the length of rupture, generating the tsunami wave. The vertical uplift of the seafloor could have been as much as several metres, displacing an enormous volume of water. In the deep water of the Indian Ocean the tsunami wave would have travelled at around 700 km/hour, taking around two hours to reach the coast of India and Sri Lanka.

On 1 January, an earthquake, with a magnitude of 5.8 Mw, occurred in the Bali region, Indonesia and killed one person, injured 29 others and damaged around 6,000 buildings on Lombok and Bali. It was felt strongly throughout the region. Later on in the year, on 15 September, another person was killed and two more were injured in Denpasar, as a result of a magnitude 5.2 Mb earthquake in the same region.

In Northern Algeria, on 10 January, a magnitude 4.5 Mb earthquake injured over 300 people and caused additional damage to many buildings, previously weakened by the magnitude 6.8 event of 21 May 2003, in the Algiers and Boumerdes areas. Two other magnitude 4.5 Mb earthquakes occurred in the same region, on 1 and 5 December, and injured a further 61 people.

On 4 February, a magnitude 6.1 Mw earthquake occurred in the border region between Panama and Costa Rica. The earthquake injured four people, caused damage to several houses and collapsed a bridge in Chiriqui, Panama. On 20 November, a magnitude 6.4 Mw earthquake, in Costa Rica, killed eight people, injured several more and damaged over 500 buildings in the San Jose area. Many bridges, roads and pipelines were also damaged and landslides and power outages were reported throughout the region.

Three fatal and damaging earthquakes occurred in the Papua region of Indonesia during 2004. The first, on 5 February, had a magnitude of 7.0 Mw and killed 37 people, injured 682 others and damaged or destroyed over 2,500 buildings. Nine bridges and the airport runway also suffered damage. The second and largest, with a magnitude of 7.1 Mw, occurred on 26 November, and killed 32 people, injured 130 others and damaged 328 buildings. The third event, on 1 December, with a magnitude of 5.5 Mw, killed one person. The casualties and damage, estimated at US$55 million, reported from these three events occurred in the Nabire area.

On 11 February, a magnitude 5.3 Mw earthquake, with an epicentre in the Dead Sea region, caused injury to four people in western Jordan. Minor damage to several buildings was reported from Jerusalem, Tel Aviv and from the Nablus area.

A magnitude 5.5 Mw earthquake occurred on 14 February in Pakistan resulting in the deaths of 24 people, of which thirteen were killed by a landslide in Batgram, and causing injury to more than 60 others. Over 1,400 buildings collapsed, another 5,000 more were damaged and several roads were cracked and blocked by landslides. The casualties and damage was mainly in the Batgram and Manshera districts in the North West Frontier Province of Pakistan. A similar sized event, magnitude 5.4 Mw, occurred in the same region, approximately 90 minutes later, causing additional damage. On 8 May, an earthquake with a relatively small magnitude of 4.4 Mb, killed one person, injured 30 others and caused minor damage to some buildings in the Quetta region of Pakistan, some 750 km southwest of the 14 February events.

In Indonesia, on 16 February, five people were killed, seven others were injured and over 100 houses were damaged in the Padangpanjang area of southern Sumatra during a magnitude 5.1 Mw earthquake in the region. A few days later, on 22 February, a magnitude 6.0 Mw earthquake occurred in the same general area (southern Sumatra) and caused injury to one person and damaged several houses in Pesisir.

On 24 February, three people were killed and 24 houses were destroyed in Ruyaga as a result of a magnitude 4.7 Mb earthquake in Burundi. It was felt strongly in Congo, Rwanda and Tanzania.

A damaging 6.4 Mw earthquake, in the Mediterranean Sea, close to the Moroccan port city of Al Hoceima, on 24 February, resulted in the deaths of at least 628 people. Over 900 others were injured and some 2,539 homes were destroyed in the epicentral region leaving approximately 15,000 people homeless. Most of the damage was to old traditional buildings, constructed from mud, stone and adobe, in the rural villages surrounding the city of Al Hoceima. The centre of the city, composed of more recent buildings, experienced less damage. A large number of aftershocks were also recorded in the region, with over 30 of them having magnitudes of between 3.5 and 5.0, and many of them caused additional damage to already weakened structures. The epicentre of the mainshock was located some 10 km south of the city of Al Hoceima in the district of Ait Kamra, Morocco. It occurred near the eastern end of the boundary between the African and Eurasian plates and in the same region as the magnitude 6.0 Mw event of 26 May 1994, which injured one person and caused significant damage in the region.

Several fatal and damaging earthquakes occurred in eastern Turkey during the year. On 1 March, an event with a relatively small magnitude of 3.8 Mb, killed six people and injured two others in Celikhan. On 25 March, ten people were killed, seven of them children, 46 were injured and 45 buildings were damaged or destroyed in Erzurum as a result of a magnitude 5.6 Mw earthquake. On 28 March, a magnitude 5.6 Mw earthquake, injured twelve people, damaged 50 buildings in ten different villages and killed scores of livestock in the Askale region. Two earthquakes in the Dogubeyazit region of eastern Turkey occurred on 1 and 30 July, with magnitudes of 5.4 and 4.8 Mb, respectively. At least nineteen people were killed, around 26 were injured and around 1,000 houses in the region suffered some degree of damage as a result of these two events. Another event, on 11 August, with a magnitude of 5.7 Mw, killed one person, injured eleven more and damaged several houses in the Elazig and Sivrice areas.

An earthquake, with a magnitude of 5.5 Mw, occurred in the Inner Mongolia Autonomous Region on 24 March. No deaths were reported but at least 100 people were injured and 38,000 buildings were damaged in the Bayan Ul Hot and Uliastai areas. Damage and economic losses from this earthquake has been estimated at around US$74 million.

In the Hindu Kush region (near the Afghanistan and Pakistan border), on 5 April, an earthquake with a magnitude of 6.6 Mw killed three people in Afghanistan and injured five people in Pakistan. The earthquake was felt over much of Afghanistan and Pakistan and was also felt in India, Kashmir, Kazakhstan, Tajikistan and Uzbekistan. This is the largest event in the region since a magnitude 6.6 Mw earthquake on 25 March 2002, when over 800 people were killed and hundreds more were injured in the Baghlan Province. Later on in the year, on August 10, at least two people were injured in Mansehra, Pakistan after a magnitude 6.0 Mw earthquake occurred in the same region.

On 13 April, an earthquake with a magnitude of 4.1 Mb, injured four people in the Bolu area of western Turkey. All four were injured as a result of them jumping from buildings. On 20 December, another earthquake, with a magnitude of 5.3 Mw, occurred in the region. Several buildings were damaged and three people were injured in the epicentral area. The injuries were caused by falling debris from damaged walls and roofs in their homes. A rockslide was also reported to have blocked the main highway in Marmaris.

In Taiwan, a landslide killed two people in Hua-lien County and a bridge collapsed in Taroko Gorge National Park during a magnitude 5.2 Mb earthquake on 1 May. Another earthquake in Taiwan, with a magnitude of 6.7 Mw, on 15 October, injured several people and damaged buildings in T'ao-yuan County. It was felt throughout Taiwan and was also felt over much of the Ryukyu Islands, Japan.

A 'strong' earthquake, with a magnitude of 6.3 Mw, occurred on 28 May in northern Iran, approximately 80 km north of the capital Tehran. It killed 35 people, injured 400 more and destroyed or damaged many homes in the Mazandaran and Qazvin Provinces resulting in damage estimates of US$165 million. Over 133 villages in the region suffered between 30% and 80% damage and minor damage was also reported in Tehran, where many people ran into the streets. At least half of the people killed were drivers, who were hit by falling rocks on the mountainous road between Chalus and Tehran. This earthquake locates approximately 220 km southeast of the magnitude 7.7 Ms event on 20 June 1990, which killed around 50,000 people and caused extensive damage in the Qazvin, Zanjan and Gilan Provinces and just over 1,000 km northwest of the magnitude 6.6 Mw event on 26 December 2003, which killed over 30,000 people and destroyed about 85% of the buildings in the Bam region of the Kerman Province.

On 12 July, a magnitude 5.0 Mb earthquake, in Slovenia, triggered a rockslide which killed one person and injured five others in the Bovec area. The epicentre was in northwest Slovenia near, within 10 km, to the epicentre of the magnitude 5.7 Mw earthquake on 12 April 1998, which killed one person, caused severe damage and left over 700 homeless in the Bovec-Kobarid area. The 12 July event was felt strongly throughout Slovenia, Austria and NE Italy as well as in parts of Croatia, Germany, Hungary and the Czech Republic.

A magnitude 5.6 Mw earthquake occurred on 18 July in North Island, New Zealand resulting in the death of one person and causing injury to two others in the Rotunga-Tauranga area. A few houses were severely damaged at Lake Roto Ma and landslides occurred on the highway between Lake Rotoiti and Lake Roto Ma.

In central Afghanistan, on 18 July, two people were killed, 40 were injured and hundreds of homes were destroyed in Paktia Province when a magnitude 5.1 Mb earthquake occurred in the region.

On August 10, a magnitude 5.1 Mb earthquake occurred in the Sichuan-Yunnan-Guizhou region of southwest China. Four people were killed (including a four year old girl), about 200 more were seriously injured and another 400 were slightly injured. Significant damage was reported in Ludlan County, Yunnan where 22 reservoirs were damaged, over 18,000 houses were destroyed and another 65,000 were damaged, leaving more than 120,000 people homeless. Another earthquake, with a magnitude of 4.8 Mb, occurred in the Yunnan region later on in the year, on 18 October, when twelve people were injured and over 20,000 houses were damaged in the Baoshan area. On 7 September, a magnitude 5.2 Mb earthquake, injured nineteen people, destroyed 600 houses and damaged another 3,800 in Gansu Province, China.

A magnitude 6.4 Mw earthquake, with an epicentre in the Catamarca Province, Argentina, occurred on 7 September. It was reported to have caused the death of one person, injured several others and damaged some buildings in Catamarca. The earthquake was felt throughout Argentina and was also felt in parts of neighbouring country, Chile.

On 21 September, in the Poland-Russia border area, an earthquake with a magnitude of 4.7 Mw, caused damage to railroad tracks near Svetlogorsk, Russia. At least three people were injured and seventeen houses were damaged in Kaliningrad, Russia and minor damage also occurred in Suwalki, Poland. This earthquake was felt throughout Belarus, Estonia, Latvia, southern Russia and northern Poland. It was also felt as far away as Copenhagen, Denmark (approx. 500 km to the northwest), Helsinki, Finland (approx. 660 km to the north) and Oslo, Norway (approx. 800 km to the northwest).

Several fatal or damaging earthquakes occurred in the coastal region of Honshu, Japan, during the year. The most significant, near the west coast of Honshu, on 23 October, with a magnitude of 6.6 Mw, killed 40 people, injured over 3,000 more, and destroyed or damaged some 6,000 buildings in the Niigata Prefecture. A high-speed bullet train was derailed (for the first time), several roads, bridges and rail lines were damaged, many fires were reported as gas, water and power lines were damaged and over 1,000 landslides occurred in the Prefecture as a result of this earthquake. On 5 September, near the south coast of Honshu, two 'major' earthquakes occurred at 10:07 UTC and 14:57 UTC, with magnitudes of 7.2 and 7.4 Mw, respectively. At least 44 people were injured and local tsunamis were reported following these two events. Wave heights of around 51 cm were generated in Wakayama Prefecture following the first event and wave heights of 86 cm and 56 cm were generated at Kushimoto and Owase, respectively after the second event. Another five events, with magnitudes between 5.1 and 6.0 Mw, occurred in the region between 6 October and 9 November, injuring another sixteen people and causing additional damage. Damage from all these earthquakes has been estimated at around three trillion Yen (US$29 billion).

Another 'major' earthquake, with a magnitude of 7.5 Mw, occurred in Indonesia during 2004. The earthquake, on 11 November, had an epicentre in Kepulauan Alor and caused the deaths of 34 people and injured 400 others. It also destroyed over 700 buildings and damaged 16,000 more on Alor, where many roads were blocked due to a number of landslides in the area.

On 21 November, a magnitude 6.3 Mw earthquake, killed one person, injured thirteen others and damaged over 60 houses at Trois-Rivieres, Capesterre-Belle-Eau, Les Saintes and Terre-de-Bas, Guadeloupe in the Leeward Islands. Another 25 houses were also damaged in northern Dominica. This earthquake was felt strongly in Antigua and Barbuda, St Kitts and Nevis and Saint Lucia.

On 24 November, an earthquake with a magnitude of 5.3 Mb, injured nine people and damaged many buildings in northern Italy. The epicentre was near the town of Sirmione at the southern end of Lake Garda. Three hospitals in the epicentral area were evacuated as a precaution. The earthquake was felt strongly throughout northern and central Italy, including in the cities of Milan, Turin, Genoa and Venice where many power outages occurred, forcing hundreds of frightened residents from their homes.

Two earthquakes struck the island of Hokkaido, Japan on 28 November and 6 December, with magnitudes of 7.0 and 6.8 Mw, respectively. The magnitude 7.0 Mw event caused injury to at least 24 people, damaged many roads, disrupted power and gas services and affected transportation in the sub-prefectures of Kushiro and Nemuro. Minor damage to docks and buildings was also reported, and a tsunami with wave heights of 10 cm was recorded at Nemuro. The magnitude 6.8 Mw event injured four people and caused additional damage in Kushiro.

UK Earthquakes

There were 131 earthquakes located by the monitoring network during the year (Figure 2), with 30 of them having magnitudes of 2.0 ML or greater and eight having magnitudes of 3.0 ML or greater. Ten events with a magnitude of 2.0 ML or greater were reported felt, together with a further ten smaller ones, bringing the total to twenty felt earthquakes in 2004.

The largest onshore earthquake had a magnitude of 3.3 ML and occurred offshore the Island of Raasay on 16 September 2004, at a depth of 5.3 km. No felt reports were received for this earthquake; this could be due to the remote location of the earthquake. A further two events were located in this area during 2004, with magnitudes of 1.7 and 0.4 ML.

The largest offshore earthquake occurred in the Northern North Sea on 13 May 2004, with a magnitude of 3.5 ML. It was located approximately 270 km northeast of Lerwick, Shetland Islands. A further nine events occurred in the North Sea and surrounding waters during the year, with magnitudes ranging between 1.1 and 3.1 ML.

An earthquake with a magnitude of 0.2 ML occurred in the Blackford area on 23 January. The BGS received one report for this event from a resident of Glendevon, who described, "felt a slight shudder" indicating an intensity of 2 EMS. This is an area that has continued to be active in recent years; 50 events occurred in 1997, of which five were felt by local residents; 10 events occurred in 1998, of which two were felt by local residents, three events occurred in 1999, four events occurred in 2000, of which three were felt, four events occurred in 2001, of which three were felt, four events occurred in 2002, of which one was felt and nine events occurred in 2003, of which four were felt. These are all in the same general area as the magnitude 3.2 ML Ochil Hills earthquake in 1979, which had a maximum intensity of 5 EMS.

Four events occurred on 29 January, in the Bridgwater area of Somerset with magnitudes between 2.7 and 3.1 ML. Reports were received from residents throughout Taunton, Wedmore, Ilminster and surrounding areas. The reports described, "the floor moved and there was a deep rumble", "the floor was shaking" and "the whole house shook", indicating intensities of 3 and 4 EMS. The events were located approximately 12 km northeast of Taunton and approximately 5 km south of Bridgwater. The four events were located within 200 metres from each other and the events occurred at a shallow depth of approximately 6.5 km.

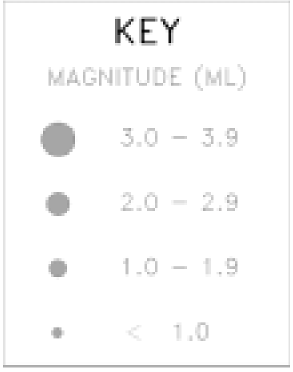
An earthquake with a magnitude of 3.1 ML occurred on 29 February, near Oldham, Greater Manchester. A number of reports were received from the Oldham area, which described, "the wardrobe shook and I heard a rumble" and "the house shook violently", indicating an intensity of 4 EMS.

A magnitude 2.1 ML earthquake occurred on 15 April, with a location near Ardtornish, Highland. One report was received for this event from Morvern, describing, "the furniture rattled and I heard a loud roar", indicating an intensity of 3 EMS.

Near Dumfries, Dumfries and Galloway, an earthquake with a magnitude of 2.3 ML, occurred on 7 August. Several reports were received from residents in the Dumfries area which described, "rumbling and a very loud banging", "felt like coming to a halt in a car", "the building shook" and "very noticeable shudder in our house", indicating an intensity of 3 EMS. A magnitude 1.5 ML earthquake also occurred in the area earlier in the year on 7 February.

Between 13 October and 30 December, a swarm of small earthquakes were detected in an area between Eskdalemuir, in the Borders, and Langholm, in Dumfries and Galloway. The BGS detected these events on nearby seismic stations. At least 39 earthquakes have occurred since 13 October. These events occurred

Figure 2
Epicentres of all UK earthquakes located in 2004 (from the Bulletin of British Earthquakes 2004).



approximately 8 km SSE of Eskdalemuir, at an average depth of 4.5 km and with magnitudes ranging between -0.4 and 2.9 ML. The largest event, with a magnitude of 2.9 ML, occurred on 28 November and was felt near Lockerbie, Langholm and Eskdalemuir. Residents reported “the whole house shook”, “felt a shudder for four to five seconds”, “heard a booming noise like a gas explosion which woke me up”, “all the china in the kitchen nearly fell of the wall” and “heavy bed jumped as well”. Similar swarms of small earthquakes have been seen in the UK before, such as Manchester (2002), Comrie (1788-1801, 1839-46), Glenalmond (1970-72), Doune (1997), Blackford (1997-98, 2000-01), Constantine (1981, 1986, 1992-4), Johnstonebridge (mid1980s) and Dumfries (1991,1999).

Four events occurred in the Johnstonebridge area of Dumfries and Galloway during 2004 with magnitudes ranging from 0.4 to 1.2 ML. Another four events occurred in the Dumfries and Galloway region during the year, this time near Lockerbie, with magnitudes ranging from 1.1 to 2.0 ML.

The coalfield areas of South Yorkshire, Nottinghamshire, Greater Manchester, Derbyshire and Gwent continued to experience shallow earthquake activity that is believed to be mining induced. Some, six coalfield events, with magnitudes ranging between 0.6 and 2.3 ML, were detected during the year. Local residents reported three of these events to be felt.

David D Galloway and **Bennett A Simpson** are both members of the Earthquake Seismology and Geomagnetism Group of the British Geological Survey.

The ‘Bulletin of British Earthquakes 2004’ edited by B A Simpson and D D Galloway and copies of previous years’ bulletins can be obtained from the Earthquake, Seismology and Geomagnetism Group Secretary, from BGS bookshops or from the Seismology Website at http://www.earthquakes.bgs.ac.uk/. For further details contact: D D Galloway, Earthquake Seismology and Geomagnetism Group, British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, Scotland, UK.

Foundation Design for Earthquakes

Report on the BGA-SECED Touring Lecture 2004 – Professor Pecker

by **Dr Robert May** (Atkins) and **Dr Ziggy Lubkowski** (Arup)

Introduction

The BGA and SECED were delighted to host a series of lectures by Professor Alain Pecker in 2004. The Touring Lecture was presented to enthusiastic audiences in Southampton, Manchester and Newcastle.

Professor Pecker is one of Europe's leading seismic and geotechnical engineers. He is the Président Directeur Général of his consultancy Géodynamique et Structure. His academic activities include professorships at Ecole Nationale des Ponts et Chaussées and Università di Pavia and he is Director of Research at Ecole Polytechnique de Paris. Among his many professional activities, he was a member of the executive committee of the International Association of Earthquake Engineering for eight years and provided expert advice to the drafting committee of Eurocode 8.

Pecker's aim was to present both the fascination and the challenge of earthquake design of foundations. His broad scope included theoretical frameworks, practical implementation and code provisions. He charted the historical development of the subject, the current state of the art and pointed the way ahead. The following is a condensed summary of some of his key themes.

Seismic design of shallow foundations

The understanding of shallow foundation performance under earthquake loading developed in the opposite direction to that followed by static foundation design. Seismic foundations design started with the development of methods for elastic response analysis. In contrast, the earliest problems to be solved for statically loaded foundations were those of ultimate capacity. The Mexico Earthquake of 1985 provided many examples of seismically induced foundation failure. This, and observed foundation failures from a number of more recent earthquakes, have spurred on the development of seismic bearing capacity theory.

The passage of earthquake waves from bedrock typically through a layered soil profile to the surface is a complex problem to analyse. The incident body waves, shear and p-waves, are refracted and reflected as they pass through the soil strata, possibly resulting in surface Rayleigh and Love waves in a free field situation. For cases where a structure

Figure 1 Mid-storey collapse due to pounding (Mexico City)

Figure 2 Bearing capacity failure (Mexico City)

and its foundation are also involved the situation becomes even more complex. The construction of the foundations and the subsequent changes in soil loading may have locally modified the soil properties. The presence of the foundation elements will generate additional reflections of the seismic waves. The excitation of the structure generates inertia forces that are imposed on the foundation. In addition, the deformation of the soil relative to the foundation generates kinematic forces. The seismic design of the foundation must account for both the inertia and the kinematic interactions. Various approaches have been developed to address this problem. Typical approaches include spring and dashpot models of varying complexity, the linear elastic substructure superposition method and direct interaction analyses by finite element or finite difference methods.

The simplest soil-structure interaction (SSI) models show that major changes occur in the fundamental frequency of the structure as the foundation stiffness reduces. Associated with these changes in fundamental frequency are changes in system damping and foundation input displacement amplitude. A significant consequence of these changes is that the direct application of a free field seismic motion to a fixed base structural model can be quite unrealistic for structures founded on soils.

Models consisting of springs, dashpots and masses can be used quite effectively to evaluate the inertial aspects of seismic SSI provided certain implicit assumptions are reasonably valid. These assumptions include:

- system linearity
- neglect of kinematic interaction
- availability of dynamic impedances

Non-linear soil stiffness effects can be incorporated into such models using a global stiffness modification factors. Uniquely among seismic codes, Eurocode 8 provides suggested factors to be applied to the small strain stiffnesses for such analyses. The neglect of kinematic interaction between the soil and the foundation may be conservative or unconservative with respect to the amplitude of structural motions. Unfortunately the kinematic interactions cannot readily be estimated without specific analysis. Dynamic impedances are complicated by the fact that in real situations with limited depths of soil, the impedances may be strongly frequency dependent. It is normally possible to correct for such effects by adding additional masses to the model with associated springs and dashpots.

Most seismic codes neglect the potential effects of soil-structure interaction. However, Eurocode 8 specifies various cases where SSI is mandatory. These include cases of massive or deep foundations (e.g. piles), slender tall structures, structures that could suffer significant P-d effects and for structures founded on soft soils (i.e. $V_s < 100$ m/s). In other cases Eurocode 8 implicitly permits SSI to be neglected although there may be benefit in performing such analyses for some of these cases also. Figure 1 shows a potential effect of ignoring SSI. The photograph shows two buildings affected by the 1985 Mexico Earthquake. The foundation soils have a shear wave velocity of around 50 – 70 m/s. Originally both structures were the same height (11 storeys). The earthquake-induced rocking lead to pounding between the structures and collapse of several intermediate stories of the structure on the left. Had appropriate seismic SSI been undertaken at the design stage, the separation between the structures would undoubtedly have been increased.

The theoretical understanding of the seismic bearing capacity of shallow foundations has developed significantly in the last 15 years. Annex F of Eurocode 8 Part 5 provides a formulation that accounts for normal and shear forces, moments and the (instantaneous) soil inertia force. Investigations using this formulation show, for high vertical loads and low static safety factors, an appreciable reduction in normalised vertical capacity as the soil inertia force increases. This provides an explanation for the observed bearing capacity failures of raft foundations in Mexico City (Figure 2) and at Adapazari in the Kocaeli Earthquake where many raft foundations were constructed with slim static factors of safety.

The seismic design of shallow foundations is likely to develop in the direction of displacement based approaches. Current formulations for such analyses are usually based on a Newmark approach which provides an approximate uncoupled analysis (i.e. soil inertia forces do not affect capacity). However, recent numerical analysis techniques using macro elements are making fully coupled displacement analyses practical. This technique was used in the pier foundation design for the recently opened Rion-Antirion Bridge.

Seismic design of piled foundations

The understanding of the seismic behaviour of piles and pile groups is not as advanced the understanding of shallow foundations. Design methods often involve significant simplifications and important factors are difficult to include in available forms of analysis.

It has been recognised for some time that kinematic interaction between piles and the soil can generate major pile loadings, particularly in the vicinity of strata boundaries which involve significant changes of soil stiffness. Eurocode 8 requires kinematic effects on piles to be considered for soft soil sites, for moderate or high levels of seismicity and for important structures. Standard practice considers such effects for two pile diameters either side of the strata boundary and within the uppermost 2.5 diameters of the pile. The seismic design of raked piles is subject to particular uncertainty.

In cohesive soils gapping may develop around the upper section of pile shafts (Figure 3). Under some circumstances gapping may extend to 6 pile diameters or more below the pile head leading to substantial changes in lateral stiffness as the earthquake proceeds. Typically gapping may increase lateral deflections and pile head rotations by a factor of two. Analytical beam on Winkler non linear spring models incorporating dashpot dampers are available for the analysis of the non-linear lateral (and vertical) behaviour of single piles.

Cyclic loading can significantly reduce the vertical capacity of floating piles, particularly in situations where complete load reversals from compression to tension and back occur during the earthquake. Figure 4 shows an example of a piled structure affected by the 1985 Mexico Earthquake. The post earthquake tilt of the structure greatly exceeds serviceability limits due to loss of vertical capacity during the shaking.

One of the most complex issues facing the designer of piled foundations for earthquake resistance is the assessment of the dynamic pile group interaction. In the static condition, the effect of any given pile on its neighbours decreases fairly rapidly with increasing distance. However, when the pile group is subjected to earthquake loading each pile shaft generates stress waves which affect all of the other piles in the group. Solutions for dynamic pile group interaction factors have been produced by Gazetas and various co-workers.

Figure 3 Gapping around piles

Figure 4 Failure of floating piled foundation (Mexico City)

Figure 5 Effect of fault displacement on bridge – (Chi Chi Earthquake)

However, the commonly used solutions involve significant simplifications including imposition of the free field soil motion at the pile location, assuming the pile vibrates in phase along its length (creating a cylindrical wave front) and imposition of an infinitely stiff pile cap. The designer must find alternative means to account for effects such as the development of gapping or pore pressure increases on the pile group behaviour as the earthquake event proceeds.

Conclusions

Professor Pecker ably demonstrated his thesis that that the seismic design of foundations is both challenging and fascinating. The subject is certainly complex and solutions are better developed for shallow foundations than for their piled counterpart. Codes such as Eurocode 8 are beginning to recognise that soil structure interaction cannot be ignored for certain classes of structure-foundation systems. In addition kinematic interaction between piles and soil strata may also be critical in certain cases. However, observation of the behaviour of foundations loaded by actual large earthquakes shows that we still have some way to go before the subject is fully understood.

Professor Pecker emphasised that appropriate seismic detailing of structures is essential to achieve adequate performance and this topic constituted the most important part of his lecture. Detailing requirements for reinforced concrete beams and columns have become better understood in recent years but detailing of foundations is just as important in many cases. Some of these detailing requirements are now appearing in seismic codes such as Eurocode 8. The following detailing issues were highlighted:

Faults - Foundations must be located clear of active faults. Figure 5 shows major vertical fault displacement between bridge piers in the Chi Chi Earthquake. Designers must recognise the potential for damaging movement on secondary faults associated with the main fault.

Homogeneous foundations - Foundation elements should be of a similar size and type beneath a structure in order to minimise differential movements between elements. Figure 6 shows the potential result of mixing piled foundations for large external columns (no settlement) with pad foundations for smaller internal columns (appreciable settlement).

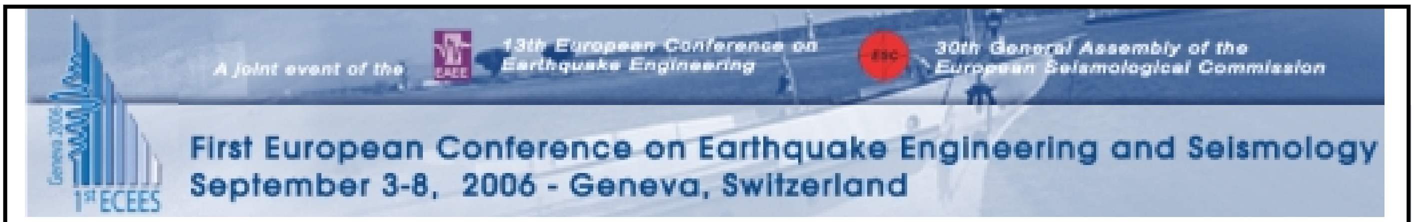
Liquefaction and seismic settlement - In cases where the foundation soils may be subject to significant pore pressure increases or liquefaction, appropriate mitigation measures must be implemented. These may typically use vibro-compaction with stone columns.

Tie beams - Shallow pad foundations should be connected with appropriately detailed tie beams. This detail restrains foundation spreading which, if it occurs, will frequently lead to structural collapse.

Pile reinforcement - Piles designed for seismic loading should be reinforced over their full depth. Eurocode 8 permits plastic design at the pile head. The designer should allow for the effects of gapping which may extend to a depth of 6 pile diameters or more in clay soils.

Raked Piles - Inclined piles should only be used with considerable caution. Under earthquake loading they attract major lateral loads from the supported structures. They may also be prone to damage from seismically induced settlements. In most seismic foundation design situations raked piles are best avoided.

Figure 6 Effect of non-homogenous foundation types



In September 2006, the First European Conference on Earthquake Engineering and Seismology (1st ECEES) will take place in Geneva. The conference aims to provide:

- An excellent opportunity for exchanges between seismologists and earthquake engineers;
- Forum for stimulating discussion;
- Convivial atmosphere for making acquaintances and renewing old friendships;
- Comprehensive grant programme to support students and young researchers from economically weak countries;
- Varied programme for participants and accompanying persons to allow full advantage to be taken of Geneva's cultural importance and geographical location at the foot of the Alps.

A number of events will take place to foster the interaction between earthquake engineers and seismologists, including common sessions, common keynote speakers and sessions discussing issues where there are opposing expert viewpoints.

Important dates to remember are:

- Submission of abstract (if intend to submit a full paper): **31st January 2006**
- Deadline for grants: **31st January 2006**
- Notification of acceptance or rejection of the abstract: **28th February 2006**
- Submission of the full paper: **30th April 2006**
- Submission of stand alone abstract (if do not intend to write a full paper): **30th April 2006**
- **Congress Dates: 4th to 8th September 2006**

Congress Venue: Centre International des Conférences de Gèneve (CICG)

Information about keynote speakers, registration fees, applying for grants and further details about the conference can be obtained at www.ecees.org

EURODYN 2005 Conference, Paris

The 6th European Conference on Structural Dynamics, popularly known as EURODYN, this year took place in Paris on September 4-7. EURODYN 2005 continued a good tradition of tri-annual meetings held in Bochum (1990), Trondheim (1993), Florence (1996) and Munich (2002). The European Association for Structural Dynamics (EASD) organised this year's meeting with the help of the University of Marne-le-Vallée, which is one of Paris' universities.

EURODYN is one of the largest worldwide gatherings of specialists in various aspects of structural dynamics applicable to civil engineering structures. This civil engineering flavour of the conference was clear from the titles of mini-symposia, special sessions and general sessions which formed the backbone of the conference during which approximately 350 papers were presented. To accommodate such a large number of papers, the conference was run in six to eight parallel sessions over three days. The specific topics included: ambient vibrations, offshore engineering, bridge aerodynamics, reliability and earthquake engineering, soil-structure interaction, wind engineering and man-induced vibrations.

It is interesting to note that the last topic was presented through the largest mini-symposium at the conference which attracted 18 papers. It was enlightening to see that human-induced vibrations (due to, say, walking, running, jumping, bouncing) and related vibration serviceability issues are finally getting the attention they are due from the worldwide professional and scientific community. The enormous complexity of the problem, in particular when crowds are involved, is being recognised. The stochastic nature of human-structure dynamic interaction was also well recognised during this mini-symposium and a number of papers presented some novel approaches. Because of this, there was a marked move towards treating the problem using probability, similar to the treatment of wind or wave loading. A stochastic approach to man-induced vibrations and vibration serviceability assessment was clearly advocated as the way forward for research and design in the years to come.

Finally and most importantly, the good news for SECED members in the UK is that EURODYN 2008 will be held in Southampton.

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NOTABLE EARTHQUAKES JULY – SEPTEMBER 2005

Reported by British Geological Survey

YEAR	DAY	MON	TIME UTC	LAT	LON	DEP KM	MAGNITUDES ML	MB	MS	LOCATION
2005	**2**	**JUL**	**02:16**	**11.25N**	**86.17W**	**27**		**5.6**	**6.4**	**NICARAGUA**
2005	**5**	**JUL**	**01:52**	**1.82N**	**97.08E**	**21**		**6.2**	**6.8**	**NIAS, INDONESIA**
			Buildings and roads damaged in the Gunungsitoli area.							
2005	**5**	**JUL**	**16:53**	**26.47S**	**27.43E**	**5**	**2.7**			**SOUTH AFRICA**
			One person killed and one injured at a mine near Carletonville.							
2005	**16**	**JUL**	**18:29**	**51.01N**	**0.39W**	**5**	**2.2**			**WEST SUSSEX**
2005	**23**	**JUL**	**07:34**	**35.50N**	**139.98E**	**61**		**6.1**		**HONSHU, JAPAN**
			At least 27 people injured and one building damaged in the Tokyo area.							
2005	**24**	**JUL**	**15:42**	**7.92N**	**92.19E**	**16**		**6.6**	**7.5**	**NICOBAR ISLANDS**
			Some buildings damaged in the Nicobar and Andaman Islands.							
2005	**25**	**JUL**	**15:43**	**46.83N**	**125.06E**	**48**		**5.0**	**4.7**	**HEILONJIANG, CHINA**
			One person killed and 12 others injured at Daqing.							
2005	**05**	**AUG**	**14:14**	**26.57N**	**103.04E**	**42**		**5.2**	**4.8**	**YUNNAN, CHINA**
			Nine people injured and 3,700 buildings damaged in Huize County.							
2005	**12**	**AUG**	**08:05**	**53.54N**	**2.38E**	**5**	**3.0**			**SOUTH NORTH SEA**
2005	**13**	**AUG**	**04:58**	**23.63N**	**104.10E**	**10**		**4.8**	**4.5**	**YUNNAN, CHINA**
			At least 26 people injured, several houses destroyed and roads and reservoirs damaged in Wenshan County.							
2005	**16**	**AUG**	**02:46**	**38.28N**	**142.04E**	**36**		**6.5**	**6.8**	**HONSHU, JAPAN**
			At least 56 people injured, several buildings damaged and landslides and power outages occurred in the epicentral region. A local tsunami with wave heights of 10 cm was generated on the coast of northern Japan.							
2005	**21**	**AUG**	**02:29**	**37.28N**	**138.59E**	**13**		**5.1**	**4.5**	**HONSHU, JAPAN**
			Two people injured at Kashiwazaki.							
2005	**24**	**AUG**	**14:32**	**49.89N**	**4.22W**	**12**	**3.0**			**ENGLISH CHANNEL**
			Felt in south Devon with intensities of at least 3 EMS.							
2005	**7**	**SEP**	**17:32**	**55.23N**	**4.48E**	**11**	**3.2**			**SOUTH NORTH SEA**
2005	**9**	**SEP**	**07:26**	**4.54S**	**153.47E**	**90**		**6.3**		**PAPUA NEW GUINEA**
2005	**17**	**SEP**	**02:37**	**56.57N**	**6.30W**	**5**	**2.1**			**ISLE OF MULL**
2005	**26**	**SEP**	**01:55**	**5.68S**	**76.39W**	**115**		**6.7**		**NORTHERN PERU**
			Five people killed, at least 60 injured, approx 70% of the houses destroyed and another 200 buildings damaged at Lamas. Further buildings damaged at Chachapoyas, Moyobamba and Tarapota.							
2005	**29**	**SEP**	**15:50**	**5.44N**	**151.84E**	**25**		**5.9**	**6.6**	**PAPUA NEW GUINEA**

Issued by: Davie Galloway, British Geological Survey, November 2005.
Non British Earthquake Data supplied by: The United States Geological Survey

New Book

Title: Numerical Models in Fluid-Structure Interaction

Published by WIT Press, this book may be of interest to SECED members. The book costs £150 and is edited by S.K.Chakrabarti, of Offshore Structure Analysis Inc.

Placing particular emphasis on practical offshore applications, this book presents state-of-the-art developments in numerical methods for the analysis of fluid-structure interaction. The book consists of ten invited chapters from recognized experts, covering the state-of-the-art on numerical methods in fluid-structure interaction. It will be of interest to all designers and researchers developing or applying tools in the area of computational fluid dynamics.

Full contents details from www.witpress.com/acatalog/8376.html

Forthcoming Events

06 January 2006
Fluid Structure Interaction
ICE 6.00pm

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. Diagrams, pictures and text should be in separate electronic files.

Copy typed on paper 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.

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 Geological 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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SECED Website

Visit the SECED website which can be found at http://www.seced.org.uk for additional information and links to items that will be of interest to SECED members.
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