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Contents

Indian Ocean Tsunami Damage

Dr Tizianna Rossetto (University College London) and Dr Chris Browitt (University of Edinburgh) report on the causes of damage as noted by EEFIT's field investigation team.

To put the Indian Ocean tsunami in the context of natural disasters over the past 50 years; together with hurricane Ivan, it lifted economic losses for 2004 to over $100bn. This has been only exceeded in 1995 when the Kobe earthquake, itself, cost around $150 billion. Most importantly, it demonstrated the continuing exponential increase in total (and insured) losses, worldwide, from natural disasters; a trend that could be reversed with better planning and redirection of resources to the preparation phase rather than purely to relief. To learn lessons for future planning and construction, a UK field investigation team of engineers (EEFIT) visited Sri Lanka and Thailand to observe and record the damage done.

Introduction

The tsunami on 26 December, 2004, was a rare event which caused damage in 12 countries around the Indian Ocean (Fig 1) and resulted in the deaths of over ¼ million of the nationals of more than 50 countries. This death toll from a natural disaster is on a par with that of the Tangshan, China, earthquake of 1976 and is only surpassed by the Shansi, China, earthquake, in 1556.

Following the tsunami, the lead author joined the UK Earthquake Engineering Field Investigation Team (EEFIT) in its missions to Sri Lanka and Thailand. Its purpose was to study damage to the built environment in relation to the degree of inundation and quality of the structures, and to report back findings and lessons learnt to engineering and disaster mitigation communities.

The study areas provided a large variation in the degree of damage experienced; from total devastation, with 70% of the buildings collapsed, to light impact on windows and shutters. Overall, damage was the result of the combination of structural vulnerability and exposure to lateral forces, themselves influenced by shore topography, bathymetry, vegetation and coral formations, as well as the height of the tsunami waves. In Sri

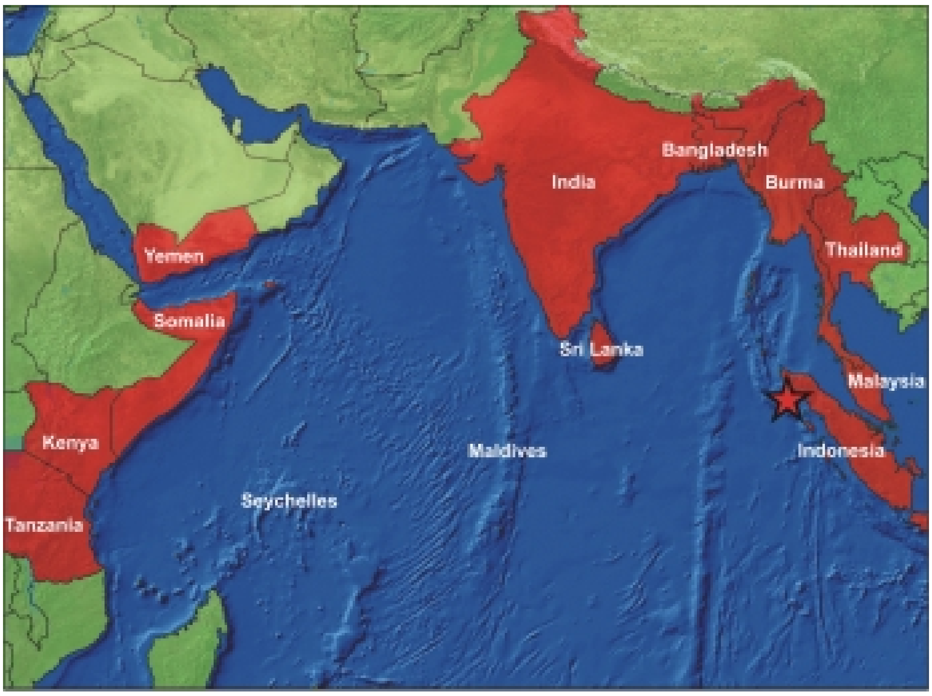

Figure 1. Countries directly affected by the tsunami

Figure 2. Damage to buildings in Khao Lak, Thailand (courtesy of EEFIT).

Lanka, average water heights were measured at 4.5m, with peaks of 10m, and, in Thailand, at 6m and 11m, respectively. Water velocities estimated from video footage, at two sites, were 3-4 m/s and 6-8 m/s (note: only Olympic sprinters can match the higher speeds).

Causes of Damage

The three main causes of damage were identified as ground scour, debris impact and water inundation. Large horizontal forces are associated with water movement and turbulence, and are enhanced by the entrainment of sediments. Hydrodynamic and hydrostatic pressures reached 30kN/m^2. Windows and masonry panels had little chance as they fail at around 15% and 30% of this level, respectively. Debris impacts (eg cars, boats, trees) were clearly the source of some damage, including to exposed structural members, but it was not possible to ascertain its contribution to the total collapse of buildings.

The main cause of damage was due to wave impact and inundation, reducing in intensity with distance from the coastline and, critically, with the number of obstacles between a building and the sea (vegetation, other buildings, infrastructure). A significant mechanism, particularly for the bridges, was the influence of ground scour (erosion). In addition to changing the coastal topography, ground scour was seen to have caused the failure of buildings founded on pad footings, and of roads and railways where they were underlain by sand. Scour damage occurred with the incoming tsunami and also on the backflow, the latter being the main cause of failure of bridges surveyed in Sri Lanka. Their abutments were rock armoured on the seaward side but not on the inland side, permitting erosion by backflow water down the river channel and the collapse of the reinforced concrete decks supported between the abutments.

Low-rise masonry houses, which formed the majority of the building stock in Sri Lanka, suffered severe damage where water heights exceeded only 2 metres. Those with reinforced concrete (RC) frames fared better although poor roof connections and scour around footings, induced damage.

Three to five-storey RC-framed buildings, which included most of the hotels in Thailand and public buildings in Sri Lanka, did not fail although their windows and infill masonry panels did. This allowed water inundation. These are engineered buildings with inherent earthquake resistance, although not specifically designed to withstand earthquake shaking. In this study, EEFIT engineers recognised that the design criteria for saving lives in an earthquake (so that the building does not collapse) need to be further enhanced for life-safety in tsunami vulnerable regions. Here, water inundation is the main threat to life.

Economic Resilience?

In Thailand, the greatest economic impact has been on tourism, but, with most hotels being insured, full recovery is expected within one to two seasons. Consequential losses in Sri Lanka are significant in the tourism and fishing industries with failure of the latter having an important longer term impact on the health of a population depending on fish for 60% of its animal protein.

For much of the built environment relating to international tourism, the lessons learnt should aid resilience to future events.

But for others, here is a question and a challenge:

With the now familiar allegations following disasters in Developing countries, that generous aid funds are slow to reach the people directly affected, is it time for the financial sector to devise “affordable” insurance schemes for fishermen and small businesses, so that rapid restoration of their commerce can act as the bottom-up engine to speed recovery?

For further information, visit www.eefit.org.uk

Scratching the Surface: The Geology of Earthquakes

David Mallard provides an account of the 30 November 2005 Meeting and **Clark Fenton's** lecture.

This well-attended gathering began with the presentation by Brian Baptie to Piroozan Aminossehe of the prize for the annual SECED British earthquake prediction competition. Students of form will be interested to know that the square where the event in question occurred had already provided a previous winner.

Then the meeting was treated to a presentation by Clark Fenton of the Department of Civil & Environmental Engineering, Imperial College entitled "Scratching the surface: the geology of earthquakes". Essentially, this was an extensively (and very well) illustrated lecture. However, the speaker has been good enough to provide the following text as a record for those who were unable to be present.

Scratching the Surface: The Geology of Earthquakes

The issue of rational, scientifically defendable source characterization is the key to good practice in Probabilistic Seismic Hazard Assessment (PSHA). Many of the criticisms of PSHA have stemmed from either inaccurate or poorly constrained source characterization or from a lack of understanding of and/or poor communication of the uncertainties in seismic source parameters. This often results in confusion over the meaning of hazard values at a particular site. Developing a robust seismic source characterization requires as full an understanding of the tectonic environment as possible and a consideration of all possible fault behaviour.

There are three simple questions to ask when characterising potentially significant seismic sources:

- *Where are they?*
- *How large are they – or what is the maximum magnitude of earthquake that they can generate?*
- *How often do they generate earthquakes?*

The relatively short duration of the instrumental and historical seismic records pose significant problems for seismic hazard assessment. Is the 100 year snapshot provided by instrumental seismicity or the partial view of an incomplete historical record sufficient to quantify seismic hazard? In the majority of cases, the answer is a resounding no! So, short of statistical gymnastics and ill-advised temporal extrapolations, how can we better understand the vagaries of the earthquake machine? Although resulting from processes occurring kilometres beneath the Earth's surface, the surface manifestations of earthquakes, in particular surface fault rupture, offer us clues of prehistoric earthquake activity.

Using tectonic geomorphology, the signature that an earthquake leaves on the surface of the Earth, we can use our knowledge of recent, historical earthquakes to look for indications of earthquakes in the recent geological past. This, in ideal environments, allows us to extend the seismicity record from the relatively short durations of the instrumental (10^2 years) and historical (10^3 years) records to something approaching the return period for large earthquakes on faults with the lowest slip rates (10^4 – 10^5 years).

The geologist, especially when armed with a strong background in structural geology, Quaternary stratigraphy, and geomorphology, has all the tools for unravelling the secrets of past earthquakes. Using the Law of Uniformitarianism (simply stated, the present is the key to the past) and the surface expression of known earthquakes as a yardstick, we can interpret the earthquake record preserved in recent geological strata. However, as with all things geological, the record is not always clear and almost never entirely complete! However, by examination of the various types of geological signatures of past earthquakes, we can begin to quantify the uncertainties arising from the interpretation of such data, and what impacts this can have on seismic hazard assessment.

As with all geological investigations, the study of seismic sources begins at a regional level before focusing in incrementally to reach a site-specific level. After all, it does help to

Surface faulting along the Lavic Lake fault
– after the Hector Mine earthquake, southern California, **M** 7.1, 16/10/99.

understand the tectonic environment and what style of faults you should be expecting before you start trenching!

The use of remote sensing imagery, including satellite images and stereoscopic aerial photographs, allows us to locate structures with tectonic geomorphology that indicates recent movement, thereby answering the first question of seismic source characterisation: Where are the seismic sources? Remote sensing data allows us to investigate a large area in a timely and cost-efficient manner. Features indicative of recent faulting include fault scarps developed on young surfaces or displacing young geological deposits, sag ponds and/or spring lines, displaced drainages, and other 'anomalous' geomorphic features. Digital data and image processing tools allow us to manipulate topographic data, in particular altering the sun angle on Digital Elevation Models (DEMs), to enhance subtle morphotectonic features and better locate surface rupturing faults. Coupled with detailed seismicity relocation studies, this becomes a powerful tool in locating and identifying active faults.

Once potentially active faults have been identified, aerial and field reconnaissance investigations are commonly the next step in seismic source characterisation. As well as investigating fault-specific geomorphology, regional landscape features, including mountain range fronts and drainage basin geometry can give an insight into the gross characteristics of recent tectonic movements, e.g., sense of displacement, strain partitioning (if any), total offset, and long-term slip rates. This also allows the selection of localities for site-specific investigation. By carrying out detailed site-specific investigations, most commonly palaeoseismic trenching, we can build up a picture of the behaviour of different faults, including their slip rates and/or interseismic recurrence intervals, style and magnitude of displacement, and by way of fault rupture length, a measure of the maximum earthquake possible on any given seismic source. Careful selection of trenching localities, detailed stratigraphic logging and reliable, accurate age-dating are the key factors in successful palaeoseismic investigations where we aim to determine fault recurrence and/or slip rate. Without age-dating all we are left with is, at best, an estimate of slip-per-event, and no temporal context within which to place these data. On its own, slip-per-event data can be used to determine earthquake magnitude, but it does not answer our third seismic source characterisation question: How often?

It is important to understand and, where possible, quantify the uncertainty in the measurement of each of these source characteristics. An ideal trenching site will have had a long history of faulting coupled with continuous sedimentation to record a continuous history of offsets. In an ideal World, the most recent faulting event (surface rupturing fault scarp) will be draped with a dateable horizon allowing an estimation of the time since the last event; in addition to a robust palaeoseismic chronology, these data can be used to enhance our estimates of probabilistic hazard assessment to include a time-dependent factor. The interpretation of multiple trench exposures along any given fault allows us to build up a model of long-term fault behaviour, including developing an understanding of fault segmentation and recurrence. Only by such extensive and scientifically rigorous field investigations can we begin to tackle some of the more difficult questions in seismic source characterisation, such as temporal scaling; how do we resolve differences between geodetically measured strain, instrumental and historical seismicity catalogues, and paleoseismological fault slip and/or recurrence intervals? Are these differences real, indicating time-variant fault behaviour, or are they merely a reflection of the relative completeness of each recording period? PSHA allows us to entertain multiple seismic source models incorporating a multitude of fault behaviour.

Detailed seismotectonic and palaeoseismic investigations allow us to obtain the data for seismic source characterisation. Fully understanding the limitations and uncertainties in these data allows the development of a comprehensive and defendable seismic source model, thereby leading to a realistic understanding of seismic hazard at a site. Thorough investigation of the seismotectonic character of a region, leading to a comprehensive suite of seismic source models, fully describing their uncertainties, should be the goal for all PSHAs. Coupled with rigorous sensitivity analysis, this should lead to more robust, believable hazard evaluations.

Discussion

The discussion which followed this presentation began with Bryan Skipp raising the issue of the converse situation where effort is directed at trying to prove that a fault is NOT active under the current tectonic regime. The need to search for cross-cutting and hierarchical relationships and for dateable materials was mentioned and a warning given concerning the 'black arts' involved in some dating techniques. In particular, it should be ensured that the technique being employed is such that the 'clock' it uses will necessarily have been reset by the most recent fault movement since this is not always the case.

Ian Smith wondered about the quantitative merits of the output from palaeoseismic studies and was told that the geometrical dimensions of the fault could be used to assess quite reliable magnitudes but that recurrence intervals were more difficult to estimate.

The applicability of palaeoseismic methods in offshore environments was raised by Phillip Cooper and it was agreed that, in such situations, reliance had to be placed in remote geophysical methods, although the precision of such methods was always improving! Bryan Skipp recalled some of the problems experienced by geophysical contractors in dealing with engineers whose specified requirements bore little relation to the output that could be achieved in practice or to the uncertainties associated with such techniques. David Mallard quoted an instance where fairly minor perturbations in the overlying depositional characteristics produced seismic sections that might have been interpreted as implying very recent movements on an old fault.

Robin Adams drew attention to the limitations of palaeoseismic methods in environments where intermediate depth events (ca. 100km) provide the greatest contribution to seismic risk (for example, mega events at 30 to 50km on subduction zones). Clark Fenton replied that the paleoseismology of subduction zones could be unravelled and referenced the work of John Adams (Adams, 1990) and Chris Goldfinger (Goldfinger *et al.,* 2003) in using detailed age-dating of deep ocean turbidites that occur over geographically wide areas to indicate large subduction zone events. The work of Kerry Sieh and his students at Caltech on coral growth rings (Zacharien *et al.*, 1999) indicating subsidence/uplift histories of reefs along subduction zones was also very useful in identifying both historical and paleoseismic events.

Questioning Clark Fenton's whole-hearted support for the probabilistic approach to hazard assessment, David Smith noted that palaeoseismic evidence might be seen as fitting more comfortably into deterministic methods where periodicity is of no concern. In the same connection, Julian Bommer pointed out that the origins of the deterministic method sprang precisely from the desire to incorporate geological evidence into hazard studies. He accepted that the most rational approach to the uncertainties involved in hazard assessment is to use logic-tree methods but considered that there is no reason why a logic-tree approach should not be used to derive deterministic hazard estimates. Notwithstanding these comments, Clark Fenton continued to advocate probabilistic methods with the stipulation that it was essential to carry out a disaggregation of the results to investigate the contribution of individual seismic sources.

Jon Hancock raised the issue of safety aspects in palaeoseismic investigations and was reassured that the statutory safety precautions should always be employed, for example, when trenching. Clark Fenton mentioned examples of hydraulically-shored and propped trenches of the order of 4.5m depth on the Maacama Fault and stepped and shored trenches up to 20m for the Wasatch Fault.

The question as to whether any new hi-tech advanced techniques were coming into the field of palaeoseismic investigations was raised by Ian Smith who was told that LIDAR was becoming increasingly useful in fault mapping, especially for small tectonic geomorphological features and in regions with dense vegetation cover. The recent work of Carol Prentice (US Geological Survey) and co-workers was cited as an example. Ground Penetrating Radar was also cited as a potentially useful technique, although the limitations of this method, particularly in water-saturated clayey soils, were emphasised.

Antonio Pomonis raised a query as to the geological timescale over which palaeoseismic techniques might be expected to provide useful evidence: could they be used, for example, in very old rocks? Clark Fenton answered that as long as there was a good, continuous, geological record, the paleoseismic record should, in theory, be limitless! However in reality, erosion, non-deposition and the limitations of high-precision age-dating techniques limited 'good' paleoseismic data to about 100,000 years. Where problems are most likely to arise is with faults that have very long recurrence intervals. The Ungava, Canada, earthquake (Adams *et al.*, 1991) was quoted as an extreme example, where a Proterozoic ductile shear zone, with no history of any Phanerozoic movement generated a surface-rupturing earthquake in 1989!

Ed Russell raised the issue of strain monitoring and was told that such measurements could be useful in highly active areas. Problems can occur, however, where GPS installations are monitored for short periods since such observations can appear to be inconsistent with the deformation rates indicated by other, longer term, diagnostics.

Tiziana Rosetto asked for confirmation concerning the minimum sizes of earthquakes that could be expected to leave geological evidence. In Clark Fenton's opinion, events of Moment Magnitude (**M**) 6¼ would be a reasonable threshold for an environment like the Basin and Range region in the USA, whereas the figure might be **M** 6½ in an environment like the Californian coastal belt. For an overall figure, covering almost all circumstances, he would suggest 6½ ± ¼.

Following this pronouncement, the meeting closed.

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The Estimation of Peak Ground Acceleration in the UK after an Earthquake

A straightforward method, based on UK instrumental data, is offered by **Chris Allen**

Introduction

For more than thirty years, the British Geological Survey (BGS) has been undertaking instrumental seismic monitoring of the UK, as a result of which a considerable database of records has been collected. Most of the data consists of very low level readings taken from instruments that measure velocity. A smaller set of data consists of higher level readings that are taken from instruments that record peak ground acceleration (pga). It is this set of data and its treatment that is the subject of this article. The article describes the regression of the data and concludes with the discussion of the application of the regression results to the estimation of pga at UK sites where this may be of use. Such sites are likely to be those where a seismic safety case has been required.

Throughout this article magnitude is expressed in terms of Local Magnitude, distance in kilometres and peak ground acceleration in %g. Furthermore, no attempt has been made in the reported work to explore the site conditions at each of the measurement stations. This is clearly a possibility for the future.

Treatment of Data

The peak ground acceleration data collected to date by BGS is listed in Table 1. This data has been subject to a straightforward multi-variable linear regression using the relationship

$$Ln\ (pga) = A.M + B.Ln(R) + C \quad \text{...} (1)$$

Where:

- pga = the peak ground acceleration in units of %g.
- M = the Local Magnitude of the Earthquake
- R = the focal distance in units of km.

A, B and C are the constants determined by the regression analysis of the data. The pga data provided is the larger of the two measured horizontal orthogonal components.

The regression analysis was undertaken using a proprietary statistical package (Axum) and was cross- checked using two separate methods in the computer program MathCad. The constants obtained from the regression analysis give rise to the following relationship.

$$Ln\ (pga) = 1.879\ .\ M - 1.254.Ln(R) - 3.969 \quad \text{...} (2)$$

The standard error of the regression is 1.054. The computation of this value has also been checked using an independent method in Mathcad. Figure 1 provides a three dimensional

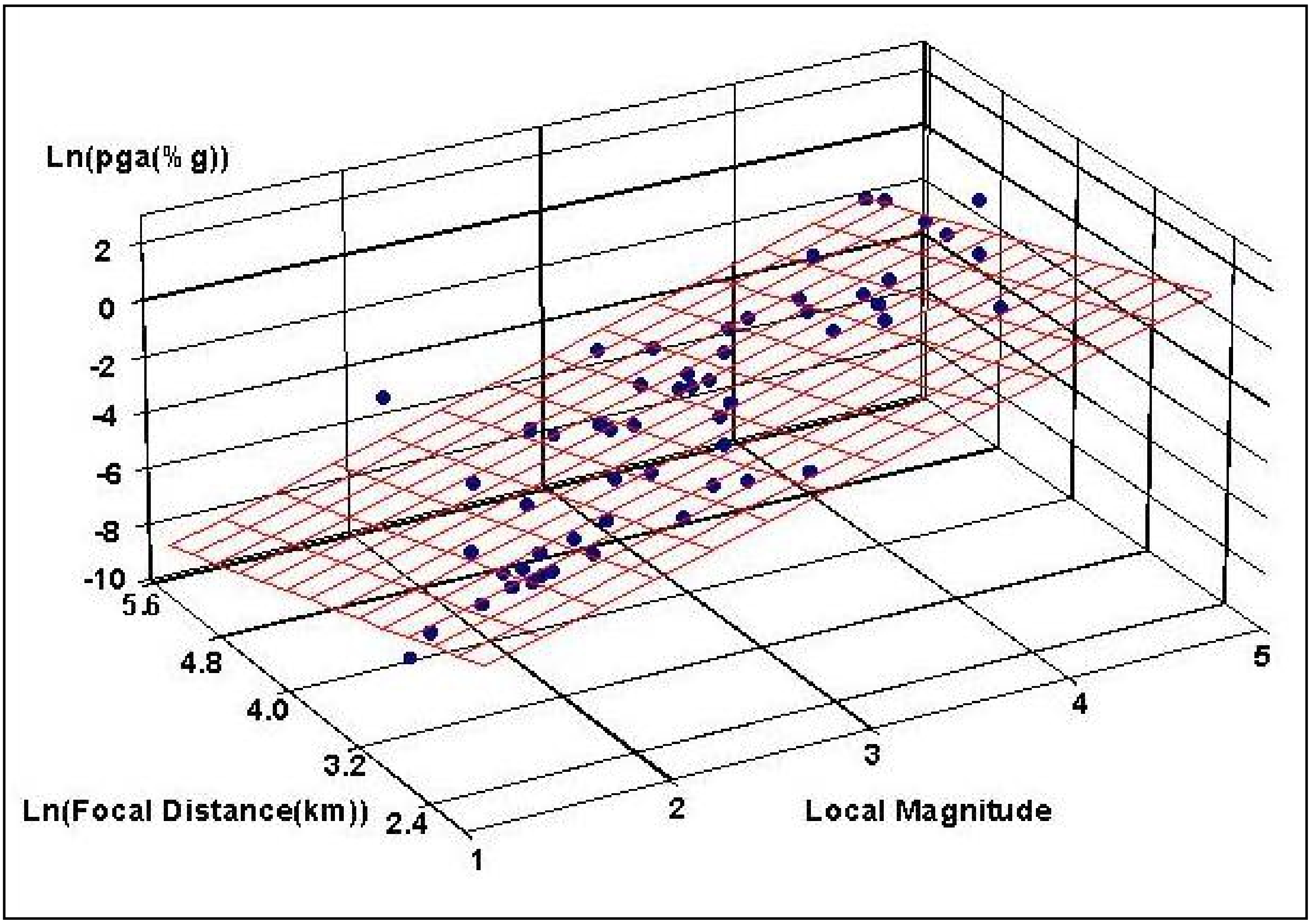

Figure 1 Three Dimensional Data Plot

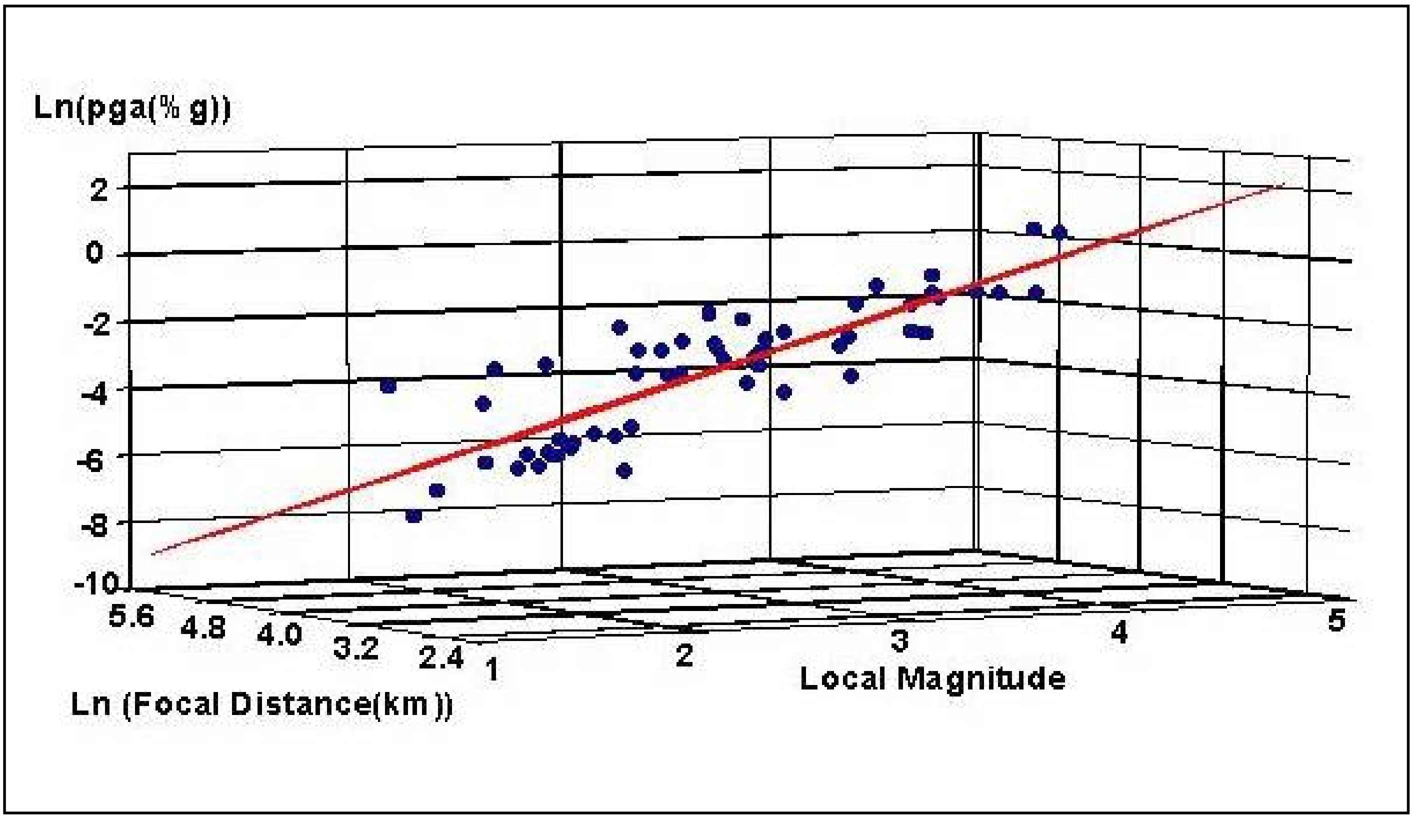

Figure 2: In Regression Plane View

plot of the data and the regression plane. Figure 2 provides the same plot, except that the view of the plot is along the regression plane.

Application of the Above Work

There are many sites within the UK that have undertaken a formal seismic assessment and therefore have in place a safety case for earthquake loading. There may be interest at such sites in the levels of pga experienced after an earthquake, either as a result of internal, or external, queries. The latter may become more frequent as a result of the implementation of the Freedom of Information Act.

Such sites may not have seismic monitoring equipment installed, or, if seismic monitoring equipment is in place, it may be such as to have a defined trigger level, below which no reading is recorded.

It is considered that the attenuation expression described herein and given in equation 2 above may be of use for such sites. It is a straightforward matter to incorporate equation 2 in a spreadsheet. This can also contain the Ordnance Survey coordinates of the sites of interest. After a significant UK earthquake, BGS will quickly provide the Local Magnitude, the focal depth and the geographical location of the epicentre. The spreadsheet can calculate the focal distance to the site from the geometry as shown in Figure 3 and use equation 2 to determine the mean pga at each site of interest and, if required, the pga corresponding to the mean plus one standard deviation level.

Each site can then use this information to provide reassurance of the levels of pga experienced and to compare with that which forms the basis of the formal seismic assessment of the site.

However, in any application of this work along the lines suggested, there would remain the matter of the range of magnitude and epicentral distance data for which the attenuation equation could be deemed to be valid. This topic is left to be resolved at the time of any future application of this work. Clearly magnitudes of above 4.7 and epicentral distances below a few 10's of kilometres may be outside reasonable limits of this attenuation

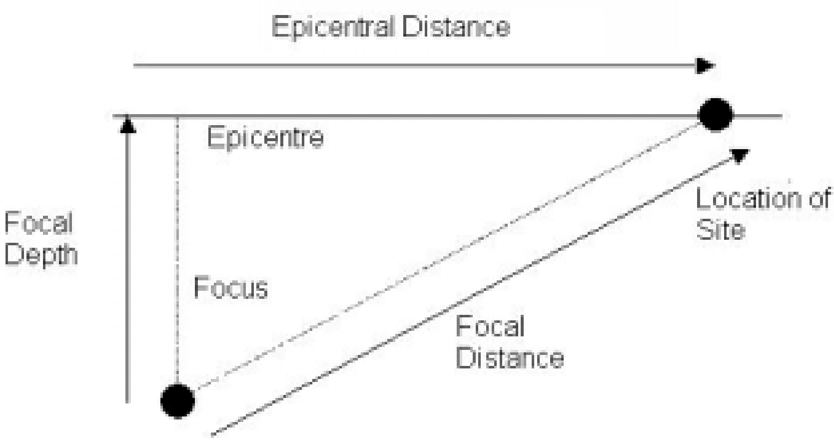

Figure 3: Basis for Calculation of Focal Distance

BGS Strong Motion Data

Date	Earthquake Locality	Local Magnitude	Focal Distance (km)	PGA (%g)
19940317	Newtown	3.1	64	0.043
19940512	Stratford	3.0	91	0.024
19940611	Constantine	2.2	10	0.147
19940817	Isle Of Skye	3.1	18	0.040
19960307	Shrewsbury	3.4	86	0.045
19960920	Llandrindod	3.0	38	0.055
19961110	Penzance	3.8	35	0.537
19970622	Jersey	2.2	21	0.098
19971108	L Maree	2.5	27	0.042
19980403	Annan	1.1	7	0.098
19980528	Wigton	1.5	21	0.024
19980721	Locharbriggs	2.0	31	0.004
19990121	Boston	2.8	96	0.103
19990304	Arran	4.0	137	0.041
19990314	Dumfries	1.9	30	0.003
19990617	Hereford	2.8	39	0.204
19990713	Jersey	1.8	22	0.069
19990903	Johnstonebridge	2.1	26	0.008
19991025	Sennybridge	3.6	40	0.385
20000107	Dumfries	1.8	30	0.003
20000212	Loghilphead	2.7	166	0.002
20000424	Calthwaite	2.6	41	0.072
20000622	Lleyn Peninsula	2.6	53	0.033
20000808	Middlesbrough	2.7	127	0.003
20000923	Warwick	4.2	77	0.212
20000923	Warwick	4.2	88	0.067
20000923	Warwick	4.2	102	0.068
20010513	Dumfries	2.9	29	0.048
20010531	Off Hartland Pt, Devon	3.6	102	0.076
20010627	Sedbergh	2.2	103	0.002
200110	Bargoed	3.0	42	0.163
20011028	Melton Mowbury	4.1	19	2.161
20011028	Melton Mowbury	4.1	144	0.145
20020922	Dudley	4.7	82	0.214
20020922	Dudley	4.7	84	1.448
20020922	Dudley	4.7	285	0.102
20020922	Dudley	4.7	117	0.194
20020922	Dudley	4.7	230	0.153
20020922	Dudley	4.7	148	0.183
20021021	Manchester	3.9	100	0.061
20021021	Manchester	3.5	101	0.063
20021029	Annan	1.8	19	0.008
20030819	Doncaster	3.1	68	0.058
20040229	Oldham	3.1	42	0.064
20040229	Oldham	3.1	99	0.062
20040229	Oldham	3.1	180	0.001
20040629	Lockerbie	2.0	180	0.017
20040807	Dumfries	2.3	29	0.009
20041013	Eskdalemuir	1.7	21	0.005
20041027	Eskdalemuir	1.3	22	0.002
20041103	Eskdalemuir	2.7	22	0.033
20041103	Eskdalemuir	1.8	21	0.005
20041103	Eskdalemuir	2.1	21	0.008
20041103	Eskdalemuir	1.3	21	0.002
20041104	Eskdalemuir	1.2	21	0.001
20041105	Eskdalemuir	1.9	21	0.006
20041128	Eskdalemuir	2.9	23	0.023

Table 1: UK Earthquake Acceleration Data

equation. On the other hand, the limit of applicability may to some extent be self- correcting, as the occurrence of, say, a magnitude 5 at some time in the future may produce hard data that will allow extension of the limits of applicability.

The Future

It is anticipated that the UK seismic monitoring project run by BGS will continue. The number of seismic instruments that can record moderate levels of peak ground acceleration has increased significantly over the duration of the project, with the result that the amount of acceleration data should increase with time more quickly than has happened in the past. It would thus be sensible to modify the regression analysis as discussed herein when new data arrives. This is an activity that the author may pursue. It would be sensible if others followed suit.

It is recognised that currently available data has been analysed on a basis that is relatively straightforward. There may be other approaches that are more elegant and perhaps better suited to the task in hand. The work herein is thus offered on the basis that there may be merit in the promulgation of the work discussed herein. Future alternative treatments of this topic are thus not excluded; indeed they are encouraged.

Information on the UK seismic monitoring project may be obtained by contacting Dr. Brian Baptie at the BGS Edinburgh office at Murchison House. Contact may be made via the BGS web site, www.bgs.ac.uk/contacts.

The permission to use the data collected by BGS is gratefully acknowledged.

Blast Intensity

Roger Musson reports on how procedures normally used for investigating macroseismic events have been used to investigate the December 2005 Buncefield explosion. A Blast Intensity Scale is proposed on which further contributions would be welcomed.

At 06h01m on 11 December 2005, a huge explosion occurred at the Buncefield fuel depot near Hemel Hempstead, causing much damage, and starting a fire that required several days to bring under control. The explosion is considered to have been the largest in post-war UK history. The blast was clearly detected by the UK seismic monitoring network at distances of up to 300 km, and the seismic record shows well the passage of both the ground-transmitted shock wave and the air wave.

The engineering impact of the blast on structures in and near the depot was the subject of an immediate investigation, the results of which at the time of writing are understood not yet to be available. However, because of the newsworthiness of the event, there was considerable public and media interest in the far-field effects of the blast. Such things are not normally studied, and no procedures are in place for handling such an investigation. In order to gather data quickly, and not miss this (thankfully rare) opportunity, the British Geological Survey (BGS) took matters in hand by implementing a survey of the wider effects of the blast using the procedures set up for handling macroseismic investigations of earthquakes. This involved setting up the BGS web questionnaire page for the Buncefield event; the relevant page was linked from the BBC's news story on the BBC web pages. About 2000 responses were received within 24 hours, and a total of 3016 responses were received before the page was closed at the end of the month.

While this was a good result, the manner of collecting the data was not ideal. There was no time to compose a web-enabled questionnaire specifically directed towards surveying blast effects, which is a difficult task in the absence of any standard model of blast questionnaire. Although there are many commonalities between the effects of explosions and earthquakes, such that the one is often mistaken for the other (at least, at far distances), there are also significant differences, reflecting the fact that in one case transmission is primarily through rock, and in the other, primarily through air.

This also affects the processing of the data. It is quite possible to take the mass of questionnaire data gathered for the Buncefield explosion and process it according to standard macroseismic procedures, as though it were earthquake data, and arrive at intensity values on the European Macroseismic Scale (EMS – see Grünthal 1998). Indeed, this was done. However, the meaning of the values is questionable, in that one is using a tool for measuring earthquake effects and applying it to blast effects.

The results are shown in Figure 1. This map covers only the south-east of England; a few isolated reports came in from as far away as Somerset, Wales and Yorkshire, but the credibility of some of these outliers is doubtful. The intensity values do show a coherent pattern, and are as regular as any earthquake data set in terms of attenuation with distance. One can also note a directivity in the blast whereby the strongest effects are biased towards the south-south-west. In terms of what the EMS intensities really mean for an explosion, the interpretation in Table 1 can be proposed.

As far as I am able to determine, there is no published intensity scale designed for dealing with blast effects. This seems a surprising omission. Presumably, in the past, those investigating blast effects within the damage zone have been content to enumerate the damaged buildings, and in the far field, either no-one has been interested in surveying the distribution of effects, or if they have, an earthquake intensity scale has been pressed into service as in the case of Buncefield. However, the possibility of producing blast effect maps is interesting, and in these days where terrorist explosions are a constant threat, possibly useful as well.

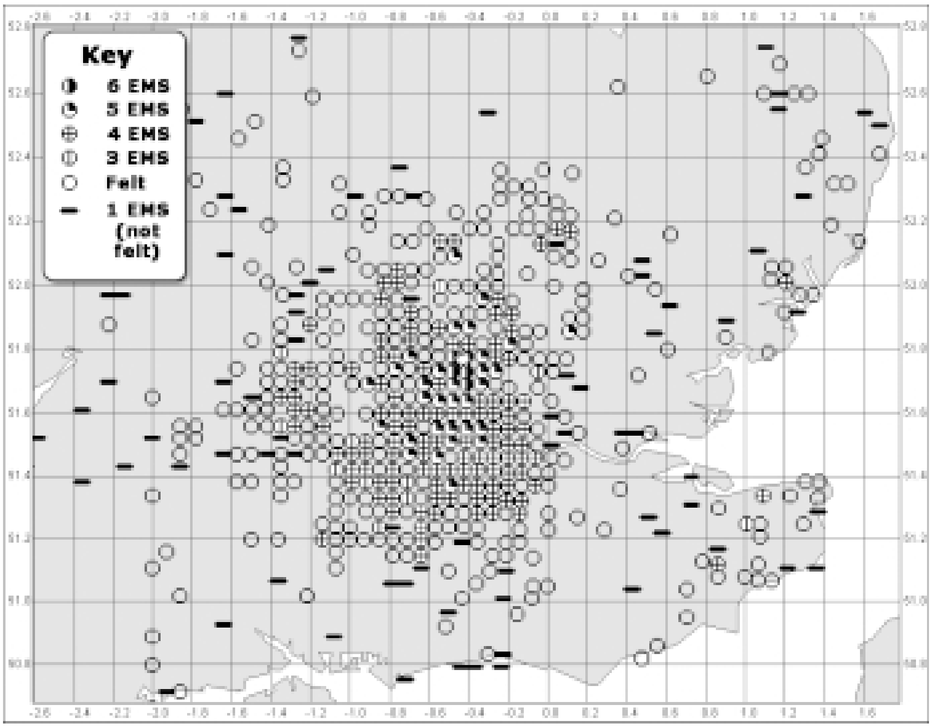

Figure 1 EMS "intensity" map of the Buncefield explosion.

EMS value	Significance
6	Strong blast, some damage caused
5	Blast sufficiently strong to be frightening or alarming
4	Observed by many people in the locality
2 or 3	Observed by a few people

Table 1 - Suggested interpretation of EMS intensity values for blasts

The following scale is tentatively proposed as a working draft for a proper blast intensity scale. It is based on a mixture of the work of Glasstone and Dolan (1977) and personal experience; it undoubtedly needs refinement and improvement from engineers with first-hand professional experience in dealing with the effects of large explosions. My aim in publishing it here is to attract attention in the hope that contributions will be forthcoming in this regard. It is not possible to use it with the data so far collected for Buncefield, partly because the data would need to be collected in a way that envisaged the scale to be used for the analysis, and also because obviously the higher degrees can only be assessed from field investigations.

The qualities that make any intensity scale good or bad are discussed at length in Musson and Grünthal (2006). In deciding the best number of intensity degrees to have in a scale, and how they should be defined, consideration needs to be given to the following issues:

- Discrimination: can the distinctions between different degrees of the scale be clearly recognised in the field?
- Consistency: do all the diagnostics for any degree of the scale really belong together at the same level of effect?
- Regularity: does the decrease in intensity with each lower degree in the scale follow an orderly progression of decreasing effects?

It is in the interests of discrimination that the number of degrees has been limited to seven, but it might be felt that, for instance, a degree could be inserted between 4 and 5. It requires experience with actual data to determine whether the scale is more regular with or without such a degree. As with earthquake intensity, when a data set is mapped, a good scale should show even logarithmic spacing of contours. If one consistently finds that some contours are bunched in violation of this, there is a fault in the scale construction. For the higher degrees of the scale I have been entirely reliant on Glasstone and Dolan (1977) as to the consistency of the proposed definitions.

Comments from the blast engineering community are invited. Whether or not such a scale has scientific applications in the investigation of explosions, it should certainly be useful in terms of communicating results to the public, who, in the case of Buncefield event, were very interested to know over what area the blast extended.

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Acknowledgements

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References

GLASSTONE, S, and DOLAN, P J. 1977. The effects of nuclear weapons. (Washington D.C.: US Department of Defense and Department of Energy.)

GRÜNTHAL , G (editor). 1998. European Macroseismic Scale 1998. Cahiers du Centre Europèen de Gèodynamique et de Seismologie. No. 15. (Luxembourg: Conseil de l'Europe.)

Musson, RMW and GRÜNTHAL , G. 2006. On the comparison of intensity scales, in preparation.

Blast Intensity Scale 2005 (Provisional Draft)

1. No detectable effect
2. A distant sound is heard; sometimes, depending on atmospheric conditions, shaking of houses will be perceptible, even without sound.
3. A loud sound is heard; buildings may shake; windows and slates may rattle.
4. Vibration of the ground is apparent even outdoors. Many windows are shattered.
5. Masonry buildings suffer cracking to walls; interior partitions may collapse; wood frame buildings collapse partly or wholly; roofs are damaged.
6. Masonry buildings suffer collapse; truss bridges and similar constructions are distorted and may collapse in some cases.
7. Modern steel frame buildings are badly damaged and may collapse; girder bridges collapse; cars and lorries are overturned or hurled in the air.

Mallet Milne Lecture and Reception 2007

The next biennial Mallet Milne lecture will be given by Professor Robin Spence and will take place on 30th May 2007 at the Institution of Civil Engineers. The lecture will be entitled “Saving lives in earthquakes: successes and failures of seismic protection since 1960”.

Report on the SECED Young Engineers Conference, March 2005

Last year's SECED Young Engineers Conference, held at the University of Bath, proved to be a truly international event. Whilst the focus was on UK research and practice, there were attendees from across Europe, Iran and as far a field as Hong Kong and Malaysia. The aim of the conference was to provide a link between young researchers and practitioners working in the fields of earthquake engineering, seismology and civil engineering dynamics. The lively discussions and debate which followed each presentation were an indication of the success of this aim. The presentations covered a wide range of topics, but the common themes which emerged were soil liquefaction, advanced structural and geotechnical test methods, vulnerability assessment of low engineered structures, the development and assessment of realistic ground motion models and methods of mitigating structural vibrations. Additionally there was a small amount of work presented on human-structure interaction and wind-structure interaction.

Of particular poignancy, with the Conference coming soon after the tragedy of the Asian tsunami, was a presentation by Yusoff Nor Azizi. Having come from Malaysia, Yusoff witnessed the devastation of the tsunami first hand and preceded his planned presentation with a discussion of the effects of the tsunami on the Malaysian population and infrastructure. This was a theme later picked up on by SECED Chairman, Zygmunt Lubkowski, in his speech following the Conference Dinner, laying down the challenge to us, as young engineers, to help prevent similar tragedies from occurring.

We were especially honoured to have two key-note speakers at the conference. From the academic side, Gopal Madabushi from Cambridge University, arriving straight from a trip to America, spoke about the latest advances in physical and numerical geotechinical modelling in the context of earthquakes. The talk focussed upon developments in centrifuge testing as a tool for validating numerical models. In particular the provision of realistic boundary conditions and evaluating strain fields and soil deformation for such physical tests were discussed. From the industry side of earthquake engineering, Edmund Booth gave an entertaining and unique insight into the drafting of the European seismic code, Eurocode 8. As a member of the drafting committee, he was well placed to describe the complex European politics and red-tape which surround the development of such a code. He also discussed the basis on which the code was developed and the impact of codes and standards on as-built seismic safety.

Prizes were given for the best papers of the Conference. Highly Commended awards of £50 were presented to Jackie Sim, from the University of Oxford, for her paper entitled "Response of a Joint Passive Crowd-SDOF System Subjected to Crowd Jumping Load" and to Paul Murtagh, from Trinity College Dublin, for his paper entitled "Effect of Aerodynamic Damping on the Damped Natural Frequencies and Mode Shapes of Towers Supporting Utilities". However, the £100 prize for the best paper of the conference went to Nick Sartain and Kubilây Hiçyilmaz, of Ove Arups and Partners, for their paper entitled "Key Issues In the Seismic Design of Immersed Tube Tunnels". Their paper really captured the essence of the Conference, combining elements of seismology, geotechnics and structural dynamics, applied to an interesting practical problem where a rigorous but pragmatic investigation is critical. The paper discussed the problems involved in such a situation and the benefits of various available analysis methods and their role in risk assessment. The paper seemed to summarise, in an applied sense, the recurring themes that were focussed on by other practitioners and researchers throughout the conference.

The Conference organisers wish to thank all those who contributed to the success of the conference. A limited number of copies of the conference proceedings are available on CD-ROM from SECED at a cost of £15.00. Please contact the SECED secretary for more information.

Antony Darby, University of Bath

Seismic Design to Eurocode 8

SECED-Imperial College Short Course with Design Workshops
21-22 September 2006 at Imperial College London

SECED will be organising a short course jointly with Imperial College London on 21 and 22 September 2006. The two-day course will take the form of a series of morning lectures from leading experts from both the university and consulting sectors, followed by practical design workshops on Eurocode 8 in the afternoon. The course will link with initiatives established by the Institutions of Civil and Structural Engineers for assisting with the implementation of the Structural Eurocodes. The programme and details are now available. For further information contact Dr Ahmed Elghazouli at Imperial College London (e-mail: a.elghazouli@imperial.ac.uk).

Forthcoming Events

29 March 2006
Force and Displacement Based Vulnerability Assessment for Traditional Buildings
ICE 6.00pm

26 April 2006
AGM and This Year's Earthquake:
Pakistan Earthquake - October 8th 2005
ICE 5.30pm

NOTABLE EARTHQUAKES OCTOBER – DECEMBER 2005

Reported by British Geological Survey

<table>
<tr><th>YEAR</th><th>DAY</th><th>MON</th><th>TIME UTC</th><th>LAT</th><th>LON</th><th>DEP KM</th><th>MAGNITUDES ML</th><th>MB</th><th>MW</th><th>LOCATION</th></tr>
<tr><td>2005</td><td>1</td><td>OCT</td><td>22:19</td><td>16.64S</td><td>70.79W</td><td>20</td><td></td><td>5.3</td><td></td><td>SOUTHERN PERU</td></tr>
<tr><td>2005</td><td>8</td><td>OCT</td><td>03:50</td><td>34.54N</td><td>73.59E</td><td>26</td><td></td><td>6.9</td><td>7.6</td><td>PAKISTAN</td></tr>
<tr><td colspan="11">At least 86,000 people killed, more than 69,000 injured and extensive damage in northern Pakistan. The heaviest damage occurred in the Muzaffarabad region of Kashmir where entire villages were destroyed and Uri where 80% of the town was destroyed. Around 4 million people in the region were left homeless as result of this earthquake.</td></tr>
<tr><td>2005</td><td>15</td><td>OCT</td><td>04:24</td><td>34.01N</td><td>74.00E</td><td>10</td><td></td><td>5.2</td><td></td><td>PAKISTAN</td></tr>
<tr><td colspan="11">Two people killed in the Uri area.</td></tr>
<tr><td>2005</td><td>15</td><td>OCT</td><td>15:51</td><td>25.32N</td><td>123.36E</td><td>183</td><td></td><td>6.2</td><td>6.5</td><td>TAIWAN REGION</td></tr>
<tr><td>2005</td><td>16</td><td>OCT</td><td>07:05</td><td>36.01N</td><td>139.77E</td><td>40</td><td></td><td>5.1</td><td></td><td>HONSHU, JAPAN</td></tr>
<tr><td colspan="11">Two people injured in the Tokyo area.</td></tr>
<tr><td>2005</td><td>20</td><td>OCT</td><td>21:40</td><td>38.15N</td><td>26.75E</td><td>10</td><td></td><td>5.5</td><td>5.9</td><td>WESTERN TURKEY</td></tr>
<tr><td colspan="11">One person killed and 15 injured at Izmir. Minor damage to several buildings at Urla.</td></tr>
<tr><td>2005</td><td>27</td><td>OCT</td><td>11:18</td><td>23.60N</td><td>107.80E</td><td>10</td><td></td><td>4.2</td><td></td><td>GUANGXI, CHINA</td></tr>
<tr><td colspan="11">One person killed, another injured at Bose and several homes damaged at Taiping.</td></tr>
<tr><td>2005</td><td>29</td><td>OCT</td><td>04:05</td><td>45.21S</td><td>96.90E</td><td>8</td><td></td><td>6.1</td><td>6.5</td><td>SE INDIAN RIDGE</td></tr>
<tr><td>2005</td><td>6</td><td>NOV</td><td>02:11</td><td>34.52N</td><td>73.39E</td><td>10</td><td></td><td>5.2</td><td></td><td>PAKISTAN</td></tr>
<tr><td colspan="11">Seven people injured at Batgram.</td></tr>
<tr><td>2005</td><td>8</td><td>NOV</td><td>07:54</td><td>9.97N</td><td>108.29E</td><td>10</td><td></td><td>5.1</td><td></td><td>SOUTH CHINA SEA</td></tr>
<tr><td colspan="11">One person killed at Ho Chi Min City, Vietnam.</td></tr>
<tr><td>2005</td><td>8</td><td>NOV</td><td>21:06</td><td>55.22N</td><td>3.11W</td><td>3</td><td>0.6</td><td></td><td></td><td>ESKDALEMUIR</td></tr>
<tr><td colspan="11">Felt in the Langholm, Dumfries and Galloway region (2-3 EMS).</td></tr>
<tr><td>2005</td><td>14</td><td>NOV</td><td>21:38</td><td>38.11N</td><td>144.90E</td><td>11</td><td></td><td>6.7</td><td>7</td><td>HONSHU, JAPAN</td></tr>
<tr><td colspan="11">A tsunami wave with a maximum wave height of 32cm was recorded at Ofunato.</td></tr>
<tr><td>2005</td><td>17</td><td>NOV</td><td>19:26</td><td>22.32S</td><td>67.89W</td><td>163</td><td></td><td>6</td><td>6.9</td><td>BOLIVIA</td></tr>
<tr><td colspan="11">Power outages occurred throughout Tocopilla, Chile.</td></tr>
<tr><td>2005</td><td>19</td><td>NOV</td><td>14:10</td><td>2.16N</td><td>96.79E</td><td>21</td><td></td><td>6</td><td>6.5</td><td>SIMEULUE, INDONESIA</td></tr>
<tr><td>2005</td><td>26</td><td>NOV</td><td>00:49</td><td>29.70S</td><td>115.69E</td><td>10</td><td></td><td>5.4</td><td>5.2</td><td>JIANGXI, CHINA</td></tr>
<tr><td colspan="11">At least sixteen people killed, 8,000 injured and over 150,000 houses destroyed in the Jiujiang and Ruichang areas. Minor damage also occurred in Wuhan.</td></tr>
<tr><td>2005</td><td>27</td><td>NOV</td><td>10:22</td><td>26.77N</td><td>55.86E</td><td>10</td><td></td><td>6.1</td><td>6</td><td>SOUTHERN IRAN</td></tr>
<tr><td colspan="11">Thirteen people killed, around 100 more injured and seven villages severely damaged on Qeshm and more than 80% of the buildings in Zirang destroyed.</td></tr>
<tr><td>2005</td><td>2</td><td>DEC</td><td>13:13</td><td>38.09N</td><td>142.12E</td><td>29</td><td></td><td>6.1</td><td>6.5</td><td>HONSHU, JAPAN</td></tr>
<tr><td>2005</td><td>5</td><td>DEC</td><td>12:19</td><td>6.23S</td><td>29.78E</td><td>22</td><td></td><td>6.3</td><td>6.8</td><td>LAKE TANGANYIKA</td></tr>
<tr><td colspan="11">At least six people killed, several others injured and more than 300 houses and a church destroyed at Kalamie, Congo.</td></tr>
<tr><td>2005</td><td>10</td><td>DEC</td><td>23:21</td><td>56.84N</td><td>5.22W</td><td>8</td><td>3</td><td></td><td></td><td>FORT WILLIAM</td></tr>
<tr><td colspan="11">Felt throughout the Fort William, Highland region. The felt area for this event is approximately 7,300 km2 (2-3 EMS), 1,100 km2 (4 EMS) and 215km2 (5 EMS).</td></tr>
<tr><td>2005</td><td>11</td><td>DEC</td><td>14:20</td><td>6.58S</td><td>152.20E</td><td>10</td><td></td><td>6.1</td><td>6.6</td><td>PAPUA NEW GUINEA</td></tr>
<tr><td>2005</td><td>11</td><td>DEC</td><td>23:14</td><td>53.11N</td><td>0.02W</td><td>3</td><td>2</td><td></td><td></td><td>BOSTON, LINCS</td></tr>
<tr><td>2005</td><td>12</td><td>DEC</td><td>21:47</td><td>36.36N</td><td>71.11E</td><td>224</td><td></td><td>5.9</td><td>6.6</td><td>AFGHANISTAN</td></tr>
<tr><td colspan="11">Five people killed in Tili, one person injured in Jalalabad and around 100 houses damaged and 300 livestock killed in Badakhshan.</td></tr>
<tr><td>2005</td><td>13</td><td>DEC</td><td>03:16</td><td>15.26S</td><td>178.57W</td><td>10</td><td></td><td>6.1</td><td>6.7</td><td>FIJI ISLANDS REGION</td></tr>
<tr><td>2005</td><td>14</td><td>DEC</td><td>03:30</td><td>53.00N</td><td>5.64W</td><td>10</td><td>2.8</td><td></td><td></td><td>IRISH SEA</td></tr>
<tr><td colspan="11">Felt coast of Wicklow, Ireland (3 EMS).</td></tr>
<tr><td>2005</td><td>23</td><td>DEC</td><td>03:25</td><td>56.68N</td><td>5.68W</td><td>7</td><td>2.7</td><td></td><td></td><td>LOCH SUNART</td></tr>
<tr><td colspan="11">Felt Strontian, Highland region (3 EMS).</td></tr>
<tr><td>2005</td><td>23</td><td>DEC</td><td>04:58</td><td>56.67N</td><td>5.66W</td><td>8</td><td>2.4</td><td></td><td></td><td>LOCH SUNART</td></tr>
<tr><td colspan="11">Felt Strontian, Highland region (3 EMS).</td></tr>
<tr><td>2005</td><td>24</td><td>DEC</td><td>02:01</td><td>35.23N</td><td>136.84E</td><td>43</td><td></td><td>4.5</td><td></td><td>HONSHU, JAPAN</td></tr>
<tr><td colspan="11">One person injured in Yokkaichi.</td></tr>
<tr><td>2005</td><td>29</td><td>DEC</td><td>04:40</td><td>56.22N</td><td>3.76W</td><td>8</td><td>1.2</td><td></td><td></td><td>GLENDEVON</td></tr>
<tr><td colspan="11">Felt Glendevon, Central region (3 EMS).</td></tr>
<tr><td>2005</td><td>31</td><td>DEC</td><td>22:40</td><td>56.27N</td><td>3.77W</td><td>6</td><td>2.5</td><td></td><td></td><td>BLACKFORD</td></tr>
<tr><td colspan="11">Felt Blackford and Auchterarder, Tayside region (4 EMS).</td></tr>
</table>

Issued by: Davie Galloway, British Geological Survey, February 2006.
Non British Earthquake Data supplied by: The United States Geological Survey

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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Editor SECED Newsletter,
c/o The Secretary,
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Institution of Civil Engineers,
Great George Street,
London
SW1P 3AA, UK.

E: john.sawyer@projectservices.com

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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