ISSN 0967-859X
THE SOCIETY FOR EARTHQUAKE AND CIVIL ENGINEERING DYNAMICS

NEWSLETTER

Volume 23 No 2
November 2011

In this issue

The following article appeared first in *Proceedings of the ICE - Forensic Engineering* (August 2011). It is reproduced with permission.

EEFIT

The UK Earthquake Engineering Field Investigation Team

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Antecedents of EEFIT

Field investigations of earthquakes by British engineers and scientists have a long history dating back to Robert Mallet (1820 – 1880) and John Milne (1880 – 1940) (Muir Wood, 1988). In our own time, Nicholas Ambraseys of Imperial College London was a pioneer in recognizing the value of field missions in grounding the often abstract discipline into hard reality. He wrote:

> *"There is little room in Engineering Seismology for 'armchair seismologists'. Field study (...) helps the young engineer choose his line of research on realistic grounds and with enthusiasm."* (Ambraseys, 1988).

Ambraseys studied the Skopje earthquake of 1963 and five other events for UNESCO (Ambraseys, Moinfar and Tchalenko, 1986) and his many and significant contributions to the discipline of engineering seismology drew on his extensive experience of earthquake field missions.

Other UK engineers, too, were carrying out field missions, and the direct origin of EEFIT lay in an investigation of the 1980 earthquake in Irpinia, Italy (Spence et al 1982). The Irpinia mission led to the realization of the value of carrying out field investigations as soon as possible after the event, and the consequent need to have a team of engineers ready to mobilize at short notice, with the attendant procedures and funding sources in place. The mission also gave rise to the main guiding principles of EEFIT.

Setting up and running EEFIT

In 1982, a small group of engineers met to discuss and agree the formation of a UK based earthquake field investigation team (Booth, 1984). EEFIT's founding objectives, essentially unaltered today, stated that its purpose was to enable British earthquake engineers, architects and scientists to collaborate with colleagues in earthquake prone countries in the task of improving the seismic resistance of both traditional and engineered structures. Training of engineers through observing how full scale structures actually responded to ground motions was subsequently added as a key objective. These goals were to be achieved principally by conducting field investigations following major damaging earthquakes and reporting to the local and international engineering community on the performance of ordinary civil engineering and building structures under seismic loading. The intention was to field a survey team within a few weeks of the event. Collaboration between the university and consulting communities was a major consideration from the outset.

An obvious course of action would have been to integrate EEFIT into the UK's earthquake engineering society SECED (www.SECED.org.uk), following the pattern of the US's Earthquake Engineering Research Institute (EERI) and its *Learning from Earthquakes* program. For various rather English reasons of compromise and circumstance, this course was not followed. However, relationships between EEFIT and SECED have always been very close and supportive; with many EEFIT members being SECED members as well, it would have been strange otherwise, and the two societies have run in an entirely complementary and mutually supportive fashion. Rather than being a sub-group of SECED, EEFIT evolved along different lines; initially it was run as an independent society on an ad hoc, volunteer basis, but at the end of the 1980's, after EEFIT had successfully published reports on about half a dozen field missions, the Institution of Structural Engineers approached EEFIT with the offer to take over administrative aspects, and this offer was enthusiastically accepted. An independent volunteer management committee continues to set policy and decide on the details of field missions, with the Institution providing secretarial and other support. This has been a very beneficial relationship; EEFIT gains from the professional support and the high profile that the Institution's leading international standing gives it. The Institution manages EEFIT's website (www.EEFIT.org.uk), on which all of the field mission reports are now posted as freely downloadable pdf documents. The Institution benefits in fulfilling part of its learned society role, particularly in an international context, by support of a topic of great importance to many of its members, especially those overseas.

As EEFIT gained in experience, the professionalism of setting up and conducting field missions has developed and increased. The procedure following a major damaging earthquake is as follows. The EEFIT management committee decides whether it might merit EEFIT investigation; if so, the secretariat e-mails all members, asking for expressions of interest in joining a possible field mission. The management committee, usually meeting by telephone conference, then decides whether or not a mission is justified, and, if so, who should be chosen to participate from those expressing interest. Each team member is required to sign a form committing, inter alia, to assisting with timely publication of the mission report. During the mission, a UK Base Contact engineer acts to provide liaison and support to the team. The most recent mission also produced a risk assessment and security plan, with assistance from the international charity RedR – Engineers for Disaster Relief (www.redr.org). These arrangements have resulted in effective working of the teams, but no doubt will continue to evolve.

Funding

The direct cost of running EEFIT has been small; the Institution of Structural Engineers provides secretarial and banking support from their own resources, and the cost of producing field reports has been low. These costs have been met by membership subscriptions (currently not more than £15 per year, with student membership free) and by corporate sponsorship; current and past sponsors are listed in Appendix A.

Funding is mainly needed for the expenses of mounting field missions. The employers of practising engineers have met the travel and other costs of their members, while generally continuing to give them a salary. The willingness – indeed, eagerness – of consulting engineers to support their employees in this way is a testimony to EEFIT's perceived value. The expenses of academic members have been met by grants from the UK Government's Engineering and Physical Sciences Research Council (EPSRC, formerly SERC). An absolutely crucial element in EEFIT's success has been the EPSRC's willingness to expedite rapidly the grant application process for field missions. Reviewing, and deciding on, whether to fund a research grant is normally a long drawn out process taking many months, but approval to fund EEFIT missions has been provided within a few weeks, and sometimes less, of submitting the grant application, making it possible to mount a field mission soon after an earthquake. New arrangements with EPSRC, described below, promise to allow even more rapid and effective response.

EEFIT's achievements

Between 1982 and 2010, EEFIT produced reports on 25 earthquakes and two more are in preparation (Figure 1 and Table 1). Most of the significant events of the last quarter century have been covered and 101 engineers, with affiliations almost equally split between industry and academies, have participated in its missions. It has collaborated

Figure 1. Some EEFIT report covers

with other international field teams, include groups from France, Italy, the US, Chile, Peru and New Zealand.

EEFIT will never have the resources or clout available to its counterparts in the US (and elsewhere), so is the effort that goes into keeping it going justified? The financial support given to EEFIT from both industry and government funding bodies is evidence that it is. The main achievements of EEFIT are considered to be the following.

1. Perhaps the most important achievement (following Nick Ambraseys' remarks quoted at the start of this paper) has been the training of over one hundred UK based engineers and scientists. Aspects of earthquake engineering are highly complex, and it is so easy to lose sight of the reality of the subject among these complexities. There is nothing like the experience of seeing the often disturbing consequences of a major earthquake on structures and those who live around them to rebalance one's approach and ground it in practical reality.
2. Important friendships have been formed between team members in the often demanding circumstances of a field mission, which has led to a number of fruitful and lasting professional collaborations, particularly between academic and practising members of EEFIT.
3. The overseas contacts made on the missions have been valuable both for academics for research purposes and for design engineers needing support when practising overseas.
4. A considerable body of research has arisen directly from or been supported by EEFIT missions, some of which is listed in Appendix B.
5. EEFIT is one of the founders of the Virtual Disaster Viewer (www.virtualdisasterviewer.com), a web platform which allows the comparison of pre- and post-earthquake satellite imagery and holds geo-referenced pictures of damage and field observations made by the EEFIT team.
6. Important information brought back from field missions has been disseminated to the rest of the profession by means of meetings and reports. The meetings often generate intense debate; a memorable one, following the Indian Ocean earthquake of 2004, concerned the value of tsunami warning versus tsunami resistant design.
7. EEFIT has lent credibility to the commitment to, and involvement in, earthquake engineering by the UK, a country not noted for its high seismicity. This has been important for the academic community, for example in gaining government support for major research initiatives, such as those at Bristol University, Oxford and Cambridge Universities, and University College London. It has also been valuable to the UK consulting industry in its efforts to gain work overseas in seismic areas.
8. Most earthquakes occur in regions that are not at a sufficient stage of economic development to fund meaningful research programmes that can improve the seismic readiness of their communities. The authors believe that developed countries like the UK have an obligation to redress this situation through their own research programmes, and EEFIT has played an important role here.

The future of EEFIT

The future of EEFIT is bright with the recent award of an EPSRC funded research grant to conduct further earthquake reconnaissance missions. This grant can be seen as an acknowledgment of the value of the work done by EEFIT

Mission Number	Year	Earthquake	Number in EEFIT team
1	1984	Liege, Belgium	1
2	1985	Chile	3
3	1985	Mexico	5
4	1986	San Salvador	2
5	1989	Loma Prieta, California, USA	11
6	1989	Newcastle, Australia	3
7	1990	Vrancea, Romania	3
8	1990	Augusta, Sicily	4
9	1990	Manjil, Iran	1
10	1990	Luzon, Philippines	3
11	1992	Erzincan, Turkey	5
12	1994	Northridge, California	14
13	1995	Kobe, Japan	10
14	1997	Umbria-Marche, Italy	6
15	1999	Quindio, Colombia	4
16	1999	Kocaeli, Turkey	13
17	1999	Ji-Ji, Taiwan	7
18	2001	Bhuj, India	10
19	2004	Indian Ocean Tsunami	8
20	2005	Kashmir, Pakistan	4
21	2007	Central Peru	3
22	2008	Wenchuan, China	9
23	2009	L'Aquila, Italy	10
24	2009	South Pacific Islands	5
25	2009	Padang, Sumatra	5
26	2010	Haiti	3
27	2010	Chile	7
28	2011	Christchurch, New Zealand	9
29	2011	North Japan	9

Table 1. List of EEFIT field missions

over the previous decades. The grant will last for 5 years and includes funding to conduct a further 5 earthquake missions. This is the first time that the academic members of the field mission will know that they have the required funding to conduct the mission before they leave; by removing this uncertainty EEFIT will be able to select from a wider range of academics, and academic mission members will be able to spend more time planning the missions rather than writing grant applications to fund them. The grant provides funding for two academics and two PhD students to spend one week in the field for each mission. It also covers all of their travel expenses as well as equipment such as notebook computers and GPS cameras. This funding will enable more rapid deployment and will allow EEFIT to add new objectives to missions, for example to observe how failed buildings and infrastructure affect disaster relief operations. It will also allow 'longitudinal studies', involving a series of missions over time to the same location, to observe how the reconstruction process operates. The continuity in funding allows EEFIT to make more robust plans for the long term, and an important part of these new plans is to improve further the quality of data collected on the missions as well as making it even more accessible to interested parties. To do this, the EPSRC grant application has proposed to develop new data collection and dissemination strategies and equipment, and the EEFIT team is collaborating with both EERI (Earthquake Engineering Research Institute) in the US and GNS (Geological and Nuclear Sciences) in New Zealand on this task.

Conclusions

In the 25 years or so that it has been operating, EEFIT has made significant contributions to the study and practice of earthquake engineering in the UK, by training engineers, fostering strong links both nationally and internationally, raising the profile of UK earthquake engineering and by furthering important research. It continues to enjoy strong support from industry and from the government funding body EPSRC. An EPSRC grant, running from 2011 to 2015, promises to make EEFIT even more effective in future.

Endnotes

- Formal comments on this paper are invited by *Proceedings of ICE – Forensic Engineering*; please e-mail contributions of up to 500 words to its editor at journals@ice.org.uk.
- Individual membership of EEFIT costs £15 a year (£10 for SECED/IStructE members, free for students); apply via www.istructe.org/knowledge/EEFIT/Pages/membership.aspx.
- An announcement of EEFIT's report on the Haiti earthquake is found on the back page of this Newsletter.

Appendix A: Corporate sponsors of EEFIT between 1990 and 2011

- AIR Worldwide Ltd
- Aon Benfield
- Arup
- BNFL (now Sellafield Ltd)
- British Geological Survey
- Buro Happold
- CREA Consultants
- EQE International (now ABS Consulting)
- Gifford & Partners
- Halcrow
- Risk Management Solutions
- Sir Robert McAlpine.

Appendix B: Selected research arising from EEFIT missions

Earthquake	Research topic	Selected references
Many and various	The formation of the Cambridge Earthquake Consequences Database (CEQID) by Cambridge Architectural Research Ltd and the Martin Centre at Cambridge University	Spence *et al*, 2010
Various	Post earthquake investigation of historic and non-engineered buildings	Hughes & Lubkowski, 1999
Mexico, 1985	Soil amplification and other effects following the Mexico earthquake of 1985	Steedman *et al*, 1986 Heidebrecht *et al*, 1990
San Salvador	Seismic design in Central America	Bommer & Ledbetter, 1987
Newcastle, Australia, 1989 Roermond, Holland 1992	Seismic hazard and risk in areas of low seismicity	Chandler *et al*, 1991 Pappin *et al*, 1994
Northridge, USA, 1994	Assessment of concrete bridges	Williams & Sexsmith RG, 1997
	Assessment of dams	Daniell & Madabhushi, 1995
Kocaeli, 1999	Mitigation of liquefaction effects	Brennan & Madabhushi, 2002
Ji Ji Taiwan, 1999	Design of piled bridge foundations for liquefaction resistance	Bhattacharya, Bolton & Madabhushi, 2005
Bhuj 2001 Kashmir 2005	Design of non-engineered masonry buildings	Patel D, Patel D & Pindoria K, 2001
	Liquefaction resistance of bridge foundations	Coelho *et al*, 2007
	Assessment of earth dams	Madabhushi & Haigh, 2001
Indian Ocean, 2004	Tsunami loading work at UCL	Rossetto *et al*, 2011, Allsop *et al*, 2008
	Post tsunami reconstruction studies	Da Silva, Lubkowski & Batchelor, 2010
Kashmir, 2005 Indian Ocean, 2004	Human casualties from earthquake damage to buildings	So *et al*, 2008
Haiti, 2010	Ground truthing assessments of damage from aerial images	Booth, Saito & Madhabushi, 2011 Clasen *et al*, 2011

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Further to the evening meeting in September, Andrew Coatsworth provides a fresh perspective on the the accident at Fukushima Dai-ichi and the implications for the nuclear industry here and abroad.

Great East Japan Earthquake: Nuclear accident and lessons in resilience

Andrew Coatsworth
Sellafield Ltd

Introduction

There has been much in the media about the Great East Japan magnitude 9.0 M_W earthquake of 11^{th} March 2011. There is also authoritative technical information about the earthquake by the UK's Earthquake Engineering Field Investigation Team (Reference 1), shortly to be supplemented by the EEFIT Report, and about the nuclear accident (Reference 2) by IAEA. I am reluctant to attempt to add anything. However, the SECED Newsletter can hardly be silent about the fourth largest earthquake since 1900, which was the initiator of the world's second worst nuclear accident, while so many of our members are employed considering the consequences of an earthquake on nuclear plants in the UK. This is especially so as there are ramifications for nuclear power in many countries, including Italy, Germany, Switzerland and Japan.

The earthquake and the tsunami it induced killed 15,821 people, and 3,929 people are still missing. The estimated total damage is about $300 billion, making it the most expensive natural disaster on record. Infrastructure has been destroyed. There were large scale power cuts, power consumption reduction measures, and consequential disruptions to the global supply chain in for example cars and electronics.

Despite this real human and economic tragedy, most of the media attention, particularly after the first few days, has concerned the resulting accident at the Fukushima Daiichi nuclear power plant. While recognizing the stress and disruption to the 140,000 residents within 20 km of the plant who were evacuated, no one has suffered an immediate death due to the nuclear accident. An earthquake – one of the most powerful forces in nature – has met two of the most powerful human emotions – ignorance and hysteria.

Initiating event

The rupture occurred along a 400-500 km segment of the plate boundary east of Honshu. The amount of slip on the interface between the two plates may have been as much as 30-40 metres. This motion resulted in uplift of the seafloor above the rupture zone by several metres, causing a tsunami, and lowered the coastline by up to 1 metre (measured at Onagawa nuclear power plant).

A learning opportunity?

Japan has the greatest seismic monitoring network in the world, and seismologists will learn about subduction earthquakes from the wealth of data created by the earthquake and the many hundreds of aftershocks.

The Earthquake Engineering Field Investigation Team (EEFIT) included civil engineer Mark Offord from Sellafield Sites Ltd as part of our company's learning strategy.

Much of the evidence of damage by the earthquake in Japan was swept away by the ensuing tsunami. The energy released by the Great East Japan earthquake was about 10,000 times more than the recent Christchurch magnitude 6.3 M_W earthquake, which itself was more powerful than a design basis earthquake for a typical UK nuclear facility. The Great East Japan strong ground motion lasted several minutes compared to the several seconds associated with a UK design basis earthquake.

Destruction of direct seismically induced damage and the disparity against UK design ground motions may limit how much we are likely to learn in purely earthquake engineering terms for the UK. However, there are certainly lessons to be learned from Japan about emergency preparedness and the resilience of plant and infrastructure. Arguably such matters are within the scope of SECED.

Tsunami effects

Large offshore earthquakes have occurred in the same subduction zone in 1611, 1896 and 1933 that each produced devastating tsunami waves on the coast of NE Japan. The magnitude 7.6 subduction earthquake of 1896 created tsunami waves as high as 38 m, and the magnitude 8.6 earthquake of

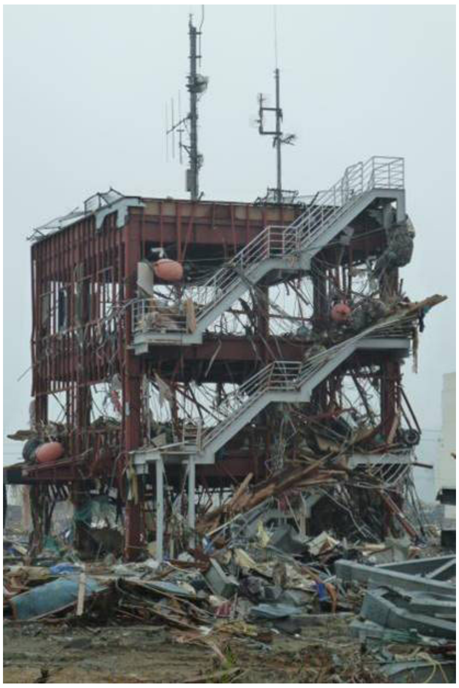

Figure 1. Emergency Operations Centre in Minamisanriku had been manned for the tsunami but was inundated with the loss of key staff (photo Stuart Fraser / EEFIT)

Figure 2. The tsunami hits Unit 2 (photo TEPCO)

March 2, 1933, produced tsunami waves as high as 29 m on the Sanriku coast. The coastline is particularly vulnerable to tsunami waves because it has many deep coastal embayments that amplify tsunami waves and cause great wave inundations. Low level plains allow waves to pass great distances inland.

The risk of tsunamis was well known in the north-east coast of Honshu. In some towns higher ground deemed to be safe was delineated from low lying ground deemed to be at risk, often by a "safe" blue line. Tragically because the tsunami was bigger than planned for, the tsunami passed the blue line. It is reported that more people died who lived above the blue line than below the blue line, because people below the blue line mainly attempted to evacuate while those above didn't. Providing detailed emergency preparedness information to the public may have tragically backfired: emergency plans need to be flexible and extendible.

Fukushima Dai-ichi nuclear power plant

In common with many other countries that obtain a high proportion of their electricity from nuclear generation, Japan has a balance of Pressurized Water Reactors (PWRs), similar to Sizewell B, and Boiling Water Reactors (BWRs), as the latter are better able to vary their output to suit load following. Both are examples of Light Water Reactors (LWRs), which, following a loss of cooling, degrade more rapidly than gas cooled reactors, such as Magnox and AGR. There are no BWRs in the UK, but although those at Fukushima Dai-ichi are up to 40 years old, neither the particular type of LWR nor their age appears at this stage to have been significant contributors to the accident.

Local infrastructure

The infrastructure (roads, electrical supply, communications, etc.) was severely impaired. Whole towns were destroyed or swept away. Against this background the operators of nuclear facilities and authorities were faced with securing the safety of nuclear facilities and people.

The nuclear accident – the earthquake

The control rods were successfully inserted automatically, tripped by the earthquake, by hydraulic pressure from *underneath* the pressure vessel, as is the case with BWRs. The control rods in the gas cooled reactors and the Sizewell B PWR in the UK fall under gravity when the magnetic clutches are de-energised. Thus for the three BWR reactors then operating at Fukushima Dai-ichi and elsewhere in Northern Japan to be successfully shut down, despite the beyond design basis ground motions, is a success story.

The reactors then entered fission product decay heat cool down. The earthquake also took out all off-site power.

The nuclear accident – the tsunami

The tsunami arrived 46 minutes following the earthquake. The tsunami caused the loss of all nine available Emergency Diesel Generators (EDGs) cooled by sea water and the loss of all but one of the three EDGs cooled by air. The sea-water pumps and motors located at the intake were totally

Figure 3. Fukushima Dai-ichi following destruction of reactor building superstructures due to hydrogen explosions (source unknown)

destroyed so the ultimate heat sink was lost.

On the entire site, no means of communication was available between the On-site Emergency Control Centre (OECC) (or if an unconfirmed report is correct, the Alternative OECC) and on-site personnel executing recovery actions. Only one wired telephone was available between the OECC and each control room. At Units 1 and 2, the 125 V DC batteries were flooded, so no instrumentation and control was available. At Unit 3, DC power and, in turn, main control room lighting and instrumentation and control systems, were available for 30 hours but were lost once the batteries drained, as the battery charger was flooded and AC power was not available.

The nuclear accident – emergency response

It is calculated that on Unit 1 the water level fell to the top of active fuel in three hours, and the fuel was completely uncovered 5 hours after the earthquake (earlier than suspected at the time). It is also calculated that on Unit 2 fuel was completely uncovered 76 hours after the earthquake. Fuel damage led to the generation of hydrogen.

The earthquake produced large sloshing waves in the fuel ponds and possibly loss of water, but due to the loss of instrumentation the water levels in the ponds of Units 1-4 were not known. The hydrogen explosions later destroyed the superstructures of Units 1 and 3, and damaged that of Unit 4, thus fortuitously giving access to the spent fuel ponds.

Safety valves, which were required to allow the various cooling systems to operate, needed DC or AC power; one valve was initially opened, but failed to a shut condition when DC power ran out. This arrangement appears not to have met the objective of a passive safety system.

The operators improvised. The lack of DC power for instrumentation required the use of car batteries to obtain intermittent readings of reactor pressure. Venting of containment pressure required instrument air as well as AC power. Staff used a construction type engine driven air compressor and engine driven generator to operate a solenoid valve.

At Fukushima Dai-ichi they were presented with a more or less complete prolonged loss of electrical power, compressed air and other services. Work was conducted in extremely poor conditions, with uncovered manholes and cracks and depressions in the ground, generally in darkness, with the risk of hydrogen explosions and mostly in very high radiation fields. All work was conducted with respirators and protective clothing, with little hope of immediate outside assistance, and with almost no instrumentation and control systems to secure the safety of six reactors, six nuclear fuel pools, a common fuel pool and dry cask storage facilities.

Health and environmental consequences

Japan has created an expert group to conduct dose assessments and has implemented a health monitoring programme, especially for the most exposed groups of residents. To date the only confirmed health effects detected in any person as a result of radiation exposure from the nuclear accident were radiation burns to the feet of three workers who stood in contaminated water.

Around 30 workers at the Fukushima Dai-ichi plant received radiation exposures of between 100 and 250 mSv, although recent information indicates that some higher internal doses may have been incurred by some workers in the early days. Doses between 100 and 250 mSv, although significant, would not be expected to cause any immediate physical harm, although there may be a small percentage increase in their risk of eventually incurring some health effects. Monitoring programmes of workers, especially those in the group of higher doses and for internal exposures, will assist in eliminating any uncertainties and in reassuring workers.

The societal and environmental impacts of the accident have been extensive and far reaching, with about 140,000 people being evacuated from around the plant, some foodstuffs and drinking water restrictions, and significant contamination of the sea. These effects have caused acute concern in Japanese society.

Previous beyond design basis events in Japan

There have been two previous earthquakes in Japan that have shaken nuclear power plants to a greater degree than they were designed for.

In August 2005 the Onagawa Nuclear Power Station experienced earthquake ground motion exceeding the design basis earthquake ground motion. A minor leakage of gas was reported, but no damage to the reactor systems.

The Kashiwazaki-Kariwa Nuclear Power is the largest nuclear generating station in the world by net electrical power rating. It was approximately 15 miles from the epicenter of the second strongest earthquake at that time to have ever occurred at a nuclear plant, the 6.6 M_W July 2007 Chūetsu offshore earthquake. This shook the plant beyond design basis and initiated an extended shutdown for inspection, which indicated that greater earthquake-provision was needed before operation could be resumed. The plant was completely shut down for 21 months following the earthquake, whilst its safety was re-evaluated. Three of the seven reactors were still shut down when Japan was hit by the March 11 2011 earthquake. The owner had already suffered financially due to an estimated $7b loss of generation at Kashiwazaki-Kariwa prior to the direct loss of $15b due to four reactors at Fukushima Dai-ichi being written off following the March 2011 tsunami.

The Japanese government faces a difficult choice as to whether to approve the restart of a Kashiwazaki-Kariwa reactor shut by an earthquake in 2007 as Japan grapples with potential power shortages after the March 2011 earthquake.

International reaction

In Japan the government's cabinet is divided on the nuclear question. Former Prime Minister Kan, who resigned in August, had proposed to scrap the construction of 14 new nuclear reactors, and to phase out nuclear generation completely.

In the USA the Nuclear Regulatory Commission is considering a major and systematic overhaul of its prescriptive regulatory framework, which has developed in a somewhat piecemeal manner over the years, and to include new regulatory requirements for safety studies previously carried out on a voluntary basis by the nuclear industry. There is currently no requirement in the USA for a Periodic Review of existing nuclear plants, and for example the design basis flood may differ for units co-located at the same site, depending on the date of licensing.

The EU Parliament voted to require all 143 operating nuclear power units in the EU to be stress tested.

Germany has already changed its nuclear policy, shutting down 7 plants and promising to shut nuclear power entirely at an accelerated pace. An Italian nuclear power referendum was held on the 13th June 2011 and the No vote won, leading to cancellation of future nuclear power plants planned during the previous years, and creating a legally binding cancellation of future plants. Switzerland, where nuclear power currently contributes about 40% of the country's electricity generation and in which country referenda on nuclear power are close to being a national pastime, decided in May to abandon plans to build new nuclear reactors.

Possible considerations for new nuclear power plant in UK

In contrast to these hasty decisions concerning the use of nuclear power, the UK's energy policy appears measured. There is a broad ambition – articulated by the Climate Change Committee – to decarbonise the entire electricity sector by 2030, by deploying nuclear and renewables in roughly equal proportions of 40% or so. Following the events at Fukushima Dai-ichi the Government commissioned a study by Mike Weightman, Chief Inspector of Nuclear Installations. The Interim Report published on 18th May provided reassurance that a similar accident was very unlikely in the UK. Perhaps in seeking to avoid appearing too complacent the report, rather early after the events, identified lessons to be learned and further studies to be done, while many of the actions were actually already covered by ONR and the UK nuclear industry. There is a balance to be struck between learning the necessary lessons from Fukushima Dai-ichi accident and a disproportionate UK reaction, which could be misinterpreted as an insufficiently safe UK nuclear industry.

Implications for the UK nuclear industry

Commercial

On 3rd August the NDA announced the closure of the Sellafield MOX Plant (SMP), citing commercial risk following the Great East Japan Earthquake. The background was that Chubu Electric, the only major customer of SMP, had decided to comply with a Japanese Government request to shut its only nuclear power plant at Hamaoka, which has three operating units, until the utility implements measures for protection against natural disasters, including building an 18 metre high tsunami embankment. Hamaoka is unfortunately located almost directly above the subduction boundary between two plates.

Engineering

A renewed interest in Dry Flask Storage of spent nuclear fuel as a more passively safe system, has emerged.

There is a renewed interest in ensuring that hydrogen ventilation systems are robust and do indeed ventilate to a safe location.

The importance of diversity, redundancy and of segregation of safety systems remains as true as ever, but location and potential vulnerability to common cause failure must be very carefully examined.

Common cause failure

In contrast with almost all internal hazards, external hazards can simultaneously affect the whole facility, including back up safety systems and non-safety systems alike. In addition, the potential for widespread failures and hindrances to human intervention can occur. For multi-facility sites this makes the generation of safety cases more complex, and requires appropriate interface arrangements to deal with the potential domino effects. ONR expects that a safety case will demonstrate that support services and facilities such as access roads, water supplies, fire mains and site communications important to the safe operation of the nuclear plant should be designed and routed so that, in the event of any incident, sufficient capability to perform their emergency functions will remain.

Correlated natural hazards

Some of the external hazards that we design against are uncorrelated, that is to say they are independent of each other. On the other hand an earthquake and a tsunami are highly correlated.

Some of the extreme weather hazards act in concert with each other, for example, high wind and rain can often be seen to be semi-correlated, as can wind and snow.

The events at Fukushima Dai-ichi are likely to increase the attention we need to give to a combination of hazards, for example degradation of a plant by one hazard before imposition of another.

Paradoxically in Japan the earthquake had a beneficial effect on the subsequent nuclear accident at Fukushima Dai-ichi in that, without apparently causing much physical damage other than cutting off-site power, it caused the plant to be automatically shut down prior to the arrival of the tsunami, giving a useful 45 minutes of post-trip cooling before the tsunami arrived.

Periodic safety reviews

Under Nuclear Site Licence Condition 15 UK nuclear site licensees are required to conduct a periodic and systematic review and reassessment of safety cases every ten years. This review includes not only the reviews of existing plants, as part of which we have evaluated the seismic capacity of our older plants, including those which were not designed against earthquake. It also requires us to review our estimate of the external hazards, for example of actual events, including magnitude frequency values, data and methodological developments, operational feedback, and consideration of the effects of climate change over the remaining lifetime of the facility.

I recognize a need to account more systematically for the risk from beyond design basis events, including though not limited to earthquakes, and to plan a response to such severe events. I am less convinced that either external hazard determination or plant qualification against external hazards are particular learning points from Japan for ourselves.

Emergency preparedness

Probable emergency preparedness considerations include:

- Any dependency on operator actions during and following severe external hazards should be practical and, wherever possible, limited to a small number through the use of automatic systems, fail safe devices, and passive safety systems;
- Equipment to prevent flood water access into buildings (sandbags, stop logs etc) should be available;
- Access routes onto/off site for essential equipment must be clear if local flood/wind damage excludes normal routes;
- Emergency equipment to repair damaged systems following a severe external hazard must be available;
- Staff and workers that can be called upon in response to bad weather warnings to complete any necessary hazard mitigation actions, before the weather deteriorates to a level that jeopardises worker safety should be planned for; location of staff and transport routes are issues;
- Emergency control centres and access points and associated equipment against external hazards must be protected;
- A nuclear facility should be designed and operated to maintain a degree of self reliance during and following external hazards that affect the surrounding regions as well as the site; typically, the UK follows USA practice in expecting a nuclear site to remain self sufficient for a period of 72 hours;
- Readings from hardened instrumentation of key plant parameters to provide input to Operating Rules and Severe Accident Management Guidelines should

be available at a central emergency control room to facilitate accident mitigation;

- Emergency preparedness needs to consider multiple plants simultaneously in distress – a challenge for complex sites;
- Training of emergency forward response teams needs to consider operation in ambient light only.

Most of these requirements were already recognized in our Sellafield Site Seismic Emergency planning. Considering the effects on the whole site and on the surrounding region of a beyond-design basis earthquake provides a systematic stress as a surrogate for some unimagined catasphrophe.

Conclusions

As a postscript I attended the IStructE North West Annual Dinner in September. A few hours before the event the hotel venue suffered first a loss of its mains supply, followed 15 minutes later by its emergency diesel generator ceasing. The dinner was moved seamlessly to another hotel. Resilience is a matter – in proportion – not only for the nuclear industry.

At Fukushima Dai-ichi the operator was presented with a more or less complete prolonged loss of electrical power, compressed air and other services, with little hope of immediate outside assistance, and having to work in darkness with almost no instrumentation and control systems to secure the safety of six reactors, six nuclear fuel pools, a common fuel pool and dry cask storage facilities. The accident has shown the need for mobile power, compressed air and water supplies to be provided in a safe place. Hardened instrumentation of key plant parameters is required and with the information to be available at a hardened Emergency Centre. Emergency planning should consider multiple plants in distress.

Loss of multiple safety systems at Fukushima Dai-ichi required improvisation, working under difficult conditions and with the additional hazards of high radiation and the risk of hydrogen explosions.

I have no doubt that a UK work-force would be equally heroic and ingenious as that in Japan, but the industry is learning and applying lessons from Fukushima Dai-ichi to minimise the likelihood of people being called upon to do so. As defence in depth staff must be also provided with all necessary training and equipment to do what may be required in the highly unlikely event of a comparable accident. We will honour the inspirational achievements of workers at Fukushima Dai-ichi by implementing the hard-earned lessons.

Postscript

After this article had been submitted to the Editor, ONR on 11th October 2011 published its Final Report. The report is more categorical as to the Great East Japan earthquake and associated tsunami being far beyond the most extreme natural events that the UK would be expected to experience. It is more ready to identify that the Japanese did not sufficiently protect against what might be considered a design basis event, and to comment on both a lack of clarity and independence of the Japanese nuclear safety regulator. Of particular interest to SECED is a new recommendation, that I had regarded as likely, concerning probabilistic safety analysis including a full range of external hazards and beyond design basis events. Depending on how this is implemented it may prove contentious in some quarters and may prove expensive to the industry. I commend those in high hazard industries to reading the report.

Acknowledgements

The author acknowledges the use of photographs by Stuart Fraser / EEFIT and TEPCO.

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[4] Office of Nuclear Regulation: 2011: Japanese earthquake and tsunami: Implications for the UK nuclear industry. Final Report

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 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. For further information about SECED contact: The Secretary, SECED, Institution of Civil Engineers, One Great George Street, London, SW1P 3AA, UK. Or visit the SECED website: http://www.seced.org.uk

Notable Earthquakes April – June 2011

Reported by British Geological Survey

Issued by: Davie Galloway, British Geological Survey, September 2011.
Non British Earthquake Data supplied by The United States Geological Survey.

			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	M_L	M_b	M_W	Location
2011	01	APR	02:34	53.83N	2.98W	2	2.3			BLACKPOOL, LANCASHIRE
Felt Blackpool, Preston and surrounding areas (4 EMS).										
2011	03	APR	20:06	9.83S	107.72E	14			6.8	JAVA, INDONESIA
2011	07	APR	13:11	17.44N	93.92W	167			6.7	VERACRUZ, MEXICO
2011	07	APR	14:32	38.28N	141.57E	42			7.1	HONSHU, JAPAN
2011	08	APR	13:55	53.53N	2.59W	14	1.8			WIGAN, GTR MANCHESTER
2011	11	APR	08:16	36.99N	140.41E	11			6.6	HONSHU, JAPAN
2011	18	APR	13:03	34.35S	179.85E	86			6.6	KERMADEC ISLANDS
2011	22	APR	17:26	60.61N	0.21W	7	1.9			SHETLAND ISLANDS
2011	23	APR	04:16	10.37S	161.22E	79			6.8	SOLOMON ISLANDS
2011	28	APR	21:26	56.39N	5.70W	15	2.1			MULL, ARGYLL & BUTE
Felt Mull and Oban (3 EMS).										
2011	01	MAY	12:39	50.05N	6.64W	10	2.0			ISLES OF SCILLY
2011	10	MAY	08:55	20.25S	168.25E	11			6.9	LOYALTY ISLANDS
2011	11	MAY	16:47	37.70N	1.67W	1			5.1	SPAIN
Ten people killed and scores injured in the Lorca area.										
2011	14	MAY	06:36	61.85N	3.81W	11	1.9			NW OF SHETLAND ISLANDS
2011	15	MAY	18:37	6.13S	154.41E	40			6.5	PAPUA NEW GUINEA
2011	27	MAY	00:48	53.82N	2.97W	2	1.5			BLACKPOOL, LANCASHIRE
Felt Poulton-le-Fylde (3EMS).										
2011	28	MAY	08:48	57.76N	4.66W	8	1.5			STRATHRANNOCH
2011	28	MAY	08:59	57.74N	4.64W	8	2.4			STRATHRANNOCH
2011	05	JUN	09:35	52.98S	2.16W	3	1.7			STOKE-ON-TRENT, STAFFS
Felt Stoke-on-Trent (3 EMS).										
2011	08	JUN	01:53	43.02N	88.25E	21		5.3		XINJIANG, CHINA
At least eight people injured, 50 homes damaged and several landslides in the Dabancheng District.										
2011	13	JUN	02:20	43.56S	172.74W	6			5.9	CHRISTCHURCH, NZ
At least 45 people injured, over 100 buildings destroyed or damaged, many roads damaged, widespread liquefaction and many landslides reported in the Christchurch/Lyttelton area.										
2011	20	JUN	16:36	21.70S	68.23W	127			6.5	ANTOFAGASTA, CHILE
2011	22	JUN	21:50	39.98N	142.25E	6			6.7	HONSHU, JAPAN
2011	23	JUN	13:43	50.57N	3.73W	3	2.7			NEWTON ABBOT, DEVON
Felt throughout south Devon (4 EMS).										
2011	24	JUN	03:09	52.07N	171.84W	52			7.2	ALEUTIAN ISLANDS
2011	24	JUN	14:06	18.34N	72.41W	8	3.5			HAITI
Seven people injured (as a result of panic in a crowded area).										
2011	28	JUN	10:03	65.02N	0.44E	32	4.2			NORWEGIAN SEA

At the SECED evening meeting on 28th October 2009, Dr Subhamoy Bhattachary spoke on the behaviour of piles under seismic excitation. The Chairman of the meeting, Zygmunt Lubkowski, has provided the following report.

Pile design in seismic areas

Dr Subhamoy Bhattacharya made a presentation entitled "Pile design in seismic areas". The lecture covered a wide range of issues related to analysis and design of pile foundations in seismic areas. Three main areas were covered:

1. Design of piles in liquefiable soils.
2. Kinematic bending moment of piles in layered soils having large stiffness contrast where none of the layers are liquefiable.
3. Inclined piles in liquefiable soils.

However, the emphasis of his presentation was on the analysis and behaviour of piles in liquefiable soils. The presentation started with a historical broad brush review on the failure of civil engineering structures. It was argued that when failures occurred in the past it was mostly due to load omission rather than inadequate factors of safety. The examples of the failure of the gas pipeline from Jamuna Bridge (Bangladesh), the Tay Bridge (Dundee, Scotland) disaster and the Tasman Bridge (Australia) collapse were considered. In each of the cases, some load or load effects were missed by the designers. Then a comment was made that if the correct mechanism of failure is considered in design, failure is unlikely unless loads are severely underestimated. This is due to the robustness of the design procedure, i.e. built in factors of safety in the design procedure to take into account uncertainties in load estimation, limits in material stress and practical factors such as minimum number of reinforcement bars, or the minimum amount of reinforcements to safeguard against shrinkage of concrete. He took an example of a typical pile design and showed that, if any code of practice is considered, factor of safety against plastic yielding (i.e. plastic hinge formation) is of the order of 4 to 8. He then showed examples of pile failure from previous earthquakes (1964 to 2004) highlighting the hinge formations and the general pattern of failures. His main point was that something is missing in the current methods of design.

The major codes of pile design (EC8, JRA, NEHRP and IS 1893) were reviewed. Dr Bhattacharya's argument was that piles in liquefiable soils are in most cases designed as laterally loaded beams, i.e. members essentially resisting bending failure. This can be substantiated by the fact that most of the piles reported in the literature are small diameter piles. He highlighted the clauses in JRA (Japanese Road Association) code which was revised following the 1995 Kobe earthquake. He noted that, following 1995 Kobe earthquake, lateral spreading of the ground (downward slope movement) has been reported to be the main source of distress in piles which led the Japanese Code of Practice (JRA 1996 or 2002) to advise engineers to design piles against bending failure assuming that a non-liquefied crust exerts passive pressure and the liquefied soil applies a lateral pressure of 30% of the total overburden pressure to the pile. He also noted that Eurocode 8 advises designers to design piles against bending due to inertia and kinematic forces arising from the deformation of the surrounding soil, recommending that piles should be designed to remain elastic, but that the sections at the pile cap and at the interfaces between layers of soil with markedly different properties should have the capacity to form plastic hinges. Other codes, such as NEHRP code and Indian Code [IS 1893, 2002] also focus on bending strength of the pile.

He then put forward his theory; Bhattacharya (2003) and Bhattacharya *et al* (2004) argue that piles become laterally unsupported in the liquefiable zone during strong shaking which may lead to buckling type instability failure mechanism under the action of axial load acting on the pile at all times. Essentially, the soil around the pile liquefies and loses much of its stiffness and strength, so the pile now acts as an unsupported long slender column and simply buckles under the action of the vertical superstructure (building) loads. The stress in the pile section will initially be within the elastic range, and the buckling length will be the entire length in the liquefied soil. Lateral loading, due to slope movement, inertia or out-of-line straightness, will increase lateral deflections, which in turn can cause the formation

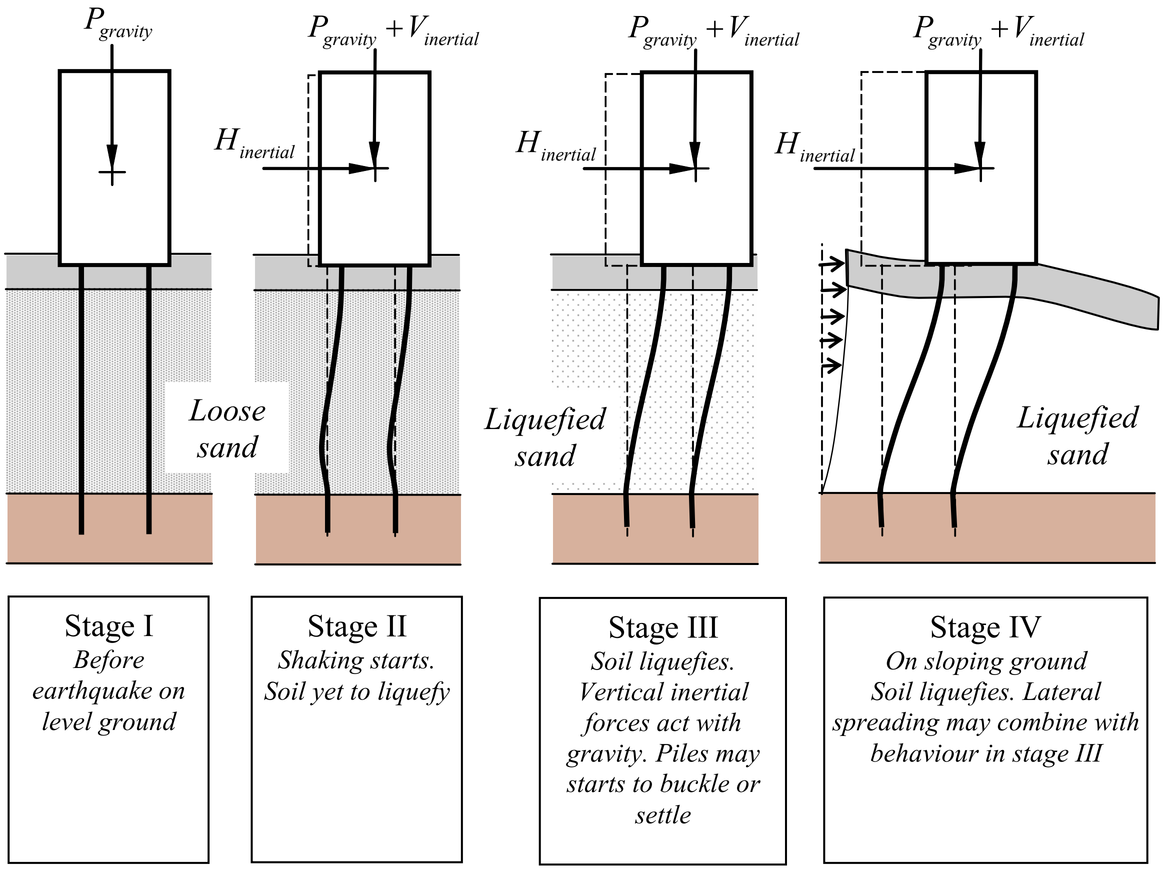

Figure 1. Various stages of loading (Bhattacharya *et al*, 2009).

of a plastic hinge, reducing the buckling load, and promoting more rapid collapse. He mentioned that this theory has later been verified by other researchers; see for example Lin *et al* (2005), Kimura and Tokimatsu (2007), Shanker *et al* (2007), Knappett and Madabhushi (2005). Figure 1 shows the various loading regimes that affect the pile stresses, and further details can be found in Bhattacharya et al (2008).

He showed the analysis of 14 case histories of pile foundation performance (from various historic earthquakes) assuming that the pile is an unsupported slender column in the liquefiable zone. He plotted the variation of two parameters (Figure 2): L_{eff}, the effective buckling length of the pile in the liquefiable zone (i.e. Euler's equivalent pin-ended strut), and r_{min}, the minimum radius of gyration of the pile, i.e.

$$r_{min} = \sqrt{\frac{I}{A}}$$

where I is the minimum second moment of area and A is the area of the pile. Obviously, L_{eff} is based on the boundary condition of the pile below and above the liquefiable zone and is necessary to normalise the pile length. Six of the piled foundations were found to survive while the others suffered severe damage. Details can be found in Bhattacharya *et al* (2005).

The study of case histories showed that a line representing a slenderness ratio L_{eff}/r_{min} of 50 can distinguish between unacceptable and acceptable pile performance. This line is of some significance in structural engineering, as it is often used to distinguish between "long" and "short" columns. Columns having slenderness ratios below 50 are expected to fail by plastic squashing whereas those above 50 are

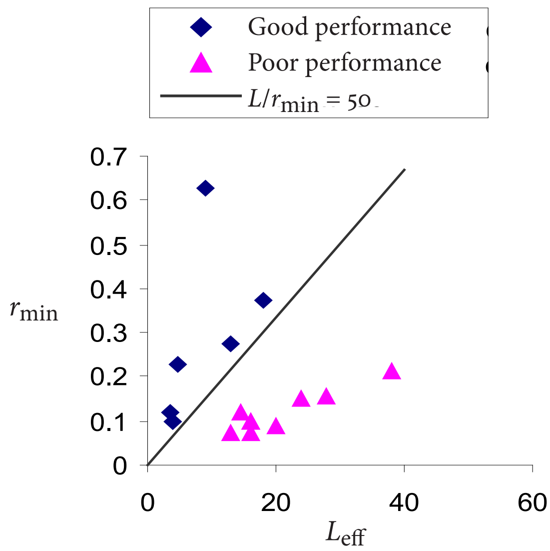

Figure 2. Performance of 14 pile foundations in liquefiable soils: plot of L_{eff} and r_{min}.

expected to fail by buckling, both modes being modified by induced bending moments. This slenderness ratio of 50 signifies length to diameter of about 12 for RCC columns. This suggests that piles in liquefiable soil should be designed as axially loaded columns carrying lateral loads, i.e. stiffness design.

Dr Bhattacharya then pointed out that while buckling mechanisms may be used to classify pile failures, the location of hinge formation or cracks in the piles (cracks or hinges forms at various depths along the length of the pile) cannot be explained by buckling instability theory or bending theory. This led to the search of any other mechanisms of failure.

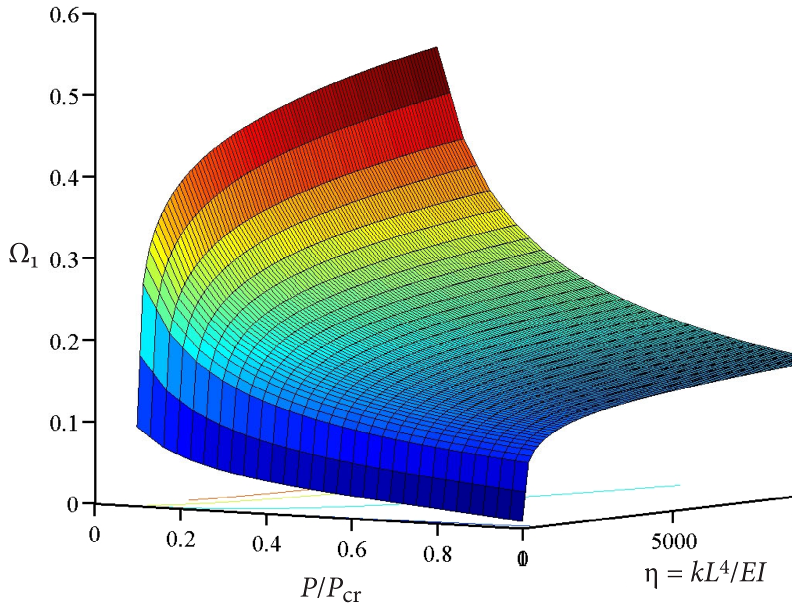

Figure 3. Variation of normalised first natural frequency Ω_1 due to normalised support stiffness η and normalised axial load P/P_{cr}.

The next thrust of Bhattacharya's argument was to consider the dynamics of the system and its link with instability phenomena. He argued that buckling of slender columns can be viewed as a complete loss of lateral stiffness to resist deformation. During liquefaction, if a pile buckles, it can be concluded that the lateral stiffness of the pile is lost. From a dynamics point of view, as the applied axial load approaches the buckling load it can also be observed that the fundamental natural frequency of the system drops to zero (Thompson and Hunt, 1984). Essentially, at the point where the natural frequency drops to zero, the inertial actions on the system no longer contribute. Thus, the system's dynamical equations of motion degenerate into a statics stability problem.

In pile context, during seismic liquefaction, the axial load on the pile in the liquefied zone increases due to the loss of shaft resistance. Due to this extra axial load, the stiffness of the pile-soil system reduces and so do the vibration frequencies. At the point of instability the fundamental vibration mode and buckling mode shapes are identical. Thus, as the soil transforms from solid to a fluid-like material, i.e. from partial-liquefaction stage to full-liquefaction stage, the modal frequencies and shapes of the pile change.

Considering the first natural frequency of the pile-soil-superstructure system, Dr Bhattacharya argued that another mechanism may probably be two effects, arising from the removal of the lateral support offered by the soil to the pile while in liquefied state, which are:

- increase in axial load in the pile in the potentially unsupported zone due to loss of shaft resistance;
- dynamics of pile-supported structure due to frequency dependent force arising from the shaking of the bedrock and the surrounding soil than can cause dynamic amplification of pile head displacements leading to resonance type failure.

Essentially, under service conditions (no earthquake and no liquefaction) the first natural frequency of a structure or the fundamental time period can be estimated without considering the effect of the piles. Typically, for a 5 storey building, the fundamental time period is about 0.5 sec which is calculated based on overall dimensions of the building. The first natural frequency is therefore 2 Hz. However when the soil starts to liquefy, the piles become an integral part of the structure and take part in the vibration. As a result, the time period alters significantly and cannot be ignored in analysis/design. For a particular case considered in the presentation, the time period increased to 4 sec, i.e. the frequency dropped to about 0.25 Hz. Bhattacharya noted that in most cases, the frequency will decrease. He referred to the paper, Bhattacharya *et al* (2009), where the first natural frequency of a pile foundation-soil-superstructure is quantified due to the effects of (1) axial force, (2) dynamic excitation and (3) reduction of the lateral support due to liquefaction. Figure 3 shows the variation of the first natural frequency (Ω_1) due to variation of normalised support stiffness (η) and Euler load ratio (P/P_{cr}). This can be used for design purposes.

Dr Bhattacharya then discussed the methods of analysis of piles based on the popular *p-y* method (beams on non-linear elastic foundation or Winkler foundation). He highlighted the importance of the shape of the load-displacement (*p-y*) curve. Figure 4 shows the current shape of a *p-y* curve for liquefied soil (either proposed or currently being used). He argued that the shape of the *p-y* curve should resemble the stress-strain curve of the soil under consideration. Based on the study of element testing of liquefied soil and model testing and full scale testing, he suggested that the shape of the *p-y* curve should be concave upward as shown in Figure 5. Details of the shape of the *p-y* curve can be found in Dash *et al* (2009). He then elucidated the implications of the *p-y* curve on the small-amplitude-vibration analysis of a pile-supported structure (Figure 6). The main parameters of a load-displacement relationship (*p-y* curve) are the stiffness and strength of liquefied soil. The stiffness of the soil, i.e. the initial tangent stiffness of the *p-y* curve, is the resistance of soil to unit pile deformation. Under non-liquefied conditions, when the differential soil-pile movement is small (i.e. the soil is not pushed to its full capacity), the resistance on the pile depends on the initial stiffness of the soil and the value of deflection (Figure 6a). In contrast, the strength of soil is an important parameter when dealing with high amplitude soil-pile interaction. In other words, when the differential soil-pile movement is large, the resistance offered by soil on the pile is governed by the ultimate strength of the soil (Figure 6a). For liquefied soil (Figure 6b), the pile response will be different for small and large amplitude vibrations. The lack of initial stiffness and strength of the liquefied soil will increase the *P*-Δ effect for small amplitude vibration, and may promote a buckling mode of failure. He stressed the importance of further research.

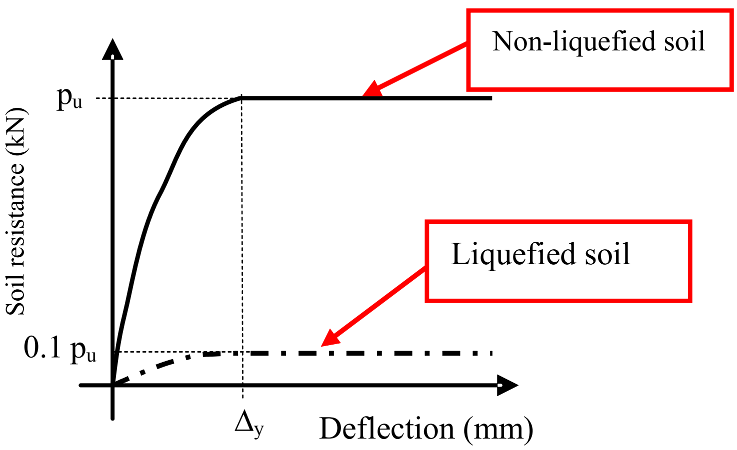

Figure 4. Shape of *p-y* curve.

Following the study of piles in liquefiable soil, he described the work on kinematic bending moments of piles in layered soil using the shaking table at the University of Bristol. This research is in the main frame of ReLUIS (La Rete dei Laboratori Universitari di Ingegneria Sismica) funded by DPC (Department of Civil Protection, Italy) carried out as a joint research amongst the University of Sannio (Italy), University of Bristol (United Kingdom) and University of Patras (Greece). The experimental part is developed at University of Bristol, and over 600 tests were carried out to physically test a soil-pile-superstructure model with various boundary conditions of the superstructure and the pile head. Three types of real Italian input motion (Sturno, Tolmezzo and Norcia) with three different scales (1:2, 1:12 and 1:5) were used in these tests. The soil consisted of two layers with varied stiffness contrast. Typical test results were shown and can also be found in Dihoru *et al* (2009). The experimental results show that the soil-pile kinematic interaction is strongly influenced by the soil deposit configuration, in particular by the stiffness ratio between the layers. Tests carried out for different seismic inputs and at different frequency scales show that the bending moment magnitude is affected by both the frequency and the energy content of the seismic input. The fixing of the end of the pile and the presence of the superstructure change the pattern of the bending moment diagram, with maximum moment migrating towards the top of the pile. Figure 7 shows the diagram of the experimental setup.

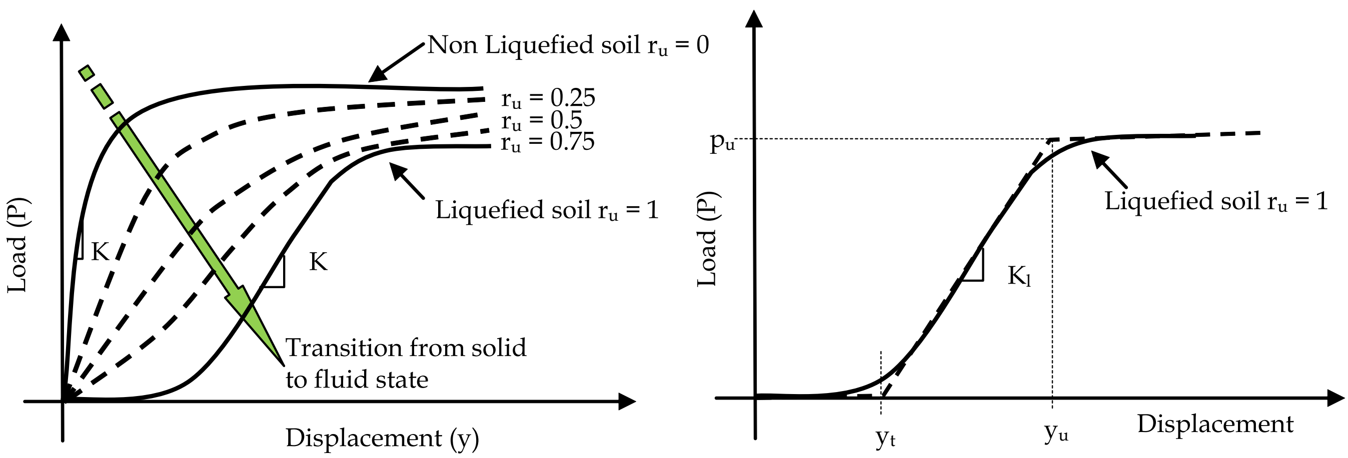

Figure 5. (a) *p-y* curve for saturated sandy soil during the process of liquefaction ; (b) Simplified *p-y* curve for liquefied soil (Dash *et al*, 2008).

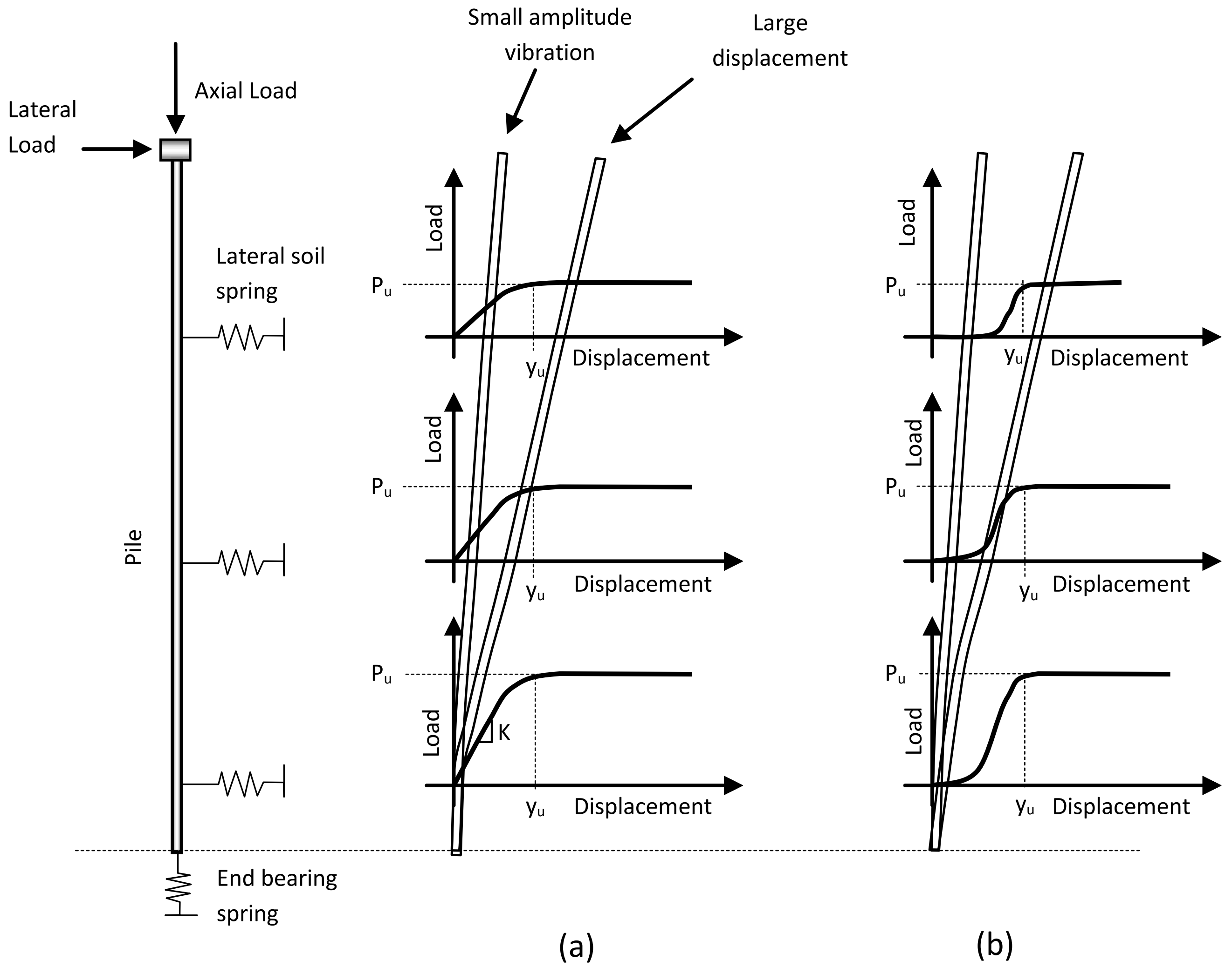

Figure 6. Design implications based on the shape of *p-y* curves (Dash *et al*, 2009): (a) pile response in non-liquefiable soil; (b) pile response in liquefied soil.

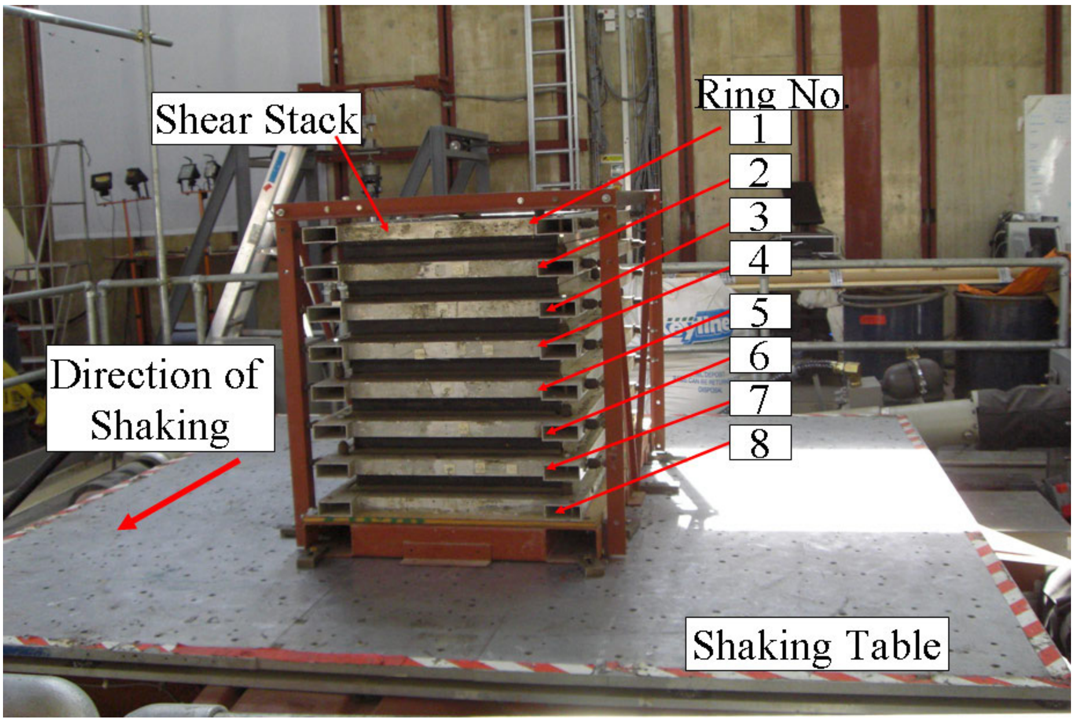

Figure 7. Shear stack in Bristol.

The third and final topic was the behaviour of raked piles in liquefiable soils. He showed some centrifuge test results carried out in collaboration with Shimizu Corporation (Japan) to study the behaviour of raked piles (Bhattacharya *et al*, 2009b). He stressed the confusion in the profession regarding the use of raked piles, i.e. whether they are beneficial. Many codes of practice prohibit the use of raked piles. His conclusions were:

- Raked piles are always stiffer than the corresponding vertical piles. Raked piles in liquefiable soils are dynamically sensitive due to the drop of natural frequency as soil liquefies.
- If properly designed raked piles can be beneficial as they limit the pile head displacements.

Acknowledgements
Dr Bhattacharya gratefully acknowledged the support and contributions from a wide range of people: past and present colleagues Mr Tom Aldridge (Fugro Limited), Dr H.J.Burd (Oxford Univ.) Dr N.Alexander (Univ. of Bristol), Prof David Muir Wood (Univ. of Bristol) and Prof C.A.Taylor (Univ. of Bristol); collaborators Dr A. Blakeborough (Oxford Univ.), Dr S.P.G.Madabhushi (Univ. of Cambridge), Prof S.Adhikari (Univ. of Wales, Swansea), Dr G.L.Sivakumar Babu (I.I.Sc, Bangalore), Dr Barnali Ghosh (Arup, London), Dr L.Dihoru (Univ. of Bristol), Prof Armando Simonelli (Univ. of Sannio, Italy), Prof Kohji Tokimatsu (Tokyo Institute of Technology), Prof George Mylonakis (Univ. of Patras, Greece) and Dr T.Tazoh (Shimizu Corporation, Tokyo); past and present students Ms Freya Kumm (Arup, Bristol), Mr Adri Kerciku (Arup, London), Mr Suresh Dash, Mr Domenico Lombardi, Mr Will Wholey, Ms Chandra Raman Devi, Mr Harry Norton, Dr Sumanta Halder (IIT Bhubaneswar) and Mr Pijush Samui; and finally his mentors Prof Malcolm Bolton (Univ. of Cambridge) and Prof Guy Houlsby (Univ. of Oxford).

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Forthcoming events

Date	Venue	Title	People
30/11/2011 at 18:00	Imperial College London South Kensington Campus	*Capability of faults*	*Speaker*: **Tim Wright** (University of Leeds) *Organiser*: **Clark Fenton** (Imperial College London)
25/01/2012 at 18:00	Imperial College London South Kensington Campus	*The origins of subduction zones and tsunamis*	*Speaker*: **Lisa McNeil** (National Oceanography Centre) *Organiser*: **Clark Fenton** (Imperial College London)
29/02/2012 at 18:00	Imperial College London South Kensington Campus	*Seismic assessment of existing and new equipment by experience-based methods*	*Speakers*: **Malcolm Goodwin, Ian Sharrock & Steve Horrocks** (ABS Consulting) *Organiser*: **Paul Doyle** (Jacobs)

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EEFIT report on Haiti earthquake

EEFIT's report on last year's earthquake in Haiti has now been published, and is freely downloadable from the EEFIT website (www.EEFIT.org.uk), which is managed by the Institution of Structural Engineers as part of their support to EEFIT. The mission to Haiti presented special difficulties, because of the uncertain security situation in and around the capital; official advice at the time of EEFIT's visit (April 2010) was against all but essential travel. The mission also differed from previous EEFIT missions, in that its main effort was directed towards a single issue, the 'ground truthing' of damage descriptions obtained from satellite and aerial photos. The Haiti earthquake presented a unique opportunity for this, because very extensive use had been made of remote images when planning the vast relief effort needed, but no detailed studies had been carried out to establish how reliable assessments made from remote images really were. The EEFIT team of three (Edmund Booth, Keiko Saito and Gopal Madabhushi) were able to make detailed comparison between damage ratings made on the ground from field observations and those based on remote images, and the report gives their findings and conclusions. The report covers other issues, too, presenting important findings on geotechnical issues, particularly relating to liquefaction, on structural performance, including that of Port-au-Prince's late nineteenth century Iron Market, on damage distribution patterns, and on the conduct of a field mission in a problematic security situation. A searchable archive of EEFIT's several hundred survey photos has been prepared, for access via the EEFIT website, complete with damage descriptions and exact geographical locations.

Publication is expected later this year of the EEFIT reports on the earthquakes in Tohoku, Japan (currently under peer review) and Christchurch, New Zealand.

SECED Newsletter

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