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THE NORTHRIDGE EARTHQUAKE OF JANUARY 17, 1994

The Northridge earthquake, a magnitude 6.6 event, struck at 4.30am Pacific Standard Time (GMT minus 8 hours) on Monday 17 January 1994. The hypocentre was directly under the Northridge district, in the San Fernando Valley area of Los Angeles. The earthquake caused extensive damage to buildings and bridges in the Valley and also some pockets of damage in northern parts of the Los Angeles Basin. The death toll from the quake is around 61. There are numerous injured and around 15,000 have been camping out because of damage to their houses or apartments. Early estimates of the cost of the earthquake vary widely, but the most commonly quoted figure is $30 billion.

A field mission organised by the UK Earthquake Field Investigation Team (EEFIT) departed for Los Angeles ten days after the quake. Prior to this, EEFIT member Martin Williams visited the area as part of a Canadian team between 19 and 22 January. Such an early arrival date gave the team the opportunity to inspect a number of bridges and buildings which have since been very rapidly demolished. This brief early reconnaissance and the main EEFIT mission are expected to fulfil complementary roles, enabling a very full picture of the earthquake to be built up.

This report is based on the early reconnaissance exercise. It is not a comprehensive account of the

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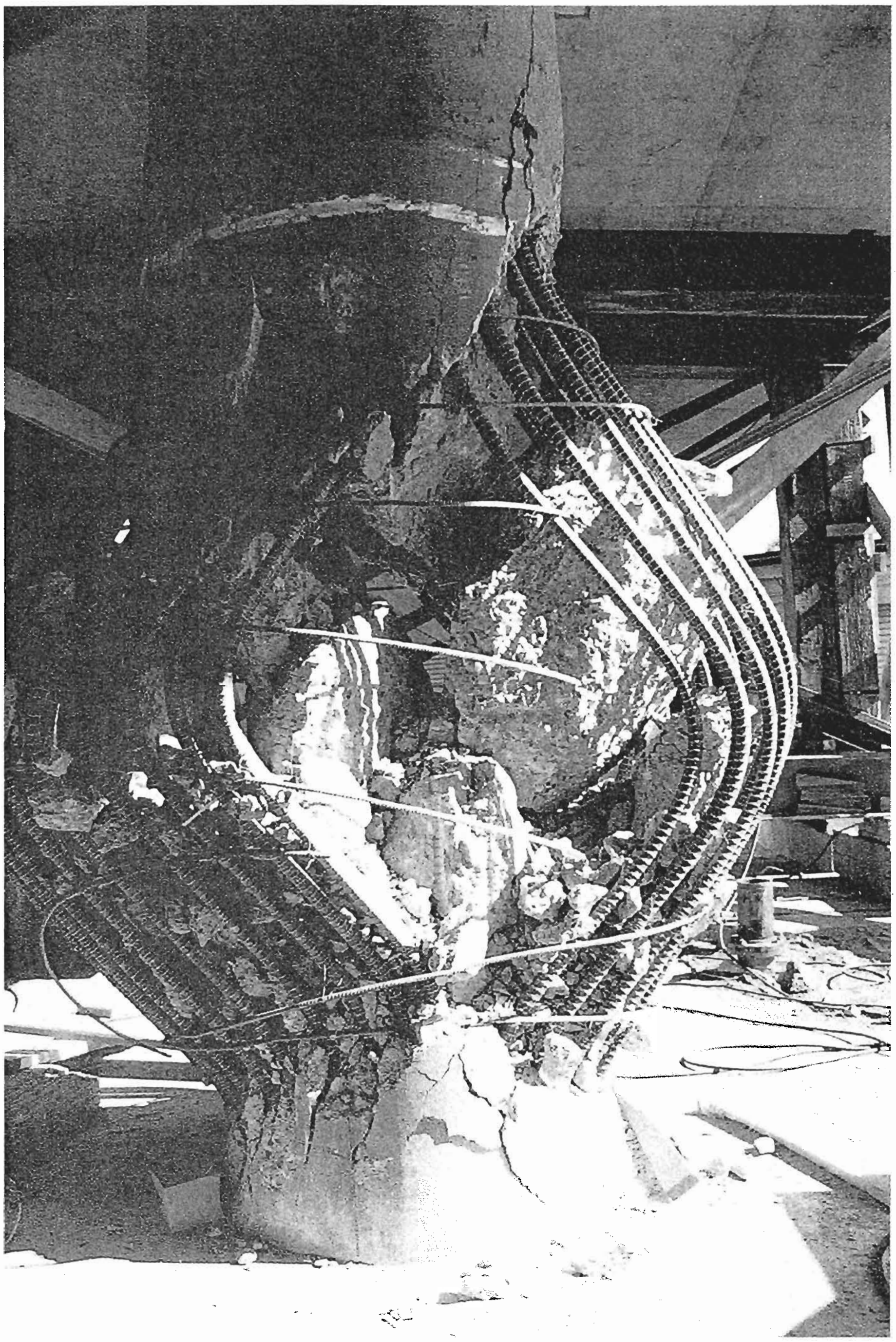


Right: Shattered highway bridge support column

*The Northridge Earthquake
continued from page 2*

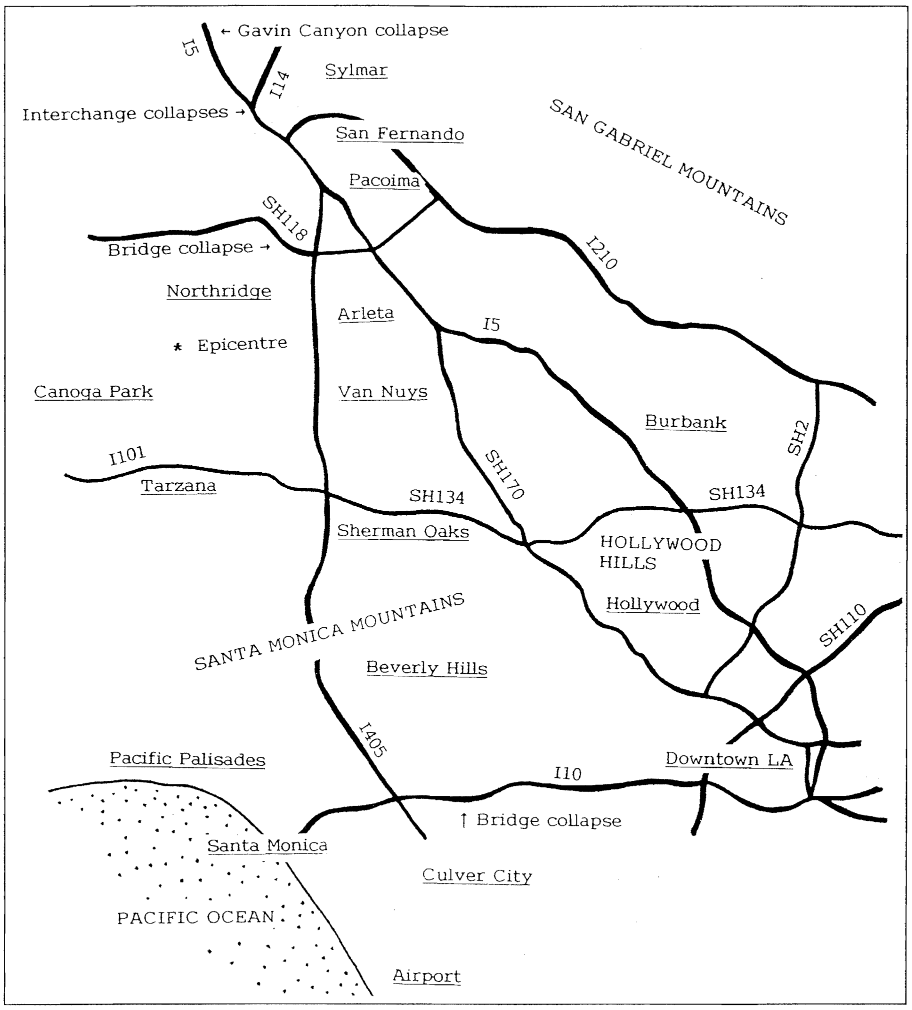
earthquake, and will be supplemented by subsequent EEFIT publications.

The Affected Area

The figure right shows a general view of the central and northern parts of Los Angeles, indicating the main areas of building and freeway damage. The majority of the city is situated in a large basin, which is separated from the San Fernando Valley to the north by the Santa Monica Mountains. LA is famous for the freeways which link the city's numerous widely spread districts. Frequently these have long elevated sections, and there are numerous complex, multi-level interchanges.

LA is in a very active seismic region and has suffered numerous earthquakes in recent years. The last major event in the Valley was the 1971 magnitude 6.6 San Fernando earthquake, which caused considerable damage to both buildings and bridges and resulted in a number of changes in design practice. In particular the high number of bridge failures at expansion joints prompted the introduction of restrainers and increased seating widths at joints.

Most of the damage caused by the earthquake is in the San Fernando Valley. The epicentre was very close to the centre of Northridge, and it is hardly surprising that this area suffered very heavy damage. Other regions of the Valley badly affected are Van Nuys, Canoga Park, Tarzana and Sherman Oaks, particularly along Ventura Boulevard. Outside the valley damage is very patchy. There are reports of damage in Hollywood, especially on Hollywood Boulevard, though when the team toured the area it saw very little. Santa Monica was badly affected, and there are pockets of damage going east from there along the Santa Monica Freeway. Most of the freeway collapses which dominated the early news coverage were just to the north of Northridge.



Seismology and Strong Motion

The main shock, magnitude 6.6, occurred at 4.30am (PST) on Monday 17 January 1994. The epicentre is estimated to be 34° 12.9′ north, 118° 32.2′ west. In terms of streets, this is on Roscoe between Reseda and Lindley, approximately 1.5km south of the centre of Northridge. The focal depth was 14.6km. The exact identity of the fault which caused the quake remains uncertain at the time of writing - a preliminary interpretative cross-section produced by USGS is shown in the figure on page 3. A number of small surface cracks have been identified, and there continues to be some debate as to whether these are fault breaks. It is clear that there is no major surface rupture.

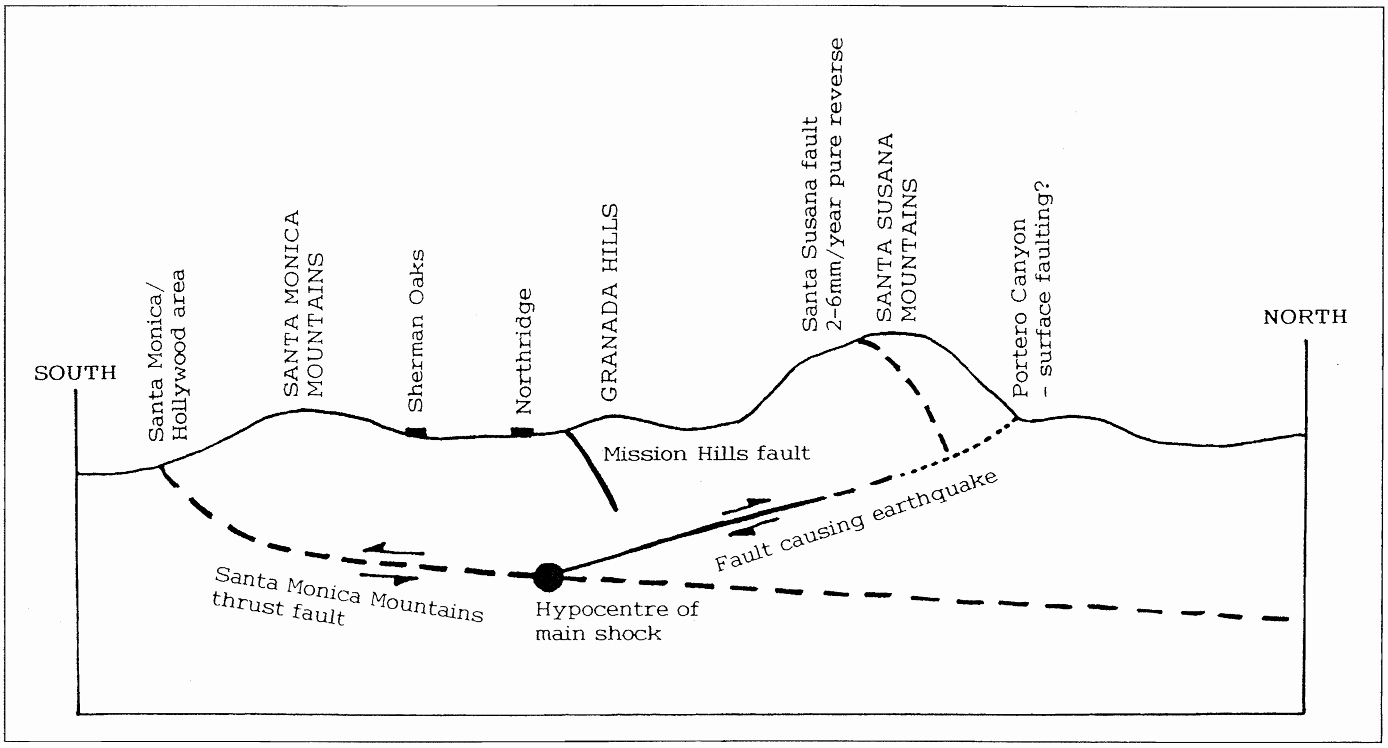
There are numerous free-field acceleration records of the main shock; a selection of peak values is shown in the table below.

Table 1. Peak free-field accelerations at selected locations, measured by California Strong Motion Instrumentation Program. Refer to key plan for approximate locations.

Location	Epicentral distance (km)	Peak Accelerations	
		Horizontal (direction)	Vertical
Tarzana	7	1.82g (EW)	1.18g
Arleta	9	0.35g (EW)	0.59g
Sylmar	15	0.91g (EW)	0.60g
Pacoima	17	0.44g (NS)	0.19g
Hollywood	23	0.41g (NS)	0.19g
Downtown LA	32	0.19g (NS)	0.10g

The closest station, in Tarzana, recorded extremely high peak accelerations in excess of 1g were sustained for over 8 seconds. However, this is thought to be an exceptional site; the instrument is situated on a small hill, and it seems likely that some unusual topographical effects were responsible. The site also gave very high readings in the 1987 Whittier earthquake. Given that this was known to be a peculiar site, it would have been interesting to have installed an additional instrument at the bottom of the hill in order to provide some values for comparison, but regrettably this has not been done. Surprisingly, when the team visited the site a selection of timber and unreinforced masonry buildings immediately adjacent to the instrument showed very little damage.

The other records suggest that peak horizontal accelerations were of the order of 0.4g in most parts of the Valley, the exception being Sylmar, where a peak of 0.91g was obtained. Several stations indicated very large vertical accelerations. The records from two of the closest stations, Arleta



Above: Preliminary cross-section showing faulting responsible for the earthquake (source: USGS).
Left: Map of central and northern Los Angeles, showing the most severely affected areas.

and Pacoima, are shown overleaf. The frequency content of these signals are roughly typical of the majority of the records so far recovered. The Tarzana record appears to differ from the others in terms of its relatively high frequency content as well as its large amplitude. At the time of writing, no spectra are available.

There have been numerous quite strong aftershocks, with epicentres moving north and spreading out both eastwards and westwards. To date two of these have been of magnitude greater than 5, and a very large number have been greater than 4. The pattern of aftershocks is roughly as would be expected, slightly more energetic.

Bridges

There appear to have been about ten major freeway bridges which suffered severe damage or collapse. Surprisingly, many of these were caused by the opening up of expansion joints due to inadequate restrainers and/or seating widths. This problem has been well understood since the San Fernando quake in 1971, and has been accounted for in both design and retrofit. At Loma Prieta in 1989, joint restrainers performed very well. It is likely that the bridges that failed in this manner at Northridge were constructed or retrofitted quite soon after the San Fernando event, with more recently built restrainers being more substantial. It could be argued that Caltrans simply did not have the time or the resources to bring all its bridges up to existing standards in this respect before the earthquake struck.

There were also a number of shear failures in piers, some pounding damage, and cracking of abutment walls. However, the vast majority of bridges were undamaged and, contrary to press reports, traffic flow problems did not appear to be severe. Caltrans has moved extremely quickly to remove badly damaged structures and get as many roads as possible open again; three days after the earthquake several bridges had already been demolished. The most notable freeway collapses were:

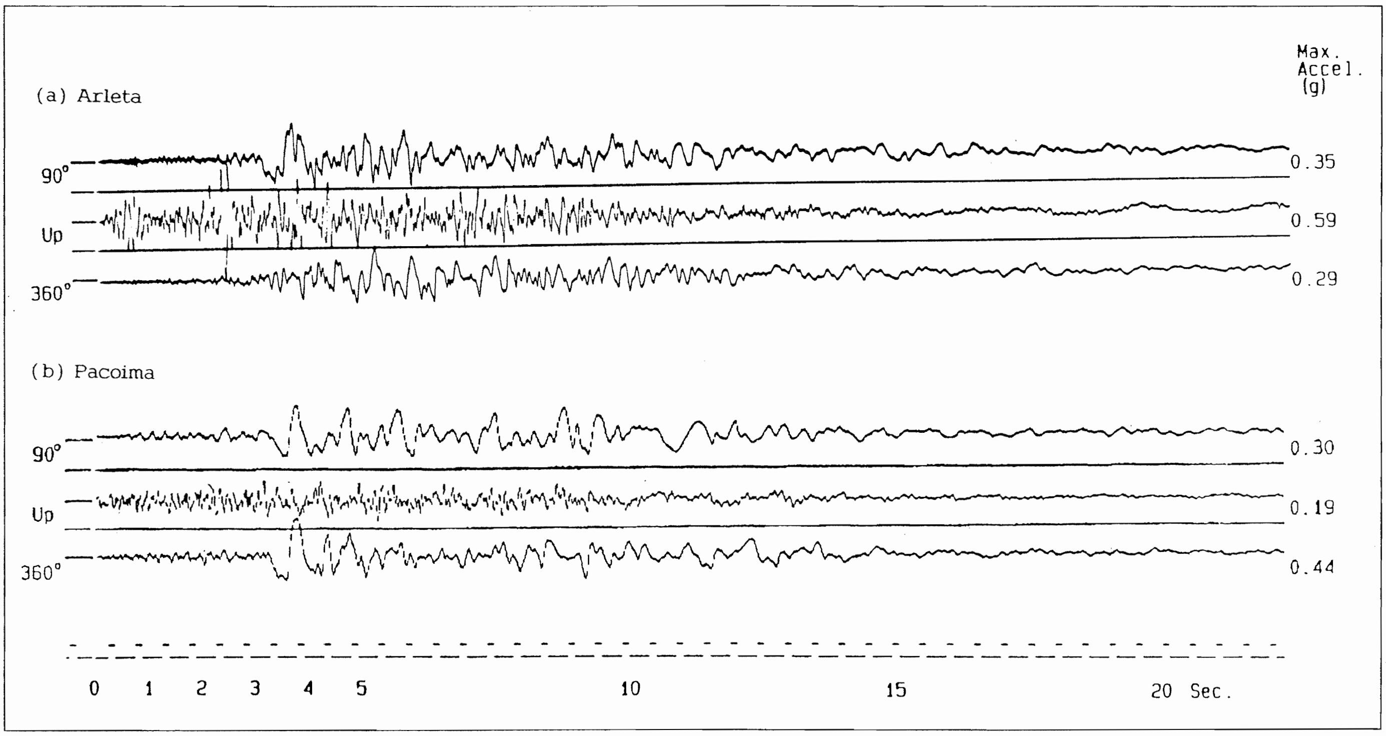
- The intersection of Interstates 5 and 14, just north of Northridge. Two elevated connecting ramps collapsed, both due to inadequate restraint and seating at joints (see page 5). A number of other elevated sections showed considerable opening of joints, not quite enough to cause collapse. Ironically, this interchange had been rebuilt following very similar damage in the 1971 San Fernando earthquake.

- The Gavin Canyon bridge, on Interstate 5, about 5km north of the intersection with Interstate 14. Again, spans collapsed due to the failure of restrainers at joints and insufficiently wide seating. This collapse has been made famous by press photographs showing vehicles stranded on a central span, with collapsed spans on either side of them.

- A two-storey interchange on Interstate 5, just south of the intersection with Interstate 210 suffered severe pounding damage where a column for the upper bridge passed through an insufficiently large opening in the lower one. From guard-rail displacements, movement of the upper deck was estimated to be in excess of 200mm.

- The overpass of State Highway 118 at San Fernando Mission collapsed due to dramatic shear failures. The columns were flared to cope with anticipated high stresses at their tops, but failed in shear just at the bottom of the flared section.

- The Balboa overpass on State Highway 118 suffered from washing out of abutment fill caused by a



Above: Free-field strong motion records measured by CSMIP at (a) Arleta, (b) Sylmar and (c) Pacoima. The angles shown are measured from due north.

Opposite: Examples of bridge failures (Damage to a transition structure at the intersection of Interstates 5 and 14. Top: Two 40mm diameter restraining bars and a seating width of 350mm were insufficient to prevent complete separation of this joint. Bottom left: This then resulted in catastrophic failure of the deck at the next support. Bottom right: State Highway 118 at San Fernando Mission. Flaring of these columns appears merely to have shifted the location of the shear failure to the bottom of the flared section.)

burst water main. There was some abutment wall cracking and pounding damage to the deck at the abutments, and spalling at the tops of the central columns.

- Interstate 10 (the Santa Monica Freeway) suffered severe sagging of several spans of an overpass at La Cienega, due to flexural and shear failures in the columns. This is thought to be an area of soft ground, which may have caused some local amplification of the shaking (Cienega is Spanish for swamp).
- There were reports of damage on Interstate 126, several miles north of Northridge, but the team was not able to visit this site.
- At the intersection of State Highways 2 and 134, access ramps were closed several days after the main shock due to the opening up of joints during aftershocks.

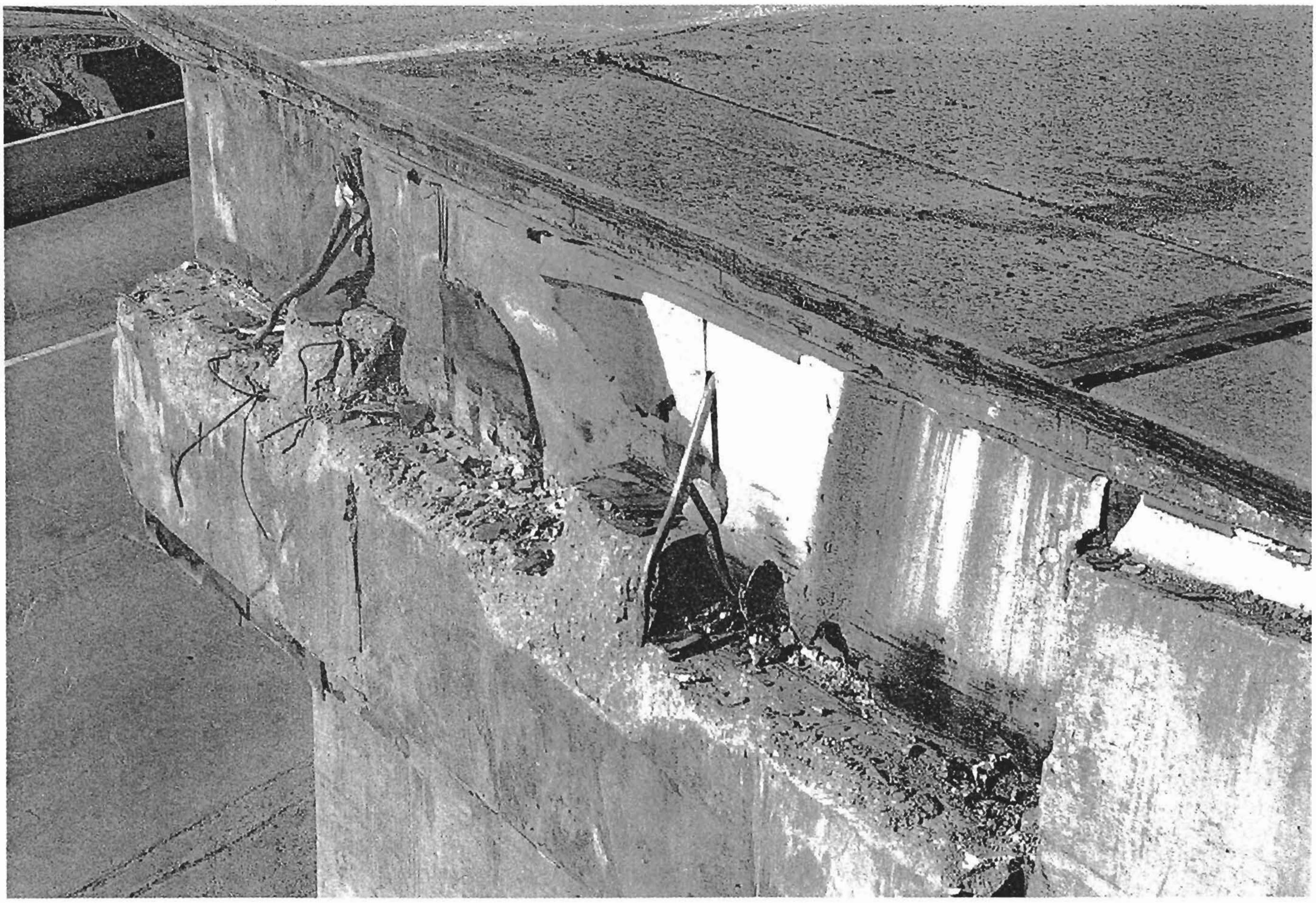
Buildings

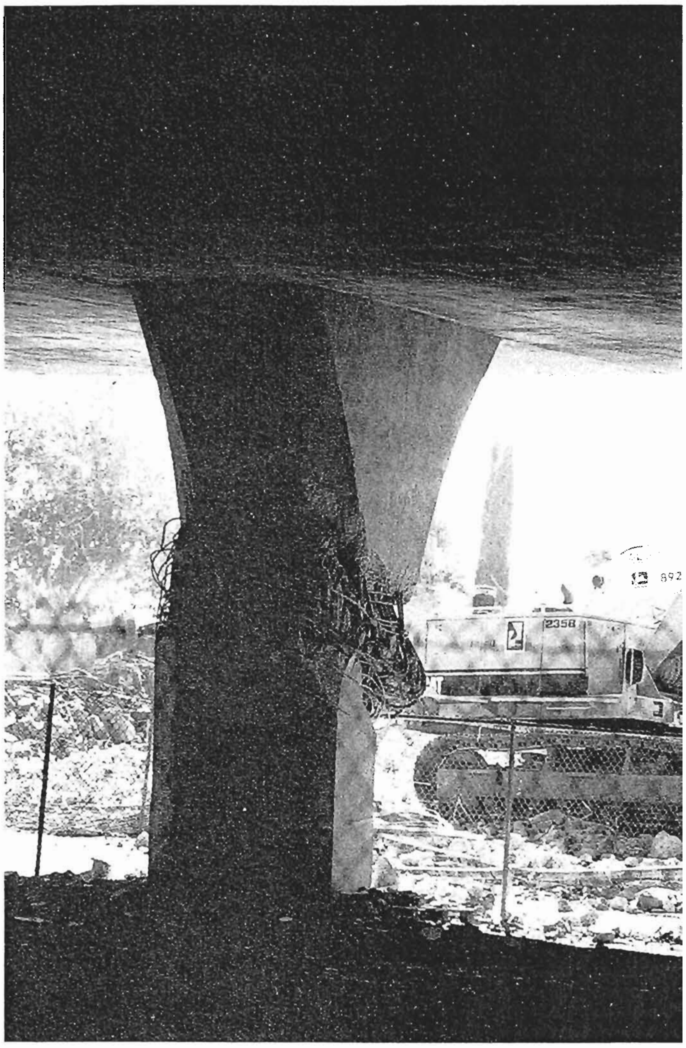
By far the worst damage to engineered buildings seems to have been concentrated in parking structures, particularly precast concrete ones. There were several spectacular collapses and numerous car parks were severely damaged. Aside from these, most of the damage to concrete buildings was unspectacular; while a large number of buildings suffered sufficient damage to make them unsafe, relatively few collapsed completely. There are very few steel buildings in LA, and virtually no damage to steel structures has been observed. Unreinforced masonry and timber houses suffered widespread damage, though again there was a quite small number of complete collapses.

The building damage was greatest in Northridge itself. The Fashion Mall shopping centre sustained severe damage, particularly to Bullock's department store. There were several apartment block collapses, mostly attributable to soft storeys, including the Northridge Meadows apartments, where sixteen people were killed. Nearly all masonry and timber houses in this area showed some signs of damage, and most boundary walls had toppled or were leaning badly. Damage at California State University at Northridge included a spectacular ductile failure of a precast concrete parking structure (see page 6), severe roof damage to the library and minor damage to a number of other structures. However, several recently constructed buildings here appeared to have performed very well.

At Van Nuys, to the east of the epicentre, there was considerable damage to masonry houses and shear failure of 4th floor columns at the Holiday Inn, a 7-storey reinforced concrete frame. Sherman Oaks, to the south-east, included several badly damaged concrete frame structures, a lot of non-structural damage to windows and shop fronts and mostly minor damage to houses, with only one or two collapses.

Outside the Valley, the worst problems appear to have occurred in the Santa Monica area. Here, several multi-storey concrete frames were sufficiently badly damaged to require demolition, and numerous unreinforced masonry structures suffered severe damage at roof level, particularly along Santa Monica Boulevard. Many of the unreinforced masonry buildings in this area had been retrofitted with varying degrees of success. Reports of widespread damage to unreinforced masonry structures in Hollywood were not confirmed by the team's brief visit to

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Above: Collapse of a parking structure at California State University, Northridge. The elements of the precast structure were inadequately tied together, giving insufficient lateral load resistance. The columns have sustained enormous deformations without shearing.

the area.

A preliminary (and non-rigorous) assessment of the damaged areas suggested that worse damage was sustained on elements spanning in the north-south direction than on those running east-west. This is in agreement with the measured accelerations at the majority of stations.

There are numerous fully instrumented buildings in the Los Angeles area, presenting some exciting opportunities to compare structural analysis predictions with measured and observed behaviour. Most of these are in the downtown Los Angeles area, some distance from the epicentre, and appear to have suffered little distress in the earthquake. However, there are also some instrumented buildings in the San Fernando Valley, and of these, two visited by the team had sustained significant damage, making them particularly interesting case studies.

Geotechnical Aspects

There were relatively few geotechnical problems caused by the earthquake. Liquefaction was observed at Redondo beach (south of LA airport) and at a parking lot at Santa Monica and Pacific Palisades, causing collapse of several clifftop houses. There were a number of landslides scattered across the LA area. All of the dams in the region appear to have performed well, although this has yet to be confirmed

Emergency Response

Several times during the team's visit to Los Angeles, we heard the sentiment expressed that the city was probably the most well-prepared for an earthquake in the world. At the time of writing, it is still too early to assess the truth of that assertion; it appears that the immediate response was very effective, but that the relief operation has subsequently run into some problems.

Immediately after the earthquake, traffic diversions were set up, fires were put out and the badly injured were quickly treated. Caltrans, in particular, moved very quickly to remove damage and get highways reopened. There was a lot of damage to water mains, and this has taken a long time to repair; six days after the earthquake most residences in the San Fernando Valley were still required to boil water. A week after the quake, tempers began to fray as the city failed to keep up with the demand for house inspections. Federal Emergency Management Agency (FEMA) offices were overwhelmed by the demand for assistance, and resorted to sending people away with appointments for the middle of February. The overall level of success of the disaster response operation is likely to remain unclear for some time yet.

Martin Williams, University of Oxford (currently on sabbatical leave at the University of British Columbia, Vancouver)

Acknowledgements

Funding for the author's visit to Northridge was provided by the SERC and by the University of British Columbia. The assistance of the Canadian Association for Earthquake Engineering, the Earthquake Engineering Research Institute and the California Office of Emergency Services is greatly appreciated.

Above: Landslides along the Pacific Coast Highway, between Santa Monica and Pacific Palisades

EARTHQUAKE IMPACT - A QUICK LOOK

Althought not the 'Big One', the M8.3 event expected in Southern California, the M6.6 Northridge Earthquake, centred 30km (18 miles) from downtown Los Angeles, may be the costliest US disaster. Early estimates of losses are approaching $30 billion. The magnitude of the potential loss raised three major issues:

1. *Was the overlying and underlying infrastructure unusually vulnerable to a moderate M6.6 earthquake, and, if so, were there geologic, seismological, engineering and public safety reasons? Will this affect the magnitude of the loss in the 'Big One'?*
2. *What would have happened to the 700,000 school children and 6 million commuters if the earthquake had occurred at 9.31am on a school and work day instead of 4.31am on a holiday?*
3. *What will be the long-term indirect cost and the impact of the devastated freeway system on the 6 million commuters and the region's economy?*

The earthquake:

- Occurred on a little known 'blind' thrust fault underlying Northridge about 20 miles from the epicentre of the 1971 M6.5 San Fernando event.
- Generated strong ground shaking throughout the major Los Angeles area with horizontal and vertical ground motions from the main shock and approximately 3,000 aftershocks during the first week ranging up to 2g.
- A test of the design criteria for engineered buildings and lifeline systems constructed since 1971 and recently developed retrofit technology for highway structures.
- Damaged portions of 11 major roads to downtown Los Angeles causing widespread traffic congestion due to rerouting around the damaged areas.
- Triggered widespread ground failure (liquefaction and landslides) causing gas and water pipelines to rupture resulting in fires, power outages and disruption of water service during the first few days.
- Damaged more than 50,000 homes and apartments causing tens of thousands to seek temporary housing.
- Damaged 150 schools throughout the area causing students to miss classes for a week.
- Damaged hospitals forcing relocation and evacuation of patients.
- Injured 6,547 and killed 61.

Walter Hays,
US Geological Survey

* * EEFIT FLIES OUT * *

EEFIT, the UK Earthquake Engineering Field Investigation Team, flew out to Los Angeles on January 27 to gather data about the Northridge earthquake from the field. The team included Peter Merriman and Ian Morris *(British Nuclear Fuels)*; Alan Gould *(Allott & Lomax)*; Gavin Trott *(R T James Ltd)*; David Smith *(Scott Wilson Kirkpatrick)*; Tony Blakeborough and Wendy Daniell *(Bristol University Earthquake Engineering Centre)*; John Owen *(Nottingham University)*; and Gopal Madabhushi *(Cambridge University)*. The team were joined by European academics Paulo Negro *(JRC Ispra)*; Guiseppe Bonacina *(ISMES, Bergamo)*; Emmanouil Vougioukas *(National Technical University, Athens)*; and Maurizio Indirli *(ENEA)*. The team plan to report shortly to the UK community of earthquake engineers.

For further information about the mission, contact the team via:

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IDNDR Conference

PROTECTING VULNERABLE COMMUNITIES

Delegates from around the world met in London last October to discuss means for protecting vulnerable communities from natural disasters. The conference was a UK contribution to the UN **International Decade for Natural Disaster Reduction**.

The three day event held at the Royal Society brought policy makers, planners, scientists and engineers together in a forum which addressed the key issues surrounding the vulnerability of communities to natural hazards. The topics included forecasting and warning; preparedness and protection; lessons learned in recovery; and technology transfer and future opportunities.

The conference maintained an aggressive pace over the three days with the conference dinner neatly slipped in at the end of the first long day. The dinner provided the occasion for the launch of the Geoff Brown memorial fund, a fund designed to support field-based projects and specialist workshops, and assist UK experts concerned with natural disaster reduction play a more active role in the International Decade.

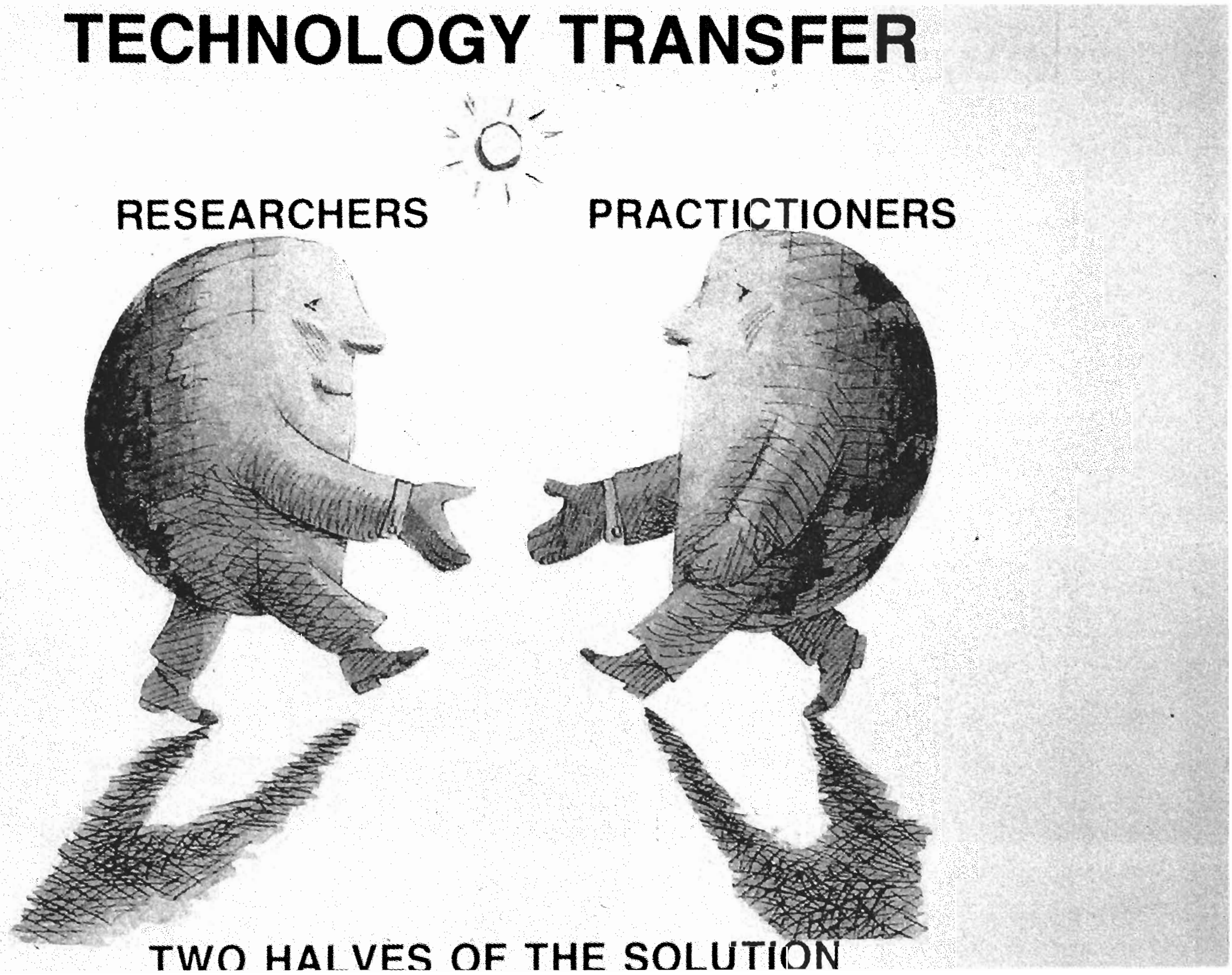
Protection against earthquakes figured prominently during the conference - rightly so since many fatalities worldwide due to natural disasters are caused by earthquakes. Two keynote speakers addressed two halves of the solution to this problem, research and application.

Robin Spence of the Martin Centre for Architectural and Urban Studies, University of Cambridge, set out a research agenda for IDNDR which was aimed to improve the assessment of vulnerability in low-income communities - an area where most risk resides worldwide. The need for systematic recording of the human dimension of earthquake loss was seen to need more emphasis than in the past. Loss estimation methods need to be calibrated to improve reliability and credibility, and cost effective ways to develop urban inventories and map damage data using state-of-the-art information technology techniques was seen to be vital in this area.

Walter Hays of the US Geological Survey presented a strategic plan to accelerate and improve worldwide transfer of available technology for natural disaster reduction. Arguably, adequate technologies are currently available to the world community, *but they are not being effectively distributed and implemented around the world.* Specific plans which identify goals, select routes, establish resources and evaluate progress are needed to achieve success. Case study examples where hazards and vulnerabilities have been properly identified and the affected communities set in a state of preparedness all show large scale benefit by the reduction of potential future earthquake loss. An opportunity to accelerate and improve such technology transfer for natural disaster reduction may never occur again. It must be seized!

For further information about the availability of the conference publication, "Protecting Vulnerable Communities", contact Rachel Coninx at the Institution of Civil Engineers, Great George Street, London SW1P 3AA, UK.

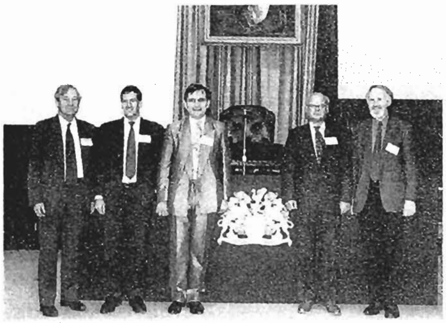
Below: Technology transfer, a major challenge for the ***International Decade for Natural Disaster Reduction*** *(courtesy Walter Hays, US Geological Survey)*



Conference Proceedings

Left: Linda Chalker, Minister for Overseas Development, sets out the UK agenda for IDNDR in the conference opening address

Below left: Robin Adams, Chris Browitt, Peter Merriman, David Oakley and Ian Davies - 5/6ths of the Organising Committee; Centre: Professor John Knill (Chairman UK IDNDR Committee), Peter Merriman (Conference Organising Committee Chairman), Mike Cottell (President of the Institution of Civil Engineers) and Baroness Cox (Conference Dinner Speaker); Right: Chris Browitt, British Geological Survey, and Janet East, Overseas Development Agency at the conference dinner.



Right: Walter Hays, US Geological Survey, stimulates the debate with concepts of worldwide technology transfer for natural disaster reduction - the way forward to make the world a safer place for the 21st Century.

Below left: Raymundo Punongbayan, Director of the Philippine Institute of Volcanology and Seismology, delivering the Conference Lecture on risk reduction - the Pinatubo experience; Centre: Stuart Mustow (now President of the Institution of Civil Engineers) introduces the studies being undertaken by the Institution of Civil Engineers in support of the IDNDR effort. The vulnerability to natural disasters of megacities is a key element of the ICE study; Below right: Professor Sir Bernard Crossland outlines the achievements of the Hazards Forum in the UK

COOPERATIVE PROGRAM FOR REDUCING EARTHQUAKE LOSSES IN THE EASTERN MEDITERRANEAN REGION (RELEMR)

The plan outlined here is based on discussions at the Seminar on Earthquake Hazards of the Eastern Mediterranean Region, which was held 16-21 October 1993 in Cairo, Egypt. It was sponsored by the U S Geological Survey and the United Nations Educational, Scientific and Cultural Organisation, and was hosted by the Egyptian Geological Survey and Mining Authority and the National Research Institute for Astronomy and Geophysics. The plan provides a framework for promoting and coordinating future earthquake studies in the Eastern Mediterranean Region.

The many destructive earthquakes experienced in the Eastern Mediterranean Region have caused enormous losses in deaths and injuries, structural damage, and socio-economic disruption. Northward drift of the Arabian plate at about 0.5 cm a year causes the earthquakes. This movement opened the Gulf of Aden and the Red Sea, caused left-lateral slip along the Dead Sea transform fault system with Aleppo and Amman moving north with respect to Cairo and Tel Aviv, and built mountains in Iran and Turkey by crustal collision.

Various mitigation and preparedness actions could substantially reduce future losses from Eastern Mediterranean Region earthquakes. This plan, entitled **Reducing Earthquake Losses in the Eastern Mediterranean Region (RELERM)**, presents these actions in the framework of seven integrated elements:

1 Seismotectonic framework studies using geological, geophysical, geodetic, seismological, archaeological and historical techniques to improve understanding of the cause and nature of the seismicity.

2 Earthquake monitoring using modern seismograph networks and strong-motion instrument arrays to determine earthquake parameters and characteristics.

3 Assessment of earthquake hazards to estimate locations, recurrence intervals, and effects of future earthquakes.

4 Assessment of risks to evaluate potential losses.

5 Implementation of earthquake risk reduction measures to reduce vulnerabilities and losses.

6 Communications to facilitate access to and exchange of information for reducing earthquake losses.

7 Awareness of the nature of the earthquake threat and options for reducing losses to improve public response.

The program activities will contribute to a broad understanding of the earthquake threat to the Eastern Mediterranean Region. The data can conveniently be structured as a master model for the Region that would provide answers to these questions:

- Where have earthquakes occurred in the past? Where will they occur in the future?
- How big (destructive) were they in the past? How big (destructive) can they be?
- How frequently might earthquakes of M 5.5 or greater recur?
- When and where is the next damaging earthquake in the Eastern Mediterranean Region likely to occur?

Prompt implementation of the plan will be achieved through the following near-term initiatives:

- Training program
- Earthquake Data Exchange, Information and Evaluations
- Earthquake Hazards of the Gulf of Aqaba Region
- Earthquake Hazards of the Levantine Region
- Earthquake Hazards of the Red Sea Region
- Seismotectonics of the Dead Sea Transform Fault System
- Geophysical Surveys of the Dead Sea Transform Fault System
- Assessment of Urban Earthquake Hazards (including the vulnerability of megacities)

The action plan and demonstration project will initially be coordinated by UNESCO and USGS, which will facilitate exchange of data and information, organise projects and meetings, and assist in acquisition of resources. In the longer term, coordination should be carried out within the Eastern Mediterranean Region. This end could be achieved through an Eastern Mediterranean Region Institute (initially without walls) for Earthquake Hazards.

With the improving prospects for peace in many Eastern Mediterranean Region countries and the extensive reconstruction programs that would ensue, it is critical that construction and land-use practices utilise modern knowledge and methodology. Otherwise, future earthquakes, which are inevitable, could destroy the new facilities, set back development, and destabilise governments. A modest investment now in earthquake mitigation would pay large dividends in reducing future losses.

Walter Hays (USGS)
Badaoui Rouhban (UNESCO)

For further information contact

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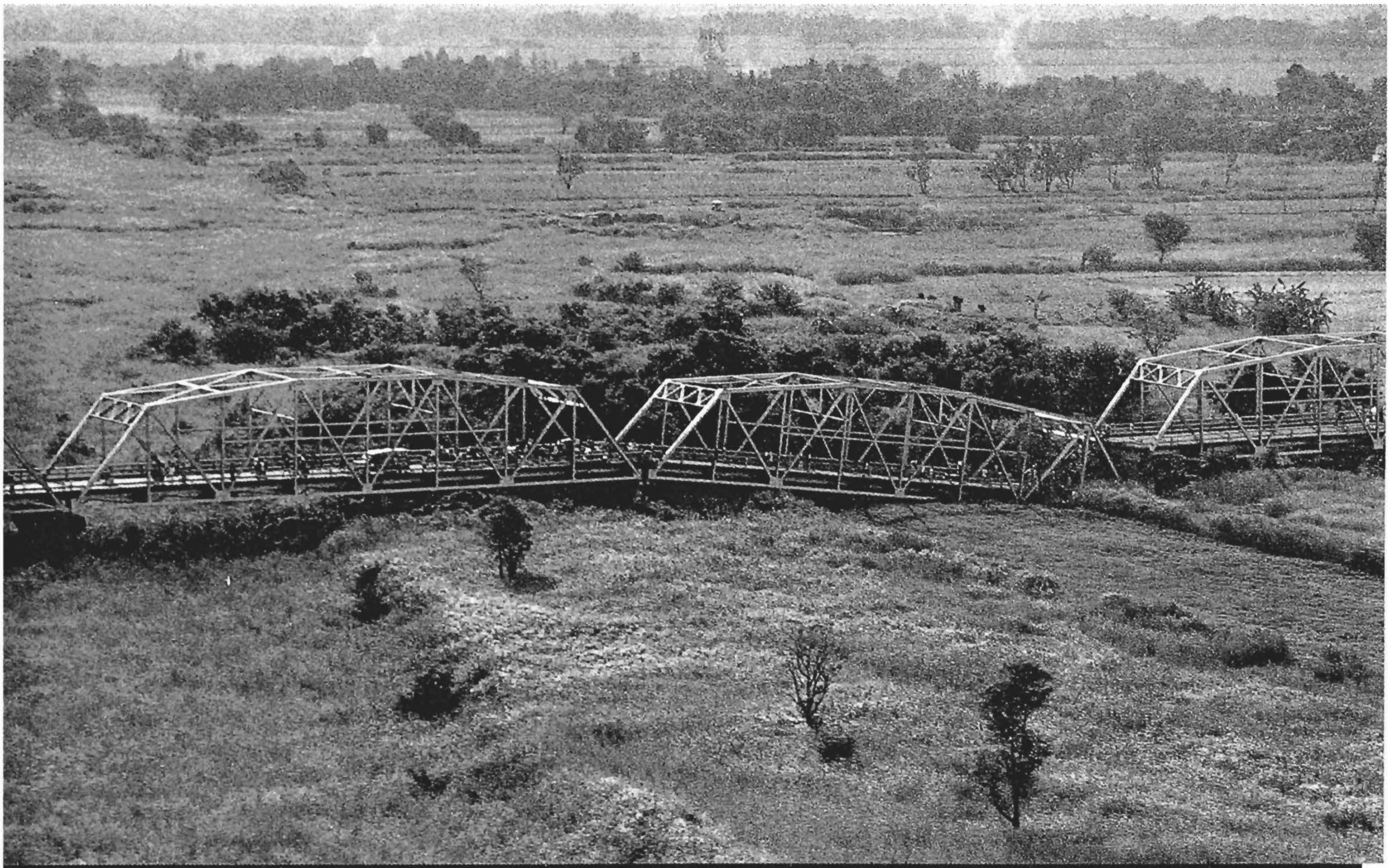


IDNDR IDEAS COMPETITION

Violent shaking of structures is only one of the destructive threats posed by an earthquake. Another major hazard can be posed by liquefaction of the foundation soils. This is caused by rising excess pore pressures leading to a near total loss of stiffness and strength. Strong ground motion from earthquakes frequently causes liquefaction in loose, saturated soils and where these form the foundations of structures, damage can be extensive. Bridges, especially river crossings on alluvial flood plains, are particularly at risk. This is because they are often located where loose materials have been deposited by the river and where there is a high water table, providing the two conditions which make liquefaction much more likely to occur.

The 1990 Luzon, Philippines earthquake was an example of what can happen; at least 24 bridges were rendered impassible or severely damaged by liquefaction, causing immediate disruption to the relief effort after the earthquake and severe longer term disruption to the economy. Major earthquakes in many other countries have caused similar problems.

Measures to predict whether or not soils will liquefy are well established. Design countermeasures are more difficult. One of the main recommendations of the EEFIT report on the Philippines earthquake was that ***'an international effort is needed to develop and disseminate further the techniques to limit the consequences of soil liquefaction'*****.** This **Ideas Competition** is intended to assist that effort in the context of bridge design. It is part of a contribution to the **UN's International Decade for Natural Disaster Reduction** commissioned from the Institution of Civil Engineers by the World Federation of Engineering Organisations.

The competition is sponsored by the following organisations.

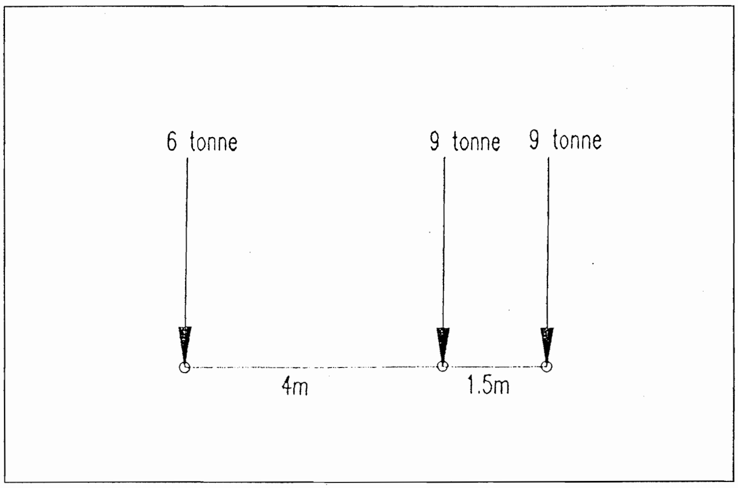
Ove Arup Partnership
University of Bristol
Sir Alexander Gibb & Partners Ltd
Thomas Telford Ltd
Trafalgar House Technology Ltd

Reference:
The Luzon Philippines Earthquake of 1990: A field report by EEFIT, Institution of Structural Engineers, London, June 1991.

Purpose of the Ideas Competition

Concepts are invited for a design solution for a bridge which will minimise the consequences of the upper layers of soil liquefying during an earthquake. At a minimum, the bridge should remain passable by a convoy of 24 tonne lorries for a period of at least a month after the earthquake. The site details and design brief are given over. Full details may be obtained from the Institution of Civil Engineers, London. The design solutions will be judged on their success in the following aspects.

- Originality, constructability, economy and elegance
- General applicability in similar conditions
- Fulfilment of the design brief for working conditions as well as extreme conditions
- Survival of the bridge after a major



Above: Axle loads and spacings for a lorry in the relief convoy for liquefaction resistant bridge design competition

Left: Rotational failure of bridge supports due to ground liquefaction in the Luzon Philippines earthquake of 1990

earthquake causing liquefaction, including ease of repair, if needed

- Appropriateness of the proposed design for conditions similar to those in the Philippines

A detailed design is not sought, nor should calculations be submitted. What is required, on one A1 drawing and up to 1000 words of accompanying text, is a viable concept for further detailed development. The concept and the rationale behind it must be clearly explained and justified in the entries.

Technical brief

The technical brief for the competition is outlined below.

Prizes

A first prize of £750 and two second prizes of £100 are offered for the entries which in the opinion of the judges provide the best solutions. There will also be a prize of £250 for the best entry by an entrant under 30 years of age.

Exhibition of entries

It is intended to display the winnning and other commended entries in London. Although the entries must be submitted anonymously (see rule 4 below), full details of the entrants will be given at the exhibition.

Judging panel

A distinguished international panel of judges will select the winners. The panel comprises:

Professor Roy Severn (chair)
University of Bristol, UK

Povl Ahm
Ove Arup Partnership, London UK

Peter Deason
Trafalgar House Technology, Croydon, UK

Professor John Knill
Imperial College, London, UK

Dr R Scott Steedman
Sir Alexander Gibb & Partners, Reading, UK

Dr Susumu Lai
Ports and Harbours Research Institute, Yokosuka, Japan

Lloyd Cluff
Pacific Gas & Electric Co, San Francisco, USA

There will also be a judge from the Philippines (name to be announced shortly).

Rules

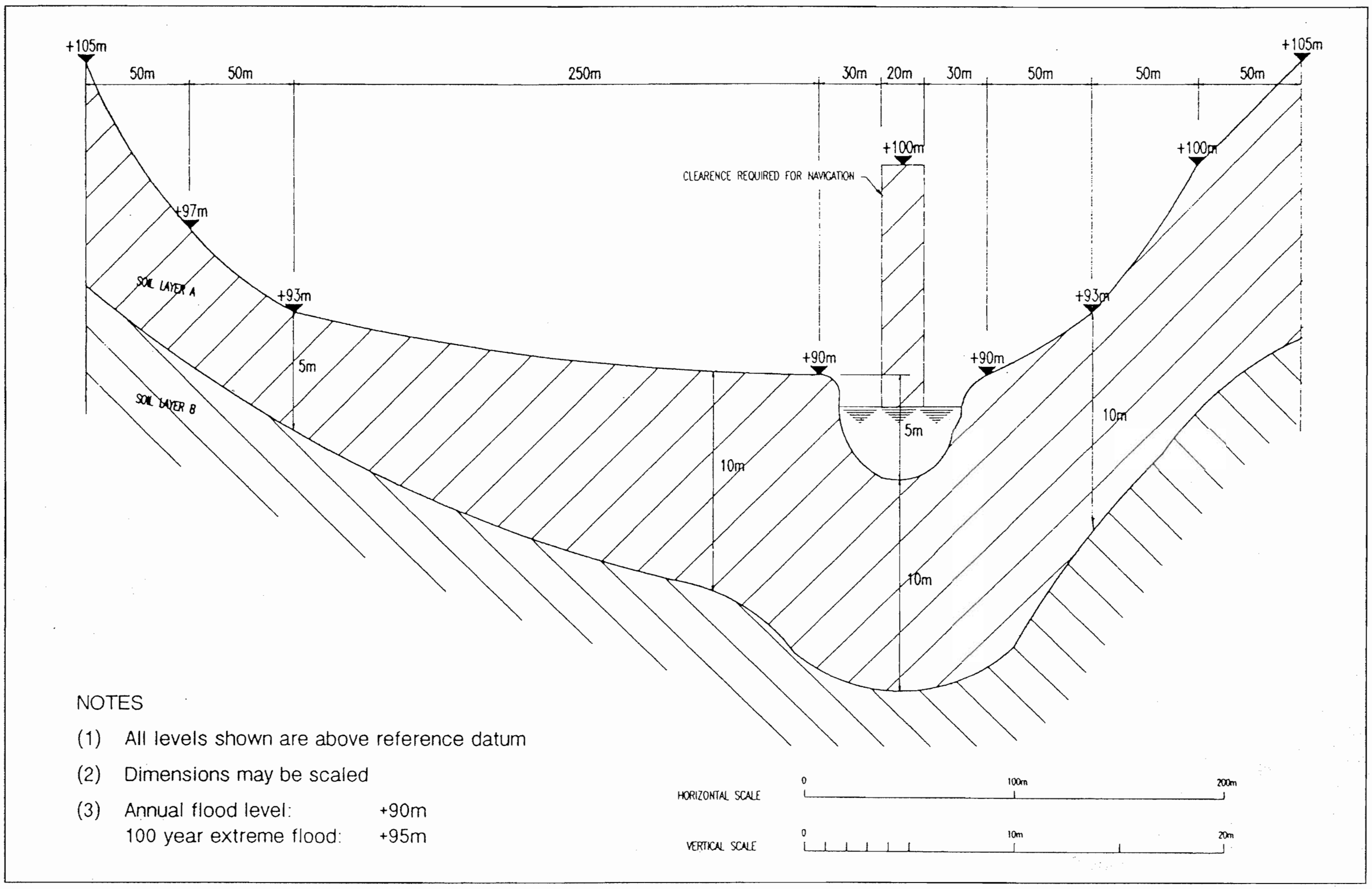
1) The competition is open to any individual or groups of individuals acting in a private capacity.

2) Entries shall be submitted as a drawing on one sheet of white paper not larger than A1 size (840mm by 594mm), accompanied by not more than 1000 explanatory words typewritten on two sheets of A4 (or similar size) paper. Colour may be used. All entries are to be in English and all dimensions shall be in SI (metric) units.

3) 4 copies of each entry are required.

4) Each competitor must apply for a separate entry form from the Institution of Civil Engineers secretariat. Not more than one entry is allowed per applicant. Each competitor will be supplied by the Secretariat with an entry number which must be written on the back of all copies of the submission. The entrant's name must not appear on the submission, and entries which do not observe this condition will be disqualified.

5) To be considered, entries must be received by the Institution of Civil Engineers London by 30 April 1994, although the judges reserve the right to consider late



NOTES

(1) All levels shown are above reference datum

(2) Dimensions may be scaled

(3) Annual flood level: +90m
100 year extreme flood: +95m

Above: Cross section through bridge site for liquefaction resistant bridge design competition

arrivals from outside the United Kingdom which are posted before that date.

6) The judges' decision is final and no correspondence on their decision can be entered into. The judges reserve the right not to award some or all of the prizes, if they consider the standard of entries is insufficient.

7) The outcome of the competition will be announced during August 1994. All competitors will be sent notification by post of whether or not they have been successful.

8) Entries should be sent to:

Helen Stow
Ideas Competition Secretariat
Institution of Civil Engineers
Great George Street
London SW1P 3AA
United Kingdom.

9) Queries on the rules of the competition should be sent in writing to the Secretariat (address given above).

10) The Institution of Civil Engineers reserves the right to publicise the entries as they choose. Entries will not be returned.

11) Competitors born after 30th April 1964 are eligible for the special prize for entrants under 30 years old. In the case of an entry by a group of individuals, all members of the competing group must have been after before the specified date to be eligible for the special prize.

Technical brief

1) Site profile is shown in the figure above.

2) The bridge is to remain essentially undamaged in the 100 year flood. Flood levels are shown in the figure. The associated river flow speed is 6m/s in the river bed and 3m/s in the flood plain.

3) The bridge must also be essentially undamaged in the 100 year earthquake, with a peak ground acceleration of 0.3g.

4) The bridge must survive an earthquake of magnitude 8 at a distance of 20 km, with an associated peak ground acceleration of 0.6g in a state that can be crossed by a convoy of lorries, within 24 hours of the earthquake. The relief convoy can be taken as a string of 24 tonne lorries at 9m centres, with axle loads and spacings shown in the figure opposite.

5) Design superimposed dead and live loading for the permanent condition should be taken at standard values, for example AASHTO HS2044.

6) Design wind speed is 50 m/s (50 year return period gust speed at 10m height). The site is inland and is not subject to the full effect of typhoon winds.

7) An existing tarmac access road comes within 500 metres of the crossing site. It gives access for 24 tonne lorries from the nearest main population centre, 40 km away.

8) Soil layer A (see drawing) consists of loose coarse silts and fine sands, which may be assumed to liquefy if the peak ground acceleration exceeds 0.2g.

9) Soil layer B consists of medium sands to unkown depth. It has increasing strength with depth; the SPT (standard penetration test) blowcount per 300mm may be assumed to be 15 + x, where x is the depth (in metres) below the top of the layer. Liquefaction can be considered unlikely in the 100 year event for x > 10. For the magnitude 8 earthquake at 20km, liquefaction may be considered unlikely for x > 15m.

10) Liquefaction of soil leads to a loss of stiffness and strength. Large permanent ground movements, both horizontal and vertical, are common particularly on river planes and these can cause structural problems. Liquefaction may also make the soils more susceptible to scour.

References

There is a wide range of literature available on soil liquefaction. References which may prove useful are as follows.

National Research Council 1985, Liquefaction of soils during earthquakes, State of the art review, Committee on Earthquake Engineering, National Academy Press, Washington DC.

Ishihara K 1993, Liquefaction and flow failure during earthquakes, The 33rd Rankine Lecture, Geotechnique 43(3), Institution of Civil Engineers, London.

For competition entry contact:

Helen Stow
The Institution of Civil Engineers
Great George Street
London SW1P 3AA
United Kingdom

Tel: +44 (0) 71 839 9964
Fax: +44 (0) 71 222 1325

SECED/WES Meeting

WIND AND EARTHQUAKE DESIGN OF TOWERS, MASTS AND CHIMNEYS

Introduction

Edmund Booth
(Ove Arup & Partners)

Part 3 of the seismic Eurocode EC8 is entitled Towers, Masts and Chimneys. It is due to be ratified as an ENV (essentially a draft for general trial and comment) in 1994, and the final version should follow after a period of 3 to 5 years.

Part 3 is not a simple document; it contains quite complex requirements for analysis, including the need to consider rotational, as well as translational, ground motions. It also specifies that a serviceability, as well as ultimate, limit state check should be performed on towers and chimneys in urban areas - a requirement not seen in other codes. On the other hand, the BSI subcommittee charged with commenting on the draft found that the damping and ductility factors proposed in the 1992 draft of Part 3 were crude and possibly unconservative. One of the suggestions of the subcommittee was that highly simplified, though very conservative, methods should be included, to identify cases where wind rather than earthquake effects clearly governed design. This would be especially useful for lattice towers and guyed masts, which can pose major analytical difficulties for seismic effects. A revised draft of EC8 Part 3 currently in preparation will (it is hoped) address at least some of these aspects.

Steel lattice and guyed masts are not noted for their susceptibility to earthquake loading, though they can be highly susceptible to wind. By contrast, concrete and masonry chimneys have been damaged in earthquakes but do not pose such difficult analytical problems. The rationale for the SECED meeting reported here was to seek the views of three people: a designer (Andrew Allsop of Ove Arup & Partners), a researcher (Professor Hans Buchholdt of Westminster University) and a telecommunications 'user' (Bill Southwood, of Arup Telecommunications). In addition, Brian Smith of Flint and Neill Partnership added a contribution from the floor on steel lattice towers. These contributions are now summarised.

Concrete Chimneys

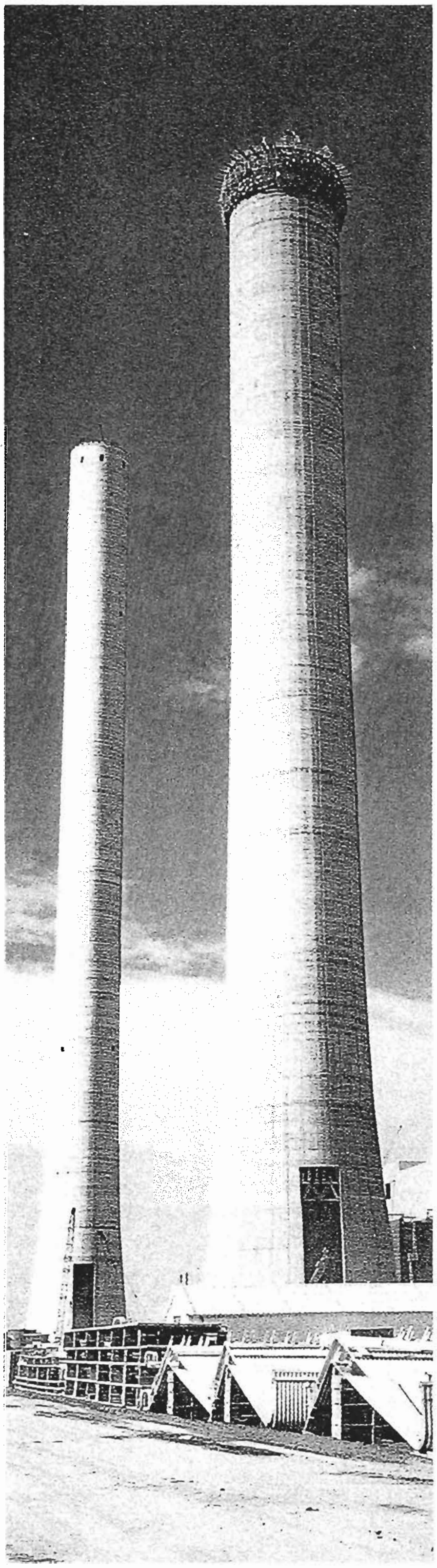
Andrew Allsop
(Ove Arup & Partners)

The influence of wind and earthquakes on the design of reinforced concrete chimneys was illustrated by comparative studies of a 240m high power station type chimney in a strong earthquake region (zone 4 of UBC). The comparisons were made for designs using the American standard ACI 307-88, which is in widespread use internationally, and draft EC8 Part 3.

Requirements for wind design are generally comparable between US and European practice, although there are some detailed differences particularly in wind speeds and load factors which are worth a little more attention.

Differences between earthquake provisions are very large. Although both are based on design earthquakes of about 500-1000 year return period and use of response spectrum methods using modal analysis, EC8 Part 3 loads are currently about 1/3 of those of ACI. The difference is due to use of a ductility factor of only 1.33 with load factor of 1.87 in the ACI code compared to 2.5 with an importance factor which is typically 1.1 in EC8. In neither case are there any requirements for detailing to ensure ductility or provide overstrength in elements which cannot behave in a ductile way.

Chimney ductility should depend on the detailing. Well reinforced and confined concrete cylinders with low diameter to thickness ratios are highly ductile. However RC chimney shells are often very lightly reinforced and their walls can be comparatively slender. Chimney section strength is normally governed by tension failure rather than concrete crushing. To a degree of accuracy much higher than our knowledge of wind or earthquake loads, the strength can be taken as

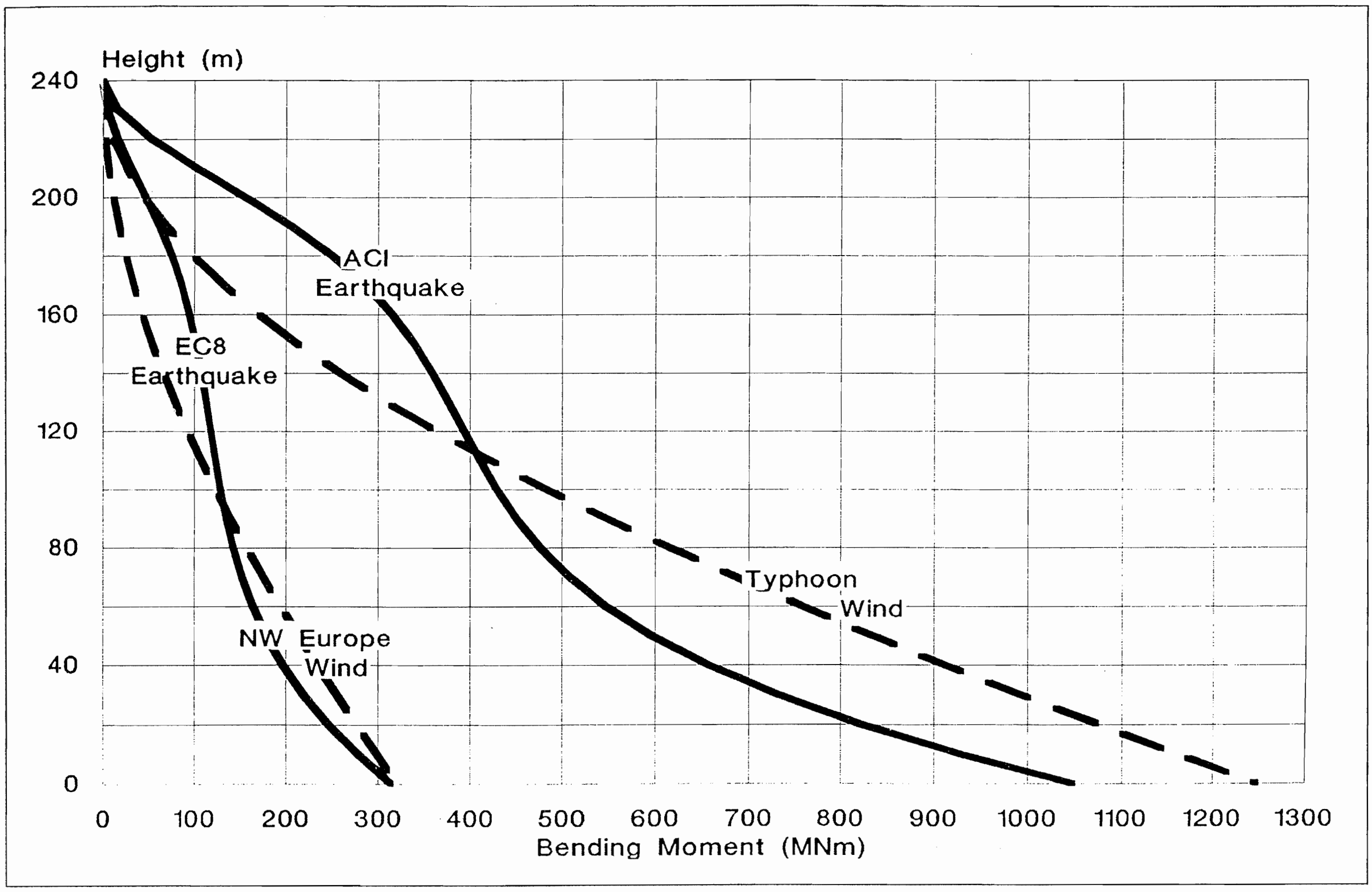


Above: Typical large chimney forms basis of studies

$$Mu = \frac{D}{2}.[W + As\ fy]\phi$$

where

Mu is the ultimate moment
D is the mean section diameter to centre of wall



Above: Comparitive studies of a tall chimney using ACI and EC8 codes (Wind - Typhoon 44 m/s, open sea, NW Europe 21 m/s, open country. Earthquakes, UBC Zone 4 (0.4g); EC8)

W is the weight of chimney supported by the section
As fy is the assumed total yield strength of vertical steel
ϕ is a factor ≈ 0.85

The formula above is obtained by taking moments about the edge of the concrete cylinder. The reduction is necessary to allow for the size of the concrete crushing zone. The value of 0.85 is appropriate for tension limited strength which is usual for chimney section design.

In a normal wind climate it is often theoretically possible to avoid the need for tension steel by varying the wall thickness and diameter to ensure an adequate axial load. Minimum levels of vertical steel of about 0.25% are required by ACI. There are benefits in using slightly higher values of reinforcement to resist typhoon winds but generally for ease of construction the reinforcement away from openings will be less than 1%.

The results of the comparative studies undertaken are shown in the figure above. The studies showed that a design optimised for zone 4 earthquakes and typhoon wind bending moments using the ACI rules led to very similar levels of vertical reinforcement (≈ 1%). Earthquake moments were similar to those due to wind at the base but higher above mid-height of the chimney. It was possible to show that significant savings in steel (reduction to 0.4% steel) could be made by redesigning the shape of the base of the windshield to meet the wind loads alone provided that a ductility factor of two could be assumed at upper levels of the chimney.

A chimney optimised for a more normal wind climate where the wind loads might be 25% of those of a typhoon climate would have the minimum amount of steel governed by code and construction requirements. Such a chimney would be more slender than required to resist typhoons and the earthquake loads in zone 4 would therefore also be smaller. However zone 4 earthquake loads of ACI would clearly govern the design. The EC8 earthquake requirements are however even lower than this normal wind load. The current draft EC8 requirements would therefore not be expected to govern chimney design even in a zone 4 earthquake region.

Clearly the available ductility of concrete chimneys is an important factor in assessing the reliability against earthquakes and also has an important influence on construction costs. Ove Arup & Partners have begun studies into available ductility using time-history methods and a paper was produced for the 1993 CICIND meeting in Edinburgh "Design of Concrete Chimneys in Regions of High Seismicity" (May 1993). We are looking for collaborators and also case studies which can be used to calibrate this kind of study.

Response of guyed masts to wind and earthquakes

Professor Hans Buchholdt
(University of Westminster)

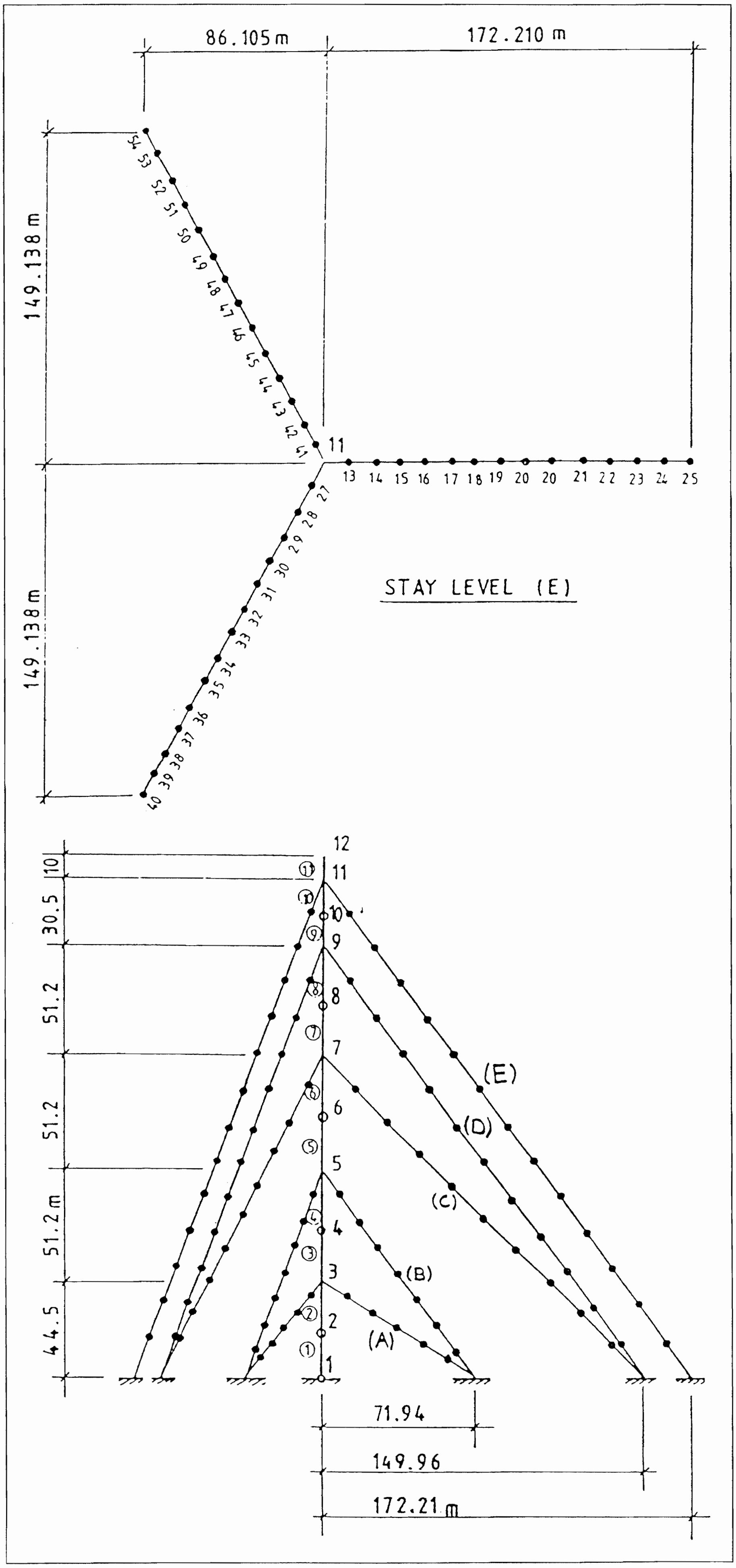
Guyed masts are highly nonlinear structures, which when subjected to wind and earthquakes will respond in a large number of closely spaced modes of which the majority are cable modes, the frequencies of which vary with the amplitude of response as well as with load.

Experience has shown that a large number of mast failures have been caused by fatigue failures of the guys, or more correctly by fatigue failures of their attachments to the towers. Fatigue cracks have also been experienced in the welds of the bracing to the vertical members in the lattice towers of some masts. Thus a complete analysis of, in particular large masts, is desirable.

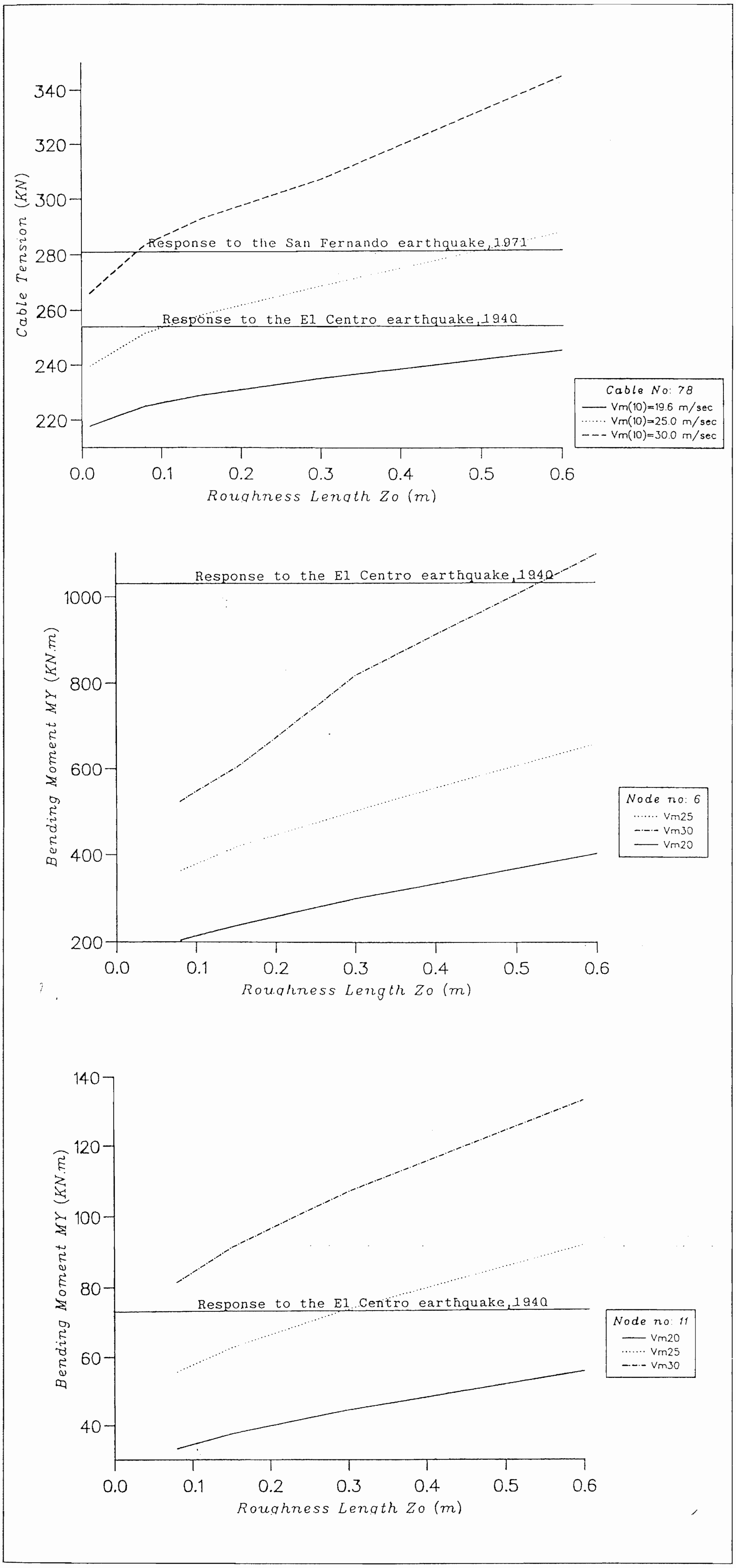
Because of the highly nonlinear characteristics of these structures such analyses have to be carried out in the time domain. The classical method of calculating the dynamic response of guyed masts is to replace the guys by elastic springs and determine the response of the towers by a frequency domain analysis using recommended spectra. This will yield, as far as can be judged a good estimate of the forces in the towers, but it is difficult to see how this approach can be used to estimate the forces and fatigue life of the cables and their attachments. Nor can this approach be used to estimate the forces induced in the mast due to a sudden cable rupture.

Because guyed masts respond in a very large number of modes the modelling of large masts frequently leads to numerical models having in the excess of a thousand degrees of freedom. This requires efficient algorithms for calculating the variation in response with time, especially since the time steps used need to be very small, usually in the order of 0.001 seconds, in order to achieve a sufficient degree of accuracy. The major effort, however, will always be concerned with the numerical modelling, and where an eigenvalue analysis is required, the additional effort to carry out a time domain analysis is minimal. Time domain analysis requires the ability to generate correlated wind and earthquake histories with the correct statistical characteristics. In the case of wind this may be achieved by first generating and then correlating histories with specified power spectra and variances by the auto regressive method. Design earthquakes may be generated in a similar manner, but require in addition that the auto regressive series are modified to take into account the change of the variance with time.

At the University of Westminster work in the field of guyed masts was



Above: Structural model of cable stayed mast



Above: Comparison between wind and earthquake responses

first commenced some 10 years ago. It has included the development of nonlinear static and dynamic response algorithms, verification of these by testing a 7.5m tall model of an IBA mast, the development of correlated numerical windfields and earthquake histories, and comparisons of the former with recorded responses of two British and one Italian mast. The work has also included the calculation and effect of guy ruptures; and comparisons of the response of guyed masts subjected to different levels of wind speeds and turbulence intensity with those due to recorded as well as generated earthquakes. The results of one such investigation of a 240m tall mast are presented in the figure opposite where the tension in one of the stays and the bending moments in the tower caused by wind with different mean velocities and turbulence intensities are compared with the same forces and moments caused by different recorded earthquakes. As can be seen from the graphs the wind may not always be the dominating force. This raises the question if a separate earthquake analysis is necessary for masts in earthquake zones when wind forces already have been accounted for. One way forward may be to project the frequency spectrum of a mast on to the power spectra for both wind and earthquakes in order to judge which of the two is most likely to excite specific significant modes.

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3. Iannuzzi, A: Response of Guyed Masts to Simulated Wind, CNAA PhD Thesis, Polytechnic of Central London*, October 1987.
4. Ashmawy, M A: Non-linear Dynamic Analysis of Guyed Masts for Wind and Earthquakes Loading, CNAA PhD Thesis, Polytechnic of Central London*, November 1991.

* Polytechnic of Central London is now University of Westminster.

continued from page 17

Lattice tower performance in earthquake country: a telecommunications engineer's experience from Papua New Guinea

Bill Southwood (Arup Communications)

The telecommunications engineer is a timorous beast when confronted with the elements. Accommodating equipment and mounting antennas to withstand the onslaught of earthquake, wind, water and lightning shake the communicator severely.

Bill Southwood spent ten years in Papua New Guinea during the transition through self-government to independence as Director of Telecommunications. The period saw a telecommunications expansion programme which involved provision of telephone exchanges, terminals and radio repeater stations in the towns, mostly in the valleys, and on mountain tops.

Papua New Guinea is in an area of high earthquake activity, but is north of the cyclone belt and therefore not usually subject to extreme wind. Nonetheless the elements had to be taken into consideration in specifications for towers, masts antennas, site works, access, power supply and equipment.

Faced with the elements the telecommunications engineer's response is usually to over-specify everything; to confuse safety and serviceability criteria; to seek out the most stringent clauses from a range of previous specifications and standards. The engineer then combines them in an even more onerous document, which becomes the benchmark for future generations.

The earthquake holds a special place in this demonology. A relatively rare occurrence, even in Papua New Guinea, it conjures up images of metal twisting and enormous cracks devouring all in their path. The reality is of course less spectacular and, for almost all cases, earthquake loading on lattice steel towers is considerably less than wind load. Neither have a significant effect on the serviceability of a microwave link.

The more dramatic effects of earthquakes in Papua New Guinea were manifested in the collapse of badly-fixed equipment cabinets, unsecured diesel generators and, in one case, an inadequately designed battery rack which deposited hundreds of litres of sulphuric acid into the cable trench.

A footnote on lattice towers

Brian Smith (Flint & Neill Partnership)

Simple static calculations undertaken on a major telecommunication tower showed that by using an equivalent static lateral load, as a fraction of 'g', seismic conditions should not govern the overall design until earthquake loading was about 0.4 to 0.5g. Initial spectral analysis calculations using the draft Eurocode 8 proposals tended to confirm that for this tower not only would the Eurocode criteria not govern, but these proposals would produce less onerous results than the simplistic static analysis for moments at the tower base. However it was accepted that this may not be the case for elements higher up in the tower, which had not been examined in these initial analyses, and which would be more severely loaded by the contribution from higher modes. In general shear elements may also be more severely loaded depending on the degree of eiffelization of the tower.

Similar calculations had been undertaken on a series of lattice towers in Iran which had been appraised by the Flint and Neill Partnership. In this case the American Code had been specified and against those provisions it was found again that earthquake response did not govern for a range of towers from 12m to 85m high. An equivalent fraction of about 0.4 to 0.6g would have been required before seismic conditions governed for these structures. Initial analyses to the requirements of draft EC8 Part 3 had not been taken to a sufficiently advanced stage to draw firm conclusions, but preliminary observations were that overall peak moments and shears at the base would be less than use of the equivalent static procedures. Again the contribution of higher modes in the upper zones of the towers may be more critical.

SECED/IStructE Meeting

STRUCTURAL ANALYSIS SOFTWARE (STANDARDS, CERTIFICATION & PRACTICE)

A joint meeting held between SECED and the Institution of Structural Engineers in September last year focused on issues of interest to both civil and structural engineers who use structural software packages for computer aided design and analysis. The topics covered included quality assurance (ISO 9001), type approval (TA0), TickIT (ISO 9000-3), and NAFEMS QSS. The meeting touched upon the 'verification and validation' of software, certification of software, experience of implementation and cost/ benefit analysis. The scope of the meeting was therefore quite substantial and really merited a longer session. The three speakers however were able to touch on most areas of this increasingly important topic. John Maguire of Lloyd's Register gave a general overview of current standards and certification applied to engineering software packages. This was followed by Phillip Jackson of Mott McDonald who gave a software developers viewpoint, and Crawford Patterson of RT James and Partners who gave the point of view of a software user.

A question posed was *"did the use of standards by the software developer enhance the final form of the product, typically a finite element program, in any definable way?"*. The management of the software development process was open to some question. It was evident that adherence to prescribed procedures in no way guarantees that the developer has utilised the correct algebraic procedures or developed an appropriate algorithm that correctly implements the basic algebraic formulation and associated data structure. What the declared use of standards provide however is knowledge that the developer has an appropriate framework for software generation and maintenance. Many of the large scale FE packages, as one questioner observed, originate in a wide variety of countries and thus it is sometimes difficult to establish precisely what standards have been used in the code development.

The **National Agency for Finite Element Methods and Standards (NAFEMS)** provides a basis for addressing the problem via the use of ***benchmarks***, that is comparative solutions to stylised geometric forms employing specific constraint configurations and loads. Confirmation that a given program yields comparative answers to the problem provides the user with some comfort that the code he/she is using is functioning (for that case) in the correct manner. The question is begged how does the user ensure that the solutions obtained for an entirely novel structural form manufactured from some multi-layer composite (for example) produce accurate solutions.

In the limit it would appear that adherence to standards by the software developer provides the software user with little more than a warm feeling. The terms validation and verification purporting to compartmentalise the checking procedure do little more than expand a growing standards vocabulary with no great benefit to the user. As one questioner remarked, testing merely confirms the existence of software errors and in no way guarantees code segments will yield correct solutions. Bearing in mind the infinite number of program routes and data combinations, error checking can only be said to identify the tips of a multiplicity of icebergs waiting to impede the progress of the coracle in which we travel.

It is inevitable that the software user has to build confidence in the product used. This is where internal company procedures and NAFEMS QSS procedures play a part in ensuring that the development of programmes themselves comply with basic requirements for maintaining accurate records and provide an audit trail for analysis studies. This facilitates the ready checking of solutions, albeit against desk top methods of calculation or even against test results obtained from physical static or dynamic tests on prototype structures where this is possible. The latter point begs the question how sure can we be that test results are themselves adequately founded.

It is perhaps obvious to all that the production of multi-coloured stress contours or modal shapes may lull the analyst into the trap of actually believing the results that appear on his/her screen as having some meaning as far as the 'real' structure is concerned. The end user has no means of confirming that the modelling, which may have been slaved over for five weeks, provides an accurate representation of the physical prototype. Other of course than his conviction that any analysis that has cost that much must in all probability be right! Checking stress levels employing increasing levels of mesh refinement may cause one to revise that conclusion.

It is arguable that the most appropriate quality assurance procedure relies upon the skill and depth of knowledge of the engineer posing and solving the problem. The temptation to adhere to a politically correct set of procedures is in the limit, some may think, counter productive, replacing diversity with stylised conformity that runs counter to the traditions of the civil and structural engineering professions. What starts out as a desirable objective in defining the need for organisational standards may have the undesirable effect of providing a vehicle for encouraging the disposal of the baby with the proverbial bathwater.

Arthur Humphrey, GEC-Marconi

References

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2. ISO 9000-3:1991 "Guidelines for the application of ISO 9001 to the development, supply and maintenance of software" (identical with BS5750: Part 13)

3. "Progress towards Type Approval", paper by J R Maguire given at NAFEMS conference, 1993 (pp 196 - 201)

4. The NAFEMS Quality System Supplement (QSS) to ISO 9001, relating to Finite Element Analysis in the Design and Validation of Engineering Products, published by NAFEMS (Ref QSSR), Issue 1.2, 31 Dec 1990

5. CIRIA Technical Note TN133 - Guidelines for Checking Computer Analysis of Building Structures. Published by CIRIA, 1998 (ISBN 0 86017 294 5).

6. "TickIT - Guide to Software Quality Management System Construction and Certification using EN29001, Issue 2.0, Feb 1992. Guide available through DISC TickIT Ofice, 2 Park Street, London, W1A 2BS

Review

Simplicity and Confidence in Seismic Design - The Fourth Mallet-Milne Lecture by Tom Paulay

Published by John Wiley, 68 pages, £18.00

Most politicians hanker after the big idea - George Bush's 'vision thing' -but it usually seems to prove elusive. Earthquake engineers are luckier. Over the past 20 years, and particularly from the writings of Tom Paulay and his associates in New Zealand, the big idea of capacity design has emerged as the most robust and sensible way of providing earthquake resistance in the majority of structures.

The idea is simple enough to grasp almost immediately. Choose those parts of the structure which will act as weak, ductile fuses in the event of an extreme earthquake, and design them to be capable of sustaining large inelastic cyclical deformations. Design the rest of the structure to sustain elastically the forces corresponding to the chosen yielding mechanism. With this approach, seismic design, becomes independent of the complexities and uncertainties of dynamic analysis, at any rate for the purpose of preventing collapse in an extreme earthquake. The major uncertainty that remains is the magnitude of inelastic deformation that the yielding regions may be subjected to, but suitable detailing should ensure that a large reserve of deflection capability can be provided at low cost.

This is the 'big idea' - the 'simplicity' in Tom Paulay's title. However, engineers (perhaps better than politicians) know that big ideas can only be realised in practice with a close attention to detail, which can never be simplistic and is often rather complex. When the medium in question is reinforced concrete under the large amplitude, reverse cycle loading characteristic of earthquakes, complexities abound. To grasp and present these complexities, while remaining practical and keeping the 'big idea' firmly to the front requires very special qualities. Tom Paulay is one of the very few figures on the international scene able to achieve this; largely as a result, his Mallet Milne lecture is the best concise statement to have been written on the seismic design of reinforced concrete.

The lecture starts by setting out the basic concepts of capacity design and the achievement of ductility. There are then admirably clear and concise sections on ductile frames, shear walls (more rationally called structural walls in New Zealand) and parallel combinations of frames and walls. Next, a lengthy section on detailing for ductility is presented, which rightly emphasises detailing as a crucial part of the design process. After a short section on structures with restricted ductility, the concluding chapter summarises the fundamentals of capacity design in five succinct points.

As David Key reminds us in his biographical introduction to the lecture, Tom Paulay spent 8 years in consulting practice before his spell of over 30 years at the University of Canterbury, New Zealand, researching the seismic response of concrete structures. This was no retreat to an ivory tower; Tom very actively maintained (as he still does) his links with design engineers, and takes great delight in helping to solve the practical problems of the real world. In the best tradition of the Mallet Milne lecture series, therefore, a lifetime of research is summarised in a format that is accessible and of great value to the profession. Of course, much of the material has been presented before, but there is important new material and the ideas and presentation have been honed and refined. The complexities of Tom Paulay's subject were referred to earlier, and there are difficult ideas to absorb, for example in the section on beam-column joints. The discussion of this complex subject is however the most helpful that this reviewer has read.

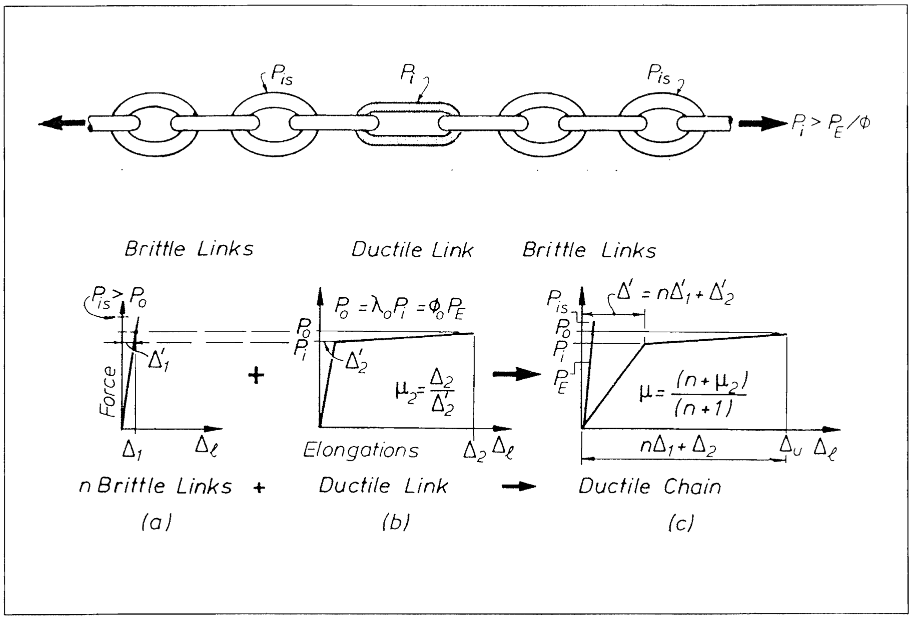
With the recent vote to approve as a working draft part 1 of Eurocode 8 (EC8: Structures in Seismic Regions), UK engineers are faced with having to abandon the crutch of the cookbook approach of the US code ACI 318 and to take on board a much more difficult set of rules. The EC8 rules for concrete are based on an attempt to capture the fundamentals of the seismic response of concrete and they are rooted in capacity design philosophy. Most engineers will need a little help with all of this. While Tom Paulay's recent text book with Nigel Priestley (ref 1) may be the bible on the subject, his Mallet Milne lecture, at one tenth the length, is bound to become indispensable reading. Future Mallet Milne lecturers may not thank Tom for the standard he has set them, but the rest of us can be grateful for such a helpful primer.

Edmund Booth
Ove Arup & Partners, London

Ref 1. T Paulay & M J N Priestley, Seismic design of reinforced concrete and masonry, John Wiley, 1992.

A limited number of copies of the second, third and fourth Mallet-Milne lectures are available to members at the reduced combined price of £25.00 per set. Please apply to the Secretary, enclosing a cheque payable to the Institution of Civil Engineers. Contact Mary Kinsella, SECED, Institution of Civil Engineers, Great George Street, London SW1P 3AA

Below: Concept of strength limits in a ductile chain



System For Technology Exchange For Natural Disasters (STEND)

For the last twelve years the Hydrology and Water Resources Division of the World Meteorological Organisation in Geneva has operated a Hydrological Operational Multipurpose System (HOMS) for collecting and sharing operational technology in hydrology, with particular emphasis on technology transfer to developing countries. The information involved usually takes the form of references to computer programs, technical manuals and hydrological instruments. The information is compiled into two-page summaries describing the technology involved, from where it is available and any cost involved. These sheets of individual "components" are collected into HOMS Reference Manuals, held at HOMS National Reference Centres, usually at the National Hydrological Service. The sheets are held in ring binders for easy modification and updating. So far there are about 430 individual components and 115 countries belong to the scheme. Since its inception nearly 3,000 individual requests have been actioned.

As part of its contribution to the International Decade for Natural Disaster Reduction, WMO recently called a meeting in Geneva to discuss extending the HOMS system to other disciplines, such as seismology, volcanology and meteorology in a broader System for Technology Exchange for Natural Disasters (STEND). The idea was enthusiastically received by the representatives of other disciplines and WMO has agreed to consult with appropriate international bodies about setting up a mechanism for soliciting and vetting proposed components. WMO is prepared to act as secretariat for the venture.

A great advantage of the proposed system is its simplicity and the fact that the technology described is already operational, and means of obtaining it clearly stated. Although the present HOMS system is exclusively in bound volumes the meeting strongly recommended that any STEND should also be available in computer form to enable rapid searching by topics.

The type of information to be made available will vary according to the discipline, and those present at the meeting each had ideas about their own subject and suggested initial classification of topics. In seismology, for example, obvious topics include network design, instruments and equipment, data analysis, hazard assessment techniques and training. Some topics, such as remote sensing, data transmission and storage and general mathematical and statistical techniques have applications in many disciplines.

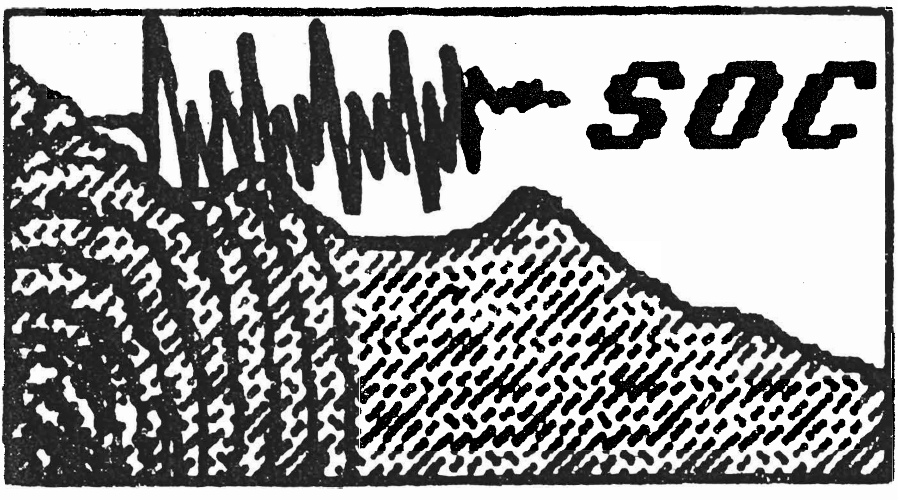
The application of STEND to the observational sciences is obvious, and relevant international scientific organisations will be consulted about the next steps required. It was agreed, however, that the system could with advantage include some parts of engineering seismology like strong motion instrumentation and analysis, microzonation and hazard assessment techniques have obvious relevance. In addition there is likely to be other information on structure monitoring and response, and perhaps simple criteria for design and construction that could be included. If WMO decides to extend the scheme to this field, they will consult relevant bodies such as the International Association for Earthquake Engineering, and British expertise in this field could make a substantial contribution.

Robin Adams
International Seismological Centre

Seismological Observatory, Yemen

The Seismological Observatory Centre of the Geological Surveying and Mineral Exploration Board of Yemen has recently completed the installation and operation of an eighteen station strong motion accelerographic network. All stations are equipped with the SSA-2 solid state accelerograph from Kinemetrics Inc. The centre is now in the process of evaluating the station distribution and triggering parameters for optimum operating conditions.

The Seismological Observatory Centre (SOC) will hopefully soon be able to contribute to the international seismological community digital strong motion data for this part of the world. In the meantime, SOC will be working during the next few months on the installation and operation of the Yemen National Seismological Network which will hopefully be operative by the beginning of next year.



Therefore, there would be another achievement for SOC when the distribution of regular seismological bulletins begin. The format and frequency of such bulletins will be decided on after passing the network test operation and finalising data dissemination protocols.

SOC would like to promote cooperation in the exchange of data, publications and experience, and would appreciate contact and inclusion on mailing lists in the development of international contacts.

For further information contact:

Dr Jamal Shoulah
Director General
Seismological Observatory Centre
P O Box 87175
Dhamar, Republic of Yemen

NOTABLE EARTHQUAKES JULY - DECEMBER 1993

Reported by British Geological Survey

YEAR	DAY	MON	LAT	LON	DEP Km	MAG ML	MAG MB	MAG MS	LOCALITY
1993	7	JUL	55.552N	4.664E	15	4.0			**CENTRAL NORTH SEA** *Felt as a 'shuddering' in the Gorm oil production complex. There was no damage but production was stopped for 2 hours.*
1993	8	JUL	54.324N	3.123W	9	1.6			**CONISTON, CUMBRIA** *Felt in Kirkby-in-Furness.*
1993	12	JUL	42.841N	139.248E	17		6.7	7.6	**HOKKAIDO, JAPAN** *At least 200 people were killed and 39 missing in the Hokkaido region. One person was killed on a fishing boat off Aomori, Honshu. Three people were missing from the south-east coast of Russia. Severe damage was caused by the earthquake and accompanying fires, landslides and tsunami in south-western Hokkaido. More than 850 houses were damaged or destroyed, including at least 600 by the tsunami. Tsunami wave heights as high as 30.6 metres were reported along the south-west coast of Okushiri Island and 3 metres at Nokhodka. The tsunami affected much of the south-eastern coast of Russia and also caused damage to a factory at Kamenka, Sakhalin Island.*
1993	14	JUL	38.243N	21.783E	20		5.2	5.5	**GREECE** *At least 5 people were injured and 200 buildings damaged at Patras. Felt as far as Attiki province.*
1993	1	AUG	15.581N	31.918E	10		5.2	5.2	**SUDAN** *At least 2 people were killed, 9 injured and damage occurred in the Khartoum area.*
1993	8	AUG	12.971N	144.744E	61		7.2	8.0	**S of MARIANA ISLANDS** *At least 48 people were injured on Guam. This earthquake was felt strongly on Guam and Saipan with extensive damage on Guam including a power outage throughout the island. A moderate tsunami was generated and port facilities were heavily damaged.*
1993	10	AUG	45.205S	166.929E	33		6.2	7.1	**SOUTH ISLAND, NEW ZEALAND** *Felt thoughout South Island and the southern part of North Island. Power outages reported in Te Anau area.*
1993	4	SEP	57.033N	5.793W	3	2.7			**MALLAIG, HIGHLAND** *Felt in Mallaig Highland.*
1993	10	SEP	14.734N	92.675W	34		6.3	7.3	**CHIAPAS, MEXICO** *At least one person was killed and 3 injured, there was considerable damage in southwestern Guatemala. Damage occurred in parts of Chiapas. Felt strongly in southern Mexico and as far away as Mexico City.*
1993	25	SEP	57.538N	5.353W	4	1.7			**COULIN FOREST** *Felt at Coulin, Highland*
1993	29	SEP	18.055N	76.424E			6.3	6.3	**SOUTHERN INDIA** *At least 9,748 people were killed, about 30,000 injured and extreme devastation in the Latur-Osmanabad area. Nearly all buildings were destroyed in the village of Khilari. Felt in large parts of central and southern India, including Bangalore, Bombay, Hyderabad and Madras.*
1993	11	OCT	53.154N	3.711W	11	2.4			**BETWS-Y-COED, GWYNEDD** *Felt in Betws-y-Coed and Nantbh, North Wales.*
1993	11	OCT	32.003N	137.852E	365		6.5		**SOUTH OF HONSHU, JAPAN** *One person died of a heart attack and at least 4 other people were injured in the Tokyo area. Felt throughout Tokyo and Yokohama.*
1993	13	OCT	5.929S	146.029E	24		6.4	7.1	**EASTERN NEW GUINEA** *At least 60 people were killed and several injured in the upper Markham Valley. Large landslides blocked the Ume River and contributed to many of the casualties.*
1993	25	OCT	5.892S	146.001E	10		6.4	7.1	**EASTERN NEW GUINEA**
1993	11	NOV	53.321N	0.970W	0	2.2			**RANSKILL, NOTTS** *Felt throughout Ranskill, Nottinghamshire*
1993	13	NOV	55.000N	158.800E	33			7.1	**E COAST OF KAMCHATKA** *Felt throughout Petropiovsk-Kamchatskiy*
1993	13	DEC	55.061N	3.856E	11	3.3			**CENTRAL NORTH SEA**
1993	27	DEC	61.202N	2.403E	10	4.3			**NORTHERN NORTH SEA**

Readers will have noted that a Notable Earthquake listing was not included in the last edition of the Newsletter. In this issue we catch up to bring the listing fully up to date for 1993. A year end summary is also given on page 23 to provide an overview of activity worldwide during 1993. The earthquake reporting is provided by the Global Seismology Unit of the British Geological Survey. For further information about the Global Seismology Unit, contact British Geological Survey, Global Seismology Research Group, Murchison House, West Mains Road, Edinburgh EH9 3LA, United Kingdom (Tel: +44 (0) 31 667 1000); Fax: +44 (0) 31 667 1877).

1993 - A Summary of the Earthquakes

Reported by the British Geological Survey

The year 1993 was not exceptional in terms of the earthquakes which occurred worldwide. There was one 'great' earthquake with a magnitude greater than 8.0, there were 9 'major' earthquakes (magnitudes 7.0 - 7.9) and 99 'strong' earthquakes (magnitudes 6.0 - 6.9). These figures are generally below the long-term average with only the great earthquake meeting the average of one per year. The average for major events is 18 per annum and for strong events it is 120. It was only in deaths caused by earthquakes that 1993 proved to be above average, with 10,039 people reported to have been killed against an average of 8,700 per annum over the past decade.

Without doubt, the Khilari earthquake of Southern India was the most disastrous earthquake of the year, accounting for the vast majority of the earthquake deaths. Occurring on 29 September it caused the deaths of 9,478 people, destroyed the village of Khilari and left 30,000 people injured. The earthquake was not, however, exceptionally large, having a magnitude of 6.3 M_L, a magnitude which can be expected roughly once a week on average worldwide. The location of this event was unusual, the epicentre was in an area with no previous history of such events. Another particularly disastrous earthquake of 1993 was the 12 July, Hokkaido event ($7.6M_L$) which resulted in the deaths of over 200 people around the Sea of Japan, due to the earthquake and the resultant fires and tsunami. Also of note was the Papua New Guinea earthquake of 13 October (7.1 M_L) which resulted in the deaths of 60 people and much destruction in the epicentral area.

The one great earthquake of 1993 occurred south of the Marinas Islands on 8 August. The magnitude was 8.1 M_L and as such it was the largest earthquake since 1989. There were no fatalities but 48 people were injured and extensive damage to property and port facilities occurred on the island of Guam. The major earthquakes of the year affected Japan, the Santa Cruz Islands, Kamatchka, New Zealand, Mexico and New Guinea. Only four of the nine major earthquakes caused fatalities, the remainder occurring in remote areas with sparse populations.

United Kingdom earthquakes also tended to be below average in numbers during 1993. There was one event with a magnitude between 3.0 M_L and 3.9 M_L and several hundreds with magnitudes less than 2.0 M_L. Twelve UK earthquakes were felt during the year; the largest occurred near Grange-over-Sands on 26 June and with a magnitude of 3.0 M_L, it was strong enough to be felt throughout southern Cumbria and northern Lancashire. Near to the epicentre some very minor damage was reported.

In the North Sea and Norwegian Sea areas adjacent to the British Isles there were 3 events with magnitudes between 4.0 M_L and 4.9 M_L, 6 in the range 3.0 M_L to 3.9 M_L and 14 in the range 2.0 M_L to 2.9 M_L. One of these events was reported felt: a magnitude 4.0 M_L earthquake was felt as a 'shuddering' on the Gorm Oil production complex in the central North Sea on 7 July. The remaining 2 events over 4.0 M_L were in the Norwegian Sea area, outside the UK sector but still affecting the earthquake hazard.

David Redmayne
Global Seismology Unit
British Geological Survey

Final Call

Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

St Louis, Missouri, USA
April 2 - 7 1995

Deadline for submission of abstracts
January 31 1994

Contact:
Shamser Prakash,
Civil Engineering Department
University of Missouri-Rolla
Rolla, MO 65401-0249 USA

Tel: 0101-314-341-4489
Fax: 0101-314-341-4992

WHAT'S ON

January - March 1994

26th January 1994
SECED/AFPS Meeting
Shaking Table Tests on a Model Shear Wall Building
Institution of Civil Engineers

8th February 1994
EEFIT Meeting
Hokkaido Japanese andGuam Earthquakes of 1993
Institution of Structural Engineers
+ EEFIT AGM

10th February 1994
The M6.4 Khilari Earthquake of September 29, 1993 + Earthquake Protection in Urban Planning
The Martin Centre, Cambridge

23rd February 1994
SECED Meeting
Blast Vulnerability of Building Structures
Institution of Civil Engineers

8th - 9th March 1994
IDNDR Meeting
Natural Hazard Assessment and Mitigation: The Unique Role of Remote Sensing
The Royal Society

13th April 1994
SECED Meeting
Damage and Intensities in the Magnitude 7.8 1929 Murchison Earthquake
Imperial College

21st April 1994
Damage Ratios for Houses in the MM10 Zone of the 1931 Hawkes Bay Earthquake
The Martin Centre
Cambridge

27th April 1994
SECED Meeting
Case Studies of Building Design for Earthquake Regions
Institution of Civil Engineers
+ SECED AGM
+ Biennial Dinner

Book now ...

SECED Biennial Dinner
7pm Wednesday, 27th April
at
The Institution of Civil Engineers

Preceded by a sherry reception

Tickets available now (£30 or £50 for member + partner) - contact Mary Kinsella on 071 839-9827

Forthcoming Events

10 - 12th May 1994
The Second International Conference on Engineering Integrity Assessment
NEL, Glasgow

18th May 1994
SECED Half Day Meeting
The Incredible British Earthquake (How Big and Bad can NW Europe Earthquakes be?)
Institution of Civil Engineers

23rd - 27th May 1994
IDNDR
World Conference on Natural Disaster Reduction: A Safer World for the 21st Century
Yokohama, Japan

1st - 3rd June 1994
Third International Conference Structures under Shock and Impact
Madrid, Spain

15th - 17th June 1994
ERCAD Berlin 1994
Second International Conference on Earthquake Resistant Design
Berlin, Germany

15th - 18th June 1994
ICVE 94
International Conference on Vibration Engineering
Beijing, China

18th - 21st July 1994
Institute of Sound and Vibration Research
Fifth International Conference on Recent Advances in Structural Dynamics
University of Southampton

3rd - 5th August 1994
First World Conference on Structural Control
Los Angeles, California

28th August - 2nd Sept 1994
European Association of Earthquake Engineering
10th European Conference on Earthquake Engineering
Vienna, Austria

31st August - 2nd Sept 1994
CENTRIFUGE 94
Singapore

26th - 30th September 1994
EURODYMAT 94
International Conference on Mechanical and Physical Behaviour of Materials under Dynamic Load
Oxford

6th - 10th September
Institute of Sound & Vibration Research
22nd Advanced Course in Noise & Vibration
Southamption

12th - 16th September 1994
2nd European Solid Mechanics Conference
Geneva, Italy

4th - 7th October 1994
ICDRCC 94
International Conference on Disaster Reduction in Coastal Cities
Beijing, China

Call for Papers

The **Fifth International Conference on Seismic Zonation** is to be held at the Acropolis Congrès in Nice, France, on 17 - 19th October 1995.

The conference will be taking place at the midpoint in the **International Decade for Natural Disaster Reduction** and will provide an international multidisciplinary forum for the assimilation and dissemination of recent advances pertinent to the reduction of losses from natural disasters worldwide.

A call for papers has been issued and the deadline for submitting abstracts is June 1, 1994. For more information about the conference or paper submission, contact EERI at 499 14th Street, Suite 320, Oakland, California 94612-1902, Tel: (510) 451-0905, Fax: (510) 451-5411; or AFPS at Domaine de Saint-Paul, BP 1, 78470 Saint-Rémy-les-Chevreuse, France, Tel: (1) 30.85.22.03, Fax: (1) 30.52.75.75.

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SECED NEWSLETTER

The SECED Newsletter is published four times a year by the SOCIETY FOR EARTHQUAKE AND CIVIL ENGINEERING DYNAMICS. The Newsletter is issued in January, April, July and October and contributors are asked to submit articles as early as possible in the month preceding the date of publication. Manuscripts should be sent typed on one side of the paper only, and a copy on a PC compatible disk would be appreciated. Diagrams should be sharply defined and prepared in a form suitable for direct reproduction. Photographs should be high quality and black and white prints are preferred wherever possible. Diagrams and photographs are only returned to authors upon request. Articles should be sent to Nigel Hinings, Editor, SECED Newsletter, Allott & Lomax, Fairbairn House, Ashton Lane, Sale, Manchester, M33 1WP, United Kingdom (Tel. +44 (0)61 962 1214; Fax +44 (0)61 969 5131).

SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics is the British 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 EEFIT, the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote cooperation 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, Institution of Civil Engineers, Great George Street, London SW1P 3AA, United Kingdom.

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