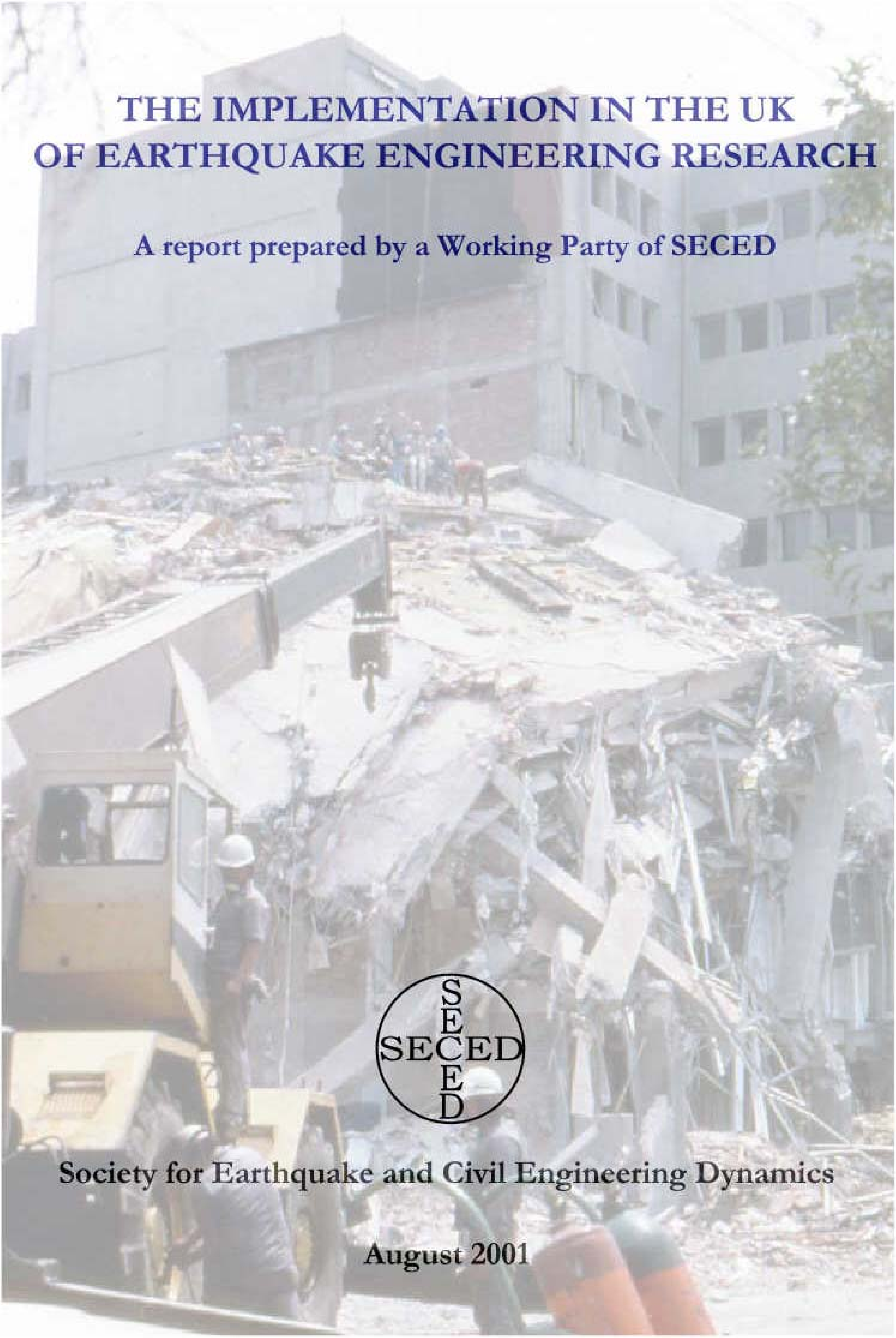
# THE IMPLEMENTATION IN THE UK OF EARTHQUAKE ENGINEERING RESEARCH

A report prepared by a Working Party of SECED



SECED

Society for Earthquake and Civil Engineering Dynamics

August 2001

# Implementation in the UK
# of earthquake engineering research

This document reports an investigation of ways to improve the use by British engineering consultancy of the latest research in earthquake engineering. It gives an extensive review of the UK's research capability in earthquake engineering, including that by the European Commission, and also reports the views of industry. Five recommendations are given that would lead to better implementation of research results.

A four page printed summary of the report can be obtained free on request by sending a stamped self-addressed C4 size envelope to:


SECED Secretary
Institution of Civil Engineers
1 Great George Street
London SW1P 3AA
Tel: 020 7665 2238 Fax: 020 7799 1325
e-mail: secretary@seced.org.uk


The report was prepared by a Working Party of SECED (the UK Society for Earthquake and Civil Engineering Dynamics), during the period May 2000 to March 2001. The Working Party, which consulted widely during its deliberations, consisted of


Roy Severn, University of Bristol (chairman)
Edmund Booth, Independent Consultant (secretary and report editor)
Scott Steedman, Whitby Bird & Partners
Amr Elnashai, Imperial College of Science, Technology & Medicine (to Dec 2000)
Christophe Junillon, W S Atkins
John Mills, Babtie Group (from Jan 2001)


SECED exists for professionals working in the fields of earthquake engineering and related disciplines, and has, since its foundation in 1969, provided an active forum where design engineers, researchers and scientists in a wide range of fields have exchanged ideas and kept themselves informed. SECED is an associated society of the Institution of Civil Engineers; it will act as host to the 12th European Conference on Earthquake Engineering, which takes place in London in September 2002.


Published by SECED August 2001

# TABLE OF CONTENTS

## FOREWORD

The SECED Committee welcomes this timely report as a very important contribution to the Society's mission to promote earthquake engineering in the UK and in particular to foster constructive interaction between industry and academia. The report, in common with nearly all SECED activities, is the product of the effort and dedication of a few highly motivated individuals, in this case the members of the Research Working Party. The undertaking has been carried out entirely in their own time and on a voluntary basis and is an excellent example of the energy and dynamism of our members giving life and purpose to the Society.

The SECED Committee is currently reviewing the recommendations of the report in order to decide which of these should be given highest priority for pursuit. The report is being made as widely available as possible in order to invite comments and suggestions from all interested parties as contributions to the debate. The Research Working Party obtained input from many academics and practitioners, but the discussion will be enriched by additional viewpoints and ideas. At the same time, it is important to bear in mind that a resolution by the SECED Committee will not automatically mean that a recommendation from the report is actually implemented: as with the production of the report itself, the successful realisation of any of its recommendations will depend on the members of SECED coming forward to take up initiatives and put them into action. Therefore at the same time as inviting contributions of ideas and suggestions, I would also like to issue an invitation for volunteers who are willing to lead or support the implementation of some of the activities envisaged in the report.

Before any of the recommendations in the report are implemented, it has already served one very significant purpose: it confirms that in the UK, despite the very low level of local seismicity, there is an enormous activity in the field of earthquake engineering and in many cases UK researchers are playing a leading role at European level. Similarly, there is clearly a great deal of expertise and activity amongst practising engineers in the UK, who have confirmed their interest in earthquake engineering research. There is little doubt that the UK has become an important player in the field of earthquake engineering, both in academia and engineering practice and SECED continues to strengthen its role in promoting and encouraging this development. It is to be hoped that research-funding agencies can also be convinced of the importance of UK earthquake engineering and continue to support the kinds of activity described in this report.

**Julian Bommer**
SECED Chairman

## 1 EXECUTIVE SUMMARY

### Working Party Brief

The Working Party's brief was agreed as follows.

1. Carry out an audit of research capabilities in the UK and report.
2. Canvas opinion in the UK construction industry and research community on current and future needs and report.
3. Review current European objectives for research into earthquake engineering, and report on the commonality with UK needs.
4. Recommend ways for the dissemination to the UK construction industry of recent research into issues of concern to the industry, with the aim of facilitating innovation.

### Basis of UK interest in earthquake engineering

Although the UK is one of the most seismically stable areas on earth, British interest in earthquake engineering dates back at least to the time of Robert Mallet (1810 – 1881) and John Milne (1850 – 1913).

The main reasons for current UK interest in seismic matters are as follows.

1) The extensive work by UK engineering consultants in active seismic regions overseas
2) The need to provide seismic safety cases for nuclear and other hazardous installations in the UK
3) The current extensive developments in earthquake engineering standards, particularly Eurocode 8.
4) The intellectual challenge of earthquake engineering, which lies at the forefront of structural mechanics.

### Audit of research capabilities

The Working Party carried out a questionnaire survey of university research departments, which found a wide range of relevant research performed in 13 centres, although 4 universities (Imperial College and the Universities of Bristol, Cambridge and Oxford) stood out as having major commitments. There has been extensive involvement by UK universities, in collaboration with institutions in other European countries, in research funded by the European Commission; however, the resulting reports have been directed at researchers and have not directly met industry's needs. Research & development projects carried out by UK industry are also important, with those by the nuclear industry being particularly notable. 'Voluntary' contributions to research involving individuals are also significant; they have involved the work of such organisations as SECED and EEFIT (the UK earthquake field investigation team), and contributions to the development of Eurocode 8.

## Survey of SECED members

The survey of SECED members concluded the following.

1. The industry considers it would benefit from greater use of the latest research in its professional practice, by allowing more efficient and/or innovative designs.
2. Barriers to applying the latest research are additional design costs, the very specific nature of published research and the stipulation of existing standards and methodologies by clients and regulatory authorities.
3. These barriers could be mitigated by making research more applicable to industry's needs, through industrial involvement in research and the publication of research guidelines for practitioners.
4. There was no consensus on the most useful fields of research, even though geotechnical issues were most often mentioned.

## Working Party recommendations

In the light of these findings, the Working Party made five specific recommendations for improving the implementation in the UK of earthquake engineering research.

1. SECED should seek partners for a project to prepare design guidelines on specific aspects of earthquake engineering. This would be an international effort, involving organisations in other parts of Europe and possibly also the Applied Technology Council in the USA. A panel of recognised experts from both industry and universities would prepare the guidelines, with the aim both of ensuring that their format met the needs of design practitioners, and also of validating the research results contained so that the guidelines gained wide acceptance.
2. SECED should establish an on-line database of academic research and researchers in the UK relating to seismic engineering, to improve awareness by designers of sources of university expertise and data.
3. SECED should host a special session at the European earthquake engineering conference (12ECEE), to be held in London during September 2002, to draft guidelines for presenting the results of seismic research in a format suitable for industry.
4. SECED should endeavour to broker an EPSRC funded Research Network in earthquake engineering. The Network would involve a consortium of industrial and academic partners sharing experience and formulating research needs.
5. Many other initiatives are possible for improving the implementation of research, and some are identified in this report. In order to ensure that the necessarily limited effort available to SECED is not spread too widely, it is recommended that the effort should be directed to the initiatives proposed above. However, the possibilities should be revisited in about two years time, to consider whether further initiatives might then be possible, in the light of progress to date, and the financial position of SECED.

***Comments on this report and suggestions for further action would be greatly welcomed; please contact RWP@seced.org.uk***

# 2 INTRODUCTION

## 2.1 Basis of UK interest in earthquake engineering

Although the UK is one of the most seismically stable areas on earth, British interest in earthquake engineering dates back at least to the time of Robert Mallet (1810 – 1881) and John Milne (1850 – 1913), brief biographies of whom are provided by Muir Wood in Ref 1.

The main reasons for current UK interest in seismic matters are as follows.

5) The extensive work by UK engineering consultants in active seismic regions overseas
6) The need to provide seismic safety cases for nuclear and other hazardous installations in the UK
7) The current extensive developments in earthquake engineering standards, particularly Eurocode 8.
8) The intellectual challenge of earthquake engineering, which lies at the forefront of structural mechanics.

## 2.2 Background to the work of the Research Working Party

In February 1998, SECED (Society for Earthquake & Civil Engineering Dynamics) held a workshop attended by 60 invited participants from industry academia and government entitled *Mechanisms of Academic-Industrial Interaction in Earthquake Engineering.* A record of the workshop was published by SECED in April 1998, and a summary is available on http://www.seced.org.uk/resedu01.htm.

As one of its responses to the workshop, SECED established a Research Working Party which met for the first time in May 2000. Its terms of reference were as follows.

a) Purpose

To review the current state of UK research in earthquake engineering, and to report on future needs and recommended changes over the next 5 years, both in a national and international context. All aspects of earthquake engineering within SECED's scope will be covered including not just structural earthquake engineering but also seismology, social issues etc.

b) Terms of Reference

1) Carry out an audit of research capabilities in the UK and report.
2) Canvas opinion in the UK construction industry and research community on current and future needs and report.
3) Review current European objectives for research into earthquake engineering, and report on the commonality with UK needs.
4) Recommend ways for the dissemination to the UK construction industry of recent research into issues of concern to the industry, with the aim of facilitating innovation.

c) Composition

1) Roy Severn, University of Bristol (chairman)
2) Edmund Booth, Independent Consultant (secretary and report editor)
3) Scott Steedman, Whitby Bird & Partners
4) Amr Elnashai, Imperial College of Science, Technology & Medicine (to December 2000)
5) Christophe Junillon, W S Atkins
6) John Mills, Babtie Group (from January 2001)

d) Method of Working

The Working Group will meet four times during the course of 2000, and will aim to produce its final report by the end of that year. The report will address the four issues identified in the terms of reference.

This document constitutes the final report of the Working Party. Edmund Booth acted as general editor, and wrote chapters 1,2, 6 and 7. Christophe Junillon wrote chapter 3. Roy Severn wrote chapter 4 and (based on a first draft by Amr Elnashai) chapter 5. Additional material was supplied by John Bethell, Martin Culshaw, Gopal Madabhushi, David Mallard, Bryan Skipp and Scott Steedman.

## 2.3 Acknowledgements

The Working Party acknowledges and thanks all those who returned the two questionnaires described later in the report. John Bethell of British Energy Generation Ltd attended two of the Working Party's meetings and reviewed this report, giving invaluable advice on research practices in the nuclear industry. Stuart Mustow (Hazards Forum/ Royal Academy of Engineering), Lee Bartlett (EPSRC), Gavin Trott (Babtie), Ian Smith (Brown & Root), Zygmunt Lubkowski (Arup), Sean Wilkinson (Newcastle University) and Nick Alexander (University of East London) all attended one of the Working Party's meetings to give the benefit of their advice and experience. These contributions are gratefully acknowledged.

# 3 UK needs for future seismic research

## 3.1 Introduction

To identify ways for a better dissemination of Earthquake Engineering research to the UK construction industry, the opinion of the industry regarding its needs in terms of research was canvassed. This was carried out through a questionnaire sent to all members of SECED. The questionnaire, responses received and accompanying letter sent by the working party are listed in Appendix A and Appendix B.

It is worth noting, in examining the response to this questionnaire, that the opinions expressed will not necessarily represent the opinion of the entire UK construction industry. The questionnaire was addressed to SECED members only, and fifteen responses were received. It is therefore likely that these responses emanated from companies and individuals particularly interested in the dissemination of research, resulting in an overall response biased in this direction.

## 3.2 Review of the questionnaire response

### 3.2.1 Perceived need for the application of latest research

Overall, the respondents considered that they were keeping abreast with the current Earthquake Engineering research, with two thirds declaring that they keep abreast and one third that they sometimes do. Interestingly a different picture was to be drawn regarding the use of the latest research in professional practice. Only a third felt that they regularly apply the latest state of research in their professional practice, half that they sometimes do and the rest that they never do. This is to be compared with the very clear consensus that professional practice would benefit from more use of the latest state of research; reasons highlighted for the difficulties in applying research are listed in section 3.2.3.

To the question of the actual benefits that would result from the application of the latest state of research to professional practice, the most common response was the development of more accurate and more cost effective designs. Designers perceive that, if they were able to convince their clients to invest in more expensive designs based on latest research, they could not only improve the quality of their design but potentially reduce the overall cost of the project through the development of more efficient designs.

### 3.2.2 Most relevant fields of research

The fields of research listed by the respondents as most relevant to their needs were very varied corresponding to the their different professional activities. No clear trend could therefore be derived even though geotechnical issues were most often mentioned. These included soil-structure interaction, liquefaction, hazard modelling and performance of piles and dock walls. Also often mentioned was the performance of masonry structures and panels. Interestingly, the number of topics not mentioned included displacement based and performance based methodologies as well as assessment of lifelines or cities. Also, the seismic performance of structures not designed to be ductile, which one could have thought to be of interest in the UK, was only mentioned once.

Similarly, no consensus could be drawn of the fields of research that are felt to have reached their limit in usefulness.

### 3.2.3 Difficulties in applying research

As discussed in section 3.2.1, the industry indicates a strong will to keep abreast and apply the latest state of research, but feels that it does not actually manage to do so. The reason most commonly given for the non-application of the latest research was the time required for such application against the efficiency of using standard practises. It is interesting to put this restriction in parallel to the perception stated in 3.2.1 that an increase in design costs might allow a reduction in overall project costs.

Also mentioned as a source of difficulty for the application of latest research was the fact that work specifications often stipulate standards or long established methodologies. Even when specifications do not specify standards and established methodology, practitioners are often resistant to depart from those because of the potential difficulties in obtaining agreement with third party peer reviewers and regulatory bodies. Finally, it is felt that research work is often too specific and not easily transferable. Suggestions for improvement of the transferability of research are listed in section 3.2.4 and further developed in section 6.

### 3.2.4 Making research more applicable

Most respondents considered that research work and research publications could be made more easily applicable to their professional practice. First, the industry felt that it could itself contribute to research programmes and ensure that these programmes could lead to more readily applicable advances. This involvement could be in the form of reviews of research programmes or research publications or direct involvement in the research itself provided that a proportion of their cost was met.

Then, it was felt that research could be better disseminated, for example in the form of 'synthesis' of research carried out on a certain topic or guidelines for practitioners on the application of recent research. The idea of guidelines similar to those published by the Applied Technology Council in the USA was well supported.

The topic of dissemination of research is further developed in section 6.

## 3.3 Conclusions

The perception of the UK construction industry needs for earthquake engineering as reflected by the response to the questionnaire can be summarised as follows:

- The industry feels that it would benefit from more use of the latest research in its professional practice.
- The main benefit drawn from such use would be the development of more cost effective and/or innovative designs.
- The industry feels it is often difficult to apply the latest research. The main reasons are the additional cost associated with the design, the excessive specificity of published research work and the stipulation of standards and methodology in specifications.
- No clear consensus could be drawn regarding the most useful fields of research even though geotechnical issues were most often mentioned.
- The difficulties in applying recent research work could be mitigated by ensuring that research work is more applicable to the needs of the industry, through the involvement of the industry in the research, and the publication of research 'synthesis' or guidelines for practitioners.

# 4 AUDIT OF UK SEISMIC RESEARCH CAPABILITIES

## 4.1 Questionnaire response by universities

The letter attached as Appendix C was sent to all 53 heads of departments of civil engineering in UK universities, with a request to solicit responses also from other university colleagues known to be interested in earthquake engineering. Appendix D is a summary of responses received. What follows draws out important features of these responses.

Of the 24 universities responding, 13 reported current seismic projects, although 4 stood out as having major commitments, Imperial College and the universities of Bristol, Cambridge and Oxford; it is valuable, therefore, to deal separately with these four laboratories.

### 4.1.1 Imperial College (IC)

Because engineering seismology is an essential component of earthquake engineering, it is necessary to note that IC has been since the mid-1960's one of the three important centres in the UK for seismology studies*. Its contribution has been at an international level, culminating in 2000 in the production, with European Commission funding, of a CD containing data of all recorded European earthquakes, which is freely available on request (see section 5.7.1). The IC seismological studies have been of great value to UK industry over many years.

In the mid-1970's experimental studies were begun with the construction (in conjunction with Principia Mechanica) of a small 2-axis shaking table, but in recent years experimental studies have given way to a major development in theoretical and design studies, to such an extent that IC is not only a principal UK centre for such research, but is also a leader and substantial contributor to European research. Section 5.4 below gives details of its role since 1990, leading to Prof. Elnashai as the current Coordinator of the European Research Network in earthquake engineering (SAFEER). This, and two earlier research networks (PREC8 and ICONS), have covered many of the most important current research topics, giving IC capabilities in all these areas, a list of which is to be found in Section 5.4 below. The educational and training role of IC should be noted. It offers the only UK fulltime 1-year M Sc course in earthquake engineering, which is well supported. It also organises study visits to earthquake sites through its Earthquake Field Training Unit (EFTU), which has carried out over 40 such missions since 1962.

### 4.1.2 University of Bristol (UB)

Theoretical studies began at UB in 1958, being part of the work of the Arch Dams Committee of the Institution of Civil Engineers. A uni-axial shaking table was built in 1970 to be succeeded in 1985 by a 3x3 metre,6-axis table having a testpiece capacity of 15 tonne. Being principally funded by the SERC as part of its Special Initiative in earthquake engineering, it was designated as a National facility and was freely available to approved SERC researchers. In 1992 UB joined with the major shaking table facilities in Athens, Lisbon and Bergamo(Italy) in founding the European Consortium of Earthquake Shaking Tables (ECOEST – see section 5.3 below), later to be joined by the reaction-wall facility at JRC Ispra and the shaking table at CEA Saclay (France). With EU funding Ecoest provided free access to its facilities for approved researchers from Member States, with UB acting

* The other two being the British Geological Survey in Edinburgh, and the International Seismological Centre which is based at Thatcham, near Reading.

as overall Coordinator. This coordinating role has continued to the present day, with ECOEST2 (1996-99) and ECOLEADER (2000-03) succeeding the original ECOEST. UB therefore has a central role in European experimental research, in which it has collaborated with the three EU-funded Research Networks described in section 5.4 below.

Since 1992, UB has been conducting research with its European partners on the true performance of shaking tables and reaction walls, as a result of which very significant advances have been made, most importantly in the provision of real-time control and the removal of spurious motions. As a consequence new research areas have opened up, in sub-structuring, inelastic behaviour, multiple support input, and continuous pseudodynamic testing on reaction walls. UB and its European partners now have experimental facilities operating at international level

The UB experimental facilities are currently being reorganised and upgraded as part of a £15 million EPSRC/HEFCE project to create the Bristol Laboratory for Advanced Dynamics Engineering (BLADE), due for completion in 2002.

### 4.1.3 University of Cambridge (U Cam)

Earthquake research in soil mechanics started at Cambridge in 1977 following the success of the 10m beam centrifuge facility. Early earthquake actuators were spring loaded, but they were replaced in the 1980's with a mechanical actuator called the 'bumpy road' system that could impart strong earthquakes to soil structure models in-flight. The bumpy road actuator was developed with funding from the US National Science Foundation, and was one of the earliest shaking tables to fly on a centrifuge.

In 1992 a new Stored Angular Momentum (SAM) based actuator was developed with the support of the UC Army Corps of Engineers and was recently upgraded with funding from EPSRC. Future developments in miniature instrumentation are envisaged with the development of MEMS (Micro Electrical Mechanical Systems) in collaboration with the University of California, Davis, under the NEES (Network for Earthquake Engineering Simulation) program of NSF.

### 4.1.4 University of Oxford (U Ox)

Before the possibility of substructuring on shaking tables had been developed, a major disadvantage of their use was the need to test models, usually at small scale. This meant that detailed study of regions of special interest (joints for example) could not be made. In 1995 U Ox addressed this issue and, taking advantage of the increasing speed of computation, developed a substructuring technique in which a small, but critical, part of the complete structure was tested at full scale using hydraulic actuators, with the remaining, greater part of the structure modelled computationally. The interface between the two parts was of course the crucial area for research. This development by U Ox is a valuable new component of UK capabilities in the experimental aspects of earthquake engineering research. The substructuring technique also opens the possibility of experiments being carried out simultaneously at a number of laboratories, each testing a different part of a large structure; there is international interest in this possibility. It has been addressed within a European context, as described in section 5.3 below.

### 4.1.5 Studies at other UK Universities.

Appendix D summarises the responses received to the SECED questionnaire, and indicates the range and extent of the research being conducted at UK universities.

## 4.2 Non university research organisations

Significant research into areas of crucial interest to earthquake engineering design practitioners has been carried out at a number of non-university research organisations in the UK.

A particular contributor has been the British Geological Survey. Its Urban Geoscience and Geological Hazards Programme has a special capability in the determination of geotechnical and engineering geological properties of rocks and soils, and their influence on the amplification of earthquake shaking, resulting in the assessment of earthquake-induced hazards. It has produced a wide variety of seismic hazard susceptibility maps for planning and other purposes, and provided response spectra for building design engineers. It has worked with industrial and university partners from the UK, continental Europe and elsewhere.

Another non-university research organisation is the International Seismological Centre, at Thatcham near Reading, which for many years has prepared definitive bulletins of the seismological parameters of earthquakes.

## 4.3 Research in other fields

Research into social sciences aspects of earthquake mitigation are also important, covering aspects such as disaster preparedness and response, planning control and social acceptability of technical solutions. These aspects are not covered elsewhere in this report, but for completeness, the capability of the Centre for Development & Emergency Practice (CENDEP) at Oxford Brookes University, the Centre for Refugee Studies at Oxford University, the Disaster Planning Unit at Cranfield University, and the Martin Centre at Cambridge University (where CURBE - Centre for Risk in the Built Environment - is based) should be mentioned. Aid agencies based in the UK such as Oxfam have also established considerable experience in these fields, and are internationally recognised as leaders in disaster response.

## 4.4 Industry Research

### 4.4.1 Introduction

The Working Party was aware that in certain parts of Industry, whose activity involves regular participation in seismic design, every structure is unique and therefore involves research and development work having specific application to that project. Such firms include the large Consultants, many of whom are corporate members of SECED. In formulating its letter (Appendix A) to these members, it did however have in mind the three aims set out there, which suggest that Industry is the user, rather than the producer, of research.

### 4.4.2 Research in the nuclear industry

British Energy and its predecessors have over the last 20 years carried out what is perhaps the most substantial amount of research into earthquake engineering matters. Currently, most research is commissioned as part of the 'Industry Management Committee' research programme which is run by British Energy jointly with BNFL. This programme seeks, amongst other things, to address issues raised in the Nuclear Research Index by the Nuclear Installations Inspectorate. Feedback on the Index is invited, both from the nuclear industry and also from researchers proposing topics. In the past, many projects were chosen with a long term view in mind, but the current focus is on projects with immediate application, such as specifying ground motion for soft sites. Typically there are half-a-dozen seismic projects current at any one time, each of one-year duration. Whilst a body of people exists within the UK nuclear industry with expertise in seismic engineering, they have many other duties.

### 4.4.3 Seismic Hazard Working Party (SHWP)

One notable aspect of research in the nuclear industry has been the investigations and publications of the Seismic Hazard Working Party (SHWP), which was founded by the Central Electricity Generating Board (CEGB) in 1982 and is currently still active. It is formed from between 10 and 20 recognised experts (as required) in the fields of earth sciences, engineering seismology and hazard assessment. Its initial brief was to advise the CEGB on the seismic hazard parameters at the potential sites of nuclear installations, and in particular on design ground motions and faulting hazard. Subsequently this has extended to work on existing nuclear sites for the CEGB's successors, currently BNFL Magnox Generation and British Energy. A strategy for the assessment of seismic hazards in Britain was developed by the SHWP, within a supporting set of thirteen methodology reports. These reports provide snapshots into the State of the Art in the wide range of cognate fields (e.g. historical seismicity, instrumental seismology, crustal stress, induced seismicity, international practice, remote sensing, microtremor monitoring, geophysics, Tertiary tectonics, neotectonics) and the essential methodologies.

In the UK it has studied many potential sites for power generation and waste disposal and subsequently has reported in the safety reviews for most existing AGR and Magnox nuclear power stations. It has also undertaken a major study for NIREX at Sellafield and carried out comparative studies in cooperation with EDF (Electricité de France). Recent work has included evaluations of dynamic soil models for various sites and studies on monitoring and site characterisation for Chornobyl, Ukraine.

The SHWP is currently carrying out work under the wing of BNFL Magnox Generation and is also developing its procedures e.g. in the use of empirical Green Functions and in the selection of appropriate real time histories. Throughout its life, the SHWP has encouraged scientific communication. It has produced more than 70 reports, about 30% of which are in the public domain, and has also generated some 75 papers in external publications, one of which was awarded the George Stephenson medal by the Institution of Civil Engineers.

### 4.4.4 Individual Contributions

The specialised nature of earthquake engineering makes it possible for individual consultants to make significant contributions, and for completeness, we note here the work of Bryan Skipp, David Mallard and Willy Aspinall in seismological hazard assessment. In structural and foundation aspects, David Key, Edmund Booth and Scott Steedman have all contributed greatly through SECED, through the European Association for Earthquake Engineering, through PIANC, and in their own consulting practices. In the development of the US Nevada test site Graham Armer has acted as a specialist consultant.

### 4.4.5 Earthquake Engineering Field Investigation Team (EEFIT)

Researchers derive great benefit from observing the effects of real earthquakes on both engineered and non-engineered structures, and the Imperial College EFTU organisation has already been mentioned (section 4.1.1). EEFIT was formed in 1980 with the financial support of the SERC during its Special Initiative in earthquake engineering. The EEFIT organisation at any one time is carried by one of the interested universities or Industry groups, with support from SECED. When an earthquake occurs, a small team, usually 2 university researchers and 2 industry members, is assembled to visit the site as soon as logistically possible after the event. Funding for the university members is now provided by the EPSRC, but Industry covers the costs of its own participants. EEFIT has carried out 16 field investigations since 1983 and reports are available for all of them. Its secretariat is provided by the Institution of Structural Engineers, based in London.

# 5 REVIEW OF EARTHQUAKE ENGINEERING RESEARCH FUNDED BY THE EUROPEAN COMMISSION (EC)

## 5.1 Introduction

This section of our Report restricts itself to research funded by the EC in its various programmes. Whilst it does not describe the totality of European research, because it does not cover work carried out under national programmes, it is the case that earthquakes are not influenced by national boundaries, and this leads to the fact that a good case can be made here for bypassing subsidiarity principles. In other words, seismic research is best carried out on a European rather than a national basis. The EC recognises this. Indeed, since the collapse of the USSR, its former satellites in Eastern Europe, referred to by the EC as 'Associated States', have been allowed to participate in many of its programmes. It is also aware that in earthquake engineering, the European Construction Industry competes at international level principally with the USA and Japan, and therefore merits the central support given by the EC. This leads to the fact that the greater part of earthquake engineering research in Europe is funded by the various EC programmes, rather than by national organisations. In these programmes UK researchers play a very significant role, as will be seen.

## 5.2 The Structure of EC-funded research

On a 3-yearly basis, the EC formulates its so-called Framework Programme (FP), covering a number of generalised themes which it wishes to support. Two such themes in the second FP (1992) which had components related to earthquake engineering, were described as Human Capital and Mobility (HCM), and as Environment and Climate. The first of these was of greater importance because it had sub-sections relating to Large-scale Experimental Facilities, and to Research Networks, details of which are given below. In the subsequent FP's (the year 2000 saw the beginning of the $5^{th}$) the precise titles of these two sub-sections were changed for greater administrative clarity, but their purpose remained the same. Right up to the FP5 there have been opportunities for seismic research, but it has thus far been a feature of the EC organisation that there has been little synergy between the HCM and the Environment Directorates.

## 5.3 Large Scale Experimental Facilities (or Infrastructures)

In the 1990 report of the Advisory Committee on the EC's Large Infrastructures Plan (LIP), the study panel on Earthquake Engineering concluded that, with the completion of the new shaking table in Lisbon (funded by LIP) and the reaction- wall at JRC Ispra, there were sufficient large facilities available, but that they were not coordinated to enable them to support an integrated European programme of research. As a consequence of this conclusion, LEE Athens and EERC Bristol were funded to begin (1991) an in-depth study of true shaking table performance. This required the construction of two identical (14T) testpieces, by use of which the real characteristics of the two tables could be explored. Attention was also paid to computing and organisational aspects.

Out of this early collaboration the European Consortium of Earthquake Shaking Tables (ECOEST) was created in the Third Framework Framework Programme (1993-96),in which Athens and Bristol were joined by ISMES, now ENEL-HYDRO, (Bergamo) and LNEC Lisbon. With EC funding, the two principal activities of ECOEST were:-

1. Continuation of the studies on actual shaking table performance.

2. Provision of free access to the 4 shaking tables for approved researchers from Member States (see Research Networks, section 5.4,below).

The studies in 1. above began to indicate serious deficiencies in the four facilities, particularly that they operated 'out-of-real-time' due to inadequate control of input to the testpiece. In effect this meant that non-linear behaviour of testpieces could not be studied; this is significant because modern approaches require non-linear behaviour to be accounted for.

Following these discoveries, the 4 ECOEST partners obtained a research contract from the EC described as - 'Control Enhancement of Shaking Tables from Analogue to Digital Systems (CESTADS)', to explore the application of recent developments on control engineering to shaking tables. In particular, the adaptive Minimal Control Synthesis (MCS) Algorithm has been used, to such an effect that 'real-time' control has been achieved, with greater accuracy than was previously possible. This has brought European testing facilities to the current International level.

In the 4th Framework Programme the reaction wall at JRC Ispra and the large shaking table at CEA Saclay were added to the existing four to form ECOEST2, with basically the same objectives as ECOEST. Moreover, the success of CESTADS had indicated the ability to carry out research into several new areas, as follows.

1 Controlled non-linear behaviour of testpieces
2 Multiple-support input
3 Continuous pseudo-dynamic testing
4 Control of spurious motions
5 Sub- structuring on shaking tables

A successor contract to CESTADS, now named FUDIDCOEEF- Further Developments in Dynamic Control of Earthquake Engineering Facilities (1998-02) was obtained to explore these topics. A promising degree of success has been obtained in all these areas.

For the 5th Framework Programme (1999-02) ECOEST2 has given way to ECOLEADER – 'European Consortium of Laboratories for Earthquake and Dynamics Engineering Research, indicating the intention to incorporate other branches of dynamics into the total activity. Since 1992 the EC has provided more than 5 million Euros to the 6 laboratories discussed above to provide free access for experimental research. On the topic of research training, it should also be recorded that JRC Ispra and EERC Bristol have been recognised as Marie Curie Training Sites (MCTS) in earthquake engineering. Here, the EC provides funds for PhD students from Member and Associated States to spend between 3-12 months at the MCTS in pursuance of their research topic.

All three large scale experimental facility programmes have been coordinated by Prof R T Severn of Bristol University.

## 5.4 Research Networks

In the various Framework Programmes since 1992, a succession of Research Networks, which were mentioned in section 5.2 above, has been successful in obtaining financial support totalling around 6 million Euros. The successive Research Networks have generally consisted of the same core group of European research laboratories; the Network names and their respective coordinators for the successive Framework programmes have been as follows.

PREC8 - Prenormative research in support of Eurocode8 (Coordinator Prof M Calvi, Pavia, Italy) 1992 to 1995
ICONS - Innovative concepts in seismic design of new and existing structures (Coordinator Dr A Pinto, JRC Ispra ) 1996 to 2001
SAFERR – Safety assessment for earthquake risk reduction (Coordinator Prof A Elnashai, Imperial College London) 2000 to 2004

Two new networks recently funded under the $5^{th}$ Framework programme (GROWTH) will include developing strategies for European research including earthquake engineering needs (see section 5.7.2)

## 5.5 Overview of the EC funded programme

Tables 5.1 to 5.6 provide an overview of the EC funded work described above. Table 5.1(a) summarises the three research networks (PREC8, ICONS and SAFERR), showing the participants and the research topics involved. These topics have been assigned references (P1 to P5 for PREC8, I1 to I5 for ICONS and S1 to S4 for SAFERR), which are subsequently described in Table 5.2 (for PREC8), Table 5.3 (for ICONS) and Table 5.4 (for SAFERR).

Table 5.1(b) mirrors Table 5.1(a) by identifying the experimental facilities (ie the "large scale facilities" institutions described in section 5.3) supporting the research networks. Three programmes (ECOEST, ECOEST2 and ECOLEADER) ran successively in parallel with the three corresponding research networks programmes, as shown in Table 5.1(b), which identifies the participants and the research topics they were involved in. The participants not only provided experimental facilities but also collaborated in formulating the research programme and in carrying it out. In fact a considerable synergy developed between the various participants, from which a coherent European earthquake engineering research programme has emerged (see section 5.6).

Tables 5.2 to 5.4 describe the topics that have been studied in the three research network programmes.

Tables 5.5 & 5.6 show the technical report series emanating from (respectively) the ECOEST/PREC8 and ECOEST2/ICONS programmes, which are now completed. The ECOLEADER/SAFERR programme is in progress at the time of writing, and subjects for the reports will emerge as research proceeds. These reports have been circulated primarily within the European research community, at which they were mainly aimed. They were intended to form a comprehensive record of the research performed, and have not been circulated or widely used within industry. The reports are further discussed in section 5.6.

| a) RESEARCH NETWORKS | | | | | |
|---|---|---|---|---|---|
| | **RESEARCH INSTITUTION** | Responsible scientist | PREC8 (Table 5.2) | ICONS (Table 5.3) | SAFERR (Table 5.4) |
| | | | Research Topic | | |
| 1 | University of Liége (Belgium) | A Plumier | P1 | I2, I4 | S1, S2 |
| 2 | Géodynamique et Structure (France) | A Pecker | P5 | I1, I3 | S1, S3 |
| 3 | GRECO/GEO – French group for Coordinated Research (France) | J Mazars<br>J M Reynouard | P1, P5 | I2, I3, I5 | S1, S2, S3 |
| 4 | Darmstadt University of Technology (Germany | **J WÖRNER** | P1 | I2, I4 | S2, S3 |
| 5 | University of Patras | M N Fardis | P1, P2 | I2, I3, I5 | S2, S3, S4 |
| 6 | Università di Basilicata (Italy) | M Dolce | P1 | - | - |
| 7 | Politecnico di Milano (Italy) | E Faccioli | P5 | I1, I3 | S1, S4 |
| 8 | Università di Pavia (Italy) | G M Calvi | P1, P2, P4 | I1, I2, I3 | S3, S4 |
| 9 | Università di Roma “La Sapienza” (Italy) | P E Pinto | P4 | I2, I3, I5 | S2, S3 |
| 10 | Universidad Politecnica de Madrid (Spain) | E Alarcon | P4 | I2, I4 | S3, S4 |
| 11 | Imperial College, London (UK) | A S Elnashai | P1, P4 | I1, I2, I4 | S1, S3, S4 |
| 12 | University of Ljubljana (Slovenia) | P Fajfar | - | - | S2, S4 |

| **B) “LARGE FACILITIES” SUPPORTING INSTITUTIONS** | | | | | |
|---|---|---|---|---|---|
| | Large scale experimental facility | Responsible scientist | ECOEST I | ECOEST II | ECOLEADER |
| | | | **RESEARCH TOPIC** | | |
| A | TAMARIS-CEA, Saclay (France) | P Sollogoub | - | I3, I4, I5 | Support by the ECOLEADER institutions to the SAFERR research network has yet to be determined |
| B | National Technical University of Athens (Greece) | G Gazetas<br>P Carydis | P1, P5 | I4 | |
| C | ISMES Bergamo (Italy) | G Franchioni | P4 | I4 | |
| D | Joint Research Center, Ispra (Italy) | A V Pinto | P1, P2, P4 | I2, I3, I4, I5 | |
| E | National Laboratory for Civil Engineering, Lisbon (Portugal) | E C Carvalho | P1, P4 | I1, I2 | |
| F | University of Bristol (UK) | R T Severn | P2, P5 | I4 | |

Table 5.1. Participants and involvements in network sub-topics

| | Topic | Aims | Scope of work |
|---|---|---|---|
| P1 | RC Frames | Quantitative interrelation between:<br>• regularity<br>• analysis method<br>• extent of capacity design<br>• $q$-factor | • Definition of numerical models, numerical analysis & experimental verification<br>• Definition of regularity parameters<br>• Table of $q$-factors<br>• Calibration of procedures for beams & columns in shear, columns in bending with axial loads, beam-column joints & structural walls |
| P2 | Infills | Definition of design philosophy and methods for modelling behaviour as a function of relative strength, stiffness, ductility and location | • Review existing research results<br>• Real-scale tests<br>• Numerical experiments for buildings<br>• Definition of criteria to account for infills |
| P3 | Reinforcing steel | Redefinition of required characteristics in light of new technology | • Numerical experiments<br>• Element / sub-assembly tests<br>• Revision of design |
| P4 | RC bridges | Definition of irregularity parameters and appropriate $q$-factors. Investigation into asynchronous motion | • Numerical experiments<br>• $q$-factor / shape, stiffness distribution relationships<br>• Large scale validation tests |
| P5 | Foundation and retaining structures | Definition of seismic action parameters of soil stability & soil / foundation (shallow & piled) interaction | • Review of existing research results<br>• Experiments to define feasible scale-reduction & shake table tests<br>• Numerical simulations<br>• Revision of seismic actions & analysis methods for safety verification |
| (PREC8 Programme Coordinator: M G Calvi, Università di Pavia, Italy) | | | |

Table 5.2 PREC8 topics, research aims and scope of work

| | Topic | Sub-topic |
|---|---|---|
| I1 | Seismic action | • Analysis of strong ground motion<br>• Simulations with SDOF/MDOF models<br>• Damage controlled spectra development<br>• Applications to bridges |
| I2 | Assessment, repair and strengthening | • Theoretical framework for assessment<br>• Rapid screening methods<br>• Selective intervention techniques<br>• Experimental verification of materials and techniques<br>• Code provisions for assessment & upgrading |
| I3 | Innovative design concepts | • Base isolation (bridges and buildings)<br>• Uplifting/rocking as base isolation<br>• Displacement based design |

| | | |
|---|---|---|
| I4 | Composite structures | • Design formulae<br>• Numerical modelling<br>• Classes of sections<br>• Tests |
| I5 | Shear wall structures | • Model Development & validation<br>• Numerical assessment of EC8 rules<br>• Improvement of EC8 |
| (ICONS Programme Coordinator: A Pinto, JRC Ispra, Italy) | | |

Table 5.3 Technical issues addressed in the ICONS programme

| | Topic | Sub-topic |
|---|---|---|
| S1 | Characterisation of seismic hazard | • Seismic hazard zonation<br>• Near source effects<br>• Long period spectral ordinates<br>• Complex geological features |
| S2 | Assessment and design in low seismicity areas | • Construction details for non-engineered buildings<br>• Resistance of non-seismically designed buildings<br>• Minimum provision shear walls |
| S3 | Strategies and techniques for risk reduction | • Base isolation<br>• Deformation of non-seismically designed buildings<br>• Strengthening strategies<br>• Flat slab structures<br>• Bridge systems<br>• Assessment and strengthening of foundations |
| S4 | Risk assessment | • Displacement-based hazard mapping<br>• Displacement based vulnerability functions<br>• Integration of hazard & vulnerability |
| (SAFERR Programme Coordinator: A S Elnashai, Imperial College, UK) | | |

Table 5.4 Technical issues addressed in the SAFERR programme

| | Report Title | Editor |
|---|---|---|
| Vol 1 | Standardisation of shaking tables | A Crewe |
| Vol 2 | Seismic behaviour & design of foundations and retaining walls | E Faccioli & R Paolucci |
| Vol 3 | Large scale shaking tests of geotechnical structures | C A Taylor |
| Vol 4 | Experimental & numerical investigations of the seismic response of bridges and recommendations for code provisions | G M Calvi & P E Pinto |
| Vol 5 | Pseudodynamic and shaking table tests on RC bridges | A V Pinto |
| Vol 6 | Experimental & numerical investigations on the seismic response of RC infilled frames and recommendations for code provisions | M N Fardis |
| Vol 7 | Numerical investigations on the seismic response of RC frames designed in accordance with EC8 | E Carvalho & E Coelho |
| Vol 8 | Shaking table tests of RC frames | P Carydis |
| Vol 9 | European activities for the development of EC8- summary report | R T Severn & G M Calvi |
| All the volumes were published by LNEC, Lisbon (Portugal) under the general editorship of R Bairrao | | |

Table 5.5 The ECOEST/PREC8 technical report series

| | Report Title | Editor |
|---|---|---|
| Vol 1 | Seismic actions | E Faccioli |
| Vol 2 | Assessment, strengthening and repair | E Carvalho |
| Vol 3 | Innovative design concepts | M N Fardis & GM Calvi |
| Vol 4 | Composite steel/concrete structures | A Plumier |
| Vol 5 | Shear wall structures | J M Reynouard/ M Fardis |
| Vol 6 | Soil dynamics and foundation structures | C Taylor & D Combescure |
| Vol 7 | Base isolation, active & passive systems | G Franchioni |
| Vol 8 | Special systems (eg cable bridges, irregular bridges, asymmetric structures) | R T Severn & C A Taylor |
| Vol 9 | Development of control in experimental facilities | D Stoten & G Magonette |
| All the volumes will be published by LNEC Lisbon (Portugal) under the general editorship of R Bairrao | | |

Table 5.6 The ECOEST2/ICONS technical report series

## 5.6 Concerted Actions

In the EC's overall Framework Programme, 15 different types of Large Scale Experimental Facilities were identified, earthquake engineering facilities being one. In order to foster the European dimension in each of these groups, the EC introduced 'Concerted Actions' (CA) contracts, to be competed for, and awarded to, the coordinator of each group. For earthquake engineering this was EERC Bristol. The funds attached to each CA contract were to be used for any activity which produced synthesis between the members of each group and of their users. For earthquake engineering, a CA has been in operation since 1994,with the two principal functions being the holding of an annual 'Round Table' and the production of technical reports of such a length (eg 200 pages) to include details of the collaborative work carried out. The Round Tables could invite internationally recognised experts to help analyse work already done, and to assist on the formulation of future programmes. The detailed reports were to be sent to 150 of the World's major research centres. Table 5.5 lists the reports published on behalf of ECOEST/PREC8, and Table 5.6 those on behalf of ECOEST2/ICONS. A similar series is planned for ECOLEADER/SAFEER.

## 5.7 Other Activities Funded By The EC

### 5.7.1 Strong Motion Development and Research

This work at Imperial College London under Prof N Ambraseys, in association with other European institutions, is being funded by the Environment and Climate programme of DGXII to produce a CD-ROM of 1000 strong- motion time histories and their response spectra; it is now freely available. The second phase, which is in progress, will establish a European internet site for strong motion data.

### 5.7.2 The European Council for Construction Research, Development and Innovation (ECCREDI)

As the name indicates, ECCREDI covers the whole of the construction industry, with its activities divided into 12 so-called 'Clusters', of which 'Seismic and Vibration Isolation' is number 4. ECCREDI, whose current president is Dr. Scott Steedman (UK), acts as an umbrella, enabling body, and to perform its function it has succeeded in obtaining (1997-2001) from the EC BRITE/EURAM programme financial support for a 'Targeted Research Action (TRA) – Environmentally Friendly Construction Techniques'. Individual researchers working under the ECCREDI umbrella are required to compete separately for financial support from the EC, but with the advantage of being within a coordinated programme. In Cluster 4 the only UK-based programme is the project coordinated by EERC Bristol on 'The Effect of Infills on the Seismic Behaviour of Reinforced Concrete Frames'; this project involves not only the EU but also states from the former Soviet Union and Eastern Europe.

A new network contract was secured in 2001, known as E-CORE, to develop the TRA activities further, including the development of a research strategy for Europe, linked to national research programmes. The scope covers all aspects of construction research, but an important part will address earthquake engineering. A sector network, GEOTECHNET, was also approved by the EC in 2001. One of the work packages within GEOTECHNET will address the field of geotechnical earthquake engineering research needs.

## 5.8 EC funded research and its relevance to UK industry

The various tables in section 5 of this report show clearly the wide range of research topics which have been funded by the European Commission during the past 10 years, and it is likely that variations on these general themes will continue in the 6th Framework Programme (2002-2005) because recent European earthquakes in Turkey, Italy and Greece have emphasised the need for this continuing research.

The topics chosen for EC-funding derive from proposals made by European researchers meeting together. Naturally, they propose their own interests, but moderated by the knowledge that the assessors appointed by the EC to adjudicate on proposals submitted, are directed to consider the value of the research to the European economy and employment. Since 1990, considerable efforts have been made by researchers in the Construction field (see section 5.7.2) to promote the importance of research to assist the European Construction Industry in its internationally competitive activities, and this has been particularly successful in earthquake engineering, assisted of course by recent major seismic events in Europe. It has been repeatedly pointed out that the study of earthquake engineering requires the highest levels of expertise across a broad range of topics in the general area of applied mechanics; the list is long, but includes advanced computing, control engineering, dynamic finite element methods, non-linear material behaviour, electronic instrumentation and data collection and processing. These topics are also of value, of course, in other branches of engineering, and so earthquake engineering research has benefits for European Industry far beyond its own sectors of immediate application.

If we now turn to the matter of value to UK Industry of EC-funded research in Earthquake Engineering, we see immediately that the resulting overall advances in applied mechanics are just as valuable to the UK as to the rest of Europe, and that the significant involvement of UK researchers in these EC-funded programmes, has major benefits for UK Industry as a whole, specifically in the advanced education of its personnel.

The UK is not a major seismic zone, but its Industry, particularly its Construction Industry, builds for the world, with at least one-half of its activity being in parts of the world where earthquakes figure in design decisions. The EC-funded research is immediately applicable in this activity. It should not be forgotten that the UK Construction Industry plays a major role in humanitarian reconstruction actions following earthquakes throughout the world, and would not be in such a position to do so if it were reliant on its own research findings. One particular area of construction activity where UK Industry is not well served by EC research in earthquake engineering is that of the nuclear industry. Only France and the UK now have any sizeable interest in nuclear energy, and the EC employs the 'subsidiarity' principle in the area of research, leaving these two countries to do their own.

# 6 Improving the implementation in the UK of earthquake engineering research

## 6.1 Possible means for improving implementation

Possible ways in which SECED could foster means of improving dissemination of research in earthquake engineering from universities to practitioners include the following.

1) Develop mechanisms so that practitioners can find out more easily the details of current seismic engineering research. Possible means are as follows.
    a) Website, moderated by SECED, on which UK researchers are invited to post details of their research. Researchers from outside the UK might also be invited to contribute
    b) Annual or six monthly supplements to the SECED newsletter
2) Set up a SECED directory of academic researchers in earthquake engineering, similar to the present SECED directory of practitioners, but probably web based and free to full time academics.
3) Publicise the results of research more widely to practitioners, through the following measures
    a) Organise technical meetings, either directly by SECED or in collaboration with other engineering organisations
    b) Encourage publication of results in journals widely read by practitioners involved in earthquake engineering, for example SECED newsletter, Journal of Earthquake Engineering
4) Take measures to ensure that the results of research are published in a form that practitioners find of direct use
    a) Prepare guidelines on the format for presenting the results of research in a format suitable for industry
    b) Commission digests of research into specific topics or fields in a format directly useful to practitioners, perhaps following the successful format of the ATC publications. The digest would need to be prepared by authorities in the field, so that the publication would have the effect of refereeing the research investigated; this should add to its acceptability by clients and approval authorities.
5) Influence the direction of future research by the following means.
    a) Attempt to influence EPSRC, EC (the two largest sources of UK research funding) and other funding agencies, on the research topics they should support. This could take the form of preparing strategic advice, on the lines of a document produced by the UK's Wind Engineering Society.
    b) Advise professional bodies such as the ICE Structures and Buildings board, IStructE Research Panel, ACE Research & Innovation committee. Establishing more formal links between SECED and these bodies would be one possibility.
    c) Influence universities directly on strategic directions for research, for example through workshops.
6) Promote direct industrial participation in academic research. Possibilities include the following.
    a) Foster the involvement of practitioners in government sponsored joint research mechanisms, (CASE, Teaching Company, etc). SECED could attempt to do this by identifying suitable projects and publicising them widely.

b) Foster the formation of research clubs, formed of industrial and academic participants. Each participant contributes by cash and kind to the project in varying proportions and has preferential access rights to the results of the research. SECED could for example offer to broker such clubs, by publicising requests for participants
c) Foster direct commissioning of academic research by industry.

Given limitations of resources, and the limit to the amount of voluntary work that can be expected from SECED members, there must be a highly selective choice of the initiatives that SECED should pursue at this stage. It should be noted, however, that the potential scope for SECED to act could radically increase if the upper bound of predictions for profit are realised from the forthcoming European conference (12ECEE), to be hosted by SECED in London during September 2002. It should also be recognised that 12ECEE represents an opportunity for furthering international initiatives, and this possibility is being pursued. For the purposes of this document, it is proposed that no financial contribution by SECED is assumed before September 2002.

## 6.2 Discussion of possible SECED initiatives

This section discusses briefly the possible SECED initiatives listed in the previous section, and recommends which should be put forward for development at this stage.

<u>1) & 2) Publicising research expertise and current research in earthquake engineering</u>

Establishing a web-based directory of current UK based academic research in earthquake engineering, in conjunction with a directory of UK based full time researchers, would be relatively simple to do. Appropriate funds should be sought for example from the IStructE or ICE research funds to hire someone to do the work, which would be monitored by the SECED research sub-committee. The aim would be to complete the work in time for the 12ECEE in 2002. The directory should aim to be comprehensive for all relevant UK based research.

It is recommended that SECED should ask its research and education sub-committee to prepare a detailed specification for this exercise, and should lend its weight to appeals for funding.

<u>3) Publicising the results of research</u>

This constitutes the main current activity of SECED and no new initiatives are proposed here.

<u>4) Making the results of research more directly useful to practitioners</u>

It is recommended that SECED should host a special session during the 12ECEE on the preparation of guidelines for the format of publication of research results.

Commissioning digests of research into a format more directly usable by design practitioners is recommended as the major initiative to be pursued at this stage by SECED. The aim would be to increase the usability, both by collating results and improving their format, and also by adding validity to research results by having them reviewed by a distinguished review panel. Clear reports on existing, well-established good practice in earthquake resistant design (as opposed to new practice) would also be a worthwhile task. The preparation of reports is discussed further in Section 0 below.

5) Influencing future strategies for earthquake engineering research

Section 3 of this document reports and comments on the profession's views of current needs for research. As far as EPSRC funded research is concerned, the main way of influencing research is through individual referees assessing projects. For a number of reasons, commenting directly on individual research proposals is something that SECED should not become directly involved in (although encouraging its industrial members to become reviewers is a worthwhile aim). Earthquake engineering is unlikely to become a major initiative for EPSRC. However, EPSRC continue to support research into basic aspects of earthquake engineering and will continue to do so. The situation in Europe as a whole is of course quite different, which is why EC funding is so important for UK based research in earthquake engineering, as further discussed in section 6.3.2.

It is not proposed that any further initiatives should be pursued at this stage on the direction and content of earthquake engineering research in the UK.

6) Promote direct industrial participation in academic research

There are some interesting possibilities. In particular, the EPSRC provides funds of up to £60,000 over three years, to support Research Networks. The Networks are intended to allow academics and industrialists to get together and discuss problems/issues of interest, share experience and discuss future research needs.

It is recommended that the possibility of SECED brokering research Networks in earthquake engineering should be further investigated.

## 6.3 Preparation of reports on earthquake engineering

### 6.3.1 Requirements for a research report

There is a highly successful and influential model for this, in the ATC reports on earthquake engineering. ATC was formed by the Structural Engineers' Association of California (SEAOC) in 1971. In the past 20 years, it has published over 40 reports on earthquake engineering. Many have become industry standards and in at least one case has been adopted by ASCE (American Society of Civil Engineers) as a prestandard, for eventual development into an ASCE standard. SECED's sister society in France, AFPS, has also produced a series of technical reports on earthquake engineering topics, which have been used by design professionals; about 2 such reports are produced every year. Another example of research guidelines is ASCE 4-98[2], which has been widely used as an authoritative source for seismic analysis in the UK as well as the USA where it was written, and has gained acceptance by regulators in the nuclear industry.

The essential features of an ATC report are as follows.

a) The report is prepared by a distinguished team of academics and practitioners, with practitioners predominating, and with a practitioner as chairman.
b) Those contributing are paid at around 65% of commercial rates.
c) Funding has usually come from the US government's Federal Emergency Management Agency, FEMA.

Procedures a) and b) have been a major feature in the success of the ATC report series, and it is recommended they should also feature in any initiative that SECED gets involved with.

### 6.3.2 Possible funding sources

Given the absence of a major earthquake risk in the UK, it is unlikely that SECED acting on its own could obtain government funding analogous to ATC's funding from FEMA. It is therefore recommended that the main SECED activity at this stage should be to act as a broker for collaborative projects, involving funding sources in the UK, from the European Commission, and elsewhere including the US. At a later stage, reports on issues of specific issue to the UK could be undertaken on a purely national level, perhaps with some 'seed funding' from the UK. Specifically, it is recommended that the SECED main committee should instigate approaches to the following, to investigate the possibility of collaborative preparation of such research reports.

1) EPSRC (Engineering and Physical Sciences Research Council, the British government research funding agency)
   EPSRC funds original research, rather than preparing research digests, but funding for dissemination of the research in a form suitable for industry is possible, as one part of the research project.
2) European Commission (EC). There are a number of possible funding sources which should be investigated further.
3) Applied Technology Council (ATC) in the USA.
   ATC has been approached for this report; its initial reaction was very positive and it indicated that ATC would definitely be interested in pursuing the possibility of working in such a collaborative fashion. The concept of collaborative efforts with organizations in other countries is included in ATC's long-term strategic plan, as developed by the ATC Board of Directors.

### 6.3.3 Possible projects for a report

A number of possible projects have been identified from within the Research Working Party and from the wider consultation exercise, carried out as part of its work (Appendix B). The following topics were mentioned, but the list is not intended to be exclusive or comprehensive.

1) Comparison of EC8 and IBC (the US code), possibly for steel or concrete buildings and maybe restricted to looking at the seismic demand side. Near final drafts of the full Euronorm (EN) version of Eurocode 8 Parts 1 and 5 are now available and they are expected to be finalised soon. This would be a suitable joint project for European/ATC collaboration.

2) Dock walls – a topic currently of great interest for UK (nuclear) application and overseas consultancy; also there is UK expertise in the field at the highest international level.

3) Review of research projects – where did we get to, what do we need to do, do we need to worry about it, where do we go for further work. Specific topics could be the following.

a) Effect of vertical accelerations on the response of structures in European near field earthquakes.

b) Displacement based methods of analysis.

c) Performance based design.

d) Remediation of large dams subject to potential liquefaction during earthquakes

It is recommended that, at this stage, this should be regarded as a working list of possibilities, for use as illustrations when contacting potential collaborators in the UK, the European Commission, the USA and elsewhere.

## 6.4 Summary

There are a large number of possible ways in which SECED could foster improved dissemination of earthquake engineering research to design practitioners in the UK. Limitations of resources make it desirable to pursue a few of the more promising ways in the first instance and then review their progress after a period of time, perhaps to coincide with the European Conference on Earthquake Engineering, which will be held in London in September 2002.

It is recommended that the following four initiatives are pursued, and that the main SECED committee should ask its research and education sub-committee to prepare more detailed specifications for them both.

The three initiatives are:

a. Preparation of a web-based directory of UK full time researchers and UK research in earthquake engineering.
b. Approaching funding organisations, including the EPSRC, European Commission and ATC to discuss collaborative projects to prepare guidance reports for design professionals.
c. Investigation of ways in which SECED might help to broker Research Networks in seismic engineering between UK industrial and academic partners.
d. At the forthcoming European conference on earthquake engineering in London (12ECEE), SECED should host a special session, aimed at drafting guidelines for presenting the results of seismic research in a format suitable for industry.

## 7 Summary of recommendations

1) At the forthcoming European conference on earthquake engineering in London (12ECEE), SECED should host a special session, aimed at drafting guidelines for presenting the results of seismic research in a format suitable for industry.

2) SECED should use the same conference as an opportunity for reviewing and furthering the international collaborative initiatives proposed in this report.

3) SECED should seek to establish a web-based directory of UK full time researchers and UK research in earthquake engineering. As a first step, it should ask its Research & Education sub-committee to prepare a full specification and funding estimate for the study.

4) It is considered that UK consulting industry would benefit from reports on particular aspects of earthquake engineering; the benefit would arise both from the organising of published research in a form directly usable by industry, and by the refereeing of the research by acknowledged authorities which should make the use of the research more acceptable to clients and approval authorities.

5) SECED should take steps to broker a collaborative effort to prepare such reports, which would be modelled on those produced by the ATC in America. As a first step, SECED should approach EPSRC in the UK, European Commission and ATC in the USA to investigate the feasibility of preparing reports. An illustrative list of possible report subjects is given in this report.

6) SECED should endeavour to broker an EPSRC funded Research Network in earthquake engineering. The Network would involve a consortium of industrial and academic partners sharing experience and formulating research needs.

7) Many other initiatives are possible for improving the implementation of research, and some are identified in this report. In order to ensure that the necessarily limited effort available to SECED is not spread to widely, it is recommended that the effort should be directed to the initiatives proposed above. However, the possibilities should be revisited in about 2 years time, to consider whether further initiatives might then be possible, in the light of progress to date, and the financial position of SECED.

## Appendix A
## Letter regarding industrial questionnaire sent to all SECED members

March 2000

Dear SECED member

One of SECED's prime objectives is to improve the relevance and accessibility of UK research in earthquake engineering. To this end, SECED has established a Working Party on earthquake engineering research in the UK; its remit is as follows.

> "To review the current state of UK research in earthquake engineering, and to report on future needs and recommended changes over the next 5 years, both in a national and international context."

The Working Party aims to report in December of this year, after carrying out a wide consultation process with industry and academia. The enclosed questionnaire marks the start of this process; it is directed towards all those with an interest in earthquake engineering research working in industry, and has the following aims.

1. To canvas opinion in the UK construction industry on the applicability and usefulness of current research in Earthquake Engineering
2. To establish industry's needs for future research
3. To establish any relevant research capabilities in industry.

Please encourage as many of your industrial colleagues with an interest in the field to respond. A second questionnaire has been sent separately to all UK departments of civil engineering. We need your replies by 15th August 2000.

Copies of the questionnaire can be downloaded in electronic format from the SECED website, http://www.bham.ac.uk/CivEng/seced/RWG/index.htm, which also gives more details of the Working Party. Replies in electronic format (by e-mail – mailto:marwood_l@ice.org.uk - or by post to myself) would be preferred but hardcopy to the Institution at the above address is also of course acceptable. If you would prefer to make a separate submission (not using the questionnaires), you are welcome to do so, using the same means of reply.

I look forward to receiving your views, and sharing the working party's conclusions with you later this year. All respondents to the questionnaire giving an e-mail address will receive a draft copy of the report for comment before its final publication.

Yours sincerely

Edmund Booth

Secretary, SECED Working Party on earthquake engineering research

**Appendix B**
**Summary of responses to SECED membership questionnaire**

Industrial Questionnaire: summary of responses

15 Responses received

| | Yes | No | Sometimes |
|---|---|---|---|
| **1. Do you keep abreast with the current Earthquake Engineering research?** | 9 | | 6 |
| **2. Do you use the latest state of research knowledge in your professional practice?**<br>3. **If not or sometimes, why?** | 5 | 2 | 8 |
| • Research work too specific and not transferable to similar problems | 5 | | 4 |
| • Results are presented in a format difficult to implement in practice | 3 | 1 | 3 |
| • Recent research work lacks credibility | 2 | 3 | 4 |
| • Standard practices are more efficient | 4 | | 5 |
| • Work specifications often stipulate standards or long established methodologies | 6 | | 2 |
| • Research results are poorly disseminated | 3 | 2 | 5 |
| • Other reasons (please specify)<br>a) I spend most time getting people to do the basics right and this is what is needed in most cases<br>b) Limited forum for technical debate<br>c) Currently, we are too busy to develop application of new methods, so we use what we know, but would like to update.<br>d) NII [nuclear regulator] acceptance of new methods. | | | |
| **4. Do you feel that your professional practice would benefit from more use of the latest state of research?** | 13 | | 2 |

| |
|---|
| **5. What could these benefits be?**<br>a) More accurate/practical use of dynamics in all projects and structures<br>b) Greater confidence in our existing analytical procedures, thus increasing cost effectiveness<br>c) Greater reliability in design and assessment<br>d) Improved understanding of structural performance. More cost effective designs. Reduction in future expenses to retrofit structures<br>e) Minimise uncertainty. Recognise uncertainty, where it is not possible to minimise it.<br>f) For my practice, the main benefit would be a competitive advantage. For the client (and perhaps society) the advantage it is hoped would be a better end product.<br>g) Latest research could be useful for design and assessment of structures which fall outside of the accepted methodologies and codes of practice<br>h) Cost effective design with more confidence<br>i) Coherent approach to hazard assessment, design processes, detailing and testing<br>j) Faster cheaper design. Reduced capital costs. Solutions where none existed before?<br>k) Leading edge, innovative design practice<br>l) Safer and more economical designs. |
| **6. What current fields of research are potentially relevant to your current needs or those of your client?**<br>a) Dynamic soil structure interaction and liquefaction<br>b) All fields<br>c) Retrofit of bridges and masonry structures<br>d) Realist soil structure interaction modelling and parameters<br>e) The list could be very long. One I would particularly single out is methods for the assessment and upgrading of high risk buildings.<br>f) Beyond yield behaviour of elements not designed to be ductile. Behaviour of masonry panels, especially for out of plane loading.<br>g) Geotechnics, seismic hazard, liquefaction<br>h) Quantification (as a code) of hazard assessment, design processes, detailing and testing – ie the research detailing & supporting the effects in such a code.<br>i) Ductile steel frames, masonry, backfitting.<br>j) Use of innovative products/ materials in structures to improve seismic performance.<br>k) Performance of buildings in earthquakes. Engineering seismology.<br>l) Dock wall behaviour<br>m) Hazard. Soil/structure interaction. Detailing. |

| |
|---|
| **7. What, if any, barriers exist in implementation of that research?**<br>a) Usually costs at design stage<br>b) The suitability of techniques to carry out appropriate tests in UK<br>c) 'Specific' research can often not be applied to design of other non-identical structures<br>d) The additional cost would be imposed on us to get them approved or verified. Clients may end up spending more money instead of a cheaper and more efficient solution.<br>e) Limited hands on experience of software and its limitations<br>f) Lack of expertise and money. This primarily an issue for developing countries, however, rather than the UK.<br>g) Making a case that results of the research can be transferred into real life case. Potential difficulty in convincing regulators/ independent assessor in validity of method<br>h) Money versus market share<br>i) Time and money (in house) to implement new methods. Conservative approach as required in a regulated industry [nuclear power].<br>j) Lack of design guidelines/instructions [on the use of innovative materials]. Lack of cost studies showing economic viability.<br>k) Money<br>l) Finance |
| **8. What fields/areas of research not currently pursued would you like to see pursued**<br>a) More attention to 'components' of uncertainty in hazard.<br>b) The UK actually has a surprisingly lively seismic research community which covers a wide field, (as I expect the results of the companion academic questionnaire to show). I don't think it needs to be comprehensive, though I do think it needs to be relevant. The UK shouldn't attempt to do it all (nor does it) because researchers overseas are just as important to UK designers. No particular area of UK weakness occurs to me; in fact, I think a satisfactorily broad field is covered.<br>c) Pile behaviour after yielding<br>d) Behaviour of piles at large displacements. Slope stability (eg Ambraseys & Menu). Practical, quantitatively supported work on inelastic response and corresponding design strategies.<br>e) Experimental work in out of plane capacity of brick infills. Correlation of FE models with response of real structures.<br>f) Development of guidelines on the use of innovative products & materials to improve seismic performance. Cost studies to show economic viability.<br>g) Hazard. Soil/structure interaction. Detailing. |
| **9. What currently pursued fields/area of research do you feel have reached their limit of usefulness?**<br>a) Development of new numerical procedures where suitable ones already exist<br>b) Numerical studies into specific design problems<br>c) Standard Cornell type seismic hazard modelling. Conventional treatment of soil behaviour.<br>d) No particular areas come to mind, though this is an excellent question to ask, which should be reviewed in the light of responses to the academic questionnaire.<br>e) Frequency dependent functions for soil/structure interaction<br>f) All the work that does not lead to clear conclusions on design rationale<br>Mathematical analysis of elastic systems.<br>g) No subject has been researched to any limit. |

| | | | |
|---|---|---|---|
| **10. Do the aims of the research necessarily conflict with the needs of industrial practitioners, making the use of recent research necessarily limited?** | 1 | 5 | 7 |

**11. If so, why?**

a) Sometimes the research is too specific

b) Perhaps because researchers are not also practitioners. However, I think some research is also important to progress understanding. We cannot expect to find an answer with every research project; that simply is not possible. I think there comes a time when you cannot make things more efficient.

c) I don't think there is *necessarily* a conflict, although there is often a tension between the immediate needs of a practitioner to get answers for a project, and the much longer timescales that typically apply to useful research. However that doesn't mean that academic research is never useful to practitioners. Two examples of research that have assisted my practice are as follows:

i) Work by Imperial over many years on nature and characteristics of earthquake ground motion records.

ii) The pioneering analysis software developed by Berkeley and now released as freeware.

ults of research are not aimed to be presented in such a way to make them applicable to real life problems

e) Competition for limited market of work

f) Aims of research should necessarily **not** conflict with requirements of industry, otherwise what is the point of research?

g) Often the research results provide general information on trends and lacks useful application information that could be used by engineers for design/analysis of real structures.

h) Conflict exist due to financial matters and deadlines.

| | | | |
|---|---|---|---|
| **12. How could the current research work be made more applicable to your professional practice?** | | | |
| • Through the publication of research on more relevant topics | 7 | 1 | 1 |

- Which ones?

a) There should be different types of publication, one for practitioners and another for researchers
b) See replies to questions 5 & 6 above
c) See reply to question 6 above.
d) See reply to question 6 above.
e) Sliding of dock walls. Liquefaction. Fluid structure interaction.
f) See reply to question 6 above.

| | | | |
|---|---|---|---|
| • Through the publication of guidelines helping professional practitioners to use recent research | 11 | 1 | |
| • Are you aware of the ATC series of guidelines? | 9 | 3 | 1 (which ATC?) |

- Other ways

a) Clearer presentation of the research in a 'design' framework
b) More 'synthesis' of the results of research carried out throughout the world. Less specific 'original research'.
c) Critical case histories with decision steps and justification
d) Ideally, there is a need for research (or more accurately development) carried out principally by practitioners paid at least 60% of commercial rates, but involving academics as well. This has worked in the States, and also on non-seismic research by CIRIA
e) Involve more practitioners in review of research projects, and make them part of a team to disseminate result of the research.
f) Link codes to real design strategies for real structures (by showing how the research should be incorporated in real design).
g) Ours is a research based consultancy. All our projects have a research element in them.
h) Lectures, short course, and technical newsletters referring to detailed papers

| | | | |
|---|---|---|---|
| 13. **Is your company able to carry out earthquake engineering research? If so, please elaborate.** | 8 | 4 | 1 |

a) Theoretical work on masonry structures and reinforced concrete
b) The funded development work has all been carried out for the nuclear industry in the fields of structural reliability and comparative code requirements. Non-funded in house development has been of software, both for artificial time history generation and non-linear structural analysis.
c) We [nuclear power industry] can help fund research which is directly related to our needs and will not otherwise take place.
d) We currently provide products [in the field of energy dissipation] at a low cost (or free) for research on seismic improvement of structures through the use of experimental testing.
e) We do work with Exeter University on some issues
f) Research is being carried out for Lebanon in our [Beirut based] company.

14. **Any other comments?**

a) As practitioners, we need to have access to the state of the art in dynamics as it affects projects, structures and components. SECED should take a lead in publications which could be directed towards reference lists on selected subjects, even if papers on appropriate subjects are not available.
b) Our understanding of the behaviour of structures has improved a lot, but the method by which we approach the problem is finding its correct shape. Maybe it is better to put the foundation of seismic design on firm grounds rather than changing it all the time.
c) Thanks for this initiative
d) I am at the service of SECED on any matters where I could help by being based in Lebanon. I work with UNESCO on earthquake research.

## Appendix C
## Letter to heads of department of civil engineering departments at UK universities.

The Society for Earthquake and Civil Engineering Dynamics (SECED) is an associated society of the Institution of Civil Engineers. One of its objectives is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics. In furtherance of this objective, SECED has established a Working Party on earthquake engineering research in the UK, with Roy Severn as chairman and myself as convener and secretary. The remit of the Working Party is:

> "To review the current state of UK research in earthquake engineering, and to report on future needs and recommended changes over the next 5 years, both in a national and international context."

The Working Party aims to report in December of this year, after carrying out a wide consultation process of industry and academia. The enclosed questionnaire is the start of this process, and is intended both to audit the UK's capability and also to canvas opinion on future needs; UK construction industry has been invited to complete a separate questionnaire. Whilst mindful of the pressures on your time, I do hope that you, or your colleagues, will take a few minutes to respond, using the attached form. We need your reply by **15th August 2000**.

This letter is being sent to Heads of Civil Engineering Departments in all UK Universities, but relevant research might also be carried out in other Departments of your University. If this is the case, would you please pass a copy of this letter and questionnaire to them. Copies of the questionnaire can be downloaded in electronic format from the SECED website www.bham.ac.uk/CivEng/seced/RWG/index.htm, which also gives more details of the Working Party. Replies in electronic format by e-mail to liz.marwood@ice.org.uk would be preferred but hardcopy to Liz Marwood at the above address is also of course acceptable.

With many thanks for your help,

Yours sincerely

Edmund Booth
Secretary, SECED Working Party on earthquake engineering research

**Appendix D**
**Summary of responses to university questionnaire**

24 responses were received. 13 reported current seismic projects, 4 reported expertise and interest in seismic or related disciplines, but no current seismic projects and 7 reported no seismic expertise or projects. The following table summarises all the responses received.

| No | University | Special capabilities & equipment | Projects | Funding sources | Industry partners | European /international partners | Important research topics + other comments |
|---|---|---|---|---|---|---|---|
| 1 | Strathclyde | None | a) 3D seismic analysis of composite structures | University scholarship; 3 years | | | (Prof Wright)<br>a) Seismic resistance of domestic framed structures (common in the middle east)<br>b) Guidance on repair and refurb of earthquake damaged buildings |
| 2 | East London | Micro concrete testing lab | a) Non linear seismic response of asymmetric rc buildings | University of East London (PhD research programme) | | | |
| 3 | Oxford | Real time dynamic structural testing rig | a) Development of real time dynamic testing | EPSRC, Leverhulme trust, Wolfson Foundation, Corus | Instron | Ispra, NTUA | (Dr Blakeborough)<br>a) Development of dissipative devices – rubber & oil dampers<br>b) Development of EC8 steel provisions to allow more freedom in dissipative design<br>c) Evaluation of performance based design |
| | | | b) Knee element seismic dissipators | EPSRC, Corus | Corus | Ispra, NTUA | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | Nottingham | Dynamic analysis (linear/non-linear), SSI and soil dynamics, post earthquake field investigations | a) Asynchronous seismic loading of bridges | EPSRC | | | (Dr Owen)<br>a) Connection behaviour<br>b) Tubular structures and connections under dynamic loading |
| | | | b) Seismic modelling of semi-rigid bolted joints | University of Thammassat, Finland | | University of Thammassat, Finland | |
| 5 | Herriot-Watt | Staff have capabilities in e/q engineering & engineering seismology.<br>Post graduate module on e/q eng is being started, and final year undergraduates sometimes do e/q eng related topics.<br>20Hz cyclic 260mm dia triaxial cell.<br>Various seismic analysis software | a) Numerical modelling of earthquake induced liquefaction | Overseas | None | None | (Dr Dymiotis)<br>a) Clearer definitions of performance based and limit state criteria.<br>b) Improvement of safety & behaviour factors, and harmonisation of design practice<br>c) Better incorporation of probabilistic methods<br>d) Resolution of issues relating to the representation of seismic loads for structural analysis (eg scaling procedures, vertical motions, adequacy of artificial records)<br>e) Risk mitigation through qc, assessment and strengthening of existing structures, awareness etc.<br>f) Experimental testing of large or full scale structures & new materials |
| | | | b) Seismic reliability of rc structures | Not secured | None | Kappos (U. of Thessaloniki) | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 | Bristol | 15 tonne 6DOF shaking table Vibration monitoring equipmen for field use Dynamic material testing facilities – concrete, steel, soils | a) Seismic response of cable stayed bridges | EU | | Dr E Caetano | |
| | | | b) Seismic response of masonry infill panels | Industry | Nuclear electric | | |
| | | | c) Seismic response of asymmetric bridges | EU | | ISPRA, ISMES | |
| | | | d) Dynamic behaviour of spillway structures | Industry | Scottish Hydro | | |
| | | | e) Masonry infills to EC8 | EU | | Dr Gostic, Dr Zarnic | |
| | | | f) Seismic design of gravity retaining walls | EU | | Dr Simonelli | |
| | | | g) Seismic design of flexible retaining walls | EU/Industry | Netlon | Prof Sofronie | |
| | | | h) Seismic retrofit of non-ductile rc frames with yielding braces | EU | | P D'Anzi | |
| | | | i) Dynamic response of reservoir intake towers | EPSRC | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | Birmingham | Software for non-linear static & dynamic analysis of structure, soil & pore fluid interaction | a) Numerical modelling of dynamic behaviour of saturated soil. | Various | | Univs. of Columbia, Colorado & Kyoto + others | (Dr Chan)<br>With increased computer power, it would be necessary to address the accuracy and reliability of numerical procedures in e/q eng.<br>Particular fields:<br>a) Development of advanced material models for cyclic loading of soil, masonry, concrete etc<br>b) Ditto, but 'practical' material models<br>c) Validation of such models<br>d) Comparative studies between empirical formulae and 1D models currently used in practice with numerical procedures which require easily identifiable parameters<br>e) Numerical studies on travelling wave effects on abutments of long span bridges |
| | | | b) Development of non-linear cyclic model for concrete | Private | | | |
| 8 | UMIST | FE analysis | a) IIW recommendations on seismic design of welded connections | | Welding Institute | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | b) Structural integrity assessment of welded steel structures under dynamic loading, inc. seismic | EPSRC | Welding Institute, Arup, EQE, Corus, HSE, Lloyds Register | American Welding Institute | |
| 9 | Bath | Dynamic actuators + strong floors and walls | a) Seismic vulnerability of historic buildings | EPSRC | | Univ. of Padova | (Dr D'Ayala)<br>a) Quantification of structural residual capacity for structures with medium seismic damage<br>b) Development of robust guidelines for repair & strengthening of various structure types<br>c) Passive & active control via dampers etc<br>d) Foundation isolation |
| | | | b) Planning and design of rc buildings in urban seismic areas | PhD studentship, 3 years | De Leuw, Cather Intern'l Ltd | | |
| | | | c) Impact dampers for seismic control of structures | EPSRC, 3 years | WS Atkins | | |
| 10 | Newcastle | Expertise in seismic analysis of high rise buildings, intra-plate earthquakes, seismic torsional | a) Improved methodology for selecting building behaviour factors | Awaited | | | (S Wilkinson)<br>a) Improvement of building practices in developing seismic regions<br>b) Improved methods of choosing ductility factors<br>c) Development of |
| | | | b) Geo-synthetic soil reinforcement in seismic areas | None | Electrical Research Association | University of Tokyo | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | coupling, seismic resistance of reinforced earth, remediation of liquefaction using geosynthetics | c) Remediation of liquefaction using geosynthetics | None | Electrical Research Association | University of Tokyo | displacement based design methods<br>d) Use of steel beams as couplers between concrete shear walls |
| 11 | Imperial College | Large scale testing<br>Extensive computing<br>Strong motion databank | a) Training of young engineers in a host of subtopics, from hazard to vulnerability | EU 1996- 2000 | Geodynamique et Structure (France) | European partners | |
| | | | b) Integrated procedures for assessment and intervention of existing structures, with emphasis on deformations | EU 1997-2001 | EQE | European partners | |
| | | | c) Large training network for a range of topics: strong motion, foundations, structures, software | EU 2000-2003 | Geodynamique et Structure (France) | European Partners | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12 | Cambridge University Engineering Department | Stored angular moment earthquake actuator on geotechnical centrifuge | a) Lateral spreading of slopes<br>b) pile foundations in slopes<br>c) performance of rock drain as liquefaction remediation<br>d) measures stability of steep slopes<br>e) hydrodynamic pressures on dams<br>f) seismic performance of bridge foundations | EPSRC, US Army Corps of Engineers, Isaac Newton Trust | Mott MacDonald, UK<br>Shimizu Corporation, Japan | University of California, Davis,<br>Santa Clara University, California | (Dr Madabhushi) |
| 13 | University of Surrey | Reliability and probabilistic studies under seismic loading | a) Ductility and failure mode control in steel building frames under seismic loading<br><br>b) Reliability-based calibration of seismic design codes | EPSRC<br><br>EPSRC studentship | British Steel (now Corus) | Politecnico di Milano (Profs Ballio and Poggi)<br><br>University of Thessaloniki (Prof Kappos) | (Prof Chryssanthopoulos)<br><br>Risk and Reliability methods for the design and assessment of structural systems |
| 14 | Nottingham Trent | No seismic projects, but work on ground vibration from high speed trains may be relevant | | | | | |
| 15 | Cardiff | None | No earthquake projects, but research into high performance FRC may be relevant to seismic repair & retrofit | | | | (Prof Barr)<br>Seismic repair and retrofit |

| | | | | |
|---|---|---|---|---|
| 15 | Cambridge University Department of Architecture – Martin Centre | a) EU Worshop “Earthquake Risk to Monuments and Structures in the EU” Editing of ProcEedings for Publication – Funding from EU<br>b) UE-Risk: a project to define a common European methodology for seismic risk evaluation, and application to 11 cities in the EU and neighbouring countries. Starting Jan 2001; funding from EU; coordinated by BRGM; Robin Spence is a member of the Steering Group<br>c) Evaluation of seismic performance of historic masonry structures in Spain (with CUED) with John Ochsendorf, Prof Heyman; funding approval expected shortly | | (Dr Spence)<br>Works closely with CambridgeArchitectural Research Ltd in a number of consultancy projects on evaluation of seismic vulnerability and risk assessment. |
| 17 | Leeds | No projects at present in Civil Engineering, though there may be in Earth Sciences | | |
| 18 | Durham | Computation of ground waves from piling & dynamic compaction. ABAQUS | No earthquake projects, but work on computation of ground waves from piling, and their effect on structures is relevant. | (Dr Selby)<br>Computation of ground waves and effect on buried service pipes (esp gas, electricity, water and fibre optics) |
| 19 | Aston | No current activities in this field | | |
| 20 | Bolton Institute | No capabilities in this field | | |
| 21 | Queens, Belfast | No capabilities in this field | | |
| 22 | Southampton | None | | |
| 23 | Cranfield | No capabilities in this field | | |
| 24 | South Bank | No capabilities in this field | | |

## References

1 Muir Wood, R. A sketch of Robert Mallet and John Milne. In Housner, G W. Coping with natural disasters (the Second Mallet-Milne Lecture
2 ASCE 4-98. Guidelines for the seismic analysis of nuclear structures. American Society of Civil Engineers, 1999.