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Vibrations of the Millennium Bridge

Martin Williams reports one of the most popular evening meetings ever hosted by SECED looking at the behaviour and retrofit of the Millennium Bridge.

The Godfrey Mitchell Lecture Theatre was packed to overflowing, on the 28 November 2001, for this fascinating account of the lateral vibration problems of the Millennium Bridge, and their solution. The two speakers, Michael Willford of Arup and Alex Pavic of the University of Sheffield, discussed the investigation into the cause of the excessive motions, the design of the system of dampers to control the vibrations and the *in situ* testing carried out in support of the remedial work.

The bridge, designed by Arup in association with architect Foster and Partners and sculptor Sir Anthony Caro, crosses the Thames in London from the Tate Modern gallery on the south bank to Peter's Hill on the north side. It has a highly unusual structural form, comprising exceptionally shallow suspension cables held at some distance from the sides of the deck by a series of transverse arms – see Figure 1.

The bridge's basic problem is well known, having attracted national media attention. Very large crowds crossing the bridge when it opened to

Figure 1. View of the Millennium Bridge looking north

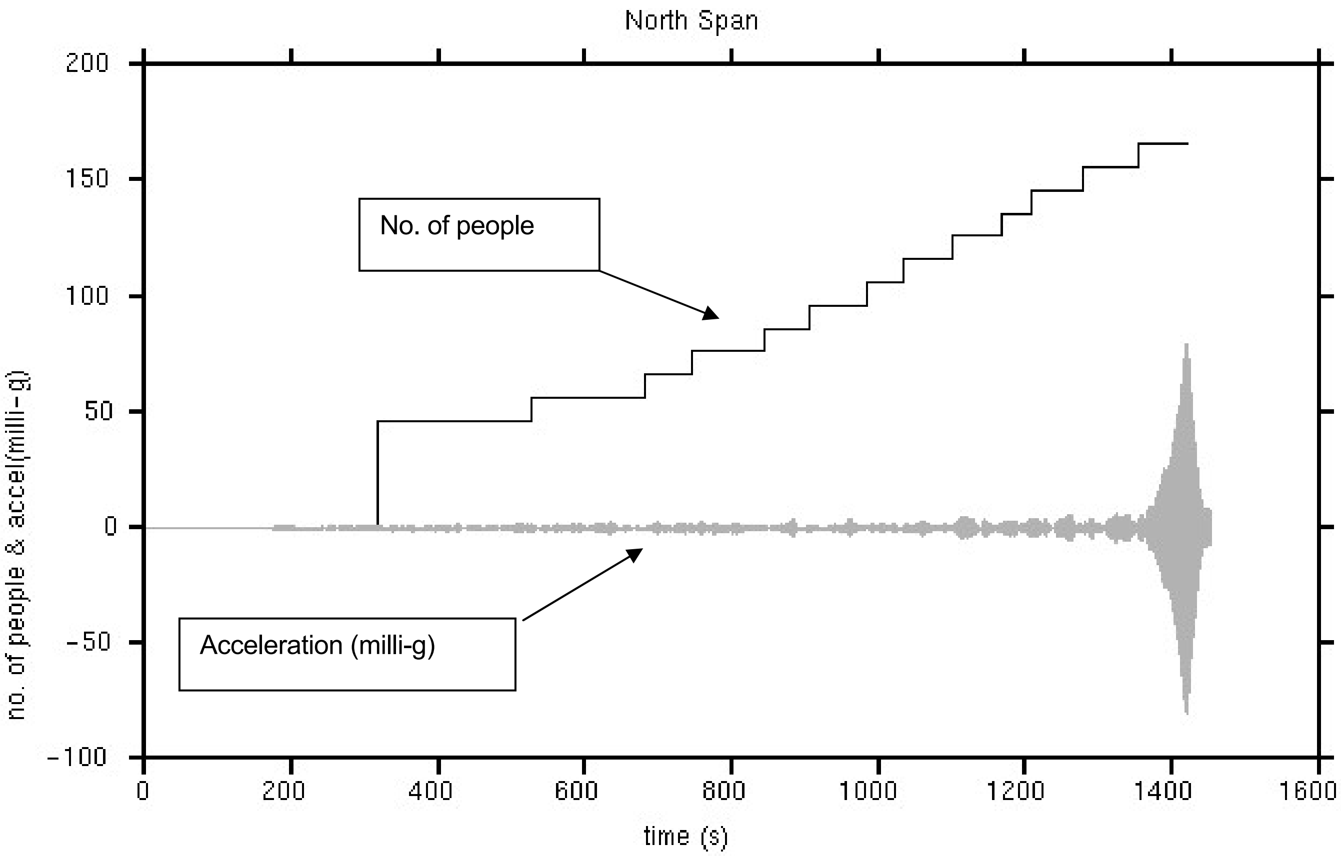

Figure 2. Variation of number of walkers and lateral acceleration of the bridge with time, showing the sudden instability when a critical number of walkers is reached

the public on 10 June 2000 caused excessive lateral sway vibrations, with peak accelerations estimated at around 0.25g. The bridge was closed after two days and has yet to reopen to the public. The case is unusual because it is normally assumed that walking imparts vertical and (to a lesser extent) torsional loads to a bridge, so that the modes of vibration likely to be excited will involve vertical and/or torsional motion. Instances of pure lateral sway vibrations are rare.

Laboratory testing commissioned by Arup identified the phenomenon of "lock-in" as the cause of the problem – pedestrians on a flexible bridge find it is more comfortable to walk in synchronisation with the lateral swaying of the deck, even if that swaying is initially very small. This instinctive behaviour causes the lateral footfall forces to be applied at the resonant sway frequency of the bridge, and at a phase which tends to amplify the motion. As the sway motion of the bridge increases, walkers tend to adopt a wider gait in order to keep their balance, so that the lateral component of their footfall forces increases.

Following the lab work, testing of the Millennium Bridge itself was performed. This comprised both modal testing to determine the as-built frequency and damping characteristics of the structure, and measurements of the structural response to crowds of walkers.

The modal testing made use of a horizontal shaker designed and built by Fugro Ltd, comprising a moving mass of 1 tonne driven by an actuator via a lever mechanism which increased the amplitude of motion well beyond the stroke of the actuator. The modes which caused the excessive vibration were successfully identified and agreed quite closely with Arup's design predictions. The lowest sway frequencies of the main span were 0.5 Hz and 1.0 Hz, with associated modal damping ratios of 0.75% and 1.3% of critical.

The walking tests confirmed the importance of lock-in for the horizontal response. They showed an almost linear increase in the horizontal exciting component of the walking force F with the horizontal velocity v of the deck, i.e. a relationship of the form $F = cv$ where c is a constant. This, of course, is the governing equation for a linear viscous damper. However, whereas a damper provides a retarding force, taking energy out of the system, a pedestrian provides an exciting force, adding energy. A pedestrian locked in to the lateral sway frequency can thus be thought of as a negative damper and the problem becomes one of stability – if the negative damping due to people crossing the bridge exceeds the inherent structural damping then the energy (and therefore the motion) of the structure will increase rapidly and uncontrollably. This is clearly demonstrated by Figure 2, which shows the results of a test where the number of walkers was gradually increased. The horizontal accelerations remained small until the number of walkers reached a critical value, at which point the negative damping exceeded the structural damping, the accelerations increased extremely rapidly, and the test had to be stopped.

Two types of solution were considered. The first was to increase the stiffness of the structure so that its lateral sway frequencies were above the range which could be excited by walking loads. Since the lateral loading due to lock-in occurs at half the pacing frequency, the highest frequency likely to be excited is half that of a fast walk, i.e. about 1.3 Hz.

Raising the fundamental sway frequency from 0.5 Hz to above 1.3 Hz (say 1.5 Hz) would require an approximately tenfold increase in stiffness, virtually impossible to achieve.

This option was therefore abandoned in favour of increasing the structural damping to a level that will always exceed the negative damping due to walkers. This is being achieved mainly through the use of a series of 37 viscous dampers fitted under the deck. The dampers are connected to chevron-braces which concentrate the relative movement over a 16m length of the bridge at each damper location – see Figure 3. In addition, eight tuned mass dampers have been added at key points in the central span to provide additional damping of the fundamental sway mode. The TMDs have high mass and damping, so that they are not too sensitive to small errors in tuning. The overall effect will be to increase the modal damping ratios to more than 20% of critical – extremely unusual for a civil engineering structure.

Before proceeding with the full retrofit, extensive modal testing was undertaken on the bridge with one and two dampers fitted. This proved the effectiveness of the approach and verified the detailed retrofit design. For example, provision of just two viscous dampers increased the damping ratio in the fundamental mode from less than 1.0% to 4.1% and one TMD provided a further increase to 5.1%. At the time of the meeting the full retrofit was being installed. Once completed, the bridge will be subjected to further testing before reopening.

Obviously there are wider lessons to be learnt from story of the Millennium Bridge. Arup engineers believe that the problems encountered could occur on any bridge with a fundamental sway frequency below about 1.3 Hz. The important difference which caused problems on the Millennium Bridge was not so much its unusual structural form as its huge popularity, with the very large amount of pedestrian traffic triggering the excessive vibrations. It is also believed that there is no lower limit to the frequency at which lock-in could occur – on a lower frequency bridge walkers may adopt a "snaking" path in response to the oscillations, resulting in a very low frequency horizontal loading function.

Should Arup have been aware of the potential problem in advance? It seems highly unlikely that a consensus will ever be reached on this question. Since the Millennium Bridge closure several previous examples of this phenomenon have come to light, and it has also emerged that there has been some published research on the problem. However, none of these events received widespread publicity and it could not be argued that the problem was a well-known one, even within quite specialist parts of the engineering community. What seems to me to be beyond dispute is that the team at Arup deserves congratulation for its impressive response to the crisis, in which they identified the problem, carried out or commissioned some important research and designed a solution within a matter of months.

Acknowledgement: Pictures from the presentation are reproduced by kind permission of the speakers.

Martin Williams

Figure 3. Viscous damper being fitted between chevron braces beneath the deck

MEETING REPORT:
"Legal Aspects of Earthquake Risk Mitigation in Turkey"

A report by Julian Bommer on the SECED meeting, 16 August 2001

A tradition is gradually developing of holding SECED Informal Discussions on social, legal and political elements of earthquake risk in the middle of summer. In August 1999, Dr. Brian Tucker of GeoHazards International (GHI), presented a lecture on the work of GHI in promoting earthquake safety in Kathmandu, Nepal. This year, on 16th August – the eve of the second anniversary of the catastrophic Kocaeli earthquake – Professor Polat Gülkan addressed a meeting on the topic of "Revising Legal Aspects of Earthquake Risk Mitigation in Turkey". Professor Gülkan is Director of the Disaster Management Implementation and Research Centre based at the Middle East Technical University in Ankara and a tireless advocate for effective risk mitigation in Turkey as well as a researcher of international renown in the field of earthquake engineering.

Prof. Gülkan's presentation began with a video film of the aftermath of the Kocaeli earthquake of 17 August 1999, bringing home the huge and terrible impact of this event on the population of the region. Views of damaged areas filmed from the air showed how earthquake hazard had been totally disregarded as new urban settlements had grown up around clearly identified segments of the North Anatolian Fault, in some cases even straddling the fault trace. Prof. Gülkan pointed out that the agencies responsible for producing the map of active geological faults and those responsible for issuing building permits both form part of the government, yet there was a clear failure to communicate and implement the hazard information. Prof. Gülkan also highlighted how the film showed how poor building practice tended to be self-perpetuating due to the tendency for 'cloning' buildings within new urbanizations, with disastrous consequences.

http://www.eeri.org/Publications/cdroms.htmlhttp://www.eeri.org/Publications/cdroms.htmlOne of the two main legal measures taken to reverse the trend of increasing seismic risk is the enactment of a decree on Building Construction Supervision in April 2000. This new legislation requires that confirmation of construction conforming to the actual design before the municipality will grant permits for occupation. Furthermore, during the first 10 years of occupation, the construction supervision firm is made responsible for offsetting any losses to the owner that may arise, including those due to natural disasters. Prof. Gülkan pointed out that a shortcoming in the decree is the absence of detailed construction inspection procedures required for quality assurance.

The second legal measure addresses the very severe financial burden created by earthquakes on the Turkish government. The Kocaeli and Düzce earthquakes of August and November 1999 resulted in estimated losses of the order of US$ 18 billion and US$ 1 billion respectively, with the responsibility for reconstruction of houses falling entirely on the Treasury. To offset such strain on the economy in future earthquakes, the government has created the Turkish Catastrophe Insurance Pool (TCIP, or DASK in Turkish), which requires all homeowners to purchase compulsory earthquake insurance through private companies acting on behalf of the government for a 12.5% commission. The government then uses part of the TCIP funds to purchase reinsurance against losses from future earthquakes. The scheme became operational on 27 September 2000 but has already achieved very significant penetration. Prof. Gülkan pointed out that despite its initial success there are still unresolved issues related to the TCIP, including making it an effective mechanism to promote seismic retrofit and strengthening. The insurance premiums are relatively low, fixed primarily by what people can and will pay, hence even if the entire premium were waived for retrofitted houses this is unlikely to come close offsetting the costs of structural intervention.

Despite this meeting being held at the very height of the holiday season, the lecture attracted an audience of 30 people. For those who could not attend and who would like to obtain information, a paper on the same theme by Prof. Gülkan can be downloaded from the web site: http://www.metu.edu.tr/wwwdmc/

Julian Bommer

Effect of the Bhuj (Gujarat, India) earthquake of January 2001 on heritage buildings

During March 2001, SECED member Edmund Booth toured the earthquake affected region of Gujarat with Rabindra Vasavada, an Ahmadabad based architect specialising in conservation who has an unrivalled knowledge of the rich collection of princely palaces and other heritage buildings in the area. Their brief was to study the effect of the earthquake on heritage buildings on behalf of the Indian National Trust for Arts and Cultural Heritage (INTACH). Their findings will be included in the main EEFIT report on the earthquake expected to be published later this year. An extended version of this material, which includes 40 photographs, has already been published on http://www.booth-seismic.co.uk/Gujarat.

Dynamic testing of structures

Martin Williams summarises the current state-of-the art in dynamic testing

Seismic testing is currently going through a period of rapid development, driven both by recent catastrophic earthquakes and by the availability of enhanced computer power, which has greatly increased the capacity for on-line control and computation. This article gives a brief overview of the recent advances, focussing on shaking tables, pseudo-dynamic testing and the new generation of real-time techniques. The coverage is necessarily brief; for those wanting to know more, much fuller accounts are available in a recently published collection of papers, on which this article is loosely based1.

Shaking tables

The basic principle of a shaking table is very simple – a model of a structure is mounted on a stiff platform which is shaken by servo-hydraulic actuators so as to apply the appropriate base motion. This generates the correct inertia forces are throughout the structure and the response to these forces can be measured.

Scaling

While shaking tables come in a wide variety of sizes, the majority are intended for the testing of quite small-scale models. For example, the table at Bristol University (Figure 1) has a plan area of 3 m × 3 m and can carry a maximum payload of 10 tonnes. The use of scaled models can cause problems. For dynamic similitude the mass scale factor should be the inverse of the length scale factor and the time scale factor should be the square root of the length scale factor. For example, a quarter-scale model will require a fourfold increase in specific mass and a halving of the time-scale. The compression of the time-scale results in an increase in the frequency content of the input earthquake which may be difficult to achieve, so that some compromise is often necessary.

One obvious way of avoiding these problems is to test at full scale. Of course, this brings its own difficulties – to apply a simulated earthquake to a full-scale building requires enormous actuators, very high oil flow rates and, crucially, a lot of money. To date, only the Japanese have adopted this approach. Their National Institute for Earth Sciences and Disaster Prevention (NIED) constructed two very large tables in the 1970s, but both had limited usefulness due to restrictions on the number of driven axes and the velocities that could be achieved. NIED is now constructing its most ambitious earthquake simulator, a six-axis table designed to be able to reproduce at full scale the very large ground motions recorded during the 1995 Kobe earthquake.

A few statistics give an idea of the awesome scale of this project: the table will have a plan area of 15 × 20 m and will carry a maximum payload of 1200 tonnes. It is designed to impose a peak ground displacement of 1 m, a maximum velocity of 2 m/s and a peak acceleration of 1.5g. This will be achieved by a total of 24 actuators, each with a load capacity of 450 tonnes. The actuators are fitted with servo-valves able to deliver oil at a rate of 15,000 l/min. (For comparison, the Bristol table uses eight 5 tonne actuators, fitted with 300 l/min servo-valves.)

This facility has required much technological innovation. For instance, the very long stroke of the actuators

Figure 1. Model of a concrete frame with masonry infills on the Bristol shaking table

gives rise to problems of flexure of the actuator pistons, requiring the development of a novel spherical hydrostatic bearing system. Similarly, the high capacity servo-valves go well beyond existing technology. Figure 2 shows four of the actuators being tested in a development rig. To give an idea of the scale, the block being shaken is 6 × 6 m in plan.

Control

Besides scaling, the other major issue in shaking table testing is how the test is controlled. The traditional control strategy is to transform the desired table motions into a set of required actuator displacements and then drive each actuator via a linear controller using feedback of actuator position, velocity or acceleration. In recent years some modifications have been made to this approach. For instance, many control systems now provide closed-loop control directly on the table degrees of freedom, rather than on the individual actuators. Also, many controllers now use three-variable control, in which the feedback parameter is a weighted combination of position, velocity and acceleration. These changes have improved the fidelity with which the desired motion is reproduced. However, the use of a linear controller with fixed gains remains a major limitation for two reasons.

Firstly, the linear controller requires knowledge of the properties of the system being controlled. Since the properties of the shaking table system (of which the test specimen itself forms a substantial part) are generally not accurately known, an iterative matching procedure must be carried out prior to the start of a test. Secondly, linear control theory assumes that the system can be represented by a linear equation which does not change with time. Any non-linearity such as damage to the test specimen will result in the control parameters ceasing to be optimal, so that the desired earthquake motion is not accurately reproduced.

One way of overcoming these limitations is to use adaptive controllers, in which the gains can be updated at every sampling interval to account for dynamic changes in the system being controlled. The minimal control synthesis (MCS) algorithm developed by Stoten at Bristol University is a particularly attractive form of adaptive controller since it requires no identification of the dynamics of the system being controlled (either prior to commencing a test or on-line), and it is well-suited to use as a retrofit strategy around existing controllers.

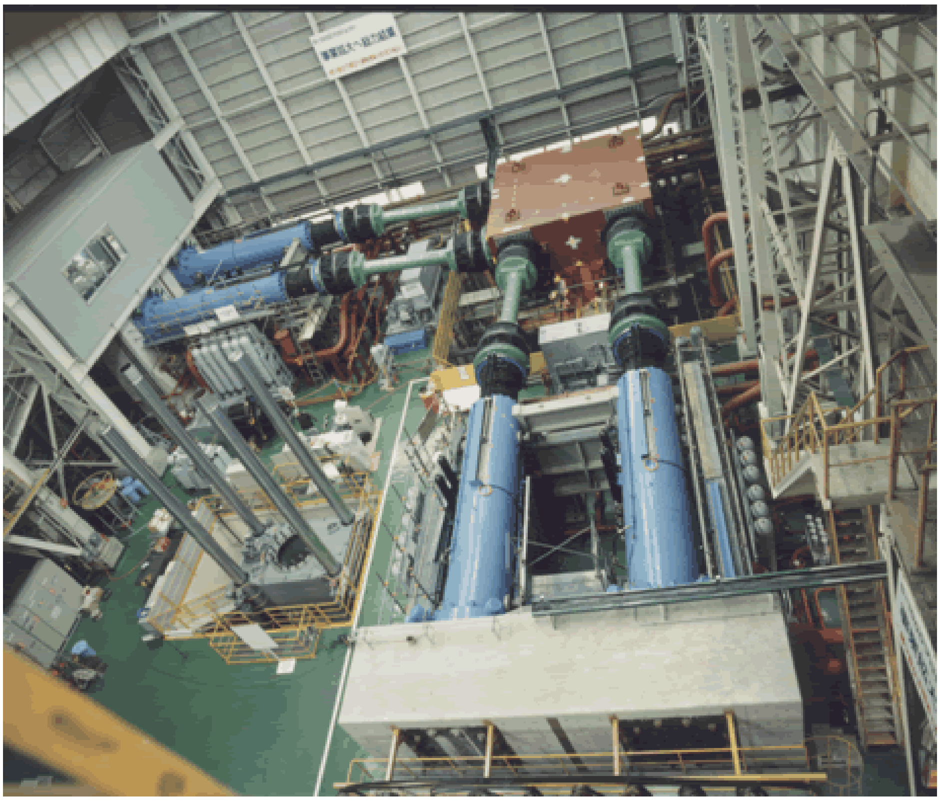

Figure 2. Commissioning test of 450 tonne actuators for the NIED 1200 tonne shaking table

MCS can either be applied directly to each actuator or, if direct access to the actuators is not available (as is often the case in existing tables) to the overall table motion. In the latter case the MCS algorithm compares the overall table demand with the actual table motion and outputs a control signal that is added to the demand signal. This is similar to the matching procedure used for conventionally controlled tables, but it is now carried out in real time, with no need for iteration at the start of a test. MCS control has now been implemented on several European shaking tables, with tangible improvements in accuracy.

Pseudo-dynamic testing

The pseudo-dynamic (PsD) test method was developed under the US-Japan Cooperative Earthquake Programme in the early 1980s. PsD testing is a hybrid method, in which the structural displacements due to the earthquake are calculated computationally using a stepwise integration procedure and applied quasi-statically to the test specimen. The resulting resistance forces are measured and fed back to the computational model as part of the input for the next calculation step. Tests are normally performed at full or very large scale, but run over a greatly expanded time axis. A particularly large and impressive PsD facility is the ELSA laboratory at the European Commission's Joint Research Centre (JRC) at Ispra, which includes a 16 m high reaction wall capable of resisting a base shear of 20 MN and a bending moment of 200 MNm (Figure 3).

Since the method's inception, considerable effort has been expended on the development of numerical algorithms for solving the equations of motion, with the aim of providing accuracy and stability while maintaining a reasonable length of timestep. It can also be helpful if the numerical algorithm used applies some damping to the higher modes, since this prevents the build-up of errors due to inaccuracies in the applied displacements. One of the most interesting approaches is the operator splitting algorithm, which is implicit (and therefore unconditionally stable) for the elastic part of the response, but explicit for the non-linear part, so that no iteration is required. Another is Chang's idea of minimising error amplification by basing the numerical algorithm on an integrated form of the equations of motion.

A potential source of error is the stepwise nature of a PsD test. Conventionally, a displacement increment is applied over a short *ramp* period and the structure is then held stationary for a *wait* period while measurements are taken and damage observations made. If the structure is yielding then significant force reductions may occur during the wait period. This problem has been overcome at Ispra by the development of the continuous PsD test, in which the wait period is eliminated, with the integration of the equations of motion performed on the fly, at the sampling rate.

A particularly attractive form of PsD test that has been developed in recent years is the substructure test, which enables tests to be performed at full scale without the need to create very expensive physical models of entire structures. In substructuring, a physical model is built only of the part or parts where non-linearity is expected (the physical substructure), with the remainder modelled computationally (the numerical substructure). The two substructures interact as the test proceeds, with forces and displacements passed between them at each timestep – the process is described in greater detail in the real-time substructure testing section below.

Figure 3. Full-scale RC frame in preparation for pseudo-dynamic testing at the ELSA reaction wall facility

Real-time test methods

Performing a dynamic test at the correct rate is essential when rate-dependent effects are significant. This is particularly important for seismic dissipative devices such as dampers, rubber bearings and frictional elements. In these instances the expanded timescales used in PsD testing are problematic. Shaking tables can provide real-time loading, however this advantage is often offset by the associated scaling problems. Considerable attention has therefore been focussed on the development of real-time test methods for full or large-scale structures, or structural elements. Three such systems are described here.

The Caltrans SRMD test system

The California Department of Transportation (Caltrans) needs realistic test data for bridge retrofit systems such as isolation bearings, dampers and lock-up devices – collectively known as seismic response modification devices, or SRMDs. These devices are generally required to undergo rapid horizontal shear deformations while supporting very large gravity loads. The SRMD test system constructed at the University of San Diego, shown schematically in Figure 4, has been designed to reproduce these conditions in the laboratory. While horizontal displacements of up to 1.2 m are provided by long-stroke actuators, a vertical gravity load of up to 5,000 tonnes is imposed by four hydrostatic bearings/actuators and is reacted against a substantial steel cross-beam. A particular difficulty is that the SRMDs often undergo significant changes in their vertical dimensions when displaced horizontally. These displacements must be accommodated while maintaining the correct vertical gravity load, requiring the vertical degree of freedom to be controlled for both displacement and load concurrently.

Real-time substructure (RTS) testing

Real-time substructure testing is an extension of the pseudo-dynamic substructuring approach mentioned earlier. Again, the structure is divided into a test specimen (the physical substructure) and a surrounding numerical substructure. As an example, Figure 5 shows a schematic control loop for a RTS test on an earthquake-resistant knee-braced frame. In this novel structural form the cross braces connect into short “knee elements” spanning diagonally across the beam-column joints. The non-linear behaviour of these knee elements dominates the structural response during an earthquake. In the example shown a physical test is performed on a single knee element. This is coupled via a control loop to a

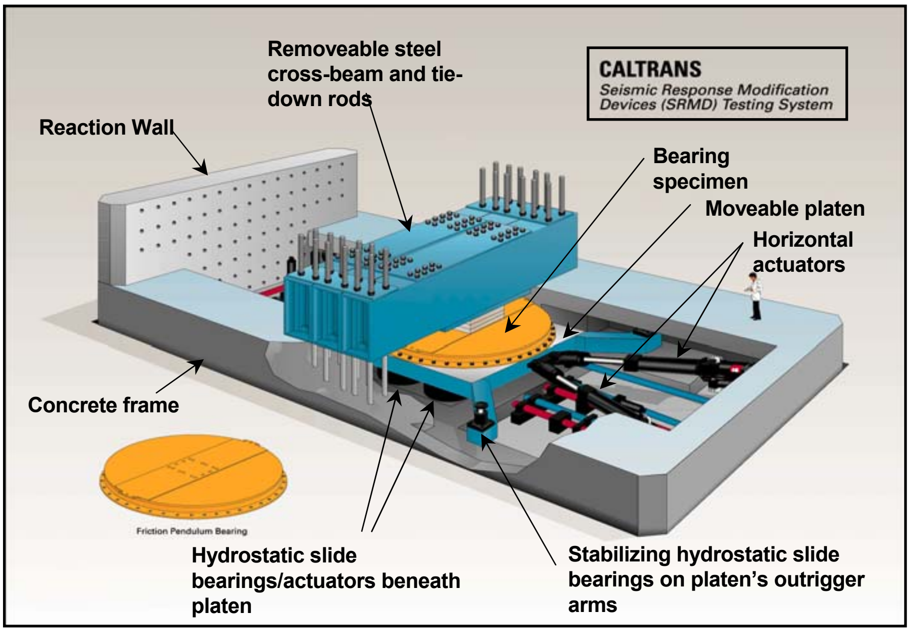

Figure 4. Schematic of the Caltrans SRMD test facility

numerical substructure which comprises a finite element model of the entire frame minus the physically tested knee element.

The test commences by analyzing the response of the numerical substructure to the first element of the earthquake time history. The displacement at the interface between the physical and numerical substructures is output and this is applied to the test specimen by hydraulic actuators. The resulting resistance force is measured and fed back to the numerical model, together with the next increment of earthquake ground motion. A new interface displacement is then calculated and applied to the test specimen, and the loop is repeated until the test is complete. For the test to proceed in real time, each cycle through the control loop must be completed in a few milliseconds, so that the loading and structural response occur at the same rate in the test as in a real dynamic loading event on a prototype structure.

The earliest RTS tests were performed in Japan, at Kyoto University and at the research labs of Hitachi Ltd. In the last few years, significant development of the method has also taken place at Oxford University. Although all three labs have performed successful tests, the method still requires some further development. Particular problems to be overcome include:

- *Actuator delays*: the finite time required for an actuator to move to the desired position can cause a real-time test to become unstable. To overcome this, some forward prediction of the desired actuator position is required, but this reduces the accuracy of the test. Improved compensation procedures are therefore needed.
- *Stability*: robust control is needed to ensure stability, particularly when the physical and numerical substructures are connected by several degrees of freedom.
- *Non-linearity* in the numerical substructure: because yielding may occur in several locations, it is desirable to be able to perform tests in which non-linearities are permitted in both the physical and numerical substructures. However, conventional non-linear analysis algorithms are too slow to run in real time. The Oxford group is currently developing a new, approximate analysis method which runs much faster than conventional algorithms and appears suitable for real-time testing.

Effective force testing (EFT)

Although the idea of running a real-time test under force control was proposed some time ago, its experimental implementation has only been attempted very recently, at the University of Minnesota. The underlying idea is attractively simple. When a structure is subjected to an earthquake, the effect of the ground motion is to apply an effective force to each structural mass equal to the mass multiplied the ground acceleration. In the EFT method these effective forces are applied directly to a fixed-base model of the structure using actuators operating under force control. The principle is illustrated in Figure 6 using the example of a planar, multi-storey frame. When the prototype structure on the left is subjected to an earthquake base motion, the absolute displacement of a storey is the sum of its displacement relative to the ground and the ground displacement. The effective force test for this structure is shown on the right. The ground motion is removed from the system and its effect on the structure is replaced by actuators. The force applied to each storey is simply

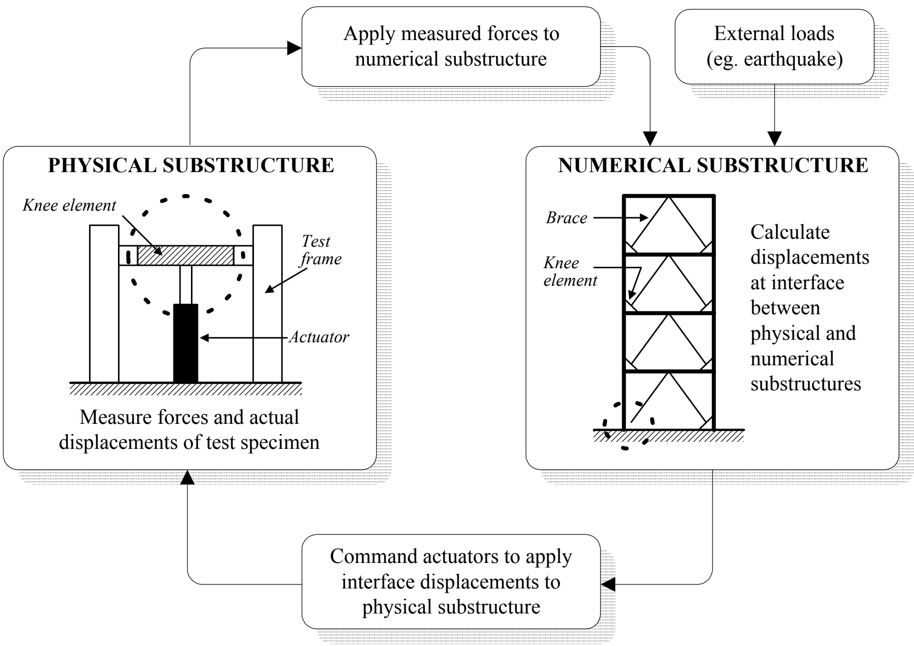

Figure 5. Control loop for real-time substructure testing

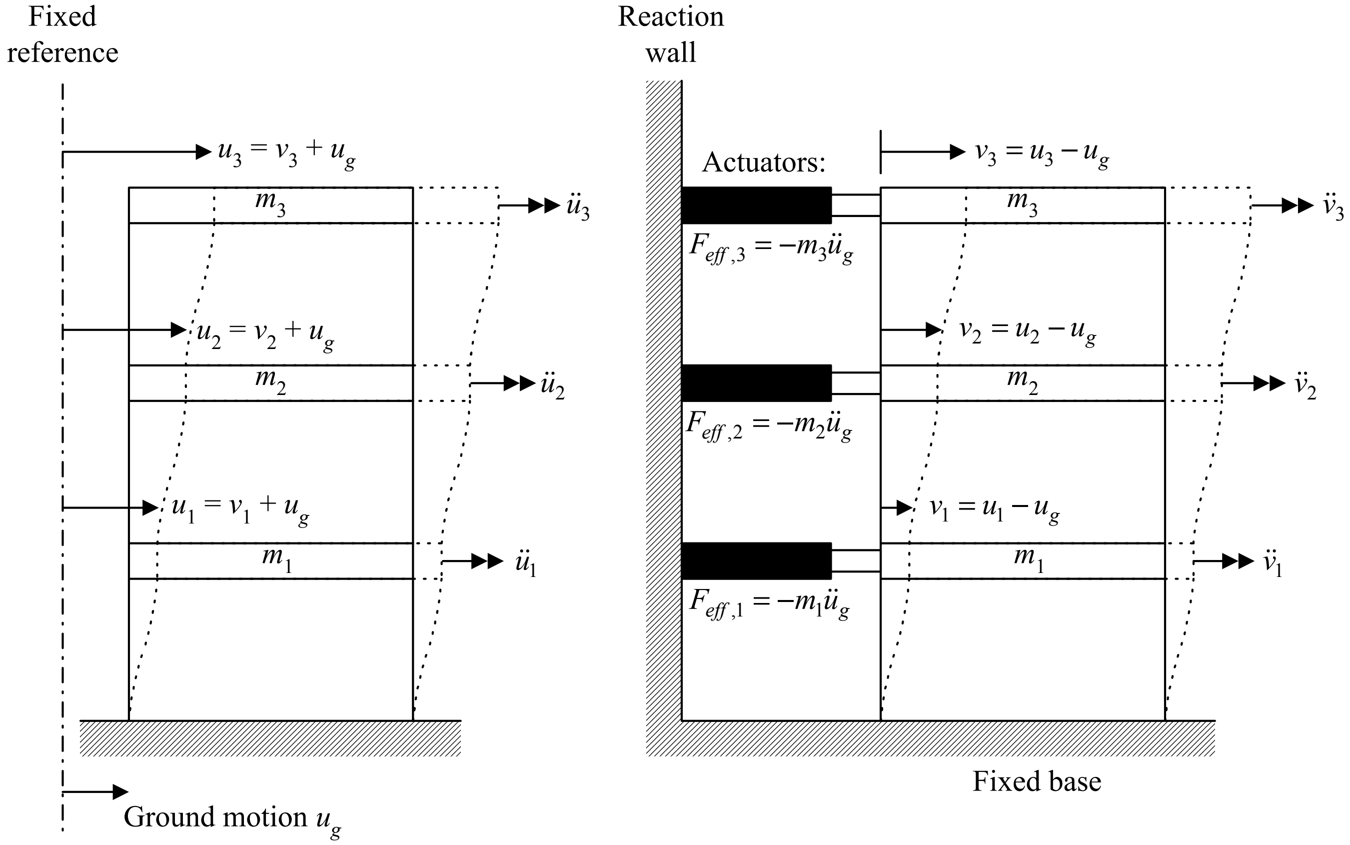

Figure 6. Effective force test method

its mass multiplied by the ground acceleration and the resulting motions are equal to the relative motions in the prototype system.

The key advantage of this approach is that, since the effective forces depend only on the ground acceleration record and the structural masses, they are independent of any non-linear behaviour of the structure. They can therefore be calculated in advance of the test and the need for on-line computations is eliminated. A disadvantage is that the full structural mass must be included in the test set-up. This may be difficult to achieve in all but the largest laboratories.

Another major problem is that accurate force control can be hard to maintain due to the natural velocity feedback that exists between the structure and the driving hydraulic actuator. This problem is particularly acute close to the natural frequencies of lightly damped structures. The Minnesota group is experimenting with control strategies which include an additional, velocity-related feedback term in addition to the force feedback. This has shown some success but requires further development.

Future directions

This article has highlighted some of the recent advances in seismic laboratory testing of structures. Whereas both shaking tables and PsD testing are mature technologies, real-time test methods have so far been implemented in only a few laboratories and require significant further development. Nevertheless, they have been shown to be feasible and their use is likely to grow rapidly in the near future.

Future development of the RTS method is likely to focus on the size and complexity of numerical substructure that can be analysed on-line, and the stability problems that arise when more than one degree of freedom is passed between the two substructures. Effective force testing also requires further refinement of control strategies to address the stability problems when attempting to provide accurate force control at the natural frequency of the test specimen.

The substructuring technique has played an important part in the development of both PsD and real-time test methods, making it possible to test at full or large scale without the need for exceptionally large laboratory facilities. Attempts are now being made to implement substructuring on shaking tables. Except in very simply cases, this is likely to involve hydraulic actuators mounted on a reaction wall in addition to the base excitation provided by the table.

Although the techniques described have been developed primarily for seismic testing of structures, they are increasingly being used for other applications. For instance, shaking tables have found applications in the aerospace industry. Real time substructuring has great potential for use in the automobile industry, where rapid product development schedules make it desirable to test components of vehicles rather than full prototypes. The method is also being applied to space structures, for example by coupling a physical test of a satellite to a numerical simulation of the launch vehicle in which it is loaded.

Another interesting future direction is the use of internet technology in dynamic testing. This is exemplified by the NEES initiative, funded by the US National Science Foundation, involving tele-networking of laboratories across the USA. This will use web-based systems to allow remote observation of tests, downloading of data and even remote operation. A possible end product will be the ability to run a distributed dynamic test using several labs, an approach which will draw heavily on the substructuring techniques being developed in Japan and Europe.

Reference

1. Williams M.S. (Editor) "Dynamic Testing of Structures," Theme issue of *Philosophical Transactions of the Royal Society of London*, Series A, Vol. 359, No. 1786, September 2001.

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Martin Williams
University of Oxford,
Department of Engineering Science,
Parks Road, Oxford OX1 3PJ, UK

The "ISET Journal of Earthquake Technology"

The "ISET Journal of Earthquake Technology" brought out by the Indian Society of Earthquake Technology (ISET) is already three years old. In this period, two special issues have also been brought out: one on "Passive Control of Structures" (Guest Editor: Professor RD Hanson) and another on "Applications of Experimental Techniques" (Guest Editor: Professor H Krawinkler). Each paper submitted to the Journal is given a high-quality review by three well-known experts in the area of the paper, and editorial decision is made within 2-3 months of submitting paper. The web-page of the Journal may be visited at the address, http://home.iitk.ac.in/~vinaykg/iset.html.

SECED members are invited to submit papers for publication in this journal. The journal is read by more than 1000 life members of ISET (most of those are based in India), and thus, by publishing their papers in this journal, the prospective authors may make the Indian earthquake engineers and researchers aware of their research findings. Prospective authors should send four copies of their papers directly to Vinay K Gupta at the address below.

Vinay K Gupta,
Professor of Civil Engineering,
Indian Institute of Technology,
Kanpur-208016, INDIA
Tel: +91-512-597118
Fax: +91-512-597395/590260/590007
Web: http://home.iitk.ac.in/~vinaykg

Third National Seismic Conference & Workshop on Bridges and Highways

More than 120 abstracts from throughout the United States and around the world, have been submitted for The Third National Seismic Conference and Workshop on Bridges and Highways. The conference, scheduled for April 28 through May 1, 2002, in Portland, Oregon, is expected to attract worldwide participation from hundreds of bridge and highway engineers, design consultants, researchers, and federal, state and local transportation agency owners. It will feature 50 to 60 formal presentations, and another 25 poster presentations. Session topics include:

Effects of near-field earthquakes on bridges
Displacement based design
Lessons learned from recent earthquakes (since 1998)
Design of major long span bridges in high or moderate seismicity areas
Design strategies for bridges subject to large ground motions
Seismic practices east of the Rockies
Emerging seismic design and retrofit technologies for bridges, tunnels, and other structures
Seismic response modification devices

The conference theme is "Advances in Engineering and Technology for the Seismic Safety of Bridges in the New Millennium." Presentations will focus on the latest advancements in earthquake design and retrofit, and on new and innovative technologies -- including the latest research and developments in earthquake engineering for bridges, highway systems, and components.

The conference will also include an International Forum comprising invited speakers from countries that have implemented advanced earthquake design and mitigation technologies and techniques. A Technology Showcase featuring as many as 40 exhibitors of new and innovative earthquake engineering technologies, and the latest information and developments in research, is also being organized.

The conference will be held at the DoubleTree Columbia River Complex, Portland, Oregon. Lodging is $77 per night for conference participants. Registration fee is $195 for local, state, and federal government employees, and $295 for all others. Registration includes: admission to all sessions, a copy of the proceedings, refreshment breaks, one luncheon, and one banquet. Registration for full-time students is $50. Tours & other activities are also planned. The conference exhibitor fee is $800 per 8 by 10-foot booth. Exhibit space will be assigned on a first come basis.

The program is sponsored by the Federal Highway Administration, Oregon Department of Transportation, and the Washington State Department of Transportation. It is organized by the Federal Highway Administration's Western Resource Center, and the Multidisciplinary Center for Earthquake Engineering Research (MCEER) headquartered at the University at Buffalo. Conference cosponsors include: the California Department of Transportation, Mid-America Earthquake Center, MCEER, Pacific Earthquake Engineering Research Center, and the Transportation Research Board.

For more information or to be placed on a mailing list for registration and exhibitor information, contact: Michael S. Higgins, P.E., Regional Manager, Eastern Region, Pure Technologies US Inc., 10015 Old Columbia Road, Suite B-215, Columbia, MD 21046; Tel: 410-309-7050; Fax: 410-309-7051; Email: mike.higgins@soundprint.com, or visit the conference web site via the MCEER home page at http://mceer.buffalo.edu.

MCEER Bulletin

The Fall 2001 issue of the MCEER Bulletin can be downloaded from their web site at http://mceer.buffalo.edu/publications/bulletin/default.asp In addition to the regular news, this issue includes a special insert featuring profiles of MCEER's Flagship and Premier Partners. In this issue there are also several reports about the WTC Disaster that may be of interest to SECED readers:

> Tragic Events Underscore Need for Preparedness, by George C. Lee. Researchers Investigate Structural Damage and Emergency Response in Wake of World Trade Center Attacks.
>
> NYCEM Researchers Assist Engineering Efforts in Aftermath of World Trade Center Disaster.
>
> Structural Engineering Reconnaissance at Ground Zero, A Seminar Sponsored by ASCE, MCEER and UB, presented by Michel Bruneau, Andrei Reinhorn and Andrew Whittaker.
>
> 7th U.S. National Conference on Earthquake Engineering Adds Session on World Trade Center Disaster.

It is possible to download the entire issue in PDF format, or each article can be read on screen in html format. For further information see:
http://mceer.buffalo.edu/publications/bulletin/default.asp

ICE virtual library is now On-line

For the past year the Institution of Civil Engineers has been working on a new service, the virtual library. This is a collection of all the technical papers (excluding conferences and Geotechnique) the Institution has ever published - since 1836 - available to download in full over the web. Phase 1 of the project is now complete, with papers published between 1936 and 1998 available to view. Papers from 1836-1934 should be available by the end of the year (though there are some 19th century papers up already).

The virtual library gives the ICE the largest and most comprehensive on-line full text collection of civil engineering papers in the world (approx 200,000 pages), and is a major achievement for the Institution. It was made possible thanks to a bequest from a long term member.

Full credit is due to the team at the library for their hard work Ensuring that the information was correct (checking and double checking every page!), to Kindi Cheema and the TT E-Services team for the site design and implementation, and to Isabel Cossar who managed the project.

The site is live now, and papers cost £15 for non-members, while members pay £5 to download a paper.

SECED readers are encouraged to have a look at the site http://www.iceknowledge.com and let the institution have any comments (good or bad!).

Preliminary Reports and Annotated Images from the El Salvador Earthquakes of January 13, and February 13, 2001

This CD contains over 300 images illustating buildings (churches, hospitals, low-rise commercial, mid- and high-rise commercial, housing and temporary shelter), landslides, liquefaction, and areas of future risk. All images may be used as long as the photographer and EERI are credited.

The CD also contains pdf files of the 12 page newsletter insert, a presentation on the January 13th earthquake, and a 53 page report written in Spanish by faculty members of the Engineering and Architecture Departments of the Universidad de El Salvador.

1999 El Quindio, Colombia Earthquake Reconnaissance Report and Separate Images

This CD contains a pdf file of the full text of the 73-page El Quindio, Colombia, Earthquake Reconnaissance Report. It covers earth science, geotechnical observations, construction overview, building damage, nonstructural components, lifeline performance, health impacts and emergency response and recovery.

All of the report figures are included in a separate html catalog with thumbnail images and captions for each image. Click on the thumbnail image to view/retrieve the larger image. All images may be used as long as the photographer and EERI are credited.

Created and produced by the Earthquake Engineering Research Institute with support from the National Science Foundation and the Federal Emergency Management Agency.

Order form can be found at:
http://www.eeri.org/Publications/cdorderform.pdf

Information on these and other EERI CDs:
http://www.eeri.org/Publications/cdroms.html

NOTABLE EARTHQUAKES APRIL - NOVEMBER 2001

Reported by British Geological Survey

YEAR	DAY	MON	TIME UTC	LAT	LON	DEP KM	MAGNITUDES ML	MB	MS	LOCATION
2001	**03**	**APR**	**14:57**	**34.92N**	**138.05E**	**30**		**5.1**	**4.8**	**HONSHU, JAPAN**
			At least eight people were injured.							
2001	**07**	**MAY**	**09:43**	**56.77N**	**3.20E**	**2**	**4.2**			**CENTRAL NORTH SEA**
			Felt throughout the Ekofisk oil field.							
2001	**13**	**MAY**	**08:26**	**55.10N**	**3.64W**	**11**	**3.0**			**DUMFRIES, D & G**
			Felt with maximum intensities of 5 EMS throughout the epicentral area.							
2001	**23**	**MAY**	**21:10**	**27.80N**	**100.98E**	**33**			**4.9**	**YUNNAN,CHINA**
			Two people were killed and approximately 600 people were injured.							
2001	**31**	**MAY**	**23:42**	**51.01N**	**4.63W**	**34**	**3.6**			**HARTLAND PT, DEVON**
			Felt with maximum intensities of 5 EMS.							
2001	**23**	**JUN**	**20:33**	**16.22S**	**73.60W**	**33**		**6.6**	**8.2**	**COAST OF PERU**
			At least 95 people were killed and 1,500 people were injured and extensive damage occurred throughout the Arequipa-Camana-Tacna area.							
2001	**24**	**JUL**	**05:00**	**19.32S**	**69.01W**	**33**		**5.9**	**6.2**	**NORTHERN CHILE**
			One person was killed and three people were injured.							
2001	**9**	**AUG**	**02:06**	**14.37S**	**72.63W**	**33**		**5.5**	**5.5**	**CENTRAL PERU**
			At least 4 people were killed, 15 people were seriously injured and extensive damage occurred throughout the Antabamba and Mollebamba areas.							
2001	**16**	**SEP**	**02:07**	**37.24N**	**22.00E**	**10**		**5.1**	**5.3**	**SOUTHERN GREECE**
			Minor damage occurred throughout the Loutro-Malta-Meropi area.							
2001	**08**	**OCT**	**01:17**	**32.90N**	**60.24E**	**33**		**4.8**	**4.1**	**CENTRAL IRAN**
			Two hundred houses were damaged in the Birjand area.							
2001	**10**	**OCT**	**02:52**	**51.70N**	**3.25W**	**7**	**3.1**			**BARGOED,MID GLAM**
			Felt with maximum intensities of 4 EMS.							
2001	**12**	**OCT**	**15:02**	**12.66N**	**144.92E**	**37**		**6.7**	**7.3**	**MARIANA ISLANDS**
2001	**18**	**OCT**	**03:50**	**51.70N**	**3.26W**	**8**	**2.5**			**BARGOED,MID GLAM**
			Felt with maximum intensities of 4 EMS.							
2001	**19**	**OCT**	**03:28**	**4.043S**	**123.93E**	**10**		**6.4**	**7.3**	**BANDA SEA**
2001	**28**	**OCT**	**16:25**	**52.84N**	**0.85W**	**12**	**4.1**			**MELTON MOWBRAY**
			Felt with maximum intensities of 5 EMS.							
2001	**14**	**NOV**	**09:26**	**35.95N**	**90.53E**	**10**		**6.1**	**8.0**	**QUINGHAI,CHINA**
2001	**28**	**NOV**	**14:32**	**15.47N**	**93.10W**	**33**		**6.1**	**5.7**	**CHIAPAS,MEXICO**
			Minor damage occurred throughout Tuxtla Gutierrez.							

Issued by: Bennett Simpson, British Geological Survey, December 2001

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24 April 2002
UK Earthquakes

29 May 2002
Plant Vibration of Structures

9-13 September 2002
12^{th} European Conference on Earthquake Engineering

SECED Newsletter

The SECED Newsletter is published quarterly. Contributions are welcome and manuscripts should be sent on a PC compatible disk or directly by Email. Copy typed on one side of the paper only is also acceptable.

Diagrams should be sharply defined and prepared in a form suitable for direct reproduction. Photographs should be high quality (black and white prints are preferred). Diagrams and photographs are only returned to the authors on request. Diagrams and pictures may also be sent by Email (GIF format is preferred).

Articles should be sent to:

Adam Crewe,
Editor SECED Newsletter,
University of Bristol,
Department of Civil Engineering,
Queen's Building,
University Walk,
Bristol BS8 1TR,
UK.

Email: A.J.Crewe@brisl.ac.uk

SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics, is the UK national section of the International and European Associations for Earthquake Engineering and is an affiliated society of the Institution of Civil Engineers.

It is also sponsored by the Institution of Mechanical Engineers, the Institution of Structural Engineers, and the Geophysical Society. The Society is also closely associated with the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics including blast, impact and other vibration problems.

For further information about SECED contact:
The Secretary,
SECED,
Institution of Civil Engineers,
Great George Street,
London SW1P 3AA, UK.

SECED Website

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

Email: webmaster@seced.org.uk