

Protecting Structures from Bomb Blast

Piroozan Aminossehe reports on this popular meeting.

SECED's October 2005 evening meeting was a joint effort with the Institution of Structural Engineers North Thames Branch.

The subject of discussion was bomb blast effects and how structures should be protected against such loads. Our two speakers were **Professor Geoff Mays** and **Dr Peter Smith** from Cranfield University, Defence Academy

of the United Kingdom, who are both eminent in this field.

Not that long ago, such a topic was only relevant for high-level security structures such as military or nuclear installations. However, due to recent events particularly after 09/11, our own problems on the 7th July and increased terrorist activities, it seems that ordinary and conventional buildings are not safe either and can

Contents

- Page 1 Protecting Structures from Bomb Blast
- Page 5 Recent Advances in Seismic Model Testing
- Page 9 EEFIT Mission to Earthquake Affected Northern Pakistan
- Page 12 Notable Earthquakes January – March 2006
- Page 12 New SECED Website!
- Page 12 Forthcoming Events

also be easily targeted by terrorist attacks and therefore it is quite important that structural engineers



Figure 1 – Blast wave visualisation: 27 tonne trial Woomera, Sept 2002

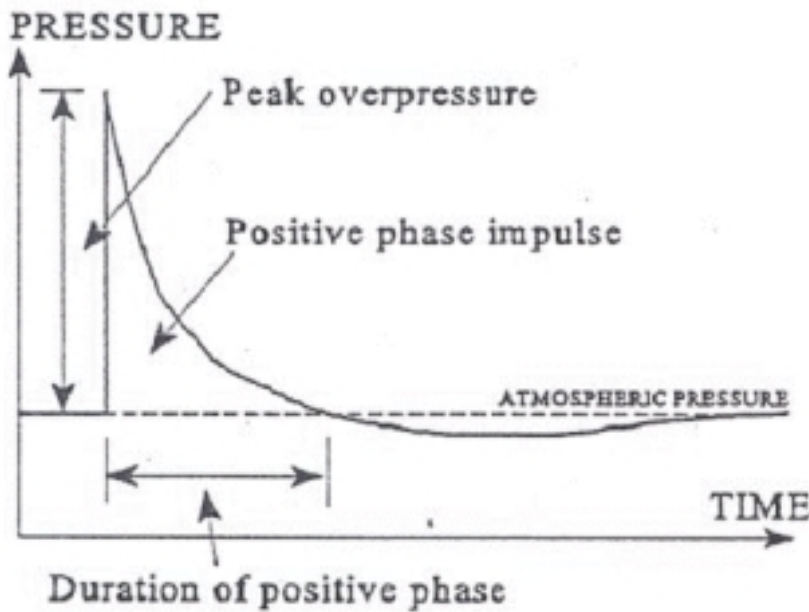


Figure 2 Pressure vs time at a fixed location

who are involved in the design of public buildings should have a good understanding and knowledge regarding such loads.

Due to our experience from the previous blast conference two years ago in October 2003 regarding the overwhelming response and welcome we received from engineers and specialists in the field, we used a larger conference room and still the conference room was packed with people standing at the back. More than 160 engineers and specialists came from different parts of the country, as far afield as Manchester, Barrow in Furness and Glasgow.

The meeting commenced with an introduction by **Piroozan Aminossehe**, on behalf of SECED and continued under the co-chairmanship of **Thomas Lai**, chairman of the Institution of Structural Engineers, (North Thames Branch) and Piroozan Aminossehe.

The first speaker was Dr Peter Smith whose speech started with blast loading and continued with case histories of blast effects and approach to structural analysis. This was followed by Professor Geoff Mays' speech on the subject of principles of structural protection and guidelines for protective design.

Dr Peter Smith described detonation as an explosive reaction proceeded by the propagation of a high intensity shock wave through the explosive material at speeds of up to 9000 mm/s. The high pressure, hot gases so produced expand violently, forcing the surrounding air to 'shock up' and form a blast wave, as shown in Figures 1 and 2.

Peter went on to describe the blast wave interactions with buildings and explained that the reflected pressure and impulse is always greater than

incident pressure and impulse. He then introduced the definition of "Scaled Distance", 'Z':-

$$Z = \frac{R}{W^{\frac{1}{3}}}$$

Where, Z is approximately a distance which debris may be expected to be thrown from an explosion.

R = range in metres from 'spherical free air burst' or 'hemispherical surface burst' charge.

W = Mass of charge in kilograms of TNT (obtained by converting actual explosive mass into 'TNT equivalent' mass).

He went on to discuss internal explosions and explained that the internal blast was the concussion effect of pressure rise caused by rapid combustion of fuel dispersed within a confined volume of air, which could be quite damaging or even disastrous. He continued that the internal blasts pressure versus time consisted of three rather distinct regions. First of these is an initial pressure rise that occurs at a rate set by chemical kinetics of the combustion reaction. The second part is the high reverberating blast pressure waves followed by the pressure decay, which is due to the cooling effects of confining

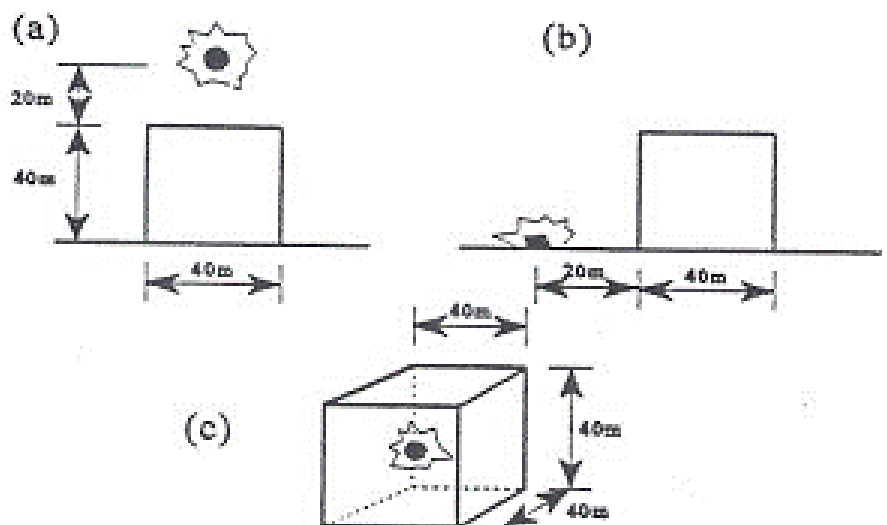


Figure 3 - 100kg Semtex detonated in three different situations but with range constant in each case

walls together with ventilating effects. For example, peak impulse and duration of a blast for 100 kg of Semtex detonating in three different situations, i.e., spherical, hemispherical and internal with a constant range in each case are 532.4, 806.1 and 2059 kPa-msec and 15.3, 17.1 and 184.1 m-sec respectively, as shown in Figure 3.

Peter warned that, while the blast pressure for a single structure subjected to a blast motion can be obtained using simple geometries such as spherical or hemispherical, for complex geometries such as an array of city streets and buildings such methods may be deficient. For internal detonations, rules are also available to estimate both reverberating blast waves as well as the gas pressure load for relatively simple geometries. However, appropriate computer programs, such as Air3d, should be used for complex conditions for both external and internal detonations.

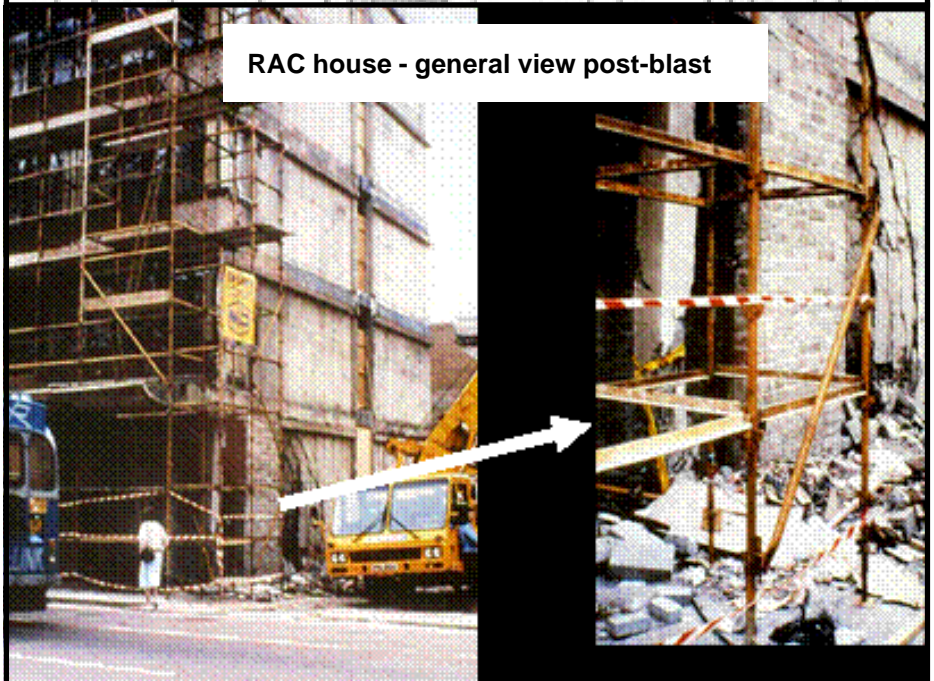
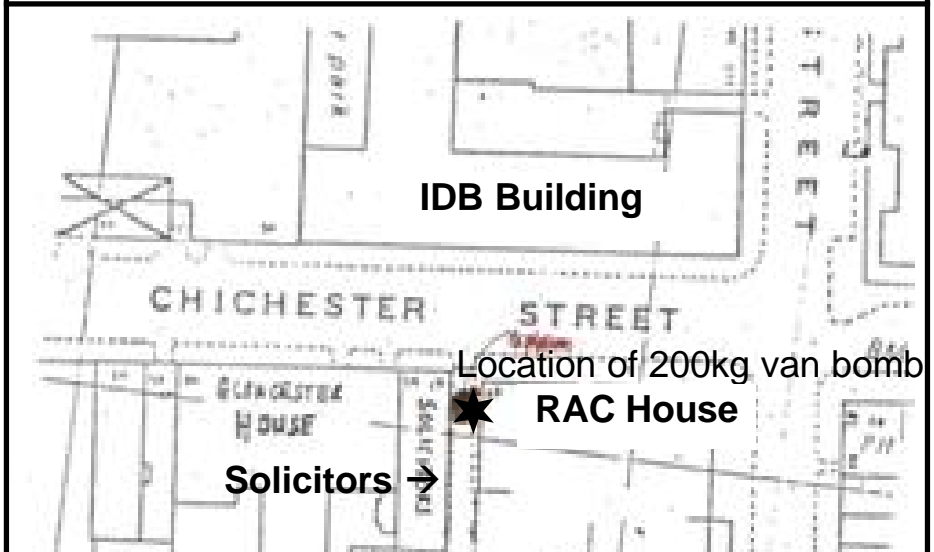
He then carried on that a structure could resist a blast load, firstly, by being massive and offering a large inertial resistance, secondly, by being designed from 'resistive' material configured in a 'resistive' geometry and lastly by having ductile behaviour. One of the main reasons of catastrophic failure of structures subjected to blast loading is lack of ductility, as shown in Figure 4.

He then said on many occasions a structure can be represented as one degree of freedom and depending on the ratio of the natural period of the simplified model of the structure 'T' and the duration of blast load t_d the following type of solution can be offered:

- If $T < t_d$ the blast loading can be applied as quasi static loading;
- If $T > t_d$ the blast loading can be applied as impulsive loading;
- If $T \sim t_d$ the blast loading can be applied as dynamic loading.

It should be noted that in the above scenario it is assumed that the applied blast loading can be simplified as a triangular time history load where the height of the triangle represents the maximum pressure and the base is t_d .

Figure 4 – Belfast 1985- 'ductile' vs 'brittle' structure. (Telephone warning at 1220, explosion at 1308. Casualties (8 wounded) low because buildings evacuated).



The analysis of the structure in order to define the response of real structure elements from first principal is complex. However, Professor Biggs of MIT, during the 1950s and 60s, developed a simplified method called "Equivalent Systems". The method is based on the assumption that a structural component can be approximately represented as an equivalent of one-degree freedom system, where its maximum displacement under the blast load is equal to the displacement of the one-degree freedom system subjected to the same blast load. However, the response of the equivalent system varies not only with the nature of the dynamic load but also with the nature of the structure. An important aspect of the latter is the ductility ratio that corresponds to a maximum acceptable damage in some particular blast situation. Charts have been developed for the equivalent static load for a triangular pressure pulse as a function of ductility ratio, pulse duration and natural period of the system.

At this stage Peter handed over to **Professor Geoff Mays** whose subject was, "Principles of Structural Protection and Guidelines for Protective Design".

Professor Mays said the principles of protection within a new building against blast hazard could be achieved through legislation, physical security, building arrangements and structural design.

Legislation addresses and regulates the essential requirements regarding safety in use where the structures must be designed and built in such a way that they do not present unacceptable risks or accidents in service or in operation.

Physical security could be external and/or internal. External security consists of items such as CCTV, fencing and stand off. Internal security comprises items such as alarms, detectors and search.

Good building arrangements, which could reduce the risk of blast hazard, consist of improving stand off and protecting vital structural components by the appropriate arrangement of external physical barriers and internal management of assets.

He continued that it should be a balance between the cost of stand off and physical hardening. By increasing the

physical hardening, the area of land used for stand off will be reduced. The cost of the stand off increases in proportion to the square of its distance from the building 'R²' and the cost of the physical hardening increases in proportion to '1/R³'. On this basis the optimum distance of 'R' can be estimated.

The protection of vital structural components is important, particularly in minimising the effects of fire. Past catastrophes have almost invariably been followed by fires and these become major causes of building damage and loss of life. There seems to be no reason to expect otherwise in possible future catastrophes.

In addition, the effects of blast should be made less severe by variations to external building profile, and by considering how to protect people from glazing hazards and from flying debris.

Geoff then turned his attention to structural design and he emphasized utilising the ductility within the structure by choosing appropriate materials as well as the continuity within the structure by ensuring the structure possesses sufficient redundancies. An important item in blast resistance structure is the use of ductile materials for absorbing some of the blast energy without the structure being totally destroyed. Structural steel ordinarily is ductile; hence properly designed steel structures are quite blast resistant. Concrete on the other hand is a brittle material unless reinforcement bars are used, but with adequate reinforcements concrete

becomes essentially ductile in blast resistant design. In balance, however, a well designed reinforced concrete structure can have some advantages in comparison to a steel structure due to its extra mass and weight.

The design of the elements within structures is generally complex. However, simplified rules could be used. For example for impulsive regime, where $T/t_g > 3$ the principles of equating energy;

Kinetic energy delivered by blast = energy absorbed due to structural deformation.

Where, the strain energy is obtained from the summation of both elastic and plastic deformation for which the amount of the utilised ductility has an important role.

He concluded his speech by illustrating how structural strength saved Pentagon lives on 9/11, as shown in Figure 5, and he summarised key features of the Pentagon as given below.

- In situ reinforced concrete wall
- Blast resistant windows and strengthened frames.
- Rows of sturdy spirally reinforced internal concrete columns.
- Good continuity at joints.
- Over designed

The evening's technical event ended with Q & A in which the participation of audience was particularly enthusiastic and overwhelming.

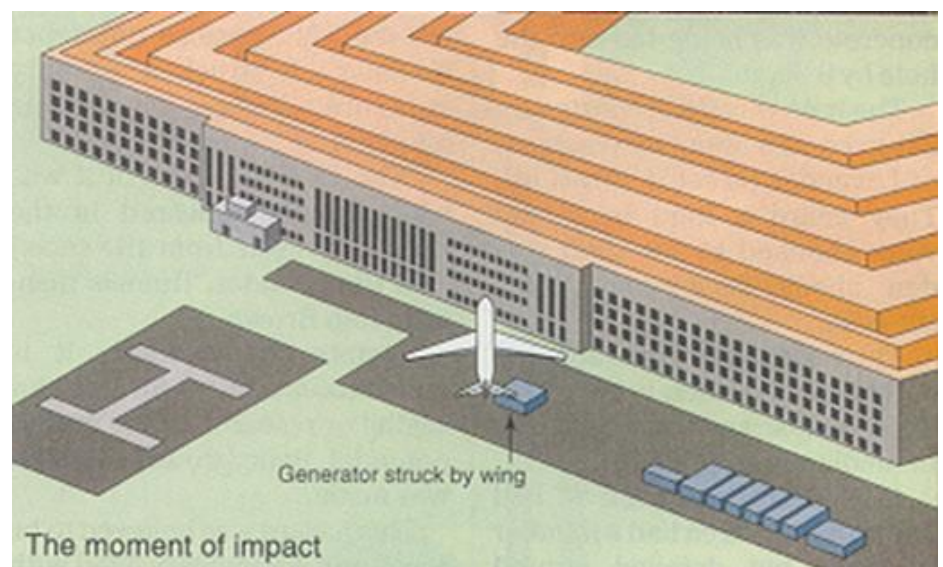


Figure 5 - Structural strength saved Pentagon lives on 9/11

Recent Advances in Seismic Model Testing

Andrew Chan provides an account of the SECED meeting held last year at Bristol University.

The afternoon programme began with the welcome and introduction to BLADE (Bristol Laboratory for Advanced Dynamics Engineering) by **Prof. Colin Taylor** of Bristol University. It was then followed by a tour of the near-completed BLADE facilities. The weather [January 2005] was cold but a good attendance of approximately 40-50 was recorded. The audience was treated to three high standard technical presentations on the topic "Recent Advances in seismic model testing":

1. "The development of real-time substructure testing" by **Dr. Martin Williams**, University of Oxford.
2. "Centrifuge" by **Dr. Gopal Madabhushi** of Cambridge University
3. "Dynamic control" by **Prof. David Stoten** of Bristol University

1. BLADE facilities

Prof. Taylor began with an overview of the BLADE facilities. It is an infrastructure investment of 18.5 million pounds with 15 million coming from the EPSRC Joint Infrastructure fund and the remaining 3.5 million coming from the Bristol University's own investment.

The facility is shared by six departments in Bristol University. The construction of the building was completed in October 2004 and the facility is expected to be fully operational by Easter 2005. (The facility is effectively fully operational at the time of writing)

The basic drivers behind the BLADE concept is that the engineering paradigms are changing. More and more, the government is reluctant to fund infrastructure renewal and expects the industry to fund and carry the risk. This is coupled by similar new business opportunities in the engineering industry.

In view of these changes in the industry, the vision of the BLADE facility is to

recognise that the real world is interdisciplinary. There is a need to eliminate as many philosophical and physical boundaries as possible. Therefore there is a need to promote interdisciplinary research.

Both dynamics engineering and engineering dynamics will be considered. While *dynamics engineering* is the process of design and realisation of the dynamical performance of a system, *engineering dynamics* are the scientific principles and theories of dynamics on which dynamics engineering depends. Both are common to all engineering application domains.

Prof. Taylor then turned to an example relating to cracks in structural walls with openings. Even though the relationship between force parameter, damage states and displacement seems to be very simple in the above example, dynamic systems can be complex and chaotic when non-linear dynamic response is involved. The response is sensitive to initial conditions, material and

numerical parameters. One of the possible conclusions is that a few time history analyses will not be able to capture the chaotic behaviour. He supported his argument with a numerical calculated collapse diagrams for a cracked masonry infill panel. The diagram showed the number of cycles to failure for different forcing frequency and amplitude. With a small change of forcing frequency and/or amplitude, the number of cycles to failure can be totally different. The resulting collapse diagram is a classical fractal one. The behaviour is totally different for different level of viscous damping applied to the system.

He went on to challenge if the current displacement based and capacity spectrum methods are adequate. Whether there are serious limitations in considering only force and displacement while neglecting velocity and possible chaotic behaviour and fractal nature of the response. He argued that more research is needed which would include large scale testing and rapid non-linear analysis methods.

After that, he went on to introduce the BLADE facilities which include the Earthquake and large structures laboratory, the shaking table and a high capacity reaction wall. Lastly, Prof. Taylor explained the management structure of the BLADE facilities which is driven by scientific themes. The laboratory management would try to deliver shared facilities that satisfy the needs of the researchers. The talk was followed by a tour of the facilities.

2. The development of real-time substructure testing

The first speaker for the main technical session was **Dr. Martin Williams** who is a Reader in Structural Engineering, Department of Engineering Sciences in



Figure 1 Shaking Table



Figure 2 Pseudo-dynamic testing

University of Oxford. His topic was “The development of real-time substructure testing”.

He also made the acknowledgements that significant contributions to the work in this presentation were made by Antony Darby, Tony Blakeborough, David Williams and Paul Bonnet. This piece of work was sponsored by EPSRC, The Leverhulme Trust, EU and the University of Oxford

According to Dr. Williams, there are two main types of Dynamic test methods:

1. Shaking tables where one can apply prescribed base motion to models (Figure 1).
2. Pseudo-dynamic testing (Figures 2 and 3) where Inertia and damping components are modelled numerically with stiffness modelled physically. Hydraulic actuators apply calculated seismic displacements and the measured stiffness forces are fed back to numerical model.

According to the speaker, the trends for the future are for the development of:

1. Very large shaking tables like the one in Japan;
2. Fast “pseudo-dynamic” methods including real-time substructure testing and effective force testing method.

The advantage of the shaking table is that it can accurately reproduce earthquake input. However, unless one is using a shaking table as big as the new NIED (National Institute for Earth

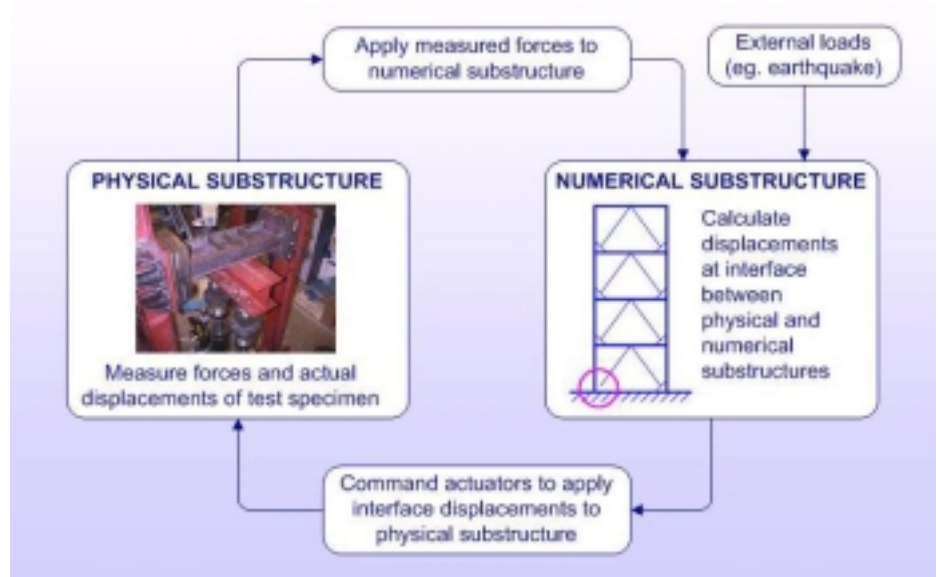


Figure 3 Pseudo-dynamic testing - physical/numerical substructure interfaces

Science and Disaster Prevention) shaking table in Miki City, Japan, one is normally limited to small-scale models. Then there are scaling problems in both physical dimension and time as well as control problems. As for the large Miki table, energy consumption and cost of experimentation could be a major issue. (Note: For comparison purposes, the Miki table has a payload of 1200 tons with a maximum acceleration of 1.5g, the maximum displacement allowable is 1m and it is controlled by twenty four 450 tonne actuators which are supplied by oil flow rate of 15,000 litre per min. The Bristol table has a payload of 15 tons. One must hasten to add that the Bristol table can also test (smaller) full scale models.)

On the other hand, the advantage of pseudo-dynamic testing is that it can be conducted at large scale. It is best suited to test flexible structures with concentrated masses. However, as it has to be tested slowly, the expanded timescale cannot capture any rate effect that may be present. With the use of feedback loop in order to calculate the change in force required, the error can accumulate which can lead to major inaccuracy or even instability in the model.

The effective force testing inputs the equivalent earthquake induced inertial forces into the structure. However, in order for this method to be applicable, the structure has to be simple in layout and the mass must be concentrated at externally accessible locations so that

equivalent earthquake induced inertial forces can be applied. Control of the load could become difficult if the structure begins to fail or the direction of loading changes due to the change in the geometry of the structure.

Real Time Substructuring (RTS)

Starting with the externally applied earthquake loading, the numerical substructure calculates the displacements at the interface between the physical and numerical substructures. Then the magnitude of displacements required is then translated into instructions to command the actuators to apply a load estimated to produce the interface displacements for the physical substructure. As the physical substructure is loaded, the forces at the interface and the actual displacement of the test specimen are then measured. The measured forces are then applied to numerical substructure as well as any external load for the next time step and the process repeats itself until the end of the experiment. For a typical experiment, the time step is of the order of 10 milliseconds.

The advantages of RTS testing include the following:

- a. it avoids the physical scaling problems associated with scaled model used in shaking tables
- b. it avoids the time scaling problems in pseudo-dynamic testing
- c. it is ideal for testing rate-dependent systems or components
- d. it is economical as only the key parts need to be modelled physically

e. it is fundamental to the development of multi-site tests where different testing facilities are used to model different parts of the overall structure. This approach is now being strongly pursued by the NSF NEES (Network for Earthquake Engineering Simulation) programme in USA.

However there are a number of requirements before RTS can be performed successfully. It requires high performance hardware so that the required numerical analysis can be completed in real time. This has to be communicated via fast, robust control and communications system to the physical components in the substructure. Lastly software that is capable of fast and accurate analysis of the numerical substructure.

The equipment set-up is as shown in Figure 4.

For tests with linear numerical model, a fast solution of the dynamic equation is required.

The equation system is first transformed via modal decomposition into individual modal shape and modal displacement to give individual modal equations. This is then truncated to eliminate the higher modes and the resulting equations are solved by explicit integration.

However the resulting equation is not very robust in practice and some improvements have to be implemented to deal with experimental errors. So in order to deal with the feedback of displacement errors, the integrated form of equation is used instead. The main problem with this approach is in the delay due to the actuator which is approximately 0.01 second for the shaking table used and it has an effect equivalent to negative damping. Therefore a forward polynomial extrapolation scheme is used to correct the displacement to be applied at the actuator.

On the other hand, a different algorithm is needed for the non-linear numerical model. Due to the non-linearity, the stiffness term will not decouple but the inertia and damping term still decouple by modal decomposition. However the use of a reduced modal basis will not accurately model the non-linear behaviour and a different basis is

needed. The new reduced basis comprises of a subset of the eigenvectors as for the linear case augmented by a set of Ritz vectors encapsulating the main non-linearities.

The issue of actuator delay compensation has to be revisited as actuator delay varies (mostly increases) with the stiffness of the specimen. The assumption of fixed delay can cause errors or even instability, especially in non-linear or multi-actuator tests. Therefore, instead of using a fixed time delay, the delay estimate is being updated using the adaptive procedure and the resulting position error of the new method is much smaller than one with a fixed delay estimate.

3. Advances in physical and numerical modelling in earthquake geotechnical engineering

The second talk was given by **Dr. Gopal Madabhushi**, who is a Senior Lecturer, Cambridge University Engineering Department and the Assistant Director of the Schofield Centre. His topic was "advances in physical and numerical modelling in earthquake geotechnical engineering".

His talk was organised into two parts with the first part concentrating on the recent developments in centrifuge modelling at Cambridge and the second part focusing on their experiences in numerical

modelling using finite element method. He first introduced why centrifuge testing is necessary.

3.1 Earthquake Actuation

In order to simulate earthquake on centrifuge, powerful actuators are needed. These actuators need to work in the high gravity field of a centrifuge. These actuators also need to impart a large quantity of energy to a model in a very short duration of time.

One of the latest developments in earthquake actuation technology in geotechnical centrifuge research is the Cambridge University Stored Angular Momentum (SAM) Earthquake Actuator. It is able to produce lateral shaking in the centrifuge model. Energy is stored in a pair of flywheels then released to the model via a fast-acting clutch. The Resultant acceleration is approximately sinusoidal. The capabilities of the SAM earthquake actuator are summarised below: (all given at prototype scale)

- g-level: Up to 100g
- Frequency of Choice: 1 to 5 Hz
- Magnitude of Choice: Up to 0.4g (pga)
- Duration of Choice: 2.5 to 100s

The advantages of the SAM system are:

1. The shaking table system is able to work at very high g-levels (> 100g)
2. It produces relatively clean single-frequency tone-bursts
3. It is relatively inexpensive to manufacturing

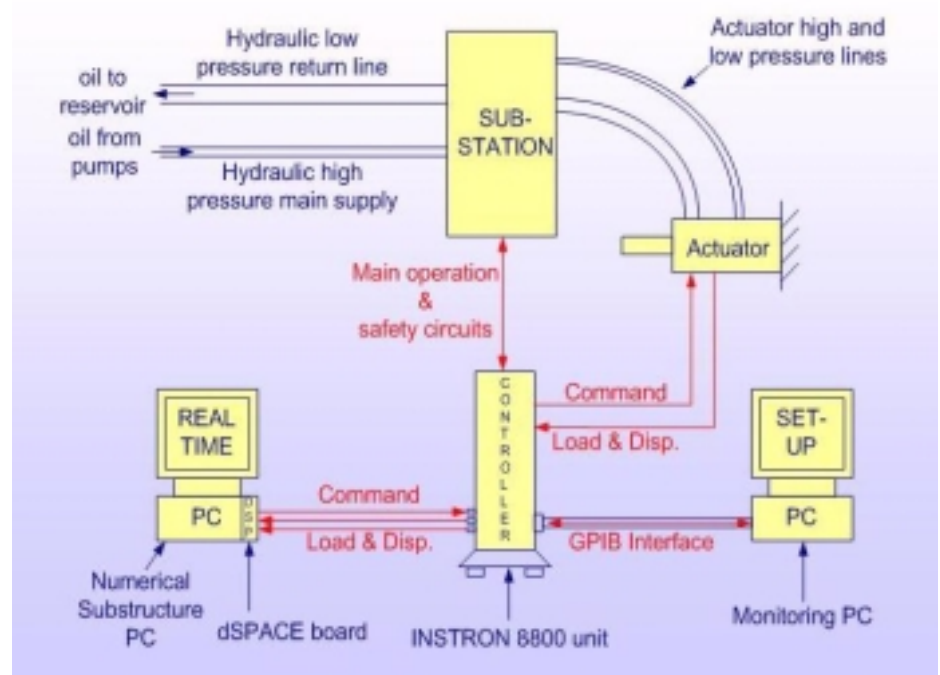


Figure 4 RTS Equipment set-up

However, it is only able to produce tone-bursts and swept-sine waves and not able to produce multi-frequency input motions.

Other new equipment recently developed or acquired include Fast digital videography (1000 frames per second at 1Mb resolution) in combination with PIV (Particle Image Velocimetry) analyses which is g-resistant but come with a £50k price tag. The PIV principle depends on comparing patches in the initial and the final images and calculates the degree of match in order to determine the final position of the PIV patch thus enabling the movement to be calculated.

3.2 Numerical modelling

The finite element program SWANDYNE was used for numerical analyses of various problems. The importance of the choice of time step size in coupled problems was established (to appear in Canadian Geotechnical Journal). Results of Class C (after results were known) analyses of retaining walls and Class A (before the experiment was conducted) analyses of In-Situ densification of bridge foundations were shown. The numerical modelling was carried out hand-in-hand with centrifuge modelling. It is felt that for complex problems such as the ones discussed here, both centrifuge modelling and finite element based numerical analyses are complementary to each other.

4. Control of dynamically substructured systems

The third speaker was **David Stoten**, Professor of Dynamics and Control, Department of Mechanical Engineering, University of Bristol. His talk was on "Control of Dynamically substructured systems"

4.1 General introduction

An example of control of dynamically substructured systems, via the MCS algorithm can be found in vehicle dynamics. While the emulated system is, for instance, a complete racing car, only the physical component of the wheel and suspension is required to be tested, while the rest of the car is modelled using a numerical model and the interaction between the physical and numerical substructure is controlled by an adaptive control system so that the displacement

compatibility at the interface is maintained using a change in the applied displacement. The change in applied displacement will result in a change in the resulting force. This resulting force is then fed into the numerical model and leads to a movement at the interface. This is adaptively controlled until the compatibility is maintained between the numerical and physical model.

MCS stands for 'minimal control synthesis: and it is an adaptive controller. MCS has been development at Bristol since around 1989, prompted by various problems in robotics

4.2 Dynamically substructured systems

The advantages of the dynamically substructured system includes:

- Avoids the necessity of real-time testing of an entire system. Instead, it allows for real-time testing of critical component(s) at full-size.
- Remaining non-critical components of the system are modelled numerically in real-time.
- This is a full-size testing method so problems associated with similitude and non-linear behaviour of small-scale model testing are avoided
- This is also a real-time physical testing method thus avoiding convergence and stability problems associated with purely numerical methods
- This is a real-time physical testing method thus avoiding problems associated with non real-time methods such as pseudo-dynamic testing.

However, there are also some potential disadvantages including:

- The synchronisation of physical and numerical components is critical so excellent control algorithm is required;
- There are problems to be solved:
 - o The establishment of a generalised dynamic substructuring framework and synthesis issues for specific systems
 - o closed loop stability and robustness issues
 - o signal noise and delay issues
- Additional transducers are required to link physical and numerical components;

- Efficient real-time numerical models are required. Therefore efficient hardware, software and communications are required.

4.3 The Minimal control synthesis (MCS) algorithm

The Research studies Press (1990) version of the MCS algorithm is based on a reference model. The output of the physical plant for a given input is compared with the reference model to generate the error. Both this error and the output of the physical plant together with the input signal are fed into the MCS Gain synthesis module. The gain on the input signal and the gain on the output from the plant are then controlled by the MCS module to adjust the input signal to the plant.

Later on in 2004, a new system called MCS with error-feedback (MCS-E) was proposed which is directly relevant to the control of dynamically substructured systems. Instead of the combination of error in output and the output of the physical plant together with the input signal, only the error in output is fed into MCS-E gain synthesis module. Instead of the output from the plant, the gain on the input signal and the gain on the error are then controlled by the MCS module to adjust the input signal to the plant.

4.4 Synthesis of controllers for dynamically substructured systems

An example of the Synthesis of Controllers for dynamically substructured systems is the substructured MIMO suspension system with the emulated system being a quarter-body road vehicle. While the suspension is modelled physically, the body, the wheel and the tyre are modelled numerically.

Various future works were mentioned at the end and one of them was the generalisation of adaptive substructuring methods for multi- and mixed-mode systems including shaking tables and reaction walls and frames.

The day was concluded with a short presentation which showed the Miki table in action followed by a number of questions and answers.

EEFIT Mission to Earthquake Affected Northern Pakistan

By Dr Navin Peiris (Arup)

Introduction

On October 8, 2005 at 08:50 local time (03:50 UTC) an earthquake of magnitude 7.6Mw occurred in northern Pakistan, which caused widespread destruction in Azad Jammu Kashmir (AJK) and in the eastern districts of North West Frontier Province (NWFP). As of January 1, 2006, the total casualty figures in Pakistan alone stood at 72,763 deaths and 68,679 injuries. Close to 400,000 homes were fully destroyed and damaged leaving about 2.8million people without shelter. The heaviest damage occurred to the cities of Muzaffarabad and Balakot (Figure 1) that were nearest to the fault rupture responsible for the earthquake. Ground shaking was also felt in the Indian side of Kashmir and in some parts of northern Afghanistan.

The Earthquake Engineering Field Investigation Team (EEFIT) of the Institution of Structural Engineers, London launched a field mission to the affected areas in Northern Pakistan and Kashmir region of Pakistan on November 22, 2005. The team led by Dr Navin Peiris (Arup) consisted of Dr Tiziana Rossetto (University College London), Dr Paul Burton (University of East Anglia) and Mr Suqlain Mahmood (Sir Robert McAlpine). The mission started from Islamabad and visited the affected areas of Abbottabad, Mansehra, Bagh, Balakot and Muzaffarabad (see Figure 1). The aim of the EEFIT mission was to observe the types of construction, construction practice and materials in order to identify recommendations for future construction, repair and retrofit

strategies and review of any existing local seismic-resistant design codes. They carried out walkover surveys and took aerial photos of the damaged areas in order to identify the distribution and extent of damage to structures, road and bridges due to the earthquake. The team also studied the landslides as these were a secondary hazard to the earthquake causing direct damage and disruption to infrastructure and lifelines (e.g. roads), which inhibited post-disaster relief efforts and the management of recovery.

Seismology and Fault Location

The epicentral region lies on the western edge of the Himalayan Arc, which denotes the area of continental-continental convergence between the

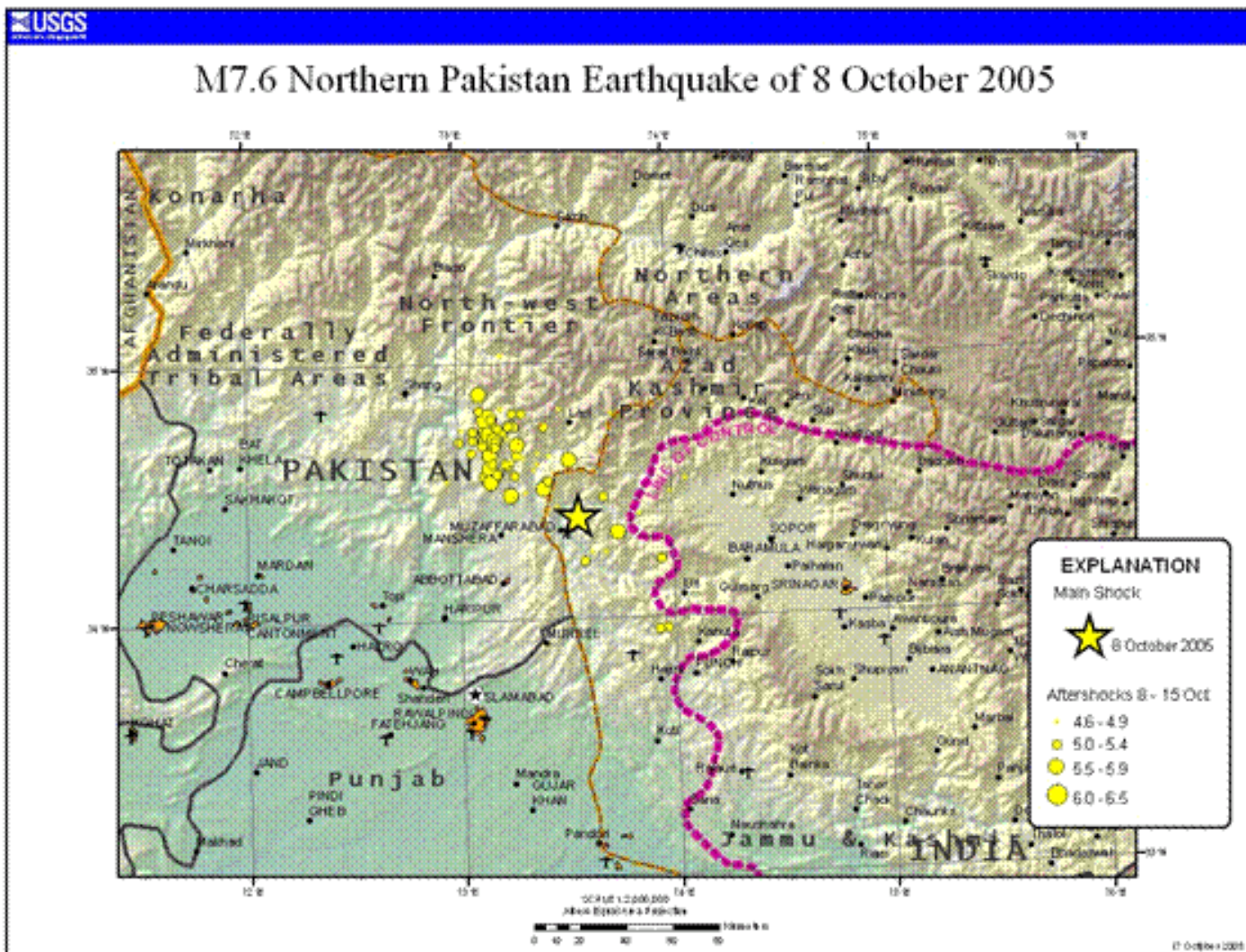


Figure 1: Earthquake epicentre and aftershocks (USGS, 2005)



Figure 2: Collapsed and heavily damaged masonry residential units on a hill northwest of Balakot city centre

Indian and Eurasian tectonic plates where the Indian plate moves northward at a rate of 40mm/year and subducts below the Eurasian plate. The earthquake of magnitude 7.6Mw and focal depth of 26km was followed by numerous aftershocks of magnitudes between 4.0Mw and 6.0Mw over a distance of about 150km in the NE-SW direction (see Figure 1).

confluence of Jhelum and Nelam rivers and has a population of about 160,000. Heaviest damage was suffered in this city given that it is only 8km southwest of the epicentre. Many commercial buildings of reinforced concrete frame and slab construction with masonry infill have collapsed or suffered extensive damage (Figure 3). Government buildings in the city have

Damage Observations

Figure 2 illustrates the damage in Balakot about 30km northwest of the epicentre. The city with a population of 80,000 built around Kunhar River has suffered collapse and extensive damage to stone and concrete block masonry residential units. Commercial structures of reinforced concrete frame and slab construction have also suffered collapse and heavy damage at the beam or slab column connections. Some of the retaining walls protecting a road descending to the city from the east have collapsed and some concrete gravity retaining walls have also displaced toward the river. The ground shaking was strong enough to displace the reinforced concrete deck of a vehicle bridge laterally by about 1m.

Muzaffarabad is the capital of Azad Kashmir (Pakistan administered Kashmir). The city is located at the

surprisingly collapsed or suffered extensive damage, which included the State Bank of Pakistan, Muzaffarabad Court House and several schools.

Mansehra about 30km southwest of the epicenter did not experience significant damage. The town was largely used for locating relief camps due to the availability of flat terrain. Abbottabad city located about 50km southwest of the epicenter generally suffered very little damage. However, there are some commercial structures of reinforced concrete construction in the northern part of the city that have either collapsed or suffered heavy damage. The damaged areas appear to be on construction carried out on the marshland side of the city, hence site response effect may have been responsible for this pattern of damage.

Islamabad is located about 100km southwest of the epicenter and experienced moderate ground shaking from the earthquake. The only major collapse reported was one of the 11-storey residential apartment buildings in the Margala Tower complex. About 100 people died due to the collapse, however there were no reported secondary damage or casualties due to fires. The building was of reinforced concrete frame construction supporting the reinforced concrete



Figure 3: Collapsed part of a reinforced concrete hotel structure in Muzaffarabad city centre

slabs with masonry infill panels separating compartments. The building had an open basement used as a parking garage and the whole building was supported on a raft foundation. The fact that adjacent buildings did not suffer major damage to the structural load bearing elements suggests that the collapsed building may have been defective.

Landslides

Landslides were a major secondary hazard in the earthquake affected areas. Landslide activity resulted in damage to houses, commercial buildings and most notable lifelines, which resulted in numerous casualties and disruption to the post-disaster emergency relief (Figure 4). Sliding failures along slopes has created instability to buildings and road sections at the top of the slope. There were many disrupted landslides, which could be triggered by another earthquake event or due to heavy rainfall or melting snow following the winter months.

Socio-Economic Impact

The estimated casualty figures as of November 12, 2005 was 72,705 deaths and 68,157 injuries from both NWFP and AJK provinces (Asian Development Bank data). The earthquake left about 2.8million people without shelter creating the need to reconstruct about 400,000 homes for the displaced population. The majority of the victims were from the already vulnerable groups, living in comparatively inaccessible mountain areas with lower levels of income compared to the national average. Many of the victims were women and children since women were caught unaware in houses when the earthquake occurred and the collapse of school buildings resulted in deaths of many school children. The damage to housing, health and education infrastructure had a profound social impact on the region.

The earthquake has resulted in asset losses amounting to US\$2.3 billion with the housing sector accounting for US\$1.0 billion worth of damage. The reconstruction cost of all assets is estimated to be US\$3.5 billion, which considers the replacement cost of the



Figure 4: Landslide blocking the road to Balakot from the north (Photo: US Army)

damaged assets and the additional cost to be incurred due to seismic resistant design. The economic sectors most affected by the earthquake are agriculture, livestock, industry and services. The impact on Pakistan's official GDP has been estimated to be minimal.

Conclusions

The earthquake resulted in substantial damage to residential, commercial and government buildings such as schools, hospitals and administration buildings. The damage may be attributed to the lack of seismic resistant design and construction practices in the region. There is therefore a clear need to educate the local population during the reconstruction process in order to minimize the vulnerability from future earthquake event. There is a need to carry out a detailed seismic hazard assessment in order to identify the ground motion levels in the region for reconstruction. It is advisable to carry out a multi-hazard risk assessment involving earthquake, flood and landslide hazards for appropriate site selection for reconstruction. Although the impact on the national economic output is considered minimal, there are severe social consequences from this earthquake given that the affected provinces record the highest level of poverty in the whole country.

NOTABLE EARTHQUAKES JANUARY – MARCH 2006

Reported by British Geological Survey

YEAR	DAY	MON	TIME UTC	LAT	LON	DEP KM	MAGNITUDES ML MB MW	LOCATION
2006	2	JAN	06:10	60.93S	21.58W	10	7.4	SANDWICH ISLANDS
2006	2	JAN	22:13	19.93S	178.18W	583	7.2	FIJI ISLANDS REGION
2006	4	JAN	08:32	28.16N	112.12W	14	6.6	GULF OF CALIFORNIA
2006	8	JAN	11:34	36.31N	23.22E	66	6.7	SOUTHERN GREECE
Three people slightly injured and minor damage reported on Crete. Around 80 homes and an airport damaged on Kythira.								
2006	12	JAN	19:03	51.30N	1.22W	15	2.6	BASINGSTOKE
2006	19	JAN	02:35	56.96N	5.61W	3	2.8	MALLAIG, HIGHLAND
Felt in Mallaig, Glenfinnan and Lochailort (3 EMS).								
2006	27	JAN	16:58	5.47S	128.13E	397	7.6	BANDA SEA
2006	2	FEB	12:48	17.75S	178.39W	598	6.7	FIJI ISLANDS REGION
2006	6	FEB	18:43	57.92N	5.50W	6	2.0	GRUINARD BAY
2006	14	FEB	00:55	27.34N	88.35E	30	5.3	SIKKIM, INDIA
Two people killed by landslides at Sherathang and 2 more injured in East Sikkim. Minor damage to buildings and roads in the Gantok area.								
2006	20	FEB	17:20	41.71N	25.54E	10	4.6	GREECE/BULGARIA
Two people injured, over 175 buildings damaged and power and telephone service interrupted in the Murgovo region, Bulgaria.								
2006	22	FEB	22:19	21.25S	33.50E	11	7.0	MOZAMBIQUE
Four people killed, 36 injured and around 300 buildings damaged or destroyed in the Espungabera and Beira areas. Felt throughout Mozambique and Zimbabwe.								
2006	28	FEB	07:31	28.13N	56.88E	18	6.0	SOUTHERN IRAN
Six people injured in Kahnaj and many buildings either damaged or destroyed in the Faryab and Baft areas.								
2006	4	MAR	12:14	55.81N	5.71W	3	2.2	SOUND OF JURA
2006	7	MAR	18:20	23.77N	70.89E	10	5.5	GUJURAT, INDIA
Seven people injured and several buildings damaged in Jatawada.								
2006	10	MAR	07:50	33.14N	73.95E	10	4.9	PAKISTAN
One person killed and 22 others injured in Mirpur District.								
2006	14	MAR	06:57	3.59S	127.21E	31	6.7	SERAM, INDONESIA
One person killed on Buru.								
2006	20	MAR	19:44	36.60N	5.39E	10	5.0	NORTHERN ALGERIA
Four people killed, 36 injured and 30 houses collapsed in the Kherrata area.								
2006	31	MAR	01:17	33.60N	48.80E	10	6.1	WESTERN IRAN
At least 66 people killed, 1200 others injured and many buildings damaged or destroyed in Lorestan Province.								
2006	31	MAR	13:21	29.44S	176.75W	10	6.5	KERMADEC ISLANDS

Issued by: Davie Galloway, British Geological Survey, April 2006.

Non British Earthquake Data supplied by: The United States Geological Survey.

New SECED Website!

Please visit our new-look website, www.seced.org.uk, which is the result of much behind-the-scenes activity over the last few months.

Your comments are welcome but please bear with us as we iron out glitches and add content!

Forthcoming Events

3 to 8 September 2006

First European Conference on Earthquake Engineering and Seismology, Geneva

www.ecees.org

29 September 2006

Earthquake Engineering in the 21st Century
ICE 6.00pm

25 October 2006

Disaster Management

November 2006

Stadia Dynamics

SECED Newsletter

The SECED Newsletter is published quarterly. Contributions are welcome and manuscripts should be sent on a PC compatible disk or directly by Email. Diagrams, pictures and text should be in separate electronic files.

Copy typed on paper is also acceptable. Diagrams should be sharply defined and prepared in a form suitable for direct reproduction. Photographs should be high quality (black and white prints are preferred). Diagrams and photographs are only returned to the authors on request.

Articles should be sent to:

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

E: john.sawyer@projectservices.com

SECED

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

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

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