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Existing Nuclear Structures Appraisal v Qualification

Andy Campbell highlights the need for a balanced input to the ALARP process.

This article is the first in a series based on the SECED/BNES Symposium - Seismic Assessment of Existing Nuclear Structures, held in May 2004. The series will continue in the next newsletter.

Andy Campbell's talk focused on the constraints of working on existing plants compared to the relative freedom to be conservative on new-build schemes.

It began with a brief overview of the evolution of British Nuclear Group seismic criteria and the context of the talk in terms of remediation of the Sellafield site. The wide range of structures on the site was introduced together with an explanation of the huge diversity in the level and type of risk from these facilities. The wide differences in each safety case mean that a more balanced picture of the seismic risk as a proportion of the total risk has become essential.

The planned remediation of the site adds another factor to the equation since the ultimate goal is to empty the existing facilities and reduce the risk by putting the inventory into a passive,

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non-mobile form housed in modern, long-term storage facilities. Any improvements to the seismic robustness of existing plants have to be weighed against the potential for delay that they might impose upon achieving the long term goals of retrieval, POCO, decommissioning, safe storage and remediation. This means, in effect, that over-conservatism in the seismic case, which generally implies reduced risk on new-build schemes, may actually result in increased overall risk on decommissioning schemes because improvements are targeted at low probability events whose importance may well be overstated. A greater benefit in safety terms may be through earlier retrieval removing the risk at source and accepting more novel seismic assessment techniques, balancing slightly enhanced short-term seismic risks against the long-term benefits of massive overall risk reductions.

The standard criteria for deciding on the need for seismic appraisal of existing structures were then reviewed against target probabilities within the NII Safety Assessment Principles (SAPs). The current methodology of deterministic appraisal upon exceeding a relatively low trigger level of radiological consequence was contrasted with the graded criteria for increasing consequences within the SAPs.

This was followed by an overview of the conservatism inherent in the standard qualification process, which is frequently used as the starting point for seismic appraisal of existing nuclear structures. The areas of conservatism and reasons for their introduction in new-build methodologies were discussed together with examples of how they have been applied in the Long Term Safety Review of existing plants. This was then extended to the British Nuclear Group approach to seismic appraisal of existing plants, applying qualification methodologies essentially on a standard conservative deterministic basis as a first pass. This used a reference 10^{-3}/year event as a surrogate deterministic measure of tolerability of risk, extrapolating upwards from this towards the Design Basis 10^{-4}/year event to decide upon whether proposed improvements are ALARP. Two difficulties in this approach were identified as being the failure to identify the degree of conservatism in the approach to allow a realistic comparison with other hazards and the adoption of the same methodology for both low and high inventory plants once the specified threshold had been exceeded.

Some potential ways of addressing this by getting a fuller picture of the seismic risk from existing plants were then introduced. These fell into the following broad categories:

- Direct quantification of risk
- Better understanding the range of performance
- Better understanding the form of response
- Project strategy

In the first category, the benefits of seismic Probabilistic Risk Assessment were summarised, particularly the ability to establish tolerability of risk against objective criteria and to prioritise potential improvements in terms of their contribution to global risk reduction.

The next category was aimed at relaxation of conservatisms to give an understanding of the difference between the single high confidence capacity predicted by qualification and the range towards best-estimate performance. These included better use of time-history techniques, adoption of alternative criteria such as displacement or energy rather than stress and less conservative estimates of the seismic demand through the use of Uniform Risk Spectra. It was argued that the appropriate point within this range of performance for the assessment to aim at would be dependent on the potential consequences.

The primary application introduced in the third category was the use of push-over analysis to get a better feel for non-linear structural behaviour, the associated interaction between response and demand and closer linking of this improved understanding to the required safety functional performance.

Finally, it was argued that a different type of project strategy was needed on existing plants than on new-build schemes because of the constraints imposed by access requirements, operational considerations, potential dose uptake and the need to balance seismic risks against those from other hazards. A number of elements that had been found to be present to some degree in successful strategies on past projects were introduced. These included:

- Interaction with the safety assessors
- Establishing tolerability
- Looking for margins
- Establishing a sequence of improvements in order of safety significance
- Early identification of interactions, both in engineering and operational considerations.

The talk concluded by trying to answer the question:
"What is it that provides balanced input to the ALARP process?"

It was suggested that the answer might encompass the following points:

a) *Perspective* - Painting a picture of the possible range of effects rather than giving a single number.
b) *Safety Focus* - Adopting a holistic approach looking at seismic issues realistically in the context of overall plant risks.
c) *An Open Mind* - Being prepared to think laterally about operational as well as engineered solutions.
d) *Practicality* - Focusing on "Reasonably Practicable" improvements where options are limited rather than getting stuck in "Paralysis by Analysis".
e) *Strategy* - Putting seismic improvements in perspective in terms of the long-term goals for the plant.

Finally, the main message was reinforced. On old plants, over-conservatism in one area does not equate to greater safety on the plant because it may lead to a focus on hypothetical risks at the expense of the real risks.

A Calculation of UK Seismic Hazard using Real Earthquake Time Histories

By **Christopher Allen** of British Nuclear Group.

Introduction

Recent years have seen major advances in instrumentation, computing and, of course, the Internet, both in terms of increased technical capability and reduced cost. This has assisted in the installation of seismic monitoring networks on an ever-increasing scale, leading to a relative profusion of instrumental earthquake records. Evidence of the increasing amount of earthquake data is provided by the recent project under the auspices of the European Council, Environment and Climate Research Programme, which resulted in the production of a compact disc containing 1068 European earthquake records [i]. A study has been undertaken using these records to obtain a further understanding of the nature of seismic hazard in the UK [ii]. This work is summarised in this paper.

Method

The work described in this paper has been undertaken for earthquakes measured on both hard and soft sites. To place a limit on the length of this paper, only the work on the hard site earthquakes is described. Similar results have been obtained for the soft site data.

In the execution of earthquake hazard studies for the UK it is usual to exclude earthquake data both below a surface wave magnitude (M_s) of 4 and above 6.5 M_s. The basis for the former is that an earthquake below 4 Ms is deemed to be non-damaging to engineered structures. For the latter, an event exceeding 6.5 M_s is deemed not to be able to occur within the UK. Accordingly all earthquakes outside this range were excluded for the reported work. No other processing of the earthquake data in the dataset has been attempted in this study.

The European Earthquake dataset was interrogated by a computer program written in PASCAL [iii]. The parameters of the earthquake associated with each time history record were identified, such as magnitude and focal depth. The following parameters that relate to each time history were then obtained for the records for the x and y directions as given in the dataset.

- Peak ground acceleration.
- Peak displacement of a 1 Hz system.
- The peak displacement of a hypothetical elastic/plastic system, which had a 1 Hz natural frequency (when elastic), and was assumed to yield at the 1 Hz spectral acceleration of a hard site PML spectrum[1] anchored to a peak ground acceleration of 0.1g. The

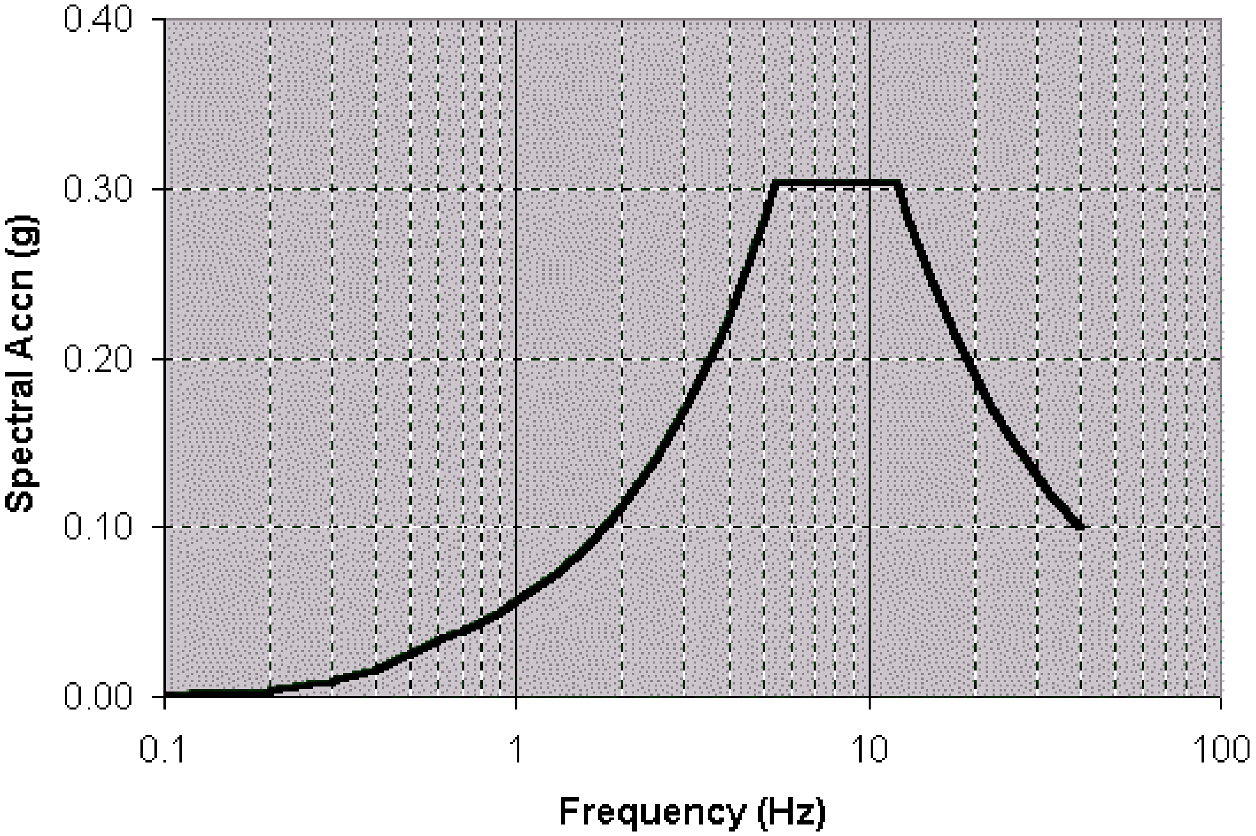

Figure 1: Hard Site PML Spectrum Anchored to 0.1g Acceleration

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[1] This is the spectral shape produced by the consultants Principia Mechanica Ltd (PML) in the early 1980s for seismic design in the UK.

response of this system was calculated using a purpose written sub-routine. The 0.1g hard site PML spectrum is shown in figure 1. This parameter is referred to in the results as the ductility demand, this being the ratio of the peak displacement of the elastic/plastic system under earthquake excitation to the displacement at yield.

- The Cumulative Absolute Velocity (CAV).

The CAV is a parameter used in the US nuclear industry as a measure of the damage potential of an earthquake time history [iv]. The CAV value calculated for this work is according to the original definition and is:

$$CAV = \int_0^t |a(t)| dt \quad \text{......... (1)}$$

where a(t) is the acceleration time history of interest.

The CAV value was calculated in order to form a view on the damage that may be caused by a specific time history. Of particular interest are the damage descriptions that are available for industrial facilities, thus enabling the possibility of consideration of the earthquake damage risk to similar facilities in the UK.

Therefore, for each time history record, several parameters of interest were determined. Hazard curves for these parameters at a typical site were then obtained.

In order to produce hazard curves, each time history record was allocated a magnitude bin and an epicentral distance bin within each magnitude bin. The magnitude bins were each of a width of 0.2 and spanned from 4 M_s to 6.5 M_s. The boundary of each epicentral distance bin was obtained by dividing the difference between adjacent epicentral distance values by two. Consider a time history in a magnitude bin spanning from M to M + ΔM. and an epicentral distance bin spanning from R to R + ΔR. The frequency, N_1, of an earthquake for the UK that exceeds magnitude M was taken as:

$$\log(N_1) = 4.22 - 1.28 \cdot M \quad \text{.... (2)}$$

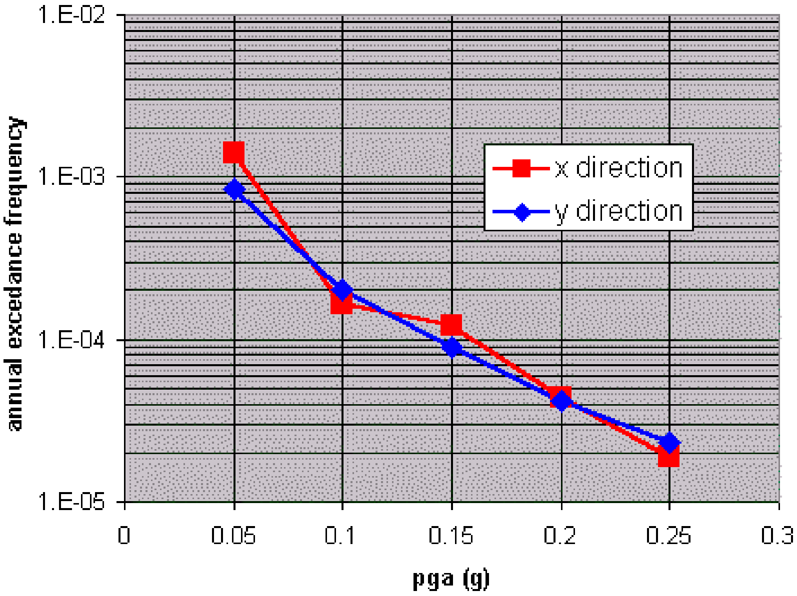

Figure 2: Hard Site Peak Acceleration Hazard

and the frequency, N_2, of an earthquake for the UK that exceeds magnitude M + ΔM was taken as:

$$\log(N_2) = 4.22 - 1.28 \cdot (M + \Delta M) \text{ .(3)}$$

Therefore the frequency of occurrence of an earthquake in the magnitude range M to M + ΔM is given by:

$$\Delta N = N_1 - N_2 \quad \text{...... (4)}$$

Now the probability, P, of an earthquake being in the epicentral distance range R to R+ΔR is given by:

$$P = \frac{\pi \cdot ((R + \Delta R)^2 - R^2)}{A_{uk}} \quad \text{... (5)}$$

in which A_{uk}, the area of the UK mainland, is taken as 2.3 x 10^5 km^2.

Therefore the frequency of an earthquake being in the above

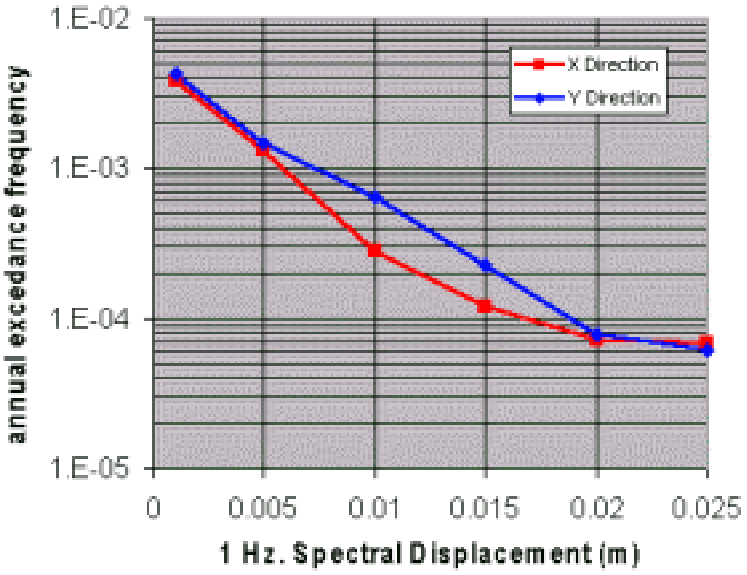

Figure 3: Hard Site 1Hz Spectral Displacement Hazard

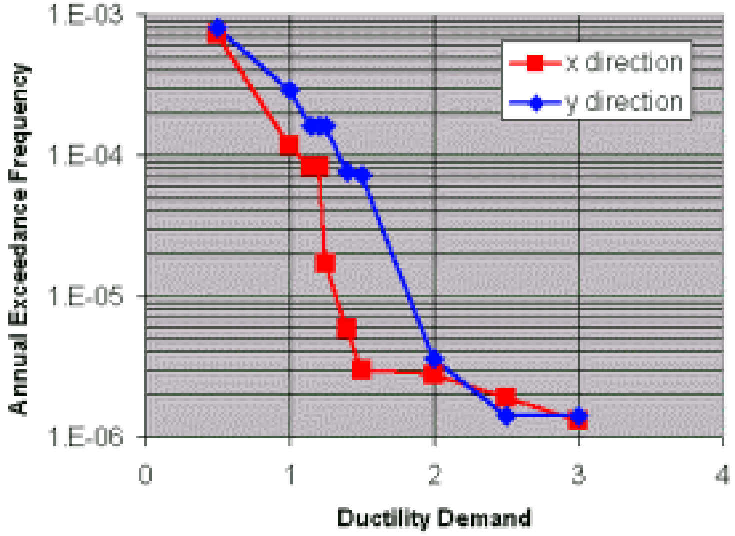

Figure 4: Hard Site Hazard for Ductility Demand

magnitude and epicentral distance bins is simply:

$$\Delta F = \Delta N \cdot P \text{ ...... (6)}$$

Now if there is an interest in a particular time history parameter Φ, then the frequency with which the value $\Phi 1$ of parameter Φ is exceeded is:

$$XF_{\Phi 1} = \sum \Delta F \text{ ...... (7)}$$

if $\Phi > \Phi 1$.

In this way, the exceedance frequencies for the parameters discussed above have been determined for a typical UK site. The results are now discussed for the hard site data. The results for the soft sites are similar.

Results

Figures 2 to 5 give the hazard curves derived using the above methods for peak ground acceleration, peak spectral displacement for a 1 Hz 5% damped system, ductility demand and CAV. These results are for time histories measured at the hard sites and are summarised in table 1.

Discussion of Results

It is interesting to note that the peak ground acceleration hazard is of a similar order to that produced using more usual hazard calculation methods.

The results for the displacement of a 1 Hz 5% damped system would indicate that a ground mounted rocking body would not fail at an exceedance frequency of 10^{-4} per annum unless it were of very slender dimensions.

The results for ductility demand underline the benefits that ductility plays in the ability to resist earthquake loading. Were the elastic/plastic system assessed using elastic methods with an allowable limit of yield, the system would only just be qualified against the PML hard site spectrum, which is generally taken to represent an earthquake of exceedance frequency of 10^{-3} per annum. However, study of figure 4 shows that, were the system able to sustain a ductility demand of 3, then it would not have failed at an exceedance frequency approaching 10^{-6} per annum.

The study conducted by EPRI [iv] showed that a CAV value of less than 2 m/s was consistent with no structural damage, other than cracks being induced in unreinforced masonry. Between values of 2 and 5 m/s, damage to unreinforced masonry may occur. Above 5 m/s, there is damage to well-constructed buildings and above 8 m/s there is damage to industrial facilities or power plants. On this basis, damage to masonry (cracking excluded) would only occur at an annual frequency of less than 10^{-4} per annum. Damage to well-constructed buildings would occur at an annual exceedance frequency approaching 10^{-6} per annum and damage at industrial facilities occurring at less than 10^{-6} per annum (excluding loss of electrical supplies and possible damage to large tanks).

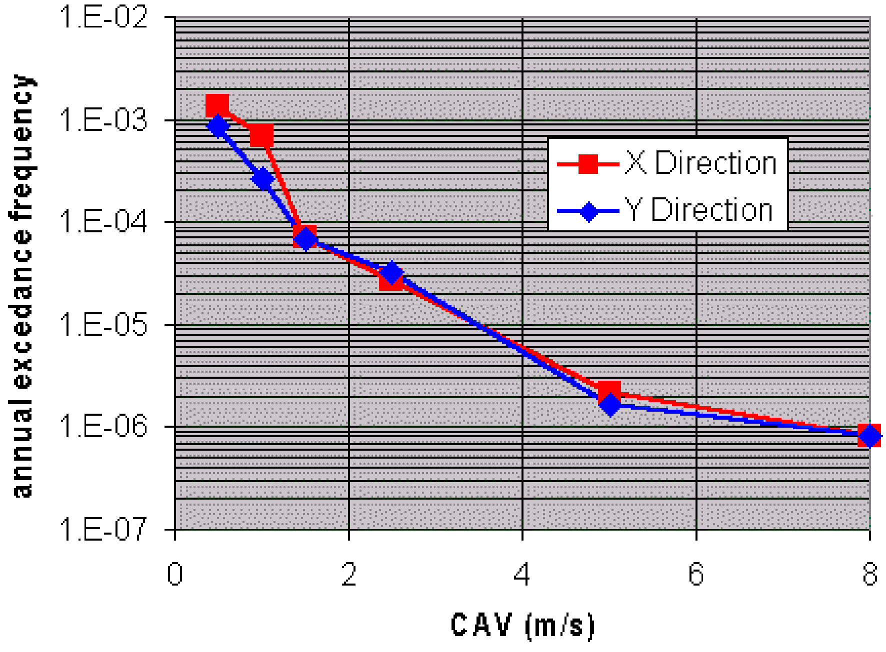

Figure 5: Hard Site CAV Hazard

Conclusion

The use of real time histories in the manner described above to obtain a view of earthquake hazard is beneficial. It allows the use of analytical models representing structural non-linearities so that the effect of properties such as ductility may be understood. It also allows the use of time history parameters related to damage, e.g. the CAV value, thus providing an appreciation of the risk of damage to structures, particularly industrial structures within the UK.

It is concluded that:

- There are no effects of any significance at a site at an annual exceedance frequency of 10^{-3}, except for the loss of off-site power.
- The risk of significant structural damage occurring at a UK site of average seismicity would occur at an annual exceedance frequency of approaching 10^{-6}, with damage to unreinforced masonry perhaps occurring at an annual exceedance frequency of below 10^{-4}.
- This method may be used for the analysis of non-linear models where it is desired to obtain the risk of exceedance of a particular response. The use of the elastic-plastic system in the study is one example.

Questions Outstanding

As a result of the study the following questions may be posed.

1) Are there significant margins in the formal methods employed for the seismic qualification of UK facilities?
2) Is the earthquake that is normally considered to be frequent (exceedance frequency of 10^{-3} per annum) of a severity such that no damage may be expected at that level of hazard?
3) Does the method described above provide a means of obtaining an understanding of the risk of earthquake induced damage that is perhaps more reasonable than other methods that may be employed?

Peer Review

The study has been subject to an independent peer review by the Seismic Hazard Working Party. Whilst there has not been time, to date, to incorporate the many points arising from the review, the review was, in general, supportive.

Acknowledgement

This study could not have been performed without the work of those who collect and disseminate instrumental earthquake data. Their significant contribution is acknowledged.

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iii Borland Delphi 5

iv A Criterion for Determining Exceedance of the Operating Basis Earthquake, EPRI NP-5930, July 1988.

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Parameter	**Annual Exceedance Frequency**	
	10^{-3}	**10^{-4}**
Peak Ground Acceleration (g)	0.05	0.15
1 Hz Peak Spectral Displacement (mm)	6	19
Ductility Demand	0.4	1.2
CAV (m/s)	0.4	1.3

Table 1: Results vs. Annual Exceedance Frequency

Seismic Assessment and Modifications of Dungeness ‘A’ Boiler Cells

By **Piroozan Aminossehe** formerly of Taylor Woodrow Construction and **Pradeep Prakash**, Vectra Group Ltd.

1 Abstract

Structural modifications were necessary to improve the seismic capability of the Dungeness A Boiler House and Duct Cell structures following the Periodic Safety Review (PSR) assessment. Any modifications of existing old structures require very careful consideration lest these should alter the load path and result in unintended consequences. A number of possible solutions were proposed and tested for feasibility. Of the feasible options, final design solutions were selected on the basis of minimum disruption, ease of implementation and cost. The modified structure with all the alterations was assessed and any deficiencies rectified.

2 Introduction

As part of the Periodic Safety Review, the Dungeness A Reactor Building was assessed against a 10^{-4} nonexceedence frequency seismic event. The assessment concluded that sufficient confidence in structural integrity of the boiler boxes could not be demonstrated. BNFL Magnox Generation therefore decided to carry out physical modifications to these structures to enhance their seismic capability.

The finite element modelling, stress analysis/interpretation of results, civil engineering design and verification were carried out by separate organisations with particular strengths in those areas. The design and analysis are interconnected: the design modifications are incorporated into the analysis models and the results of the analysis are fed to the designers who in turn make the modifications to the initial design based on the analysis results. So this was an iterative process involving a large number of steps.

This paper summarises the analytical and design works, which have been carried out interactively by Vectra (as analyst consultant), Taylor Woodrow (as design consultant) and Magnox Electric (as co-ordinator).

3 Description Of The Reactor Building Structure

At Dungeness A Nuclear Power Station there are two separate reactor units. Each unit comprises a Reactor Building and two Boiler Houses. A central Change and Control Block Building separates the two Reactor Buildings.

Each Reactor Building and its two Boiler Houses are supported on their own foundations and are therefore structurally independent. The Reactor Building consists of the reactor pressure vessel, primary shield (Bioshield), secondary shield, and the duct cells. The boiler houses each consist of a foundation block, boiler box and steam drum house (SDH). The reactor building and adjacent boiler houses are separated from each other by one-inch thick ‘Flexcell’ joints with connections at two positions only. These are: i) the vertical edge of the central dividing wall within the boiler house (levels 68ft to 141ft) which is connected to the duct cell wall by proprietary unistruts; ii) at the 141ft

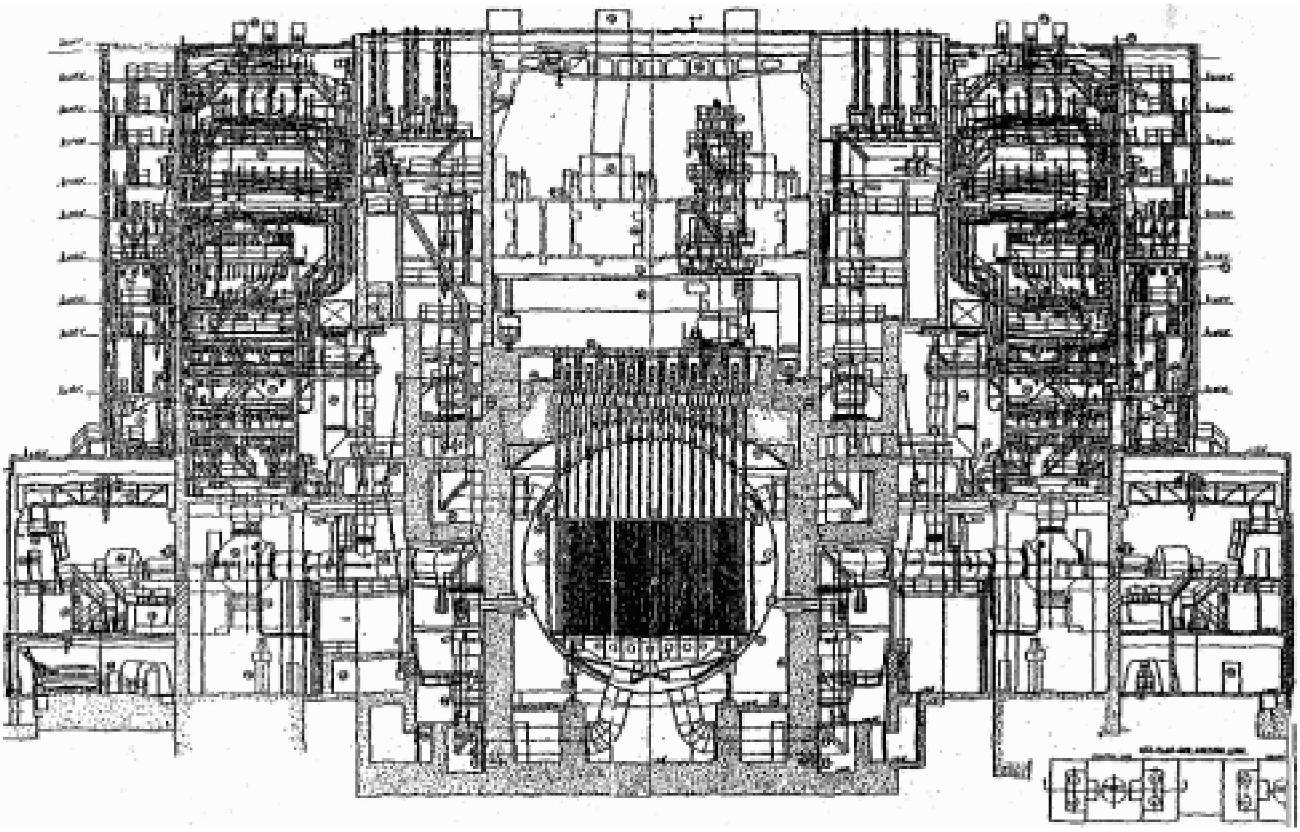


Figure 1 Longitudinal EW Section Through Reactor Building

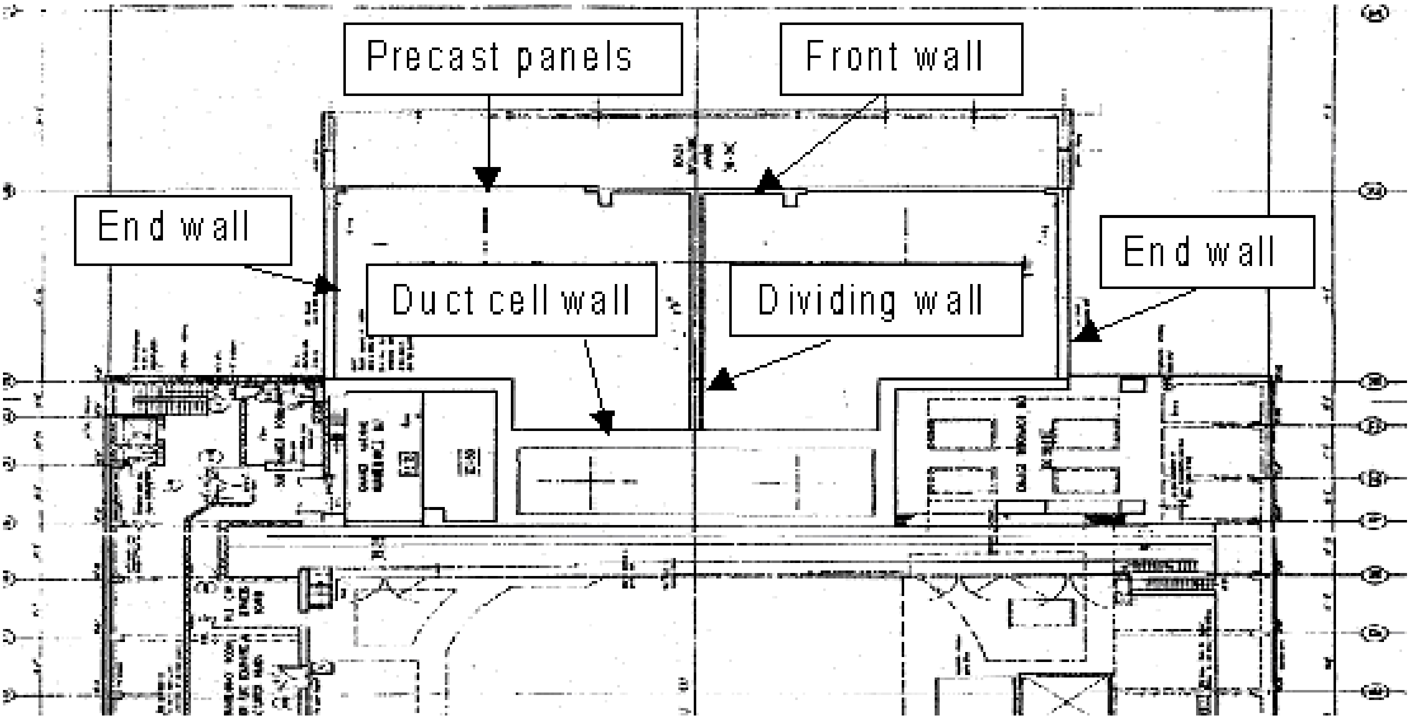


Figure 2 Plan view showing the west boiler box and duct cells

level, the SDH connects the upper duct cell structure and the boiler house front wall through friction. The end walls are also connected to the duct cell wall by ties at 5ft centres but these are less substantial fixings.

The two boiler houses are reinforced concrete box-like structures with large rectangular slots cut out at the front for boiler access. The two cutouts are covered by a series of precast panels bolted to the concrete structure. The boilers are enclosed on three sides by concrete walls, with the fourth side formed by the bioshield and secondary shield in the reactor building. The boiler boxes extend to the 141ft level where the front wall of the boiler house forms one end of the support for the SDH.

The SDH is a precast reinforced concrete box supported by the front wall of the boiler house and the duct cell wall. There is no external restraint other than friction between the SDH and the supporting structure.

Figure 1 shows a longitudinal section (E-W) through the Reactor Building. The plan on the boiler box and duct cell is shown in Figure 2.

4 Major Shortfalls

The assessment of the unmodified structure showed that the main areas of concern were:

The integrity of the connection of the pre-cast panels to the front of the boiler house and consequent dropped load hazard.

Excessive out-of-plane moments at the base of the boiler house end walls due to cantilever mode bending. (Damage to the base of the walls could create stability problems, as the walls become free-standing once the boiler house roof beam connections are lost.)

Excessive out-of-plane moments about the vertical axis in the boiler house front wall resulting from forced displacement of the ends of the wall at the SDH support location against the relatively rigid central wall. (The loss of stiffness of the front wall could create a stability problem for the columns at either of the edges of the front wall, supporting the SDH.)

Large twisting and out-of plane bending moments about the vertical axis in the duct cell wall supporting the SDH. (The integrity of this wall is essential for the continued support of the SDH.)

5 Proposed Solutions

To overcome the potential deficiencies in the seismic ruggedness of the structure, physical modifications were necessary. The purposes of the proposed modifications were essentially:

1. To prevent the precast panels from falling.

2. To support the boiler house end wall towards the top by connecting it to the duct cell structure at one end and to the front wall through the precast panel at the other. This measure would prevent the cantilever bending of the end wall.

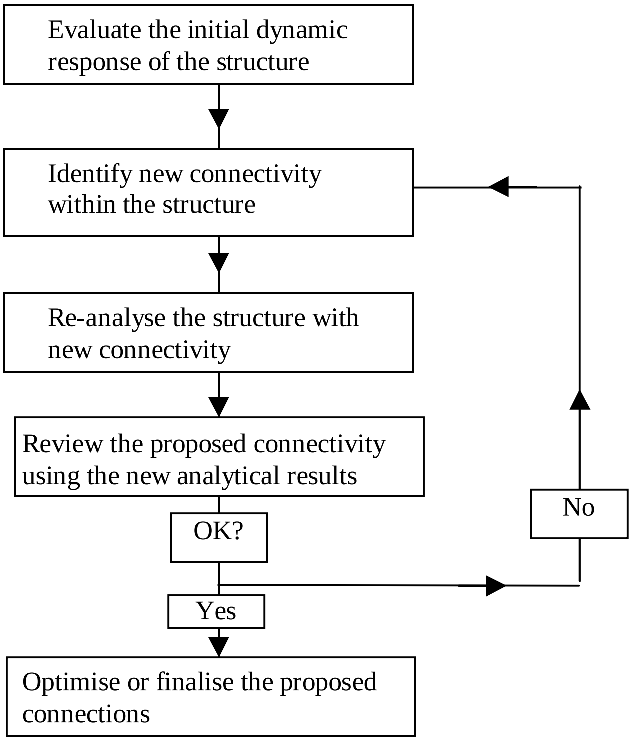
3. To connect the SDH to the central dividing wall, the front wall and the duct cell wall in a directional manner such that the supporting walls resist the imposed loads in their in-plane (strong) direction only (to be achieved by dowelling and installation of low friction bearings). This measure prevents out-of-plane bending of the front wall and the duct cell wall.

6 Structural Strengthening Approach

The presence of major discontinuities in the structures had significant effects on the dynamic response of the structure. The modification of the joints and connections during the design process of the structural strengthening therefore resulted in a change of the stiffness of the structure and hence its dynamic response. This therefore necessitated further analytical works to ensure that the correct strengthening process was implemented. The following flowchart shows how this process was implemented.

The major discontinuities in the structures, which have been modified during retrofitting the boiler cell are shown in Figure 3, and are given below:

A bolted connection of pre-cast panels to end walls
B bolted connection of pre-cast panels to front/central wall
C movement joint between end walls and duct cell wall
D movement joint between central wall and duct cell wall
E SDH bearings, front wall
F SDH bearings, duct cell wall
G gap between SDH floor and central wall



Flow Chart Showing the Interactive Process Between Analysis and Design

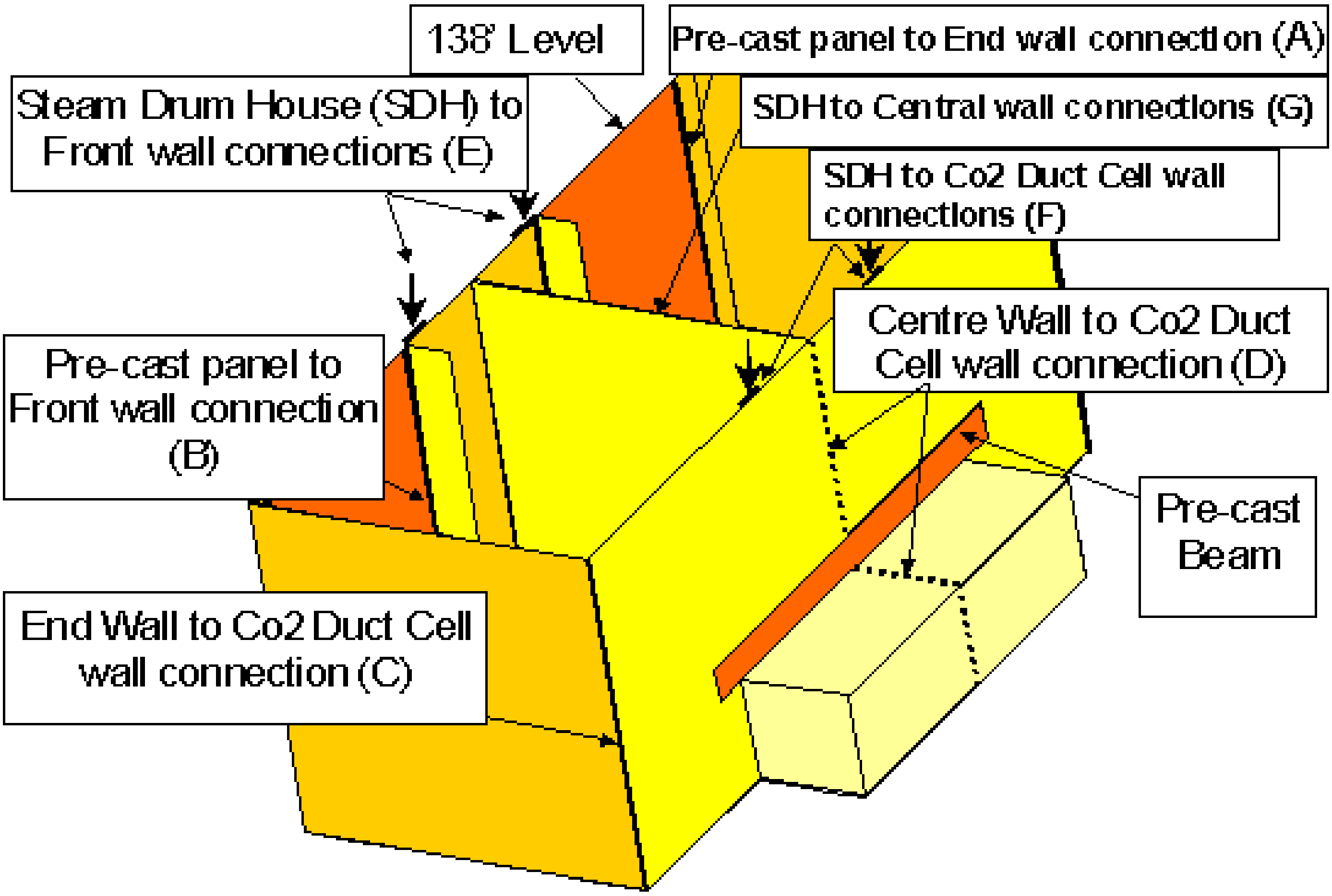


Figure 3 Isometric sketch of the boiler box

7 Evaluation Criteria For Alternative Options

Feasibility of the strengthening options was judged against the following criteria:

Safety - nuclear and personnel
Cost - development and implementation
Disruption - minimising disruption to station operations and ability to generate, capability to carry out modifications on load
Requirement to relocate services and plant
Timescale for implementation
External visual impact

8 Analysis

8.1 Finite Element Model

The boiler houses are symmetrical about the centre of the reactor, however there are some differences between the east and west duct cell at certain levels. To minimise the size of the finite element analysis, and also to retain the advantage of the global result, more suited to the concrete assessment, only the west side was modelled in detail with shell elements.

The primary shield, the secondary shield, the east boiler house and duct cell, and the east SDH were idealised into a system of beams and masses (stick model). The west boiler house, duct cell, the foundation block and the SDH were represented in greater detail using 3D shell elements. The stick elements capture the global behaviour of the structure. The beam properties are calculated such that the bending, shear and torsional stiffness are appropriately represented. The stick was modelled at its centroid with the shear centre specified as a property of the stick. The floor mass was attached to the appropriate node at its centre of gravity. The mass of the walls and columns was applied via the stick density such that correct mass, centre of gravity and mass moment of inertia were modelled. The shell elements were capable of modelling the local detail that could not be adequately captured by the stick elements, such as the duct cell and end walls and the attachment of the precast panels to the front boiler house wall.

The finite element model is shown in Figure 4. Some of the relevant and more unusual aspects of the modelling are described in more detail below.

8.1.1 Precast Panels

The precast concrete panels, which were installed to cover the boiler access openings in the front boiler house walls between 93ft and 153ft, do not form part of the shear resisting system. Each panel is bolted at one end to the end wall and at the other to the front wall. These bolts are within clearance holes allowing in-plane movement. As part of the modification, brackets have been provided to restrain the precast panels.

Beam elements with appropriate

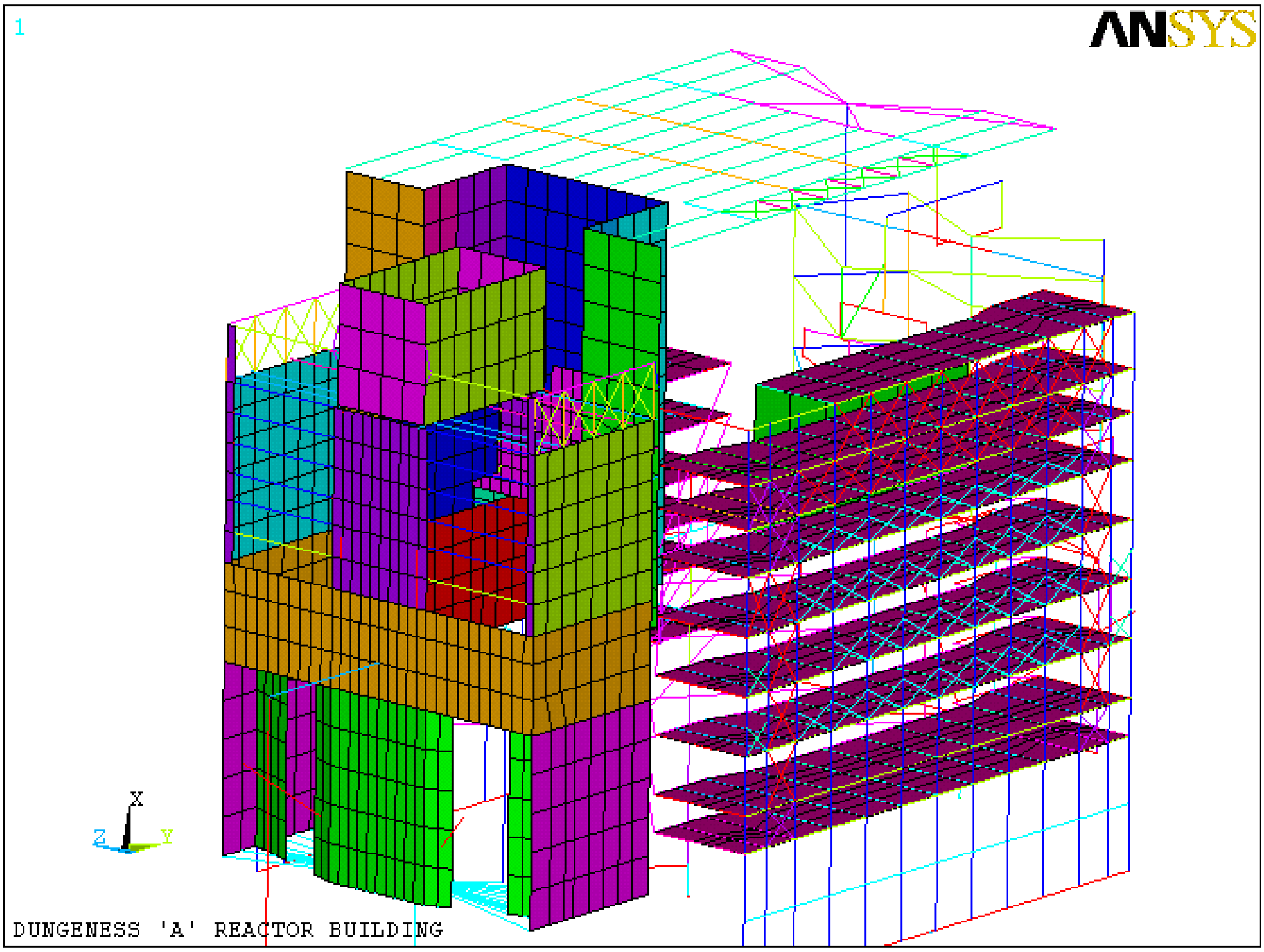


Figure 4 The Finite Element Model of the Reactor Building

boundary conditions were used to represent these precast panels. The brackets were incorporated as axial springs with appropriate stiffness. In other degrees of freedom, the brackets are assumed rigid.

The panels rest on top of one another and are located in position by stepped sections along the adjacent edges. Once placed in position on mortar beds they were bolted at their ends. The effect of this is to transfer their self-weight down to the 93ft level without imposing any reaction in the connecting bolts. For the static analysis therefore, the mass of the panels is directly imposed at the front wall of the boiler house at 93ft level. For the dynamic analysis however, the concrete panels mass was specified at the location of the panel so that the vertical and out-of-plane dynamic inertial forces were resisted by the appropriate bracket.

8.1.2 Boiler House End Wall to Duct Cell Wall Connection

All dowel connections were represented by a linear north/south spring connection together with a torsional spring where multiple dowels were being represented. The latter accounts for the moment of resistance about the east/west axis in the local dowel 'bolt group'. At 39.9m OD on the north wall, the arrangement consisted of a linear spring and torsional spring to represent a set of three dowels. Also a single linear spring at 42.3m OD represented a single dowel. For the south wall, there are four dowels at 39.9m OD, which were represented by a linear and a torsional spring.

8.1.3 SDH Interface

The SDH is a precast unit lifted on top of the boiler house and is positioned in place using two jacking points. One end of the SDH is supported by the outer wall (front wall) of the boiler house over the two columns and the other end is supported by the duct cell wall. These modifications essentially connect the SDH to the walls of the duct cell and the boiler box in a directional manner such that the load imposed by the SDH is transferred to the supporting walls in their in-plane direction.

8.1.4 Assessment of Results

The structural assessment was performed by means of dynamic transient analyses using the direct time marched integration technique within the ANSYS finite element program.

For structural integrity assessment of the concrete structures, maximum tensile, compressive and shear stresses were extracted for each element at each load step. These stresses were then divided by the limiting tensile compressive and shear stresses to obtain the utilisation ratios (demand/capacity). The maximum values of the utilisation ratios were then extracted for each element.

A value of less than one implies a satisfactory state. A utilisation ratio of greater than one immediately shows the extent of overstress in any particular area.

The shell representation of the west side of the reactor building was undertaken to model more detailed and localised behaviour of the structure. Where the modelling was represented in more detail on the west side, similar changes were made to the stick model on the east side. The effect of using shell elements is that it can capture the panel modes, which are lost in the stick model.

8.2 Ductility

Ductility is one of the most important aspects which accounts for structural robustness against earthquake loads. In spite of the linear elastic capacity being exceeded, a large amount of energy can be dissipated by non-linear response of the structure. Although significant ductility was available within the structure, only a limited amount of it was used in the assessment of the modified structure for reasons of being conservative.

Ductility can be expressed as the ratio of ultimate strain to the strain at first yield. Under-reinforced sections, such as those present in the boiler house and duct cell structures, in the flexural mode, fail in a ductile manner as the steel reaches yield long before crushing of the concrete can occur. Large strains in the reinforcement combined with a small neutral axis depth provides large plastic hinge rotation capability for the section.

As the seismic loads are cyclic in nature some recognition of the deterioration from reversing load is required, although it should be noted that there will only be limited number of cycles for very short duration UK earthquakes. In order to achieve this, a restriction of two thirds of the maximum ductility appropriate for monotonic loads was adopted.

For low frequency response, governed by constant displacement, the ductility ratio (μ) can be used directly as the response reduction factor (K). For higher frequencies, the response is governed by the velocity (or kinetic energy). Using the reserve energy method, the elastic energy is equated to the elasto-plastic energy dissipation which gives a response reduction factor $K = \sqrt{(2\mu-1)}$.

If $\mu = 6.6$ (the maximum permitted after a 2/3rd factor for cyclic response), the response reduction factor is 3.5. This implies that the elastic response for a flexural mode i.e. moments, should not exceed 3.5 times the section capacity. Note however, the elastic deformations should be multiplied by (μ/K) to obtain the elasto-plastic deformations.

To fully benefit from ductility, a check was carried out (particularly where there was a large ductility requirement) to ensure that it could be mobilised at that location based upon the actual section details.

This check included factors such as the following:
1) That the governing failure mode is ductile. If compression failure was to occur then ductility arguments could not be made.
2) That the reinforcement can reach its yield strength without local bond failure occurring. This has been confirmed by checking the continuity of reinforcement in the tension areas and ensuring sufficient anchorage.

The results showed that the maximum ductility demand was significantly less than the conservatively calculated available ductility of 3.5. (In practice a maximum ductility of 1.5 was utilised)

9 Design

9.1 Design Approach

Examinations of the results of the

analyses, indicated that all structure with the exception of the front and end walls were capable of resisting the seismic loads. Further studies demonstrated that these walls were capable of mobilizing large amounts ductility, see §8.2. However, where strengthening was undertaken, the ductility factor was conservatively kept to unity. In the design of the restraints, it was also been assumed that all connections behaved elastically with a general additional margin of 20% to 50% where applicable and practicable.

The style of the restraints was dictated by limiting the size and the weight to 0.5te, so that the components could be manually handled in the congested plant and equipment areas, and site welding could be avoided wherever possible.

9.2 Modifications

9.2.1 Fixing of Precast Panels

The functional requirement of the precast panel restraints was to resist the horizontal seismic forces in the N-S, E-W directions and the in-plane moment. The restraints comprise two main beam type components connected by a pinned joint and anchored to the pre-cast unit and the in-situ concrete. Figure 5 shows the general concept of connections.

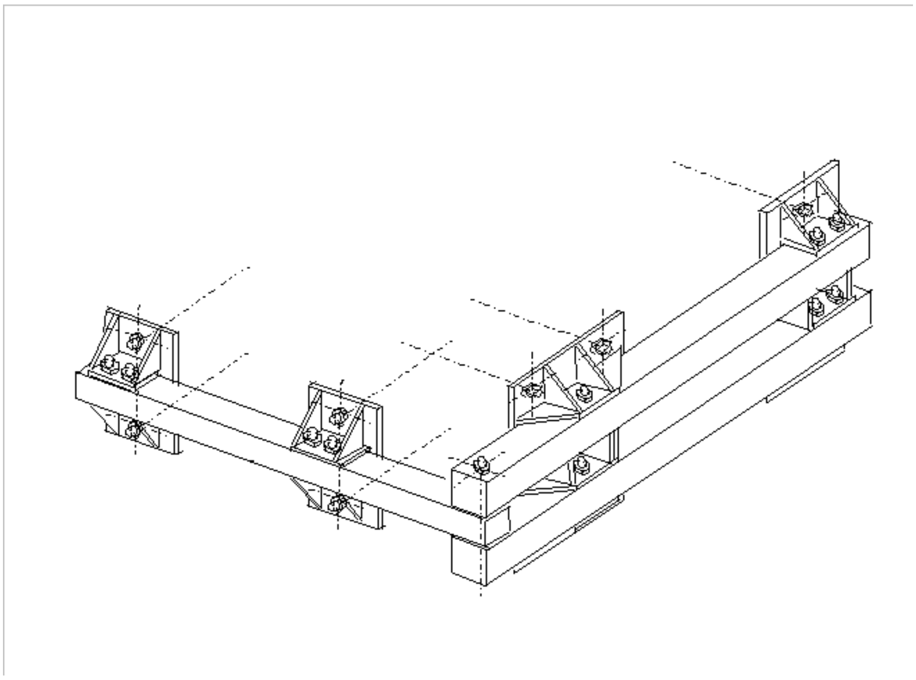


Figure 5 Precast Panel Restraints (Typical)

9.2.2 Connection of Boiler House End Walls to The Duct Cell

The boiler house end walls were attached to the duct cell wall towards the top five metres below the parapet at 141ft level using dowels such that only north/south connectivity is achieved. The boiler house and the duct cell remain isolated in the vertical and east/west directions. The fixing has been achieved using 75mm diameter macalloy steel bars.

9.2.3 Fixing of the SDH

The fixing of the SDH to the Boiler House achieved the following :

1. Directionally restrained the SDH floor to the boiler house central division wall in the east/west direction only (in plane of the division wall). Sixteen 75mm diameter dowels were used through slotted holes (N-S direction) in the floor slab and into the top of the central dividing wall below.

2. Directionally restrained the outer supports of the SDH to the boiler house front wall in the north/south direction only (in-plane direction of the front wall) and reduced the friction at the bearing points (by the installation of low friction bearings) to prevent out-of-plane loading.

3. Restrained the SDH to the duct cell wall in the north/south direction only by using the extended duct cell wall adjacent to the SDH and reducing the friction at the bearing points (by the installation of low friction bearings). The principle of connectivity of the SDH to the boiler box is illustrated in Figure 6.

In addition to the modifications described above other works as described below were also carried out:

a) The modifications resulted in increased predicted in-plane stresses in the front wall. To compensate, steel strengthening works were therefore installed on the lower half of the front wall, from the 93 ft level upwards, to substantially enhance the in-plane shear capacity of this wall as shown in Figure 7.

b) Equal strengthening on both sides of the end walls with the use of Carbon Fibre Reinforced Polymer (CFRP) strips bonded to the wall with epoxy adhesive to provide extra bending resistance in both directions. The CFRP was designed to limit the ductility ratio in the wall to unity. The design has assumed the use of CFRP “Embrace” sheets, which were applied in 300mm wide strips in multiple layers 0.117mm thick up to the required thickness.

10 Concluding Remarks

The Dungeness ‘A’ Reactor Building was assessed for its resistance to the 10^{-4} URS seismic motion with the modifications in place. Generally it was concluded that the main purpose of the structural modifications was fulfilled. The modifications prevent the precast panels from falling and also give added support to the boiler house end walls. The modifications also protected the duct cell wall and positively anchored the SDH to the boiler house and the duct cells.

As is usual with such projects, various challenges were encountered, some usual some unusual. All these challenges were faced and overcome by application of technical skills and sometimes thinking ‘out of the box’. Innovative, yet conservative solutions were evolved. Numerous analyses

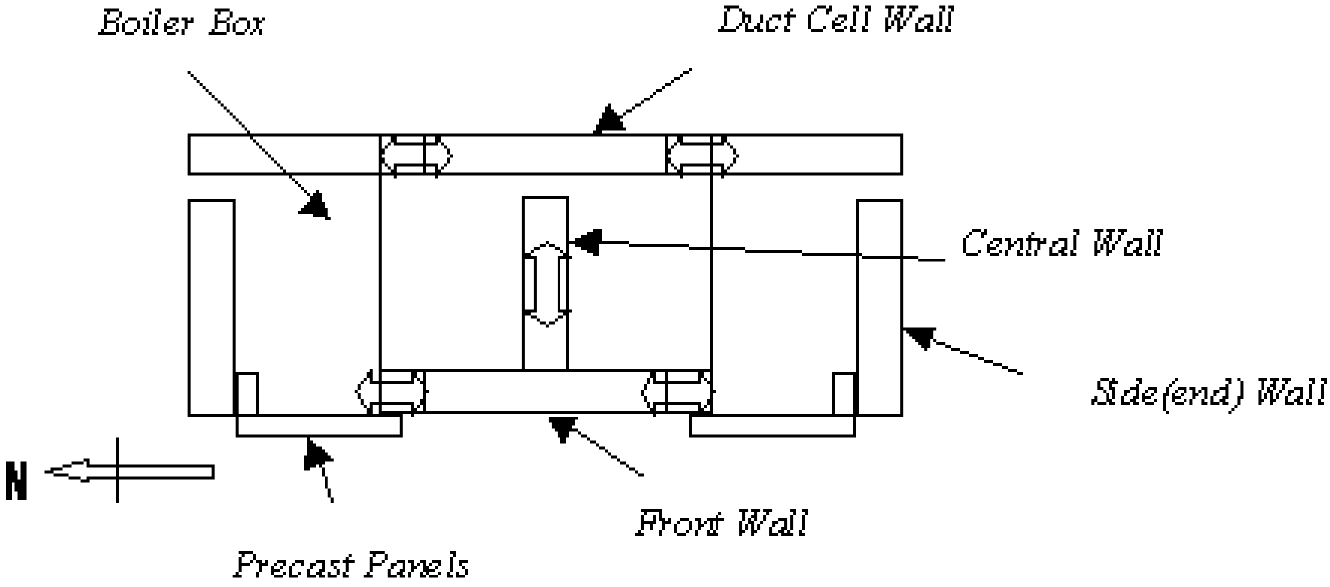


Figure 6 Plan on the East Boiler Box illustrating the SDH Fixing

exploring various options were undertaken so that optimum modifications could be implemented.

In depth understanding of the dynamic response, material behaviour and understanding of the likely failure modes are needed if effective solutions are to be developed.

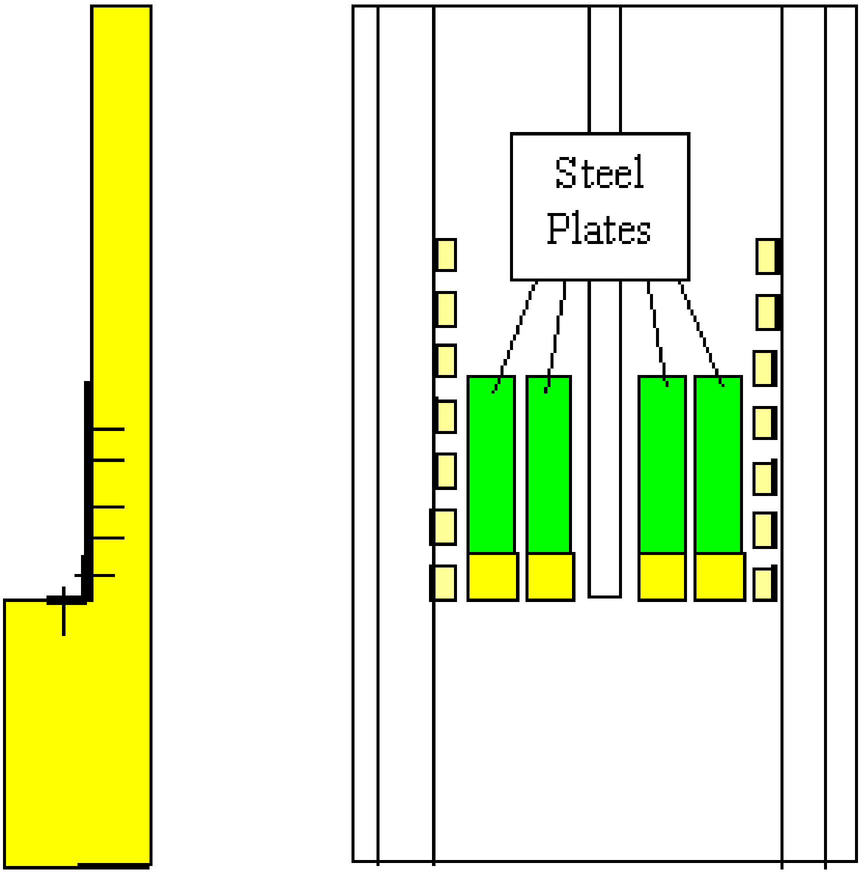


Figure 7 Front Wall strengthening

Earthquake Engineering on the Internet: Strong-Motion Data

By **Julian Bommer** and **Fleur Strasser**, Imperial College, London

The Internet has become an excellent resource for obtaining all manner of information regarding seismology and earthquake engineering, ranging from reports on the source parameters of earthquakes that occurred within the last few hours to collections of photographs of earthquake damage, from tutorials on the basics of earthquake mechanics and structural response to software for non-linear dynamic analysis. The problem facing the engineer or researcher seeking information from the Internet is that he or she will generally be spoilt for choice in terms of sites, and some may be far more useful and user-friendly than others. And as with all information on the web, there is very little quality control and therefore one has to sift the wheat from the chaff in downloading information.

In order to assist SECED members to navigate their way through the maze of Internet sites offering earthquake-related information, a series of articles is in preparation for the *SECED Newsletter*, each focusing on a specific topic. This first article deals with strong-motion records. Before introducing a few important strong-motion web sites, there are two useful sites through which users can access large numbers of earthquake-related web sites, including accelerogram databanks. Professor Stephen Malone of Washington University maintains a wonderful web site called “Seismosurfing the Web” (http://www.geophys.washington.edu/seismosurfing.html) that provides links, organized by geographical area, to a large number of seismological web sites. Another great site is that maintained by Dr Stelios Antoniou, “Seismolinks” (http://www.seismolinks.com/), which also provides links to a large number of sites, organized by subject area. This site is an ideal starting point for anyone seeking earthquake-related information, providing a brief synopsis of each site adjacent to the hyperlink. A portal site specifically dedicated to strong-motion data was set up by Dr David Wald of the US Geological Survey (Wald, 1997) but the site (http://pasadena.wr.usgs.gov/info/smdata.html) was last updated in April 1997 and hence it is somewhat out of date; similar information can be found in the “Guide to Obtaining Strong Motion Records” provided by the Multidisciplinary Center for Earthquake Engineering Research (http://mceer.buffalo.edu/links/agrams.asp).

Many agencies operating strong-motion recording networks maintain web sites and some of these allow users to access and download their accelerograms. Two outstanding examples are the web sites for Japanese K-Net and Kik-Net networks (http://www.k-net.bosai.go.jp/k-net/index_en.shtml and http://www.kik.bosai.go.jp/). These networks make digital accelerograms available online within a few hours of them being recorded, as well as providing remarkably detailed geotechnical information for all stations. Probably the most useful sites for general engineering applications are those that provide access to data from many countries or regions. There are three main web sites from which large collections of strong-motion data can be downloaded, each having merits and disadvantages in terms of data availability, search facilities and ease of downloading data (Bommer & Acevedo, 2004).

The databank of accelerograms from Europe and the Middle East, containing almost three times as many records as were previously distributed on CD-ROM, can now be searched via the Internet Site for European Strong-Motion Data (ISESD) launched in March 2002 (http://www.isesd.cv.ic.ac.uk) (Ambraseys *et al*., 2004). The site allows the user to search records in terms of different combinations of parameters such as magnitude, distance and site classification, and peak ground acceleration (PGA) can also be used as a search parameter.

The PEER databank (http://peer.berkeley.edu/smcat) includes 1,557 uniformly processed records from 143 earthquakes in tectonically active regions, for which the time-histories and response spectra for different damping ratios can be downloaded. Using the PEER database, searches can be performed in terms of magnitude, distance, site classification, rupture mechanism, the peaks of ground acceleration (PGA), velocity (PGV) and displacement (PGD), or alternatively in terms of the maximum spectral acceleration in a user-specified period range. The PEER Center is currently leading the NGA (Next Generation of Attenuation) project – details of which are at http://peer.berkeley.edu/lifelines/tclee2003/Chiou/pdf – for which a very large databank of strong-motion accelerograms with uniformly estimated magnitudes, focal mechanics, distances and site classifications has been compiled. Should this full databank be uploaded to the PEER web site, it will be a very valuable resource.

The COSMOS web site (http://db.cosmos-eq.org) contains a database of more than 18,000 freely available acceleration traces from about 400 events and 2,500 stations around the world (Squibb *et al*., 2004), 35% of which are from western US, 23% from Japan and about 14% from New Zealand, the original objective of the site being to make as many records as possible available to users (Stepp, 2000). A specific feature of the COSMOS web site is that it functions as a search facility rather than a data repository. The COSMOS Virtual Data Center does not hold any actual data (hence its name), but rather allows the user to fetch in one operation data from multiple agencies satisfying his or her search criteria. Simple searches can be performed in terms of ranges of magnitude, distance and PGA, as well as by region. Moment magnitudes are provided for almost half of the earthquakes in the database; distances can be searched as hypocentral or distance from the fault rupture, but the latter is provided for a much smaller proportion of the data. Advanced searches can be performed in terms of several other parameters, including mechanism, rake angle, site geology, peak ground velocity (PGV), and spectral ordinates at a few response periods, although these parameters are not provided for all records. Simple maps showing the locations of selected stations and events can also be generated. Another useful feature of COSMOS is an electronic alert service informing registered users of additions to the database. Once the search is complete, COSMOS allows the user to download the selected records by fetching them from the relevant servers. One advantage of this approach is that the data stays with its owner, allowing updates without the risk of conflicting versions. However, the process can become cumbersome when the user wishes to retrieve larger datasets; in particular, data from a single earthquake is often easier to download as a bundle from the underlying data provider (e.g. USGS's National Strong-Motion Program website: http://nsmp.wr.usgs.gov/).

The PEER database lists some earthquakes for which the digitized records are not actually available at the site, most of these corresponding to European events. The COSMOS site also includes very few accelerograms from Europe, which makes the ISESD a useful complement to the COSMOS and PEER sites.

Once a user has downloaded the records, an excellent and very user-friendly software for manipulating accelerograms, calculating strong-motion parameters and generating elastic and inelastic response spectra is SeismoSignal, which can be downloaded free of charge from http://www.seismosoft.com.

Finally, users interested in the structural response of buildings, bridges and dams can select records according to the type of structure from the PEER database or other database projects, such as that of the California Integrated Seismic Network (http://www.quake.ca.gov/cisn-edc/).

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Editor's Note

SECED Members are invited to submit similar articles on other aspects of seismic web surfing, whether they deal with photograph collections, software, earthquake damage reports, seismological data, basic tutorials or any other topic of interest to readers of the *SECED Newsletter*.

5th Japan-Europe Seismic Risk Workshop

Proceedings Now Available

The proceedings of the 5th Japan-Europe Seismic Risk Workshop (5th JESRW) hosted by the University of Bristol, 5th-7th July 2004, are now available both online and on cd.

Following on from a series of biennial Japan-UK Seismic Risk Fora held alternately at Imperial College and Tokyo Institute of Technology, the 5th JESRW promoted an exchange of current research ideas and developments between Japanese and European earthquake engineering researchers. With some fifty participants, the scope of the workshop was unconventionally broad. Sessions included: Soil structure interaction and geomechanics; Response, damage and awareness; Facilities and testing techniques; Ground motion; Steel; Dams and bridges; and Concrete.

The proceedings of the workshop can now be obtained both online (at http://fifth-jesrw.eerc.bris.ac.uk/) and on cd (while stocks last, by writing to David Muir Wood, Faculty of Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR).

Bob Park

As this edition of the Newsletter went to press, we learned of the sudden death of Professor Bob Park of the University of Canterbury, New Zealand. Bob was one of the most influential researchers in the field of seismic design of concrete structures. He started his academic career at Bristol University in the early 1960's before returning to New Zealand to lead the development of the internationally renowned earthquake engineering research group at Christchurch.

SECED extends its deepest sympathy to Bob's family, friends and colleagues.

A full appreciation of Bob's contribution to earthquake engineering is planned for the next edition of this Newsletter.

NOTABLE EARTHQUAKES FEBRUARY - SEPTEMBER 2004

Reported by British Geological Survey

YEAR	DAY	MON	TIME UTC	LAT	LON	DEP KM	ML	MW	MB	LOCATION
2004	**5**	**FEB**	**21:05**	**3.62S**	**135.54E**	**17**			**7.1**	**PAPUA, INDONESIA**
At least 37 people were killed and 682 people were injured.										
2004	**7**	**FEB**	**02:42**	**4.00S**	**135.23E**	**10**			**7.5**	**PAPUA, INDONESIA**
Additional damage occurred in the Nabire area.										
2004	**14**	**FEB**	**10:30**	**34.77N**	**73.22E**	**11**			**5.2**	**PAKISTAN**
At least 24 people were killed and approximately 40 people were injured in the Balakot-Batgram-Mansehra area.										
2004	**24**	**FEB**	**02:27**	**35.14N**	**3.99W**				**6.4**	**STRAIT OF GIBRALTAR**
At least 628 people were killed, 926 people were injured and 2,539 homes were destroyed and approximately 15,000 people were left homeless.										
2004	**29**	**FEB**	**03:08**	**53.57N**	**1.99W**	**12**	**3.1**			**OLDHAM, GTR MAN**
Felt throughout the Oldham, Greater Manchester area with maximum intensities of 4 EMS.										
2004	**11**	**APR**	**20:22**	**65.10N**	**6.98E**	**32**	**3.9**			**NORWEGIAN SEA**
2004	**13**	**MAY**	**06:58**	**62.04N**	**1.92E**	**15**	**3.5**			**N NORTH SEA**
2004	**28**	**MAY**	**12:38**	**36.25N**	**51.62E**	**17**		**6.2**		**NORTHERN IRAN**
At least 35 people were killed, 400 people were injured and many buildings were damaged in the Mazandaran and Qazvin provinces.										
2004	**1**	**JUL**	**22:30**	**39.77N**	**43.98E**	**5**		**5.4**		**EASTERN TURKEY**
At least 18 people were killed and 21 people were injured.										
2004	**15**	**JUL**	**04:27**	**17.66S**	**178.76W**	**566**		**6.4**		**FIJI REGION**
2004	**25**	**JUL**	**14:35**	**2.43S**	**103.98E**	**582**		**6.8**		**SOUTHERN SUMATRA**
2004	**7**	**AUG**	**05:54**	**55.11N**	**3.62W**	**8**	**2.3**			**DUMFRIES, D & G**
Felt throughout the Dumfries area with maximum intensities of 3 EMS										
2004	**10**	**AUG**	**10:26**	**27.27N**	**103.87E**				**5.1**	**CHINA**
At least 4 people were killed, 600 people were injured and approximately 120,000 people were left homeless.										
2004	**5**	**SEP**	**10:07**	**33.07N**	**136.64E**	**14**			**7**	**WESTERN HONSHU**
At least 4 people were injured in the Kyoto area.										
2004	**5**	**SEP**	**14:57**	**33.19N**	**137.07E**	**10**			**7.1**	**HONSHU, JAPAN**
Approximately 40 people were injured in the Kyoto area.										
2004	**6**	**SEP**	**23:29**	**33.21N**	**137.23E**	**10**			**6.3**	**HONSHU, JAPAN**
2004	**7**	**SEP**	**12:15**	**34.68N**	**103.85E**	**19**		**5.1**		**GANSU, CHINA**
At least 19 people were injured, approximately 600 houses were destroyed and 3,800 houses were damaged in the Gansu Province.										
2004	**16**	**SEP**	**08:17**	**57.44N**	**5.97W**	**5**	**3.3**			**ISLAND OF RAASAY**

Issued by: Bennett Simpson, British Geological Survey, October 2004
Non-British Earthquake Data supplied by: The United States Geological Survey

Forthcoming Events

24 November 2004
Selection of Appropriate Time Histories
ICE 6.00pm

26 January 2005
Recent Advances in Seismic Model Testing
Bristol University
2.00pm Tour of earthquake/dynamics laboratory
4.00pm Presentations

23 February 2005
Structural Health Monitoring
ICE 6.00pm

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:

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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.

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SECED Website

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