SEISMIC RISK MANAGEMENT OF AN INTERNATIONAL PORTFOLIO OF BUILDINGS

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ABSTRACT

The British Council operates in 110 countries worldwide and needs to manage the earthquake risk in the buildings it works in. Accordingly, it commissioned a desk study intended to create a shortlist of buildings that required detailed on-site seismic inspections. 85 buildings in 60 countries were chosen for the desk study, in areas where the seismic hazard exceeded a rock PGA of 10%g for a 475 year return period. Information on the structure of the buildings was obtained by means of a specially prepared questionnaire, designed to be completed by the (non-specialist) local managers of the buildings. The seismic hazard at the sites was re-evaluated, based on a variety of readily available sources, to account for local soil and seismological influences on ground motions, and a 475 year return period intensity value was calculated at the site of each building. The structural and intensity data were then used to evaluate the risk of collapse and risk of death, based on databases of building damage and human casualties in earthquakes prepared by CAR Ltd. For buildings where these risks exceeded defined thresholds, an on-site assessment by a suitably qualified seismic engineer was recommended.

The study enabled British Council to understand better the risk that earthquakes posed to staff and other users of its buildings, and to compare it to other risks such as fire. It also proved to be a cost effective way of identifying potentially high seismic risk buildings which needed an on-site inspection to determine possible seismic retrofitting measures.

KEYWORDS: Seismic risk, seismic hazard, building vulnerability, casualty rate, property management

1. INTRODUCTION

The British Council (BC) operates in 110 countries worldwide to create mutually beneficial relationships between people in the UK and other countries (British Council, 2006). It therefore needs to manage the risk in the buildings it works in. As part of this risk management process, it has commissioned a number of studies of the risk posed by various hazards, including fire and earthquake. The study described here concerns the seismic risk and was intended to identify those buildings occupied by BC which might pose a higher than acceptable level of risk, in terms of both structural damage and personal injury, without the need for carrying out costly on-site inspections of all its properties. The buildings concerned comprised both BC's offices and also the residences of its staff. The study was intended primarily as a screening process to create a shortlist of buildings that required on-site inspections. It was performed purely by means of desk studies based on readily accessible published sources, supplemented by information elicited from the local managers of BC's properties, who of course were not themselves structural engineers, let alone seismic specialists. This was done by means of a specially designed questionnaire. The process enabled the initial list of 85 buildings in 60 seismically active countries to be reduced to seven buildings in seven countries; for these seven buildings, an on-site inspection by specialist engineers was recommended.

As a screening study, relatively simplistic methods were judged to be appropriate. The seismic hazard at the site was characterised principally by the 475 year Modified Mercalli Intensity (MMI). Rather than carrying out a full probabilistic hazard assessment for each site (unfeasible with the time and budget available), this was evaluated approximately from published sources and relationships between ground motions and MMI. However, it was recognised that local conditions, particularly soil conditions, would significantly affect the hazard and so some effort was made to get the best readily available information on these conditions.

The structural data from the questionnaires completed by the local BC managers were used to classify each building into a standard type, using the classification system developed for the GEVES seismic risk evaluation system (Spence *et al,* 2008). GEVES provides a seismic vulnerability curve for each standard building type, describing the expected damage for a given MMI value, and also its probability distribution. Thus, knowing the site MMI and building type enabled the collapse risk to be evaluated for each building, and hence enabled the properties to be ranked in order of seismic risk. The detailed methodology is described in subsequent sections.

The study was carried out by Cambridge Architectural Research Ltd (CAR), working in collaboration with Edmund Booth Consulting Engineer. Regular meetings were held with BC staff to report and monitor progress and to develop the methodology for the study.

2. EVALUATION OF LOCAL SEISMIC HAZARD

2.1 Initial selection of properties for the study

85 buildings in 60 countries were selected for the study, on the basis that they were the BC buildings areas where the seismic hazard exceeded a rock PGA of 10%g for a 475 year return period. This selection (made by BC staff) was made purely by reference to the seismic hazard map prepared by the Global Seismic Hazard Assessment Program, GSHAP (see seismo.ethz.ch/GSHAP).

2.2 Establishing the 475 year return MMI at the site

The initial allocation of 475 year return PGA on rock was refined by replacing some of the GSHAP results by those from other sources. In particular, for European sites the SESAME map (Jiminez, M-J, Giardini, D and Grunthal G, 2003) was used. The next stage was to estimate the PGA on soil at the site, and the associated 475 year response spectrum, allowing for the soil types at the site. This was done by establishing the soil type from a number of sources: readily available published sources, data supplied in the questionnaire (see section 3.2), information obtained by correspondence with local engineers and finally careful examination of Google Earth pictures of the sites (http://earth.google.com/) in their freely downloadable versions. In general, the soil PGA and site spectra were obtained from assigning the soil to one of the standard types defined by Eurocode 8 (EC8) and using the 'basic' ground motion spectra recommended in clause 3.2.2 of EC8 for Type I spectra. In a few cases (including Bucharest, Mexico City and Caracas), standard EC8 spectra were judged inappropriate and more appropriate shapes were sought from the literature.

The objective of this stage of the study was to estimate the 475 year MMI at each site from the 475 year spectra, by means of formulae proposed by Wald *et al* (1999). These formulae relate MMI to PGA and PGV (peak ground velocity) based on southern Californian data. Since the seismic vulnerabilities assumed for the BC properties allowed for regional differences in construction practice, as discussed in Section 3, the use in this study of Wald *et al*'s Californian data for buildings worldwide is considered valid. PGA could be easily obtained from the 475 year response spectra as the zero period value, but obtaining PGV was less straightforward. For this study, equation 3.11 from Booth (2007) was used. This allows for the influence on PGV (and hence damage) of spectral shape, i.e. the frequency content of the ground motion. The MMI value was then used to estimate the probability of building collapse, as described in the next sections.

3. EVALUATION OF BUILDING VULNERABILITY

3.1 The GEVES system

GEVES (Global Earthquake Vulnerability Estimation System) was prepared by CAR Ltd (Spence *et al*, 2008) primarily for use by the insurance industry in estimating losses to a portfolio of buildings for a given earthquake scenario. It includes a set of vulnerability relationships for 28 different types of buildings, and for each type describes the expected loss ratio (expected damage divided replacement cost) for a given level of ground motion, quantified in terms of MMI. Information is also provided on the statistical distribution of results, so that the probability of exceeding a given loss ratio can be estimated for a given value of MMI. The vulnerability relationships differ depending on what region of the world is being considered; they are based on an extensive database, collected over 25 years, of worldwide building damage observed in real earthquakes. It was these vulnerability relationships which were used in the present study.

3.2 The questionnaire

In order to assign a particular GEVES vulnerability curve to a structure, its structural type (according to the standard GEVES classification described above) must be known. This was done by means of a questionnaire sent to the local managers of all the BC properties involved (see Appendix). It had to be comprehensible to non–technical staff and to involve information that would not require too much effort to collect. The questionnaire asked for location and use of the property, a description that would reveal something about its structural characteristics and (perhaps most usefully) photos. Some judgement and interpretation of the returns were required; for example, the photos suggested that in some cases, buildings described as having 'shear walls' in fact were probably concrete frames with masonry infill. Nevertheless, excellent and usable information was supplied in almost every case, with sufficient clarity for the purposes of the study. This information was then used to assign a standard GEVES structural type to each building and hence a building vulnerability curve.

4. EVALUATION OF SEISMIC RISK

4.1 Evaluating probability of collapse given the 475 year event, and the annual probability of collapse

Given the appropriate building type and 475 year MMI, the probability of total collapse (taken as a loss ratio exceeding 90%) followed readily from the GEVES vulnerability curve.

To determine the total annual risk of collapse, the contribution to the risk is needed from not only the 475 year earthquake, but also those of other return periods and thus different intensities. This involves constructing, for each location, a hazard curve giving the annual probability of exceedence for each intensity level. Information for constructing such hazard curves for each location is far from complete. However, investigation of the hazard for a number of the cities suggests that the relationship between Intensity I and log(p_e) (where p_e is the annual exceedence probability of that intensity) is reasonably linear, especially in the important range of intensities VI to XI. Thus equation 4.1 should adequately define the annual exceedence probability for any intensity in this range.

$$\log (p_e/0.002) = k^*(I - I_{475}) \tag{4.1}$$

where p_e is the annual exceedence probability for an MMI value of I and I_{475} is the intensity for a 475 year return period. The constant k defining the slope of the line has a value lying between 0.5 and 1.0 for all the locations investigated. Where the hazard data was not adequate to determine a value of k, a value of 0.8 was assumed (as proposed in Eurocode 8); the results turned out not to be very sensitive to the value of k.

Equation 4.1 was used to calculate the annual probability of earthquakes in each intensity interval VI to XI (i.e. VI to VII, VII to VIII and so on), and hence the probability of collapse due to earthquakes in each intensity step. The total annual probability of collapse was estimated as the sum of the contributions from each intensity interval.

4.2 Evaluating annual probability of death

To calculate the expected annual death rate for any regular user of the building, the estimated occupancy time of the building was calculated, using data supplied by the questionnaires, and the expected lethality rate for the building class was estimated using data for worldwide earthquakes assembled by CAR Ltd. The lethality rate is the average proportion of occupants who will be killed, assuming that the building collapses or is seriously damaged. It was assumed that a regular occupant of an office building spends 25% of his/her time in the building, whereas for a regular occupant of a residential building 75% of the time is spent in the building. This leads to higher expected annual death rates for residential than office buildings; however this should not necessarily mean that these buildings should be given priority, as the number of users should also be taken into account.

4.3 Establishing threshold values of risk

The previous sections outlined the methods of obtaining the probability of collapse for each property, given the 475 year event, and also the annual probabilities, both of collapse and of death. The use made of these data was as follows.

As a first step, the 85 properties investigated were ranked in order of the probability of collapse in the 475 year event. The question then arose as to what might be considered as an acceptable value for this risk. Eurocode 8 (EC8) recommends that 'ordinary' buildings should be designed to resist the 475 year earthquake motions, which have a 10% chance of exceedence in 50 years. However, given occurrence of this design earthquake, buildings designed to EC8 would have a very low probability of collapse, because of many inherent safety factors. EC8 does not state explicitly what that conditional probability of failure is, given the design earthquake, but a commonly accepted figure is 10^{-3}. Accordingly, the buildings where this risk was found to exceed thirty times this value (see Table 4.2) were studied further by calculating annual figures for risk of collapse, and also of death of occupants, calculated as described in sections 4.1 and 4.2.

The failure probabilities corresponding to the 475 year earthquake provide only partial information, because less frequent earthquakes will also contribute to the overall failure probability. In this respect, the Eurocode suite does gives explicit information on what overall reliability should be aimed for in new construction. The recommended maximum frequency of ultimate failure for any type of loading, including earthquake loading, is given by EN1900 (Eurocode Basis for Design) as $1.3x10^{-6}$ in one year, or 72 $x10^{-6}$ in 50 years. These probabilities relate to the failure of a single element, such as a column or beam, but life threatening collapse of the entire structure would not necessarily result if only one element failed. Moreover, the recommended failure probability corresponds to meeting the bare minimum requirements of the standard; in practice, structures on average exceed these minima for many reasons - minimum required dimensions are rounded up, concrete strength is set to achieve greater than the design strength to avoid the possibility of rejection and so on. Offsetting this, the target probabilities assume the absence of gross human errors of design or construction, such as major calculation errors or using the wrong diameter or strength of reinforcing steel. In practice, therefore, the probability of collapse under earthquake loading of buildings designed to the Eurocode standards may somewhat exceed a frequency of $1.3x10^{-6}$ per year, because gross human errors are found to play a significant part in actual failures. For new buildings, it was judged that a failure frequency of $10x10^{-6}$ per year would be greater than reasonable expectations.

However this value of failure probability is not necessarily appropriate for existing buildings in earthquake areas, because it would condemn as unsafe a very large part of the existing building stock. Part 3 of Eurocode 8, which deals with strengthening existing buildings, does not state a general compliance requirement, leaving this to individual regions to determine. Where requirements for strengthening existing buildings have been formulated (as in New Zealand and California), requirements generally allow a significantly lower resistance than is required for new buildings, but there is at present no generally accepted international norm. For this study, an annual probability of failure 25 times greater than the figure for new buildings – i.e. 250 $x10^{-6}$ - was taken as the threshold above which further investigation was recommended (see Table 4.2).

The acceptable level of risk of death to occupants of buildings has been discussed by the UK Health and Safety Executive, (HSE, 2001) who state: "HSE believes that an individual risk of death of one in a million per annum for both workers and the general public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and the tolerable region". IN fact, the average annual risk of death in the UK to all workers in service industries is 3 per million, rising to 13 per million in manufacturing industries (HSE, 2001). To supplement these figures, some other often-quoted indicators of tolerable risk were considered, for example those given in Table 4.1.

Table 4.1: Indicators of tolerable risk (Melchers, 1999)

Annual risk of death per person	Characteristic response
1000×10^{-6}	Uncommon accidents: immediate action taken to reduce the hazard
100×10^{-6}	People spend money, especially public money to control the hazard
10×10^{-6}	Mothers warn their children of the hazard (eg fire, drowning, poisons)
1×10^{-6}	Not of great concern to the average person

Based on these data, a threshold figure of annual probability of death greater than 10×10^{-6} was chosen for this study. The various thresholds chosen for the study, and the numbers of buildings falling into each category, are summarised in table 4.2.

Table 4.2: Stages of the study, threshold criteria and numbers of buildings involved

Stage of the study	Threshold criterion	Number of buildings
Initial selection of buildings	475 year return PGA on rock exceeds 10%g, from GSHAP map	85
Selection of buildings needing further detailed desk studies	Probability of total collapse of building exceeds 30×10^{-3} given the 475 year event	22
Full on-site inspection by qualified seismic engineers recommended	a) Annual probability of total collapse exceeds 250×10^{-6} and/or b) Annual probability of death of an occupant exceeds 10×10^{-6}	7

5. OUTCOMES OF THE STUDY

The British Council (BC) risk management approach is centred on its duty of care to its staff and visitors. Its risk management systems are subject to constant review and include areas such as security and fire risk. As part of this continual review to update the risk management system, it includes the requirement to review the seismic risk of the properties BC use or are intending to use which are located in recognised seismic regions.

As the organisation's property portfolio is extensive, the methodology for the study provided the geographical coverage which enabled all buildings currently occupied by the organisation as requiring a review, to be investigated. The process was able to reduce the number of buildings requiring further detailed investigation down to a manageable quantity and thus prioritise resources. This supports the fundamental precepts of risk management by addressing the high risk issues as a matter of priority, allowing a planned approach to addressing the seismic risk. .

An additional part of the study was to define a procedure for evaluating the actions needed to address seismic risk when considering the acquisition by BC of a new property. Although not described further in this paper, this contributed to shaping the property acquisitions strategy through equipping the organisation with a methodology which empowers decision making when acquiring new properties in seismic regions, therefore reducing the risk to staff and visitors while also contributing to the Business Continuity plan. As this particular risk management approach evolves, the organisations seismic risk exposure will be continuously reduced as the property portfolio is renewed with properties of a greater seismic integrity.

6. CONCLUSIONS

The study enabled a cost effective and rapid identification of British Council (BC) properties in which the risk to its occupants is relatively low, and of those in which the risk needed further detailed study by means of an on-site inspection by a specialist engineer. It also produced a system for addressing seismic risk in newly acquired buildings, helping to ensure that BC's seismic risk exposure will be continuously reduced as the property portfolio is renewed with properties of a greater seismic integrity.

The GEVES system (Spence *et al* 2008) proved an effective tool for evaluating seismic risk in buildings for a wide range of locations and building types.

A questionnaire was developed for the study to obtain the structural information on the buildings needed to develop seismic vulnerability curves. The questionnaire proved capable of eliciting the information, despite the limitations of it being filled in by non-technical staff. However, in some cases, judgements were needed to modify or supplement the data provided.

Google Earth photographs at the maximum resolution available freely on line, proved an invaluable tool for helping to evaluate the local site conditions (soil type, topography etc) affecting seismic hazard.

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APPENDIX: Questionnaire for building evaluation.

The questionnaire is set up as a Microsoft Word 'form', and the questions are to be given by completing the text fields, or choosing a response from the drop-down fields or checking the appropriate boxes, as appropriate. Most fields have help text, accessed by pressing the F1 key. The tab key takes you to the next field, and shift+tab to the previous field.

Part 1 – LOCATION

1.1 Please provide your name, job title and the full international address of the building.

1.2 We need to be able to locate the building accurately. Please provide longitude and latitude in degrees, minutes, seconds, or degrees to three places of decimals. NB: If the building can be located from an aerial photo in Google Earth (downloadable from www.earth.google.com), the longitude and latitude of the pointer location will appear on the bottom of the screen.

Part 2: BUILDING USE

2.1 What use does the British Council make of the building?

2.2 Does the British Council occupy all the building?

2.3 If BC only has part occupation,

a) please specify which floors are occupied by BC. Please adopt the British notation that the ground floor refers to street level, and 1st and subsequent floors to higher floors.
b) describe the ground floor use, if not by BC
c) describe the use of 1st and higher floors, if not by BC

2.4 If the building is an office:
a) how many British Council employees regularly work in the building?
b) Working hours per week
c) in a typical working week, how many visitors does the building have?
d) Typical length of stay of each visitor

2.5 If the building is a residence, how many British Council employees and their dependents live there?

Part 3: BUILDING DESCRIPTION

3.1 How many storeys does the building have?

3.2 How many basement levels (below street level) does the building have?

3.3 If there are basements,
a) approximately how large is the basement area, compared to the ground floor?
b) what are the basements mainly used for?

3.4 We need to know approximately the plan size and shape of the building, and the storey heights. If you have architect's or engineer's plans and elevations, please attach them, indicating the areas that the British Council occupies. If they are not available, either attach a simple hand-drawn sketch showing the overall plan dimensions (to the nearest metre) and storey heights (to the nearest 0.1metre) or complete question 3.5.

3.5 If architect's drawings or sketches are not available, please specify the plan size and shape of the building and the storey heights in the following boxes. NB: for simple rectangular buildings, this information will be quite sufficient for us. You could measure the plan dimensions by pacing along the building perimeter (one long pace ≈ 1 metre). You could measure the storey height from the staircase (storey height = height of one step times number of steps between floors).

Plan shape of building
Overall dimension along entrance façade metres
Overall dimension at right angles to entrance façade metres
Total floor area occupied by British Council sq metres
Storey heights: ground floor, upper levels metres

3.6 If you are able to, please estimate the date when the building was first built, and let us know how confident you are with this estimate.
Estimated year of first construction and confidence with which this date is estimated

3.7 Structural changes to the building after construction can change its seismic resistance significantly.
Are you aware of any significant changes to the building since it was first constructed?
If there have been changes, please describe them. Attach any sketches or architects plans that are available.

3.8 The material from which the load bearing structure (columns, walls, beams) of the building is constructed can greatly affect the seismic resistance. However, often the main beams, columns and walls holding up the building are hidden by cladding such as decorative stone or plaster, and so it is difficult to determine the construction. Using your current knowledge, please indicate the form of construction from the list below, and give the associated level of confidence.

Building material
Confidence in determining structure type

3.9 Please also indicate the floor construction, if known

Floor construction type

3.10 The standard of maintenance of the building can also affect the seismic resistance, which can be greatly weakened by defects occurring during and after construction. If you are aware of any significant defects, please indicate them here.

Known or suspected defects
Please briefly describe any defects

3.10 Is the building on level ground, or is it on sloping ground? If sloping, please indicate roughly how steep the slope is.

Part 4: PHOTOS

Digital photos attached to this questionnaire are an essential aid to help us estimate the building's seismic resistance. Please attach one or more photos to cover each of the following and check the appropriate box in the table below. A figure in a doorway is a very useful indication of scale for outside shots of elevations, and a 3metre tape placed next to a close up of a defect or special feature (such as cracked concrete or corroded reinforcement) will also help give us a sense of scale.

Front elevation.		Typical internal shot of basement, if present	
Back elevation.		Typical shot of stairwell	
Left and right side elevations		Adjacent buildings and their relationship to BC building	
Typical internal shot inside BC offices		Close up of any defects	
		Close up of any special features (e.g. additions or renovations)	

Part 5: OTHER INFORMATION

If you have any other information easily available, which you think might be useful to us, please attach it. For example, a seismic zoning map of the city, issued by the authorities, or a geological map of your area, would assist us greatly.

Additional information attached Yes/No If yes, please briefly describe it.