Evening meeting

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Eurocode 8 and its implications for UK-based structural engineers

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Synopsis

The six parts of Eurocode 8 (*EN1998: Design of structures for earthquake resistance*) cover a very wide range of structures. Part 1 & 5 have recently received technical approval for launching the formal vote for acceptance as a full Euronorm and approval for the remaining four parts is expected to follow within 12 months. After an introduction to the code, the paper discusses its general implications for UK-based designers of earthquake resistant structures in Europe and elsewhere. The extent to which design of UK structures may be affected is also discussed in some detail. Possibilities for the future development of Eurocode 8 are outlined.

Introduction

EN1998: Design of Structures for Earthquake Resistance occupies a rather unusual position in the suite of 11 Eurocodes[*]. The first in the suite, *EN1990: Basis of Structural Design* sets out the general principles underpinning all the subsequent Eurocodes, while the second, *EN1991: Actions on Structures* specifies the definition of the loading that structures should be designed to withstand. Eight of the remaining nine Eurocodes then give information on how to provide structures with sufficient strength and robustness to withstand those loads; steel, concrete, composite, timber, masonry and aluminium structures each have their own Eurocode, as does the subject of geotechnical design, essentially covering the resistance properties of foundation materials. EN1998 is the odd one out, since it not only covers material strength and detailing issues, but it also covers the determination of design actions for the special case of seismic loading. Moreover, uniquely, one of its parts covers the assessment and retrofit of existing buildings.

More tidily, perhaps, seismic loading would have been included with gravity, snow, wind and fire loads in EN1991, and the special detailing rules for seismic cases would have been distributed to the appropriate material Eurocodes. Appropriately in the authors' opinion, this option was rejected right from the start of the Eurocode drafting process. From a purely practical point, it means that designers of structures in very low seismicity areas of Europe can ignore seismic provisions and Eurocode 8 entirely, since such areas are excluded from the scope of Eurocode 8, as explained later on in this paper. In addition, there are important technical reasons for treating seismic loading separately. Firstly it differs from the others in being essentially dynamic and involving no externally applied forces above foundation level; the loads actually depend as much on the dynamic characteristics of the structure and its foundation materials as earthquake ground motion 'actions'. Therefore, it requires an essentially different treatment from other types of loading. Equally importantly, the performance criteria under earthquake loading must consider the protection of life in rare events as well as the maintenance of function in more frequent ones. While this may equally be true for other types of loading, the skewed probability distribution of earthquakes (fig 1) implies that satisfying only the serviceability condition may well lead to structures which have an unacceptable risk of collapse. As a consequence, the economic design of most structures for the no-collapse condition makes use of a ductile response well into the post-yield region[1], to the extent probably only seen elsewhere in blast and impact design. Seismic design loads therefore depend not only on the dynamic characteristics of the structure and its foundation materials but also its ductility, and this implies another inextricable link between loading and structure. This link is further strengthened by the need to include 'capacity design' considerations[2], whereby design actions on some structural elements depend not on any external actions but on the yield strength of other elements. For example the strength of columns in ductile frames must be sufficient to develop the strength of the beams connected to them.

For good reasons, therefore, since the early 1980s, Eurocode 8 has been developed as a separate document treating both loading and resistance aspects of seismic design. It is not a stand-alone document, and reference must still be made to other Eurocodes for many aspects of element strength determination and for determining the gravity actions that must be considered together with the seismic ones. However, Eurocode 8 does gather together into a single document prepared under the guidance of a single steering committee all the aspects of seismic design for a broad range of material types and a wide range of structural types. It also includes the geotechnical aspects so crucial in seismic design. This unified approach over a very broad spectrum of materials and structural types makes Eurocode 8 a unique international document, and gives it much of its special value.

Scope and state of progress on EN1998

Eurocode 8 is in six parts, as shown in Table 1. Notable exclusions from its scope are 'special structures' such as nuclear power plants, off-shore structures and large dams. The scope of Part 2: Bridges excludes suspension bridges, timber and masonry bridges and also moveable or floating bridges. Even

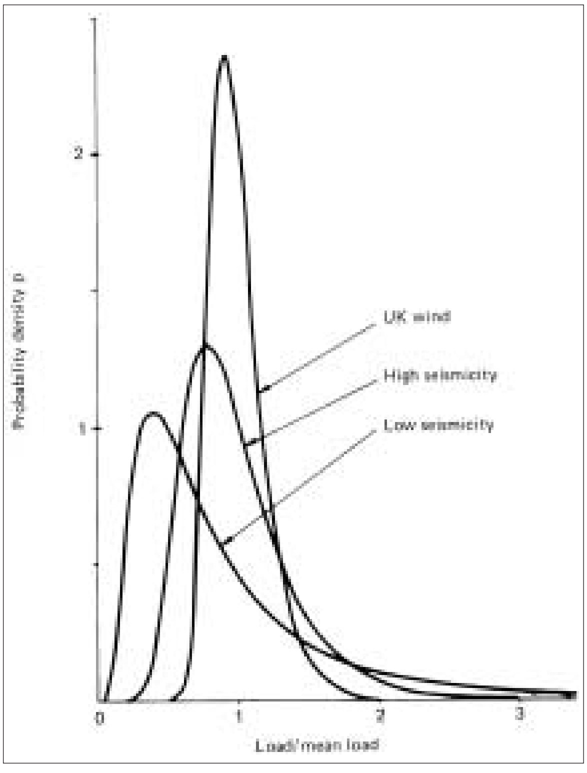


Fig 1. Comparison of probability density for wind and earthquake loading (from Booth[3])

*A good general introduction to the Eurocode suite is given in a special issue of Civil Engineering[5]

Table 1: Timetable for final issue of the six parts of EN1998. Design of structures for earthquake resistance

	Technical approval by CEN Committee CEN/TC250/8	Likely issue as a full Euronorm	Likely issue as a British Standard Euronorm (with UK National Foreword)
Part 1: General rules, seismic actions and rules for buildings: Clause 1: General Clause 2: Performance requirements and acceptance criteria Clause 3: Ground conditions and seismic action Clause 4: Design of buildings Clauses 5 – 9: Specific rules for buildings in concrete, steel, composite steel-concrete, timber, masonry Clause 10: Base isolation	July 2002	Spring 2004	2005
Part 2: Bridges	September 2003 (Note A)	Spring 2005	2005
Part 3: Assessment and retrofitting of buildings	September 2003 (Note A)	Spring 2005	2005
EN 1998-4 contains specific provisions relevant to tanks, silos and pipelines	May 2004	Autumn 2005	2006
EN 1998-5 contains specific provisions relevant to foundations, retaining structures and geotechnical aspects	July 2002	Spring 2004	2005
EN 1998-6 contains specific provisions relevant to towers, masts and chimneys	September 2003 (Note A)	Autumn 2005	2006

Note A: subject to approval in May 2004 of changes agreed in outline in September 2003

with these exclusions, it can be seen from Table 1 that a very wide range of structural types is covered.

Eurocode 8, by its very nature, covers complex matters that would be regarded as specialist by engineers working in low seismicity regions such as the UK. Of course, structural engineers working in the highly seismic areas of southern Europe might properly regard seismic engineering as an essential part of their discipline. In fact, Eurocode 8 has no specific guidance on the attributes assumed for users of the code, beyond referring to the assumption stated in EN1990: 'The choice of structural system and the design of a structure is made by appropriately qualified and experienced personnel'. Experienced structural engineers without a background in seismic engineering would be well advised to seek specialist assistance before using Eurocode 8, since no commentary is provided and the logic behind the code provisions may often not be apparent to non-specialists. The Eurocodes Expert initiative[4] set up by the Institution of Civil Engineers may help address this shortfall.

The conversion of ENV1998 into EN1998

The ENV (drafts for trial use) versions of Eurocode 8 were issued during 1994 to 1996. The period since then has seen a great deal of work in preparing full Euronorm versions of the code, and some radical revisions have been involved. The UK has played a full part in this process, with five UK experts being members of the project teams drafting all the parts except Part 4. UK delegations have also been active contributors to the CEN committee overseeing the development of Eurocode 8 and its conversion to a Euronorm. The Department of Trade & Industry, through the Office of the Deputy Prime Minister, recognises this as sufficiently important to provide some of the funding essential for this activity.

The BSI committee B525/8, under the chairmanship of Dr Bryan Skipp, has also been active and has acted as a co-ordinator and clearing house for the comment and review process within the UK. Even after the Euronorm versions have been published, it is envisaged that this committee will continue its activities to ensure that the UK view is heard during the process of maintaining the first generation of Euronorms, and preparing for the issue of the second generation.

National Annexes, and their role in EN1998

Achieving consensus on Eurocode provisions among the 19 nations involved has not always been straightforward. From the start of the drafting process, a device was introduced to allow some national differences in practice to remain after the introduction of the Eurocode suite. The device (in the form adopted for the final Euronorm version of the codes) has been to require each nation to publish their own edition of the code in an agreed *verbatim* translation, but with a unique National Foreword, which can in turn refer to a National Annex. This National Annex can provide national alternative versions to a strictly limited number of code provisions which have been identified and agreed to be recommendations rather than definitive provisions. In this way, some variation in the application of the codes within national territories is permitted. The expectation is that in most cases, countries will adopt the recommended provisions.

In principle the amendable clauses should only deal with matters affecting safety and reliability, while consensus and uniformity have to apply to all technical matters. Thus for example, partial safety factors and return periods of loading can be designated as recommended only, and so can be modified in National Annexes, while determination of resistance and acceptable methods of analysis cannot. In practice, the nationally determined parameters cover a rather wider range of aspects and have been used as a device for achieving consensus. In Eurocode 8, there are 56 clauses which allow for national variation, and some of these involve key aspects of the code. Some, such as the return period of the design earthquake ground motions, the importance factors for buildings or the threshold acceleration level below which seismic design need not be explicitly considered are clearly concerned purely with safety. Others, such as the shape of the design response spectrum or the q (behaviour) factors for the design of certain masonry buildings, are less clearly based on safety rather than technical considerations. The expectation is that in future issues of the Eurocodes, the scope for national variation will be reduced, and there will also be strong pressure from the centre for nations to justify their reasons for adopting procedures different from the recommended ones. Further discussion of National Annexes and other general matters relating to Eurocodes is given in a special issue of Civil Engineering[5].

Distinctive features of EN1998

The following sections describe the distinctive and (in some cases) innovative features of Eurocode 8, in comparison with current US and other international codes of practice.

a) General

From the start of its development in the early 1980s, Eurocode 8 was conceived as being a fully rational and transparent code, with its recommendations based on justified models mainly developed as part of a series of large research programmes funded by the European Commission[6]. This was to be in contrast with the more empirical approach found particularly in US codes of the time. This distinction still remains, although US practice in the mean time has become to some extent less empirical and more transparent, while the huge scope of Eurocode 8 and the dwindling resources available to develop it have meant that some of its recommendations represent conservative compromises rather than fully rigorous methods. Indeed, the main method of seismic analysis in Eurocode 8 (as in all other current codes) is elastic response spectrum analysis reduced by semi-empirical 'behaviour' (q) factors. It was originally intended that these q factors should be justified by extensive non-linear dynamic analyses, rather than by the largely empirical approach to choosing them adopted in US codes. In practice, this has only been partly successful, in the authors' opinion mainly because of the inherent inability of elastic response spectrum analysis to model inelastic behaviour satisfactorily[7]. Indeed, for more unusual elements such as steel masts or concrete chimneys in Part 6, for which few data exist, the q values given are little more than informed but conservative guesses.

Nevertheless, the rigorous theoretical basis remains in evidence in many places, and sometimes results in quite complex procedures. An early decision was taken that a commentary would not be developed alongside the code provisions; perhaps this decision was, in retrospect, mistaken. It will certainly make the code harder to adjust to. The basic theoretical approach has also meant a style that contains more elements of a textbook than UK engineers may be used to finding in codes.

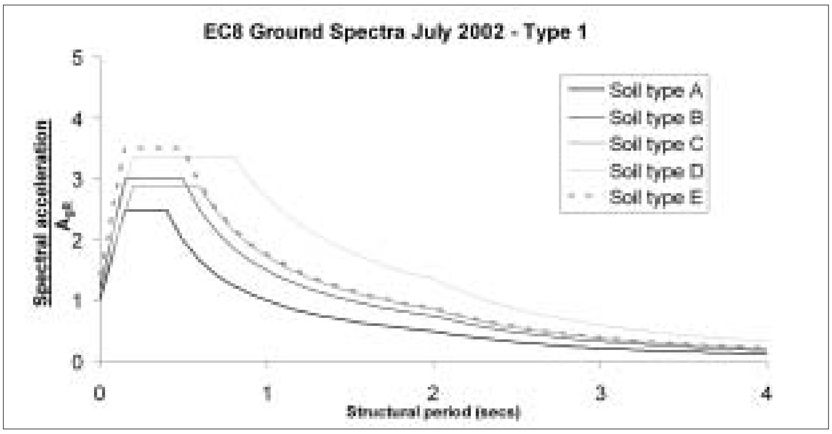
b) Seismic hazard and loading

Seismic hazard is expressed by a single parameter, namely the peak (zero period) horizontal acceleration a_{gR} at the surface on rock for a reference mean return period chosen by National Authorities but recommended to be 475 years. By contrast the US code IBC[8] characterises seismicity by two parameters (spectral acceleration at spectral peak and at 1 sec) for a much longer return period of around 2000 years. The 475 year return period in Eurocode 8 provides the design condition for the 'no-collapse' limit state (which in terms of Performance Based Engineering, corresponds essentially to a 'life-safety' requirement[9]) in structures of 'normal' importance. Seismic zonation – i.e. choice of a_{gR} for a particular location – is a matter for an appropriate authority within each country. Although there are some international cooperative efforts within the EU[6] and such initiatives as GSHAP[10] there is no definitive European seismic zonation.

A single parameter however is insufficient to characterise the ground motion hazard, because the frequency content as well as the amplitude of the ground motion affects structural response. The standard method in Eurocode 8 (in common with all current international codes) is to describe the frequency content by a response spectrum, although time histories, real, artificial and synthetic are also covered and some aspects of spatial variation in design motions are addressed.

Two influences on frequency content are recognised by Eurocode 8, namely the type of soils present at the site under consideration and the magnitude of earthquake. The former is accounted for by describing various standard classes of ground condition, which are used to select an appropriate shape of elastic response spectrum. The layers may be characterised by their shear wave velocity in the upper 30m of soil, but (in common with US codes) penetration resistance and undrained shear strength of upper layers may also be considered. There is a recognition in Eurocode 8 that deep geological features may also influence seismic action; however, this aspect must be quantified on a case by case basis by national authorities in their National Annexes. Thus, recommended shapes of elastic response spectrum are provided only for cases where the 30m of soil immediately below the site dominates the frequency content of the design motions. This will cover most cases found in practice, but deeper geology can become important in alluvial basins, particularly at their margins. Unusually, realistic elastic spectra are also provided for very long period motions in an informative annex based on work at Imperial College London and Politecnico di Milano[11] and this may prove useful for current 'displacement based' methods of structural analysis.

The influence of earthquake magnitude is included by providing two sets of recommended response spectra, one (Type 1) where large magnitude earthquakes dominate the hazard and another (Type 2) for magnitudes less than 6. Identification of areas subject to Type 1 and type 2 earthquakes must be provided by the national authorities in their zoning maps. This is different from US practice found in IBC[8], which allows for the effect by the two parameter hazard description referred to previously. Another feature not found in US codes is that information is given on the effect of topographic (relief) effects, and this must be considered for important structures. Yet another difference is that in IBC[8], the amplification of long period motions in soft soils is taken as dependent on amplitude, allowing for the observed fact that soft soils tend to respond non-linearly with higher damping



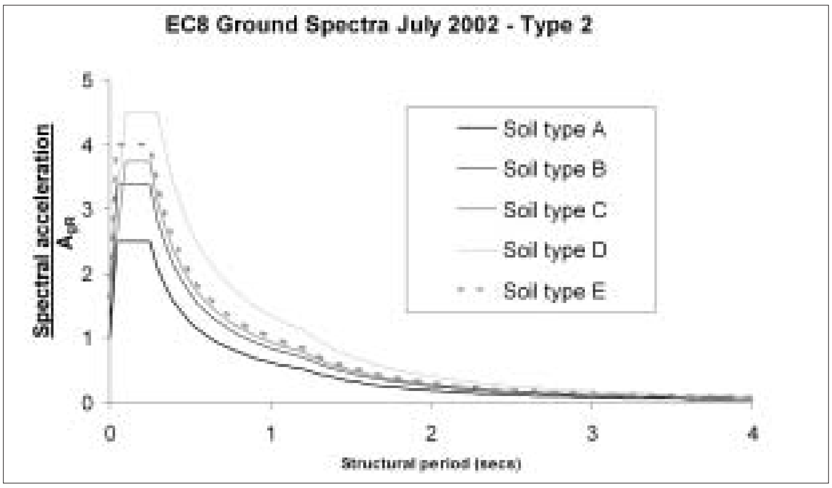
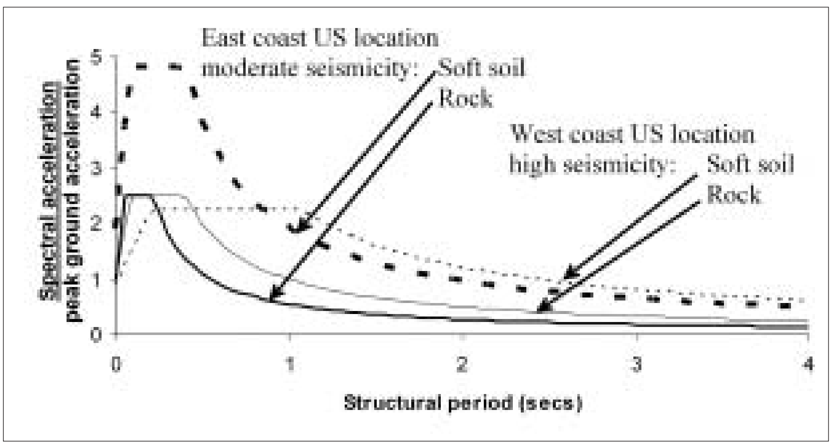


Fig 2. (top) Eurocode 8 recommended spectra for M>5.5
Fig 3: (above) Eurocode 8 recommended spectra for $M \leq 5.5$

and reduced stiffness under high intensity shaking, and so amplify the ground motions less than for moderate or low intensities. By contrast in Eurocode 8, for a given soil and earthquake type, the spectral shape is independent of the intensity of the shaking.

Fig 2 shows the recommended shapes of elastic response spectra in the Eurocode for cases where large magnitude earthquakes dominate (Type 1 spectra), while Fig 3 gives the moderate magnitude case (Type 2 spectra). The letters A to E represent soil types ranging from A: hard rock to E: soft alluvium. The elastic spectra are the standard against which the characteristics of time history or power spectrum representations of ground must be judged. They are also used in displacement based methods of analysis. However, for use in response spectrum analysis of structures (the standard method currently envisaged by the code) they must be converted to 'ductility modified' design spectra appropriate to the structure under consideration. This is done using the 'behaviour factor' q, in a way similar (but not identical) to that found in the US seismic code IBC[8] using the 'response modification factor' R. Fig 4 shows response spectrum shapes from IBC[8] for a moderate seismicity site on the east coast of the USA, and for a high

Fig 4. (below) Response spectrum shapes in IBC[8] for moderate and high seismicity areas



seismicity site on the west coast. The former will be dominated by lower magnitude earthquakes than the latter, and some of the characteristics provided for in Eurocode 8 can be seen. Thus the smaller magnitude earthquakes produce relatively high response at low period (at any rate for soft soils) and much less at long period (at any rate for rock) in a way rather similar to the relation between Type 2 and Type 1 spectra in Eurocode 8. However, the relative amplification between soft soil and rock sites at a given period in the US code is much greater for the moderate than the high seismicity area, because (as discussed previously) the amplitude of the motions is less, while in Eurocode 8, the relative amplification is given as practically the same.

(c) Geotechnical aspects

Part 5 of Eurocode 8 covers determination of soil properties, assessment of site characteristics, foundations design, soil structure interaction and earth retaining structures. The rules complement those of Eurocode 7. In the past 20 years, there have been notable advances in geotechnical earthquake engineering and soil dynamics (for example ECOEST No 2[12]). Some of this research is embodied in the informative annexes, which cover (*inter alia*) liquefaction, topographic effects and the seismic bearing capacity of shallow foundations. This range of detail is much greater than that found in other current international seismic codes.

Eurocode 8 has adopted the current state of the art position in characterising soils by initial small strain behaviour, complemented by constitutive relations relating dynamic behaviour to states of stress and cyclic strain rate.

The problem of proximity to seismically active faults is touched upon and absence of movement in the Quaternary may be used to identify non-active faults for most structures that are not critical for public safety. In this case, special geological investigations are to be carried out, although no specification is given.

The general requirements for site investigation are discussed. Geophysical approaches are favoured and Part 5 states, 'The profile of the shear wave velocity v_s in the ground shall be regarded as the most reliable predictor of the site dependent characteristics of the seismic action at stable sites'.

Part 5 has a short section setting out the conditions when soil structure interaction has to be taken into account. These are:

- structures where P-δ (2nd order) effects are significant
- structures with massive or deep seated foundations
- slender tall structures
- structures on very soft soils v_s <100m/s

d) Design of buildings

An unusual feature of Eurocode 8 Part 1 is that it provides a set of desirable 'characteristics of earthquake resistant buildings' giving largely qualitative goals for the following:

- structural simplicity;
- uniformity, symmetry and redundancy;
- bi-directional resistance and stiffness;
- torsional resistance and stiffness;
- diaphragmatic behaviour at storey level;
- adequate foundation.

A procedure for carrying out a non-linear static pushover analysis is also provided for buildings. This appears to be the first time pushover techniques have been discussed in detail in building codes, although design documents such as FEMA 356[13] in the USA have given such methods for existing buildings for some time. For new buildings, the procedure is incomplete, in that no guidance is yet provided on the plastic deformation limits compatible with the ultimate and damage limitation states considered in Eurocode 8. Such information is provided for existing buildings in Part 3 of Eurocode 8 (as is also the case for FEMA 356). 'Capacity design' procedures (described more fully below) are required for the foundations of buildings; such procedures appear in current New Zealand but not US codes.

e) Material specific rules for buildings

Rules are provided in Part 1 for strength determination and detailing of structural elements in buildings constructed from concrete, steel, composite steel-concrete, timber and masonry. In keeping with the theoretically rigorous approach mentioned above, a relatively complete 'capacity design' procedure is enforced for steel, concrete and composite structures of high ductility. In this procedure, elements which must be protected from yielding (for example, columns in concrete frames, or connections in steel frames) are designed to remain elastic under the full plastic strength of elements intended to yield in a major earthquake. Capacity design is required in US codes, but to a less complete extent[14]. Another innovation is the explicit recognition that force reduction or behaviour factors (called q in Eurocode 8 and R in the US International Building Code) include an allowance not only for available ductility but also for strength development after initial yield due to redistribution effects and strain hardening. The element of q due to this increase may be based either on standard values given in the code, or be based on a static pushover analysis. Again in keeping with the 'rigorous' approach, some quite complex theoretical models are given for failure modes in concrete which results in the section on concrete design being longer and less straightforward than its equivalent in US codes. The rules for composite steel-concrete buildings are not found in other codes and are based in part on work carried out by Imperial College London[15].

The timber rules are relatively brief but complete. The rules for masonry buildings include useful rules for 'simple' buildings which – provided they conform to limits on height, wall spacing, compactness of shape and wall area – can be considered as meeting code requirements without the need for more complex analysis. By contrast with US codes, Eurocode 8 also permits (within strictly controlled height and other limits) the use of both unreinforced and 'confined' masonry (the latter being masonry built into a concrete beam/column frame complying with certain requirements), which would not be permitted in new construction in US areas of high seismicity.

f) Base isolation

Clause 10 of Part 1 gives rules for the base isolation of buildings mounted on bearings intended to isolate them from seismic motions. In common with US practice, the superstructure of base isolated buildings must remain essentially elastic in the design earthquake and this possibly conservative requirement has given rise to controversy and debate within the UK community.

g) Existing buildings

Part 3 of Eurocode 8 gives codified rules for the assessment and retrofit of existing buildings. Although extensive and excellent guidance on this subject has been published in the US (notably FEMA 356[13]), as far as is known Part 3 is currently the only code to deal with the subject. It is also the only part of the Eurocode suite to deal with existing buildings. The normative clauses in this section are relatively brief, and would need to be supplemented in practice by other guidance material. They require use of static pushover analysis in cases where there is a non uniform spread of plastic deformations under earthquake loading. In other cases, simple force based analysis is permitted, but the q (behaviour) factors given are conservative, and may prohibit this from being an economic or viable option in many cases. The bulk of Part 3 comprises three informative (i.e. non-mandatory) annexes. The two annexes relating to concrete and steel structures give guidance on appropriate limitations on plastic deformations, to complement the normative clauses on static pushover analysis. The annex on masonry structures includes information on repair and strengthening techniques.

h) Bridges

Eurocode 8 Part 2 is perhaps the part of Eurocode 8 which draws most fully on US practice. A complete procedure is provided for static pushover analysis, which (unlike the case for the design of new buildings) includes a procedure for assessing maximum acceptable plastic deformation from first principles. The procedure is similar to that in Caltrans[16]. However, whereas Caltrans envisages static pushover to be the standard analysis procedure, in Eurocode 8 Part 2 the standard procedure remains elastic response spectrum analysis. Part 2 also provides an informative (ie non-mandatory) annex on how to deal with the effects of non-synchronicity of motions between piers, although it is mandatory to consider such effects where geological discontinuities or marked topographical features are present, and also in all bridges longer than 600m. One section of Part 2 deals with bridges provided with base isolation bearings, serving to protect the deck from seismic motions; these contain no radical departures from US practice. The strength verification rules for concrete, steel and steel-concrete composite bridges are also similar to those in US practice, including AASHTO[17] . Less standard materials such as timber, masonry or fibre reinforced plastics are not included within the scope of Part 2. A more complete comparison between AASHTO and the Eurocode is provided by Barr[18].

i) Other structural types

A wide range of structures are dealt with in Parts 4 and 6 of Eurocode 8, including concrete chimneys, steel towers and guyed masts, water tanks and pipelines. The material is quite similar to that published elsewhere, but it is to be found in a variety of different places. The value to the UK engineer will be that the code requirements are gathered together under a common format.

Application of EN1998 to seismic design in continental Europe

In common with other Eurocodes, use of Eurocode 8 (if applicable) will be mandatory for the design of public construction works in the European Union if the value exceeds €5m. However, the expectation (and hope) of the present authors is that Eurocode 8 will become much more widely used than that, even before national seismic codes have been withdrawn. These national codes have widely differing approaches to fundamental issues such as the definition and quantification of seismic hazard and none are nearly as comprehensive in scope as Eurocode 8. The great attraction of Eurocode 8 to the design engineer is that it provides a single methodology for the complex subject of seismic design which covers not only most types of construction, but also is applicable throughout Europe, and is suitable for use in many other parts of the world as well. Fewer structural engineers will be as wedded to their own national way of doing things in seismic engineering as they are for say standard concrete or steel design, so there should be less resistance to change. In fact, it may be that the need to use the more standard Eurocodes in conjunction with Eurocode 8 proves a spur to the earlier adoption of these standard Eurocodes. The only rival comprehensive set of seismic codes widely used in the UK has hitherto comprised US codes. With the existence of a European alternative, it will be most interesting to see whether UK practice changes. There are cultural as well as technical issues involved here. While it is probable that the oil majors will continue to specify US seismic codes in preference to Eurocode 8 for some time to come, other multinationals (for example in the pharmaceutical industry) may take a different view.

It must be frankly admitted that the ENV (draft for trial use) version of Eurocode 8 did not find much acceptance or use among the design community in the UK or elsewhere in Europe. (The same, it seems, applies to the other ENV Eurocodes as well[5]). Partly this was because there was no mandatory requirement to use them. However, in the authors' view, it was also partly because there was much that needed improving in ENV1998. In the 8 years since its publication, there has been much hard work (to which, as noted above, the UK has made a significant contribution) to effect that improvement, which in the authors' opinion has resulted in a viable code. It is frankly admitted within Eurocode circles that publishing the complete Eurocode suite as Euronorms is a more important goal than producing flawless recommendations. However, no codes are perfect, even US seismic ones, as was discovered after the Northridge, California earthquake of 1994[19]. It is fairly certain that the main importance of Eurocode 8 for UK based-engineers will be the need to use the code for designs in seismic areas of Europe and (as discussed later) the rest of the world.

Application of EN1998 within the UK

a) Seismic design in areas of low seismicity

There are particular problems which apply to design in areas of low seismicity. Fig 1 shows that the risk in such areas lies in the tail of the probability distribution, and therefore is dominated by very low probability (and hence uncertain) events. It is consequently difficult to decide whether accounting explicitly for seismic design is justified. In normal times, the extra cost of providing seismic resistance may be politically unacceptable, but if the extreme event were to occur, causing damage and fatalities, then equally there might be serious political consequences in not providing for an event which though rare, was accepted scientifically as perfectly credible.

Eurocode 8 treats the problem by providing simplified design methods for low seismicity conditions and dispensing with the need for explicit seismic design for areas of very low seismicity. The recommended definition is that low seismicity areas have a peak ground acceleration of not more than 8%g on rock, or 10%g on soil surfaces; the recommended figures reduce to 4%g and 5%g respectively for very low seismicity areas. These criteria have been the subject of much discussion and indeed dissension in the ENV to EN transition period they are only recommended values and may be altered by National Authorities. As discussed below, the particular problem for the UK is that, while the majority of the UK clearly lies in the recommended 'very low seismicity' zone, significant areas probably lie just within the recommended 'low seismicity' zone.

b) The seismicity of the UK

Notwithstanding the numerous site specific hazards studies undertaken in the UK since 1983, a zoned onshore map of UK peak ground acceleration that would meet with a general consensus is not available. However, a recent map of intensity is available for the reference return period of 475 years[20], which is reproduced here as Fig 5. It shows that significant areas of the UK have a 475 year return intensity of 6 to 7, which implies that the corresponding peak ground acceleration is likely to exceed 0.04g (although the correlation between intensity and acceleration is notoriously weak). Three studies[21-23] of the North Sea and UK continental shelf are in the public domain. A fourth synoptic appraisal[24] has been published and includes a

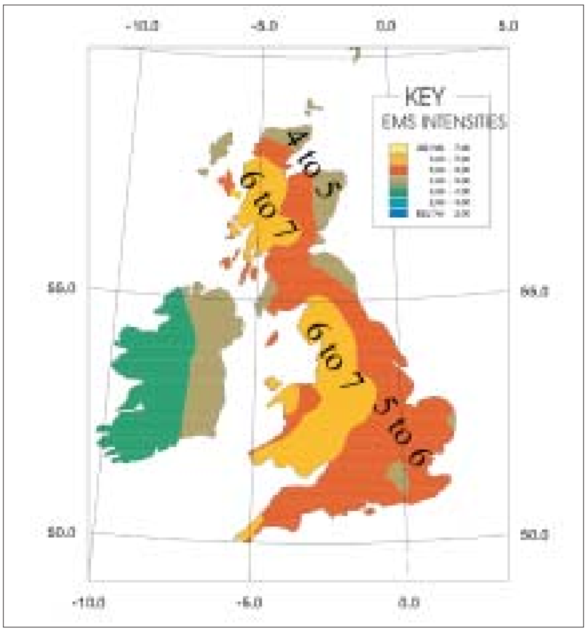


Fig 5. 475 year return period EMS intensities for the UK (from Musson and Winter[20])

comparison between hazard contours offshore near coastlines with onshore site specific studies for nuclear power stations and other facilities. The HSE studies will be put on the HSE web site in the near future. The current GSHAP[10] map of UK seismic hazard, and SESAME[25], the related follow-up study for Europe, is not considered to be sufficiently detailed to support decisions on the seismic zonation of the UK for the purposes of Eurocode 8; for this purpose, the intensity-based zonation of Musson and Winter, shown in fig 5, is preferred, since it is closer to the original historical data on which all seismic hazard assessments of the UK rely.

It is possible that a compilation of all the studies so far carried out could definitively point to a situation where some part of the UK would need to be classified as 'low seismicity' according to the recommended definition, and hence would require seismic design, albeit in simplified form. The matter is not one to be taken lightly – the cost of fitting out and training consulting engineers in the intricacies of Eurocode 8 would not be trivial. The UK is not bound to accept the recommended definition in Eurocode 8, but to reject it would need a clear technical as well as cost justification.

c) Implications for design of standard construction in the UK
If the UK National Annex specifies that part or all of the UK has sufficient seismic activity to lie within the scope of Eurocode 8 (albeit with simplified rules applying) then there are potentially large implications for design in the UK, as discussed above. The question of what the UK National Foreword will rule on the applicability of Eurocode 8 is therefore important.

The UK National Foreword to the ENV versions of the code stated clearly: 'Within the UK, the application of Eurocode 8 should not be necessary, unless the client or user of the works assesses that the associated seismic risk is such that it needs to be addressed.' No further guidance was given as to when this need to address seismic risk might arise in the UK.

In a recent poll of 500 engineers by the *NCE* magazine[26], shortly after a magnitude 4.8 earthquake in the West Midlands, 75% responded No to the statement 'Should building regulations require developers to provide more earthquake resistant buildings?', 7% responded Yes, while 18% didn't know. The surprising aspect of this is that as many as 7% believed that more earthquake resistance was required, although this may have been because the question did not unambiguously refer to construction in the UK. The common sense view, reflected in the poll, is that there are more effective ways to improve the safety and utility of standard public and private construction in the UK than putting them through a series of seismic design hoops. A study 10 years ago[27] estimated that the average annual loss due to earthquakes in the UK was around £10m, compared with £800m due to fire and £434m due to extreme weather. This low but non-negligible figure for earthquake loss must be considered in the light of the fact that the average figure in fact was dominated by the estimated contribution from a very rare (but credible) event, such as a magnitude 6 earthquake occurring directly under alluvial soils in a major conurbation such as London or Liverpool. Much of that loss would occur in older buildings, and of course changes to the building regulations would take many years to affect an appreciable proportion of the building stock.

Given the significant implications of introducing a requirement to use Eurocode 8 in some of the UK, and the rather doubtful benefits that would result, it is likely that the UK National Foreword to the full Euronorm (EN) version will be rather similar to that of the ENV version quoted above. If this turns out to be the case, then in the authors' view more guidance is needed on when seismic risk might need to be addressed in ordinary construction. One contribution to that debate was made in 1995 by Booth and Pappin[28]. Another contribution was contained in studies by Arup[29] and CAR[30], which examined the extent to which the robustness and wind loading provisions of the current Building Regulations provides seismic resistance. In their capacity as members of the BSI committee charged with drafting the UK National Foreword to Eurocode 8, the present authors would value contributions to the debate on what the UK position on this subject should be.

d) Implications for design of high risk installations in the UK
The nuclear power industry is currently the only major sector for which seismic design is carried out for UK facilities on any regular basis, although large dams and some long span bridges in the UK have also been subjected to seismic checks. The scope of Eurocode 8 is explicitly stated to exclude nuclear power plants (as well as large dams and suspension bridges). Will the publication of the Euronorm version of Eurocode 8 then have any impact on the practice of seismic design for UK nuclear power facilities?

Eurocode 8 does not exclude from its scope nuclear power plants because their response is fundamentally different from that of other structures. Rather, the exclusion arises because Eurocode 8 does not present a complete methodology for the special safety and performance issues which apply to nuclear power plant. The same laws of physics apply to both nuclear power related and 'standard' construction and there is much of relevance to the former in Eurocode 8. Despite the notorious reluctance of nuclear regulators to accept anything new, it is the authors' expectation that parts of Eurocode 8 will be increasingly referenced in the development of seismic safety cases for nuclear power and other hazardous plant. This process has in fact already started.

Application of EN1998 outside the CEN area

In principle, Eurocode 8 can be applied anywhere in the world, subject to five conditions:

a) An estimate of the peak ground motions on rock for a 475 year return period earthquake is available.
b) The type of construction falls within the scope of one of those types envisaged by the drafters of Eurocode 8.
c) Ground conditions exist which can be adequately described by the standard profiles adopted by Eurocode 8.
d) The basis exists to choose whether Type1 or Type 2 spectra apply
e) The expertise exists to interpret and implement the recommendations of the code.

Guidance on 475 year return period earthquake motions has recently been published for the entire world[10], so the first condition should be easily met, at least on a superficial level. The construction types and ground profiles envisaged by Eurocode 8 apply widely but not universally. The code is advanced in the sense that it needs a high level of expertise to interpret correctly and some of the construction requirements (for example in the detailing of ductile concrete frames) also require enhanced skills to implement. These latter aspects may limit the applicability of Eurocode 8.

Future developments of EN1998

Once Eurocode 8 has been published as a full Euronorm, there will be an understandable tendency to heave a sigh of relief and get on with other things. However, there will still be work to be done. At a basic level, errors, ambiguities and contradictions will be discovered and need to be corrected. A maintenance group will be established for this task, and it is expected that the UK will contribute to this. However, there is already the realisation that the first Euronorm version of Eurocode 8 will need improvement in more fundamental ways; many improvements would be possible and some desirable. Some areas to address, taken from the authors' personal preferences, are as follows.

a) Harmonisation of seismic zoning within the CEN area by means of common studies.
b) Rules need to be developed to allow for the dependence of local amplification of ground motions by the soils on the amplitude of motion.
c) Guidance on the selection and scaling of real-time histories for design purposes (see Bommer *et al*[31]).

d) The usability of the code will need to be carefully considered. At first sight, the complexity of some of the sections is daunting, and some will never be straightforward. Could the section in Part 1 on design of concrete buildings be simplified, for example? Could shortened rules for simple buildings be drafted, along the lines of the IStructE/ICE manuals for (non-seismic) design of concrete, steel and masonry buildings?
e) Complete procedures for pushover analysis in new design need to be developed.
f) Prestressed concrete, high strength steel and concrete and other materials such as fibre reinforced composites could be further addressed.
g) The rules for chimneys, towers, masts, silos, tanks and other structures described in Parts 4 and 6 may need to be reviewed and refined.
h) Rules for design of passive and active damping devices may be needed.
i) Preparation of guidance for engineers on the use of the code.

Conclusion

The publication of the Euronorm version of Eurocode 8 will almost certainly have significant implications for UK based engineers involved in designs in seismic areas of Europe; it is also likely to impact the design of structure in other seismic parts of the world, and possibly also the establishment of seismic safety cases for structures in UK nuclear power plant and other high risk installations. The implications for normal construction in the UK are less certain; the most likely outcome is that there will be little or none, but there are other possible outcomes too. The probable impact on overseas work and the potential for impact on UK work makes it important to maintain the UK involvement in the continuing development of Eurocode 8. Contributions on the form and content of the UK National Forewords and Annexes and on future developments of the code are invited to the BSI committee responsible, B525/8, which may be made through the authors of this paper.

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REFERENCES

1. Booth, E. D.: 'An overview of earthquake-resistant design.' In: Booth E. D. (editor): *Concrete structures in earthquake regions*, Longman Scientific and Technical, Harlow UK, 1994
2. Paulay, T.: 'Simplicity and confidence in seismic design'. The Fourth Mallet-Milne lecture, SECED/Wiley, 1993
3. Booth, E. D.: 'Assessment of seismic hazard', *The Arup Journal*, **19**/2 Ove Arup Partnership, London, June 1984
4. Eurocodes Expert. http://www.eurocodes. co.uk
5. Civil Engineering, Special Issue on Eurocodes. *ICE Proc. Civ. Eng.*, **144** /spec issue, 2 Nov 2001
6. Severn, R.: Review of earthquake engineering research funded by the European Commission. In: *Implementation in the UK of earthquake engineering research*. Society for Earthquake & Civil Engineering Dynamics, London, Aug 2001. www.seced.org.uk/rwp /report.htm
7. Priestley, M. J. N.: 'Myths and fallacies in earthquake engineering, revisited'. IUSS Press at the Rose School, Pavia, Italy (www.roseschool.it/files/ IUSSpress.htm) 2003
8. 'IBC, International Building Code', *Int. Conf. of Building Officials*, Whittier California, 2003
9. Bertero, V. V.: Performance-based seismic engineering: a critical review of proposed guidelines. In: Fajfar, P, and Krawinkler, H. (eds), *Seismic design methodologies for the next generation of codes*. Balkema, Rotterdam, 1997
10. GSHAP. Global Seismic Hazard Assessment Program. http://seismo.ethz.ch /GSHAP/
11. Bommer, J., Borzi, B., Chlimintzas, G., Elnashai, A., Lee, D., Faccioli, E. and Tolis, S.: 'Definition of displacement response spectra for design', in *Seismic Actions*, (eds) Faccioli, E. and Paolucci, R. *ECOEST2/ICONS Report No 1*, p 3-34, November 2001
12. ECOEST (European Consortium of Earthquake Shaking Tables), Faccioli, E. and Paolucci, R. (eds.). *Seismic behaviour and design of foundations and retaining structures,* Laboratorio Nacional de Engenharia Civil, Lisbon, Portugal, 1996
13. FEMA 356. 'Prestandard and commentary for the seismic rehabilitation of buildings'. Federal Emergency Management Agency, Washington DC November 2000
14. Booth, E., Kappos, A. J. and Park, R.: 'A critical review of international practice on seismic design of reinforced concrete buildings'. *The Structural Engineer*, **76**/11, June 1998
15. Elnashai, A. S., Broderick, B. M. & Dowling, P. J.: 'Earthquake-resistant composite steel/concrete structures'. *The Structural Engineer*, **73**/8, p 121-132, 18 April 1995
16. Caltrans Seismic Design Criteria Version 1.2, California Department of Transportation Division of Engineering Services, December 2001
17. AASHTO 17th Ed. *Standard Specifications for Highway Bridges.* American Association of State Highway and Transportation Officials Washington DC, 2002
18. Barr, J.: 'The seismic safety of bridges: lessons learned and EC8 and AASHTO compared', *ACI Int. Conf. Seismic Bridge Design and Retrofit*, La Jolla, USA, 2003
19. Burdekin, F. M. (ed.): 'Seismic design of steel buildings after Kobe and Northridge'. Institution of Structural Engineers / SECED January 1996
20. Musson, R. and Winter: Seismic hazard maps for the UK, *Natural Hazards*, 1997, **14**, p 141-154. The map is also published on www.earthquakes.bgs.ac.uk/hazard/hazuk.htm
21. Principia Mechanica Ltd, 1997 North Sea seismicity. *UK Department of Energy Offshore Technology Report No OTH 86219*, HMSO London 1986
22. British Geological Survey/Ove Arup & Partners, UK Continental Shelf seismic hazard, *Health and Safety Executive Offshore Technology Report OTH 93 416*, HMSO London 1993
23. EQE International. Seismic hazard – UK Continental shelf. *Health and Safety Executive Offshore Technology Report, 2002/005*, 2002
24. Mallard Partnership: 'An appraisal of existing seismic hazard estimates for the UK continental shelf', *HSE Books*, HMSO also www.hse.gov.uk/research/rrpdf/rr166.pdf 2003
25. Jiménez, M. J., Giardini, D., Grünthal, G. and the SESAME Working group: 'Unified seismic hazard modelling throughout the Mediterranean region, *Bull. Geof. Teor. Appl.*, 42, p 3-18, 2001.
26. Parker, D. 'Design codes debate unmoved by UK quake'. *New Civil Engineer*, 26 Sept. 2002
27. Ove Arup & Partners: *Earthquake hazard and risk in the UK*. Study for the UK Department of the Environment. London 1993
28. Booth, E. D. and Pappin, J. W.: 'Seismic design requirements for structures in the United Kingdom'. In: Elnashai A (ed.) *Fifth SECED conference: European seismic design practice*, Balkema, Rotterdam, 1995
29. Ove Arup & Partners: *UK building vulnerability study: Interim Report and Follow Up study*. Study for UK Department of the Environment through the Institution of Civil Engineers. London 1989 and 1990
30. CAR: *Seismic vulnerability of low-rise domestic buildings in the United Kingdom*. Study for UK Department of the Environment through the Institution of Civil Engineers. Cambridge Architectural Research, Cambridge 1988
31. Bommer, J. J. and Ruggeri, C.: 'The specification of acceleration time-histories in seismic design codes', *European Earthquake Engineering*, **16**/1, p 3-17, 2002