Creating a vision for the future of Eurocode 8

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SUMMARY
The six parts of Eurocode 8 (EN 1998) were published during 2004-6, the outcome of a 15 year drafting period. Although in many respects the code represented the state of the art when published, sections have become outdated and in the authors' view fundamental changes are needed in order for Eurocode 8 to be regarded as the international seismic code of choice in the period after 2020. What is urgently needed but currently lacking is an overarching plan for developing the code, along the lines that the US earthquake engineering community produced so successfully 17 years ago in SEAOC's Vision 2000 Report. The paper presents views on what Eurocode 8's vision should be and the main areas where significant change is needed, in the hope that it may initiate a fruitful discussion, and perhaps lead to the formation of a working party of the EAEE to carry the matter forward.

Keywords: Eurocode 8, international standards

1. INTRODUCTION

The six parts of Eurocode 8 (EN 1998) were published during 2004-6, the outcome of a drafting period lasting well over 15 years. The introduction of the Eurocode suite represented a major upheaval in the practice of European engineers and it was decided that a period of stability was needed after their initial introduction. Therefore, the European Committee for Standardisation (Comité Européen de Normalisation or CEN), which is responsible for the Eurocodes, has directed that only corrections and clarifications should be allowed in any of the Eurocodes for at least ten years after first publication. The next major revisions to the Eurocodes are now scheduled to be published during 2015 to 2020, and the 'enquiry period', during which redrafting takes place, starts during 2013. A primary aspiration for the next generation of Eurocodes will be to bring national practices more into line, by reducing the variation between the values and procedures for which national choice is permitted, as expressed in each nation's National Application Document. While that may be sufficient for many of the Eurocodes, the recent rapid and radical developments in earthquake engineering demand something more for Eurocode 8.

Creating a comprehensive and co-ordinated set of design rules for a very wide range of seismic engineering issues was a major task. The scope of the six parts of Eurocode 8 exceeded any of the pre-existing European seismic codes, or indeed that of any seismic code anywhere in the world. It had to cover the very wide range of seismic hazard and construction types that exists over the various parts of Europe, and it also covered not only building structures but a wide range of industrial and civil structures. Some innovative features made aspects of Eurocode 8 more advanced than any other code available in 2004; for example, the treatment of geotechnical issues was particularly ambitious. Therefore, the successful publication of Eurocode 8 eight years ago was a considerable achievement, and it has subsequently been used as a model for codes in countries outside Europe, such as Egypt and Vietnam. However, in the authors' view, it is now clear that fundamental changes are needed in order for Eurocode 8 to establish itself as the international seismic code of choice in the period after 2020. Earthquake engineering is a rapidly developing field, perhaps changing more rapidly than applies to the topic of any other Eurocode. The long period of drafting means that many of the procedures and approaches in the code are considerably older than eight years. The feedback from users during the next revision process will of course provide much useful information on what needs changing, and the process of harmonising national choices will also be useful. However, what the authors believe to be urgently needed and currently lacking is an overarching plan for the code, along the lines that the US earthquake engineering community produced so successfully 17 years ago in the Vision 2000 Report (SEAOC, 1995). The rest of this paper sets out the authors' views on what Eurocode 8's vision should be and the main areas where significant change is needed, in the hope that it may initiate a fruitful discussion, and perhaps lead to the formation of a working party of the European Association for Earthquake Engineering (EAEE) to carry the matter forward. The authors are both practising structural or geotechnical consulting engineers with many years of specialist experience in earthquake engineering; *inter alia,* one is the chair of the British Standard Institution committee on Eurocode 8 while the other sits on that committee and is a member of the EAEE council. Both worked with French and British colleagues on a manual for Eurocode 8 (Institution of Structural Engineers, 2010), which gave rise to many of the views expressed below. They remain, however, the personal ones of the authors.

2. A VISION FOR EUROCODE 8

Successful revision of Eurocode 8 will require a set of goals to be aimed at. Inevitably, not all the goals will be fully achievable; different member countries of CEN may have mutually conflicting aspirations and even where there is pan-European agreement, goals such as simplicity of requirements, economy of the resulting structures and comprehensive coverage may conflict to some extent. However, without a clear vision developed by a full debate among European partners, the outcome is likely to be less than ideal. As a contribution to this debate, a set of ideal aspirations from an end user's (i.e. design engineer's) point of view is proposed below. These would of course have to be achieved within the context of the CEN specifications for a Eurocode, which are taken as read.

1. Incorporates state-of-the-art technology, yet remains user friendly.
2. Allows state-of-the-art buildings to be designed without undue restrictions on creativity, yet provides clear and practical guidance for standard buildings implementable without unnecessary or impracticable demands on designers' expertise and time.
3. Provides the appropriate level of earthquake performance for a variety of limit states without excessive conservatism, allowing designers and their clients to define and control with confidence structural response to an earthquake.
4. Provides guidance on the use of emerging technologies, at least to some extent, and where such technologies are not explicitly referred to, does not prevent their use.
5. Applicable across a wide range of seismic hazard conditions, from very low to very high.
6. Provides procedures for specifying design ground motions adequate for standard cases, but also provides comprehensive guidance on more sophisticated procedures for non-standard cases.
7. Provides straightforward analysis methods for superstructure and foundations which are adequate for standard cases, but also provides comprehensive guidance on more sophisticated methods.
8. Applicable across the entire range of structural types covered by the Eurocode suite, including different construction materials (steel, concrete, masonry, timber etc.), and different end uses (commercial, residential, industrial, infrastructure, etc.).
9. Within its coverage of building design, applicable to a wide range of types, from high rise, high tech to simple low rise unreinforced masonry.
10. Gives guidance on the seismic assessment and retrofit of existing structures, as well as on design of new buildings.

3. AREAS FOR REVIEW

How well does the current version of Eurocode 8 meet these aspirations and where does it fall short? The ten points in the previous section are now reviewed from this perspective.

1. *Incorporates state-of-the-art, yet user friendly*
   Some sections of Eurocode 8 still provide leading information not found in other international standards (e.g. shear strength models for structural walls, confinement models for concrete beams and columns, bearing capacity models for shallow foundations). However, some are substantially out-of-date. Examples include the hazard and ground motion specification methods of Chapter 3 of EN 1998-1, the normative liquefaction procedures of Annex B of EN 1998-5, the structural analysis methods suitable for ensuring adequate performance in building structures of Chapter 4 of EN 1998-1, design procedures for steel moment resisting frame building structures of Chapter 6 of EN 1998-1 and the assessment methods for existing buildings of EN 1998-3. Review of some of the fundamental concepts is also needed, for example, the concept of ductility class, as discussed in section 4.4.
2. *Allows for state-of-the-art buildings, yet provides clear and practical guidance for standard buildings*
   The drafters of Eurocode 8 were well aware that the code would be used for widely varying levels, both of sophistication in the type of structure and of specialist expertise available to the designers, and accordingly provided a range of different procedures. Thus concrete buildings could be designed to the sophisticated requirements of ductility class high (DCH), or to the more straightforward ones of ductility class medium (DCM), while masonry buildings might be designed to rules of thumb that required no analysis at all. In a number of respects, this has not been successful. Thus, the rules for DCH concrete structures are reported as being impossible to achieve in some cases, while the DCM rules are sometimes unnecessarily complex (for example, for capacity design in shear of beams and columns) while in other cases are arguably not sufficiently rigorous (for example, for the design of concrete floor diaphragms and structural walls). The rules of thumb for masonry buildings also need review.
3. *Provides appropriate levels of earthquake performance for a variety of limit states without excessive conservatism*
   A number of issues arise. ***Firstly***, how many limit states should be considered, and in how much detail? Although nominally considering two limit states, in practice Eurocode 8 currently deals with only one (ultimate limit state) for structural elements, with serviceability limit state checks confined to simplistic and almost certainly inadequate checks of deflection. Non-structural elements are given more attention, but the provisions do not fully represent current best practice. The number of limit states to consider needs review; for example, should a limit state of near collapse be included for new structures? The target performance level for each limit state and the degree of detail that each should receive also need careful consideration. ***Secondly***, the difficult and major issue of how to achieve the specified performance levels for each limit state with ‘adequate reliability’ needs to be tackled, especially if Eurocode 8 is to achieve the status of ‘international seismic code of choice’. As one important example, the lateral strength demands of the code are much greater than those for equivalent structures designed to US or New Zealand codes, and though there is evidence that the latter may be insufficient in this respect, at any rate for high rise buildings (see for example Willford *et al, 2008),* the lateral strength requirements of Eurocode 8 need serious review. The authors cannot quote specific cases in which the greater lateral strength demands of Eurocode 8 led to a rejection of its use in favour of other codes, but would be surprised if this has not already happened.
4. *Provides guidance on emerging technologies*
   The current provisions for base isolated buildings are insufficient, and there is nothing on supplemental damping and other current innovative techniques of improving seismic performance. This needs to be addressed!
5. *Applicable across a wide range of seismic hazard conditions (very low to very high)*
   Effectively Eurocode 8 provides for three levels of seismicity, namely **very low** (where the robustness and other provision of non-seismic Eurocodes are deemed to provide adequate

seismic reliability), **low** (where a lateral strength check using low values of the behaviour factor q is required, but seismic detailing and capacity design are not required) and **moderate to high**, (where full seismic analysis, detailing and design are required). In essence, that appears to be a sufficiently nuanced approach. However, the definitions of the transitions between the three conditions needs review; the UK National Application Document to Eurocode 8 provides an alternative approach, and recognises that not only the level of regional hazard (very low for Great Britain), but also the Consequence Class (i.e consequences of failure) of the particular structure under consideration, as well as its structural form and local soil conditions may need to be accounted for when deciding if seismic design is needed. It may also be that the case of masonry design in areas of low seismicity should receive special treatment, perhaps in the form of largely qualitative provisions.

6. *Specification of design ground motion*.
   Eurocode 8's current specification of ground motions using a single value of peak ground acceleration (PGA) coupled to standard spectral shapes is clearly inadequate and is generally considered obsolete. The spectral shapes currently recommended are also inadequate to capture the known variation in seismicity across Europe; for example in Romania and Portugal the spectral shapes are considerably different to the norm. Although individual countries have the option to define more appropriate shapes within their national annexes (and some countries have exercised this option), the current recommendation results in a lack of consistency between countries on how hazard is defined. For over a decade US codes have used short and long period spectral acceleration maps to define the spectral shape. A similar approach would overcome most of the issues of variation of hazard characteristics across Europe. In addition Eurocode 8 is silent about the designer or client choosing to develop site specific hazard spectra. Clearly this is not possible for all projects but should be permitted, assuming an appropriate level of study is undertaken. Other more minor issues also exist, for example the values of the period T_D corresponding to initiation of constant spectral displacement. The recommended values of T_D values are thought to be low, which could result in the under-prediction of displacement demand for long period structures, such as tall buildings, long bridges or LNG tanks.
7. *Methods of analysis*.
   Eurocode 8 currently provides that ductility modified response spectrum analysis is the 'reference' method for building structures, with equivalent static analysis allowed for simple buildings and non-linear static and dynamic methods given partial treatment. That was probably the right choice for the world as it was at the end of the 20th century, but is no longer adequate for the second decade of the 21st. More complete treatment is needed of non-linear methods of analysis; the more recent developments in displacement based design (for example, Priestley *et al*, 2007) should probably be included and a model for EC8 has been proposed – see www.iusspress.it/pc/viewPrd.asp?idcategory=25&idproduct=96. Sufficient guidance is needed so that clear and comprehensive guidance is given on the analysis of innovative structures incorporating novel devices. A more difficult decision is what should replace ductility modified response spectrum analysis as the new reference method. The theoretical flaws and inconsistencies in the method's treatment of non-linear behaviour are powerful arguments against its use, yet in many ways it has served rather well in ensuring that building structures have adequate lateral strength, when used in conjunction with other measures such as capacity design, controls on structural irregularity and ductile seismic detailing. The question of whether an elastic response spectrum remains the best way of specifying design ground motions is another difficult one, which should be examined.
8. *Applicable across the entire range of structural types covered by the Eurocode suite*
   Having a common approach to the design of structures as diverse as buildings, bridges, water towers and pipelines is one of the greatest current strengths of Eurocode 8, and the Eurocode suite more generally, and one of the strongest elements in its claim to be 'international standard of choice'. But ideally, the Eurocodes should fling their net even wider, to cover (*inter alia*) dams, large buried structures and perhaps even nuclear power plants.
9. *Guidance on the seismic assessment and retrofit of existing structures*.
   In the view of the authors, Part 3 of Eurocode 8 is in many ways unsatisfactory. The guidance

it gives on both assessment and retrofit design is much less helpful and comprehensive than the US Standards ASCE 31 and 41. Those US documents set a high standard to aspire to – and of course exceed! The analysis methods proposed by EN 1998-3 are also rather curious, and in urgent need of review. The unique information present in the informative annexes of Part 3 is impressive, but perhaps does not have the degree of testing needed for fully confident acceptance by design engineers.

4. SPECIFIC SUGGESTIONS FOR CHANGES

Discussion now follows on the specific changes needed to address some of these aspirations.

4.1. Hazard and design ground motion definitions

Several issues need to be considered, as follows. In all cases, the international precedents being developed by the Global Earthquake Model foundation (www.globalquakemodel.org) should be taken on board, and should the results of the SHARE project (www.share-eu.org).

4.1.1 Seismic hazard maps showing spectral values at multiple structural periods
To ensure a consistent approach across Europe, the authors recommend the development of spectral acceleration maps at multiple structural periods, similar to the short period and one second spectral acceleration maps given by ASCE 7 (ASCE, 2010) for the United States and which have also been developed for other countries such as Saudi Arabia and the United Arab Emirates. Eurocode 8 need not limit itself to two structural periods; one possibility would be to recommend three separate maps of peak spectral response on rock, one each for acceleration, velocity and displacement. These maps could then be used to define appropriate response spectra.

4.1.2 Probability levels for seismic hazard maps
Hazard maps are needed at two or possibly three levels of probability as has been done for use with the Russian code SNiP II-7-81(Russian Academy of Sciences, 2001), in order to be able to verify that the corresponding performance levels are satisfied.

4.1.3 Definition of spectral values
The issue of how spectral ordinates are defined needs review; for example, should the definition be based on max-of-2-recorded, as at present, or on geometric mean or on max-of-all-orientations?

4.1.4 Ground type and site response analysis
One leading aspect of Eurocode 8 is the definition of site class, and in particular the recognition in ground type E, that presence of a relatively thin layer of soil over bedrock is an important consideration for design ground motions. However, the code should provide the option to use site response analysis to characterise the amplification and attenuation of bedrock ground motions directly rather than just relying on some enveloping coefficients, such as F_a and F_v as defined by ASCE 7 (ASCE, 2010). Additional cases also need to be defined where site response analyses should be mandatory; clause 20.3.1 of ASCE 7 provides a possible checklist.

4.1.5 Use of direct calculation of hazard as an alternative to use of a national seismic hazard map
The code should permit the calculation of seismic hazard directly. Clearly such analyses are very specialised and a technically challenging and clear specification will need to be developed to ensure that site-specific studies are suitably conservative and not just used as a means for reducing the design load.

4.1.6 Dependence of spectral shape on ground motion intensity
One thing to note is the significant difference between the S factor in EN 1998-1 and the F_a and F_v factor specified in NEHRP. Figure 1 below shows a comparison of amplification factors at long periods, ranging from areas of low seismicity (PGA = 0.075g) to high seismicity (PGA = 0.40g) and

compares it to the Eurocode 8 Type 1 (high seismicity) and Type 2 (low seismicity) spectra. The difference is very marked and it should be investigated, especially for Eurocode 8 site class C and D, where the difference is greatest. It should be noted that the difference is almost insignificant at shorter periods.

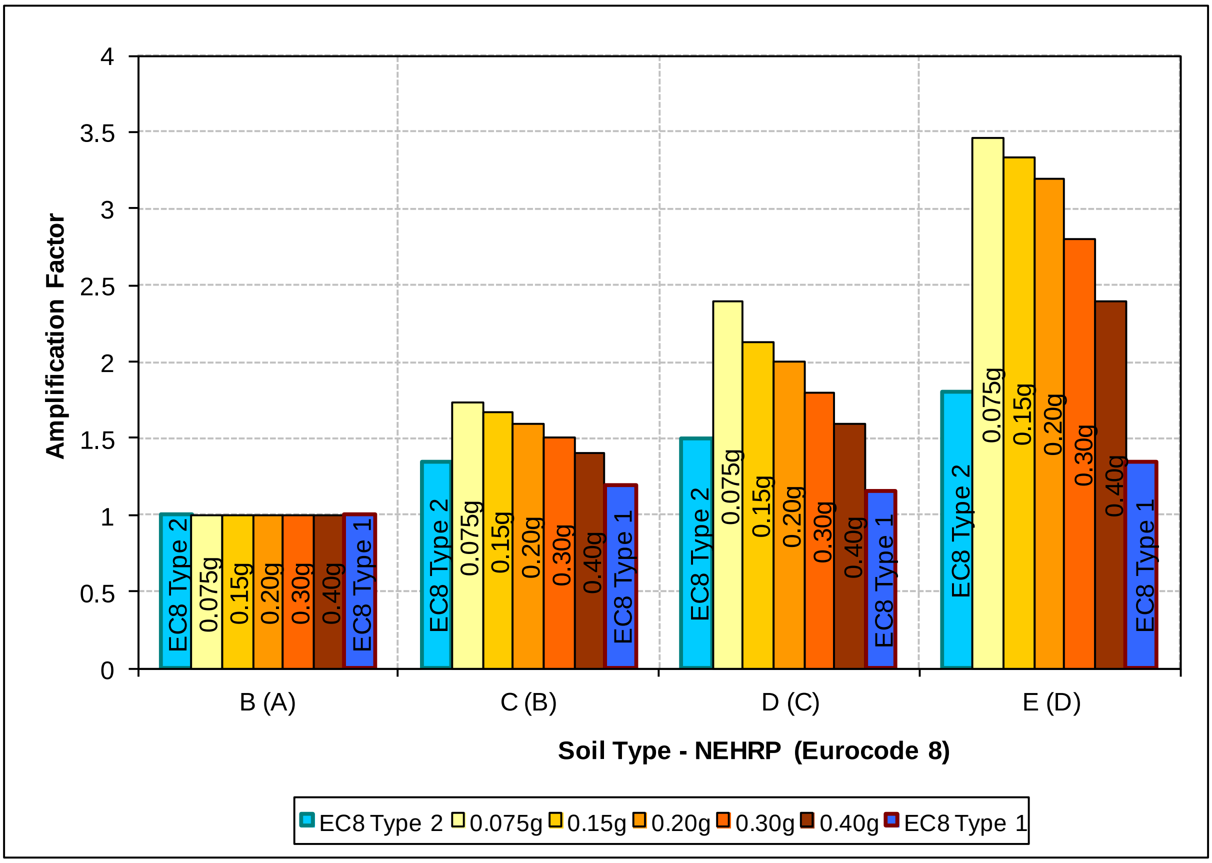

Figure 1. Comparison of Eurocode 8 and NEHRP amplification factors for long periods

4.1.7 Scaling of time histories

Finally, the selection and scaling of time histories need to be further developed, taking into account recent work such as ATC 82 (NEHRP Consultants Joint Venture, 2011). In particular it should now be standard practice for a minimum of seven time histories to be used, as the variability of responses from similarly scaled time histories is otherwise too great. In addition the Conditional Mean Spectra (Baker, 2011) concept should be permitted as an allowable alternative, so time histories are selected or developed that have greater realism and the potential to challenge the structural performance more severely.

4.2 Geotechnical issues

Eurocode 8 Part 5 is one of the best geo-seismic codes to have been published, and the original authors should be congratulated at covering the important aspects. However, there are a number of issues that need amending as they are either overly conservative or are now considerably out of date.

4.2.1 Assessment of liquefaction potential

Section 4.1.4 of Eurocode 8 Part 5 describes the requirements for assessing liquefaction potential. Furthermore the code provides a normative methodology which relies on SPT testing in Annex B. Since the code's development there have been numerous developments in liquefaction assessment methodologies, for example Cetin *et al* (2004) and Idriss and Boulanger (2004). The code should allow the latest methods to be used, and a choice between alternative methods of in-situ testing such as CPT or shear wave velocity should be explicitly permitted. It should also be noted that in particular circumstances, the methods described in the current Appendix B may be potentially unconservative, especially for materials with high fines content. At the very least Appendix B should be made informative rather than normative.

4.2.2 Earth pressures on retaining walls

Annex E provides guidance for the calculation of earth pressures on retaining walls, using either the Mononobe-Okabe method for flexible walls or the Wood (1973) method for rigid walls. As has been shown by Atik and Sitar (2008), who carried out a range of centrifuge tests on retaining walls, the rigid wall assumption used in Wood's method is overly conservative. Furthermore they have shown that designing retaining walls for maximum dynamic earth pressures and maximum wall inertia is overly conservative and unnecessary. Ideally the code should be requiring designers to carry out appropriate finite element analysis of such problems, so the soil-structure interactions can be properly addressed, rather than using methods which are at least 40 years old.

4.2.3 Deep basements and effective ground type

The impact of deep basements on structural response has been known for some time, yet very few codes permit a change in effective ground type for deep basements passing through loose or soft surficial soils to more competent bedrock. For example Lubkowski *et al* (1998) showed that a deep basement passing into bedrock responded due to the bedrock motion and not the surrounding soil.

4.3 Methods of analysis

Chapter 5 of EN 1998-1 was distinctive in placing ductility curvature demand and supply μ_ϕ explicitly at the centre of its requirements for ductile detailing of reinforced concrete members. This was a radical and theoretically rigorous step impossible to imagine as appearing in the pragmatically based codes of the USA! However, linking μ_ϕ to the behaviour or ductility factor q was an essentially flawed concept, although it was necessary given the role of response spectrum analysis as the reference method of analysis. The flaws arise because q is a global measure of ductility demand, which gives a poor prediction of local demand expressed by a parameter such as μ_ϕ, and hence an equally poor predictor of performance. Evaluating local ductility demand necessitates a non-linear analysis, and although it is true that Eurocode 8 gives more guidance on the use of non-linear static (pushover) analysis than appeared in any other contemporary code at the time of its publication, it was not complete for building structures in Part 1, although it was for bridges in Part 2.

Given the advances in available computing power and (arguably) more widespread understanding of complex non-linear analysis, there seems a clear case for moving away from response spectrum analysis as the 'reference' method. The nature of its replacement is more problematic. It needs to give direct information on the spread of non-linear behaviour through a structure, because this can then be linked directly to structural performance. It also needs to be linked to the ways in which design ground motions are specified, and it is hard to imagine these will change from being based on spectral parameters for many years to come. Non-linear static analysis certainly ticks both boxes, but there are issues on how to deal with multi-modal, multi-directional response which might be difficult to solve in a way suitable for inclusion in a code. These issues will need careful consideration and debate.

4.4 Ductility classes

Currently, three ductility classes are recognised, namely high (DCH) and medium (DCM) which are recommended for areas of medium or high seismicity, and low (DCL) for areas of low seismicity. Allowing the designer the freedom, within strictly prescribed limits, to balance provision of strength against provision of ductility is in principle a commendable idea, but in practice it has not worked out well.

For concrete buildings, as noted above, the DCH rules for concrete often appear to be hard to satisfy in practice, and in any case there are two general reasons why providing high ductility is often of no advantage. Firstly, structures such as tall or flexible buildings which are governed by deflection rather than strength gain no advantage from high levels of ductility. Secondly, with increasing emphasis on serviceability performance, a high ductility option is becoming less attractive. The best option is likely to be to dispense with the DCM/DCH distinction altogether. For concrete structures, a radical review of DCM provisions would be needed; some of the existing rules for DCH (e.g. for shear strength of walls) could be moved to informative annexes. For steel buildings, the DCM/DCH distinction makes little practical difference in any case, and its removal would be a less radical change.

4.5 Rules for masonry and timber buildings

Safe and simple rules for low rise domestic buildings in masonry and timber are clearly important. Section 9.7 of Eurocode 8 Part 1, commendably, gives rules for masonry buildings which do not require a seismic analysis. However, they have not found much favour, suiting the needs of neither the low seismicity areas of northern Europe, nor the high seismicity areas of southern Europe. A fundamental review seems needed, accommodating the needs of both the north (where much research has recently been carried out) and the south. A review of the provisions for confined masonry, which has been the subject of work internationally, is also needed. Chapter 8 on timber buildings needs review, too; the pragmatic rule based approach of US codes might teach us many useful things here.

4.6 Base isolation and supplemental damping

In the authors' opinion, the rules of chapter 10 of Eurocode 8 Part 1 for base isolated structures form an incomplete and unsatisfactory basis for design, compared with those currently found in US codes, and in places chapter 10 sits uneasily with the rules for base isolated bridges in Part 2. Generic requirements for passive methods of response control, including base isolation and supplemental damping, should not appear at the end of Part 1, as they do now, but in Chapter 2 – performance requirements and compliance criteria –which should also perhaps refer to other systems, such as active control. Separate chapters on both base isolation and on supplemental damping in buildings are then needed to follow the material specific chapters for buildings.

5. CONCLUSIONS

Extensive revisions to Eurocode 8 are desirable, possibly to a greater extent than for any of the other structural Eurocodes. Before embarking on such revisions, it is suggested that it is essential to formulate a clear vision for the future of the code. It is fairly clear that funding for such a task, let alone for the radical revisions of the code that might follow, will not be provided by CEN. It is therefore proposed that EAEE (European Association for Earthquake Engineering) should as a matter of urgency set up a working party of distinguished European practitioners and academics in earthquake engineering, tasked with providing a vision and roadmap for the future development of Eurocode 8. In order carry the work through to a successful conclusion, funding, ideally through the European Union, would be needed.

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