2019 SECED Conference
Earthquake risk and engineering towards a resilient world
9-10 September 2019, Greenwich, London

PREPARING EUROCODE 8 FOR MID-21ST CENTURY SEISMIC ENGINEERS

Edmund BOOTH[1]

Abstract *In 2013, a Working Group (WG1) of the European Association for Earthquake Engineering (EAEE) was established, entitled 'Future directions for Eurocode 8'. WG1 did not set out to make detailed proposals for revisions to specific clauses of EC8; rather, inspired by the example of the seminal SEAOC document 'Vision 2000' published in California in 1995, it set out to propose broad directions and general principles that EC8 should follow. Its first report was published in December 2018, covering recommendations for both the Second Generation of EC8, currently being prepared, and also looking ahead to a future Third Generation of the standard; the report is freely downloadable from the EAEE website.*

WG1 is now preparing a second report directed exclusively towards the Third Generation of EC8, which it hopes to publish in 2020. It will review those of its previous proposals which were not included in the Second Generation (although many have been adopted) and will consider whether they might still be appropriate for the Third Generation. It will also discuss other, perhaps more radical, changes which could be considered for the Third Generation. These include how national seismic zoning maps might develop, how seismic performance goals should be determined and specified, the role of EC8 in assisting engineers with the seismic assessment and retrofit of buildings, and more generally, how the anticipated radical changes to the earthquake engineering profession, including the tools at its disposal, should be reflected in EC8.

Introduction: WG1- future directions for Eurocode 8

History and activities of WG1 to date

In 2013, the European Association for Earthquake Engineering (EAEE) established a Working Group entitled 'WG1: Future directions for Eurocode 8'. Its inspiration was the seminal US report Vision 2000 report (SEAOC, 1995), and its purpose was to make recommendations for future editions of EN1998, hereinafter EC8. The WG comprised 18 seismic engineering experts drawn from nine countries; it did not set out to make detailed proposals for revisions to specific clauses of the Eurocode but rather to propose the broad directions and general principles that should be followed. Its work was directed at both for the 'Second Generation' of EC8, being prepared at the time of WG1's first report, and also towards a future 'Third Generation' of EC8. The full scope is given in an appendix to this paper.

By the time WG1's first report was published (December 2018) a substantial number of drafts of the Second Generation of EC8 were available, some in a form expected to be nearly final. Many of the recommendations developed by the WG during its five years of existence had already been adopted by the Project Teams writing these drafts. Since eight of the WG members also served on the Project Teams, this is perhaps hardly surprising. The first report therefore recorded the WG's work to date and identified which of its recommendations were likely to be adopted in the Second Generation of EC8 and which of its unadopted recommendations might still need to be considered for the Third Generation. The report is freely available for open access on the EAEE's website (see link in the Reference section).

The report's scope was restricted to considering building structures, although WG1 may in future extend its work to non-building structures (bridges, towers and masts, etc.) included within the scope of EC8.

Future activities of WG1 – preparing EC8 for the mid-21st century

The Second Generation of the Eurocodes is still some way from final ratification – the current anticipated date is 2025 – so it may seem strange to be thinking already about a Third Generation.

[1] Principal, Edmund Booth Consulting Engineer, Tring, UK, edmund@booth-seismic.co.uk

However, this is exactly what WG1 is doing. There are currently 34 member states of CEN[2], the European Committee for Standardization, and ensuring that there is the opportunity for full discussion and subsequent consensus among them during the revision process is necessarily time-consuming. Moreover, although Eurocodes are nominally updated on a five-year cycle, the second major set of revisions will appear twenty years after first publication; European deadlines have a long tradition of being postponed! By contrast, the Vision 2000 document referred to earlier was so successful in the context of the clockwork regularity of the four-year cycle of revision for US seismic standards. Moreover, the seismic revisions are dominated by the Californian earthquake engineering community; this is in stark contrast to European seismic standards, where the widely differing approaches to seismic engineering are both a drag on speedy revision - but also a huge resource.

Arguably, SC8, the CEN sub-committee responsible for EC8, did not prepare fully enough in advance for the scope of revisions that it proposed to CEN for the mandate for revising EC8. To a certain extent, its hands were tied because there was a clear instruction from CEN to maintain 'stability' in all the Eurocodes – i.e. to limit the changes involved. This was because the switch from national standards to Eurocodes had caused significant additional work for structural engineers and was far from universally popular. Therefore, CEN did not want to be seen as making new demands on the profession just as it was beginning to get familiar with the First Generation of the Eurocodes. It has to be said that even in the UK, where the National Standards Body has been very active in promoting the Eurocodes and where the national standards they replaced have been officially 'withdrawn' (i.e they are no longer updated), the old withdrawn standards are still used by a few designers. Official support in some other parts of Europe is rather less complete.

Arguably, in the fast changing field of seismic engineering, continuous and quite radical developments in the field are the norm, and so EC8 may present a somewhat different case from the other Eurocodes, where the technology is generally developing less rapidly. Certainly the changes that are emerging from the near final drafts of the first parts of EC8 are much more significant that I personally had expected. However, the opportunity – and indeed necessity – is likely to exist for making even more radical changes in a future Third Generation edition of EC8, but they need to be debated and prepared well in advance. The second report of WG1 aims to start that debate

Proposed topics for the second report of WG1

Unadopted proposals from the first report

As noted previously, many of the changes that the WG proposed for the Second Generation of EC8 are likely to be adopted in its final version. However, a number were not adopted; for example, the WG recommended that hybrid structures (i.e. structures consisting of two separate structural systems or materials) should be added to the scope of the standard, but this topic did not appear in the CEN mandate for revising EC8 and understandably is not included in the drafts currently available. However, it probably should be considered for the Third Generation. There are a number of such unadopted proposals in the first report, many specifically directed towards the Third Generation, and the WG will consider whether they are still valid. It should be noted that the WG had no intention of reviewing and commenting on the Second Generation drafts; this is solely the task of CEN sub-committee TC250/SC8, and the representatives of the National Standard Bodies that sit on SC8.

The rest of this paper sets out some of the topics that the WG will develop in its second report, all of which are directed towards the Third Generation. As befits suggestions for a document which will not be drafted for at least another 10 years, the recommendations are necessarily of a very broad nature.

Seismic hazard, and the setting of design ground motions.

A major change in the Second Generation of EC8 will be the abandonment of a single parameter - peak or zero period ground acceleration - to define regional seismic hazard in favour of a dual

[2] There seems little doubt that the UK will continue its membership of CEN and play a very active role in the future development of the Eurocodes, whatever its future relationship with the European Union (BSI, 2018)

parameter system, based on short period and long period spectral accelerations. This will bring the standard into line with the changes made in US standards some 20 years ago. Another likely change is that the value of these parameters developed by the SERA project (www.sera-eu.org/en/home/) will be reported within EC8 and given as the recommended, but not mandatory, values for National Standards Boards to adopt. This would in principle allow design response spectra to reflect uniform hazard spectra much more closely than at present, and also to provide data for the much wider range of return periods now referenced by EC8. It would also reduce the risk of discontinuities in design ground motions across national borders.

These are very significant changes. However, further advances in seismic hazard assessment are very likely to be made in the next decade, and the WG will be considering the following issues and no doubt others too.

- Epistemic (knowledge) uncertainties in hazard assessment, estimated by means of logic trees, are generally found to have a significant impact on results. The best way of allowing for the effects on design motions of aspects that are under-researched or controversial needs to be carefully reviewed, in the context of the probabilistic basis of the standard, discussed in the next section.
- Review is needed of the degree to which local factors (basin effects, topographical factors, fault proximity) should be taken into account to modify the regional hazard. Both First and Second generation versions of the code allow for these local factors to some extent, and indeed the modification they cause to ground motions can be quite dramatic, but they are not easy to calculate. However, there is a need to balance accuracy with what can be implemented practically by designers. Moreover, ground motion prediction equations account for one-dimensional soil effects in only a rather broad way, and do not currently include other local effects, which might then be considered as adding to the randomness and uncertainty of ground motion predictions.
- Given the tendency of seismic hazard estimates to develop quite swiftly with time, perhaps the parts of EC8 dealing with design ground motions should be subject to more frequent review and update than other parts.
- Both First and Second Generation editions of EC8 base design spectra on uniform *hazard* estimates. By contrast, US standards have changed to uniform *risk* estimates – the spectral accelerations at each period which result in a specified annual probability of exceeding the limit state of interest for a given type of structure. This has a number of attractions and should be considered as a possibility for the Third Generation; in particular, the threat of 'beyond design basis events' is accounted for in a rational way. However, in addition to the shape of the hazard curve, it is also influenced by the characteristics of the structure assumed when calculating the uniform risk spectrum, which is therefore structure as well as location dependent' the consequences of this need to be reviewed.
- Setting design ground motions by means of response spectra is currently a near-universal international practice in building standards. However, 10 years from now the use of ductility modified response spectrum analysis, and indeed pushover analysis, may well be on the wane; perhaps other means of hazard definition, such as regional sets of ground motion time histories, may become more appropriate and useful to designers.

Seismic risk and seismic performance standards

The use of probabilistic measures to set the values of safety parameters used in structural engineering design was first developed in Russia after the second world war, and is deeply embedded in EN1990, which sets the basis of design for all the Eurocodes. The application of these 'limit state' concepts to earthquake engineering can however be traced to the US, and an early statement of the 'performance based' principles involved is given in the Vision 2000 document (SEAOC, 1995) referred to earlier.

Limit state design still has its critics for design in the UK, where gravity loads, and in some cases a well-researched wind environment, tend to dominate the risk of exceeding a limit state in the absence of design or construction errors. Alasdair Beal (e.g. Beal, 2010) continues to write scathingly about the design complexities based on probabilistic principles which are required by EN1990, arguing that they come from purely theoretical considerations and have little or no advantage for economy or utility in the real world. While I reluctantly concede that Beal may make have a point in the well-controlled loading and regulated environment of the UK, I believe a probabilistic basis for design is essential in areas of moderate and high seismicity. This is because the statistical variation in loading is so high, albeit usually subject to high epistemic ("we don't have much of a clue") uncertainty.

The Second Generation of EC8 will introduce a further development of performance based design requirements. Thus, in Part 1 of EC8, it introduces four limit states compared with two in the First Generation, and the definitions of the limit states are more extensive. However, verification is still principally achieved by means of load factors, and the limit state definitions are insufficient for LNG plants, dams, ports or major bridges which need much more definition on both design levels and limiting criteria. Moreover, checking the 'Significant Damage (SD)' limit state will be the only mandatory requirement for most structures, although national standards bodies have the power to require other limit states, such as 'Damage Limitation (DL)', to be checked as well. In the First Generation, checks on both SD and DL were mandatory, but the latter were rather crude, being based solely on limiting drifts. In its first report, WG1 argued that eventually EC8 should consider setting out a much more extensive performance based design approach, allowing clients to choose the level of risk they wanted of exceeding a range of economic and functional limit states, while of course ensuring a minimum life safety standard. These are issues which require careful consideration and review.

Setting acceptable performance standards

The provisions of the Eurocodes are developed by technical committees, reporting back to their National Standards Bodies (NSBs). Final ratification comes from voting by the NSBs, which in principle allows a wider community than that of structural engineers to have their say, although in practice this wider involvement is rarely, if ever, realized. This is a perfectly satisfactory arrangement for technical clauses – the cyclic shear strength of reinforced concrete, say, or the design of steel moment frame connections – but the technical committees also make judgements on what performance standards should be aimed for. For example, is the 'wider community' concerned only with human safety, or do other considerations play an equally important part – for example post-earthquake recovery *or* community cohesion *or* preservation of cultural heritage? On a broader field, societal pressure to address issues of sustainability and climate change may become very powerful in shaping future structural standards; there may be lessons to be learnt from how the car and aerospace industry has handled these issues. In my Mallet-Milne lecture (Booth, 2018), I quoted Scott Steedman, director of standards at the British Standards Institution, as follows:

> In other fields [than seismic engineering], for example in smart cities, the development of better practice standards has followed a different path, a path that may provide lessons for earthquake engineers and other technically focused communities. Smart city projects will clearly require hundreds of new standards addressing highly technical issues. But as this is a new field, there was an opportunity to take a holistic approach and to ask city authorities themselves what they needed by way of better practice standards to accelerate their work programmes. The city authorities asked for standards of terminology, guides for city leaders (see reference BSI, undated 1), framework and decision making, even business case standards. These new types of standard were made in a cooperative effort by all the affected stakeholders, including the technical experts.

One impression I derived from the work I did on my Mallet-Milne lecture was that good seismic resilience depends on more than just the presence of competent earthquake engineers; it is also essential that there is an active participation and acquiescence by the wider community in the required measures. Adopting Scott Steedman's ideas might help with this, and the ideas are worth pursuing by WG1, I hope with Scott's help.

Geotechnical aspects

The Second Generation of EN 1998-5 has attempted to begin a transition towards displacement based, as opposed to stress based, geotechnical seismic design. However, this transition has barely started and WG1 will consider ways in which it can be progressed towards full implementation.

'Non-structural elements'

The bulk of EC8 deals with the design of structural elements and their foundations, but the other parts of buildings not only contribute a substantial part of their economic value, but also often play a major part in seismic safety and post-earthquake recovery. A Third Generation of EC8 should consider ways in which the seismic design of non-structural elements could be dealt with more fully and accurately, perhaps to include the possibility of creating a new part of the Eurocode specifically to address the subject. This new part might include assessment as well as design, a topic notably lacking from the current Part 3 of EC8.

Seismic retrofit of buildings

The Second Generation of EN 1998-3 (EC8 Part 3) presents much new data on the assessment and analysis of concrete, steel, masonry and timber structures, in particular for elements which do not conform to current standards of seismic design, or which have been retrofitted in various ways. The approach in EC8 Part 3 is essentially analytically based and contrasts with a wider approach taken by recent US and New Zealand standards, where qualitative and judgementally based approaches, informed by experience assembled from field data of earthquake performance, are also included and play an essential part. *Inter alia*, this has the important advantage of allowing a phased approach to assessment, so that an initial judgement on what the main issues are likely to be – and indeed, on whether the structure in question is a seismic disaster, a low-risk case or somewhere in between – before moving on to the finely-honed analytical procedures that is the current strength of EC8 Part 3. The possibility of adopting some of these ideas in the Third Generation of EC8 Part 3 is well worth considering, along with similar approaches taken in Greek and Italian national documents. One issue to consider is whether, with this more qualitative approach, it is still possible to cover the very wide range of building types found across the member nations of CEN.

Advanced building systems

There seems little doubt that by the time the next generation of EC8 is being planned, new and increasingly sophisticated building systems will be available. Seismic engineers will have a wider choice of sophisticated technologies to provide earthquake resistance and resilience. They may also need to consider how to protect other aspects of smart building technology (i.e., those not specifically designed to improve earthquake resistance); this may lead to issues previously faced only by designers of highly sophisticated installations such as nuclear power plants, and not by designers of standard residential, commercial or industrial buildings. To what extent should EC8 cover such issues?

Currently, EC8 is somewhat ambivalent on this. On the one hand, it seems that the main intention of the Second Generation EC8 is intended to cover 90% of 'standard' structures without attempting to cater for the high-tech end of the scale. On the other hand, the Second Generation of EC8 contains many complex analytical provisions, and has added a clause (i.e. whole chapter) on buildings with energy dissipation systems, as well as revising the clause on seismic isolation systems.

Within the context of EC8's provisions for buildings (as opposed to other types of structure), it could be argued that limiting EC8's scope to 'standard' buildings would best suit the needs of structural engineers in CEN member nations. This is because the provisions can be shorter and simpler (incidentally, a key demand of CEN) and that 'standard' buildings contribute far more than proportionately to seismic deaths and injuries than 'high tech' ones. On the other hand, excluding some new technologies and possibilities from EC8 might discourage their use in cases which might be highly beneficial for citizens of CEN member nations. Also, one of the 'selling points' of the Eurocodes has been that it is an advanced, state-of-practice code; restricting its scope in this way might reduce EC8's appeal and applicability both within Europe and outside.

Within this context, various options should be examined for the scope of the Third Generation of EC8. Some possibilities are as follows; note that they are not necessarily mutually exclusive.

- Cover high tech design options in 'informative' (i.e. advisory rather than normative) annexes, leaving the main normative part of the standard to cover general principles and more usual cases.
- Attempt to represent the most up to date 'state-of-practice', allowing countries to develop simplified version of the standard for standard cases. There is a precedent for this approach in the ISE/AFPS manual on EC8 (ISE/AFPS, 2010).
- Give normative guidance on the general procedures to apply to the design of unusual – and in particular high tech – buildings not covered elsewhere in the standard, but leave it to the designer to demonstrate that the general principles are followed.

Particular aspects associated with high tech buildings that might be considered for inclusion in a future EC8 are suggested by Damian Grant (personal communication, 2019) as follows.

- *Further provisions for low damage design* – see for example Pampanin (2012).
- *Further provisions for tall buildings*, treated as a special case of non-standard buildings. Many tall buildings are – and will continue to be – under construction not only in Europe but also in other parts of the world that are adopting the Eurocodes.
- *Development of procedures for peer review and the relation to the building regulation process.* This applies particularly in relation to tall buildings, but also more widely for structures not covered by EC8. It is notable that in the US, the use of performance based earthquake engineering methods such as those originally published by PEER (Porter, 2003) has subsequently developed quite markedly. In place of a purely performance based approach, which arguably allowed designers too much freedom, a process monitored by peer review has emerged in which sophisticated analytical methods controlled by the designer have been combined with more prescriptive and standardised measures, building on the experience gained in the last 15 years.

To Damian's list might be added consideration of whether active seismic control will be an idea whose time has finally come by 2030; in aerospace, adaptive control has been relied on since the time of the first Airbus, and an adaptive timber dome structure (Sobek, 2016) has recently been constructed to resist moving loads, so perhaps future seismic standards should cover active control, too.

Digital revolutions

The practice of structural engineering has changed beyond recognition since I started in the profession 50 years ago with my slide rule and drawing board. Even since drafting the First Generation of EC8 in the late 1990's and early 2000's, things have moved on in a radical way. The possibilities afforded by the near-universal availability of powerful computing facilities to seismic engineers are recognised to some extent in the Second Generation; for example, the increased sophistication of the analysis methods required would be scarcely implementable without modern hardware and software. However, the Third Generation may need to go much farther than that. Two aspects that WG1 wishes to review (and no doubt there will be more) are as follows.

- The format of Second Generation EC8 will look rather similar to standards around 50 years ago (except in terms of length!) Perhaps the Third Generation should harness the possibilities afforded by digital publication, such as cross referencing between provisions, including those in other Eurocodes, presentation of formula with macros to tabulate design values and links to supporting and explanatory material. BSI Eurocodes Plus (BSI undated 2) currently provides this facility commercially for the First Generation of Eurocodes. If these possibilities were embedded in the original drafting of the standards, at least at a basic level, there might be significant advantages to the engineers applying the standard.
- More fundamentally, the increasing use of artificial intelligence, and other means of automating the design process, may fundamentally affect standards in ways that need to be considered. At the least, and in a rather negative way, quality assurance measures to avoid misuse of these techniques are likely to need specification. In a positive way, the possibilities opened up by them may need to be covered to some extent and perhaps even encouraged. For example, optimising designs to reduce lifetime carbon emissions might become mandatory if certain classes of project are to claim compliance with the Eurocodes.

Closing remarks

The practice of seismic engineering is likely to be very different by the time the Third Generation of EC8 is published. It is too early to write a detailed specification for it – that would be impossible; Andrew Marhall, a senior foreign policy advisor to six successive US presidents, said 'If you want your fortune told, ask a gypsy' (Financial Times, 2019) and there are of course huge uncertainties involved in trying to anticipate what changes might apply to the seismic world in ten or fifteen years. However, discussion needs to start now on what broad directions a mid-21st century EC8 might take. EAEE WG1 - "Future directions of Eurocode 8" - intends to continue its work by doing just that, and hopes to publish its findings in 2020. As convenor of the WG, I would greatly value any comments and suggestions for the WG's work that are emailed to me.

Acknowledgements

Thanks to Damian Grant and Ziggy Lubkowski who provided extensive and very helpful reviews of this paper, and to Tim Sullivan and Graeme Weatherill, who also commented most usefully. Although this paper draws on material in the consensus first report of WG1 (EAEE WG1, 2018), the opinions expressed are those of the author.

Appendix: Terms of Reference of WG1

1. Review state-of-practice and state-of-art methods in the seismic design of new buildings and their contents which are currently employed by engineers in Europe and elsewhere, and identify the ways in which EC8 currently does not address these methods.
2. Set out a long term vision for EC8 to be achieved by the year 2025.
3. In the light of the CEN proposals for the current evolution process, identify those changes necessary to achieve this long term vision which would be feasible within the current process.
4. Recommend changes to EC8 to take place during the subsequent evolution period, in order to achieve the long term vision more fully.
5. Prepare notes on additional aspects to consider for the seismic resistant design of non-building structures (bridges, towers & chimneys, pipelines, tanks, silos).
6. Prepare notes on additional aspects to consider for the seismic retrofit of buildings & bridges.
7. Deliver the report on the Working Group's findings and recommendations to the EAEE executive committee, with a copy to CEN sub-committee TC250/SC8.

NB: the second report of the WG will only cover buildings, as did its first report, so item 5) in the list above is not currently being addressed, and item 6) is only addressed for buildings.

References

Beal, A.N. (2010). *Eurocodes in Britain: the questions that still need answering.* Proceedings of ICE: Civil Engineering 163, February, pp. 27-34. Thomas Telford Ltd, London

Booth, E. (2018) *Dealing with earthquakes: the practice of seismic engineering 'as if people mattered'.* Bull Earthquake Eng, https://doi.org/10.1007/s10518-017-0302-8 (Accessed 02/04/2019)

BSI (undated 1). *A Guide to Smart Cities: How to start implementing standards in your city*. Available at: https://www.bsigroup.com/en-GB/smart-cities/A-Guide-to-Smart-Cities/ . (Accessed 24/04/2019)

BSI (undated 2). *Eurocodes Plus*. Available at: https://www.bsigroup.com/en-GB/our-services/standards-subscription-services/Eurocodes-Plus/ . (Accessed 03/04/2019)

BSI (2018). *Brexit and standards position statement*. Available at: https://www.bsigroup.com/globalassets/localfiles/en-gb/about-bsi/nsb/brexit/bsi-brexit-position-report-february-2018.pdf (Accessed 28/03/2019)

EAEE WG1 (2018). *Future directions for Eurocode 8: Report 1*. Available at: http://www.eaee.org/Media/Default/Working%20Groups/EEAE%20WG1%20-%20Report%201%20Dec%202018.pdf . (Accessed 03/04/2019)

EN 1998 Parts 1 to 6, *Eurocode 8: Design of structures for earthquake resistance.* European Committee for Standardization, Brussels, 2004 to 2005.

EN 1998-3. *Design of structures for earthquake resistance. Part 3: Seismic assessment and retrofit of buildings and bridges.* European Committee for Standardization, Brussels.

EN 1998-5. *Design of structures for earthquake resistance. Part 5: Foundations, retaining structures and geotechnical aspects.* European Committee for Standardization, Brussels

Financial Times, (2019). *Obituary, Andrew Marshall*. FT Weekend, 5th April 2019.

ISE/AFPS (2010). *Manual for the design of steel and concrete buildings to Eurocode 8*. Institution of Structural Engineers, London.

Pampanin, S. (2012) *Reality-check and renewed challenges in earthquake engineering: implementing low-damage structural systems – from theory to practice*. Bull N Z Soc Earthq Eng 45(4):137–160, ISSN 1174–9875

Porter, K.A. (2003). *An Overview of PEER's Performance-Based Earthquake Engineering Methodology*. Ninth International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP9), San Francisco. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.538.4550&rep=rep1&type=pdf. (Accessed 24/04/2019).

SEAOC (1995), *Vision 2000 Report: Performance-based Seismic Engineering of Buildings.* Structural Engineers Association of California, Sacramento, CA, USA.

Sobek, W (2016). Ultra-lightweight construction. International Journal of Space Structures, Vol. 31(1) 74–80.