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D2.6 – Suggestions for Updates to the European Seismic Design Regulations

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Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
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1. Recommendations to EuroCode 8 Committee

In order to make recommendations to the EuroCode 8 Committee on the future of seismic actions in design codes in Europe, the following activities were undertaken in WP2:

- A critical review of recent seismic hazard practice in many countries including US, New Zealand, Japan, Italy and Canada was undertaken, leading to Deliverable D2.2.
- Deliverable D2.3 considered the use of loss assessment for the calibration of seismic design codes.
- Deliverable D2.4 looked at the minimum capacity of buildings designed without seismic actions, to understand the level of hazard below which zonation is not needed (as a detailed description of the seismic actions for design would not be needed).

The preliminary recommendations from these deliverables, which were discussed with a number of European engineers in a final meeting on 20th January 2013, were divided into short-term, mid-term and long-term categories.

Short-term (using directly the outputs of SHARE)

1. The two spectral shapes (Type 1 and Type 2) anchored to PGA could be removed and replaced by zonation maps of F_0, T_B, T_C and T_D such that spectral shapes can vary with location and return period.
2. The use of site-specific spectral shapes would require a change in the approach to amplify the spectra which in the short term could be period-dependent and derived from current EC8 recommendations.
3. Should recommendation 1 not be adoptable immediately, it is recommended that Mw should replace Ms in the definition of Type 1 and Type 2 spectra.
4. Explicit recommendations should be provided regarding the means of estimating of the controlling scenario (e.g. disaggregation at the period of vibration of the structure of interest, multiple scenarios where necessary).
5. The k-value suggested within EC8 should be revised, and possibly based on the outcomes of SHARE. An upper and lower bound return period that can be estimated with these k-values should also be reported in EC8. As an alternative to this, linear interpolation (in log space) between return periods could be permitted.

Mid-term (with more research, building upon outputs of SHARE)

1. New vertical spectral shapes need to be derived for EC8, building upon the outputs of WP4 (SHARE)
2. A zonation-based approach should be removed, and the UHS provided and used directly (through a web-portal).
3. Amplification factors and site classification table in EC8 could be updated, building upon the research from WP4. Deeper geological characteristics could also be accounted for in the site amplification.
4. Displacement spectra require more attention, and the current informative annex should be revised.
5. Further consideration on the use of the epistemic uncertainty could be given.

Long-term (with more research, building upon outputs of SHARE)

1. Significant modifications to the way in which seismic actions are presented within design codes in the future should be investigated, considering the following three suggestions which increasingly depart from current practice: i) Risk targeted seismic design actions; ii) The possible use of aggregate hazard analyses, rather than site specific, for design actions; iii) A new paradigm for the future of seismic design codes which considers the influence of design choices (in terms of stiffness, strength and ductility) on the aggregate losses to urban areas.

Each of these recommendations are further expanded upon in the following section. This report will be sent to the EC8 Committee, together with a request to attend their next meeting to present these recommendations.

2. Justification and Support for the Recommendations

Short-term Recommendation 1

Eurocode 8 defines the seismic action input in terms of the Peak Ground Acceleration on reference (Type A) bedrock (a_{gR}), which is used to anchor an elastic response spectrum. The shape of the spectrum is fixed by four points (a_g, T_B, T_C and T_D), together with F_0 which is an effective amplification factor, fixed at 2.5 for all soil conditions (Figure 2.1). The lower limit of the constant acceleration part of the spectrum is given by T_B, and the upper limit by T_C. The third parameter is T_D, which marks the lower limit of the constant spectral displacement part of the spectrum.

The recommendations provided in EN 1998-1 define two types of elastic response spectrum (Type 1 and Type 2). The former is intended to be applied when the surface-wave magnitude of the controlling earthquake is greater than or equal to M_S 5.5, the latter when it is less than M_S 5.5. The spectrum corner parameters (S, T_B, T_C and T_D) are defined for each spectrum type and for each soil type; these are Nationally Determined Parameters that are provided in the National Annex.

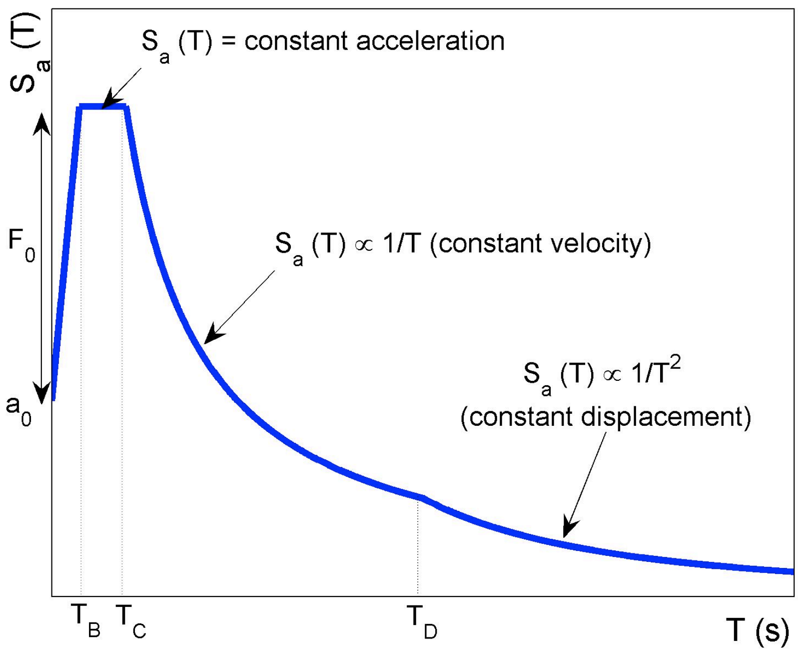

Figure 2.1. Eurocode 8 acceleration response spectral shape

Whilst the current Eurocode requires only PGA to anchor the elastic response spectrum, it has become widespread practice to define the seismic input in terms of a uniform hazard spectrum

(Abrahamson, 2000; 2006) or even a conditional mean spectrum (Baker & Cornell, 2006), as discussed thoroughly in Deliverable 2.2. Uniform hazard spectra for a number of return periods have been estimated across Europe within SHARE, and these have been used to estimate how the spectral shape in Figure 2.1 varies geographically and with return period. Deliverable 2.7 presents maps of these parameters (one example of which is given below in Figure 2.2), which could be provided as zonation maps within National Annexes such that engineers can select the parameters at a given site to better constrain the uniform hazard spectrum. Such an approach is a compromise between providing the uniform hazard spectra on a grid of points (see Mid-term Recommendation 2) and the current approach of just two spectral shapes (Type 1 and Type 2).

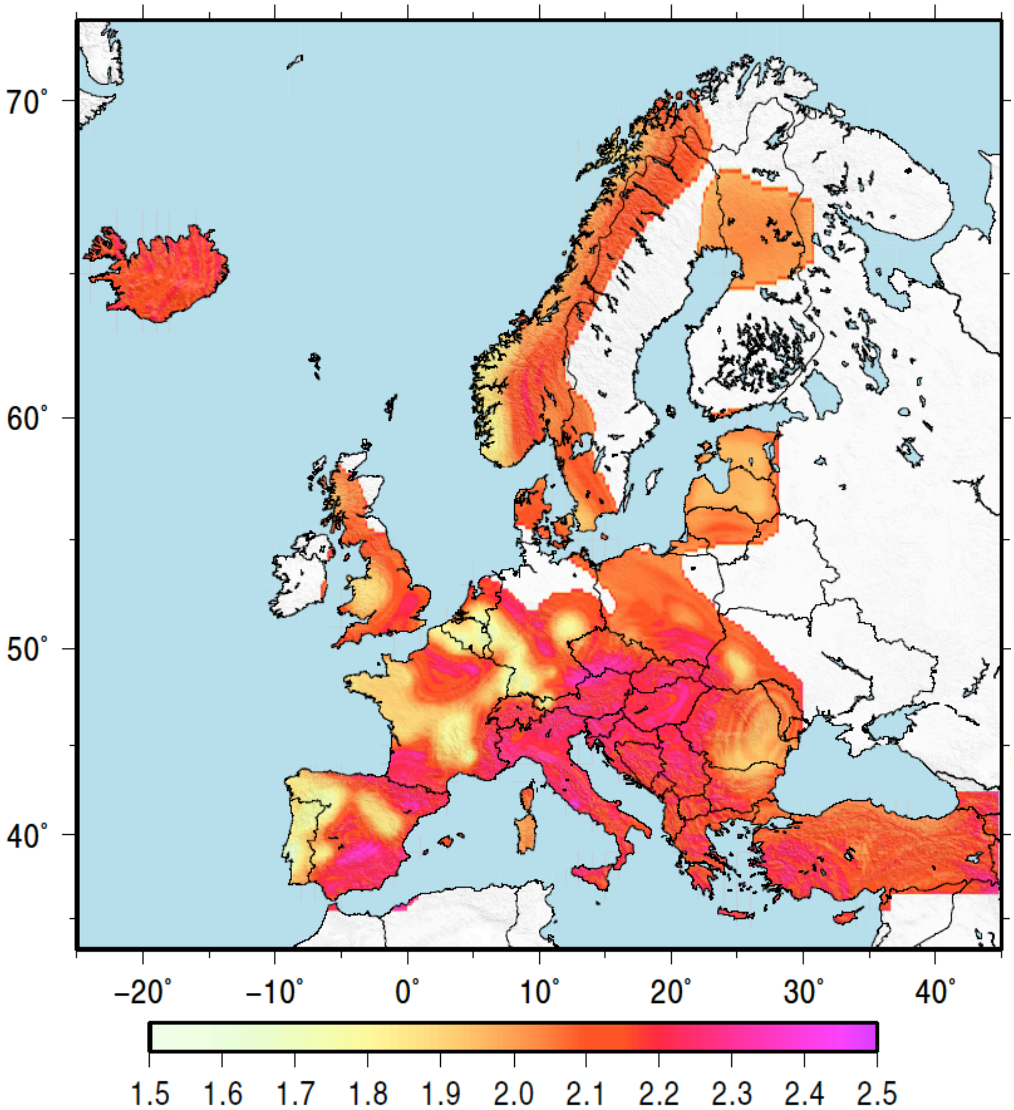

Figure 2.2. Spectral amplification factor F_0 derived from the SHARE area source model for the 475 year return period

Short-term Recommendation 2

The use of the SHARE spectral shapes for rock (as described above) would require a change in the approach to amplify the spectra in Eurocode 8, as the amplification changes the shape of the spectrum, and SHARE has not provided UHS for different site conditions. In the short-term, the amplification factors could be period-dependent, and derived from the current recommendations for spectral amplification in Eurocode 8.

Short-term Recommendation 3

Should Short-term Recommendation 1 not be adoptable immediately, it is nevertheless recommended that the magnitude definition used to distinguish between Type 1 and Type 2 spectra (surface wave magnitude, M_s) is replaced by moment magnitude, M_w, given that the latter has become the standard magnitude parameter in empirical ground motion prediction models and for probabilistic seismic hazard analysis in general. Conversion between magnitudes introduces additional error, which is entirely unwarranted given that the arbitrariness of the M_S 5.5 boundary. It is thus strongly suggested that this particular requirement be amended in EN 1998.

Short-term Recommendation 4

Disaggregation of the seismic hazard (McGuire, 1995; Bazzurro & Cornell, 1999), whilst rarely made explicit in seismic design codes, may be an inherent part of the seismic hazard process to meet other key provisions. This recommendation calls for explicit guidance within Eurocode 8 on the means for estimating the “controlling [scenario] earthquake”, which is required to define the Type 1 or Type 2 spectrum, and also to guide the selection of acceleration time histories in terms of compatible magnitude, distance, fault mechanism and site type.

Where the current EN 1998 provisions for the identification of the controlling earthquake scenario are most limiting is in the implicit consideration of a scenario earthquake based on PGA disaggregation. The simple categorisation of Type 1 and Type 2 spectra does not reflect the influence of larger magnitude earthquakes on ground motions at longer periods, which may be more relevant to the structure under consideration. For most structures it may be more appropriate to select the controlling earthquake scenario using disaggregation of the 1s spectral acceleration or peak ground velocity (PGV). Ultimately this means that disaggregation should be possible for several ordinates of the uniform hazard spectrum, and/or PGV, and that the design spectrum should correspond more closely to the uniform hazard spectrum than is currently prescribed in EN 1998 (see Short-term Recommendation 1).

Short-term Recommendation 5

Although the range of return periods recommended for performance requirements in EN 1998 is typical of those found in other codes, there is a complicating factor. The return period for each limit states is assigned as a Nationally Determined Parameter, thus allowing the value to be selected by each participating country's National Authority. It is therefore necessary for the hazard to be defined at a range of return periods, or allow for hazard at a site, to be scaled to intermediate levels. EN 1998 suggests a convenient scaling relation for this approach; however, the recommended scaling power (k) is shown to vary significantly from that suggested in the code. If the scaling approximation is to be applied, particularly by virtue of modification of the design return period within a National Annex, it may be useful to identify the k-value appropriate to each site (as presented in the maps in Deliverable 2.7) and to outline the limitations (in terms of upper and lower bound return periods) of the approximation.

As an alternative, linear interpolation (in log space) between return periods could be permitted within EN 1998 to allow the estimation of hazard at intermediate return periods not provided within the National Annexes.

Mid-term Recommendation 1

Table 2.1 presents the recommended values of the parameters to define the vertical response spectrum in Eurocode 8 for Type 1 and Type 2 spectra, based on the spectral shape given by the following equations.

$$0 \le T \le T_B:\ S_{ve}(T) = a_{vg} \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot F_0 - 1)\right] \tag{2.1a}$$

$$T_B \le T \le T_C:\ S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \tag{2.1b}$$

$$T_C \le T \le T_D:\ S_{ve}(T) = a_g \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C}{T}\right] \tag{2.1c}$$

$$T_D \le T \le 4.0s:\ S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C T_D}{T^2}\right] \tag{2.1d}$$

where:

- $S_{ve}(T)$ is the vertical elastic response spectrum (i.e., pseudo-spectral acceleration at vibration period T of a linear single-degree-of-freedom system)
- a_{vg} is the design vertical peak ground acceleration

- η is the damping correction factor with a reference value of $\eta = 1$ for 5 % viscous damping

Table 2.1 Recommended values of parameters describing the vertical response spectrum

Spectrum	a_{vg}/ag	T_B (s)	T_C (s)	T_D (s)
Type 1	0.90	0.05	0.15	1.0
Type 2	0.45	0.05	0.15	1.0

The required outputs of SHARE defined in Deliverable 2.1 did not include vertical spectra and thus these have not been computed. However, investigation of the database of strong-ground motion collected within SHARE (and presented in Deliverable 4.1) has shown that the spectral shape of vertical components and the ratios between horizontal and vertical spectral ordinates can vary significantly from those proposed within Eurocode 8. Considering that the latter are NDPs that can be defined within the National Annex, harmonised proposals for vertical spectral shapes across Europe are needed for future revisions to EC8 and should be considered in future research activities.

Mid-term Recommendation 2

With the development of a web portal for dissemination, as undertaken within the SHARE project, there exists a practical means of allowing designers to select spectral ordinates at a number of periods at a given site, in order to better constrain the uniform hazard spectrum (UHS) and to carry out disaggregation at different response periods. Such an approach is currently available in Italy (see http://esse1-gis.mi.ingv.it/s1_en.php). A zonation-based approach (either based on PGA or the spectral shape parameters, as discussed in Short-term Recommendation 1) would no longer be required under this scenario, but could be provided in parallel. As this would be quite a radical departure from the current Eurocode 8 practice, it has been recommended for mid-term implementation.

Mid-term Recommendation 3

Within WP4 of SHARE, an investigation on the need to modify the amplification factors and site classification table in EC8 was initiated (see Deliverable 4.3). Further research in this direction is needed, together with the development of uniform hazard spectra for different site conditions, in order to improve the definition of UHS on sites other than rock. This research would improve upon the results adopted for the Short-term Recommendation 2.

In addition, deeper geological characteristics could be accounted for in the site amplification within the code, (e.g. by using both the horizontal-to-vertical spectral ratio fundamental period (T_0) and Vs for the full soil column, as discussed in Deliverable 2.2).

Mid-term Recommendation 4

Displacement spectra require more attention in future revisions of Eurocode 8, and in this respect the current informative annex for defining a displacement spectrum should be revised. The map of the period T_D (which defines the constant displacement portion of the spectrum) presented in Deliverable 2.7 show that this value exceeds the 2 seconds recommended in the Eurocode 8 informative annex for much of southern Europe, and even extends well beyond 5 seconds in southern Italy, Greece and Turkey.

Spectral shapes may not be necessary (if the uniform hazard acceleration spectra go up to 10 seconds and the results are available on a web portal), but they might be practical as in some cases the UHS might produce accelerations that fall below the minimum level to be used in design.

Further discussion on displacement spectra is provided in Deliverable 2.7.

Mid-term Recommendation 5

The hazard curves produced within SHARE consider a number of sources of epistemic uncertainty, which are presented through hazard curves for different percentiles (e.g. 16^{th}, 50^{th}, 84^{th} percentiles). However, the consideration of such uncertainty is rarely considered by designers and it is thus recommendation that future research considers how this uncertainty can be propagated to design. For example, could the maps of different percentiles of hazard be considered for the definition of importance factors (such that a building with a high importance factor is not designed to the mean or median UHS at a given return period, but to the 84^{th} percentile UHS))?

Long-term Recommendation 1

In the long-term, signification modifications to the way in which seismic actions are presented in design codes around the World are expected. In order for Eurocode 8 to be ready to adapt to these changes, it is recommended that research on the following three aspects is carried out: i) Risk targeted seismic design actions; ii) The possible use of aggregate hazard analyses, rather than site specific, for design actions (Malhotra, 2008); iii) A new paradigm for the future of seismic design codes which considers the influence of design choices (in terms of stiffness, strength and ductility) on the aggregate losses to urban areas. These three proposals are briefly described below.

The 2009 revision to the NEHRP Provisions introduces a new conceptual approach to the definition of the input seismic action (NEHRP, 2009). The seismic input (maximum considered earthquake) is modified by a risk coefficient (for both short and long periods). This coefficient is derived by assuming a uniform probability of collapse across the country (Luco *et al*., 2007). Douglas *et al*. (2012) have looked at the risk targeted approach in France, and have highlighted some areas where further considerations are needed before this approach could be applied in Europe.

The possible use of aggregate hazard analyses, rather than site specific, for design actions (e.g. Malhotra, 2008) requires further consideration. The consequences of earthquakes simultaneously affect large areas leading to a high societal impact, and as such the seismic design of buildings should not be considered in isolation, but as part of a system of buildings over a given city or region. The joint probability of exceeding ground motions over large areas should thus be considered when defining seismic actions.

A new paradigm for the future of seismic design codes, which considers the influence of design choices (in terms of stiffness, strength and ductility) on the aggregate losses to urban areas, together with the resulting costs, has been proposed in Deliverable 2.3. State-of-the-art seismic loss assessment using hazard models for the region, microzonation studies and vulnerability models for building typologies for different levels of design (with different costs) is carried out. The optimal design level in each location is identified by the one that produces the lowest combined sum of the cost of design and the resulting loss. Reliable vulnerability models are needed for the different types of buildings that are planned to be built in a given region, and further research on this topic is thus recommended.

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SHARE Deliverable 2.1 "Hazard output specifications requirements document jointly approved with EC8 Committee" Available from URL: http://www.share-eu.org/node/52

SHARE Deliverable 2.2 "Report on seismic hazard definitions needed for structural design applications" Available from URL: http://www.share-eu.org/node/52

SHARE Deliverable 2.3 "Calibration of Seismic Design Codes using Loss Estimation"

SHARE Deliverable 2.4 "Results from study on minimum hazard levels for explicit structural seismic analysis and design" Available from URL: http://www.share-eu.org/node/52

SHARE Deliverable 4.3 "New site classification scheme and associated site amplification factors" Available from URL: http://www.share-eu.org/node/52