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POTENTIAL IMPACTS OF CHANGES IN EUROCODE 8 TO DESIGN IN THE UK

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Abstract: *The EN Eurocodes apply to the structural design of buildings and other civil engineering works including earthquake ground motions and geotechnical aspects. These have applied to design in the UK since the publication of the National Annexes in 2005. In 2012, the European Commission issued mandate M/515 to amend the existing Eurocodes and extend their scope. This has resulted in the current evolution activities with the aim of publishing the second generation of Eurocodes by 2026. As part of this development, Eurocode 8 (EN1998) is also being updated. This paper provides a brief review of the use of the current EN1998 in the UK, and highlights the efforts undertaken by the BSI 525/8 committee for this update, with focus on the potential impacts to the UK. The paper also discusses the new seismic hazard map developed by the British Geological Survey (BGS) for the UK and relevant implications with respect to the changes adopted within the second generation of EN1998.*

Introduction

Mandate M/515

In response to the European Commission mandate M/515 published in 2012, the European Committee for Standardization (CEN) set out a work programme for developing the second generation of Eurocodes. The key targets for the update included the following:

- The assessment for potential reduction of the number of Nationally Determined Parameters (NDPs).
- The improvement of the user-friendliness of Eurocodes, without reducing their applicability, to facilitate new entrants to the market and small and medium-sized enterprises.
- The incorporation of recent studies, research, and experience relevant to innovation in design and construction, as well as contribution of structural design to sustainability – in particular, new areas were developed including the assessment of existing structures and the use of structural glass, fibre-reinforced polymers and membrane structures.
- The adoption of ISO standards to supplement the Eurocode family in the fields of atmospheric icing of structures and action of waves and currents on coastal structures.
- The development of auxiliary guidance documents to facilitate feedback from stakeholders and practical local implementation.
- The elaboration of a clear and complete list of background documents.
- The development of a technical report analysing and providing guidance for potential amendments of the Eurocodes (general and material specific), with regard to structural design addressing relevant impacts of future climate change.

Project Teams started working on the second generation of Eurocodes in 2015, and the mandate was completed in 2022. The standards are now in review, and they are due to be published sometime after 2025.

Contents of EN1998

As part of the second generation of Eurocodes, EN 1998 is also being updated and will now consist of six parts. The current Part 1 (General and Buildings) will now be divided into two parts, the first for general rules and the second for buildings. The current Part 6 (Towers, masts and Chimneys) will also be merged with the current Part 4 (Silos, tanks and Pipelines). The scope

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and applicability of all parts of the code has increased to cover a wider range of structures. The different parts of the second generation of EN1998 will be as follows:

Part 1-1 General rules & seismic action.

Part 1-2 Rules for new buildings.

Part 2 Bridges.

Part 3 Assessment and retrofitting of existing buildings & bridges.

Part 4 Silos, tanks, pipelines, towers, masts and chimneys.

Part 5 Geotechnical aspects, foundations, retaining structures and underground structures.

Main updates in EN1998

Many changes are being implemented in the second generation of EN1998. Some of the key updates include the following:

- New content related to various aspects including those related to European seismic zonation, soil-structure interaction, ancillary elements, flat slab systems, infilled frames and claddings, aluminium structures, assessment of existing bridges, timber bridges, assessment of existing timber bridges, verification of operational limit state, development of displacement-based approaches, pushover procedures for various new and existing structures, structures equipped with various energy dissipation devices, and guidance on testing of components.
- Significant changes to several procedures including those related to the direct use of consequence classes alongside return periods and performance factors instead of importance factors, redefinition of the elastic response spectrum using two spectral parameters instead of the peak ground acceleration, modified definition of site classification with due account for the depth of the bedrock formation, modification of resistance partial factors, simplification of global safety choices, homogenisation of seismic zone definition, spatial model of seismic action.
- Other important changes on the structural side include the explicit representation of the behaviour factor (q) as a product of its three constituents related to overstrength (q_s), redistribution (q_R) and deformation capacity and energy dissipation (q_D), as well as the replacement of the low, medium, and high ductility classes (DCL, DCM, DCH) with DC1, DC2 and DC3 - with DC3 typically lying between DCL and DCM (requiring usually only local ductility criteria) while DC3 is equivalent to DCM or DCH depending on the material (requiring satisfaction of the full failure mode control and capacity design procedures).

Current use of EN1998 in the UK

National Forward

The UK National Foreword to BS EN1998-1 and BS EN1998-5 states the following:

> "*There are generally no requirements in the UK to consider seismic loading, and the whole of the UK may be considered an area of very low seismicity in which the provisions of EN 1998 need not apply. However, certain types of structure, by reason of their function, location or form, may warrant an explicit consideration of seismic actions.*"

Therefore, EN 1998 has generally not been used for the design of building like structures in the UK. Based on a brief review, the following is an overview of UK projects where seismic design or assessment is known to have been considered, excluding nuclear projects.

Large Dams

The requirement for seismic assessment of dams in the UK is dependent on the recommendations of the Qualified Civil Engineer (QCE) responsible for the reservoir and dam in question. Several assessments have been carried out following the BRE guidelines (Charles at al., 1991). A couple of recent studies include:

- Retaining wall assessments under seismic loading for two reservoirs for Scottish Water. (Neves et al., 2017).

- Following the 2019 incident at Toddbrook Reservoir, the stability of the embankment dam was assessed. The qualified civil engineer (QCE) required an assessment of the seismic performance of the embankment. Most of the work did not consider EN1998 (Lubkowski et al., 2022).

High Speed Rail

At the time of design of the Channel Tunnel Rail Link (CTRL) from Folkstone to London, there were no seismic design requirements in the UK. The draft of Eurocode 8 (ENV 1998-1) was in circulation and a UK National Forward had been published, which stated that "*Within the UK, the application of Eurocode 8 should not be necessary unless the client or user of the works assesses that the associated risk is such that it needs to be addressed.*"

The Rail Link Engineering (RLE) technical report for seismic design presents the seismic design philosophy for Central Structures. This recognised that the seismic load case is unlikely to be critical for the majority of structures. Nevertheless, design checks were carried out for all geotechnical structures, bridges and tunnels. The key requirement was to prevent collapse under seismic loading. Station buildings did not consider seismic loads unless these were essential to the safety of the railway.

With the development of High Speed 2 (HS2) seismic design criteria were again considered. The Act of Parliament that defines the HS2 project required the project to achieve at least the same level of safety as had been achieved for the Channel Tunnel and CTRL projects.

Therefore, a technical standard for seismic design was developed, which is based on BS EN1998. This sets out the performance criteria, as follows:

- Importance class II structures shall ensure no collapse under the ULS event (2,500 year).
- Importance class III structures (tunnels, embankments, bridges etc.) shall ensure no collapse under the ULS event and shall remain elastic under the DLS event (475 year).

Important Bridges

The contract documents for the new Queensferry Bridge across the Firth of Forth required seismic design to be considered for this multi long span cable stayed bridge. A site-specific seismic hazard assessment was undertaken to define the seismic hazard criteria. Checks were carried out to BS EN1998-2, though seismic loading was found not to be significant for design.

Energy Projects

Both South Hook LNG and Dragon LNG in South Wales were required to consider seismic loading following the requirements of BS EN1473 (2021). This necessitated a site-specific seismic hazard assessment to define the Safety Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE). BS EN1998 was one of the codes used to design the tank and jetty structures. It is understood a major gas pipeline linking these facilities was also assessed for seismic loading.

A series of seismic design standards/guidance documents were written for National Grid, for use on critical assets. These documents included policy documents, design guides, specifications, post-event management plans etc. They were written around BS EN1998 with many cross-references to clauses, figures and tables in BS EN1998 and the UK supporting documents. The focus on BS EN 1998 was at the request of the client, as they wanted their suite of guidance documents to be Eurocode compatible as far as reasonably practicable.

The analysis methods laid out in EN1998 have often been used in the nuclear industry. The UK approach to nuclear design requires the consultant to apply Relevant Good Practice (RGP), which is found in the Eurocode suite of documents. This approach is supported by the Office for Nuclear Regulation's guidance set out in the Safety Assessment Principles (ONR, 2020) and Technical Assessment Guides (ONR, 2022a, b), and various other HSE legislation.

More recently, with the growing development of offshore windfarms, seismic aspects are also increasingly being discussed within the various design and assessment considerations (e.g., DNV 2021).

Selected Key Changes

For the purposes of this paper, we have concentrated on some of the key changes (Labbe, 2018) to EN 1998 Parts 1 and Part 5, and their implications on design in the UK. The first change is subdivision of Part 1 into two separate sections Part 1-1 General rules & seismic action and Part 1-2 Buildings. Some of the key changes in Part 1-1 are discussed firstly below.

Limit states

Four limit states have been introduced, which included a revision of the existing definitions. The four limit states are Near Collapse (NC), Significant Damage (SD), Damage Limitation (DL) and Fully Operational (OP). Only the SD non exceedance verification is mandatory. The SD and NC limits states are considered as Ultimate Limit States, whilst the DL and OP limit states should be considered as Serviceability Limit States.

Seismic actions are specified in terms of their return periods. The attainment of the performance requirements are achieved by selecting appropriate return periods ($T_{LS,CC}$) depending on the specified limit states and consequence class of the structures. The specific limit state and associated return periods are presented in the respective part of EN1998. Alternatively, performance factors ($\gamma_{LS,CC}$) can be used. These are both NDPs, and it will be the responsibility of the BSI 525/8 committee to define appropriate values for the UK. As an example, the return periods for buildings and geotechnical structures are given in Table 1 and Table 2 respectively.

Limit state	**Consequence Class**			
	CC1	**CC2**	**CC3a**	**CC3b**
NC	600 (1.00)	1600 (1.50)	2500 (1.75)	5000 (2.20)
SD	275 (0.80)	475 (1.00)	600 (1.10)	900 (1.25)
DL	100 (0.60)	115 (0.60)	125 (0.65)	140 (0.65)

Table 1. Updated return periods $T_{LS,CC}$ and performance factors $\gamma_{LS,CC}$ (in brackets) for buildings.

Limit state	**Consequence Class**		
	CC1	**CC2**	**CC3**
NC	800 (1.20)	1600 (1.50)	2500 (1.80)
SD	250 (0.80)	475 (1.00)	800 (1.20)
DL	50 (0.40)	60 (0.50)	60 (0.50)

Table 2. Updated return periods $T_{LS,CC}$ and performance factors $\gamma_{LS,CC}$ (in brackets) for geotechnical structures.

The first point to note is the return periods (and performance factors) are not consistent for different structural forms. At first glance this appears somewhat confusing, however, the common aspect is to achieve a consistent target probability of exceedance of a limit state or reliability index for a given consequence class, for which guidance is given in Informative Annex F of Part 1-1.

It should also be noted that for geotechnical systems, the seismic actions associated with each specified limit state should be the same as the seismic action of the structure (i.e., as in Table 1) for buildings or as in Part 2 for bridges. For standalone geotechnical structures (e.g., an individual slope or retaining wall), the seismic actions associated with the return periods in Table 2 should be applied.

Site categories

The site categorisation has been redefined to be dependent both on the shear wave velocity (V_{SH}) and the depth to rockhead with a V_{SH} greater than 800m/s (H_{800}). A review of the categorization and comparison with the existing approach is presented in Paolucci et al., (2021). The reason for the change was to smooth the large jumps in the site amplification factors between one category and another. The new categorization is shown in Table 3.

Depth class	**Ground class**	**Stiff**	**Medium stiff**	**Soft**
	V_{SH} range / **H_{800} range**	**400m/s ≤ V_{SH} < 800m/s**	**250m/s ≤ V_{SH} < 400m/s**	**150m/s ≤ V_{SH} < 250m/s**
Very shallow	$H_{800} \leq$ 5m	A	A	E
Shallow	5m < $H_{800} \leq$ 30m	B	E	E
Intermediate	30m < $H_{800} \leq$ 100m	B	C	D
Deep	H_{800} > 100m	B	F	F

Table 3. Updated site categories.

Seismic zonation and seismic action

The concept of zoning is replaced by a map for each national authority that provides the hazard value at any location in a territory. In its absence, some information through a European wide hazard map is provided in Informative Annex A of Part 1-1. More details on the UK map are given below.

The scaling parameter of the seismic input motion is not related to the peak ground acceleration (PGA) as in the first generation. Instead, as illustrated in Figure 1, the seismic action is described in terms of two parameters, namely:

- $S_{\alpha,ref}$, the spectral acceleration corresponding to the constant acceleration range.
- $S_{\beta,ref}$, the reference spectral acceleration at the vibration period T_β = 1s.

These are based on the horizontal 5% damped elastic response spectrum (which can be adapted for other damping ratios), on site category A, for the return period T_{ref}. The reference return period T_{ref} is equal to 475 years, except otherwise decided for a country by the national authorities.

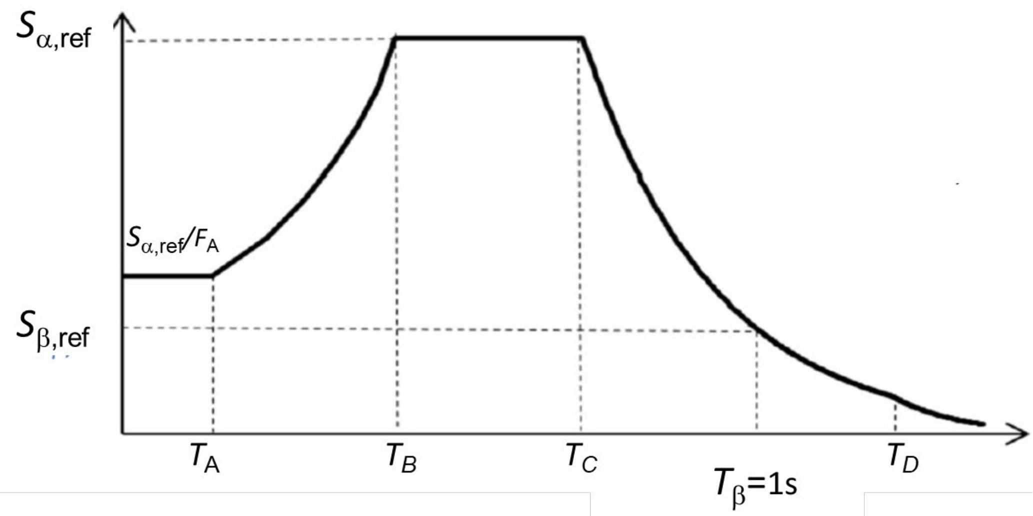

Figure 1: Reference seismic action $S_{\alpha,ref}$ and $S_{\beta,ref}$ on Site Category A for return period T_{ref}.

Performance requirements

Structures shall be designed so that, in the event of earthquakes, the following objectives are met with an appropriate degree of reliability:

- Human lives are protected.
- Damage is limited.
- Facilities important for civil protection remain operational.

The seismic design cases should be categorised in seismic action classes according to Table 2, depending on the value of the seismic action index, S_δ, defined by the equation below.

$$S_\delta = \delta\, F_\alpha\, F_T\, S_{\alpha,475} \quad (1)$$

Where:

δ is a coefficient that depends on the consequence class of the considered structure.

F_α is the site amplification factor.

F_T is the topography amplification factor.

$S_{\alpha,475}$ is the spectral acceleration for the return period of 475 years.

The default values of δ (which is an NDP) are given in the relevant parts of EN 1998 according to the type of structure considered. For buildings the default values are 0.60, 1.0, 1.25, 1.60 for CC1, CC2, CC3-a, CC3-b, respectively. For geotechnical structures, the default values are 0.60, 1.0, 1.50, respectively.

The definition of the seismic action class has also changed and is now based on the value of S_δ, as derived from the equation above, and the ranges as given in Table 4.

Seismic action class	Range of seismic action index
Very Low	$S_\delta < 1.30m/s^2$
Low	$1.30 \leq S_\delta < 3.25m/s^2$
Moderate	$3.25 \leq S_\delta < 6.50m/s^2$
High	$S_\delta \geq 6.50m/s^2$

Table 4. Definition of seismic action classes

As with the original EN1998, the provisions may be neglected in cases of very low seismic action class. In cases of low seismic action class and for well-defined categories of structures, simpler rules may be followed.

Importantly, the seismic action index S_δ is used to define the limit of application of the different ductility classes (i.e., DC1, DC2, DC3) depending on the structural system and material. For example, for reinforced concrete structures, DC1 design is not permitted with S_δ > 2.5 m/s^2 for moment resisting frame-equivalent or wall-equivalent structures as well as with flat slab systems; similarly; DC1 is also not permitted with S_δ > 5.0 m/s^2 for wall structures, and DC3 should be used for moment resisting frames when S_δ > 5.0 m/s^2; other limitations are also placed. In flat slab systems which should not be adopted altogether for S_δ > 5.0 m/s^2 and should not be designed for DC3; otherwise DC2 and DC3 can be adopted for all levels of S_δ and structural types. Similarly, for steel structures, the upper limit on S_δ for using DC1 varies between 2.5 m/s^2 and 5.0 m/s^2, while the upper limit for using DC2 is between 5.0 m/s^2 and 7.5 m/s^2, depending on the structural system adopted, while there is no upper limit for using DC3 in typical steel systems.

Part 5

One of the most significant changes in geotechnical earthquake engineering design is the move towards performance based or displacement based design for geotechnical structures. As such displacement limits have been proposed for the various limit states and geotechnical analyses as indicated in Table 5. Force based methods may still be used, however, an additional factor (χ_H) is utilised, which is related to the amplitude of acceptable permanent displacement. These also vary with the limit state.

Geotechnical Analysis	Limit States		
	DL	SD	NC
Slope stability	30 to 50mm	60 to 100mm	120 to 200mm
Retaining structures	30 to 100mm	100 to 150mm	150 to 200mm
Sliding analysis of footings	<15mm	20 to 50mm	50 to 100mm
Piles under lateral loading	<15mm	20 to 50mm	50 to 100mm

Table 5. Range of permanent displacements

As previously required by Part 5, an assessment of the stability of the construction site shall be carried out considering fault rupture, slope instability, liquefaction, lateral spreading, and excessive soil settlement. It is interesting to note that the impact of potentially active faults has been reduced compared to the previous requirements. For example, CC2 and CC3 structures may now be constructed in the vicinity of potentially active faults if a continuous stiff foundation is provided, and the soil cover exceeds a certain thickness (at least 40m in high seismic action zones). This is based on the observation of numerous examples of successful performance of 3 to 5 storey buildings, bridges, pylons, and bunkers on top of major fault ruptures. Though not of significance to the UK, this goes against design practice in both the USA and New Zealand, and it will be interesting to see whether the observations from the 2023 Kahramanmaraş earthquake sequence will change the current draft.

Another major addition is a chapter on the design of large underground structures. This includes different types of tunnels and other underground structures, such as pipelines, culverts, metro stations and underground parking garages. For important underground structures, 2D or 3D dynamic time history analysis of the coupled soil-structure system, may be used (Hashash et al., 2001; Pitilakis and Tsinidis, 2014) to efficiently describe the kinematic and inertial aspects of the soil-structure interaction. It is highlighted that the stress state before the seismic loading, as well as construction stages should be properly considered through static analyses steps, before undertaking the dynamic analysis.

Impact for the UK

The BSI 525/8 committee needs to consider the impact of the new draft of EN1998 on UK design practice and additionally define the revised NDPs, write the National Application Documents for each part and revise our published document (PD 6698:2009). Through the efforts of BGS we have a new seismic hazard map for the UK, which is consistent with the new draft. Details can be found in Mosca et al., (2022) and highlights are described below.

With regard to implementation of EN1998 in the UK, there are some initial questions to consider:

1. The new definition of seismic hazard could result in some parts of the UK requiring seismic design for normal structures. How significant is this issue and is this reasonable?
2. Based on the last 20 years of design experience, seismic design has been focused on more critical and safety related structures. Therefore, should the UK focus seismic design only on special structures such as long span bridges, dams, tanks, and wind turbines rather than buildings?
3. How do we steer clients to focus on seismic design where it is important?
4. How do we mitigate the misuse of the NA and PD documents by UK consultants?

New UK Seismic Hazard Maps

Following a direct request from the British Standard Institution's (BSI) sub-committee B/525/8 for EN1998, BGS seismologists developed a new set of seismic hazard maps for the UK. This has been undertaken with support from the Institution of Civil Engineers as well as other seismologists and engineers based in the UK (Mosca et al, 2022).

The new seismic hazard maps are given for three ground motion measures: peak ground acceleration (PGA) and spectral acceleration (SA) at 0.2 s (5 Hz) and 1.0 s (1.0 Hz); examples are shown in Figure 2. The maps show these results for rock conditions (assuming V_{S30} of 800m/s) and have been computed for four return periods: 95, 475, 1100 and 2475 years. These return periods correspond to probabilities of approximately 41%, 10%, 5% and 2%, respectively, of exceeding a particular level of ground motion in a 50 year period.

For a return period of 475 years, the maps show that the PGA hazard for Wales, the West Midlands and the Pennines generally exceeds 0.04g. The maps confirm that seismic hazard is generally low across most of the UK but that the hazard is highest in Northwest Wales near Bangor and the Menai Straits. The pattern of seismic hazard largely reflects the higher rates of historical earthquake activity in these regions.

The seismic hazard data and technical describing the development of the maps, and the data files containing the main elements of the model and key datasets can be downloaded from: http://www.earthquakes.bgs.ac.uk/hazard/UKhazard.html. The maps can be interactively viewed on the BGS GeoIndex (onshore) map viewer.

Seismic Action Class

Based on the new UK seismic hazard map and the recommended NDPs in Part 1-1, we have estimated the impact of the code on three different locations within the UK, namely Bangor (Ba), Cardiff (Ca) and Stoke on Trent (St). These were selected as Bangor falls in the region of highest UK seismic hazard, whilst Cardiff and Stoke on Trent represent areas of moderate UK seismicity in South Wales and the West Midlands respectively.

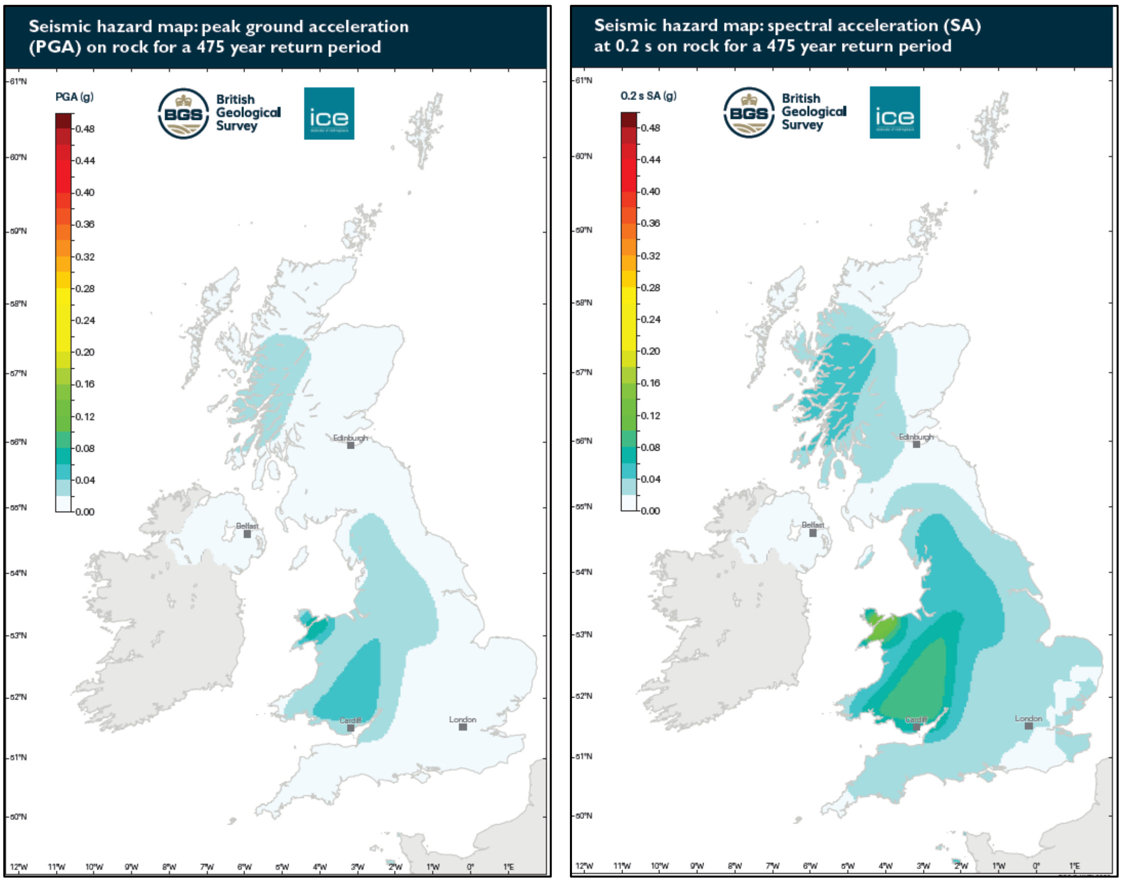

Figure 2: Seismic hazard maps (PGA and 0.2s SA) for a return period of 475 years.

The value of $S_{\alpha,475}$ for the three locations is 1.32m/s², 0.66m/s² and 0.66m/s² respectively. If we assume level ground (F_T = 1.0), and three site classes, ranging from stiff to soft, the results are shown in Table 5. This indicates that CC1 structures generally fall into the very low seismic action class. For site class E, all CC2 structures fall into the low seismic action class. For Bangor, CC3a on site class E and CC3b structures on site class C or E fall into the moderate seismic action class requiring seismic design to EN1998.

Consequence class	**Site Class A**			**Site Class C**			**Site Class E**		
	Ba	**Ca**	**St**	**Ba**	**Ca**	**St**	**Ba**	**Ca**	**St**
CC1	VL	VL	VL	VL	VL	VL	L	VL	VL
CC2	L	VL	VL	L	VL	VL	L	L	L
CC3a	L	VL	VL	L	VL	VL	M	L	L
CC3b	L	VL	VL	M	L	L	M	L	L

Table 6. Example seismic action classes

In broad terms these conclusions are consistent with the recommendations of Booth et al., (2008), for considering seismic design in the UK. These only applied to consequence class CC3 structures, and assuming the absence of statutory or contractual requirements, required two of three unfavourable features to be present before seismic design was recommended during preliminary design.

- Exceedance of regional seismic hazard at the site above a PGA of 0.06g.
- The presence of soils overlaying rock at the site which might lead to a high amplification of seismic actions.
- The presence of unfavourable structural features.

Maintaining this consistency, or suggesting any deviation, would require careful consideration of the hazard, in conjunction with NDP values of δ for the different consequence classes (ranging from 0.60 to 1.60 as noted above) which are applied to S_α through Equation (1) above to obtain the value of the seismic action index S_δ. As discussed before, this has a direct implication on the seismic action classification which, in turn, is used to define the requirements for seismic design and the limitations for adopting different ductility classes.

Conclusions

This paper provided an overview of some of the key changes introduced in the second generation of Eurocode 8 (EN1998), with focus on the representation of the seismic action and the various limitations and selected nationally determined parameters (NDPs). Emphasis was given to the potential implications of using the suggested provisions of EN1998 in the UK. To this end, the new seismic hazard map developed by the BGS for the UK are discussed and used to highlight the level of seismicity implied for selected UK locations. It was shown that most of the UK falls in the very low or low seismic action class. However, depending on the consequence class and using default NDP values, several locations would fall into the moderate seismic action class. Moreover, within the areas falling into the low and moderate classes, some would exceed various upper limits imposed on the seismic action index for DC1 and would therefore necessitate the application of the requirements of at least DC2, depending on the consequence class and type of structure. This points to the need for a careful consideration of the hazard, in conjunction with relevant NDP values incorporated in the seismic action index, within the national guidance proposed for the application of EN1998 in the UK.

Acknowledgments

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