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Foreword

Publishing information

This Published Document is published by BSI and came into effect on 31 July 2009. It was prepared by Subcommittee B/525/8, *Structures in seismic regions*, under the authority of Technical Committee B/525, *Building and civil engineering structures*. A list of organizations represented on these committees can be obtained on request to their secretary.

Information about this document

This Published Document is a background paper that gives non-contradictory complementary information for use in the UK with the following parts of BS EN 1998, *Design of structures for earthquake resistance*, and their UK National Annexes:

- *Part 1: General rules, seismic actions and rules for buildings;*
- *Part 2: Bridges;*
- *Part 4: Silos, tanks and pipelines;*
- *Part 5: Foundations, retaining walls and geotechnical considerations;*
- *Part 6: Towers, masts and chimneys.*

It is not planned to issue a UK National Annex or Published Document to BS EN 1998-3, *Assessment and retrofitting of existing buildings*, because it is considered that little use will be made of this part for buildings in the UK.

Presentational conventions

The word "should" is used to express recommendations of this Published Document. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Contractual and legal considerations

This publication does not purport to include all necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document cannot confer immunity from legal obligations.

Introduction

When there is a need for guidance on a subject that is not covered by the Eurocode, a country can publish documents containing non-contradictory complementary information that supports the Eurocode. This Published Document provides just such information and has been cited as a reference in the UK National Annexes to BS EN 1998-1:2004, BS EN 1998-2:2005, BS EN 1998-4:2006, BS EN 1998-5:2004 and BS EN 1998-6:2005.

1 Scope

This Published Document provides non-contradictory complementary information for use in the UK with BS EN 1998-1:2004, BS EN 1998-2:2005, BS EN 1998-4:2006, BS EN 1998-5:2004 and BS EN 1998-6:2005, and their UK National Annexes.

This Published Document gives background information and some additional guidance on the clauses subject to National Choice in these parts of BS EN 1998.

This document only covers the United Kingdom and does not consider conditions applicable to British Overseas Territories, where seismological and other aspects might be very different. It is restricted to considerations for the design of new structures within the scope of BS EN 1998-1, BS EN 1998-2, BS EN 1998-4, BS EN 1998-5 and BS EN 1998-6 to resist seismic actions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 1990:2002, *Eurocode – Basis of structural design*

BS EN 1991-1-5:2003, *Eurocode 1: Actions on structures – Part 1-5: General actions – Thermal actions*

BS EN 1998-1:2004, *Eurocode 8 – Design of structures for earthquake resistance – Part 1 General rules, seismic actions and rules for buildings*

BS EN 1998-2:2005, *Eurocode 8 – Design of structures for earthquake resistance – Part 2 Bridges*

BS EN 1998-4:2006, *Eurocode 8 – Design of structures for earthquake resistance – Part 4 Silos, tanks and pipelines*

BS EN 1998-5:2004, *Eurocode 8 – Design of structures for earthquake resistance – Part 5 Foundations, retaining walls and geotechnical considerations*

BS EN 1998-6:2005, *Eurocode 8 – Design of structures for earthquake resistance – Part 6 Towers, masts and chimneys*

3 Assessing the need for seismic design of structures within the UK

3.1 Function, location and form of structure

The UK National Forewords to BS EN 1998-1 and BS EN 1998-5 state 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."

3.2 to **3.4** discuss in turn how the *function*, *location* and *form* of a structure in the UK affect the need for seismic design.

3.2 Influence of function

For most engineered and non-engineered structures in the UK, natural hazards, such as wind, flood, ground movements due to moisture change, and extreme temperatures, pose a substantially higher risk of injury and economic loss over the lifetime of a structure than the risk posed by earthquakes. However, in some cases the function of a structure is such that failure due to very low probability events, including earthquakes, might need to be considered. At least four such categories of structure can be distinguished, as follows.

1) Structures where failure poses a large threat of death or injury to the population. Examples include nuclear power plants and major dams (both of which are explicitly outside the scope of BS EN 1998) and certain petrochemical installations, such as liquid natural gas (LNG) storage tanks and high pressure gas pipelines (which are within the scope of BS EN 1998).
2) Structures which form part of the national infrastructure and the loss of which would have large economic consequences. An example is a major bridge forming a transportation link vital to the national economy.
3) Structures whose failure would impede the regional and national ability to deal with a disaster caused by a major damaging earthquake.
4) Strengthening or upgrading of historic structures forming an important part of the national heritage.

In many cases, structures could fall into more than one category; for example, the seismic failure of a busy estuarial bridge might cause extensive human casualties, affect the regional or national economy and also impede the flow of disaster relief into the area affected by the earthquake.

In some cases, UK legislation requires an explicit consideration of seismic design for certain types of infrastructure. In other cases, seismic considerations have been widely applied, even in the absence of legislation, for example in the assessment of major dams and in the contractual specifications for the design of major bridges. There might be other cases where the owner of a structure decides that an explicit seismic design is required for economic or other reasons; the local level of seismic hazard and the particular sensitivity of the structure to seismic excitation (as discussed in **3.3** and **3.4**) are likely to influence that decision.

3.3 Influence of location

The location of a structure affects the regional seismic hazard, which varies significantly across the UK, as discussed in Clause **4**; that is, the earthquake ground motions for a given annual probability of exceedence are significantly greater in some parts of the UK than others, although everywhere the hazard is very low by international standards.

Location also affects the local influences on seismic hazard; in particular, the effect of superficial soil deposits in modifying seismic ground motions.

3.4 Influence of structural form

All structures possess some degree of earthquake resistance, and this is greatly enhanced by regulatory requirements to provide measures enhancing robustness, such as peripheral ties in buildings and detailing to increase ductility, and by the provision of wind resistance. In many cases, these are considered to provide sufficient protection against seismic actions in the UK. However, certain features might result in designs that are satisfactory for resisting wind but are vulnerable to seismic loading. Examples of such seismically unsatisfactory features in building structures are open and relatively weak ground storeys, very heavy roof masses and large eccentricities between centres of mass and stiffness. Examples for bridges are bridge decks on bearings which provide poor lateral restraint, and concrete bridge piers which are poorly confined by transverse reinforcement.

3.5 Decision on seismic design

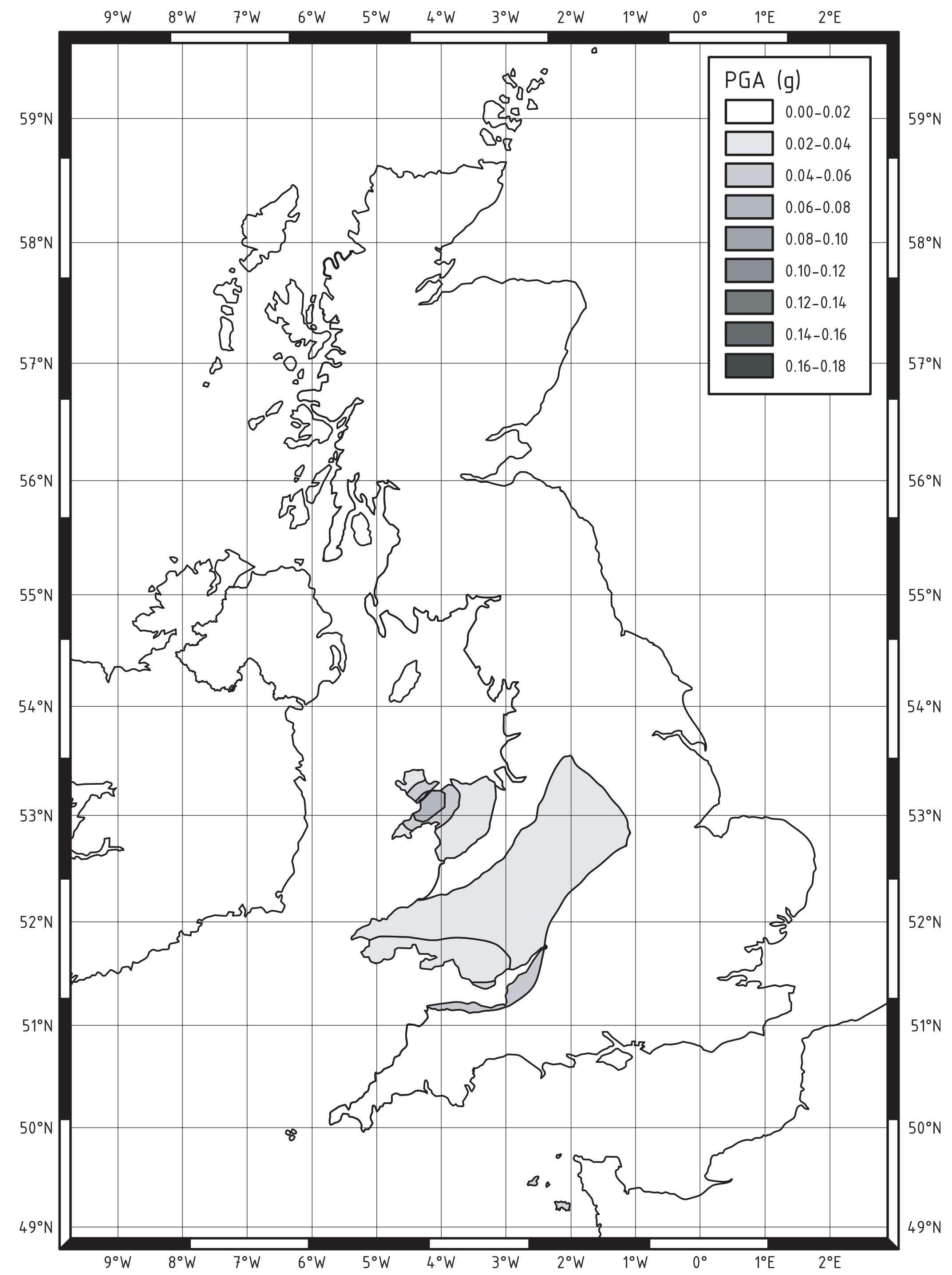
It is the responsibility of the designer to establish whether statutory or other considerations require an explicit seismic design. In the absence of statutory requirements or contractual specifications, structures classified by BS EN 1990:2002, Table B1, as being in consequence classes CC1 or CC2 are unlikely to warrant seismic design, provided they are adequately designed for non-seismic design conditions.

For structures in consequence class CC3, the need for an explicit seismic design should be considered, although in many cases examination of the consequences of failure, location and structural form will indicate that an explicit seismic design is not warranted. Specific advice for the design of buildings, bridges, and silos, tanks and pipelines is given in Clauses **7**, **8** and **9** respectively.

4 Seismic hazard in the UK

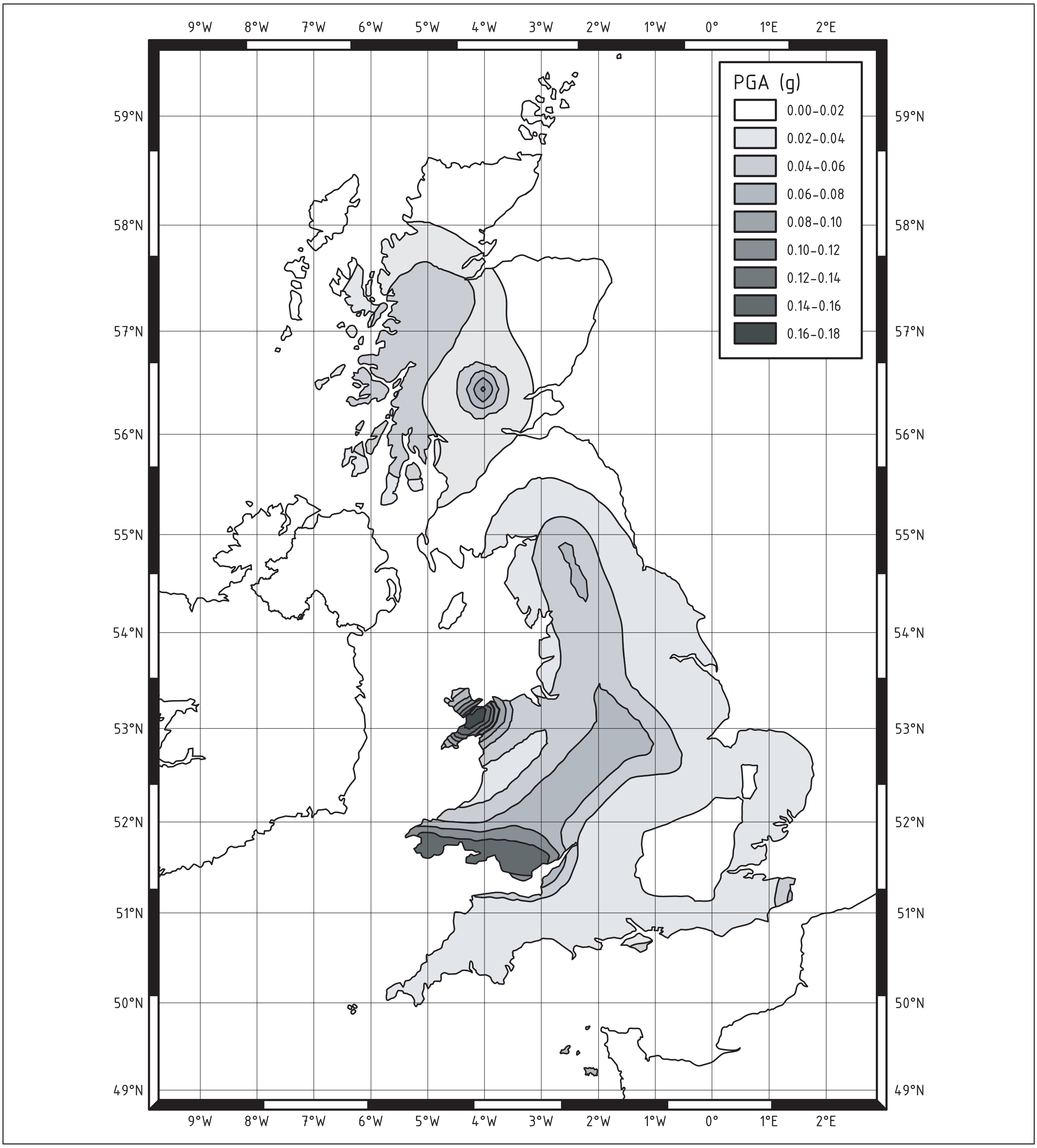
An assessment of the seismic hazard in the UK was carried out at the British Geological Survey by Musson and Sargeant [1], for the purposes of preparing the UK National Annex to BS EN 1998-1 and this Published Document. Figure 1 and Figure 2 show the seismic hazard maps that resulted from this exercise. Note that Figure 1 corresponds to the definition of a_{gR} in BS EN 1998-1 for the recommended reference return period of 475 years.

Figure 1 **Seismic hazard map of 475 year return period Peak Ground Acceleration (PGA) on rock** (redrawn from Musson and Sargeant [1])



Comparison of the peak ground acceleration (PGA) values shown in Figure 1 with PGA values found worldwide (see, for example, GSHAP [2]) shows that seismic hazard in the UK is very low by international standards. The recommended definition of a very low seismicity region in BS EN 1998-1 is an a_{gR} value of less than 0.04 g for a 475 year return period; application of the Eurocode is not required in such regions. It can be seen from Figure 1 that only a very small part of Wales exceeds this recommended value and Musson and Sargeant's study [1] found no values exceeding 0.08 g. The zoning of the whole of the UK as an area of very low seismicity given in the UK National Forewords to BS EN 1998-1 and BS EN 1998-5 therefore essentially accords with the definition of very low seismicity recommended by the Eurocode. It may be observed, however, that the Eurocode provides an alternative definition of very low seismicity regions as those where the product a_{gRS} (i.e. the design PGA on soil) exceeds 0.05 g; this represents the PGA at the reference return period after allowing for the amplifying effects of soil on the bedrock motions. It is likely that a rather larger area of the UK would exceed the "very low" seismicity threshold on this definition, but the area would still be relatively small.

Figure 2 **Seismic hazard map of 2 500 year return period Peak Ground Acceleration (PGA) on rock** (redrawn from Musson and Sargeant [1])



5 Limit states and choice of associated design ground motions in the UK

Booth and Skipp [3] demonstrate that the values of return periods and importance factors recommended in the main body of BS EN 1998 are inappropriate for an area of very low seismicity such as the UK, and are too small for the no-collapse requirement defined in BS EN 1998-1, **2.1**(1)P; therefore, alternative advice is provided in the UK National Annexes. This is summarized as follows.

In cases where an explicit seismic design is considered warranted for a consequence class CC3 structure (see **3.5**), it is recommended that the mapped acceleration values of Figure 2 for a 2 500 year return period are used for selection of the design PGA a_g, where $a_g = \gamma_I \cdot a_{gR}$ [a_g, γ_I and a_{gR} are defined in BS EN 1998-1, **3.2.1**(3)]. Effectively, the return period T_{NCR} is taken as 2 500 years, and the importance factor γ_I is taken as 1,0. A return period of 2 500 years for the design motions for CC3 is judged sufficiently conservative for most CC3 structures. Since the lifetime reliability is fairly insensitive to the design life when considering such long return periods, it is recommended that the same return period is used for structures with design lives ranging from 50 years (typical for buildings) to 120 years (typical for UK bridges).

Alternatively, values of the design PGA $a_g = \gamma_I \cdot a_{gR}$ may be selected by carrying out a site-specific hazard analysis. The return period associated with the parameter a_g in this analysis should be chosen accounting for the function and consequences of failure of the facility involved. A site-specific hazard analysis enables account to be taken of local influences on PGA that are not accommodated in Figure 2. It is also likely to produce a more realistic response spectrum shape than the standard shapes recommended by BS EN 1998-1, as discussed in Clause **6**. Site-specific hazard analysis is recommended for structures and facilities, the failure of which would have very significant regional or national consequences for the population or the environment.

Conversely, the seismic design motions recommended in the main body of BS EN 1998 are inappropriately high for the damage limitation requirement in areas of very low seismicity. This limit state is unlikely to govern in the UK and may be neglected. However, it is recommended that the drift limits specified for buildings in BS EN 1998-1, **4.4.3.2**, should still be checked as part of the seismic design, since excessive deflection, as well as excessive strength and ductility demand, could affect the no-collapse limit state.

6 Choice of response spectrum

6.1 Introduction

BS EN 1998-1, Clause **3**, recommends response spectrum shapes, the ordinates of which are multiplied by the design PGA a_g to produce a design spectrum. Where a_g has been selected from Figure 2, as discussed in Clause **5**, a response spectrum shape is needed to define a response spectrum for design purposes. The shapes recommended by BS EN 1998-1, Clause **3**, depend on the profile of the soil underlying the site in question. **6.2** and **6.3** discuss the appropriateness for UK conditions of the soil profiles and the corresponding spectral shapes recommended by BS EN 1998-1.

6.2 Soil profiles in the UK

Booth and Skipp [3] provide advice on the appropriateness to the UK of the standard soil profiles given in BS EN 1998-1, Table 3.1.

6.3 Horizontal elastic response spectra in the UK

The UK National Annex to BS EN 1998-1 states that in the UK the parameters defining standard shapes for horizontal spectra in BS EN 1998-1, **3.1.2**(2), for Type 2 earthquakes may be used, but advises reference to this Published Document.

Booth and Skipp [3] discuss the appropriateness to the UK of the Type 2 spectral shapes recommended in BS EN 1998-1. They note that the spectral shapes, particularly for sites underlain by soft soils, are subject to large uncertainties. Therefore, it is recommended that a site-specific seismic hazard analysis is conducted to establish more reliable design spectra for structures and facilities, the failure of which would have very significant regional or national consequences for the population or the environment.

6.4 Vertical elastic response spectra in the UK

In many cases, explicit consideration of vertical seismic ground motions is not required by BS EN 1998-1, and in the UK the load factors on gravity loads will usually be sufficient to ensure these effects are adequately catered for. The UK National Annex to BS EN 1998-1 does not provide values for the parameters defining standard shapes for vertical spectra in BS EN 1998-1, **3.2.2.3**(1)P. It advises that, in cases where explicit design for vertical motions is required, the recommended values in BS EN 1998-1, Table 3.4, are used, assuming a Type 2 spectrum.

7 Additional advice specific to BS EN 1998-1: General rules, seismic actions and rules for buildings

7.1 Recommendation on the need for seismic design of buildings

7.1.1 General

It is suggested that seismic design is not required for buildings classified by BS EN 1990:2002, Table B1, as being in consequence class CC1 or CC2. Following the discussion of **3.5**, buildings classified as consequence class CC3 do not necessarily require explicit seismic design, but should be assessed to see if that need applies.

Booth and Skipp [3] propose a screening procedure for establishing whether CC3 buildings warrant an explicit seismic design, and outline suggested methods of preliminary and final design in cases where it is found to be warranted. Consequence class CC3 corresponds to importance classes 3 and 4 in BS EN 1998-1 and other Eurocodes.

7.1.2 Domestic buildings up to five storeys

It is unlikely that new, low-rise domestic buildings in the UK require an explicit seismic design. Features of such buildings potentially vulnerable to seismic activity are discussed in Booth and Skipp [3]. See also **7.9**.

7.2 Need for additional ground investigations

Booth and Skipp [3] discuss the extent to which additional ground investigations might be needed for seismic design purposes, beyond those needed for non-seismic considerations.

7.3 Defining centres of stiffness and torsional radius

The centre of stiffness and torsional radius have to be defined in order to check whether a building structure is "regular" in plan. Irregularity in plan results in undesirable torsional response during earthquakes. In a building where the lateral force resisting system consists of a combination of two dissimilar types, such as shear walls combined with moment-resisting frames, the centre of stiffness becomes ill-defined. IStructE/AFPS [4] provides advice and proposes methods for checking plan regularity.

7.4 Geographical limits on ductility classes

As described in Clause **4**, the whole of the UK is an area of very low seismicity, characterized by earthquakes of low energy release, short duration and relatively low amplitude of ground motions in the epicentral area. Where it is assessed that an explicit seismic design is warranted, as discussed in **3.5**, in most cases it will be sufficient to design to the requirements of Ductility Class Low (DCL) without specific measures to ensure dissipative behaviour (i.e. ductile performance after the formation of plastic yielding mechanisms within the structure). In general, design to DCL only requires checks on strength and deflections under seismic actions, without the need for seismic detailing or other seismic checks.

However, some highly critical facilities in the UK could also require a demonstration that performance is acceptable in events beyond the design basis. One way of achieving this is to provide some degree of dissipative performance, for example by adopting some of the seismic detailing provisions required by BS EN 1998-1 for Ductility Class Medium (DCM) or Ductility Class High (DCH) structures.

7.5 Specific issues relating to concrete building structures

The UK National Annex to BS EN 1998-1 generally adopts the recommended values, with some minor modifications based on European and other practice. Further discussion is provided by Booth and Skipp [3].

7.6 Specific issues relating to steel building structures

7.6.1 General

Instances where the UK National Annex to BS EN 1998-1 modifies the recommended values for steel buildings are discussed in the following subclauses.

7.6.2 Upper limit on *q*-factor for low-dissipative behaviour [BS EN 1998-1, 6.1.2(1)]

There is extensive evidence that steel buildings designed to modern non-seismic codes perform well under low levels of earthquake loading. In view of the short duration of design events in the UK, even for return periods as long as 10 000 years, the upper limit on q-factor allowed by BS EN 1998-1 (i.e. $q = 2$) is recommended for low-dissipative (DCL) design. This is because the short duration limits low-cycle fatigue effects, which are particularly important for the seismic performance of steel structures.

Note that if $q = 2$, rather than 1,5, is adopted for a DCL design, BS EN 1998-1 makes one additional recommendation. This is that cross-sectional class 4 members are not allowed as primary seismic elements (i.e. those which contribute to design seismic resistance), whereas they are permitted for $q = 1{,}5$ [see BS EN 1998-1, **6.1.2**(3)]. In other respects, design for DCL can follow entirely the requirements of BS EN 1993, without the need to consider other parts of BS EN 1998-1, Clause **6**.

7.6.3 Requirements for fracture toughness and through thickness properties in the seismic design situation [BS EN 1998-1, 6.2(7)]

Refer to IStructE/AFPS [4] for advice on when the requirements relating to steel material ductility might need to be supplemented for the seismic design case.

7.6.4 Design of steel connections [BS EN 1998-1, 6.5.5(7)]

The design of steel connections in dissipative structures is crucial to satisfactory performance, particularly for unbraced moment-resisting frames. However, BS EN 1998-1 mainly provides generic advice rather than detailed rules. Further information on connection design is provided by IStructE/AFPS [4].

7.6.5 Residual post-buckling resistance of diagonal braces [BS EN 1998-1, 6.7.4(2)]

In dissipative V-braced frames, the horizontal brace is subject to an out-of-balance vertical force when the compression diagonal brace buckles. BS EN 1998-1 requires this vertical force to be resisted by the horizontal brace, and recommends that the force should be estimated assuming that the post-buckling resistance of the compression brace is a ratio $\gamma_{pb} = 0{,}3$ of its design yield strength in tension. This could overestimate the residual load for slender braces, and underestimate it for stocky braces. The UK National Annex therefore proposes the following.

$$\gamma_{pb} = \frac{\gamma_{pb} * N_{b,Rd}\left(\overline{\lambda}\right)}{N_{pl,Rd}}$$

$N_{b,Rd}$ = design buckling resistance of diagonal brace

$N_{pl,Rd}$ = design resistance in tension of diagonal brace

$\overline{\lambda}$ = normalized slenderness ratio of diagonal brace

$\gamma_{pb}* = 0{,}7$ for $q \leqslant 2$

$\gamma_{pb}* = 0{,}3$ for $q \geqslant 5$

For $2 \leqslant q \leqslant 5$, $\gamma_{pb}* = 0{,}3$ may be conservatively assumed, or some other appropriate assumption may be made. See Elghazouli [5] and Goggins *et al* [6] for the research on which this advice is based. IStructE/AFPS [4] gives further information.

7.7 Specific issues relating to steel/concrete composite building structures

Generally, the recommended values are adopted; where appropriate, refer to the discussion in **7.6**.

7.8 Specific issues relating to timber building structures

The only issue of National Choice relating to timber building structures is the possibility of placing geographical limits on the use of the various ductility classes, and no such limits are appropriate for the UK.

It may be observed that *q*-factors exceeding 3 for Ductility Class DCH timber structures are based on sparse experimental data, and might need to be confirmed by testing.

7.9 Specific issues relating to masonry building structures

7.9.1 Material specification [BS EN 1998-1, 9.2.2(1) and 9.2.3(1)]

Booth and Skipp [3] present evidence that low-rise domestic masonry buildings conforming to current Building Regulations [7, 8 and 9] have a low risk of damage from seismic actions in the UK. Therefore, the UK National Annex to BS EN 1998-1 proposes that no modification to the material specification for non-seismic design situations is appropriate if seismic actions need to be considered in the UK.

7.9.2 Perpend joints [BS EN 1998-1, 9.2.4(1)]

The UK National Annex to BS EN 1998-1 permits fully grouted or mechanically interlocked perpend joints for seismic resistance, but requires ungrouted perpend joints to be validated before seismic resistance can be assumed. The nature of the perpend joints affects the seismic resistance of masonry walls, particularly for out-of-plane loading.

7.9.3 Minimum thickness of unreinforced masonry [BS EN 1998-1, 9.3(2)]

The minimum thickness of 170 mm recommended by BS EN 1998-1 for low seismicity areas is adopted in the UK National Annex; however, a lower minimum thickness might be satisfactory given the very low seismicity in the UK and the associated short duration of earthquakes. See also, however, **7.9.4**.

7.9.4 Maximum ground acceleration for the use of unreinforced masonry [BS EN 1998-1, 9.3(3)]

The UK National Annex to BS EN 1998-1 permits the use of unreinforced masonry for ground accelerations up to 0,25 g, which is somewhat greater than the value of 0,2 g recommended by BS EN 1998-1. This may be justified by the very short duration of UK events, even at long return periods. A PGA of 0,25 g would only be likely in the UK for very long return periods, exceeding 5 000 years. If an unreinforced masonry building were required to achieve the "no-collapse" performance level, as defined in BS EN 1998-1, **2.1**(1)P, then a minimum thickness of unreinforced masonry of at least 240 mm would most likely be required.

7.9.5 *q*-factors in masonry buildings [BS EN 1998-1, 9.3(4)]

In the UK National Annex to BS EN 1998-1, the *q*-factor for unreinforced masonry buildings conforming only to BS EN 1996-1 has been increased from the recommended value of 1,5 to 2,0. This is because of the inherent resistance of masonry construction in current UK practice, as discussed by Booth and Skipp [3], and the very short duration of UK earthquakes.

No data have been found on masonry systems providing enhanced ductility, and the UK National Annex therefore recommends that the appropriate *q*-factor should be considered on a case-by-case basis.

7.9.6 Geometric requirements for masonry shear walls [BS EN 1998-1, 9.5.1(5)]

The values recommended by BS EN 1998-1 are adopted by the UK National Annex, but could be conservative in view of the low levels of seismicity and short earthquake durations applicable in the UK.

7.9.7 Minimum areas of shear wall for simple design [BS EN 1998-1, 9.7.2(1)]

There appears to be evidence that the values recommended in BS EN 1998-1, Table 9.2, are conservative. Pending further research, the UK National Annex provides no specific advice.

7.10 Specific issues relating to base-isolated structures [BS EN 1998-1, 10.3(2)P]

Base isolation bearings have to be checked for a displacement equal to γ_x times the displacement calculated for the no-collapse limit state. The recommended value of γ_x is 1,2. The UK National Annex recommends a value of 1,5 for buildings. This brings the recommendation into line with that in BS EN 1998-2 for bridge structures, and also closer to the values required by US design practice for base-isolated buildings. It allows for the possibility of greater-than-expected deflection response in the base isolation bearings, particularly due to long period excitation caused by unusual site effects.

8 Additional advice specific to BS EN 1998-2: Bridges

8.1 Seismic design of bridges

There is no need to consider seismic actions for the design of bridges in consequence classes CC1 and CC2. For bridges in consequence class 3, the need to design bridges for seismic actions should be considered on a project-specific basis. Factors to be considered include the safety, economic, social and environmental consequences of failure, and also the seismicity of the site. Examples of bridges where the consequences of failure might be high enough for a seismic design to be considered are shown in Table 1. Such bridges do not necessarily require explicit seismic design, but should nevertheless be assessed to see if that need applies. A consideration of the structural form and vulnerability, location and consequences of failure might indicate that the seismic risk and vulnerability are sufficiently low for an explicit seismic design to not be required (see **3.2** to **3.5**). Advice on the design of bridges for seismic actions, where required, is provided in **8.2** to **8.17**.

Table 1 **Examples of bridges with high consequence of failure where seismic design might need to be considered**

Factor influencing decision	Typical example
Economic impact	Bridges where loss of serviceability would have a major regional or national economic impact
Impact on post-earthquake relief	Bridges where loss of serviceability could have a major impact on the rescue effort or on aid delivery
Historic or cultural importance	Strengthening or upgrading of bridges which are an important part of the national heritage
Structural form (see Note)	Bridges that carry more than one level of traffic
	Bridges with suspension systems supporting spans over 50 m (see Note)

NOTE Certain types of bridge, including suspension bridges and historic bridges, are not included in the scope of BS EN 1998-2, so other sources of standards would be needed for their design.

8.2 Design ground motions for bridges

Advice on design ground motions for bridges is provided in BS EN 1998-2, **2.1**, Clause **3** and Annex A.

As recommended in Clause **5** of this Published Document, where an explicit seismic design is considered warranted, the mapped acceleration values of Figure 2 for a 2 500 year return period may be used for selection of the design PGA $a_g = \gamma_I \cdot a_{gR}$. These values may be used in conjunction with the spectral shapes recommended in BS EN 1998-1, Clause **3**, as discussed in Clause **6** of this Published Document.

Alternatively, a site-specific hazard analysis may be conducted. In this case, the value of return period associated with the design

PGA $a_g = \gamma_I \cdot a_{gR}$ and associated spectral shape should be selected on a project-specific basis, taking into account the function and consequences of failure of the facility involved. Site-specific hazard analysis would be appropriate for the selection of design ground motions for major projects of national significance, including long span suspension bridges. However, since suspension bridges are outside the scope of BS EN 1998-2, alternative design procedures would be needed for such bridges.

Very short return period events are negligible in the UK, and seismic action during the construction phase need not be considered.

8.3 Simplified analysis applicable to seismic design of UK bridges [BS EN 1998-2, 2.3.7(1) and 6.5.1(1)P]

Following the recommended procedure in BS EN 1998-2, seismic design of all bridges in the UK should follow the procedures for limited ductility/essentially elastic design. This involves the use of a behaviour factor $q \leqslant 1,5$ (see BS EN 1998-2, **2.3.2.3**). BS EN 1998-2, **2.3.4**, **2.3.5**, **5.3**, **5.6.3** and Clause **6**, do not apply to bridges designed for limited ductility or elastic response.

8.4 Treatment of seismic actions as accidental [BS EN 1998-2, 2.2.2(5)]

Damaging earthquakes are rare in the UK, and it is not economically justified to design bridges in the UK to avoid all damage. Hence, seismic actions may be treated as accidental in nature. BS EN 1998-2, **2.2.2**(3) and (4), may therefore be relaxed to the extent compatible with allowing the passage of emergency vehicles after the earthquake, and avoiding the creation of a significant safety threat to users of the bridge travelling in vehicles at the relevant design speed. Economic considerations might also arise where the cost of repairing damaged elements would be considerable; however, design using a behaviour factor $q \leqslant 1,5$ will generally ensure that significant damage is avoided. See also **8.8**.

8.5 Consideration of near source effects [BS EN 1998-2, 3.2.2.3]

Seismic hazard in the UK is dominated by events smaller than magnitude 6,5. Therefore, in accordance with BS EN 1998-2, **3.2.2.3**, near source effects need not be considered.

8.6 Spatial variability of earthquake ground motions

Requirements for consideration of spatial variability of earthquake ground motions are specified in BS EN 1998-2, **3.3**, which also provides a simplified method of analysis. More sophisticated methods are given in BS EN 1998-2, Annex D.

In the UK, the effect of spatial variability gives rise to action effects which are likely to be small compared to those arising from the assumption of perfectly correlated motions. Where bridges with continuous decks are founded on approximately uniform soils, the UK National Annex to BS EN 1998-2 recommends that spatial variability may be neglected for rock sites and for sites on stiff to very stiff soils (soil types A, B and C). However, they should be checked for the looser soil types D and E where the length of continuous bridge deck exceeds the recommended value of L_{lim}. This is because, in softer soils, seismic ground motions have relatively longer periods, involving larger displacements for a given acceleration level, and shorter wavelengths than apply to stiffer soils. Therefore, where soft soils are present, differential movements between bridge supports are more likely to give rise to significant effects.

BS EN 1998-2, **3.3**(1)P, requires that all bridges with continuous decks are checked for spatial variability where they are supported on more than one ground type. The simplified method proposed in BS EN 1998-2, **3.3**(4) to (7), will usually be adequate, and the more sophisticated methods given in BS EN 1998-2, Annex D, are unlikely to be required.

8.7 Simplified analysis for P-delta effects [BS EN 1998-2, 5.4(1)]

More sophisticated analysis than that recommended may be used to investigate whether a less conservative estimate of P-delta effects is appropriate for limited ductility design, corresponding to $q \leqslant 1,5$.

8.8 Extent of damage to elastomeric bearings [BS EN 1998-2, 6.6.2.3(3)]

Any damage to bearings should not interfere with relief effort after an earthquake, and should not pose a threat to the safety of people crossing the bridge in vehicles immediately after an earthquake. See also **8.4**.

More stringent requirements might need to be considered where the cost of replacement of the bearings is large.

8.9 Seismic displacement at abutments [BS EN 1998-2, 6.7.3(7)]

The seismic displacement should be limited in order to achieve the objectives discussed in **8.4**.

8.10 Value of control period T_D for the design spectrum of bridges with seismic isolation [BS EN 1998-2, 7.4.1(1)P]

Unless a site-specific hazard analysis has been carried out to demonstrate otherwise, it is recommended that the value of T_D is taken as infinitely large (i.e. there is no transition from "constant velocity" to "constant displacement" in the design response spectrum). Further discussion of T_D is given in IStructE/AFPS [4].

8.11 Value of γ_m for elastomeric bearings [BS EN 1998-2, 7.6.2(5)]

The recommended value of γ_m is 1,0 rather than the increased value of 1,15 recommended in BS EN 1998-2. A proposal was made to amend the value recommended in BS EN 1998-2 to $\gamma_m = 1,0$, but this had not been formally approved at the time of publication of this Published Document.

8.12 Lateral restoring capability of the isolation system [BS EN 1998-2, 7.7.1(2)]

BS EN 1998-2, **7.7.1**(1), provides the principle for limiting residual displacements in seismic isolation bearings. Implementation procedures aimed at satisfying BS EN 1998-2, **7.7.1**(1), are specified in BS EN 1998-2, **7.7.1**(2). Since the publication of BS EN 1998-2, concerns have been expressed about the adequacy of these procedures under all circumstances. Alternative procedures, based on those initially proposed by Medeot [10], were prepared and recommended for acceptance by the Eurocode 8 Maintenance Group, but, at the time of publication of this Published Document, they had not formally been accepted. It is therefore recommended that specialist advice should be sought on the adequacy of specific base isolation systems to conform to the principle set out in BS EN 1998-2, **7.7.1**(1).

8.13 Minimum isolator temperature in the seismic design situation [BS EN 1998-2, J.1(2)]

The equation recommended in BS EN 1998-2 does not seem appropriate for selecting a minimum temperature to use when selecting upper bound design properties of elastomeric bearings, i.e. their stiffness and damping, and a revised form of the equation is proposed.

BS EN 1998-2 gives no recommendation on the maximum temperature to be used when selecting design properties for elastomeric bearings, which are less sensitive to maximum temperatures than minimum temperatures. As a guide, the maximum temperature appropriate for setting elastomeric bearing lower bound properties may be taken as:

$$T_{max,b} = T_{ave} + \psi_2 (T_{max} - T_{ave}) - \Delta T_1$$

where:

T_{max} is the value of the maximum shade air temperature at the bridge location having an annual probability of 0,0083 (120 year return period) that a higher temperature is recorded, in accordance with BS EN 1991-1-5:2003, **6.1.3.2**, adjusted by Annex A and its National Annex. Note that an annual probability other than 120 years may be specified for an individual project, in which case the adjustment from Annex A should be modified appropriately.

T_{ave} is the average shade air temperature at the bridge location throughout the year. In the absence of more precise data, T_{ave} may be taken as:

$$T_{ave} = (T_{min} + T_{max})/2.$$

T_{min} is the value of the minimum shade air temperature at the bridge location having an annual probability of 0,0083 (120 year return period) that a lower temperature is recorded, in accordance with BS EN 1991-1-5:2003, **6.1.3.2**, adjusted by Annex A and its National Annex. As previously noted, a different annual probability may be specified for an individual project.

ψ_2 = 0,50 is the combination factor for thermal actions for seismic design situation, in accordance with BS EN 1990:2002, Annex A2.

ΔT_1 depends on the bridge deck type. Its value may be taken as equal to that for the calculation of minimum isolator temperature, as reproduced in the following table.

Value of ΔT_1 for the determination of minimum isolator temperature

Deck	Concrete	Composite	Steel
ΔT_1 (°C)	7,5	5,0	–2,5

8.14 λ-factors for commonly used isolators [BS EN 1998-2, J.2(1)]

For a particular type of elastomeric isolator, whether low damping or high damping, the λ-factors for ageing and temperature effects may differ significantly from the guidance values given in BS EN 1998-2, **JJ.1**.

8.15 Relationship between displacement ductility and curvature ductility factors of plastic hinges in concrete piers [BS EN 1998-2, Annex B]

As an alternative to BS EN 1998-2, Annex B, other values may be obtained from the technical literature. As noted in **8.3**, UK bridges will generally be designed for limited ductility or elastic response, in which case this annex is not relevant.

8.16 Effective stiffness of reinforced concrete ductile members [BS EN 1998-2, Annex C]

The advice on effective concrete stiffness given in IStructE/AFPS [4] is acceptable as an alternative to the use of BS EN 1998-2, Annex C, or other values may be obtained from the technical literature.

8.17 Probable material properties and plastic hinge deformation capacities for non-linear analyses [BS EN 1998-2, Annex E]

As an alternative to BS EN 1998-2, Annex E, other values may be obtained from the technical literature. As noted in **8.3**, UK bridges will generally be designed for limited ductility or elastic response, in which case this Annex is not relevant.

9 Additional advice specific to BS EN 1998-4: Silos, tanks and pipelines

9.1 Recommendation on the need for seismic design of silos, tanks and pipelines

The design of silos, tanks and pipelines of consequence classes CC1 and CC2 need not consider seismic actions. Consequence classes are defined in BS EN 1990:2002, Table B.1.

It is recommended that all CC3 silos, tanks and pipelines are assessed on a project-specific basis to determine whether an explicit consideration of seismic actions is required. A seismic design should be carried out for CC3 facilities unless a consideration of the structural form and vulnerability, location and consequences of failure indicate that seismic design is not required. The discussion of Clause **3** is relevant.

9.2 Additional requirements for facilities associated with large risks to the population or environment [BS EN 1998-4:2006, 1.1(4)]

The regulatory basis for the design of high consequence of failure facilities within the scope of BS EN 1998-4 in the UK is discussed by Booth and Skipp [3]. It is recommended that a site-specific hazard analysis should be carried out for facilities associated with large risks to the population or environment.

It is recommended that, within the framework of the relevant regulatory requirements, the provisions of BS EN 1998-4 and its UK National Annex, together with this Published Document, should be used for the seismic design of non-refrigerated storage tanks in the petroleum industry, for cases where there are high consequences of failure. The use of BS EN 1998-4 is recommended in preference to the use of those parts of BS EN 14015 which deal with seismic design. BS EN 1473 refers to the seismic design of LNG tanks, but specifies BS EN 1998-4 as a normative standard.

9.3 Return periods for design and associated importance and reduction factors [BS EN 1998-4:2006, 2.1.2(4)P, and 2.1.4(8)]

As discussed in Clause **5**, the design return periods and importance factors recommended in the main body of BS EN 1998 are inappropriate for the UK. Facilities assessed as posing a large risk to the population or environment require a site-specific hazard assessment to establish appropriate design motions (see **9.1**). Other consequence class CC3 facilities may use design PGA $a_g = \gamma_I \cdot a_{gR}$, taken from the 2 500 year return figures shown in Figure 2. Note that BS EN 14015 and BS EN 1473 (see **9.2**) both specify return periods for seismic design.

10 Additional advice specific to BS EN 1998-5: Foundations, retaining structures and geotechnical considerations – Assessment of liquefaction

It is recommended that the assessment of the liquefaction potential of soils using BS EN 1998-5 should be carried out taking account of the additional advice contained in IStructE/AFPS [4]. Liquefaction assessment is a rapidly developing field and in most cases specialist advice is required.

11 Additional advice specific to BS EN 1998-6: Towers, masts and chimneys

11.1 Recommendation on the need for seismic design of towers, masts and chimneys

The design of category CC1 and CC2 facilities need not consider seismic actions, but all CC3 facilities should be assessed to determine whether consideration of seismic actions is required. A seismic design should be carried out for CC3 facilities unless assessment of the structural form and vulnerability, location and consequences of failure indicate that seismic design is not required (see also Clause **3**).

11.2 Design ground motions for towers, masts and chimneys

As indicated in Clause **5**, the design return periods and importance factors recommended in BS EN 1998 are inappropriate for the UK. Where the 2 500 year return period accelerations shown in Figure 2 are used to define the value of a_{gR}, the importance factor γ_I may be taken as 1. Where a site-specific hazard analysis is conducted as an alternative to the use of Figure 2, the value of return period associated with the design PGA $a_g = \gamma_I \cdot a_{gR}$ should be selected on a project-specific basis, taking into account the function and the consequences of failure of the facility involved.

Annex A (informative) List of clauses subject to National Choice in BS EN 1998-1, BS EN 1998-2, BS EN 1998-4, BS EN 1998-5 and BS EN 1998-6, with cross-references to relevant (sub)clauses of PD 6698

Table A.1 **BS EN 1998-1: General rules, seismic actions and rules for buildings**

(Sub)clause subject to National Choice in BS EN 1998-1	PD 6698 (sub)clause giving advice
2.1(1)P	**5**
2.1(1)P	**5**
3.1.1(4)	**7.2**
3.1.2(1)	**6**
3.2.1(1),(2),(3),(4),(5)	**4**
3.2.2.1(4), **3.2.2.2**(1)P	**6.3**
3.2.2.3(1)P	**6.4**
3.2.2.5(4)P	*None*
4.2.3.2(8)	**7.3**
4.2.4(2)P	*None*
4.2.5(5)P	**5**
4.3.3.1(4)	*None*
4.3.3.1(8)	*None*
4.4.2.5(2)	*None*
4.4.3.2(2)	**5**
5.2.1(5)	**7.4**
5.2.2.2(10)	*None*
5.2.4(1),(3)	*None*
5.4.3.5.2(1)	*None*
5.8.2(3)	*None*
5.8.2(4)	*None*
5.8.2(5)	*None*
5.11.1.3.2(3)	*None*
5.11.1.4	*None*
5.11.1.5(2)	No specific advice, but Clause **4** is relevant
5.11.3.4(7)e)	*None*
6.1.2(1)	**7.4**, **7.6.4**
6.1.3(1)	*None*
6.2(3)	*None*
6.2(7)	**7.6.2**
6.5.5(7)	**7.6.3**
6.7.4(2)	**7.6.4**
7.1.2(1)	**7.4**, **7.6.4**
7.1.3(1),(3)	*None*
7.1.3(4)	*None*
7.7.2(4)	*None*
8.3(1)	**7.4**
9.2.1(1)	**7.9.1**
9.2.2(1)	**7.9.1**
9.2.3(1)	**7.9.1**
9.2.4(1)	**7.9.2**
9.3(2)	**7.9.1**
9.3(2)	**7.9.3**
9.3(3)	**7.9.4**
9.3(4), Table 9.1	**7.9.5**
9.3(4), Table 9.1	**7.9.5**
9.5.1(5)	**7.9.6**
9.6(3)	*None*
9.7.2(1)	**7.9.7**
9.7.2(2)b	*None*
9.7.2(2)c	*None*
9.7.2(5)	*None*
10.3(2)P	**7.10**

Table A.2 **BS EN 1998-2: Bridges**

(Sub)clause subject to National Choice in BS EN 1998-2	PD 6698 sub(clause) giving advice
2.1(3)P	**8.2**
2.1(4)P	**8.1**
2.1(6)	**8.2**
2.2.2(5)	**8.4**
2.3.5.3(1)	*None*
2.3.6.3(5)	*None*
2.3.7(1)	**8.3**
3.2.2.3	**8.5**
3.3(1)P	**8.6**
3.3(6)	*None*
4.1.2(4)P	*None*
4.1.8(2)	*None*
5.3(4)	*None*
5.4(1)	**8.7**
5.6.2(2)Pb)	*None*
5.6.3.3(1)Pb)	*None*
6.2.1.4(1)P	*None*
6.5.1(1)P	**8.3**
6.6.2.3(3)	**8.8**
6.6.3.2(1)P	*None*
6.7.3(7)	**8.9**
7.4.1(1)P	**8.10**
7.6.2(1)P	*None*
7.6.2(5)	**8.11**
7.7.1(2)	**8.12**
J.1(2)	**8.13**
J.2(1)	**8.14**

Table A.3 **BS EN 1998-4: Silos, tanks and pipelines**

(Sub)clause subject to National Choice in BS EN 1998-4	PD 6698 sub(clause) giving advice
1.1(4)	**9.1**
2.1.2(4)P	**5**
2.1.3(5)P	**5**
2.1.4(8)	**5**
2.2(3)	**5**
2.3.3.3(2)P	*None*
2.5.2(3)P	*None*
3.1(2)P	*None*
4.5.1.3(3)	*None*
4.5.2.3(2)P	*None*

Table A.4 **BS EN 1998-5: Foundations, retaining walls and geotechnical considerations**

(Sub)clause subject to National Choice in BS EN 1998-5	PD 6698 sub(clause) giving advice
3.1(3)	*None*
4.1.4(11)	**10**
5.2(2)c)	*None*

Table A.5 **BS EN 1998-6: Towers, masts and chimneys**

(Sub)clause subject to National Choice in BS EN 1998-5	**PD 6698 sub(clause) giving advice**
3.1(1)	*None*
3.5(2)	*None*
4.1(5)P	**11.1**
4.3.2.1(2)	*None*
4.7.2(1) P	*None*
4.9(4)	**11.1**

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 1473, *Installation and equipment for liquefied natural gas – Design of onshore installations*

BS EN 1993, *Eurocode 3 – Design of steel structures*

BS EN 1996-1, *Eurocode 6 – Part 1: Design of masonry structures*

BS EN 14015, *Specification for the design and manufacture of site built, vertical, cylindrical, flat bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperatures and above*

BS EN 14620-1:2006, *Design and manufacture of site built, vertical, cylindrical, flat bottomed, above ground, welded, steel tanks for the storage of refrigerated liquefied gases with operating temperatures between 0 °C and –165 °C – Part 1: General*

Other publications

[1] MUSSON R. and SARGEANT S. Eurocode 8 seismic hazard zoning maps for the UK. British Geological Survey Seismology And Geomagnetism Programme Technical Report Cr/07/125. Research Report for the Institution of Civil Engineers. January 2008.

[2] GIARDINI, D. 1999. The Global Seismic Hazard Assessment Program (GSHAP) – 1992/1999. Annali di Geofisica, Vol. 42, 957-976. www.seismo.ethz.ch/GSHAP

[3] BOOTH E. and SKIPP B. Establishing the necessity for seismic design in the UK. Research Report for the Institution of Civil Engineers. January 2008.

[4] IStructE/AFPS. Manual for the seismic design of steel and concrete buildings to Eurocode 8. Institution of Structural Engineers, London. 2009.

[5] ELGHAZOULI, A. Y. "Seismic Design Procedures for Concentrically Braced Frames", Proc. Instn. Civ. Engrs., Structures and Buildings, 156 (2003), 381-394.

[6] GOGGINS, J. M. BRODERICK, B. M., ELGHAZOULI, A. Y. and LUCAS, A. S. "Experimental Cyclic Response of Cold-Formed Hollow Steel Bracing Members", Engineering Structures, 27(7), (2005), 977-989.

[7] GREAT BRITAIN: The Building Regulations 2000, as amended, SI 2000, No. 2531, London: The Stationery Office.

[8] GREAT BRITAIN: The Building Standards (Scotland) Regulations 1990, as amended, SI 1990, No. 2179, London: The Stationery Office.

[9] NORTHERN IRELAND: The Building Regulations (Northern Ireland) 2000, SR 2000, No. 389, London: The Stationery Office.

[10] MEDEOT, R: Re-centering capability evaluation of seismic evaluation systems based on energy concepts. 13th World Conference on Earthquake Engineering, Vancouver, B.C. Canada.

[11] BOOTH E. and SKIPP B. Eurocode 8 and its implications for UK-based structural engineers. The Structural Engineer, Vol 82/3, Feb 2004.

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