MANUAL FOR THE SEISMIC DESIGN OF STEEL AND CONCRETE BUILDINGS TO EC8

Edmund Booth[1] and Philippe Bisch[2]
[1] *Edmund Booth Consulting Engineer, London E17 9NJ, UK edmund@booth-seismic.co.uk*
[2]*Groupe IOSIS Ingénierie, 4, rue Dolorès Ibarruri 93100 Montreuil, France p.bisch@iosisgroup.fr*

ABSTRACT

A Manual (IStructE/AFPS, 2008) has been prepared to assist practising design engineers in implementing the provisions of the new European seismic standard, Eurocode 8 (EC8). EC8 contains a number of innovative features, and has significant differences from previous seismic standards, but despite various sources of advice being available, the practising engineer still faces a formidable task in implementing it for the first time. The UK Institution of Structural Engineers (IStructE), in conjunction with SECED (the UK branch of IAEE) and its French counterpart society AFPS therefore decided to prepare a Manual on EC8. It is intended to form a stand-alone source for the seismic design of common building types, limited to steel and concrete (but not composite) construction, not more than 40m tall and without highly irregular configurations in plan or elevation. The Manual forms part of a suite of Manuals on the Eurocodes planned or published by IStructE. It simplifies the provisions of EC8 by limiting the scope of buildings covered, provides charts and tables to assist in computation and gives explanatory text, particularly where EC8 may be incomplete or somewhat imprecise. Where more recent information has become available since publication of EC8, further advice is provided. Although neither the UK nor (generally) France is an area of high seismicity, the Manual is also intended to assist engineers designing in other, more seismically active countries. The Manual is expected to be published during 2008, with parallel texts in French and English.

KEYWORDS: Eurocode, seismic design standard, design aids, steel, concrete, regularity

1. BACKGROUND TO THE MANUAL

Eurocode 8: Design of structures for earthquake resistance (EC8) forms part of the suite of European standards for construction that is currently being widely implemented across Europe. The Eurocodes are intended to be mandatory for European public works and are likely to become the de-facto standard for the private sector in Europe and perhaps also more widely. EC8 has been developed and approved by an international group of experts from all over Europe. It contains a number of innovative features, and has significant differences from previous seismic standards. Although a “Designer’s Guide” to EC8 (Fardis *et al*, 2005) is available to provide essential background information and advice on the code, the practising engineer still faces a formidable task when implementing it for the first time. The UK Institution of Structural Engineers (www.istructe.org), in conjunction with SECED (www.SECED.org.uk, the UK branch of IAEE) and its French counterpart society AFPS (www.afps-seisme.org) therefore decided to prepare a Manual on EC8 (IStructE/AFPS, 2008).

In addition to buildings, EC8 covers a wide range of other types of structure, including bridges, towers, chimneys and pipelines but these are outside the Manual’s scope. The scope is further restricted to the more common types of building; this has allowed EC8’s provisions to be simplified considerably in places. The main requirements are that the buildings are of steel or concrete (but not composite) construction, not more than 40m tall and should avoid highly irregular configurations in plan or elevation. Concrete buildings of the highest ductility class (DCH) are also excluded.

The Manual is intended to form a stand-alone source for the seismic design of buildings. Designs prepared using the Manual can be taken to be compliant with EC8’s provisions, provided the buildings lie within the scope of the Manual. Drafting and approval of the Manual is being carried out jointly by French and UK engineers; it forms part of a suite of manuals by IStructE, covering building design to the Eurocodes. Those on

Eurocodes 2, 5 and 6 have already been published; further manuals on Eurocodes 1 (including Basis of Design), 3 (and parts of 4) plus 7 are in preparation.

The Manual offers the practising engineer using EC8 the following features.

1) By limiting the scope to the more usual cases, the number of requirements is significantly reduced.
2) Design charts and tables are provided to facilitate computation of some of the more complex requirements.
3) Explanatory text is provided within the document to assist the engineer with interpreting and implementing its requirements, particularly where EC8 may be incomplete or somewhat imprecise.
4) Where more recent information has become available since publication of EC8, further advice is provided.
5) The values of the 'Nationally Determined Parameters' (NDPs) fixed by the French and UK National Annexes are included, as well as indicating (in brackets) the values recommended by EC8.

The publication will contain parallel texts in French and English. Although France is generally an area of moderate to low seismicity (though small parts are of higher seismicity), and the UK of low to very low seismicity, the Manual is also intended to assist engineers designing in other, more seismically active countries. At the time of writing the paper, the text of the Manual had received formal approval from both French and UK supervising committees, and publication is expected during 2008. Subsequent sections of this paper describe some of the main features of the Manual.

2. AIM, SCOPE AND CONTENTS

2.1 Aim

The Manual aims to provide seismic design application rules for the majority of low to medium rise steel and concrete buildings falling within the scope of EC8, for all levels of seismicity. It may still be useful for some aspects of the preliminary design of a wider range of buildings, for example high rise buildings or buildings required for a post-earthquake emergency, but in these cases, for detailed design, engineers will need to refer to EC8.

Users of the Manual are not expected to have prior knowledge of EC8, but must be suitably qualified and experienced engineers, since the Manual is not intended to be a primer on earthquake engineering. The integrity of a building under seismic loading depends not only on the performance of its superstructure but is also very strongly dependent on the behaviour of its foundations and supporting soils; therefore suitably qualified and experienced geotechnical engineers, as well as structural engineers, need to be involved. Users must also have some experience of the Eurocode set of standards, since use of other Eurocodes, in addition to EC8, is necessary to conform to EC8's requirements.

2.2 Scope

The Manual is intended for the seismic design and analysis of most steel and concrete buildings of regular and moderately irregular configuration up to 40m in height – see Table 2.1. Design of buildings within its scope which comply with the French text of the Manual can normally be taken as complying with EC8, as it applies in France; similarly remarks apply to the English text and UK compliance. In countries other than France and the UK, reference should always be made to the relevant National Annex, to determine whether additional or alternative rules apply. The Manual is primarily intended for application in areas of moderate to high seismicity, although EC8's much simpler rules for areas of low seismicity are also covered.

2.3 Contents

The chapter and main sub-heading titles of the Manual are shown in Table 2.2.

3. ANALYSIS

The Manual gives the EC8 provisions for the conduct of both response spectrum and equivalent static methods of analysis, with some advisory material on the limitations of the former method, which is permitted without restriction by EC8. Advice is given on appropriate assumptions for concrete stiffness to allow for cracking, which goes further than that in EC8. The discussion of non-linear static and dynamic analysis is introductory in nature; sources of advice are identified, but the subject is not covered in detail.

4. GEOTECHNICAL ISSUES AND FOUNDATION DESIGN

Some quite extensive additional commentary is provided to supplement the material in EC8. This includes advice on active faults, slope stability, soil properties, settlement and liquefaction; on the latter, it is advised that the procedures given in Annex B of EC8 Part 5 should be supplemented by reference to more recent procedures. In the discussion on standard spectral shapes, it is advised that EC8's recommended values of T_D (the period where the spectrum changes from constant velocity to constant displacement) may be unconservatively low in some cases. The section on foundation design covers both piled and shallow foundations, and gives advice on capacity design aspects.

Table 2.1: Scope of the Manual

	Within scope of Manual	**Outside scope of Manual**
Site conditions	No limits are placed on minimum or maximum design horizontal ground acceleration	
	Soil types A,B,C, D & E, as defined by EC8	All other soil types excluded
		Design for vertical seismic accelerations
		Slope stability issues, ground faulting
		Assessment of liquefaction potential
General structural configuration	Buildings up to 40m in height above effective ground level.	Buildings taller than 40m
		Highly irregular in plan or elevation
	Regular or moderately irregular in plan or elevation	Concrete frames built after construction of the masonry walls.
		Buildings required for a post earthquake emergency
		Composite steel-concrete structures
	Steel and concrete frames with masonry infill panels in contact with the frames, but added after construction of the frames	Prestressed concrete structures
		Structures not of concrete or steel
		Seismically isolated structures
Concrete structures	Ductility class DCL and DCM	Ductility class DCH
	Ductile shear walls, squat shear walls	
	Large lightly reinforced shear walls	
	Moment frames, dual systems, coupled shear walls	
Steel structures	Ductility class DCL, DCM and DCH	Eccentrically braced frames
	Braced frames with composite or non-composite floors	Steel structures where the connections are designed as dissipative.
	Moment frames with non-composite members	Moment frames where the beams act compositely with concrete floors

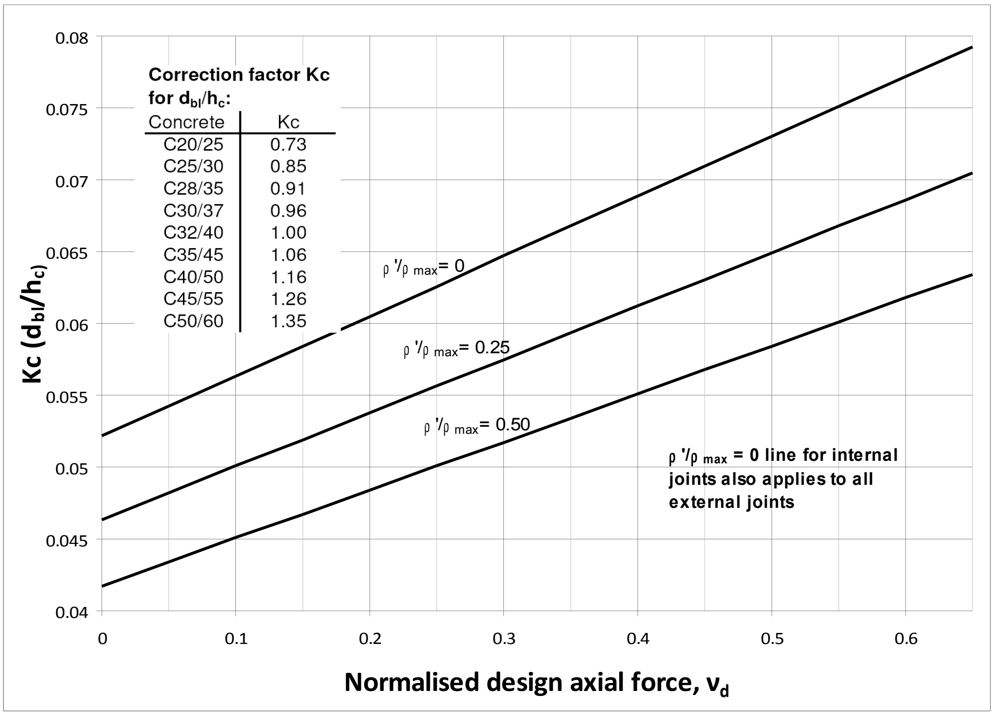
Table 2.2: Contents of the Manual

1 Aim and Scope 1.1 Aim 1.2 The Eurocode system 1.3 Scope of Manual 1.4 Contents	**9 Analysis** 9.1 Choice of analysis method 9.2 General assumptions 9.3 Equivalent linear analysis 9.4 Non-linear methods 9.5 P-D effects
2 Reference documents 2.1 Other Eurocodes 2.2 National Forewords and Annexes 2.3 AFNOR and BSI supporting documentation 2.4 Other Eurocode Manuals 2.5 Other sources of information **3 National Annexes and NDPs** 3.1 Purpose of the National Annexes 3.2 Treatment of NDPs 3.3 French National Annexes 3.4 UK National Annexes **4 Performance objectives** 4.1 No collapse requirement. 4.2 Damage limitation requirement	**10 Reinforced concrete buildings** 10.1 Overview of main differences between seismic and non-seismic design 10.2 Design to Eurocode 2 (DCL design) 10.3 Ductile design (DCM and DCH design) 10.4 Design strength of materials 10.5 Types of rc buildings and q factors 10.6 Moment resisting frames 10.7 Walls 10.8 Detailing of confinement reinforcement 10.9 Laps and splices 10.10 Secondary seismic elements 10.11 Provisions for concrete floor diaphragms 10.12 Local effects due to infills 10.13 Precast frames and precast floor systems
5 Design fundamentals 5.1 Desirable characteristics 5.2 Primary and secondary elements 5.3 Dissipative structures and zones 5.4 The behaviour factor, q 5.5 Ductility classes 5.6 Capacity design method 5.7 Flow charts of the design process	**11 Steel buildings** 11.1 Material specification 11.2 Design to EC3: DCL Design 11.3 Ductile design (DCH and DCM Design) 11.4 Types of steel buildings and q factors 11.5 Requirements for compactness 11.6 General rules for connection design 11.7 Moment resisting frames 11.8 Concentrically braced frames 11.9 Unbraced frames with masonry infill
6 Regularity in plan and elevation 6.1 Introduction 6.2 Consequences of regularity classification 6.3 Regularity in plan 6.4 Regularity in elevation **7 Geotechnical aspects** 7.1 Influence of site conditions 7.2 Site investigation	**12 Foundations** 12.1 General principles 12.2 Capacity design of foundations 12.3 Seismic capacity for shallow foundation 12.4 Shallow concrete foundations 12.5 Design of piled foundations **13 Seismic joints** **14 Damage limitation**
8 Design ground motions 8.1 Introduction 8.2 Importance classes 8.3 Ground type 8.4 Horizontal elastic response spectrum 8.5 Horizontal design spectra	**15 Non-structural elements** **References** **Appendix A**: Example calculations of torsional radii and radius of gyration

5. CONCRETE BUILDINGS

Chapter 5 of EC8 "Specific rules for concrete buildings" constitutes 30% of the length of the main provisions of the code and the chapter is nearly twice as long as any other, and 2½ times longer than the steel chapter. The approach used is rather rigorous in nature, relating directly to fundamental parameters, in particular curvature ductility demands. This approach, which is in contrast to the more empirical framework of US seismic codes, makes the intention of EC8 transparent, and gives confidence in its applicability over a wide range of situations, including non-standard ones. However, the chapter undoubtedly poses a challenge to first time users, however experienced in earthquake engineering. It also posed the greatest challenge to the drafters of the Manual, who had the task of trying to unravel some of the complexities, while remaining strictly compliant with the code's requirements. A fourfold approach was taken to achieve this, described below.

1) The provisions for DCH (ductility class high) buildings were excluded. This considerably shortened and simplified the provisions needed. Whether DCH will be used much in design practice is a matter of conjecture at the moment, which will be resolved in the course of time. DCH structures, by embodying more ductility, result in lower force demands. The consequent reduction in structural cost will be offset to some extent by more complex detailing, and the designer is given a significant increase in design effort (possibly for the same or lower fee). Structures, in particular tall structures, may in any case be governed by deflection, where the use of DCH is of no advantage. Also, the reinforcement grade required for DCH concrete is not at the moment universally available.
2) Extensive explanatory material, in the form of textual advice, figures and reference to additional resources is provided.
3) Guidance is given on the sequence of design.
4) Design charts, such as those in figure 5.1, are provided for the design of confinement steel in columns, maximum and minimum reinforcement ratios and bar diameters through joints. These should give the designer greater confidence that the often complex series of equations in EC8 have been correctly interpreted.



Kc	Correction factor depending on concrete grade	ν_d	Normalised axial force ($=N_{Ed}/f_{cd}\cdot A_c$)
ρ'	compression steel ratio of the beam bars passing through joint	ρ_{max}	maximum allowed tension steel ratio.

$d_{bl}/_{hc}$ Ratio of main beam bar diameter to joint depth

Figure 5.1 Maximum bar diameters of horizontal steel in internal and external beam column joints

EC8 introduces the innovative concept of "lightly reinforced walls" which has been substantiated by many recent experiments. Their feature is that their behaviour is based on energy transformation associated with uplift due to their large length. Figure 5.2 shows a typical flow chart given in the Manual for designing such walls.

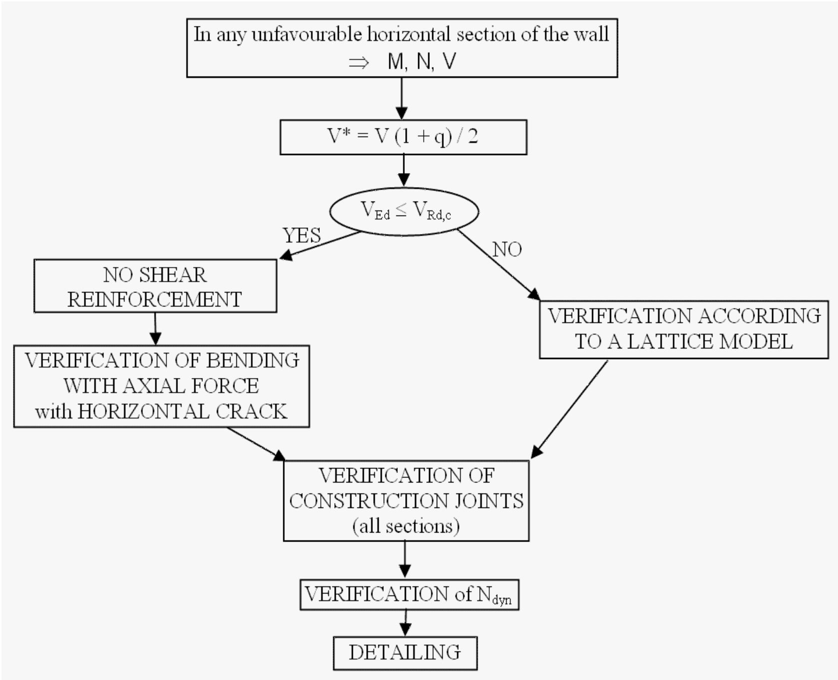


Figure 5.2 Flow chart for the design of large lightly reinforced walls

6. STEEL BUILDINGS

A similar approach was taken for steel buildings. However, since the additional requirements for DCH steel structures in EC8 are considerably less complex than is the case for concrete, DCH steel structures were included. The Manual provides advice on reference sources for designing connections in ductile moment frames, a topic where few application rules are provided in EC8.

7. EVALUATION OF REGULARITY

7.1 Introduction

While it is universally acknowledged that regularity (or the lack of it) is a crucial factor in the seismic performance of buildings, there is currently no international agreement on how it should be evaluated, despite many years of academic study. The approach taken in EC8, especially to regularity in plan, is not straightforward, and application rules are not given to cover all details. The Manual aims to assist the designer in the evaluation. It also introduces a new concept which is not found in EC8 (although it does appear in French and US seismic design practice) - that of distinguishing between 'moderate' and 'high' levels of irregularity. The rationale for this distinction was as follows.

EC8, although it discourages irregularity, does not forbid it; the consequences of an irregular structure, according to EC8, are the requirement to design for higher force demands, and to consider more complex methods of analysis – usually 3D response spectrum analysis including (for irregularity in plan) simultaneous excitation in the two principal horizontal directions. It is clear that a Manual giving simplified methods may be inadequate to deal with the complexity and uncertainty of a high degree of irregularity, and so it was decided to exclude such structures from the scope of the Manual. However, it was judged that excluding all buildings classified as irregular from the scope of the Manual would be too restrictive, and satisfactory results could be obtained for 'moderately' irregular structures using methods described in the Manual, provided all the relevant requirements of EC8 (3D response spectrum analysis, reduced q factors, etc.) were met. The next sections describe in more detail the approach taken in the Manual.

7.2 Regularity in plan

EC8 specifies one of its criteria for regularity in plan in terms of the ratio of the torsional radii, r_x and r_y to the eccentricity between centres of stiffness and centre of mass, e_{oy} and e_{oy} – see equation 7.1. The torsional radius r_x is the square root of the ratio of torsional stiffness (moment per unit rotation) to lateral stiffness in the y direction (force per unit deflection). A similar definition applies to r_y.

$$r_x > Xe_{ox}; \quad r_y > Xe_{oy} \tag{7.1}$$

Where equation 7.1 is satisfied, with X=3.33 (the value given in EC8), the structure may be classified as regular in plan. The Manual classifies 'moderate' irregularity in plan as applying to structures where X reduces from 3.33 to 2.5; this reduction is based on judgement and may need to be reviewed in the light of experience.

There are other criteria for regularity in plan, according to EC8. The most complex requirement addresses the issue that even symmetrical structures where e_{oy} and e_{oy} are small (hence satisfying equation 7.1) may perform in an unsatisfactory way if the torsional rigidity is low, because shifts in stiffness due to member stiffness degradation, variability in the centre of mass and perhaps torsional ground excitations are prone to cause an unstable response. Therefore, EC8 classifies concrete structures as 'torsionally flexible' where:

$$r_x < l_s; \quad r_y < l_s \tag{7.2}$$

l_s is the radius of gyration, the square root of the ratio of the polar moment of inertia (calculated about the centre of mass) to the mass. Torsionally flexible concrete buildings attract a greatly reduced (less favourable) behaviour factor q; curiously, there is no penalty given in EC8 for torsionally flexible steel buildings. It was decided to exclude all torsionally flexible buildings from the scope of the Manual, using the definition of equation 7.2 without modification, because it was considered that simple linear elastic methods of analysis might be inadequate to account satisfactorily for their behaviour.

These EC8 definitions are based on evaluating centres of stiffness and mass, and hence the distance between them, namely e_{oy} and e_{oy}. These are physically meaningful concepts that can be helpful to the designer when considering how to arrange structural elements. The problem is that no rigorous definition of 'centre of stiffness' is possible, other than for single storey buildings, and the concept becomes particularly unclear when mixed lateral load-resisting systems are used, such as shear walls combined with moment frames. The Manual proposes some approximate charts that may be useful for evaluating compliance of some common structural layouts with equations 7.1 and 7.2. It also proposes a method of evaluating centre of stiffness, including a check that it is sufficiently reliable for dual wall-frame systems. Finally, in cases where evaluation of the centre of stiffness is too problematic, it proposes alternatives procedures as follows.

a) As an alternative to using equation 7.1, a structure may be classified as 'moderately irregular' (as opposed to 'highly irregular') in plan where the maximum storey drift within each storey under the design seismic loading nowhere exceeds 1.4 times the average storey drift in that storey (i.e. the average of the drifts at opposite ends of the storey. The storey drift equals the difference in deflection between top and bottom of that storey). This is based on Table 12.3-1 of ASCE/SEI 7-05 (ASCE, 2005).
b) As an alternative to satisfying equation 7.2, the periods of the first two predominantly translational modes may be shown to exceed the period of the first predominantly torsional mode. Where this is not satisfied, the structure must be classified as 'highly irregular' in plan and excluded from the scope of the Manual, at least for final design. This part of the classification involves an immediate transition from 'regular' to 'highly irregular', with no intermediate 'moderately irregular' stage.

An appendix is provided, giving a worked example of quantifying regularity in plan for two example structures.

In fact, a strict compliance with EC8 does not require regularity in plan (or elevation) to be demonstrated; instead, the requirements for analysis and strength in irregular structures can be implemented. However, EC8 makes it clear (and every earthquake engineer knows) that regularity is very significant for seismic response, and so ways of quantifying the degree of irregularity were judged important. Moreover, for the purposes of the Manual, quantification *is* necessary, because highly irregular structures are excluded from its scope.

7.3 Regularity in elevation

Quantification of regularity in elevation is much more straightforward than in plan. The Manual provides guidance on how to quantify EC8's qualitative requirement that mass and stiffness must either remain constant with height or reduce only gradually, without abrupt changes. Based on ASCE 7-05 (ASCE, 2005), it recommends that in a building where the mass or stiffness of any storey exceeds 70% of that of the storey above or more than 80% of the average of the three storeys above, then the building satisfies this requirement. These percentages reduce to 60% and 70% for moderate irregularity. Similarly, in buildings with moment-resisting frames, EC8 specifies that the lateral resistance of each storey should not vary "disproportionately" between storeys. Based on ASCE 7-05, the Manual recommends that where the strength of any storey is more than 80% of that of the storey above, the building satisfies this requirement. This percentage reduces to 65% for moderate irregularity.

8. SPECIAL ISSUES RELATING TO FRANCE & UK

The Manual claims that structures within its scope and designed to its provisions are also compliant with EC8. Since EC8 has statutory force in France, it was essential that the Manual should be comprehensive and should also clearly identify which of its parts relate directly to EC8 requirements, and which contain additional, complementary advice. This has been done by using *italic script* for such complementary material. In France, the Manual is identified as a source of 'non-conflicting complementary information' and designs to its provisions will be recognised as such by the designers, although compliance with EC8 is finally the only legal reference when its application is mandatory.

The UK National Forewords to EC8 specify that the UK is an area of very low seismicity, for which the application of EC8 is not required. However, the UK Forewords state that certain types of structures may warrant an explicit consideration of seismic actions. The Manual does not address the issue of when this may apply in the UK, since relevant advice is provided elsewhere (BSI, 2008), and the main use of the Manual by UK engineers is envisaged to be for the design of structures in seismic areas overseas.

9. CONCLUSIONS

The Manual is intended as a useful resource for seismic engineers for applying and interpreting the provisions of EC8 to buildings in seismic areas throughout the world. It also provides additional guidance by extending and updating EC8 in some respects, and this may form a basis for discussion when EC8 is next revised.

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