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Assessment of Eurocode 8 Seismic Force Calculation

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Summary

The basis of earthquake force calculations given in EC8 are reviewed in this paper. After a description of the procedure given in the code, a brief assessment of the various regulations is undertaken. Special emphasis is placed on the recommended spectral shapes and values for the horizontal and vertical earthquake components. Comparison with a carefully selected data set, mainly from strong near-field earthquakes, indicates that EC8 horizontal spectrum caters well for such potentially damaging events whilst the vertical spectrum is unconservative.

1. Introduction

Parts 1.1 (Seismic Action), 1.2 (General and Building) and 1.3 (Material Related Chapter) of EC8 have been voted upon and have been subsequently issued as ENV. This is a milestone in the development of EC8, which has occupied many researchers and practitioners for several years.

In the United Kingdom the British Standards Institution committee B/525/8 is entrusted with collating and distilling comments on the code. In spite of the very low seismic hazard level in the UK, and the known reluctance of official organisations in the UK to foster even the simplest of lateral robustness regulations, UK earthquake engineers have been particularly active in commenting on the code thus reflecting the quality of research and development, as well as intellectual interest, of UK engineers in the subject.

The work presented below is not intended to represent a European perspective, but rather a personal one. It is based on the author's work, in collaboration with colleagues from Imperial College and European, particularly within the network 'Prenormative Research in Support of EC8' funded by the European Community.

2. Basic Requirements and Seismic Action

EC8 requires seismic design to be undertaken for a single event, the design earthquake. This is in contrast to the Japanese and the New Zealand codes, where a serviceability and a maximum earthquake scenarios are explicitly given. It is implicit in EC8 that the safety verification for the design event would lead to a no-collapse condition under the maximum event. Whilst the no-collapse condition is deemed to be satisfied if the structure is designed to resist forces calculated using the behaviour factor q, and the elastic response spectrum, the serviceability criterion is imposed by specifying deformation (drift) limits.

Different levels of design reliability are included my means of an importance factor γ_I. This parameter implicitly also accounts for different return periods of the design event as well as different probabilities of exceedance of the design ground acceleration.

2.1. Limiting Ground Accelerations and Response Spectra

The code depicts that seismic design is not necessary where a design ground acceleration (not clearly defined) is equal to or less than 0.04g. Simplified procedures of design and detailing may be used for design ground accelerations of 0.1g or less. The design ground acceleration is evaluated as equal to the peak ground acceleration for medium to large events at moderate to long distances from the site. It is less than the peak ground acceleration for small events in the vicinity of the site.

2.1.1. Elastic Response Spectrum

The elastic spectrum for the horizontal component of earthquake ground motion is given as follows:

$T \leq T_B$

$$S_e = a_g\, s \left[1.0 + \frac{T}{T_B}(\eta\beta_o - 1.0) \right] \qquad (1)$$

$T_C \geq T \geq T_B$

$$S_e = a_g\, s\, \eta\beta_o \qquad (2)$$

$T_D \geq T \geq T_C$

$$S_e = a_g\, s\, \eta\beta_o \left[\frac{T_C}{T}\right]^{k_1} \qquad (3)$$

$T \geq T_D$

$$S_e = a_g\, s\, \eta\beta_o \left[\frac{T_C}{T_D}\right]^{k_1} \left[\frac{T_D}{T}\right]^{k_2} \qquad (4)$$

where S_e Spectral acceleration normalised by g

a_g Peak ground acceleration in g

s Soil condition parameter

η Damping correction (other than for 5% damping) given by

$$\sqrt{\frac{7}{2+\xi}} \geq 0.7$$

ξ percentage of critical damping

T_B, T_C, T_D	Corner periods
k_1, k_2	Exponents
β_o	Amplification factor for zero period acceleration

The various parameters are given in Table 1 below.

Soil Class	s	β_o	k_1	k_2	T_B	T_C	T_D
A	1.0	2.5	1.0	2.0	0.10	0.40	3.0
B	1.0	2.5	1.0	2.0	0.15	0.60	3.0
C	0.9	2.5	1.0	2.0	0.20	0.80	3.0

Table 1. Parameters for EC8 Horizontal Spectrum

The vertical spectrum is defined as a function of the horizontal spectrum as follows:

$$T < 0.15 \qquad S_{av} = 0.7\, S_{ah} \tag{5}$$

$$T > 0.5 \qquad S_{av} = 0.5\, S_{ah} \tag{6}$$

$$0.15 \leq T \leq 0.5 \qquad \text{linearly interpolated between 0.7 and 0.5} \tag{7}$$

In Figure 1, the shapes of typical vertical and horizontal spectra for EC8, intermediate soil class (B) are shown. This indicates that the code, in common with all existing seismic codes, defines the vertical spectral amplification as a fixed (70%) of the horizontal value. Moreover, whereas EC8 has opted for an improved spectral shape, where by there is a slight difference in the frequency content of the two components for the intermediate period range, the ratio of vertical-to-horizontal peaks drops to 0.5. Another novelty of EC8 is the introduction of a third corner period T_D to account for reduction of amplification in the very long period range (> 0.3 sec).

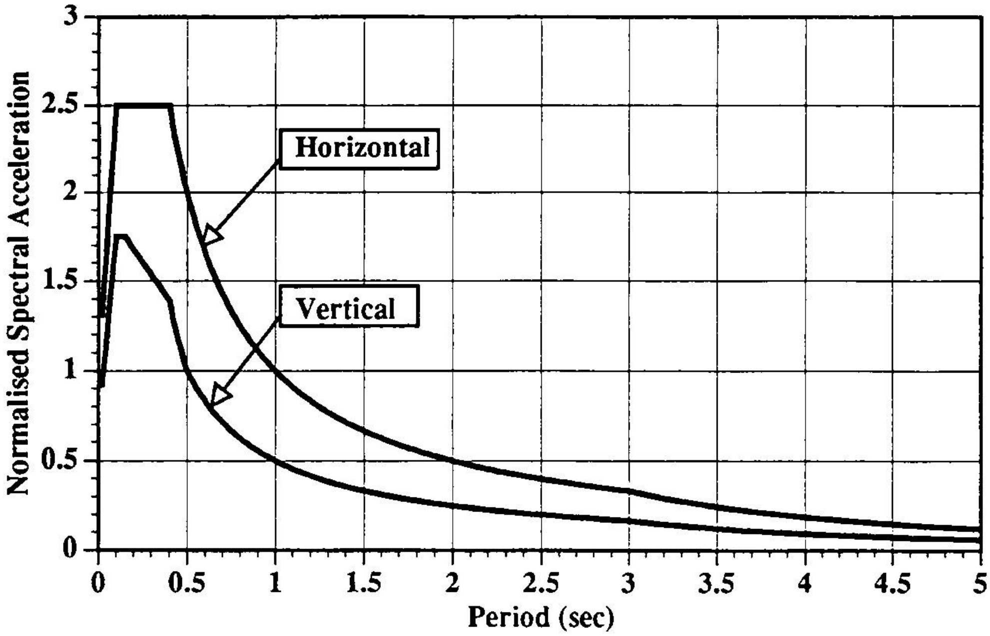

Fig. 1. Horizontal and Vertical Spectra for Soil Class B in EC8

2.1.2. Behaviour Factors ‘q’ and Design Spectra

Seismic design hinges on the selection of an appropriate behaviour factor (R in US practice and q in European practice). This parameter accounts for the force-delimiting mechanisms from hysteretic and other sources of damping for structures responding in a controlled inelastic manner. EC8 recommends q factors for various structural systems and construction material, to arrive at design spectra, given by the following:

$T \leq T_B$

$$S_d(T) = \alpha\, s\, [1 + \frac{T}{T_B}(\frac{\beta_o}{q} - 1)] \qquad (8)$$

$T_C \geq T \geq T_B$

$$S_d(T) = \alpha\, s\, \frac{\beta_o}{q} \qquad (9)$$

$T_D \geq T \geq T_C$

$$S_d(T) = \alpha\, s\, \frac{\beta_o}{q}\left[\frac{T_C}{T}\right]^{k_{d1}} \geq 0.2\,\alpha \qquad (10)$$

$T \geq T_D$

$$S_d(T) = \alpha\, s\, \frac{\beta_o}{q}\left[\frac{T_C}{T_D}\right]^{k_{d1}}\left[\frac{T_d}{T}\right]^{k_{d2}} \geq 0.2\,\alpha \qquad (11)$$

All the symbols are as defined for equations 1 through 4, whilst a is the ratio of ground acceleration to gravitational acceleration, and k_{d1} and k_{d2} are exponents assuming values dependent on the soil class (recommended at 2/3 and 5/3, respectively, in EC8).

3. Assessment of Elastic Spectra

The elastic spectra for horizontal and vertical action in EC8 are supposed to represent uniform hazard, ie. the probability of exceedance for all structural periods is approximately the same. In an attempt to assess the adequacy of the EC8 spectral shapes and amplification factors, a carefully selected earthquake data set was examined. These represent records within about 25 km from the recording station, at intermediate depths and magnitudes above m_S=5 (Ambraseys and Srbulov, 1995). In Figure 2, the 5% damped horizontal elastic spectrum of EC8 is compared to the mean and the mean plus one standard deviation spectrum from the selected data set, comprising 35 earthquakes (Elnashai and Papazoglou, 1995). It is evident that the EC8 horizontal spectrum is provides and excellent fit, especially when taking into account that the data set was selected without regard or relationship to Eurocode 8.

The spectra for the vertical components of the same set of earthquakes are compared to EC8 vertical spectrum in Figure 3. It is clearly demonstrated in the above that the vertical spectrum in EC8 requires major changes to render it representative of observed earthquake motion, especially within 20-30 km from the site. Herein, no comment is made regarding the structural significance of the vertical component of earthquake motion; analytical and observational assessment of this is given elsewhere (Elnashai and Papazoglou, 1995).

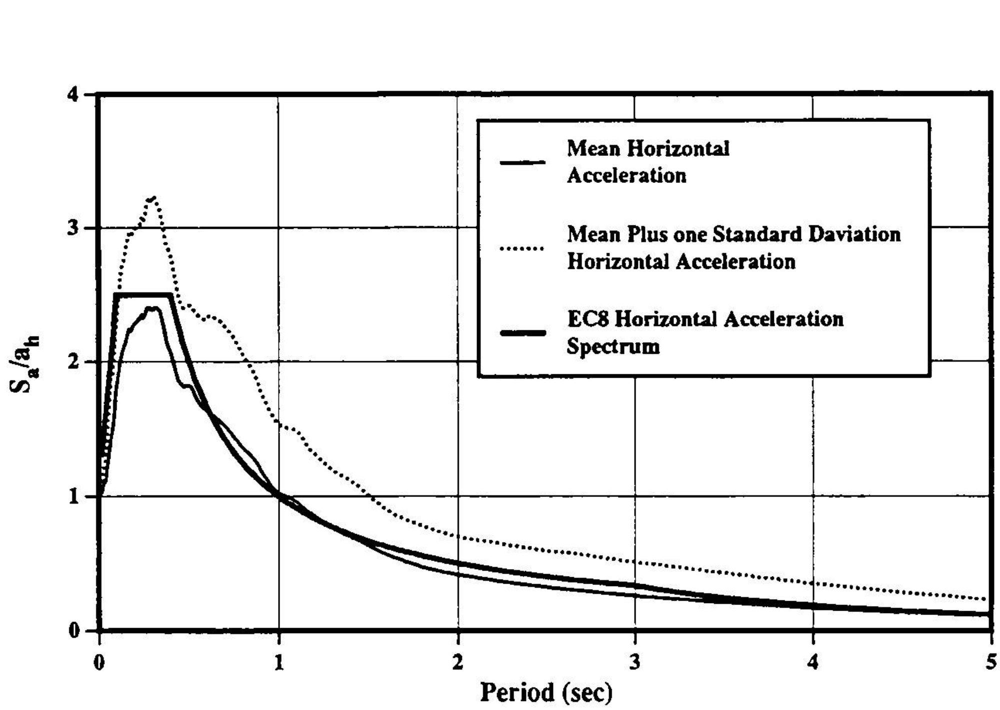

Fig. 2. Comparison of EC8 Horizontal Spectrum and 35 Earthquake Spectra

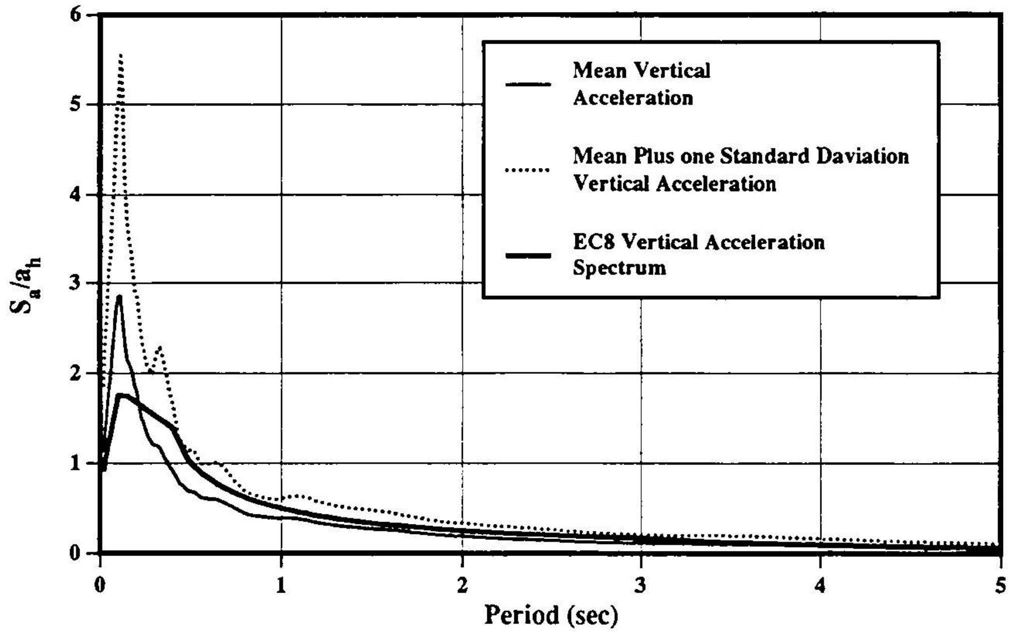

Fig. 3. Comparison of EC8 Vertical Spectrum and 35 Earthquake Spectra

The main reason for the discrepancy between the EC8 vertical spectrum and the measured spectra is the fixed ratio between ground accelerations in the horizontal and vertical directions employed by the code, in common with all existing seismic codes. Observations indicate that this ratio is dependent on earthquake magnitude and source-site distance. In the work of Elnashai and Papazoglou (1995), a variable ratio is proposed, based on engineering seismology studies by Ambraseys and Simpson (1995) and Abrahamson et al (1989). These relationships are depicted in Figure 4, where the code-specified fixed ratio is also indicated. Use of such an approach will render EC8 vertical spectra representative of true observations. Recommended spectral shapes were also given in Elnashai and Papazoglou (1995).

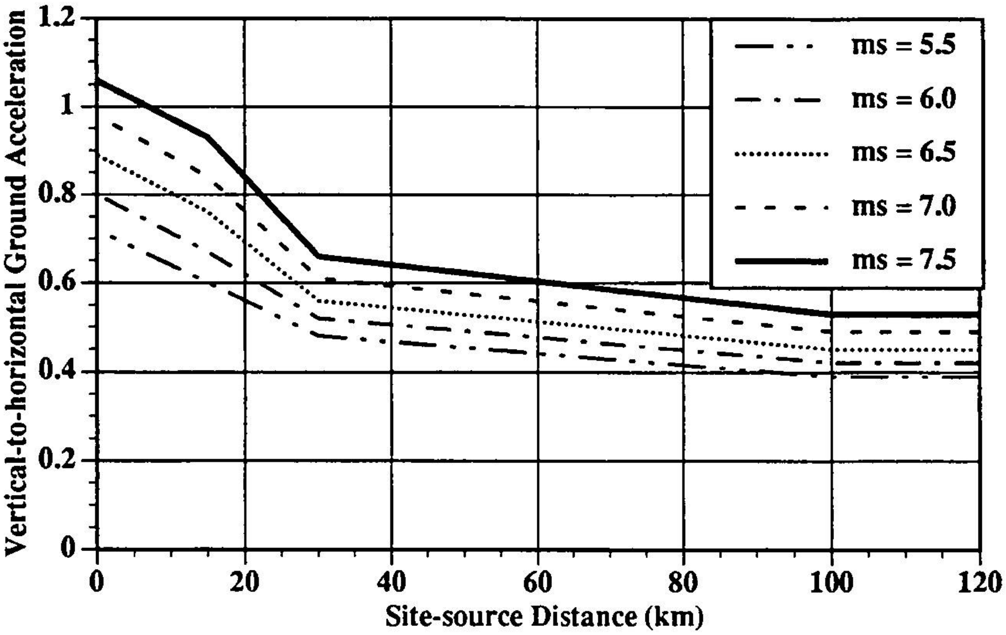

Fig. 4. Relationships for Vertical-to-horizontal Ground Acceleration (Elnashai and Papazoglou)

A question arises with regard to recommended damping ratio s for vertical spectra as well as response modification factors. Whereas the latter is discussed briefly in subsequent sections, the former requires considerable effort. It is not known what level of damping is appropriate to represent hysteretic and other sources of force reduction in vertical vibration modes. For conservatism, it is prudent to recommend low values, pending further research, hence 1% of critical is recommended for the time being.

4. Behaviour or Response Modification Factors

As postulated by equations 8 through 11, the behaviour factor q is used to scale the elastic forces to arrive at a set of design forces. EC8 gives q factors for RC and steel structures which vary from 1 (plastic limit design) to a maximum of 8. For RC structures, the behaviour factor is defined for various structural systems, such as moment resisting frames, coupled wall-frame and core-frame structures and assumes a constant value regardless of the specific details of the structure within its class. For steel, a method based on the structural overstrength (defined as the ratio of the load multiplies at yield and at ultimate) is employed. The overstrength term, through, is fixed to 1.2, with an exceptional allowance up to 1.6 in special cases.

For all systems, and indeed in all other seismic codes, the behaviour factor is period-independent. Many studies have highlighted the inadequacy of this approach as well as the concept of a behaviour factor solely linked to the ductility of the structure. Fajfar (1994.a) studied the relationship between an overstrength factor (q_s), a ductility-related behaviour factor (q_μ) and the final behaviour factor q, and recommended the use of the former two to arrive at the latter. In another study, Fajfar (1994.b) indicated that the use of a period-independent q factor may be a reasonable approximation, but it obscures the sources of force reduction under seismic loading. Various energy measures were also used to assess recommended values of response modification factors.

To highlight the period dependence of the ductility-based behaviour factor, Figure 5 is examined, where the ratio between ordinates of the elastic and inelastic spectra for the JMA Kobe record (Elnashai et al, 1995) are plotted versus period.

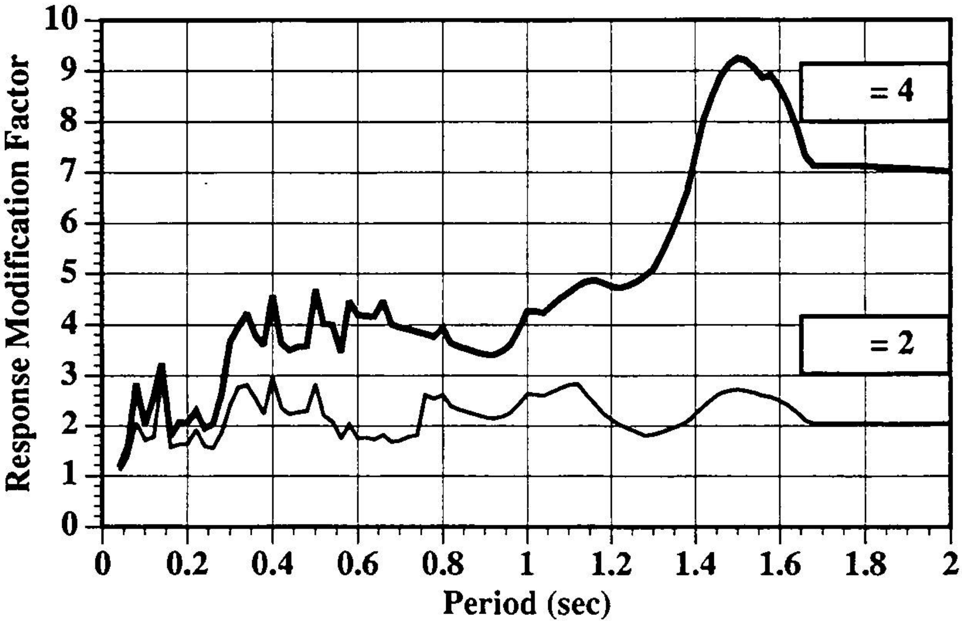

Fig. 5. Behaviour Factors for JMA Kobe Record; Ductility Factors 2 and 4

Several interesting observations emanate from Figure 5. Firstly, it is clear that in the very short period range, inelastic response does not greatly affect the force level generated within a structural system. Hence, it is reasonable to assume a ductility-related behaviour factor of unity in this range. Secondly, for the intermediate range, the behaviour factor increases monotonically, up to a point when it becomes constant and independent of period. Finally, the relationship between μ and q is less uniform for higher ductility (in Figure 5 μ of 4).

In the light of the above discussion, adopting an approach whereby the overall behaviour factor is an aggregate of two constituents; ductility-related and overstrength-related, would render the concepts underlying seismic design more transparent to the user.

5. Conclusions

The EC8 approach to elastic seismic force calculation in the horizontal direction is adequate and represents actual observations, whilst the vertical component is not adequately described. It is therefore recommended to utilise a ratio of vertical-to-horizontal ground acceleration which is dependent on magnitude and distance, instead of the constant factor used currently.

With regard to behaviour factors, Eurocode 8 recommends values independent of the period of vibration. Alternative approaches have been recommended in the literature. It is considered that regardless of whether these approaches lead to different values of q, their adoption leads to a more transparent procedure that is of greater value to the end-user.

Many issues remain subject to ongoing development and improvement. For instance, the dynamic amplification factors given in the recent National Earthquake Hazard Reduction Program (NEHRP) are worthy of consideration.

It is hoped that the ongoing ENV period and extensive studies on various parts of EC8 currently underway will result in improvements that will reinforce the position of the code as an international reference document.

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