Ground conditions and seismic action

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Ground conditions

Earthquake vibration at the surface is strongly influenced by the underlying ground conditions

EN 1998-1 requires that appropriate investigations (in situ or in the laboratory) must be carried out in order to identify the ground conditions, with two main objectives:

- allow the classification of the soil profile, in view of defining the ground motion appropriate to the site (i.e. allowing the selection of the relevant spectral shape)

- identify the possible occurrence of soil behaviour during an earthquake detrimental to the response of the structure
Ground conditions

Five ground types:

A - Rock
B - Very dense sand or gravel or very stiff clay
C - Dense sand or gravel or stiff clay
D - Loose to medium cohesionless soil or soft to firm cohesive soil
E - Surface alluvium layer C or D, 5 to 20 m thick, over a much stiffer material

2 special ground types $S_1$ and $S_2$ requiring special studies

Ground conditions defined by shear wave velocities in the top 30 m and also by indicative values for $N_{SPT}$ and $c_u$
Ground conditions

Table 3.1: Ground types

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Description of stratigraphic profile</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.</td>
<td>(v_{s,30} \text{ (m/s)}) (N_{SPT}) (blows/30cm) (c_u) (kPa)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 800</td>
</tr>
<tr>
<td>B</td>
<td>Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.</td>
<td>360 – 800</td>
</tr>
</tbody>
</table>
## Ground conditions

### Table 3.1: Ground types

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Description of stratigraphic profile</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$v_{s,30}$ (m/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_{SPT}$ (blows/30cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$c_u$ (kPa)</td>
</tr>
<tr>
<td>C</td>
<td>Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.</td>
<td>180 – 360</td>
</tr>
<tr>
<td>D</td>
<td>Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.</td>
<td>&lt; 180</td>
</tr>
</tbody>
</table>
# Ground conditions

## Table 3.1: Ground types

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Description of stratigraphic profile</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>A soil profile consisting of a surface alluvium layer with $v_s$ values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s &gt; 800 \text{ m/s}$</td>
<td>$v_{s,30}$ (m/s)</td>
</tr>
<tr>
<td>$S_1$</td>
<td>Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI &gt; 40) and high water content</td>
<td>&lt; 100 (indicative)</td>
</tr>
<tr>
<td>$S_2$</td>
<td>Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or $S_1$</td>
<td></td>
</tr>
</tbody>
</table>
Seismic zonation

Competence of National Authorities

Described by $a_{gR}$ (reference peak ground acceleration on type A ground)

Corresponds to the reference return period $T_{NCR}$

$a_{gR}$ modified by the Importance Factor $\gamma_I$ to become the design ground acceleration (on type A ground) $a_g = a_{gR} \cdot \gamma_I$

Objective for the future updating of EN1998-1: European zonation map with spectral values for different hazard levels (e.g. 100, 500 and 2,500 years)
Seismic zonation

Seismic Hazard Analysis

Attenuation relationships

Sample law: Ambraseys et al. [1996]

valid for:

- Intraplate seismicity (Europe)
- Rock sites
- $4.0 < M < 7.3$
- $3 \text{ km} < R < 200 \text{ km}$

Spectral law:

$log \ SA [g] = c_1 + c_2M + c_4 \ log R$

<table>
<thead>
<tr>
<th>T (s)</th>
<th>$C'_1$</th>
<th>$C_2$</th>
<th>$C_4$</th>
<th>$h_0$</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGA</td>
<td>-1.48</td>
<td>0.27</td>
<td>-0.92</td>
<td>3.50</td>
<td>0.25</td>
</tr>
<tr>
<td>0.10</td>
<td>-0.84</td>
<td>0.22</td>
<td>-0.95</td>
<td>4.50</td>
<td>0.27</td>
</tr>
<tr>
<td>0.20</td>
<td>-1.21</td>
<td>0.28</td>
<td>-0.92</td>
<td>4.20</td>
<td>0.27</td>
</tr>
<tr>
<td>0.30</td>
<td>-1.55</td>
<td>0.34</td>
<td>-0.93</td>
<td>4.20</td>
<td>0.30</td>
</tr>
<tr>
<td>0.40</td>
<td>-1.94</td>
<td>0.38</td>
<td>-0.89</td>
<td>3.60</td>
<td>0.31</td>
</tr>
<tr>
<td>0.50</td>
<td>-2.25</td>
<td>0.42</td>
<td>-0.91</td>
<td>3.30</td>
<td>0.32</td>
</tr>
<tr>
<td>1.00</td>
<td>-3.17</td>
<td>0.51</td>
<td>-0.89</td>
<td>4.30</td>
<td>0.32</td>
</tr>
<tr>
<td>1.50</td>
<td>-3.61</td>
<td>0.52</td>
<td>-0.82</td>
<td>3.00</td>
<td>0.31</td>
</tr>
<tr>
<td>2.00</td>
<td>-3.79</td>
<td>0.50</td>
<td>-0.73</td>
<td>3.20</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Spectral shape

Effect of Magnitude on Response Spectra (Rock, 5% damping)

Period T (s)

Magnitude
5
6
6.5
7

R = 30 km
Spectral shape

Effect of Magnitude on normalised shape (Rock, 5% damping)

![Graph showing the effect of magnitude on normalised shape](image-url)
Spectral shape

Effect of Epicentral Distance on Response Spectra
(Rock, 5% damping)

\[ S_e (g) \]

Distance (km)

Period T (s)

M = 6

Distance (km)

- 15
- 30
- 50
- 100

Se (g)

\[ 0.30 \]
\[ 0.25 \]
\[ 0.20 \]
\[ 0.15 \]
\[ 0.10 \]
\[ 0.05 \]
\[ 0.00 \]
Spectral shape

Effect of Epicentral Distance on normalised shape

(Rock, 5% damping)
Elastic response spectrum

Common shape for the ULS and DLS verifications

2 orthogonal independent horizontal components

Vertical spectrum shape different from the horizontal spectrum (common for all ground types)

Possible use of more than one spectral shape (to model different seismo-genetic mechanisms)

Account of topographical effects (EN 1998-5) and spatial variation of motion (EN1998-2) required in some special cases
Definition of the horizontal elastic response spectrum

Four branches

\[ 0 \leq T \leq T_B \quad S_e(T) = a_g \cdot S \cdot (1 + T/T_B \cdot (\eta \cdot 2,5 - 1)) \]

\[ T_B \leq T \leq T_C \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \]

\[ T_C \leq T \leq T_D \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \left(\frac{T_C}{T}\right) \]

\[ T_D \leq T \leq 4 \text{ s} \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \left(\frac{T_C \cdot T_D}{T^2}\right) \]

\( S_e(T) \) elastic response spectrum

\( a_g \) design ground acceleration on type A ground

\( T_B \), \( T_C \), \( T_D \) corner periods in the spectrum (NDPs)

\( S \) soil factor (NDP)

\( \eta \) damping correction factor (\( \eta = 1 \) for 5% damping)

Additional information for \( T > 4 \text{ s} \) in Informative Annex
Normalised elastic response spectrum

Standard shape

Control variables

• $S$, $T_B$, $T_C$, $T_D$ (NDPs)
• $\eta (\geq 0.55)$ damping correction for $\xi \neq 5\%$

Fixed variables

• Constant acceleration, velocity & displacement spectral branches
• acceleration spectral amplification: 2.5
Normalised elastic response spectrum

Correction for damping

$$\eta = \sqrt{\frac{10}{5 + \xi}} \geq 0.55$$

To be applied only to elastic spectra
Two types of (recommended) spectral shapes

Depending on the characteristics of the most significant earthquake contributing to the local hazard:

- **Type 1** - High and moderate seismicity regions \((M_s > 5.5)\)
- **Type 2** - Low seismicity regions \((M_s \leq 5.5)\); near field earthquakes

Optional account of **deep geology effects** (NDP) for the definition of the seismic action
Recommended elastic response spectra

Normalised shape for Type 1 and Type 2 seismic action (rock)
Recommended parameters for the definition of the response spectra for *various ground types*

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Seismic action Type 1</th>
<th>Seismic action Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S$</td>
<td>$T_B$ (s)</td>
</tr>
<tr>
<td>A</td>
<td>1,0</td>
<td>0,15</td>
</tr>
<tr>
<td>B</td>
<td>1,2</td>
<td>0,15</td>
</tr>
<tr>
<td>C</td>
<td>1,15</td>
<td>0,2</td>
</tr>
<tr>
<td>D</td>
<td>1,35</td>
<td>0,2</td>
</tr>
<tr>
<td>E</td>
<td>1,4</td>
<td>0,15</td>
</tr>
</tbody>
</table>
Recommended elastic response spectra

Type 1 - $M_s > 5.5$

Type 2 - $M_s \leq 5.5$
Recommended elastic response spectra

Type 1 - $M_s > 5,5$
Recommended elastic response spectra

Type 2 - $M_s \leq 5,5$
Definition of the **vertical** elastic response spectrum

Four branches

\[ 0 \leq T \leq T_B \quad S_{ve}(T) = a_{vg} \cdot (1 + T/T_B \cdot (\eta \cdot 3,0 -1)) \]

\[ T_B \leq T \leq T_C \quad S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \]

\[ T_C \leq T \leq T_D \quad S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left( T_C / T \right) \]

\[ T_D \leq T \leq 4 \text{ s} \quad S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left( T_C \cdot T_D / T^2 \right) \]

- **\( S_{ve}(T) \)**: vertical elastic response spectrum
- **\( a_{vg} \)**: vertical design ground acceleration on type A ground
- **\( T_B, T_C, T_D \)**: corner periods in the spectrum (NDPs)
- **\( \eta \)**: damping correction factor (\( \eta = 1 \) for 5% damping)

**Soil factor not influencing** the vertical response spectrum
Definition of the vertical elastic response spectrum

Recommended parameters

<table>
<thead>
<tr>
<th>Seismic action</th>
<th>$a_{vg}/a_g$</th>
<th>$T_B$ (s)</th>
<th>$T_C$ (s)</th>
<th>$T_D$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>0.90</td>
<td>0.05</td>
<td>0.15</td>
<td>1.0</td>
</tr>
<tr>
<td>Type 2</td>
<td>0.45</td>
<td>0.05</td>
<td>0.15</td>
<td>1.0</td>
</tr>
</tbody>
</table>

EN1998-1 Vertical Elastic
Displacements

Design **ground displacement** \( d_g = 0,025 \cdot a_g \cdot S \cdot T_C \cdot T_D \)

Elastic displacement response spectrum in Informative Annex A of EN 1998-1

<table>
<thead>
<tr>
<th>Soil</th>
<th>( T_E ) (s)</th>
<th>( T_F ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4,5</td>
<td>10,0</td>
</tr>
<tr>
<td>B</td>
<td>5,0</td>
<td>10,0</td>
</tr>
<tr>
<td>C</td>
<td>6,0</td>
<td>10,0</td>
</tr>
<tr>
<td>D</td>
<td>6,0</td>
<td>10,0</td>
</tr>
<tr>
<td>E</td>
<td>6,0</td>
<td>10,0</td>
</tr>
</tbody>
</table>
Design spectrum for elastic analysis

Derived from the elastic spectrum

\[ 0 \leq T \leq T_B \quad S_d(T) = a_g \cdot S \cdot \left(\frac{2}{3} + \frac{T}{T_B} \cdot \left(\frac{2.5}{q} - \frac{2}{3}\right)\right) \]

\[ T_B \leq T \leq T_C \quad S_d(T) = a_g \cdot S \cdot \frac{2.5}{q} \]

\[ T_C \leq T \leq T_D \quad S_d(T) = a_g \cdot S \cdot \frac{2.5}{q} \cdot \left(\frac{T_C}{T}\right) \geq \beta \cdot a_g \]

\[ T_D \leq T \leq 4 \text{ s} \quad S_d(T) = a_g \cdot S \cdot \frac{2.5}{q} \cdot \left(\frac{T_C \cdot T_D}{T^2}\right) \geq \beta \cdot a_g \]

- \( S_d(T) \) design spectrum
- \( q \) behaviour factor
- \( \beta \) lower bound factor (NDP recommended value: 0.2)

Specific rules for vertical action: \( q \leq 1.5 \)
Design spectrum for elastic analysis

Derived from the elastic spectrum but:

Correction factor for damping $\eta$ not included

Values of the behaviour factor $q$ already account for the influence of the viscous damping being different from 5%

The behaviour factor $q$ is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure.
Design spectra for elastic analysis

EN1998-1
Soil C

Behaviour factor

- 1,5
- 2
- 3
- 4,5
Alternative representations of the seismic action

Time history representation (essentially for NL analysis purposes)

Three simultaneously acting accelerograms

- **Artificial accelerograms**
  Match the elastic response spectrum for 5% damping
  Duration compatible with Magnitude ($T_s \geq 10$ s)
  Minimum number of accelerograms: 3

- **Recorded or simulated accelerograms**
  Scaled to $a_g \cdot S$
  Match the elastic response spectrum for 5% damping