Overview of Eurocode 8
General
Seismic Action

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Presentation based on a support by
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Structural Eurocodes

- EN1990 Eurocode 0: *Basis of structural design*
- EN1991 Eurocode 1: *Actions on structures*
- EN1992 Eurocode 2: *Design of concrete structures*
- EN1993 Eurocode 3: *Design of steel structures*
- EN1994 Eurocode 4: *Design of composite steel and concrete structures*
- EN1995 Eurocode 5: *Design of timber structures*
- EN1996 Eurocode 6: *Design of masonry structures*
- EN1997 Eurocode 7: *Geotechnical design*
- EN1998 Eurocode 8: *Design of structures for earthquake resistance*
- EN1999 Eurocode 9: *Design of aluminium structures*

Published by CEN (2004-2006)
The structure of a Eurocode:

- main text in several « Parts »
  in EC8 = EN1998
  EN1998-1: General and seismic action
  Rules for buildings
  EN1998-2: Bridges
  etc…

- In each Part, Annexes: Normative Annexes
  Informative Annexes

- In each country: a « National Annex »
  - decides on « Nationally Determined Parameters »
  - provides additional information or rules
Nationally Determined Parameters

Parameters which are **left open** in the Eurocodes for national choice (**NDP’s** - Nationally Determined Parameters):

• **values** and/or classes where alternatives are given in the Eurocode,
• **values** to be used where a symbol only is given in the Eurocode,
• **country specific** data (geographical, climatic, etc.), e.g. snow map, seismic zonation
• **the procedure** to be used, where alternative procedures are given in the Eurocode.

It may also contain

• decisions on the application of **informative annexes**, 
• references to **non-contradictory complementary information** to assist the user to apply the Eurocode.

**NDP’s** are defined in the “**National Annexes**”
Eurocode 8 - Design of structures for earthquake resistance

- EN1998-1: General rules, seismic actions and rules for buildings
- EN1998-2: Bridges
- EN1998-3: Assessment and retrofitting of buildings
- EN1998-4: Silos, tanks and pipelines
- EN1998-5: Foundations, retaining structures and geotechnical aspects
- EN1998-6: Towers, masts and chimneys
EN1998-1: General rules, seismic actions and rules for buildings

- no repetition of rules present in other Eurocodes
- applied in combination with other Eurocodes
Contents of EN 1998-1

1. General
2. Performance requirements and compliance criteria
3. Ground conditions and seismic action
4. Design of buildings – General rules
   5 to 9: Specific rules by materials
5. Concrete buildings
6. Steel buildings
7. Composite Steel-Concrete buildings
8. Timber buildings
9. Masonry buildings
10. Base isolation
Nationally Determined Parameters (NDPs) in EN 1998-1:

General aspects and definition of the seismic action: 11
Modelling, analysis and design of buildings: 7
Concrete buildings: 11
Steel buildings: 6
Composite buildings: 4
Timber buildings: 1
Masonry buildings: 15
Base isolation: 1

TOTAL 56
Objectives of seismic design according to Eurocode 8

In the event of earthquakes:

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

Special structures – Nuclear Power Plants, Offshore structures, Large Dams – outside the scope of EN 1998
Fundamental requirements

No-collapse requirement:

Withstand the design seismic action without local or global collapse

Retain structural integrity and residual load bearing capacity after the event

Requirement related to the protection of life under a rare event through the prevention of local or global collapse. After the event, a structure may be economically unrecoverable but should ensure safe evacuation protection against after shocks.

Requirements associated with the **Ultimate Limit State (ULS)** in the framework of the Eurocodes.
No-collapse requirement:

For ordinary structures this requirement should be met for a reference seismic action with 10\% probability of being exceeded in 50 years (recommended value) i.e. with a \textit{475 years Return Period}.
Fundamental requirements

**Damage limitation requirement:**

- **Withstand a frequent seismic action without damage**
  
  For ordinary structures:
  a *seismic action* with 10% probability of exceedance in 10 years (recommended value) i.e. with **95 years Return Period**

- **Avoid limitations of use & high repair costs**

Requirement related to the reduction of economic losses in frequent earthquakes (structural and non-structural):

- Structure without permanent deformations
- Elements retain original strength and stiffness
  no need for structural repair.
- Non-structural damages repairable economically.

Requirement associated with the **Serviceability Limit State** (SLS) in the framework of the Eurocodes
Reliability differentiation

Target reliability of requirement depending on consequences of failure

Classify the structures into importance classes

Assign a higher or lower return period to the design seismic action

In operational terms multiply the reference seismic action by the importance factor $\gamma_1$
## Importance classes for buildings

**Table 4.3 Importance classes for buildings**

<table>
<thead>
<tr>
<th>Importance class</th>
<th>Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Buildings of minor importance for public safety, e.g. agricultural buildings, etc.</td>
</tr>
<tr>
<td>II</td>
<td>Ordinary buildings, not belonging in the other categories.</td>
</tr>
<tr>
<td>III</td>
<td>Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.</td>
</tr>
<tr>
<td>IV</td>
<td>Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.</td>
</tr>
</tbody>
</table>

NOTE Importance classes I, II and III or IV correspond roughly to consequences classes CC1, CC2 and CC3, respectively, defined in EN 1990:2002, Annex B.
Importance factor and return period

At most sites the annual rate of exceedance, $H(a_{gR})$, of the reference peak ground acceleration $a_{gR}$ may be taken to vary with $a_{gR}$ as:

$$H(a_{gR}) \sim k_0 a_{gR}^{-k}$$

with the value of the exponent $k$ depending on seismicity, but being generally of the order of 3.

If the seismic action is defined in terms of the reference peak ground acceleration $a_{gR}$, the value of the importance factor $\gamma_i$ multiplying the reference seismic action to achieve the same probability of exceedance in $T_L$ years as in the $T_{LR}$ years for which the reference seismic action is defined, may be computed as

$$\gamma_i \sim \left(\frac{T_{LR}}{T_L}\right)^{-1/k}.$$
Importance factor and return period

**Importance factors for buildings** *(recommended values)*:

- $\gamma_I = 0.8$ (I);
- $1.0$ (II);
- $1.2$ (III) and
- $1.4$ (IV)

**Reduction factor** *(recommended values)* to account for the lower return period for damage limitation verification:

- $\nu = 0.4$ (III and IV) or
- $0.5$ (I and II)
**Ultimate limit state (ULS)**

The *resistance and energy-dissipation capacity* to be assigned to the structure are related to the extent to which its non-linear response is to be exploited.

In operational terms such balance between resistance and energy-dissipation capacity is characterised by the values of the behaviour factor $q$ and the associated ductility classes.

$q \approx \text{ratio of}
\begin{align*}
\text{the seismic forces that the structure would experience if its response was completely elastic} \\
\text{to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure.}
\end{align*}$
An earthquake imposes a relative displacement \( \Delta_{\text{required}} = S_{De}(T) \) between center of mass & basis. \( \Delta \approx \) independent of type of response—elastic.

- **Elastic design**
  - resistances > action effects
  - \( EC8 \ DCL = \text{Ductility Class Low} \)

- **Dissipative or ductile design**
  - resistances ≥ action effects
  - computed under reduced action accounting for energy dissipation in cyclic plastic mechanisms
  - capacity of deformation \( \Delta_{\text{capable}} > \Delta_{\text{required}} \)

\( EC8 \ DCM = \text{Ductility Class Medium} \)

\( DCH = \text{High} \)
**Ultimate limit state (ULS)**

A limiting case for structures classified as low-dissipative
no account is taken of any hysteretic energy dissipation
behaviour factor $\leq 1,5$

$(1,5$ accounts for overstrengths$)$

For dissipative structures
the behaviour factor $> 1,5$
accounting for the hysteretic energy dissipation
that occurs in specifically designed zones
called “dissipative zones” or “critical regions”
Compliance criteria

Design verifications

**Ultimate limit state (ULS)**

- Resistance and Energy dissipation capacity
- Ductility classes and Behaviour factor values
- Overturning and sliding stability check
- Resistance of foundation elements and soil
- Second order effects
- Non detrimental effect of non structural elements

- Simplified checks for **low seismicity** cases \((a_g < 0.08 \text{ g})\)
- No application of EN 1998 for **very low seismicity** cases \((a_g < 0.04 \text{ g})\)
Compliance criteria

Design verifications

Damage limitation state (DLS/SLS)

Deformation limits
(Maximum interstorey drift due to the “frequent” earthquake):

- 0.5 % for brittle non structural elements attached to the structure
- 0.75 % for ductile non structural elements attached to the structure
- 1.0 % for non structural elements not interfering with the structure

=> Sufficient stiffness of the structure for the operationality of vital services and equipment

Note: in many cases DLS control the design
Design verifications

Take Specific Measures
- intended to reduce the uncertainty
- promote a good behaviour of the structure even under seismic actions more severe than the design seismic action

Implicitly equivalent to the satisfaction of a third performance requirement:

*Prevention of global collapse under a very rare event (1.500 to 2.000 years return period).*

Denoted Near Collapse (NC) Limit State in EN 1998-3, very close to the actual collapse of the structure and corresponds to the full exploitation of the deformation capacity of the structural elements.
Compliance criteria

Specific measures

- Simple and regular forms (plan and elevation)
- Control the hierarchy of resistances, the sequence of failure modes (capacity design)
- Avoid brittle failures
- Control the behaviour of critical regions (detailing)
- Use adequate structural model (soil deformability and non-structural elements if appropriate)

In zones of high seismicity formal Quality Plan for Design, Construction and Use is recommended
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. selecting the relevant response spectrum)

- identify the possible occurrence of soil behaviour detrimental to the response of the structure during an earthquake
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>$v_{s,30}$ (m/s) $N_{SPT}$ (blows/30cm) $c_u$ (kPa)</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>$v_{s,30}$ (m/s) $N_{SPT}$ (blows/30cm) $c_u$ (kPa)</td>
</tr>
</tbody>
</table>
## Table 3.1: Ground types

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$v_{s,30}$ (m/s)</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>
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<tr>
<th>Ground type</th>
<th>Description of stratigraphic profile</th>
<th>Parameters</th>
<th></th>
<th></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>
<td>( N_{SPT} ) (blows/30cm)</td>
<td>( c_u ) (kPa)</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>
<td>( - )</td>
<td>10 - 20</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>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Seismic zonation

Competence of National Authorities

- Described by $a_{gR}$ (reference peak ground acceleration on type A ground) in different zones of the country

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

- $a_{gR}$ modified by the Importance factor $\gamma_I$ becomes the design ground acceleration $a_g$

\[ a_g = a_{gR} \cdot \gamma_I \]  

(on type A ground)

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:

\[
\log \text{SA} [g] = c_1 + c_2M + c_4 \log R
\]

<table>
<thead>
<tr>
<th>T (s)</th>
<th>C'1</th>
<th>C2</th>
<th>C4</th>
<th>h0</th>
<th>σ</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>
Effect of Magnitude on Response Spectra (Rock, 5% damping)
Spectral shape

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

![Spectral shape diagram](image)
Spectral shape

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

$S_e (g)$

Distance (km)

Period $T$ (s)

$M = 6$
Effect of Epicentral Distance on normalised shape

(Rock, 5% damping)

Spectral shape
Basic representation of the seismic action in Eurocode 8

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 of the elastic response spectrum

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

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

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

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

- \( S_e (T) \): 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**
- \( S, T_B, T_C, T_D \) (NDP’s)
- \( \eta \geq 0.55 \) 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
Elastic response spectrum

Two types of (recommended) spectral shapes

Type depends on 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 EQ

Optional account of deep geology effects \( \text{(NDP)} \)
Recommended elastic response spectra

Normalised shape for Type 1 and Type 2 seismic action (rock)
### Recommended elastic response spectra

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 - $M_s \leq 5.5$
Definition of the **vertical** elastic response spectrum

**Four branches**

\[
\begin{align*}
0 \leq T &\leq T_B & S_{ve}(T) &= a_{vg} \cdot (1 + T/T_B \cdot (\eta \cdot 3,0 -1)) \\
T_B \leq T &\leq T_C & S_{ve}(T) &= a_{vg} \cdot \eta \cdot 3,0 \\
T_C \leq T &\leq T_D & S_{ve}(T) &= a_{vg} \cdot \eta \cdot 3,0 \left(\frac{T_C}{T}\right) \\
T_D \leq T &\leq 4 \text{ s} & S_{ve}(T) &= a_{vg} \cdot \eta \cdot 3,0 \left(\frac{T_C \cdot T_D}{T^2}\right)
\end{align*}
\]

\(S_{ve}(T)\) **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**

- Period $T$ (s)
- $S_{ve}/a_g$
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

\[ S_d (T) = a_g \cdot S \cdot (2/3 + T/T_B \cdot (2,5/q - 2/3)) \]

\[ S_d (T) = a_g \cdot S \cdot 2,5/q \]

\[ S_d (T) = a_g \cdot S \cdot 2,5/q \cdot (T_C / T) \geq \beta \cdot a_g \]

\[ S_d (T) = a_g \cdot S \cdot 2,5/q \cdot (T_C \cdot T_D / T^2) \geq \beta \cdot a_g \]

\( S_d (T) \) design pseudo acceleration = design spectrum

\( q \) behaviour factor

\( \beta \) lower bound factor for long period structures

\( \beta \) 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 present in expressions of spectrum branches:
values of $q$ 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

$S_d$ (cm/s²)

T (s)
Alternative representations of the seismic action

Time history representation
(essentially for Non Linear analysis purposes)

Three simultaneously acting accelerograms

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

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