Bridges equipped with antiseismic devices

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Clause 8: Specific rules for bridges equipped with antiseismic devices

CEN/TC250/SC8 N1327 prEN1998-2:2024 “Design of structures for earthquake resistance - Part 2: Bridges”

- 8.1 General
- 8.2 Seismic action, basic requirements and compliance criteria
- 8.3 General provisions concerning antiseismic devices
- 8.4 Methods of analysis
  - 8.4.1 General
  - 8.4.2 Equivalent linear - lateral force method
  - 8.4.3 Equivalent linear - response spectrum method
  - 8.4.4 Response-history analysis
- 8.5 Minimum overlap length at connections

Mandate M/515

SC8.T6: Evolution of EN 1998-2 (Phase 4)

Sub-task Ref.: 3 / Sub-task name: Seismic isolation, new technologies etc.

The section should be updated given the more recent technologies in passive control and improve the interface between the design standard (EN1998) and the relevant product standard (EN15129). Additionally, this Part should be made consistent with the definition of the seismic zonation and seismic action that shall be introduced in EN 1998-1.

Clause 8

Scope

- **Redrafting** of Section 7 (Bridges with seismic isolation) of EN 1998-2:2005 and the Annexes related to this subject (Annexes J, JJ and K).
- Covers **fully isolated** and **partially isolated** bridges.
- Interface with the relevant **product standard** (**EN15129/EN1337**) is improved.
- **Common principles** for structures equipped with antiseismic devices **moved to EN1998-1-1**.

Clause 8: Specific rules for bridges equipped with antiseismic devices

CEN/TC250/SC8 N1327 prEN1998-2:2024 “Design of structures for earthquake resistance - Part 2: Bridges”

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- Antiseismic Devices
- Seismic action, basic requirements & compliance criteria
- General provisions concerning antiseismic devices
- Methods of analysis
- Minimum overlap length at connections

Bridges: ”with Seismic Isolation” vs “equipped with Antiseismic Devices”

Seismic Isolators | **Seismic Links**

Ref to EN15129 & EN1337

- **1.5.3.6 Seismic isolation** — **EN1998-2:2005**
  - Provision of bridge structures with **special isolating devices** for the purpose of reducing the seismic response (forces and/or displacements)

- **1.5.3.9 Seismic links** — **EN1998-2:2005**
  - **Restrainers** through which part or all of the seismic action may be transmitted. Used in combination with bearings, they may be provided with appropriate slack, so as to be activated only in the case when the design seismic displacement is exceeded

Bearings

- **6.6.2 Bearings** — **EN1998-2:2005**
  - Fixed bearings, Moveable bearings
  - Elastomeric bearings
  - Seismic links
  - Holding-down devices
  - Shock transmission units (STUs)

EN1998-2:2005

Bridges: ”with Seismic Isolation” vs “equipped with Antiseismic Devices”

Seismic Isolators — EN15129 (6.8.2.4(1))

Energy Dissipation Devices — EN15129 (6.9.1(2))

EN1998-1-1

- **3.1.15 Energy dissipation device**
  - Disposable **element** of the energy dissipation system that **dissipates energy** caused by relative motion of each end of the device and does not form part of the main structural system.
- **3.1.16 Energy dissipation system**
  - **Collection** of structural members that includes all the **energy dissipation devices** and all structural members required to transfer the forces from the energy dissipation devices to the main structural system and to the base of the structure. It also includes all **pins**, **bolts**, **gusset plates**, **brace extensions** and other components required to connect the energy dissipation devices to other elements of the structure.

EN1998-1-1

- **3.1.21 Isolators**
  - **Device** possessing the characteristics needed for seismic isolation, namely, the ability to support gravity loads from the superstructure and the ability to accommodate horizontal displacements.
- **3.1.20 Isolation system, isolation interface**
  - **Collection** of isolators used for **providing seismic isolation**, which are arranged within the isolation interface
- **3.1.19 Full isolation**
  - A **superstructure** on a isolation system is fully isolated if, in the seismic design situation, it **remains within the elastic range**; otherwise, the superstructure is **partially isolated**.

CEN/TC167 "Structural bearings": EN1337

- Scope

This European Standard is applicable to structural bearings, whether used in bridges or in other structures. This European Standard does not cover:

a) bearings that transmit moments as a primary function;
b) bearings that resist uplift;
c) bearings for moving bridges;
d) concrete hinges;
e) **seismic devices**.

Although it is not intended to regulate temporary bearings this standard may be used as a guide in this case (temporary bearings are bearings used during construction or repair and maintenance of structures).

NOTE 1: Although the specifications given in this European Standard are necessary, they are not sufficient in themselves for the overall design of the structures and for the consideration of geotechnical aspects.

- EN 1337 "Structural bearings" consists of the following 11 parts:

Part 1 – General design rules
Part 2 – **Sliding elements**
Part 3 – **Elastomeric bearings**
Part 4 – **Roller bearings**
Part 5 – **Pot bearings**
Part 6 – **Rocker bearings**
Part 7 – **Spherical and cylindrical PTFE bearings**
Part 8 – **Guided bearings and restrained bearings**
Part 9 – Protection
Part 10 – Inspection and maintenance
Part 11 – Transport, storage and installation

- References by Eurocodes (1st Gen.)

EN1993-2 ("3.5 … Bearings should conform to EN 1337", Annex A Technical Specification for bearings)
EN1993-3-1 ("6.5.1 Mast base Joint … The design bearing stress on the spherical pinned connection should be based on the design rules for rocker bearings, see EN 1337-6.")
EN1993-6 ("3.5 … Bearings should comply with EN 1337")
EN1998-2 ("6.6 Bearings and seismic links…", 14 times)

Product Standard: EN15129

CEN/TC340 "Anti-seismic Devices": EN15129

- Scope

This European Standard covers the design of devices that are provided in structures, **with the aim of modifying their response to the seismic action**. It specifies functional requirements and general design rules for the seismic situation, material characteristics, manufacturing and testing requirements, as well as evaluation of conformity, installation and maintenance requirements. This European Standard covers the types of devices and combinations thereof as defined in 3.4.

NOTE Additional information concerning the scope of this European Standard is given in Annex A.

- EN 15129 "Most common types of Anti-seismic devices":

Description of the Device			Relevant Clause	Graphic Representation: Plan view	Elevation view: Direction x	Elevation view: Direction y	Notes
Rigid Connection Devices (RGDs)	Permanent Connection Devices (PCDs)	Fixed	5.1				This type of device corresponds to type 8.1 (Restraint bearing) in Table 1 of EN 1337-1:2000 (*)
		Moveable	5.1				This type of device corresponds to type 8.2 (Guide bearing) in Table 1 of EN 1337-1:2000 (°)
	Fuse Restraints	Mechanical Fuse Restraints (MFRs)	5.2			-	
		Hydraulic Fuse Restraints (HFRs)	5.2			-	
	Temporary Connection Devices (TCDs)		5.3			-	This type of device is usually referred to as Shock Transmission Unit (STU)

Group	Device	Clause	Plan view	Direction x	Direction y	Notes
Displacement Dependent Devices (DDDs)	Linear Devices (LDs)	6.1			-	
	Non linear Devices (NLDs)	6.2			-	
Velocity Dependent Devices	Fluid Viscous Dampers (FVDs)	7.1			-	This graphic representation applies also to two-shaft dampers
	Fluid Spring Dampers (FSDs)	7.1			-	
Seismic Isolators	Elastomeric	8.2				The isolators are shown in the deformed position to underscore their horizontal flexibility
	Lead Rubber Bearings	8.2				
	Curved Surface Sliders	8.3				The symbols apply to both Single and Double Curved Surface Sliders
	Flat Surface Sliders	8.4				The symbols apply to both types 2.3 (free sliding pot bearing) and 3.5 (free sliding spherical bearing) in Table 1 of EN 1337-1:2000 (■)

Note 1 (*): This type of device will correspond to type F.0 (Restraint bearing) in Table 1 of the revised version of EN 1337-1.
Note 2 (°): This type of device will correspond to type G.1 (Guide bearing) in Table 1 of the revised version of EN 1337-1.
Note 3 (■): This type of device will correspond to types P.2 and S.2, respectively, in Table 1 of the revised version of EN 1337-1.

- **Rigid Connection**
- **Displacement Dependent**
- **Velocity Dependent**
- **Seismic Isolator**

- References by Eurocodes (1^{st} Gen.)

EN1998-2 ("6.6 Bearings and seismic links…", 14 times)

Common Devices/Isolators

Slider

- Linear Response
  - Displacement Dependent
- If guided → Link

Elastomeric Bearings

- ≈ Linear Response (LD)
  - Displacement Dependent
- Non Linear Response (HD)
  - Energy dissipation

Lead Rubber Bearing

- Non Linear Response
  - Displacement Dependent
  - Energy dissipation

Friction Pendulum System

- Non Linear Response
  - Displacement Dependent
  - Friction Dependent
  - Energy dissipation

Viscous Damper

- Non Linear Response
  - Velocity Dependent
  - Energy dissipation

Spring Viscous Damper

- Non Linear Response
  - Velocity Dependent
  - Displacement Dependent
  - Energy dissipation
- If preloaded → Link

Many devices provide a combination of :

Isolation (lengthening of the period)

\+

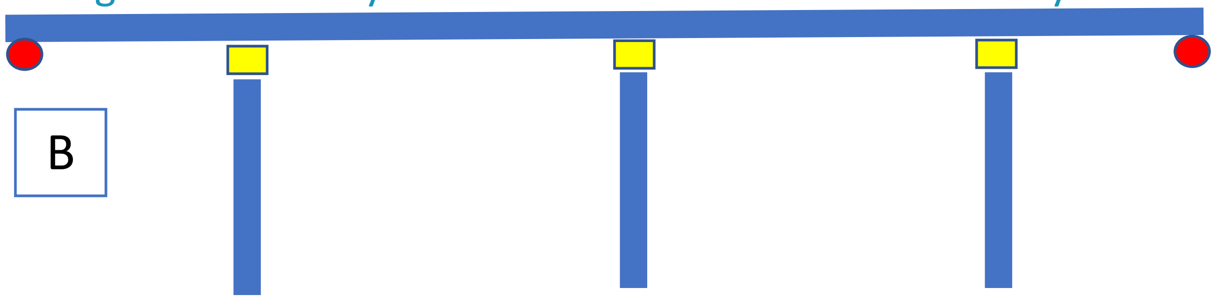
Energy Dissipation (increasing damping)

These effects should not be considered separately!!!

Which Product Standard should we apply EN1337 or EN15129?

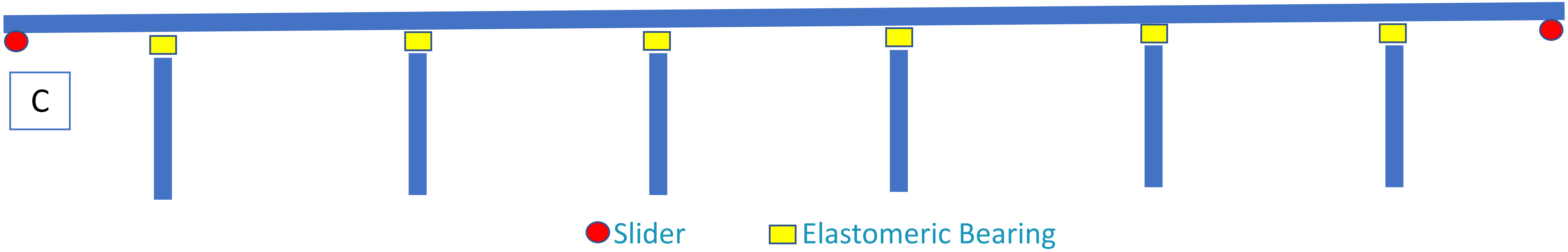
Bridge is not fully seismic isolated

Bridge is seismically isolated but we are in Low Seismicity Area



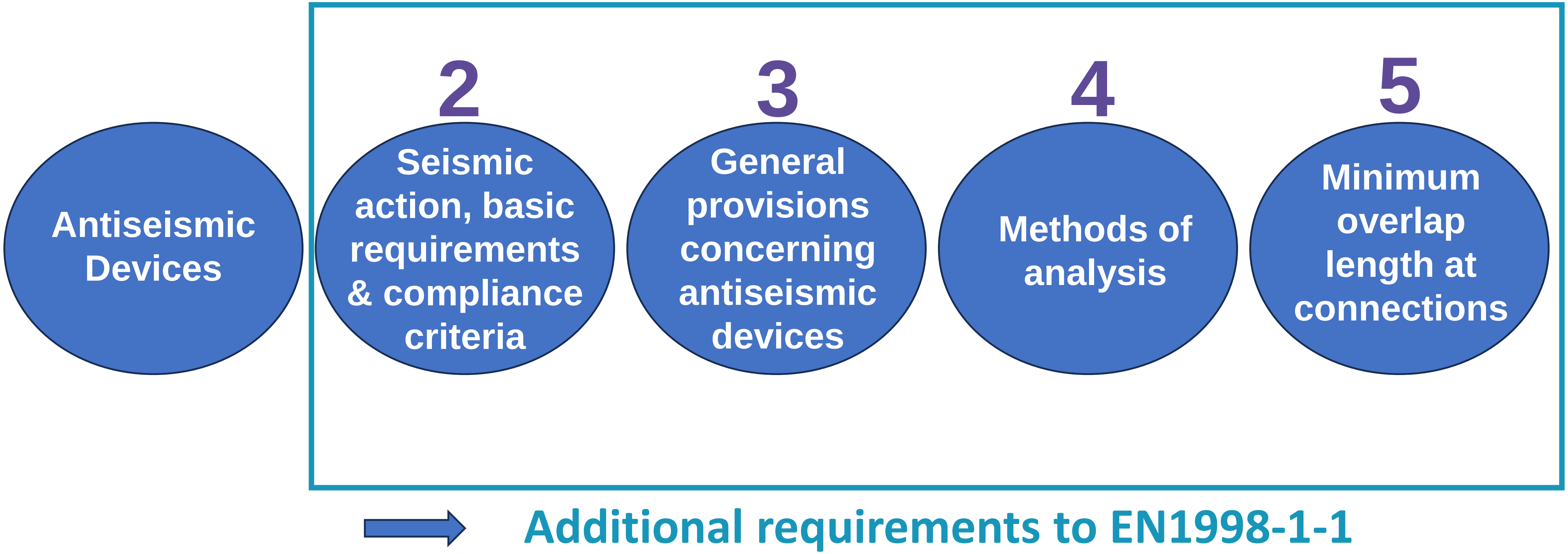
According to EN1998-1-1 &6.8.2.3 :

- the antiseismic devices should conform to EN15129 or should be covered by an ETA.
- In low seismic action class, rigid connection devices and bearings should conform to EN1337 or should be covered by an ETA.



Clause 8: Specific rules for bridges equipped with antiseismic devices

CEN/TC250/SC8 N1327 prEN1998-2:2024 “Design of structures for earthquake resistance - Part 2: Bridges”



EN1998-1-1

Structures equipped with antiseismic devices

6.8

- 6.8.1 Scope
- 6.8.2 Basis of design for structures equipped with antiseismic devices
  - 6.8.2.1 Performance requirements
  - 6.8.2.2 Compliance criteria
  - 6.8.2.3 General provisions concerning antiseismic devices
  - 6.8.2.4 Re-centring capability of isolation system
  - 6.8.2.5 Restraint of isolation system
- 6.8.3 Seismic action
- 6.8.4 Modelling
- 6.8.5 Analysis of structures equipped with antiseismic devices
  - 6.8.5.1 General
  - 6.8.5.2 Equivalent linear model
  - 6.8.5.3 Fundamental-mode equivalent linear response-spectrum analysis
  - 6.8.5.4 Multi-mode equivalent linear or non-linear response-spectrum analysis
  - 6.8.5.5 Response-history analysis
- 6.8.6 Verifications of antiseismic devices to limit states

EN1998-2:2005

- 6.6.1 General requirements → principles moved to EN1998-1-1
- 6.6.2 Bearings
  - 6.6.2.1 Fixed bearings
  - 6.6.2.2 Moveable bearings
  - 6.6.2.3 Elastomeric bearings

→ partially covered by EN15129 & principles moved to EN1998-1-1

- 6.6.3 Seismic links, holding-down devices, shock transmission units
  - 6.6.3.1 Seismic links
  - 6.6.3.2 Holding-down devices
  - 6.6.3.3 Shock transmission units (STUs)

→ partially covered by EN15129 & principles moved to EN1998-1-1

- 6.6.4 Minimum overlap lengths → EN1998-2 &8.5

EN1998-2:2005

- 7.1 General
- ~~7.2 Definitions~~
- ~~7.3 Basic requirements and compliance criteria~~
- ~~7.4 Seismic action~~
  - ~~7.4.1 Design spectra~~
  - ~~7.4.2 Time-history representation~~
- 7.5 Analysis procedures and modelling
  - 7.5.1 General
  - 7.5.2 Design properties of the isolating system
    - 7.5.2.1 General
    - 7.5.2.2 Stiffness in vertical direction
    - 7.5.2.3 Design properties in horizontal directions
      - 7.5.2.3.1 General
      - 7.5.2.3.2 Hysteretic behaviour
      - 7.5.2.3.3 Behaviour of elastomeric bearings
      - 7.5.2.3.4 Fluid viscous dampers
      - 7.5.2.3.5 Friction behaviour
    - 7.5.2.4 Variability of properties of the isolator units
  - 7.5.3 Conditions for application of analysis methods
  - 7.5.4 Fundamental mode spectrum analysis
  - 7.5.5 Multi-mode Spectrum Analysis
  - 7.5.6 Time history analysis
  - 7.5.7 Vertical component of seismic action
- 7.6 Verifications
  - 7.6.1 Seismic design situation
  - 7.6.2 Isolating system
  - 7.6.3 Substructures and superstructure
- 7.7 Special requirements for the isolating system
  - 7.7.1 Lateral restoring capability
  - 7.7.2 Lateral restraint at the isolation interface
  - 7.7.3 Inspection and Maintenance

EN15129

Redrafted & Common principles moved to EN1998-1-1

Partially covered by EN15129 & Principles moved to EN1998-1-1

- ANNEX J (Normative) VARIATION OF DESIGN PROPERTIES OF SEISMIC ISOLATOR UNITS
  - J.1 Factors causing variation of design properties
  - J.2 Evaluation of the variation
- ANNEX JJ (Informative)-FACTORS FOR COMMON ISOLATOR TYPES
  - JJ.1 λmax-*values* for elastomeric bearings
  - JJ.2 λmax-*values* for sliding isolator units
- ANNEX K (Informative) TESTS FOR VALIDATION OF DESIGN PROPERTIES OF SEISMIC ISOLATOR UNITS
  - *K.1 Scope*
  - *K.2 Prototype tests*
    - K.2.1 General
    - K.2.2 Sequence of tests
    - K.2.3 Determination of isolators characteristics
      - K.2.3.1 Force-displacement characteristics
      - K.2.3.2 Damping characteristics
      - K.2.3.3 System adequacy
  - *K.3 Other tests*
    - K.3.1 Wear and fatigue tests
    - K.3.2 Low temperature tests

Fully covered by EN15129

Seismic action, basic requirements and compliance criteria

- In **fully isolated bridges**, the **superstructure** should remain within the elastic range under the capacity design effects.
- **Substructure** of fully isolated bridges and the secondary structural members (i.e. isolated supports) of partially isolated bridges should be designed as non dissipative (verifications for DC1 should be adopted).
  - Exception: For tall heavy piers or pylons (i.e. where pier self-weight fundamental vibration mode contribution exceeds 50 % of the total design bending moment at the base), in moderate or high seismic action class, verifications and detailing for DC2 should be adopted.
- The action effects corresponding to the elastic range may be calculated with $q = q_S$.
- **No uplift** of seismic isolators carrying vertical force should occur in the seismic design situation. In case vertical forces can induce uplift, these should be handled by choosing suitable isolators and/or restrainers used to prevent uplifting.

General provisions concerning antiseismic devices

- According to EN1998-1-1 &6.8.2.3(11):

  The antiseismic devices that carry vertical loads should be sufficiently stiff in the vertical direction.

- In fully isolated bridges, this condition may be considered satisfied if vertical deformations of the seismic isolators are less than 5% of the horizontal deformations in the **seismic design situation**. This condition may be neglected if sliding or elastomeric bearings are used as seismic isolators.

EN1998-1-1

Re-centring capability of isolation system

6.8.2.4

General requirement:

$$E_S \geq \frac{1}{4} E_D$$

- E_S is the reversibly stored energy (elastic strain energy and potential energy)
- E_D is the energy dissipated by the antiseismic devices

Alternatively, for systems with **bilinear behaviour** *in the horizontal direction above re-centring capability may be considered satisfied if :*

$$\frac{K_p d_{Ed}}{F_0} \geq \frac{1}{2}$$

- d_{Ed} is the seismic displacement of the isolation system
- K_p is the post-elastic (tangent) stiffness
- F_0 is the force at zero displacement

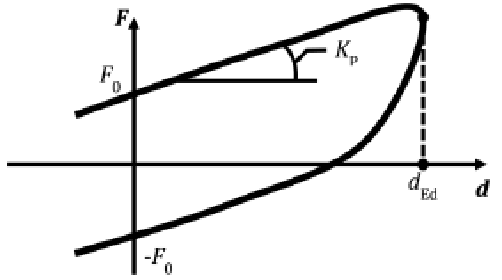


Figure 6.3 — Definition of the equivalent bilinear model for the evaluation of re-centring capability

If $\frac{K_p d_{Ed}}{F_0} < \frac{1}{2}$ *then either change the device* (F_0, K_p)*, or, increase the deformation capacity of the isolator* (d'_{Ed}) *by :*

$$\rho_d = 1 + 1.5\left(1 - 2\frac{K_p d_{Ed}}{F_0}\right) \geq 1$$

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CEN/TC250/SC8 N1327 prEN1998-2:2024 "Design of structures for earthquake resistance - Part 2: Bridges"

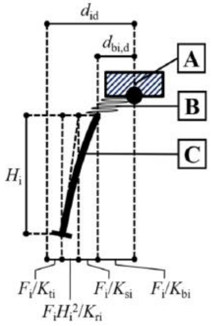
- **Antiseismic Devices**
- **Seismic action, basic requirements & compliance criteria**
- **General provisions concerning antiseismic devices**
- **4 Methods of analysis**
- **Minimum overlap length at connections**

Methods of analysis

- The basic requirements in EN 1998-1-1, should be satisfied.
- The analysis methods:
  - Equivalent linear lateral force method
    - Equivalent linear model / Predominant-mode equivalent linear response-spectrum analysis
  - Equivalent linear response spectrum method
  - Response-history analysis
- In fully isolated bridges, the effects of the vertical component of the seismic action may be determined by equivalent linear response spectrum analysis, regardless of the method used for the determination of the response to the horizontal seismic action.

Methods of analysis

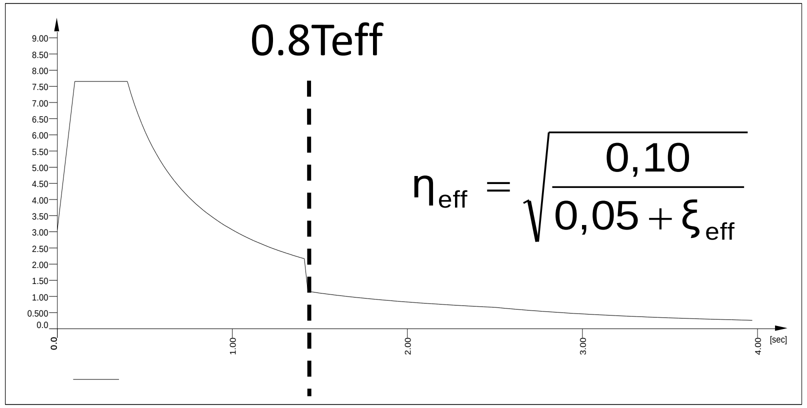
- Equivalent linear lateral force method (SDOF):



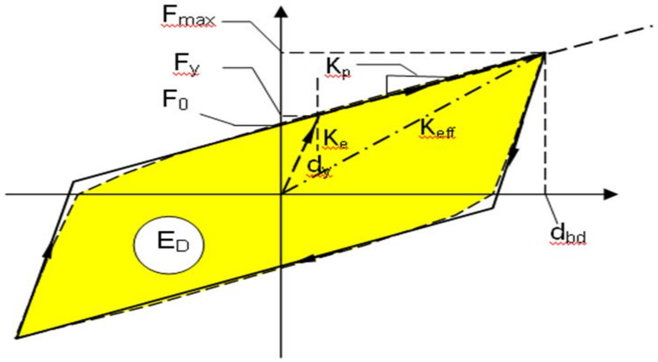
  - Effective stiffness of the isolation system, K_{eff}
  - Effective damping of the isolation system, ξ_{eff};
  - mass of the superstructure, M_d;
  - Spectral acceleration $S_e(T_{eff},\eta_{eff})$ corresponding to:
    - Effective period, T_{eff},
    - Damping correction factor, $\eta_{eff} = \eta_{eff}(\xi_{eff})$.

(See EN1998-1-1 &6.8.5.3)

- Equivalent linear response spectrum method:



$$\eta_{eff} = \sqrt{\frac{0{,}10}{0{,}05 + \xi_{eff}}}$$



(See EN1998-1-1 &6.8.5.4)

- Response-history analysis

(See EN1998-1-1 &6.8.5.5)

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- Antiseismic Devices
- Seismic action, basic requirements & compliance criteria
- General provisions concerning antiseismic devices
- Methods of analysis
- Minimum overlap length at connections

Minimum overlap length at connections

- At supports where relative displacement between supported and supporting members is intended under seismic conditions, a minimum overlap length should be provided.
- The overlap length should be such as to ensure that the function of the support is maintained under total design displacements in the seismic design situation

$$l_{ov} = l_m + d_{eg} + d_{es}$$

l_m	**minimum support length** (>400mm)
$d_{eg} = (2d_g / l_g) l_{eff} \leq 2d_g$	**relative displacement** (spatial variation)
d_g	expected ground displacement
l_g	distance parameter
l_{eff}	effective length of the deck
d_{es} (= d_{Ed} or $d_{Ed}+s$)	**effective seismic displacement** (s, the link slack)

- At separation joint between two sections of the deck: SRSS($l_{ov,1}$, $l_{ov,2}$), at an end support of a deck section on an intermediate pier: l_{ov}+ max $d_{E,Pier}$.

Second Generation of Eurocode 8

Bridges equipped with antiseismic devices

Telemachos Panagiotakos

Thank you for your attention!

Questions & answers

New Bridge: Menidi Bridge

Applications of Bridges equipped with antiseismic devices

New Bridge: Lianokladi Overpass

Existing Bridge: River Selinountas Bridge