Second Generation of Eurocode 8

Assessment and retrofit of bridges

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Clause 12: Specific rules for bridges

CEN/TC250/SC8 N1236 prEN1998-3:2022 “Assessment and retrofitting of buildings and bridges”

Mandate M/515

SC8.T3: Evolution of EN 1998-3 (Phase 1)

Sub-task Ref.: 4 / Sub-task name: Bridges

Extension of the scope of EN1998-3 to cover the **assessment and retrofitting of bridges**. The provisions shall be mostly applicable to **concrete and steel / composite bridges**. They shall also cover the retrofitting of **foundations** and **bearings**. Introduction of **base isolation** and/or **dissipation devices** as part of the retrofitting solution for bridges shall also addressed.

Clause 12

Scope

- Clause 12 contains provisions **additional** to those in other relevant clauses of part 3 or other parts of EN 1998, which should be applied for the assessment and retrofitting of existing bridges.
  - NOTE In applying provisions of EN 1998-3, **bridge piers are assimilated to columns**.
- Clause 12 primarily covers the seismic assessment and retrofitting of existing bridges where **in the horizontal seismic actions are mainly resisted by the piers and/or abutments**.
- **Suspension bridges**, **timber** and **masonry** bridges, **moveable** bridges and **floating** bridges **are beyond the scope of this clause**.

Clause 12: Specific rules for bridges

CEN/TC250/SC8 N1236 prEN1998-3:2022 "Assessment and retrofitting of bridges and bridges"

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- Performance requirements
- Compliance criteria
- Information for structural assessment
- Assessment procedures
- Design of structural interventions

Set the targets (Performance requirements) → **Limit State**
→ **Seismic Action** ← Importance

- The **Limit States** to be used in the assessment of bridges should be as defined in prEN 1998-1-1:2022, 4.3(1).
  - Near Collapse (NC)
  - Significant Damage (SD)
  - Damage Limitation (DL)
  - Fully Operational (OP)
- The influence of the **importance** of the bridge should be expressed either in terms of **return period** ($T_{LS,CC}$) or a **performance factor** ($\gamma_{LS,CC}$) according to 4.1(2) and prEN 1998-2:2022, 4.2.1(1).
  - NOTE: The importance of a bridge depends on failure consequences in terms of human life, on their importance for maintaining communications, especially in the immediate post-earthquake period, and on the economic consequences of collapse.

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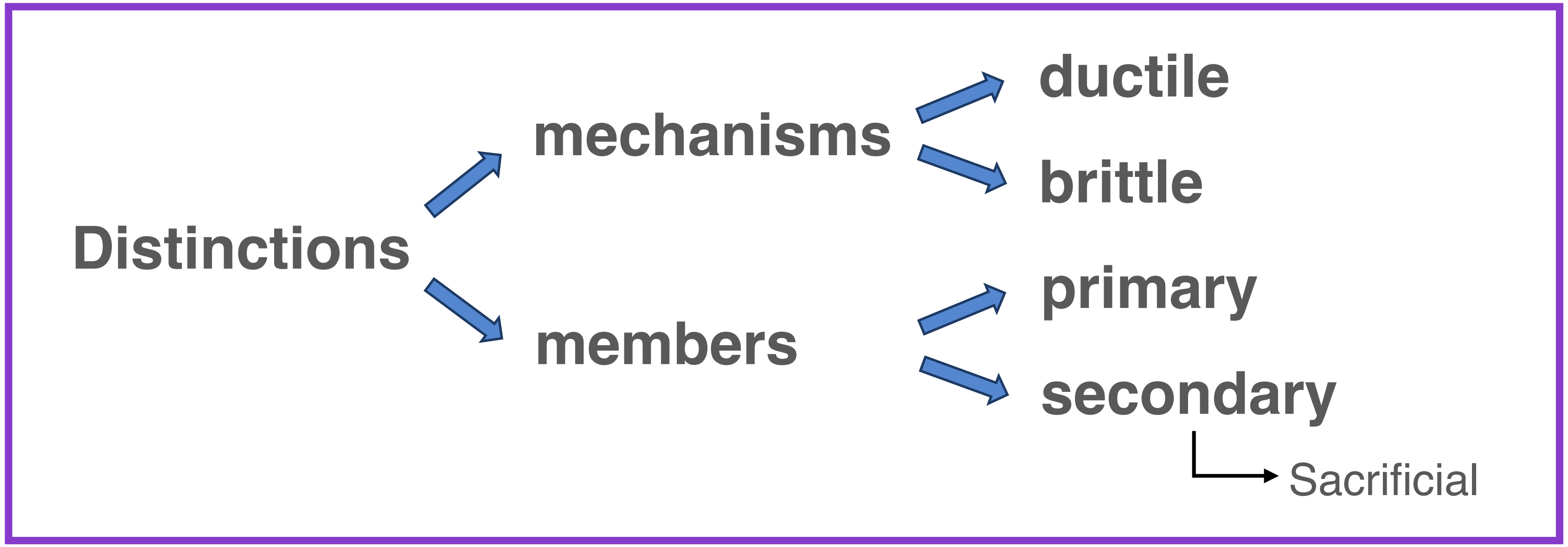

Distinction between “ductile” and “brittle” mechanisms

- The distinction between “**ductile**” and “**brittle**” mechanisms should be applied to the **individual structural members** of bridges.
    - NOTE This distinction refers to structural members, not to the entire structure.

Distinction between “primary” and “secondary” seismic members

- **Except those listed as secondary seismic members**, all structural members of the bridge should be designated as **primary seismic members** in accordance with the definitions in prEN 1998-2:2022, 4.3.2.
- A limited number of **secondary seismic members** may be considered as **sacrificial** according to 4.2.2(3).
  - NOTE Both secondary seismic members and sacrificial members may be neglected in modelling (which is also the case with ancillary elements), since they do not form part of the lateral load-resisting system. Secondary members , however, need to be capable of sustaining gravity loads at the horizontal displacement induced by the seismic action, implying that their collapse is not permitted. For this reason, it is expected that secondary members are going to be included in the model neglecting their stiffness with respect to horizontal loading. On the other hand, sacrificial members are allowed to fail under the specified conditions, implying that they do not support other members; they are usually included in the structural model prior to their failure. Examples of sacrificial members are sacrificial backwalls in seat-type bridge abutments and sacrificial shear keys.

Secondary / Sacrificial

Primary & Secondary seismic members: prEN1998-2:2022 4.3.2

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Investigation scheme ⇒ Obtaining information ⇒ Target Knowledge Level

- For **obtaining information** for structural assessment, the extent of the **investigation scheme** should be decided considering the **target Knowledge Level** for each **bridge component**. There may be different Knowledge Levels for different structural components. The finally attained Knowledge Level should be determined based on the amount and reliability of information collected regarding the corresponding data on geometry, materials and details.
  - NOTE In seismic assessment, the target Knowledge Level for each component depends on its contribution to seismic resistance. With the exception of single-span framed or box-type bridges, the seismic resistance of the bridge depends mainly on the strength of the bearings and on the strength and ductility of the piers and abutments, including their foundations.

Investigation scheme → Obtaining information → **Target Knowledge Level**

- Three steps of the **investigation procedure**, should be followed to obtain the highest feasible **Knowledge Level**.
  - ***Step 1: Collection of information and first inspection***
  - ***Step 2: Simulated design***
  - ***Step 3: Detailed Survey and Investigation***

Procedure of investigations

Step 1: Collection of information and first inspection

- The first step should consist of:
  - **gathering all available information** concerning the existing bridge
  - performing the **first visual inspection**

- Gathering of information should include collection of all available information related to the bridge (i.e. as-built drawings if available, otherwise design or construction drawings, calculation notes, specifications, site report, subsequent interventions and damage reports, soil boring and test logs, geotechnical report, hydrological report, maintenance records, etc.).

- During the first visual inspection, **a geometrical and topographical survey** should be performed in order to establish (or verify if drawings are available) the geometry of the bridge. In the absence of verified (e.g. through spot checks) drawings, new general arrangement drawings should be issued after the survey. Also, all **structural defects** that can be recognised through the first inspection should be recorded.

Procedure of investigations

Step 2: Simulated design

- The second step should consist of a **simulated design** using the results of the previous step, **in order to verify uncertainties on the geometrical and topographic survey and design assumptions** (such as tendon geometry, pre/post tensioning forces, reinforcement, hidden or unavailable details). Where discrepancies are found, a supplementary geometrical and topographic survey should be carried out.

- **If reliable as-built drawings are available, this step may be omitted.**

Simulated design ⇒ Annex A: Preliminary Analysis

Procedure of investigations

Step 3: Detailed Survey and Investigation

Detailed Survey & Investigations → **Geometrical & Structural Survey** / **Investigations**

- The third step should consist in completing **the geometrical and structural survey** of the bridge and **investigations**.
- Detailed **geometrical and structural survey** may be necessary for:
  - the assessment of hidden foundation details through appropriate investigation shafts or use of georadar (ground-penetrating radar);
  - locating tendons and reinforcement through electromagnetic scans and cuts.
- **Investigations** should be performed where insufficient information is available, to determine if the existing structure can resist seismic action effects or preliminary evaluation indicates that retrofitting is required (critical locations of the bridge).

Step 3: Detailed Survey and Investigation

Detailed Survey & Investigations → **Geometrical & Structural Survey**
→ **Investigations**

- **Investigations** for the **properties of materials** should consist of:
  - **estimate concrete quality and properties** using destructive and non-destructive tests (concrete coring – laboratory compression tests, ultrasonic pulse velocity measurements, pull out tests, Schmidt hammer test, pull-off tests, etc.) [see also 8.2.4].
    - NOTE EN 13791 is also applicable to concrete bridges
  - **estimation of type, grade, properties and condition of structural steel**, **reinforcing steel** and **tendons** (e.g. tensile, chemical and metallurgical tests on steel, type of tendons).
  - investigations for the **estimation of the condition of bearings and connections**.
    - NOTE See EN 1337-10 and EN 15129 for bearings. In steel bridges connections include steel joints, whose properties and condition should be assessed.
  - investigations for the **estimation of the effect of age and durability** on the structure (e.g. carbonation depth, chloride content at different depths of the concrete members, detection of cavities, holes and delamination of concrete using infrared thermography).

Procedure of investigations

Step 3: Detailed Survey and Investigation

Detailed Survey & Investigations → **Geometrical & Structural Survey**
→ **Investigations**

- In situ **dynamic load testing** may be applied as a complementary approach.

Investigation scheme ⇒ obtain **highest** feasible **Knowledge Level**

Investigation scheme → Obtaining information → Target Knowledge Level

Assessment of Knowledge Level

- With the exception of box-type bridges, **six types of structural components** should be identified per bridge for the purposes of the assessment of knowledge level:
  - **Deck**
  - **Pier**
  - **Foundation**
  - **Abutment**
  - **Bearing**
  - **Joint & Connection**

←

Information categories:
- **G**eometry
- Construction **D**etails
- **M**aterials

Knowledge levels:
- Minimum
- Average
- High

Target Knowledge Level

Assessment of Knowledge Level

- The Knowledge Level for each category of information, namely Geometry, Construction Details and Materials, should be representative of the critical region of each component.
- For the Geometry, as a minimum, **Average** Knowledge Level should be attained through investigation scheme.
- For each component and material, the achieved KL on Materials (**KLM**) based on the collected information is defined in 8.2.4 for concrete members and 9.2.4 for steel/composite members.
- For each component and material, the achieved KL on Details (**KLD**) based on the collected information is defined in 8.2.3 for concrete members and 9.2.3 for steel/composite members.

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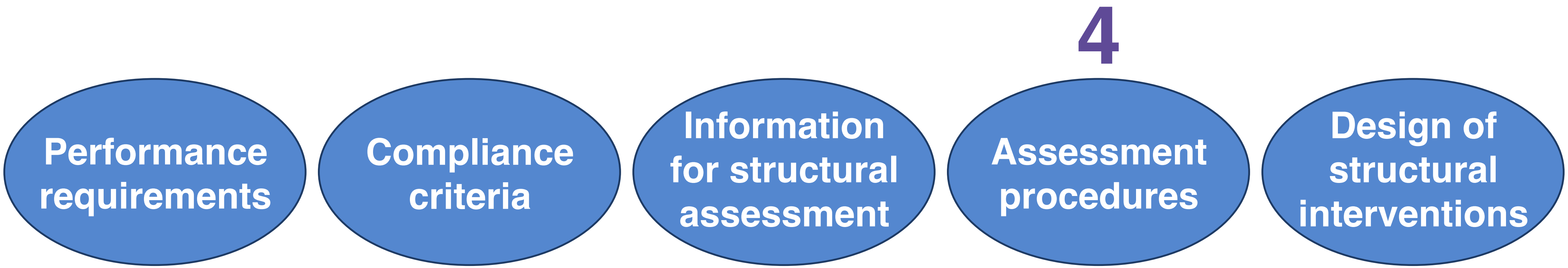

Bridge → **inertial seismic action is dominant**
Bridge → **kinematic seismic action is dominant**

Different approach for:

- Single-Span Framed or Box-type Bridges where the main part of the seismic action induced in these structures comes from earth pressures acting on the back faces of their abutments that are in contact with the earth or the road embankment and the seismic design should be based on a deformation compatibility approach (**kinematic seismic action is dominant**)

- Bridges with two or more spans (**inertial seismic action is dominant**)

Inertial seismic action is dominant

- **Seismic analysis** → Clause 6
- **Soil structure interaction** effects → prEN 1998-2:2022, 5.1.1(13)
- **Resistance** of existing, modified or new members → Clause 8 or 9
- **Non-linear analysis**:
  - non-linear modelling of bridge components that are expected to yield
  - other components may be modelled as linear-elastic
- **Displacement-based approach**:
  - Effective stiffness for members with a non-linear behaviour
    - Clauses 6 and 8.3 (for concrete bridges)
  - Stiffness of the uncracked sections for members with a linear behaviour
    - Exception of torsional stiffness → prEN 1998-2:2022, 5.1.1(8)
- **Material properties & deformation capacities** of members for the considered LS:
  - with a non-linear behaviour → Clauses 8 & 9
  - with a linear behaviour, bending moments → < My
- Action effects for the **shear verification**:
  - In non-linear analysis → from analysis.
  - In linear analysis → prEN 1998-2:2022, 6.3.2
- **Axial force of piers**:
  - may be taken to be constant ($G+\psi_2 Q$)

kinematic seismic action is dominant

- A realistic estimation of the seismic action effects for these bridges requires consideration of **soil structure interaction** and of the dependence of earth pressures on the back faces of the abutments on the **compatibility of deformation between soil and bridge**.
- The **analysis methods** in prEN 1998-2:2022, 10 should be applied.
  - force-based approach (q?) → prEN 1998-2:2022, 10.3.2
  - displacement-based approach (preferred) → prEN 1998-2:2022, 10.3.3
- **Assessment** or **intervention** in the abutment backfills may require special strategies, taking into account the serious limitation due to traffic suspension even for retrofitting relatively small bridges. Such special strategies may entail either:
  - allow all structural members to be designated → as secondary seismic
  - adopt the verification → in global terms as per 6.5.2.4.

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Design of structural interventions

- The general procedure for retrofit design (Clause 7) should be applied to bridges.
- The provisions of EN 1998-2 concerning seismic isolation should be applied.
- Existing, modified and new members should be verified according to EN 1998-2.
- In designing an intervention scheme should be taken into account:
  - all deficiencies in the resistance of **primary seismic members** (i.e. bearings, piers, abutments, foundations) should be remedied by suitable interventions including either retrofitting (increasing the resistance) or reduction of actions effects
  - interventions in **decks** should remedy deficiencies related to permanent actions and may also be necessary to avoid kinematic problems (i.e. impact, loss of support, etc.)
    - NOTE The deck usually is not critically stressed by an earthquake, except in some cases of prestressed decks subjected to the vertical component.
  - a strategy of seismic retrofitting which does not require retrofitting of **foundations** should be preferred
    - NOTE Retrofitting of foundations is much more expensive and cumbersome than retrofitting of piers. Inspection of strengthened foundations after earthquake is also cumbersome.

Intervention on piers

- Intervention on piers may include:
  - complete or partial replacement
  - addition of supplemental pier contributing to seismic resistance
  - shear and/or flexural retrofitting
  - improvement of pier ductility through confinement
  - reduction of action effects on the pier through seismic isolation

- Reinforced concrete pier retrofitting techniques may include
  - steel jacketing
  - reinforced concrete jacketing
  - FRP jacketing
  - active confinement by prestressing

- Retrofitting techniques which **increase the ductility and/or strength** of the piers but **do not substantially affect their stiffness**, should be generally preferred, as they do not entail an increase of the seismic action.

- Intervention on foundations may include:
  - enlargement of existing foundation members
  - shear and/or flexural strengthening
  - addition of piles or micropiles and/or soil- or rock-anchors
  - improvement of the critical soil volume (jet grouting, injection etc.)
  - complete or partial replacement

- Foundations should be verified and when necessary retrofitted to prevent **flexural**, **shear** and **sliding** failure.

- The potential effects of **soil liquefaction**, **lateral spreading** with or without associated liquefaction or **cyclic softening** and **landslides** should be addressed according to EN 1998-5.

- Intervention on abutments and retaining structures may include:
  - shear and/or flexural strengthening
  - provision of longitudinal support to the top of the abutment by connection to piles constructed behind the abutment acting in bending. The connection may be either by an ad-hoc tensile member or through a slab
  - adding soil or rock anchors. The anchors should extend at a sufficient distance into the backfill to avoid being affected by the backfill movement during an earthquake;
  - replacing part of the earth fill with special foams (like expanded polystyrene – EPS) or with reinforced soil
  - complete or partial replacement

- Retrofitting of abutments may be achieved as for piers and foundations

- Abutments may also be retrofitted by reducing earth pressures induced by the backfill.
  - NOTE Since a very significant part of the abutment and retaining structures loading is due to the earth fill behind the abutment (backfill), both in the form of vertical load and horizontal earth pressures, a simple and efficient way for retrofitting an abutment is to reduce these loads.

Intervention to bearings

- Intervention to bearings may include:
  - replacement and/or retrofitting of existing bearings
  - replacement of existing (common) bearings with seismic isolation bearings
  - addition of energy dissipation devices and/or shock transmission units

- Interventions to bearings may be required to **assure that forces of the deck are effectively transmitted to the piers and abutments**.

Intervention to deck

- Intervention to the deck may include:
  - reduction of dead load
  - providing horizontal longitudinal continuity to avoid impacts or deck unseating and securing a better distribution of the seismic force at the supports
  - retrofitting the deck
  - retrofitting the deck-pier joint to restrict plastic hinges to the piers
  - pier crossbeam strengthening and/or stiffening
  - increasing the overlap length between the deck and its supporting elements
  - use of restrainers for horizontal and/or vertical motion
  - complete or partial replacement
- Intervention on the deck may be required to **assure that inertial forces in the deck are effectively transmitted to the bearings and the piers**.
- Deck unseating from its supports should be prevented.

Second Generation of Eurocode 8

Assessment and retrofit of bridges

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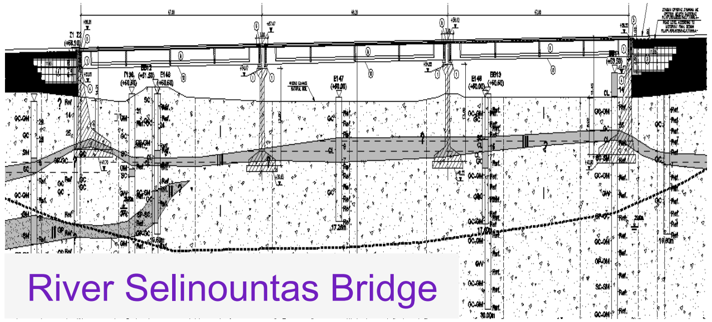
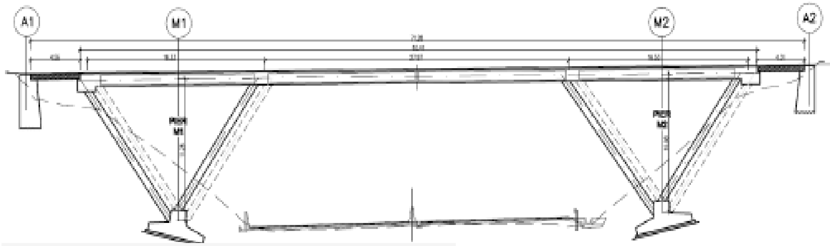
Thank you for your attention



River Selinountas Bridge



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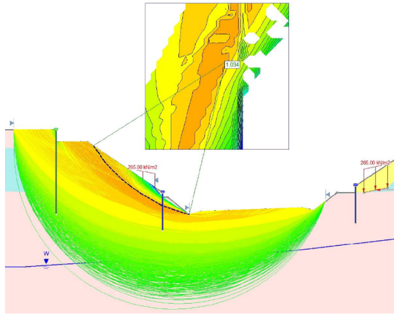

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