Civil Engineering Structures According to the Eurocodes
Civil Engineering Structures
According to the Eurocodes

Inspection and Maintenance

Xavier Lauzin
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An important factor in the design of new structures and repairs to existing structures is *the expected service life*.

In France, for major civil engineering works such as bridges, this duration is around 100 years (the British even go as far as 120 years).

For more modest structures such as water treatment plants, storage silos, etc., this duration was tacitly defined as around 50 years.

There are many factors that can influence this:

– the nature of the materials used in the construction (masonry, steel, concrete, wood, etc.);
– the quality of these materials (high-performance concrete, stainless steel, etc.);
– the constructive arrangements used (accumulation of water on metal structures, lack of encapsulation of steel in a reinforced concrete structure, etc.);
– quality of the execution (quality of the welding, implementation of concrete, etc.);
– monitoring and maintenance.

Within the context of the European Regulation for Calculation and Implementation, all these criteria have been taken into account when determining the duration of use of a structure.

This means that the design of the structures is obsolete if the maintenance conditions are not respected.
Let us recall section 2.4 of EN 1990:

“2.4 Durability

(1) The structure shall be designed such that deterioration over its design working life does not impair the performance of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.

(2) In order to achieve an adequately durable structure, the following should be taken into account:

– the intended or foreseeable use of the structure;
– the required design criteria;
– the expected environmental conditions;
– the composition, properties and performance of the materials and products;
– the properties of the soil;
– the choice of the structural system;
– the shape of members and the structural detailing;
– the quality of workmanship, and the level of control;
– the particular protective measures;
– the intended maintenance during the design working life”.

The question also arises for repairs carried out on a structure: what life expectancy should they be given?

With regard to new structures, EN 1990 indicates the following durations in Table I.1.

<table>
<thead>
<tr>
<th>Design working life category</th>
<th>Indicative design working-life (years)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>Temporary structures(^a)</td>
</tr>
<tr>
<td>2</td>
<td>10–25</td>
<td>Replaceable structural elements, for example rolling beams, supporting devices</td>
</tr>
<tr>
<td>3</td>
<td>15–30</td>
<td>Agricultural structures and the like</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>Buildings and other structures</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>Monumental structures of buildings, bridges and other civil engineering structures</td>
</tr>
</tbody>
</table>

\(^a\)Structures or parts of structures that can be disassembled for reuse should not be considered as temporary.

**Table I.1. Indicative design working life**
In the section “Execution of concrete structures”, section 4.1 of EN 13670 also specifies the need for an inspection program:

“(5) This standard assumes that the structure after completion is used as intended in the design and submitted to planned inspection and maintenance necessary to achieve the intended design working life and to detect weaknesses or any unexpected behavior”.

This requirement implies providing access to the main structural elements at the design level.

Examples include:
– suspended bridges where replacement of the suspension has not been studied at design stage;
– water treatment plants for which it was not possible to empty the tanks (non-bypassable treatment line).

It also implies the need for a “state 0” during the reception for new constructions as well as a structure maintenance plan.

From this state, the sequence of tasks that is required to guarantee the duration of use of the structures is presented in the figure below:

![Figure I.1. Sequence of tasks required to guarantee the duration](image-url)
The purpose of this book is to create an inventory of the methodologies used for inspections of civil engineering structures and to present the elements that can serve as a basis for the diagnosis and maintenance program of concrete structures.

We present the main topics that the reader can deepen their knowledge of by reading the standards cited.

**How to use this guide**

For a better understanding of the methodology used, in the last part of each inspection methodology listed in Chapter 1 is a paragraph about “points of to look out for”, which refers to Chapter 3 for probable causes of the pathology and to Chapter 4 for the means of reinforcement that can be considered.

Chapter 2 gives the basic notions of resistance of the materials that are required for proper comprehension of the behavior of concrete and the interpretation of the observed disorders.

The examples in the Appendix are informative; they aim to show a type of connection in adequation with the inspected structure. They are purely formal.
Inspection and diagnosis of structures are the most important phases of a maintenance operation and, eventually, of renovation. They require asking oneself a few questions before discussing the planning and recovery solution.

The questions are generally the following:

– what is the typology of the damage?
– what could be their cause?
– what is their scope?
– what is their probable evolution?
– what are the consequences for the structure?
– can the damage be repaired (technically and financially)?

To answer this question, the following methodology is usually applied:

– the first step involves a detailed visual assessment. This should be carried out by an expert civil engineer. It is similar to a health check without thorough analysis;
– the second step consists of a diagnosis by auscultation of the structure. This is managed by a civil engineer who relies on a specialized (and possibly multidisciplinary) laboratory.

1.1. Bridges

1.1.1. General information

For bridges, the Centre of Research and Expertise for Risks, Environment and Transport (CEREMA) formalized this principle and set up a methodology for monitoring and diagnosing this type of structure, which is summarized hereafter.
The management of structures is based on:

– *Recording of bridges*: this is a preliminary phase that consists of recognizing and recording the various heritage structures. The necessary data are: the type of structure, its *exact location*, its *main dimensional characteristics* and its *use*. The information should be verified in the field in order to take information into account that may not be included in the files;

– *The project file*: this is a document that gathers all the features of the structure along with its history. The contents of the file are defined in the Technical Instructions (ITSEOA);

– *Monitoring of structures*: this is of significant importance for maintaining the heritage and safety of users. It consists of following the evolution of various structures from a reference state (initial detailed inspection (IDI)), which is defined at the end of the construction or in the management takeover. The reference state can be modified by carrying out significant works such as expansion and extension. This monitoring is carried out over two levels:

  - *periodic inspections*;
  - *periodic detailed inspections*.

**NOTE.**– There is also a *detailed end-of-warranty inspection* to ensure the condition of a structure under contractual guarantee or 10-year liability.

### 1.1.1.1. *Periodic inspections*

<table>
<thead>
<tr>
<th>Aim</th>
<th>Frequency</th>
<th>Requirements</th>
<th>Achievement</th>
</tr>
</thead>
</table>
| It applies to all structures if they are not carried out in the same year as another inspection (periodic or exceptional detailed inspection). | From 1 year (annual check) to 3 years (assessment visit) maximum. | – Detect any change in the pathologies that had already been noticed.  
– Take note of serious damages that pose a threat to users.  
– Identify the nature of routine or specialized maintenance. | Visual inspection without special access by trained agents. |

*Table 1.1. Periodic inspections table*
1.1.1.2. *Periodic detailed inspections*

<table>
<thead>
<tr>
<th>Aim</th>
<th>Frequency</th>
<th>Requirements</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish a health check of the structure and define the actions related to routine or specialized maintenance. It should be exhaustive and requires using means for access.</td>
<td>Six years but can be reduced to 3 years for weaker structures or increased to 9 years for robust structures. For underwater inspections, the frequency must be adapted according to the sensitivity of the structure (generally between 3 and 6 years).</td>
<td>– Check that the condition of the structure has not deteriorated abnormally. – Check that user safety devices are in good condition. – Check that there are no apparent threats to safety.</td>
<td>Visual inspection with special access carried out by agents who have received specific training.</td>
</tr>
</tbody>
</table>

**Table 1.2. Periodic detailed inspections table**

1.1.1.3. *Conditional monitoring actions*

These actions generally concern structures in exceptional conditions.

These are mainly as follows:

– exceptional visits or inspections following accidental events such as floods, landslides, violent storms, accidents, shocks, etc. or following observations from periodic inspections;

– enhanced monitoring or high-level monitoring activities for structures in critical condition.

<table>
<thead>
<tr>
<th>Aim</th>
<th>Frequency</th>
<th>Requirements</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete the conventional monitoring actions and provide the information needed to carry out a major repair study (compilation of additional surveys, specific tests, sampling, etc.)</td>
<td>After examination during the periodic inspection, as a result of exceptional events, etc.</td>
<td>Establish a detailed diagnosis of the structure with a view to making major repairs.</td>
<td>Done by a specialized service provider with specific equipment.</td>
</tr>
</tbody>
</table>

**Table 1.3. Exceptional inspections table**
1.1.1.4. Monitoring results

The purpose of monitoring is to assess the level of service of a structure.

This service record can be classified as:

– **normal or quasi-normal**: structure generally in good condition (the only defects are due to routine maintenance) or minor defects that can be remedied by specific or specialized maintenance;

– **defective**: a structure with major structural damage for which the severity is assessed as likely to jeopardize the safety or durability of the whole structure;

– **doubtful**: analysis of a structure carried out at the end of a monitoring phase for which it was not possible to draw conclusions (actual or potential gravity, degradation of materials, etc.) or for which damages have not been highlighted (for example calcite sediment that may lead to corrosion of steel).

![Organization chart of the principle of structure monitoring](image)

**Figure 1.1. Organization chart of the principle of structure monitoring**

1.1.2. Regulatory documents

1.1.2.1. Booklet 3 of ITSEOA

This booklet deals with “auscultation, enhanced monitoring, high-level surveillance, immediate safety measure or safeguard”.

In particular, it defines:
– the approach to be followed in relation to the monitoring results;
– auscultation;
– enhanced monitoring;
– high-level monitoring;
– immediate safety and safeguarding measures.

1.1.2.2. The revised ITSEOA from 1979

This document includes the following structures:
– Booklet 01: Project files;
– Booklet 02: General information on monitoring;
– Booklet 03: Auscultation–enhanced monitoring–high-level monitoring security measures;
– Booklet 04: Topometric monitoring;
– Booklet 10: Aquatic foundations site;
– Booklet 11: Ground-site foundations;
– Booklet 12: Bearings;
– Booklet 13: Support devices;
– Booklet 20: Area of influence–access–approaches;
– Booklet 21: Equipment of structures (protection against water–coatings–road and sidewalk joints–railings–restraint systems);
– Booklet 30: Masonry bridges and viaducts;
– Booklet 31: Bridges made up of unreinforced and reinforced concrete;
– Booklet 32: Prestressed concrete bridges;
– Booklet 33: Metal bridges (steel, iron, cast iron);
– Booklet 34: Hanging bridges and cable-stayed bridges;
– Booklet 35: Emergency bridges;
– Booklet 40: Tunnels, covered trenches, protective galleries;
– Booklet 50: Metal nozzles;
– Booklet 51: Retaining structures;
– Booklet 52: Cuttings and embankments;
– Booklet 53: Protective structures.

### 1.1.3. Human resources

The achievement of a structure inspection service requires three levels of intervention:

– a project manager whose role it is to carry out the bid review, contract review, program review and file review. He is the person in charge of the study;

– a structure inspector whose role it is to intervene in each phase of the service in coordination with the project manager. He is responsible for the report;

– an inspection officer responsible for the inspection.

The qualification levels of various stakeholders are summarized in Table 1.4.

<table>
<thead>
<tr>
<th>Function</th>
<th>Mission</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project manager</td>
<td>Establish the diagnosis</td>
<td>Bac+5</td>
</tr>
<tr>
<td></td>
<td>Propose a follow-up</td>
<td>Bac+2</td>
</tr>
<tr>
<td></td>
<td>Finalize the inspection report</td>
<td></td>
</tr>
<tr>
<td>Inspector</td>
<td>Write the report</td>
<td>Bac+2</td>
</tr>
<tr>
<td></td>
<td>Propose diagnostic elements</td>
<td>Bac</td>
</tr>
<tr>
<td>Inspection officer</td>
<td>Assist the inspector</td>
<td>Bac</td>
</tr>
<tr>
<td></td>
<td>Carry out plans and monitoring</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.4. Qualification level table**

### 1.1.4. Material resources

A preliminary preparation phase is required to determine the material resources that are needed to carry out the inspection.

This phase is essential to ensure:

– stakeholder safety;
– quality of service.
In this context, the inspector will endeavor to verify:

- **visibility and accessibility** of the structures during a previsit with the site manager. He will thus be able to ascertain the presence of any vegetation, overhead lines, catenary lines, cleanliness and also identify any potential obstacles to carrying out the inspection;

- **means of access** to structures (propelled bridges or aerial platforms, vans equipped with collapsible scaffolding, ladders, ropes, craft, etc.).

Based on these elements, the intervention plan can be defined while bearing in mind the following elements:

- time required for technical and safety preparation;
- operational constraints of pathways leading to and from and crossed by the structure;
- delays in delivery of the service;
- the nature of structures to be inspected.

Before any intervention takes place, a risk analysis should be carried out, which should at least highlight the following points:

- definition of the conditions of intervention on frequented roads with the manager of the structure and preparation of requests for orders or notices for rerouting;
- verification of the conformity of means of access and staff qualification (CACES, etc.);
- EC certificate of the visiting craft;
- verification of PPE.

Inspections should always be carried out by two inspectors.

Each bridge inspector should have:

- a measuring tape, decameter and caliper;
- a digital camera;
- binoculars, magnifying glasses, flashlight;
- a fissurometer;
- a hammer, chisel, brush;
- a depth gauge;
– a spray can or a marker pen;
– a plumb line, spirit level;
– a bag for sampling;
– a rust scale;
– a measuring board;
– a mobile phone or walkie talkie.

1.1.5. The project file

Each structure has a file containing three subfolders that include the following:

– Subfolder 1 “Design and construction” contains all the information relating to the structure before it was put into service, in particular the Subsequent Intervention on the Structure File (SSIF);

– Subfolder 2 “Reference state” defines the initial state of the structure, which will serve as a reference for subsequent monitoring;

– Subfolder 3 “Life of the structure” contains the information after the reference date: VP of the monitoring actions, maintenance work, repairs, etc.

Elements necessary for the preparation of an inspection are as follows:

– for an IDI: the execution plans of the structure, calculation notes and technical sheets as well as a summary of the construction and repair checks;

– for an EDI: plans of the structure and reports of events;

– for a DEWI: the purpose and content of the guarantees;

– for all DIs, the Image Quality Structures (IQS) classification of the structure and previous inspection reports;

– the evolution of the level of operation (expansion, reloading of the rolling layers, limitation of loads, etc.);

– monitoring and auscultation VP (topo, cracks, thickness, etc.).

It is also important to have:

– the date of construction (for understanding the constructive dispositions, recalculation of the structure, etc.);

– the method and phasing of the project;
– the materials and processes used;
– the foundation method;
– possible on-site incidents.

1.1.6. How an inspection is carried out

The role of the inspector in the execution of the inspection program is to:
– establish access means and equipment;
– evaluate meteorological conditions (rain, wind, snow, ice, etc.) with indications of temperatures;
– get a record of special conditions;
– conduct a close visual inspection detailing any defects encountered. Any defect shall be characterized by:
  - its type (crack, spalling, etc.);
  - its physical appearance and dimensions;
  - its extent;
  - its location.

The observations to be made on-site and to be recorded in the inspection report include:
– the area of influence (embankment, excavation, environment, etc.);
– the deck (extrados and intrados);
– the equipment (roadway, sidewalks, storm water system, cornices, guardrails, gates, waterproofing, road joints, monitoring devices, etc.);
– the support system (bosses, bearings, etc.);
– supports (piers, abutments);
– the foundations (on land, river or maritime sites, protection against shocks, etc.);
– accessibility;
– crossings (nature of the roadway crossed, nature of the crossing, clear height, crossing gauge, etc.);
– the characteristics of the structure.
1.1.7. The inspection report

The inspection report must include:

– a chapter identifying the structure;
– a chapter specifying the general characteristics;
– a chapter containing information on the design and execution of the structure;
– a chapter on the life of the structure;
– a chapter on the findings and measurements carried out as part of the inspection;
– a chapter on tests, auscultations, investigations;
– a summary chapter on the state of the structure and its evolution;
– appendices with:
  - plans of the structure (longitudinal, transverse, elevation);
  - plans and diagrams of pathologies encountered;
  - photographic report.

During evaluation visits (IQS visits), the classification of structures is shown in Figure 1.2.

![Figure 1.2. Classification of structures](image-url)
1.1.8. *Points to look out for*

Points to keep an eye on are listed by type of structure in each IQS booklet from the CEREMA database.

1.1.9. *Classification example*

<table>
<thead>
<tr>
<th>Observations</th>
<th>Class</th>
<th>Photos</th>
</tr>
</thead>
<tbody>
<tr>
<td>North:</td>
<td></td>
<td><img src="image1.jpg" alt="Image 1" /></td>
</tr>
<tr>
<td>– Efflorescences due to trails of lime contained in the concrete through the internal water circulation and its deposit in the form of calcite in the cladding.</td>
<td><img src="image2.jpg" alt="Image 2" /></td>
<td></td>
</tr>
<tr>
<td>South:</td>
<td></td>
<td><img src="image3.jpg" alt="Image 3" /></td>
</tr>
<tr>
<td>– Bursting and loosening of the patching concrete due to the thrust exerted by oxidation of the reinforcements and accumulation of water between the spacer and the sole of the abutment.</td>
<td><img src="image4.jpg" alt="Image 4" /></td>
<td></td>
</tr>
</tbody>
</table>

1.2. *Structures for the retention and transportation of liquids*

1.2.1. *General information*

In the same vein as for structures, the CEMAGREF published a guide to the ITBTP editions (ITBTP annals no. 532 of March/April 1995) under the title of:

“Pathology and repair of concrete structures for the storage and transportation of liquids”.

The CEMAGREF guide has two parts:

– the first part looks at the possible modes of repair depending on the type of damage and the severity index;
the second part gives a detailed review of the inspection methodology, the pathologies and the choice of repair techniques.

It specifies the elements necessary for carrying out a diagnostic test of liquid retention structures, in particular the following points:

– knowledge of the structure’s history;
– quantitative and qualitative description of the various damage;
– identification and extent of the various damage;
– recognition of the physicochemical characteristics of the base material;
– comparison of these characteristics in healthy areas and altered areas;
– the parameters test determining the main pathologies that are generally recognized on the type of structure being considered;
– an assessment of the likely evolution of the damage;
– if necessary, recalculation of the structure (reinforcement).

Along the same lines as the CEREMA guide for civil engineering structures, the CEMAGREF guide proposes the following methodology for evaluating structures for storage and transportation of liquids.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Type of investigation</th>
</tr>
</thead>
</table>
| 1     | *Inventory of structures to be inspected.*  
*Examination of the project file.*  
*Summary inspection and initial evaluation* in the normal operation of the structure, usually dedicated to the owner. |
| 2     | *Detailed inspection* of the structure.  
*Complementary investigations.* |
| 3     | *Detailed civil engineering inspection* concerning the quantification and qualification of the damage that affects the structure; this could be accompanied or not by *a diagnosis* of the materials and the structural behavior by auscultation and/or instrumentation. |
| 4     | *A diagnosis* to bring the structure back to its initial operating objectives or to a higher level of service (reinforcement) or demolition. |

*Table 1.5. Methodology for evaluating structures*
1.2.1.1. Step 1

For this stage, the report should provide the following information:

– location, type of environment and information specific to this type of structure;
– general characteristics of the structures (constituent materials, type of foundation, roofing, waterproofing, etc.);
– technical and dimensional characteristics of the structures (studying the “project file”, which includes formwork and reinforcement plans, calculation notes and technical details such as the treatment of the concreting reworks, etc.);
– the type of internal waterproofing selected at the design stage and carried out on the site;
– the type of external waterproofing of the structure (roof, buried part of structures, etc.);
– previous maintenance and maintenance procedures;
– visual inspection accompanied by a photograph file. The photos should be listed and localized;
– an initial evaluation of structures according to the codification below.

1.2.1.2. Step 2

If the report in step 1 classifies the structure as levels 2, 3 or 4 in the Table 1.7, a more detailed inspection of the structures must be carried out and additional investigations can be considered:

– determination of the physical and chemical characteristics of concrete and other materials (waterproofing, etc.). Core drilling of concrete structures is usually carried out on structures that compression tests and chemical characterization tests are carried out on;
– determination of the characteristics of steel coating (for example pachometric tests);
– instrumentation and monitoring of identified pathologies.

A complementary report will then be produced by analyzing the evolution of pathologies, repairs that can be considered, the constraints on the operation and maintenance of structures.

1.2.1.3. Step 3

This is the proper diagnostic phase, which encompasses the set of steps 1–3.
It is carried out by a civil engineering expert and must reveal the following points:

– determination of the causes of pathologies;
– evaluation of the structure overall and per component;
– indication of repair or demolition solutions with the technical requirements inherent to the different processes;
– recalculation of structures;
– evaluation of the cost of repairs;
– estimated service life after repair.

1.2.1.4. **Step 4**
This is the project of renovating a structure once the repair solution is chosen.

1.2.2. **Regulatory documents**
The aforementioned CEMAGREF guide; it may be supplemented by the CEREMA guides for civil engineering works.

1.2.3. **Human resources**
An inspection service involves three levels of intervention:

– a civil engineering inspector whose role it is to intervene in each phase of the service in coordination with the inspection officer. He is responsible for the report;

– an inspection officer who is responsible for inspection.

The qualification levels of the various stakeholders are summarized in Table 1.6.

<table>
<thead>
<tr>
<th>Function</th>
<th>Mission</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil engineering inspector</td>
<td>Establish the diagnosis</td>
<td>Bac+5</td>
</tr>
<tr>
<td>Project manager</td>
<td>Propose follow-up</td>
<td>Bac+2</td>
</tr>
<tr>
<td></td>
<td>Finalize inspection report</td>
<td></td>
</tr>
<tr>
<td>Inspection officer</td>
<td>Assist the inspector</td>
<td>Bac</td>
</tr>
<tr>
<td></td>
<td>Carry out plans and monitoring</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.6. Stakeholder qualification levels**
1.2.4. The material means

The determination of the material means necessary for carrying out the inspection requires a preliminary preparation phase.

This phase is essential to ensure:
– stakeholder safety;
– quality of service.

In this context, the inspector will endeavor to verify:
– visibility and accessibility of the structures during a previsit with the manager. He will thus be able to ascertain the presence of any vegetation, overhead lines, catenary lines, cleanliness and identify any potential obstacles to carrying out the inspection;
– means of access to structures (propelled bridges or aerial platforms, vans equipped with collapsible scaffolding, ladders, ropes, craft, etc.).

Based on these elements, the intervention plan can be defined while bearing in mind the following elements:
– time required for technical and safety preparation;
– operational constraints of the structures (draining, cleaning, etc.);
– delays in delivery of the service (for example inspection of the tank of a drinking water reservoir during the period of cleaning and disinfection);
– the nature of structures to be inspected.

Before any intervention takes place, a risk analysis should be carried out, which should at least highlight the following points:
– definition of the conditions of intervention with the manager, in particular if access and inspection requires work on ropes;
– verification of the conformity of means of access and qualification of staff (CACES, etc.);
– EC certificate of the visiting craft;
– verification of sensors (CH₄, H₂S, etc.);
– verification of PPE.
Like for bridges, an inspection should generally be carried out by two inspectors. Each inspector should have:
- a measuring tape, decameter and caliper;
- a digital camera;
- binoculars, magnifying glasses, flashlight;
- a fissurometer;
- a hammer, chisel, brush;
- a depth gauge;
- a spray can or a marker pen;
- a plumb line, spirit level;
- a bag for sampling;
- a rust scale;
- a measuring board;
- a mobile phone or walkie talkie.

1.2.5. The project file

Each structure has a file containing three subfolders that include the following:
- Subfolder 1 “Design and construction” contains all the information relating to the structure before it is put into service, in particular the SSIF;
- Subfolder 2 “Reference state” defines the initial state of the structure, which will serve as a reference for subsequent monitoring;
- Subfolder 3 “Life of the structure” contains the information after the reference date: VP of the monitoring actions, maintenance work, repairs, etc.

1.2.6. How the inspection is carried out

The role of the inspector in the execution of the inspection program is to:
- establish access means and equipment;
- evaluate meteorological conditions (rain, wind, snow, ice, etc.) with indications of temperatures;