1

Inspection of Structures: Methodologies

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 siginificant 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*

Aim	Frequency	Requirements	Achievement
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*

Aim	Frequency	Requirements	Achievement
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.	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).	– 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.	Visual inspection with special access carried out by agents who have received specific training.

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.

Aim	Frequency	Requirements	Achievement
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.)	After examination during the periodic inspection, as a result of exceptional events, etc.	Establish a detailed diagnosis of the structure with a view to making major repairs.	Done by a specialized service provider with specific equipment.

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).

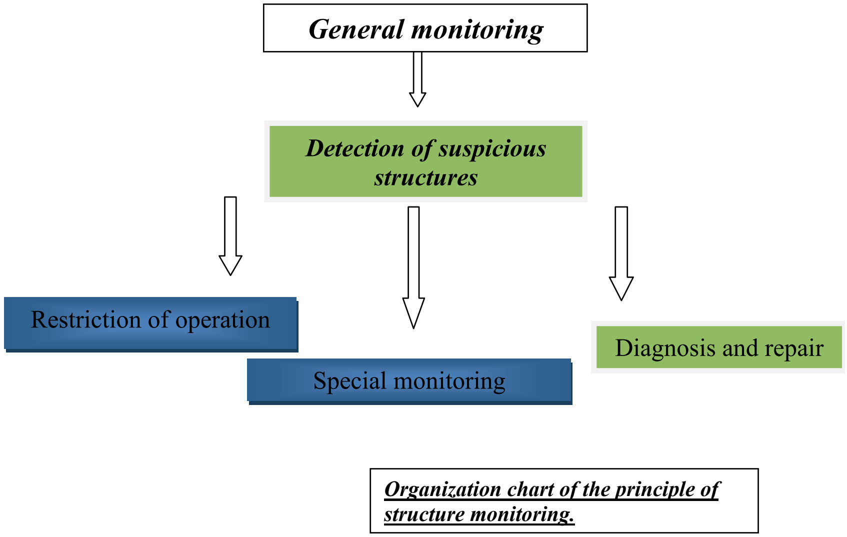


Figure 1.1. *Organization chart of the principle of structure monitoring*

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.

Function	Mission	Level
Project manager	Establish the diagnosis Propose a follow-up Finalize the inspection report	Bac+5 Bac+2
Inspector	Write the report Propose diagnostic elements	Bac+2 Bac
Inspection officer	Assist the inspector Carry out plans and monitoring	Bac

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.

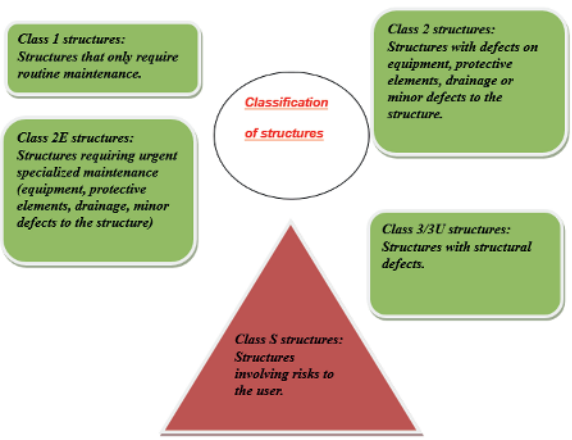


Figure 1.2. *Classification of structures*

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*

Observations	Class	Photos
North: – 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.	1	
South: – 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.	2	

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.

Steps	Type of investigation
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.

Function	Mission	Level
Civil engineering inspector. Project manager	Establish the diagnosis Propose follow-up Finalize inspection report	Bac+5 Bac+2
Inspection officer	Assist the inspector Carry out plans and monitoring	Bac

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 (CH_4, H_2S, 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;

– get a record of special conditions;

– conduct a close visual inspection detailing any defects encountered. Any defect shall be characterized by:

- type (fissure, spalling, etc.);

- physical appearance and dimensions;

- the extent;

- location.

The observations to be made on-site and to be recorded in the inspection report include:

– the area of influence (environment of underground area, aerial zone, etc.);

– the tank (area in contact with the liquid, area in contact with air, area in contact with the ground);

– equipment (guard rails, ladders, cover seal, interior waterproofing of the basin, etc.);

– tower tank columns;

– foundations (on land, river or maritime sites, protection against shocks, etc.);

– surroundings and access;

– the features of the structure.

1.2.7. *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.

The classification of damages proposed in this methodology can be summarized as seen below.

Level	Defects class	Description of the level	Follow-up (type of investigation)
1	A	Structure in good condition (new or old, without defects).	Nothing in particular to report, follow-up and normal maintenance of the structure (annual, biannual depending on nature) Periodic inspection.
	B	Defects existing right from the beginning of the structure and with no significant consequence other than aesthetic.	
2	C	Some defects, risk of abnormal evolution.	Visual inspection.
3	D	D1: defects that show some evolution D2: defects that indicate advanced development for parts that are not in contact with liquids D3: defects that show an advanced evolution for parts in contact with liquids.	Detailed civil engineering inspection possibly with tests on materials.
	E	Defects that reflect a change in the structural behavior of the structure involving its life expectancy (or use).	
4	F	The structure cannot function reliably. The risk of ruin is significant. Possible first-aid solutions and/or demolition of the structure must be considred.	Complete and instrumented diagnosis of the structure with auscultation and sampling.

Table 1.7. *Classification of damages table*

An example of classification of a tower tank can be seen in the table below.

Parts of the structure	Definition of probable causes	Severity index	Possible repair solution
Surroundings		B	
Tank support posts	Carbonation of concrete	B	Technical painting after purging and local repairs
Dome	Carbonation of concrete and corrosion of steel	C	Sealing of the tank
Tank and tank walls (interior)	Carbonation of concrete and corrosion of steel	C	Sealing of the tank
Tank walls (exterior)	Carbonation of concrete and corrosion of steel	C	Technical painting after purging and local repair
Cover dome	Carbonation of concrete and corrosion of steel	E	Recover the subsurface with shotcrete after purging. Additional protection against moisture.
Overall structure (max. severity index)		E	

NOTE.– A full example can be found in Appendix 1.

1.2.8. *Points to look out for*

The tables below list the points to keep an eye on and links them with a severity index and repair solutions.

1.2.8.1. *Concrete structures*

Type of defect	Probables causes	Severity index	Repair solution
Steel portion	Cover defect Shock (see Chapter 3, section 3.1)	D or E	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)
Segregation	Sealing failure of formwork. Poor implementation of concrete. Inadequate rheology.	D	Timely repair (see Chapter 4, section 4.1.5)

Bubbling	Poor implementation of concrete. Inadequate rheology.	On raw concrete structure: B On waterproof or adherent waterproofing support structure: D	Timely repair (see Chapter 4, section 4.1.5)
Disintegration of concrete	Quality of concrete not adapted to the environment Implementation defect Abrasion from sand carried by water. (see Chapter 3, section 3.1)	D	Depending on the results of the chemical analysis of the concrete (see Chapter 4) In the latter case, an antiabrasion mortar may be considered.
Concrete peeling	Shock Aggressive environment Quality of concrete (see Chapter 3, section 3.1)		Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4)
Faience	Withdrawal Alkali-reaction Internal sulfate reaction (see Chapter 3, section 3.1)	B D, E or F D, E or F	Removal: protection by technical painting (I3, I4) In the case of alkali-reaction or ISR to be seen depending on chemical analyses
Isolated cracks $w \leq 2/10$ mm $2/10 < w \leq 20/10$ $20/10 < w$	(see Chapter 3, section 3.1) Check whether the crack has changed		Timely repair (see Chapter 4, section 4.1.5) in first two cases To analyze in the third case (lizards)
Multiple cracks $w \leq 2/10$ mm $2/10 < w \leq 20/10$ $20/10 < w$	(see Chapter 3, section 3.1) Check whether the crack has changed		Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)
Cracks from loading or unloading	Sizing defect (dynamic effects) (see Chapter 3, section 3.1; check whether or not the crack has changed)		Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)

Visible foundations	Scouring, compaction of the soil around the silo	E or F	Backfill. Recovery in the underground (see Chapter 4, section 4.3)
Verticality defect	Differential settlement Hydrology of the site Compaction of the embankment Evacuation of storm water	Rotation without influence on operation: D Rotation that does not compromise stability and waterproofness: E Rotation that compromises stability and/or operation: F	Recovery in the underground (see Chapter 4, section 4.3)

1.2.8.2. *Masonry structures*

Type of defect	Probables causes	Severity index	Repair solution
Alteration of masonry	Environmental aggression	Superficial B or C In the mass D or E	According to the chemical analysis of the pathogen (remineralizing, coating, etc.)
Crumbling masonry	Mechanical or chemical aggression	C or D	Reconstitution or replacement
Shattering	Compression, freezeshock, etc.	C or D	Reconstitution or replacement
Grouting defect	Chemical alteration	Localized D to E Widespread E to F	Timely restoration (see Chapter 4, section 4.1.5) Projected mortar (see Chapter 4, section 4.1.4)
Corrosion of tie rods	Corrosion	C to E	Treatment or replacement. Cathodic protection (see Chapter 4, section 4.2)
Cracking of masonry	see Chapter 3, section 3.1	C to E	Timely restoration (see Chapter 4, section 4.1.5) Projected mortar (see Chapter 4, section 4.1.4) Recovery in the underground (see Chapter 4, section 4.3)

1.2.8.3. *Exterior coatings*

Type of defect	Probables causes	Severity index	Repair solution
Peeling off	Adhesion defect Defective humidification of the substrate. Freeze (see Chapter 3, section 3.1)	B or C	Partial detachment: localized recovery possible General detachment: total repairs after demolition
Faience	Withdrawal. Defective humidification of the substrate. (see Chapter 3, section 3.1)	B or C	Protection by technical paints
Chalking	Drying defect. Defective humidification of the substrate (see Chapter 3, section 3.1)	B or C	Protection by technical paints
Cracking	See Chapter 3, section 3.1	B–D	Depending on the nature of the cracking

1.2.8.4. *Waterproofing coatings based on hydraulic binders*

Type of defect	Probables causes	Severity index	Repair solution
Peeling off	Adhesion defect Defective humidification of the substrate. Freeze Underground pressure (see Chapter 3, section 3.1)	C or D	Partial detachment: localized recovery possible General detachment: total repairs after demolition.
Faience	Withdrawal. Defective humidification of the substrate. (see Chapter 3, section 3.1)	B or C	Protection by technical paints.
Chalking	Drying defect. Defective humidification of the substrate (see Chapter 3, section 3.1)	B or C	Protection by technical paints.
Cracking	see Chapter 3, section 3.1	B–D	Depending on the nature of the cracking.

1.2.8.5. *Tank waterproofing coatings based on synthetic resins*

Type of defect	Probables causes	Severity index	Repair solution
Peeling off	Adhesion defect Underground pressure (see Chapter 3, section 3.1)	Localized defects: C Widespread defects: D	Partial detachment: localized recovery possible General dislocation: total repairs after demolition.
Polymerization defect	Poor composition Poor implementation Commissioning was too fast (see Chapter 3, section 3.1)	D	Total rebuild after demolition.
Chalking	Physicochemical attack (UV type) Product evolution (see Chapter 3, section 3.1)	C	Total rebuild after demolition.
Cracking	See Chapter 3, section 3.1	D	Depending on the nature of the cracking.

1.2.8.6. *Waterproofing membranes*

Type of defect	Probables causes	Severity index	Repair solution
Peeling off Blistering	Adhesion defect Underground pressure (see Chapter 3, section 3.1)	Localized defects: C Widespread defects: D	Complete replenishment or replacement of the membrane
Sealing defect at the welds	Poor welding Poor material	D	Recovery of seals
Sealing defect at singular points	Complexity of welding	D	Resumption of singular points (resin, etc.)
Surface degradation	Physical–chemical attacks	D	Complete replenishment or replacement of the membrane

1.3. Storage structures for petroleum products

1.3.1. *General information*

The topic discussed here is mainly that of concrete structures located inside a fuel park.

It therefore concerns the retention basins and the foundations of tanks, the latter mostly being made up of steel in accordance with the CODRES requirements and are the subject of DT 94.

Figure 1.3. *Retention basin of an oil storage tank*

The UFIP (*Union Française des Industries Pétrolières* – the French Petrolium Industries Union) has produced a guide:

"Maintenance guide for civil engineering works and structures" (DT 92).

This guide provides instructions for the setting up of a monitoring procedure by field agents instructions comprising:

– monitoring visits;

– visits with increased control.

The inspected structures (mainly retention basins and tank foundations) are classified according to the level of danger of the products stored within it.

Type of structure	Classification
All structures except those in category II	Category I
Critical structures in terms of environmental risk (see "Professional guide for defining the perimeter as part of the modernization plan") Storage of flammable liquids.	Category II

Table 1.8. *Classification of structures according to the level of danger*

Along the same lines as for bridges, the guide recommends creating a "monitoring record" that contains the following elements:

– a summary technical sheet specifying the location of the structure and its description, the geometric and technical characteristics, its category (I or II);

– a technical file containing the project documentation (formwork and reinforcement plan, calculation notes, type of waterproofing, type of foundation, geotechnical studies, etc.), a history of the interventions carried out on the structure (structural modifications, replacement of pipes, change of fire seals, etc.), inspections already carried out.

This monitoring file must be accessible at each periodic inspection and updated after each inspection.

A *monitoring program* shall then be established including:

– the classification of the structure according to its condition:

Condition of structure	Definition of the category	Comments	Nature of the intervention
1	Satisfactory condition only requiring routine maintenance		Cleaning of basins and expansion joints Cleaning of drainage Control of access devices to basins, pipes, etc.
2	Fair condition with mild damage that is beyond routine maintenance	Specialized maintenance should be provided.	Drainage repair Recovery of expansion joints Repair of local damage (small cracks, spalling, etc.) Treatment of corrosion of metallic elements Repair of sealants and fire protection provisions
2E	The same as state 2 but with a risk of evolution of the pathologies (evolutionary state)	Implementation of enhanced monitoring	
3	Degraded structural condition requiring repair work	Diagnosis and repair	Major structural repairs (walls, paving, foundations, etc.) Replacing anchor bolts Installation of a structure instrumentation
3P	The same as state 3 but with a priority deadline (integrity, retention capacity, bearing capacity that can be quickly defected)	Diagnosis and repair as soon as possible	

– the frequency of monitoring visits should be dependent on the state of conservation and the category of the structure, in other words at least:

- 1 year for Category II structures;
- 5 years for Category I structures.

1.3.2. *How the inspection is carried out*

The previous requirements for bridges or tanks are also valid for oil repositories with the following specificities:

– as the installation is classified with respect to the environmental risks, each visit requires an application for authorization;

– the visiting equipment must include at least the individual safety equipment, a camera that meets the ATEX zone requirements, measuring tools, etc.

1.3.2.1. *Periodic visits*

At the end of the visit, the agent should draw up a monitoring card comprising the following points:

– the nature of the structure and its category;

– its location or denomination;

– a precise description of the pathologies;

– the level of damage (D1, D2, D3) according to the above classification;

– the results from a counter-visit;

– the need to re-evaluate the structure after further analysis and investigation.

Following an analysis of the monitoring sheets or additional investigation (if these are necessary), the final classification of structures is carried out as follows:

– *a structure is class 1* if no level 2 or 3 damage has been noted on any of the components;

– *a structure is class 2* if no level 3 damage has been found on any of the components but if there is at least one level 2 damage;

– *a structure is class 3* (or 3P) if a level 3 (or 3P) damage has been detected on at least one of the components.

1.3.2.2. *Visits with reinforced control*

To assess the risk of evolution of the damage, an action plan will define the details of the checks to be carried out, such as:

– evolution of a crack opening or a cracked surface;

– verification of the verticality of a storage basin;

– control of foundation compaction.

The reinforced control must conclude either to the absence of evolution risk or to the need for repair.

The response times are summarized in Table 1.9.

Final classification of the structure	Actions to be taken	Implementation timeframes
1		
2E	Reinforced control	According to action plan
2	Corrective operations (according to action plan)	5 years maximum or during the deactivation of the reservoir (*) if it occurs within 5 years
3	Corrective operations (according to action plan)	3 years maximum or during the deactivation of the reservoir (*) if it occurs within 3 years
3P	Implementation of priority measures	6 months maximum
	Corrective operations (according to action plan)	3 years maximum or during the deactivation of the reservoir if it occurs within 3 years

NOTE.– A full example is given in Appendix 2.

Table 1.9. *Periodicity table according to DT92*

1.3.3. *Specificities for this type of structure*

The different basins (according to INRS) are presented in Figures 1.4–1.6.

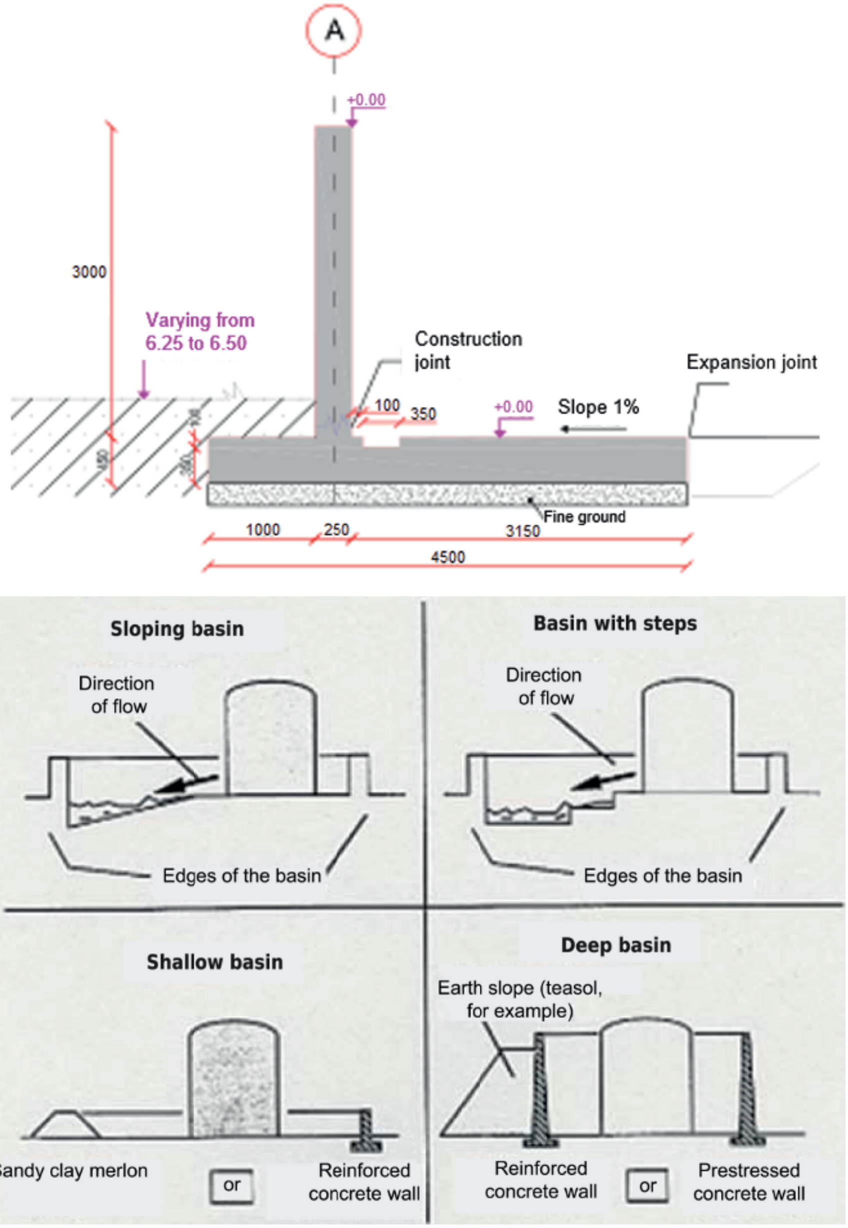


Figure 1.4. *Detailed diagram of the retention basin wall*

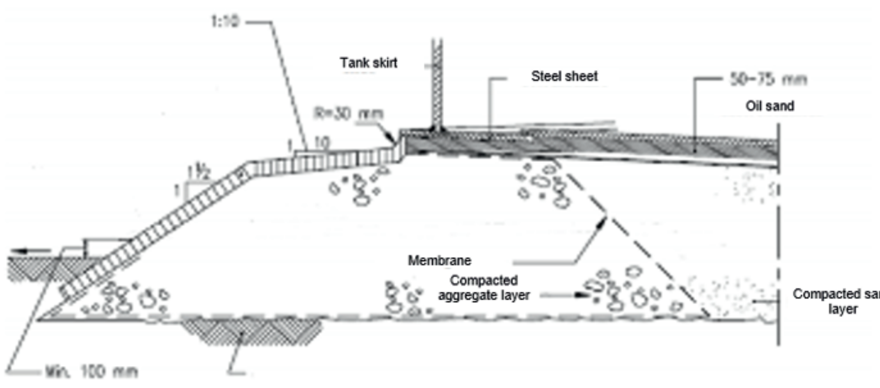


Figure 1.5. *Detailed diagram of the tray of the basin bottom*

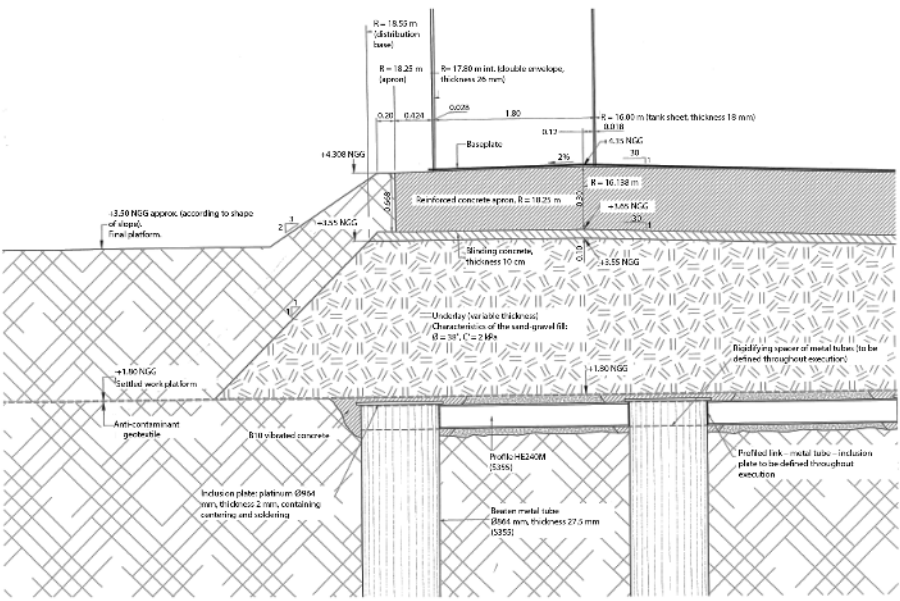


Figure 1.6. *Construction on ground reinforcements*

1.3.4. *Points to look out for*

1.3.4.1. *Concrete base foundation (peripheral base)*

Type of defect	Probables causes	Severity index	Repair solution
Settlement Sinking	Geotechnical study defect Scouring	2E to 3	Recovery in the underground (see Chapter 4, section 4.3)
Cracking	Mechanical malfunction. Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	3–3P	Dependent on the nature of the pathology
Concrete degradation	Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	2–3	Timely repairs (see Chapter 4, section 4.1.5) Projected mortar (see Chapter 4, section 4.1.4)
Visible steel	Cover defect Shock (see Chapter 3, section 3.1)	2–3	Timely repairs (see Chapter 4, section 4.1.5) Projected concrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2, with particular attention for ATEX areas)
Corroded or absent anchor bolts	Aggressive environment	2–3	Replacement

1.3.4.2. *Foundations of the basin on soft foundation base*

Type of defect	Probables causes	Severity index	Repair solution
Settlement sinking	Geotechnical study defect Scouring	2E to 3	Recovery in the underground (see Chapter 4, section 4.3)
Leak detection drain defects	Shear break	3P	Replacement

1.3.4.3. *Concrete structures (low walls, blocks, etc.)*

Type of defect	Probables causes	Severity index	Repair solution
Settlement sinking	Geotechnical study defect Scouring	2E to 3	Recovery in the underground (see Chapter 4, section 4.3)
Cracking	Mechanical malfunction. Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	3–3P	Dependent on the nature of the pathology
Concrete degradation	Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	2–3	Timely repairs (see Chapter 4, section 4.1.5) Projected mortar (see Chapter 4, section 4.1.4)
Visible steel	Cover defect Shock (see Chapter 3, section 3.1)	2–3	Timely repairs (see Chapter 4, section 4.1.5) Projected concrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2, with particular attention for ATEX areas)
Degraded seals	Wear, environmental conditions, etc.	3–3P	Replacement

1.3.4.4. *Paving with sealing function*

Type of defect	Probables causes	Severity index	Repair solution
Settlement sinking	Geotechnical study defect Scouring	2E to 3	Recovery in the underground (see Chapter 4, section 4.3)
Cracking	Mechanical malfunction. Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	3–3P	Dependent on the nature of the pathology
Concrete degradation	Physicochemical alteration (alkali-reaction, ISR, etc.) see Chapter 3, section 3.1	2–3	Timely repairs (see Chapter 4, section 4.1.5) Casting of a new slab Implementation of protective resin
Visible steel	Cover defect Shock (see Chapter 3, section 3.1)	2–3	Timely repairs (see Chapter 4, section 4.1.5) Projected concrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2, with particular attention for ATEX areas)
Degraded seals	Wear, environmental conditions, etc.	3–3P	Replacement

1.3.4.5. *Bottom of basin made of earth*

Type of defect	Probables causes	Severity index	Repair solution
Settlement sinking	Geotechnical study defect Scouring	2E–3	Recovery in the underground (see Chapter 4, section 4.3)
Vegetation animals	Lack of maintenance	2–3	Routine maintenance
Waterproof membrane	Punching. Wear, tear.	3	Timely repairs Replacement

1.3.4.6. *Waterproofing and fireproofing*

Type of defect	Probables causes	Severity index	Repair solution
Degradation of waterproof coatings	Aggressive environment UV	3–3P	Repair or replacement
Degradation of fire-resistant coatings	Aggressive environment UV	3–3P	Repair or replacement

1.4. Maritime structures

1.4.1. *General information*

As the approach used for inspections such as it has been indicated above for civil engineering structures is difficult to apply to port and maritime structures, the CETMEF has proposed a simplified method called the comparative simplified visit (CSV) method.

The principle of the method described in the CETMEF guide is based on the following actions:

– ascertain a nomenclature of port heritage as has been done for other types of civil engineering structures;

– establish an inspection plan including visits to define the mechanical state and the state of use of the various structures listed in the nomenclature;

– prioritize levels of degradation and vulnerability and thus establish a plan of priorities;

– plan the diagnostics required and any necessary reinforcement work.

This guide may apply in particular to:

– docks (on piles, in caisson, etc.);

– pontoons and moorings;

– dikes;

– riprap;

– footbridges, locks, etc.

The specificities of the maritime environment lie mainly in the aggressiveness of the environment with respect to concrete and steel:

– physicochemical aggressiveness of seawater that contains both chlorides and sulfates and is more or less sensitive depending on the exposure area (submerged zone, low water zone, splash zone, tide and spray zone). Eurocode 3 defines the values presented in Table 1.10;

– mechanical aggressiveness, particularly due to swell.

Duration of use of the project	5 years	25 years	50 years	75 years	100 years
Ordinary fresh water (river, navigable canal, etc.) in the high attack zone (water line)	0.15	0.55	0.90	1.15	1.40
Heavily polluted freshwater (wastewater, industrial effluents, etc.) in the high attack zone (water line)	0.30	1.30	2.30	3.30	4.30
Sea water under temperate climate in the high attack zone (low water and spray zone)	0.55	1.90	3.75	5.60	7.50
Seawater in temperate climates in the permanent immersion zone or in the tidal zone	0.25	0.90	1.75	2.60	3.50
NOTES.– 1) The highest corrosion rate is usually found in the spray zone or in the low water area. However, in most cases, the highest bending moment is in the permanent immersion zone. 2) The values given for 5 and 25 years are based on measurements, while the other values are extrapolated.					

Table 1.10. *Corrosion sacrificial thickness according to EC3*

The forces are defined in the "Recommendations for calculation at the limit states of maritime structures" (so-called Rosa 2000 recommendations).

– mechanical aggressiveness of mooring and docking of boats;

– mechanical aggressiveness of port equipment (cranes, etc.);

– chemical aggressiveness of products stored on the platforms.

1.4.2. *Principles of the CSV method*

The CSV method can be summarized in Figure 1.7.

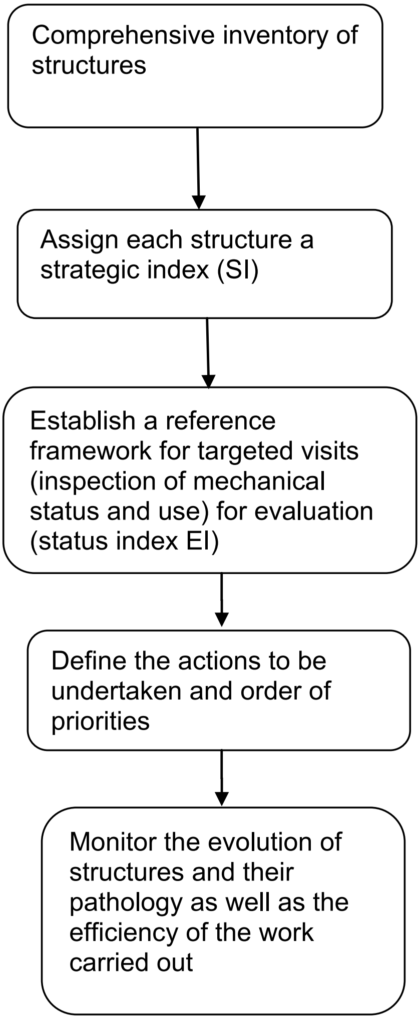


Figure 1.7. *Principle of the CSV method*

During the inspection of the structures, each element is allocated:

– *a mechanical state index (EIm*), which can vary from 1 to 4 as presented in Table 1.11.

EIm index	Evaluation of the state
1	Structures with severe mechanical damage with risk of immediate ruin
2	Structures with serious mechanical damage without risk of immediate ruin
3	Structures with minor degradation or pathology
4	Structure in good condition

Table 1.11. *Evaluation of the mechanical state table*

– *a status indicator (EIu)* to evaluate operating conditions and safety problems relating to use. During the inspection, each structure is graded from 1 to 4 (Table 1.12)

EIu index	Evaluation of the state
1	Elements of use presenting degradations capable of generating immediate safety problems
2	Elements of use presenting degradations likely to generate operating problems
3	Elements of use presenting degradations likely to generate discomfort problems
4	Elements of use in good condition

Table 1.12. *Evaluation of the state table*

The status index of the structures is then defined as:

$$EI = Min\ (EIm;\ EIu)$$

The actions to be carried out are then defined according to the EI value (Table 1.13).

EI index	Actions to be taken
1	– Prohibition of access and operation – Information on the risk of ruin – Temporary safety works (purging, etc.) – Complete diagnosis of the structure – Monitoring
2	– Additional diagnostics including detailed inspection, material testing, underwater inspections, etc. – Monitoring of the structure – Study of the structural reinforcement project – Implementation of reinforcement or demolition works
3	– Additional diagnostics including detailed inspection, material testing, underwater inspections, etc. – Monitoring of the structure – Study of the structural repair project – Repair and specialized maintenance of works (painting, etc.)
4	Maintenance of the structure in good condition through: – Cleaning – Routine maintenance

Table 1.13. *Actions to be taken table*

1.4.3. *Determination of the strategic index SI*

The SI index is defined as "the value of strategic importance of the structure within the heritage".

Strategic decisions can be made by:

– a group of structures (set of structures with the same general use); a classification is then established by the manager (for example swell protection structures that are more strategic than the wharves);

– a family of structures (for example a family of unloading stations may be more strategic than a family of wharves);

– the structures directly.

In the CSV method, each structure is assigned:

– a name;

– a location;

– a specific function.

The decision-making criteria defined in the CETMEF guide are generally the following:

– the value added of landed goods;

– passenger traffic on the structure;

– the possibility of by-passing the structure;

– the lost value added;

– the value of the new structure;

– the heritage value of the structure;

– the strategic nature;

– ease of repair.

For each criterion, the manager gives a score of 1–4 (for example value added: (1) significant, (2) average, (3) low, (4) very low).

1.4.4. *Frequency of visits*

The periodicities are generally the following:

– mechanical visits: between 3 and 5 years;

– usage visits: between 6 months and 1 year.

1.4.5. *Defining the priorities*

The definition of priorities is obtained by crossing the SI and EI indices.

This crossing is done by the manager of maritime structures within the context of a risk analysis.

An example is given in the CETMEF document in Figure 1.8.

Management emphasizing the mechanical aspect

Decreasing priority

	EI	SI
A	1	1
B	1	2
C	1	3
D	1	4
E	2	1
F	2	2
G	2	3
H	2	4
I	3	1
J	3	2
K	3	3
L	3	4
M	4	1
N	4	2
O	4	3
P	4	4

Management emphasizing the strategic aspect (*)

Decreasing priority

	EI	SI
A	1	1
B	1	2
C	1	3
D	1	4
E	2	1
I	3	1
M	4	1
F	2	2
J	3	2
N	4	2
I	2	3
L	3	3
O	4	3
J	2	4
M	3	4
P	4	4

(*) Note: Even with a management policy that favors strategy, structures with a Status Index equal to 1 have priority because they require immediate safety.

Figure 1.8. *Example of management (source: CETMEF). For a color version of this figure, see "http://www.iste.co.uk/Lauzin/engineering.zip*

1.4.6. *Summary of the CSV method*

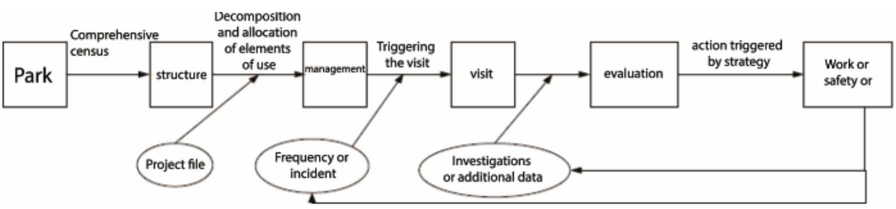


Figure 1.9.

NOTE.– An example of use can be found in Appendix 3.

1.4.7. *Points to look out for*

1.4.7.1. *Structure weight of masonry*

Type of defect	Probable causes	EIm severity index	Repair solution
Alteration of the laying mortar	Mechanical wave action Chemical action of sulfates in sea water	1–3	Replenishing joints Sprayed mortar (see Chapter 4, section 4.1.4)
Deformation of the cladding	Pressure on the wall Overload on the median Alteration of the laying mortar	1–3	Complete wall recovery Injection behind the curtain (see Chapter 4, section 4.3) Limitation of overloading
Vertical or oblique crack	Differential compaction Scouring	1–3	Underpinning (see Chapter 4, section 4.3)
Horizontal crack	Pressure on the wall Alteration of the laying mortar	1–3	Sprayed mortar (see Chapter 4, section 4.1.4) Limitation of overloading Injection behind the sheet (see Chapter 4, section 4.3)
Opening in the compartment parallel to the wall	Wall tilting Foundation scouring Large sliding circle	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods
Lack of support of superficial foundations	Scouring Too much dredging	1–2	Underpinning (see Chapter 4, section 4.3)
Wall tilting	Load too high Foundation scouring Excessive soil stress Shocks or moorings	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring
Sliding of the base of the structure	Earth pressure Overload on the median Subdimensioning of the foundation	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading

1.4.7.2. *Concrete weight structure*

Type of defect	Probable causes	EIm severity index	Repair solution
Alteration of concrete	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Deformation of the cladding	Pressure on the wall Overloading on the median	1–3	Complete wall recovery Injection behind the curtain (see Chapter 4, section 4.3) Limitation of overloading
Vertical or oblique crack	Differential compaction Scouring Restraint of concrete	1–3	Underpinning (see Chapter 4, section 4.3)
Horizontal crack	Pressure on the wall Scourings	1–3	Underpinning (see Chapter 4, section 4.3) Limitation of overloading Injection behind the sheet (see Chapter 4, section 4.3)
Opening in the compartment parallel to the wall	Wall tilting Scouring of the foundations Large sliding circle	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods
Lack of support of superficial foundations	Scouring Too much dredging	1–2	Underpinning (see Chapter 4, section 4.3)
Wall tilting	Excessive load restrained Scouring of the foundations Excessive soil stress Shocks or moorings	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring
Sliding of the base of the structure	Earth pressure Overloading on the median Undersizing of the foundation	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading

1.4.7.3. *L-shaped reinforced concrete wall*

Type of defect	Probable causes	EIm severity index	Repair solution
Alteration of concrete	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Visible steel Corrosion	Coating defect Shock Chloride attack (see Chapter 3, section 3.1)	2–3	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)
Deformation of the cladding	Pressure on the wall Overloading on the median	1–3	Complete recovery of the wall Injection behind the sheet (see Chapter 4, section 4.3) Limitation of overloading
Vertical or oblique crack	Differential settlement Scourings Restraint of concrete	1–3	Underpinning (see Chapter 4, section 4.3)
Horizontal crack	Pressure on the wall Scourings	1–3	Underpinning (see Chapter 4, section 4.3) Limitation of overloading Injection behind the sheet (see Chapter 4, section 4.3)
Opening in the compartment parallel to the wall	Wall tilting Scouring of the foundations Large sliding circle	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods
Lack of support of superficial foundations	Scouring Too much dredging	1–2	Underpinning (see Chapter 4, section 4.3)
Wall tilting	Excessive load restrained Scouring of the foundations Excessive soil stress Shocks or moorings	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring
Sliding of the base of the structure	Earth pressure Overloading on the median Under-sizing of the foundation	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading

1.4.7.4. *Sheet piling*

Type of defect	Probable causes	EIm severity index	Repair solution
Corrosion of the sheet	Corrosion protection defect Water pollution	2–3	Cathodic protection (see Chapter 4, section 4.2) Replacement Create a new sheet in front of the old one
Rips in the sheet Unpicking of locks	Mechanical actions Stresses greater than those calculated Failure to comply (threshing)	1–3	Limit overloading Welding of the keys
Deformation in the sheet plane	Stresses greater than those in the calculations Excessive stretching or breaking of tie rods Anchorage length is too weak Drainage defect behind the sheet	2–3	Limit operating loads Replacement of tie rods or implementation of a new bed of tie rods Increase foot stop Provide drainage
Deformation in the plane perpendicular to the sheet	Lack of ground bearing capacity Vertical stresses greater than those in the calculations	1–2	Underpinning (see Chapter 4, section 4.3) Limit overloading on the sheet
Tilting of the sheet toward the ground	Sliding of the bottom of the wall Stresses greater than those in the calculations Failure to comply	1–2	Restore the foot stop Limitation of overloading Prohibition of mooring
Tilting of the sheet toward the sea	Anchorage length is too weak Failure to comply Detension or rupture of tie rods Scouring or excessive dredging Stresses greater than those in the calculations	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring Restore the foot stop

Land collapse behind the sheet	Fox phenomenon (bringing about ores) Burst pipe	2–3	Injection behind the sheet (see Chapter 4, section 4.3) Recovery of pipes
Land compaction behind the sheet	Natural consolidation Fox phenomenon Burst pipe	2–3	Injection behind the sheet (see Chapter 4, section 4.3) Recovery of pipes
Ground cracking behind the sheet	Sheet deformation Large sliding circle	1–3	Anchor rods
Alteration of the piercap	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Visible steel Corrosion	Coating defect Shock Chloride attack (see Chapter 3, section 3.1)	2–3	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)

1.4.7.5. *Diaphragm walls*

Type of defect	Probable causes	EIm severity index	Repair solution
Concrete degradation	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)

Degradation of panel joints	Mechanical actions Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1 Failure to comply	2–3	Injection (see Chapter 4, section 4.3) Prohibit mooring
Cracking in the piercap	Thermal actions Shrinkage Stresses greater than those in the calculations See Chapter 3, section 3.1	1–3	Injection of cracks (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Limit operational overloading
Deformation in the curtain plane	Stresses greater than those in the calculations Excessive stretching or breaking of tie rods Anchorage length is too weak Drainage defect behind the sheet	2–3	Limit operating loads Replacement of tie rods or implementation of a new bed of tie rods Increase foot stop Provide drainage
Deformation in the plane perpendicular to the curtain	Lack of ground bearing capacity Vertical stresses greater than those in the calculations	1–2	Underpinning (see Chapter 4, section 4.3) Limit overloading on the sheet
Tilting of the curtain toward the ground	Sliding of the bottom of the wall Stresses greater than those in the calculations Failure to comply	1–2	Restore the foot stop Limitation of overloading Prohibition of mooring
Tilting of the ~~sheet~~ curtain toward the sea	Anchorage length is too weak Failure to comply Detension or rupture of tie rods Scouring or excessive dredging Stresses greater than those in the calculations	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring Restore the foot stop
Land collapse behind the curtain	Fox phenomenon (bringing about ores) Burst pipe	2–3	Injection behind the sheet (see Chapter 4, section 4.3) Recovery of pipes
Land compaction behind the curtain	Natural consolidation Fox phenomenon (runoff of fine soil particles) Burst pipe	2–3	Injection behind the sheet (see Chapter 4, section 4.3) Recovery of pipes
Ground cracking behind the curtain	Sheet deformation Large sliding circle	1–3	Anchor rods

1.4.7.6. *Concrete dock on piles (metal or concrete)*

Type of defect	Probable causes	EIm severity index	Repair solution
Concrete degradation	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Alteration of reinforcements Corrosion of metal structures	Chemical action of chlorides Cathodic protection defect See Chapter 3, section 3.1	2–3	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)
Cracking of the platform slab	Thermal actions Shrinkage Stresses greater than those in the calculations Defect in bearing capacity of piles See Chapter 3, section 3.1	1–3	Injection of cracks (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Limit operational overloading Underpinning (see Chapter 4, section 4.3)
Settlement of piles	Lack of ground bearing capacity Vertical stresses greater than those in the calculations	1–2	Limit operational overloading Underpinning (see Chapter 4, section 4.3)
Cracking of the ground behind the platform	Sheet deformation Large sliding circle Compaction	1–3	Anchor rods Injection behind the sheet (see Chapter 4, section 4.3)

1.4.7.7. *Rockfill wharf*

Type of defect	Probable causes	EIm severity index	Repair solution
Concrete degradation	Mechanical wave action Chemical action of sulfates in sea water ISR See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Sag in the coating	Cavities Leakage of fine materials Compaction	1–3	Injection behind the sheet (see Chapter 4, section 4.3) Replacement Recovery in the underground (see Chapter 4, section 4.3)
Vertical or oblique crack in the cladding	Compaction Cavities	1–3	Injection behind the sheet (see Chapter 4, section 4.3) Replacement Underpinning (see Chapter 4, section 4.3)
Horizontal crack in the cladding	Stresses in the cladding greater than those in the calculation Compaction	1–3	Sprayed mortar (see Chapter 4, section 4.1.4) Limitation of overloading Injection behind the sheet (see Chapter 4, section 4.3)
Cracking of the ground behind the riprap	Insufficient foot stop Large sliding circle Scouring	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Restore the foot stop
Alteration of riprap	Mechanical wave action Chemical actions of seawater See Chapter 3, section 3.1	1–3	Replacement of the wall Sprayed mortar (see Chapter 4, section 4.1.4)

1.4.7.8. *Coffered reinforced concrete piers*

Type of defect	Probable causes	EIm severity index	Repair solution
Concrete degradation	Mechanical wave action Chemical action of sulfates in sea water ISR Accidental actions (mooring, etc.) See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4)
Alteration of reinforcements Corrosion of metal structures	Chemical action of chlorides Cathodic protection defect See Chapter 3, section 3.1	1–3	Replacement of the wall Shotcrete (see Chapter 4, section 4.1.4) Resumption of cathodic protection (see Chapter 4, section 4.2)
Vertical or oblique cracking of the caissons	Thermal actions Shrinkage Stresses greater than those in the calculations Differential settlement See Chapter 3, section 3.1	1–3	Underpinning (see Chapter 4, section 4.3) Strengthening of structure (see Chapter 4, section 4.1.4) Limitation of overloading
Horizontal cracking of caissons or at block joints	Stresses greater than those in the calculations Scouring See Chapter 3, section 3.1	1–3	Underpinning (see Chapter 4, section 4.3) Limitation of overloading
Cracking of the ground behind the platform	Deformation of the wharf wall Large sliding circle Compaction	1–3	Underpinning (see Chapter 4, section 4.3) Limitation of overloading Injection behind the sheet (see Chapter 4, section 4.3)
Tilting	Scouring Excessive dredging	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading Prohibition of mooring
Sliding	Stresses greater than those in the calculations Foot stop defect	1–2	Underpinning (see Chapter 4, section 4.3) Installation of tie rods Limitation of overloading

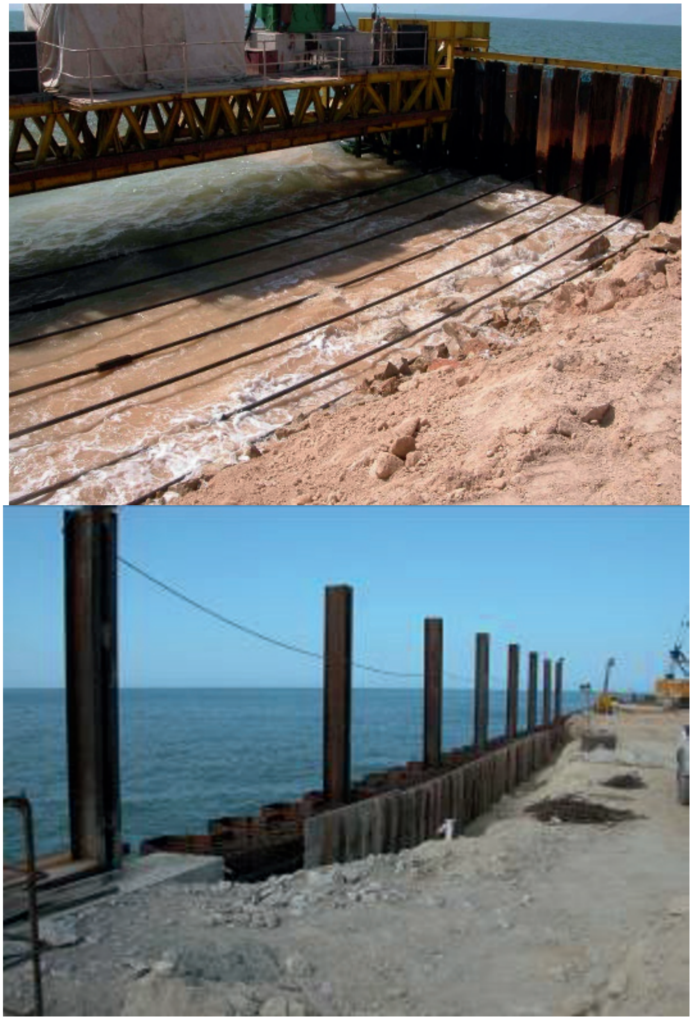


Figure 1.10. *For a color version of this figure, see http://www.iste.co.uk/Lauzin/engineering.zip*

1.5. *Silos*

1.5.1. *General information*

Regarding silos (cereal storage facilities), INERIS has published an inspection and maintenance guide.

This guide mainly focuses on:

– storage of grain, flour;

– movable storage walls;

– fertilizer boxes;

– metal tanks;

– polyester tanks;

– retention basins (storage of liquid fertilizers, plant protection products, extinguishing water, etc.);

– various facilities (mill, reception pits, gallery, etc.);

– safety accessories.

In addition, the “Guide to Art on Silos” recalls that structures must be *monitored*.

1.5.2. *Reminder on the regulations for the mechanical operation of silos*

The loads that should be applied to the silo walls are described in EN 1991-4.

These loads mainly consist of:

– ensiled material;

– the weight of civil works.

The forces generated by the ensiled material and taken up by the walls of the silo depend on the following parameters (section 4.3 of EN 1991-4):

– specific weight of bulk material γ;

– wall friction coefficient μ;

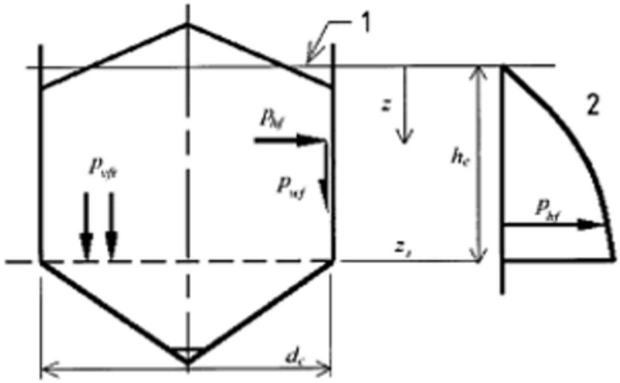
– internal friction angle φi;

– coefficient of lateral constraint K;

– cohesion C;

– coefficient of localized pressure C_{op}.

The forces are then summarized in Figure 1.11 (for slender silos).



Legend

1 Surface area

2 Horizontal stress along the vertical wall section

Figure 1.11. *Silo forces*

These forces depend on the parameters above, so any change in the initial hypotheses (change in silage material, modification of the friction coefficient on the walls, etc.) must be justified.

These various parameters are measured for each test and are summarized in Table 1.14.

1.5.3. *Principle of inspection*

Similar to the aforementioned structures, the inspection plan can be divided into several stages in the following manner:

– an inspection (level 1) to ascertain the state of the structure from visual observations, which will or will not trigger a level 2 visit;

– a more targeted inspection of the critical pathological points (level 2), which will establish the causes of the damage and possible remedial solutions;

– a level 3 inspection with experts on this type of structure if the previous two visits did not reach a formal conclusion.

Type of material [d), e)]	Specific weight [b)] γ (in kN/m^3)		Angle of rest Φ_r (in degrees)	Internal friction angle Φ_i (in degrees)		Lateral coefficient of stress K		Coefficient of wall friction [c)] μ ($\mu = \tan \varphi_w$)				Reference coefficient for localized load C_{op}
	γ_l	γ_u		φ_m	a_φ	K_m	a_K	type D1	type D2	type D3	a_μ	
	inferior	additional		average	factor	average	factor	average	average	average	factor	
Default material [a)]	6,0	22,0	40	35	1,3	0,50	1,5	0,32	0,39	0,50	1,40	1,0
Aggregates	17,0	18,0	36	31	1,16	0,52	1,15	0,39	0,49	0,59	1,12	0,4
Alumina	10,0	12,0	36	30	1,22	0,54	1,20	0,41	0,46	0,51	1,07	0,5
Mixtures for animal feed	5,0	6,0	39	36	1,08	0,45	1,10	0,22	0,30	0,43	1,28	1,0
Tourteau	6,5	8,0	37	35	1,06	0,47	1,07	0,23	0,28	0,37	1,20	0,7
Barley ○	7,0	8,0	31	28	1,14	0,59	1,11	0,24	0,33	0,48	1,16	0,5
Cement	13,0	16,0	36	30	1,22	0,54	1,20	0,41	0,46	0,51	1,07	0,5
Clinker of cement	15,0	18,0	47	40	1,20	0,38	1,31	0,46	0,56	0,62	1,07	0,7
Coal ○	7,0	10,0	36	31	1,16	0,52	1,15	0,44	0,49	0,59	1,12	0,6
Coal dust ○	6,0	8,0	34	27	1,26	0,58	1,20	0,41	0,51	0,56	1,07	0,5
Coke	6,5	8,0	36	31	1,16	0,52	1,15	0,49	0,54	0,59	1,12	0,6
Fly ash	8,0	15,0	41	35	1,16	0,46	1,20	0,51	0,62	0,72	1,07	0,5
Flour ○	6,5	7,0	45	42	1,06	0,36	1,11	0,24	0,33	0,48	1,16	0,6
Iron mineral pellets	19,0	22,0	36	31	1,16	0,52	1,15	0,49	0,54	0,59	1,12	0,5
Hydrated lime	6,0	8,0	34	27	1,26	0,58	1,20	0,36	0,41	0,51	1,07	0,6
Limestone powder	11,0	13,0	36	30	1,22	0,54	1,20	0,41	0,51	0,56	1,07	0,5
Corn ○	7,0	8,0	35	31	1,14	0,53	1,14	0,22	0,36	0,53	1,24	0,9
Phosphate	16,0	22,0	34	29	1,18	0,56	1,15	0,39	0,49	0,54	1,12	0,5
Potatoes	6,0	8,0	34	30	1,12	0,54	1,11	0,33	0,38	0,48	1,16	0,5
Sand	14,0	16,0	39	36	1,09	0,45	1,11	0,38	0,48	0,57	1,16	0,4
Clinker of slag	10,5	12,0	39	36	1,09	0,45	1,11	0,48	0,57	0,67	1,16	0,6
Soybeans	7,0	8,0	29	25	1,16	0,63	1,11	0,24	0,38	0,48	1,16	0,5
Sugar ○	8,0	9,5	38	32	1,19	0,50	1,20	0,46	0,51	0,56	1,07	0,4
Beet pellets	6,5	7,0	36	31	1,16	0,52	1,15	0,35	0,44	0,54	1,12	0,5

Table 1.14. *EN 1991-4: Appendix C*

Following the level 2 inspection, each structure or part of the structure is assigned an index of damage (Table 1.15).

Level	Class of defects	Description of the level	Follow-up (type of investigation)
1	d1	Structures in good condition for which any damage can be repaired through conventional maintenance	Nothing in particular to report, follow-up and normal maintenance of the structure (annual) Periodic inspection
2	d2	Defects that can be repaired through specialized maintenance or that can evolve over time	Repairs to consider. Maintenance plan to be updated
3	d3	Damage that may call into question the general or local stability of the structure. A priority building given the amount of damage.	Immediate repair. Put under surveillance. Security perimeter.

Table 1.15. *Level of inspection table*

This hierarchy of damages then makes it possible to classify the structure (Table 1.16).

Class of structure	Description of the level
1	Structure without any level d2 or d3 damage.
2	A structure without any level d3 damage but capable of presenting level d2 damage.
3	Structure with level d3 damage

Table 1.16. *Class of structure table*

For the inspection, we refer the reader to sections 2.3 and 2.4.

1.5.4. *Follow-up file*

The purpose of the follow-up file is to provide a good knowledge of a structure from its construction with the history of any interventions that have been carried out (maintenance, equipment works, structural modifications, etc.).

This file should include at least:

– the implementation plans (formwork, reinforcement, materials, etc.), everything that constitutes the aforementioned project file for the structures;

– the activity of the installation during its design (cereal silo, transfer silo, etc.);

– the current activity of the structure (if modified in relation to the initial activity);

– the characteristics of the use (rate of rotation, etc.);

– inspection sheets that have already been completed (level 1 and 2);

– modifications or repairs that have been undertaken (reinforcement, opening of chute, etc.);

– the protective coatings used (inner resin, exterior coating, cathodic protection, etc.);

– incidents that have occurred;

– safety equipment (footbridges, guardrails, etc.).

1.5.5. *Inspection procedure*

The role of the inspector in carrying out the inspection program is to:

– establish access means and equipment;

– survey the meteorological conditions (rain, wind, snow, ice, etc.) with indications of the temperatures;

– run a statement of special conditions;

– conduct a close visual inspection detailing the defects encountered. Any defect shall be characterized by:

- its type (crack, spalling, etc.);

- its physical and dimensional characteristics;

- its scope;

- its location.

The observations to be made on-site and to be recorded in the inspection report are:

– the zone of influence (buried environment area, aerial zone, etc.);

– the silo (area in contact with the ensiled material, area in contact with the air, area in contact with the ground);

– equipment (guard rails, ladders, cover seal, optional silo interior seal, etc.);

– cell support posts and sails;

– the foundations;

– approach and access;

– the features of the structure.

1.5.6. *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 operation 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:

- the plans of the structure (longitudinal, transverse, elevation);

- plans and patterns of pathologies encountered;

- photographic report.

1.5.7. *Points to look out for*

Type of defect	Probable causes	Severity index	Repair solution
Visible steel	Cover defect (see Chapter 3, section 3.1)	Localized d1 Widespread d2d/3	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)
Segregation	Formwork sealing failure. Poor implementation of concrete. Inadequate rheology.	d1	Timely repair (see Chapter 4, section 4.1.5)
Disintegration of concrete	Quality of concrete not adapted to the environment Implementation defect (see Chapter 3, section 3.1)	d2/d3	Depending on the results of the chemical analysis of the concrete (see Chapter 4)
Concrete peeling	Shock Aggressive environment Quality of concrete (see Chapter 3, section 3.1)	Non-changing d1 Changing d2	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4)
Faience	Shrinkage Alkali-reaction Internal sulfate reaction (see Chapter 3, section 3.1)	d1 d2/d3 d2/d3	Shrinkage: protection by technical paint (I3, I4) For an alkali-reaction or ISR: to be seen depending on chemical analyses
Isolated cracks w ≤ 2/10 mm 2/10< w ≤ 20/10 20/10< w	See Chapter 3, section 3.1 Check whether the crack has changed	D1 d2/d3 d3p	Timely repair (see Chapter 4, section 4.1.5) in the first two cases To analyze in the third case (lizards)
Multiple cracks w ≤ 2/10 mm 2/10< w ≤ 20/10 20/10< w	See Chapter 3, section 3.1 Check whether the crack has changed.	D1 d2/d3 d3p	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)
Cracks under loading or unloading	Sizing failure (dynamic effects) (See Chapter 3, section 3.1, check whether the crack has changed)	d3	Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)

Visible foundations	Scouring, compaction of the soil around the silo	Localized d1 Widespread d2d/3	Backfill Underpinning (see Chapter 4, section 4.3)
Verticality defect	Differential compaction Hydrology of the site Compaction of the backfill Evacuation of stormwater	Stabilized without cracking d1 Stabilized with cracking d2 Non-stabilized d2 /d3	Underpinning (see Chapter 4, section 4.3)
Cracking of the udders (roundheads) Visible steel Petal roundheads Opening between elements	Cover defect (see Chapter 3, section 3.1) Pipe passage Failure to comply	Localized d1 Widespread d2d/3 d2/d3	Timely repair (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2) Strapping Shotcrete (see Chapter 4, section 4.1.4)

EXAMPLES.–

Figure 1.12. *Opening of the skirt of the silo following the implementation of an internal lining*

Figure 1.13. *Vertical cracking of the skirt of the cylindrical silo*

1.6. Gantry, metal hanger and high masts

1.6.1. *General information*

The topic discussed here is mainly that of concrete and metallic structures as defined in the LCPC technical guide "Gantry, metal hanger, high masts".

1.6.2. *Principle of inspection*

Similarly to the aforementioned structures, the inspection plan can be divided into several stages in the following manner:

– an inspection (level 1) to ascertain the state of the structure from visual observations, which will or will not trigger a level 2 visit;

– a more targeted inspection of the critical pathological points (level 2), which will establish the causes of the damage and the possible remedial solutions;

– a level 3 inspection with experts on this type of structure if the previous two visits did not reach a formal conclusion.

The guide does not mention the classification of structures; however, it is possible to approximate the classification for the structures, as mentioned in section 1.7.

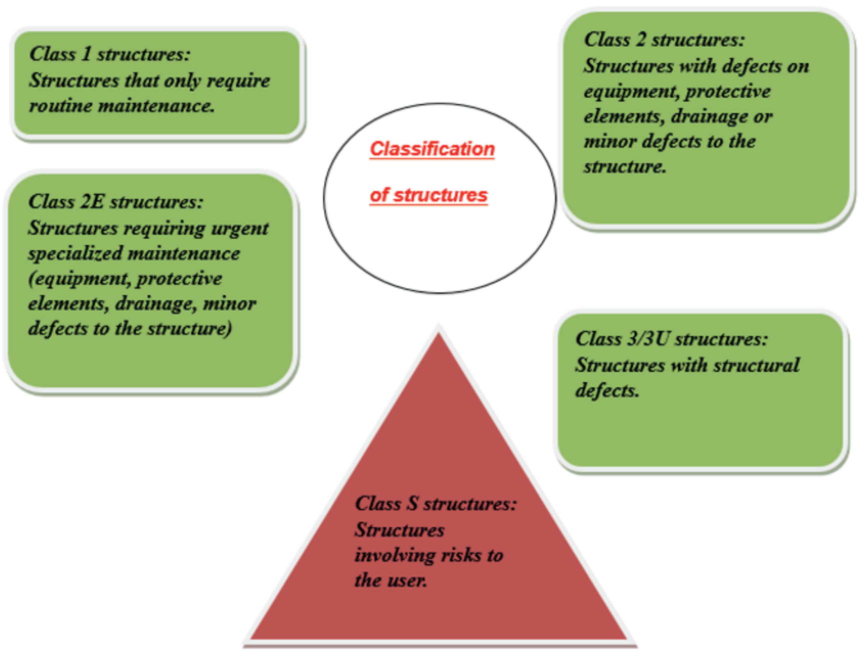


Figure 1.14. *Classification of structures*

1.6.3. *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 operation 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:

- the plans of the structure (longitudinal, transverse, elevation);
- plans and patterns of pathologies encountered;
- photographic report.

NOTE.– An example of a report can be found in Appendix 4.

1.6.4. *Points to look out for*

Type of defect	Probable causes	Severity index	Repair solution
Mass			
Visible steel	Cover defect (see Chapter 3, section 3.1)		Timely repairs (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Cathodic protection (see Chapter 4, section 4.2)
Segregation	Formwork sealing defect Poor implementation of concrete Inadequate rheology		Timely repairs (see Chapter 4, section 4.1.5)
Disintegration of concrete	Quality of concrete not adapted to the environment Implementation defect (see Chapter 3, section 3.1)		Depending on the results of the chemical analysis of the concrete (see Chapter 4)

Concrete peeling	Shock Aggressive environment Quality of concrete (see Chapter 3, section 3.1)		Timely repairs (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4)
Faience	Shrinkage Alkali-reaction Internal sulphate reaction (see Chapter 3, section 3.1)		Shrinkage: protection through technical paint (I3, I4) In the case of alkali-reaction or ISR to be seen depending on chemical analyzes.
Isolated cracks ($w \leq 2/10$ mm $2/10 < w \leq 20/10$ $20/10 < w$)	Check for any change in the condition of the crack (see Chapter 3, section 3.1)		Timely repairs (see Chapter 4, section 4.1.5) in the first 2 cases. To analyze in the 3rd case (lizards)
Multiple cracks ($w \leq 2/10$ mm $2/10 < w \leq 20/10$ $20/10 < w$)	Check for any change in the condition of the crack (see Chapter 3, section 3.1)		Timely repairs (see Chapter 4, section 4.1.5) Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)

Cracks under loading or unloading	Sizing failure (dynamic effects) (see Chapter 3, section 3.1) Check for any change in the condition of the crack		Shotcrete (see Chapter 4, section 4.1.4) Additional prestressing (see Chapter 4, section 4.1.3)
Visible foundation	Scouring, soil compaction		Backfill Underpinning (see Chapter 4, section 4.3)
Verticality defect	Differential settlement Hydrology of the site Compaction of the embankment Evacuation of storm water		Underpinning (see Chapter 4, section 4.3)
Baseplate			
Condition of the baseplate		Presence of eath dirt Water retention Degraded anti-corrosion protection Corrosion Deformation of the plate Deformation of the gussets	
Welding state		Cracks Deblocking blow-holes Lack of material Corrosion Evolutionary defect	

Column	
General appearance	Geometric defect Localized deformation Shock Degraded corrosion protection Corrosion
Verification of welds	Cracks Deblocking blow-holes Lack of material Corrosion
Access hatch	Presence of hatch Presence of closing elements Watertightness of the hatch Condition of the bolt
Transom beam of frame	
General appearance	Geometric defect Localized deformation Shock Degraded corrosion protection Corrosion Link between column and beam
Verification of welds	Cracks Deblocking blow-holes Lack of material Corrosion
Access hatch	Presence of hatch Presence of closing elements Watertightness of the hatch Condition of the bolt

Traffic signs	
General appearance	Geometric defect Localized deformation Shock Degraded corrosion protection Corrosion
Verification of mechanical-fixings	Nature of the fixings Number of missing elements Number of loose elements Presence of locking nuts Corrosion
Access hatch	Presence of hatch Presence of closing elements Watertightness of the hatch Condition of the bolt