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# Spanish guides and code specifications on concrete bridges inspection and maintenance: an overview

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**Abstract**

The maintenance needs of bridges have often resulted in costly interventions, not only due to the lack of an adequate inspection and maintenance plan, but also due to a common practice in the design-building process focused on solving requirements under "instantaneous" economic conditions. This situation is not compatible with the new paradigm of environmental, social and economic sustainability. Aspects related to durability, service life, life cycle, circular economy, etc. are increasingly present in codes and practice guides, so the inspection and maintenance take special relevance by considering economic factors of "deferred" scope. To contextualise the Spanish case, this paper presents a practical overview of the main documentary references that, in the form of regulations and guides, establish mandatory specifications and/or provide tools to facilitate the inspection and maintenance of concrete bridges. From a historical perspective, the changes introduced by the evolutions of main rules are highlighted, starting from the double conception of reinforced concrete and prestressed concrete, passing through the integration towards structural concrete, and reaching our days with the recent appearance of the Structural Code contextualized in the framework of the Eurocodes.

**Keywords**

Code, Guide, Bridge, Concrete, Inspection, Maintenance, Assessment

## 0 Acronyms

ACHE: Asociación Científico-Técnica del Hormigón Estructural (Scientific-Technical Association for Structural Concrete)
ATC: Asociación Técnica de la Carretera (Road Technical Association)
ATEP: Asociación Técnica Española del Pretensado (Spanish Prestressing Technical Association)
CEB: Comité Européen du Béton (European Committee for Concrete)
EH: Instrucción para el proyecto y la ejecución de obras de hormigón en masa o armado (Code for the design and execution of plain or reinforced concrete constructions)
EHE: Instrucción de Hormigón Estructural (Structural Concrete Code)
EHPRE: Instrucción para la fabricación y suministro de hormigón preparado (Code for the manufacture and delivery of ready-mixed concrete)
EF: Instrucción para el proyecto y la ejecución de forjados unidireccionales de hormigón armado o pretensado (Code for design and execution of oneway reinforced or prestressed concrete floors)
EFHE: Instrucción para el proyecto y la ejecución de forjados unidireccionales de hormigón estructural realizados con elementos prefabricados (Code for the design and execution of unidirectional structural concrete floors made with precast elements)
EP: Instrucción para el proyecto y la ejecución de obras de hormigón pretensado (Code for the design and execution of prestressed concrete)
FIB: Fédération Internationale du Béton (International Federation for Structural Concrete)
FIP: Fédération internationale de la précontrainte (International Federation for Prestressing
GEHO: Grupo Español del Hormigón (Spanish Concrete Group)
H: Instrucción para el proyecto y ejecución de obras de hormigón (Code for the design and execution of concrete constructions)
HA: idem EH
JCSS: Joint Committee on Structural Safety
PIARC: Permanent International Association of Road Congresses (also World Road Association)
SDG: Sustainable Development Goal
SLS: Serviceability Limit State
ULS: Ultimate Limit State

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## 1 Introduction

Existing infrastructure and the built environment represent approximately 50% of national wealth in most developed countries [1], and the costs associated with their maintenance constitute about 50% (and tending to increase) of the total construction sector [2].

In Spain, the first inventory of road bridges was carried out in 1985 [3], and more than 15,000 structures with spans of at least 10 m in length —technically "bridges"— were identified in 2010. In view of these orders of magnitude, infrastructure maintenance should not only involve repairing what has deteriorated (reactive approach), but also prevention through maintenance plans (active approach), in order to avoid or delay the appearance of problems that would otherwise be more complicated to solve and would cost much more money.

In the case of structures, and in view of the new paradigms of sustainability, the development of a maintenance plan conceived from the design phase of the structure should not be missing in new structures. So that, the time dimension should not be forgotten, as has often been the case with existing structures, to which little technical and regulatory attention has been devoted from the maintenance point of view, in contrast to the deserved recognition of maintenance in areas as different as the automotive or aviation sectors.

Bridges are a valuable asset for a society as a whole that is evolving towards higher levels of demand and commitment from the perspective of sustainability. Proof of this is the new benchmark: the Sustainable Development Goals (SDGs) as part of the 2030 Agenda [4]. In the case of new bridges, current trends are oriented towards improving inspection and maintenance tasks right from the design phase of bridges [5,6]. In the case of existing bridges, there is a long way to go to implement measures aimed at achieving the SDGs, because although the first maintenance plans for bridges in Spain date back several decades, their number is very low due to the absence of regulations that would require them to be drafted and carried out. By way of example, in the case of railway bridges, it was not until 2005 that Spain had a Code dedicated to the maintenance and monitoring of railway structures [7], which sets out and develops the purpose, scope and consistency visual inspections, introducing the concepts of basic inspection and major inspection, as well as the possibility of developing other works under the concept of special inspection [8].

In this context, this paper provides a practical review with a historical perspective of the main Spanish documentary references that, in the form of regulations and guides, establish mandatory specifications and/or provide tools to facilitate the inspection and maintenance of concrete bridges. The changes introduced by the evolution of main rules are highlighted, starting from the double conception of reinforced concrete and prestressed concrete (GEHO-CEB-FIP period), passing through the rules integration towards structural concrete (ACHE-FIB period), and reaching our days with the recent appearance of the Structural Code [9] contextualised in the framework of the Eurocodes.

## 2 Current status

in the recent report 2019R37EN [5], which presents the results of an investigation to improve inspections and maintenance of bridges from the initial design, it has been shown that in the case of Spain there are no project provisions and practical guides for bridges oriented to facilitate their inspection and maintenance in crucial aspects such as structural scheme, selection of materials, dimensions, necessary instrumentation or prestressing elements.

Many existing structures have not had maintenance plans from the moment they were put into service, nor have they been instrumented in such a way as to allow monitoring of their behaviour over time. One of the reasons for the scarce proliferation of maintenance plans is probably the absence of reference documents that could serve as a guide for designers and those responsible for inspection and maintenance. In this respect, it is noteworthy the recent contribution of the ATC-PIARC Bridge Committee and the Working Group 4/4 of ACHE Commission 4 in the form of a monograph [10]. Commission 5 "Structural Service Life Aspects" of the FIB, which in turn is one of the 6 international professional associations that make up the JCSS, also worked on it.

The design and construction phases are very important because they require, among other things, a large economic outlay, although their time span is, especially nowadays, very short compared to the useful life (e.g. 100 years). A great deal of effort has been devoted to these design and construction phases in terms of teaching (this is what has been taught in universities), standardisation (structural codes have been designed to regulate the design and construction of new works, not to maintain existing ones) and economics, and consequently much of the efforts of designers, builders and administrations are focused on the feasibility of construction and the economic optimisation of the resources that lead to the "putting up" of the structure. However, procedures and regulations up for the inspections along the service life phase of the structure have only recently been developed [11-14].

The lifetime phase is the longest, so that the maintenance of a structure covers almost its entire life cycle, and therefore the reasons that invite a structural assessment respond to a very varied casuistry, either according to the activities carried out in the maintenance plans -causes intrinsic to the structure-, such as the detection of cracking and/or excessive deflections, degradation due to corrosion of the reinforcement or chemical alterations of the concrete components, ... or due to other (extrinsic) causes such as, for example, change of use, adaptation to new regulations, extraordinary events (impact, fire, etc.), effects of nearby works, etc. For a large number of existing bridges, the design life has been or will be reached in the near future, as highlighted in FIB bulletin no. 80 "Partial factor methods for existing concrete structures" (2016) [15].

It should be taken into consideration that the assessment of the condition of structures is a highly complex issue that requires criteria and guidelines for action, well-trained teams and continuity over time to detect the speed of

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changes in the level of deterioration or performance of the structures and the related risks [16]. From the outset, the task of assessing a structure is always more complex than that of designing it, as the technician who is faced with it does not have the same idea as the original designer about its resistance scheme, and it is very likely that he does not have exhaustive information about the material properties, reinforcement layout, etc. In fact, the use of design-oriented methods to assess existing structures often leads to a high degree of conservatism [17]. Therefore, there is a regulatory vacuum in this area: there is currently no specific regulation that provides a clear and unequivocal methodology to address the assessment of a concrete structure with the same range and level of detail as that achieved for its design, as indicated in the document "Assessment of Reinforced Concrete Structures" (2019) [18], prepared by Working Group 4/1 of ACHE Commission 4, which at the same time emphasises the lack of sufficient research on crucial aspects such as the methodology to be followed to address the safety treatment of existing constructions. Moreover, as stated in [19], the scientific method and state-of-the-art knowledge for the assessment of existing structures should be promoted.

## 3 Structural Concrete standards in Spain

Although Spain was one of the countries that had achieved great success in public and private constructions with the use of plain and reinforced concrete in the 20th century, the first Code (H-39) began to be drafted in March 1938 and was officially published in February 1939. Afterwards, the Code was revised (H-44). Figure 1 shows the chronological sequence of the different Codes (or Official Standards) on concrete in Spain

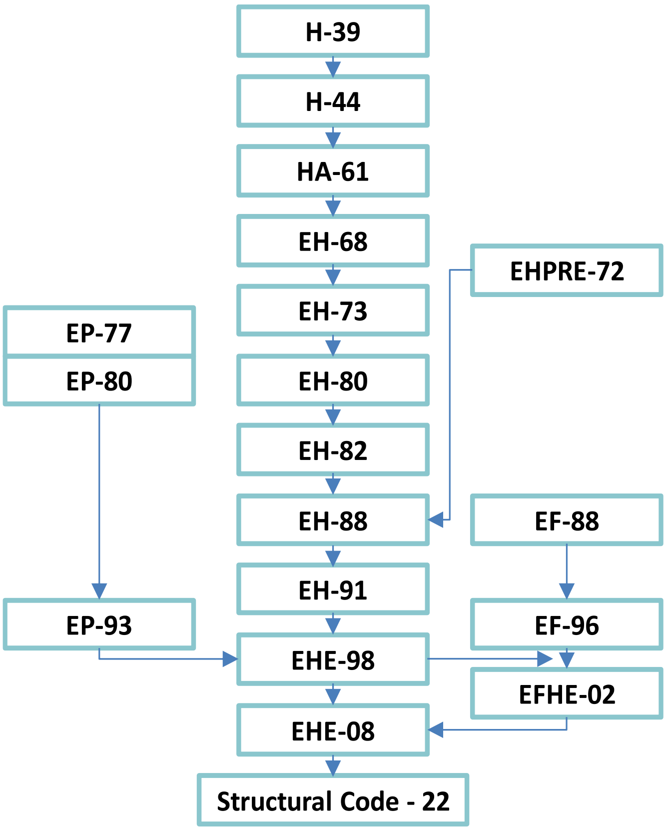


**Figure 1** Chronological sequence of related Concrete Standards in Spain

The HA-61 was significant since it was conceived by E. Torroja from a strong structural perspective focused on reinforced concrete. With this format, several evolutions and actualisations were made until 1991.

Regarding prestressed concrete, the first Code appeared in 1977 (EP-77), and several evolutions and actualisations were made until 1993.

Taking into account that: (a) both EH-91 (Reinforced Concrete) and EP-93 (Prestressed Concrete) were coincident in some points of their content; (b) in numerous infrastructures, structural elements coexist that are studied and designed in both reinforced and prestressed concrete; and (c) the treatment that, both in technical texts related to concrete and in European and international technical regulations, is made of this material, it was considered appropriate to draft a single Code related to the design and execution of concrete constructions, both in mass and reinforced or prestressed, merging in it the two Codes mentioned above. Thus, through the EHE-98, the treatment of concrete was unified and, in this way, the design and execution of these constructions was regulated by a single official provision.

Other related Codes are also shown in Figure 1, which focused on aspects such as ready-mixed concrete, one-way reinforced or prestressed concrete floors, precast members. All of them were integrated and merged at some point in time.

The EHE was revised in 2008 [20] and was pioneer in including explicitly specific provisions regarding maintenance aspects of concrete structures.

Finally, the current Spanish main code [9] includes not only structural aspects for concrete, but also for steel structures and composite structures. This main code, which has been conceived within the framework of the Eurocodes, introduces new regulations regarding the management of existing structures during their service life, which was outside the scope of the previous concrete and steel Codes, and systems for the protection, repair and strengthening of concrete structures.

## 4 First explicit consideration of maintenance aspects (EHE-08) [20]

### 4.1 Definition of maintenance

According to EHE-08 [20], maintenance of a structure means the set of activities necessary to ensure that the level of performance for which it was designed does not fall below a certain threshold during its design life, linked to its mechanical strength, durability, functionality and with appropriate aesthetic characteristics.

Maintenance is a preventive activity, which avoids or delays the appearance of problems that would otherwise be more complicated to solve and cost much more money. To this end, from the entry into service of the structure, the Owner must schedule and carry out maintenance activities in a consistent manner with the criteria adopted in the project. EHE-08 establishes that it is the responsibility of the Owner to organise the maintenance tasks around the indi-

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cated lines of action in order to have, at all times, information about the level of performance of the structure.

### 4.2 Maintenance Strategy

The activities related to the maintenance of the structure are part of a broader overall context which can be referred to as the "structure management system". These activities are of great responsibility and require to be carried out by appropriately trained and equipped personnel. From an operational point of view, such a management system includes the following elements:

- Complete documentary archiving of the structure. It is the responsibility of the Owner to keep the complete Construction Project, as well as the projects, reports or reports that may eventually succeed it by virtue of repairs, reinforcements, extensions, etc., linked to the history of the structure.
- Routine inspections. It is also the responsibility of the Owner to carry out routine inspections to ensure the correct functioning of the elements linked to the operation and durability of the structure (e.g. auxiliary, non-structural elements with a useful life shorter than that of the structure and whose degradation may negatively affect the structure, such as drains, waterproofing, joints, etc.). The frequency of these inspections shall be established by the Author of the Project, depending on the operational and seasonal conditions.
- Major inspections. Carried out at the request of the Owner by technicians with training, means and accredited experience in this type of work, they constitute the set of technical activities which, in accordance with a prior plan, allow the detection, where appropriate, of damage to the structure, its conditions of functionality, durability and safety of the user, as well as estimating its future behaviour.
- Special inspections and load tests, which require specific auscultation of the structure and its subsequent analytical assessment for the formulation of diagnoses.

### 4.3 Maintenance Plan

The design of all types of structures shall be required to include an Inspection and Maintenance Plan defining the actions to be carried out throughout their useful life and specifying, at least, the following points:

- Description of the structure and the exposure classes of its elements.
- Considered useful life.
- Critical points of the structure, requiring special attention for the purposes of inspection and maintenance.
- Frequency of inspections.
- Auxiliary means for access to the different areas of the structure, where appropriate.
- Recommended inspection techniques and criteria.
- Identification and description, with the appropriate level of detail, of the recommended maintenance technique, where such a need is foreseen.

The process begins with the performance of a first main, initial or "state 0" inspection, which will be the result of the control of the constructed element. From then on, with varying frequency, successive major inspections will be carried out, which will give an account of the evolution of the state of the structure. Having assessed the state of the structure and, where appropriate, its rate of deterioration by comparison with previous inspections, it shall be specified whether a special inspection is to be undertaken or whether, on the contrary, it can wait for the next scheduled major inspection in accordance with the protocol established by the Author of the Project or, where appropriate, by the Owner. The frequency of carrying out major inspections shall be defined by the Project Owner in the corresponding Inspection and Maintenance Plan and shall not be less than that established by the Owner, if applicable.

## 5 Current requirements (Structural Code) [9]

### 5.1 Coincidences with EHE-08

In general terms, the definition and the maintenance strategy described in [9] coincide with [20], even with the same words in many cases.

### 5.2 Differences to EHE-08

Among the differences that the current Structural Code [9] presents with respect to the previous Code EHE-08 [20], there are:

- Explicit consideration of new construction and the cases of repair or strengthening of an existing structure.
- Use of the term "additional" life.
- Different descriptions of points to be included in a Maintenance Plan (see 5.3).
- Additional prescriptions focused on Maintenance Plan after completion of the execution of the construction works (see 5.4).
- Additional prescriptions focused on assessment of existing structures (see 5.5).
- Additional prescriptions focused on management of concrete structures during their service life.
- New regulations regarding structural interventions such as repair and strengthening of concrete structures, with particular reference to the respective Inspection and Maintenance plans (see 5.6).

### 5.3 Maintenance Plan

According to [9], the project, whether for new construction or for the repair or strengthening of an existing structure, shall include a maintenance plan which reflects the maintenance strategy and defines the maintenance actions to be carried out throughout the useful life of the project, which starts from zero in the case of new structures and should be understood as "additional" life to that already satisfied by an existing structure.

The maintenance plan shall contain a precise definition of at least the following points: [*in italic, added/changed specifications to those already indicated in EHE-08*]

- Description of the structure and the exposure classes of its elements.
- Considered service life *of the structure and of its constituent elements, given that some components of the construction will have shorter service lives (drainage*

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*systems, defences, support apparatus, paints, coatings, corrosion protection systems, etc.)*.
- Critical points of the structure, which require special attention *for the purposes of their conservation and therefore* for inspection and maintenance purposes. *The plan shall establish the points to be inspected in both basic and major inspections*.
- Periodicity of *both basic or routine* inspections and *major inspection*s.
- Auxiliary means for access to the different areas of the structure, where appropriate.
- Recommended inspection techniques and criteria.
- Identification and description, with the appropriate level of detail, of the recommended maintenance *operations*, where such need is foreseen, *including, where appropriate, frequency of action*.

It should be borne in mind that the maintenance activity occupies practically the entire life cycle of a structure, so it is highly recommended that the maintenance plan includes an approximate assessment of the activities it contemplates. This assessment during the project is of great importance as it can lead to reconsideration of aspects and details of the project that may lead to exaggerated maintenance costs during the lifetime of the structure.

### 5.4 Maintenance Plan after completion

Incidents arising during construction, as well as any design faults detected, will be included in a revision of the inspection and maintenance plan of the project, which will be drafted at the end of the execution of the works, whether they are of new construction or of repair or strengthening.

The inspection and maintenance plan drawn up after completion of the work must be made available to the responsible for the operation of the structure. Based on this maintenance plan, which replaces that of the project, and taking into account the indications of the project manager, the owner will be responsible for the elaboration of the maintenance program.

### 5.5 Maintenance Strategy vs Assessment

The Structural Code [9] defines the basis and procedures for the assessment of the structural capacity and residual service life of existing constructions, in accordance with the principles of structural safety analysis and durability prognosis.

It should be noted that the Maintenance Strategy is related to the structural assessment process of an existing structure, which shall normally be carried out by means of a quantitative verification of its bearing capacity and, where appropriate, its serviceability, taking into account possible deterioration processes.

The process of structural assessment of an existing structure should be progressive, i.e. it starts from simple assessment procedures, associated with few data, and then, if necessary, using more sophisticated and more demanding formulations in terms of the amount of information, until it is possible to give an opinion about the suitability of the structure to accept defined actions with sufficient certainty.

For this purpose, a step-by-step assessment procedure can be adopted including the following phases: preliminary, detailed and advanced assessments. In particular: (a) An initial inspection and the compilation and review of available documentation, including actions arising from the inspection and maintenance program, constitutes a first step in a preliminary assessment; and (b) The determination of the condition of the structure by means of a special inspection, including quantification of possible damage in the form of damage mapping, is required in a detailed assessment. Moreover, a special inspection (together auscultation and/or load testing) is considered in the Level 3 of the structural analysis defined in the assessment framework, which is aimed to carry verifications in a semi-probabilistic context, but using updated information in the form of residual/deduced strength properties and applying partial coefficients adjusted in order to obtain the same reliability as for new construction.

On the other hand, a 'qualitative validation' is possible in the case of structures for which there are no sanctioned procedures for quantitative structural analysis, no performance increments are required and have exhibited previous positive performance. Regarding load-bearing capacity, a major inspection must confirm the static scheme, must not disclose significant damage or deterioration, and the foreseeable deterioration of the structure shall not jeopardise structural safety, at least until the next scheduled major inspection. Regarding serviceability, a major inspection must not show any signs of damage or deterioration, or of excessive deformation, displacement or vibration, whereas taking into account the foreseeable deterioration, as well as the planned maintenance schedule, an adequate durability must be ensured.

According to the prescriptions about management and assessment of existing structures [9], the determination of the residual service life of a concrete consists of deducting the period of time, from the instant of assessment, during which it takes for the structure or any part of it to reach one of the SLS or ULS identified either at the design stage or at the time of assessment. Acceptance thresholds, for both SLS and ULS are implicit in the project basis and, where applicable, in the Inspection and Maintenance Program. Thus, the implication of an Inspection and Maintenance Program in the assessment is inevitable.

### 5.6 Maintenance Strategy vs Structural Intervention

In general, intervention on an existing structure is justified in order to:

- a) To ensure that the expected service life is achieved when the evolution of deterioration has been accelerated in relation to the scenario foreseen in the design phase and ordinary and specialised maintenance actions are not sufficient in the replacement of elements with a shorter service life than that of the structure.
- b) To restore the performance of the structure after an accidental action.
- c) To give new performance or additional service life to the structure (e.g. when there is a change of use involving changes in stress levels or other functional aspects).

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Scenarios a) and b) correspond to repair interventions, whereas c) is associated with strengthening interventions. Therefore, there may be situations where may need to be considered:

- Repair, to prevent or slow down the progress of deterioration or to restore damage following an accidental situation, but without aiming to carry out a "reset" of the construction.
- Strengthening, to bring the structure to a new baseline state with improved performance and prospects for a longer service life.
- Both actions simultaneously.

#### 5.6.1 Inspection and Maintenance Plan in case of repair

For the drafting of the repair project, it is required to carry out a prior special inspection which, as a general rule, should be carried out before concluding on the need to undertake a repair project. As a result of such inspection, a damage or deterioration map must be prepared from the perspective of the repair solution and not so much from the repair solution rather than the aetiology of the damage or deterioration.

In line with the principles set out above, the repair project shall contain, as in the case of new construction, an Inspection and Maintenance Plan with the contents referring to the repair actions undertaken, with specific mention of the following specific aspects:

- The expected service life of the repaired structure.
- The desirable frequency of follow-up inspections of the repaired structure.
- The specific inspection criteria, if any, to be followed by the inspectors.
- The routine or specialised maintenance actions to be carried out, if any.

In a similar manner to the case of a new building project, once the work has been completed, the project manager will be responsible for drawing up the updating of the maintenance plan included in the repair project. This plan shall be submitted to the owner for the management of the maintenance of the structure.

#### 5.6.2 Inspection and Maintenance Plan in case of strengthening

For the drafting of the strengthening project, it is required to carry out a prior special inspection which, as a general rule, shall have been carried out before concluding on the need to undertake a strengthening project. Particularly important at this point is the assessment of the level of safety, because the extent and magnitude of the strengthening depends on it. In addition, the study of strengthening alternatives is required in order to have different possibilities, with their pros and cons, including construction and subsequent maintenance phases.

In line with the principles set out above, the strengthening project shall contain, as in the case of new construction, an Inspection and Maintenance Plan with the contents referring to the repair actions undertaken, with specific mention of the following specific aspects:

- The expected service life of the strengthened structure as a whole and that of its partial elements, if any.
- The desirable frequency of follow-up inspections of the strengthened structure.
- The need, where appropriate, to provide and auscultation system for monitoring.
- The specific inspection criteria, if any, to be followed by the inspectors.
- The routine or specialised maintenance actions to be carried out, if any.

In a similar manner to the case of a new building project, once the work has been completed, the project manager will be responsible for drafting an Inspection and Maintenance Program to complete or update the forecasts of the Inspection and Maintenance Plan included in the strengthening project. This Program shall be submitted to the Owner for the management of the maintenance of the structure.

## 6 Conclusions

A practical overview of the main Spanish documentary references that, in the form of regulations and guides, establish mandatory specifications and/or provide tools to facilitate the inspection and maintenance of concrete bridges, have been presented. The main conclusions are:

- The principle of designing structures with future inspections and maintenance in mind has been routinely overlooked in the past.
- At the design stage, the emphasis has been placed on meeting only the "initial requirements" of the structure - primarily structural safety and serviceability - and then on minimising the initial capital cost. This approach has, in many cases, resulted in costly future maintenance that has far outweighed the initial capital savings based on disregarding inspection and maintenance issues.
- Structures must be designed in such a way that they can be properly and easily inspected and maintained. This requires that inspections and maintenance be an integral consideration in the design rather than treated as an afterthought.
- In the case of bridges, all elements of a bridge should be designed in such a way that the owner can inspect and maintain them, as well as take into account the elements that will need to be replaced over the life of the bridge.
- The current Spanish Structural Code presents until now the most complete treatment regarding Inspection and Maintenance of concrete structures.

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## References


[1] Plos, M.; Shu, J.; Zandi, K.; Lundgren, K. (2017) *A multi-level structural assessment strategy for reinforced concrete bridge deck slabs*. Struct and Infrastr Eng 13, 2, pp. 223–241.

[2] Long, A.E.; Henderson, G,D,; Montgomery, F.R. (2001) *Why assess the properties of near-surface concrete?* Constr Building Mat 15, pp. 65–79.

[3] Spanish Governement (2010) *Guia para la realización del inventario de obras de paso*. Madrid: Ministerio de Fomento.

[4] United Nations (2015) *A/RES/70/1: Transforming our world: the 2030 Agenda for Sustainable Development*. United Nations, Treaty Series, 1771, No. 30822.

[5] PIARC (2019) *2019R37: Bridge design towards improved inspection and maintenance.* La Défense Cedex, France: World Road Association.

[6] Spanish Governement (2014) *Recomendaciones para la redacción de los proyectos de construcción de carreteras*. Madrid: Ministerio de Fomento.

[7] Spanish Governement (2005) *Orden FOM/1951/2005 del 10 junio de 2005 por la que se aprueba la Instrucción sobre las Inspecciones Técnicas en los Puentes de Ferrocarril (ITPF-05)*. Madrid: Ministerio de Fomento.

[8] Esteras, L.; Gómez, J.A. (2021) *Past and Future of Maintenance and Monitoring of Railway Bridges*. Hormigón y Acero 72, 294/295, pp. 151–161.

[9] Spanish Governement (2021) Real Decreto 470/2021, de 29 de junio, por el que se aprueba el Código Estructural. Madrid: Ministerio de la Presidencia, Relaciones con las Cortes y Memoria Democrática.

[10] ACHE (2015) *M-27: Guía para la Redacción del Plan de Mantenimiento en Puentes.* Madrid: Asociación Científico-Técnica del Hormigón Estructural

[11] PIARC (2011) *2011R07: Inspector Accreditation, Non-destructive Testing and Condition Assessment for Bridges.* La Défense Cedex, France: World Road Association

[12] PIARC (2016) *2016R05: Risk-based management of the bridge stock.* La Défense Cedex, France: World Road Association.

[13] Spanish Governement (2012) *Guía para la realización de inspecciones principales de obras de paso en la Red de Carreteras del Estado*. Madrid: Ministerio de Fomento.

[14] PIARC (2022) *2022R20: Advancement of inspection techniques/technologies as a part of bridge management systems.* La Défense Cedex, France: World Road Association.

[15] FIB (2016) *Bulletin nº 80: Partial factor methods for existing concrete structures*. Lausanne: Fédération Internationale du Béton.

[16] León, J.; Corres, H. (2021) *Experiences Related to Non-Evident Risks in Existing Bridges*. Hormigón y Acero 72, 294/295, pp. 233–248.

[17] Tanner, P- (2021) *Standards for the Assessment of Existing Structures: Real Need or Caprice of Code Makers?*. Hormigón y Acero 72, 294/295, pp. 77–84.

[18] ACHE (2019) *M-33: Evaluación de Estructuras de Hormigón Armado*. Madrid: Asociación Científico-Técnica del Hormigón Estructural.

[19] PIARC (2020) *Strategic Plan 2020-2023*. La Défense Cedex, France: World Road Association.

[20] Spanish Governement (2008) *Real Decreto 1247/2008, de 18 de julio. por el que se aprueba la instrucción de hormigón estructural (EHE-08)*. Madrid: Ministerio de la Presidencia.


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