PLAN OF BRIDGES MAINTENANCE

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ABSTRACT

The entry to force of Spanish Standard EHE-08 implied the necessity to draw up plans of maintenance of the newly built structures. It is a novelty of great interest that contributes both the Property and the designer to feel involved, from design phase, with the idea of durability and maintenance: a bid to raise sustainability.

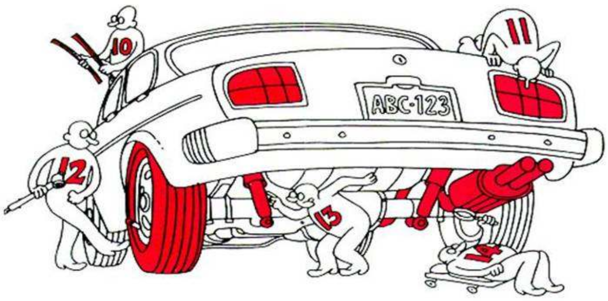
It is, indeed, the incorporation to the Spanish rules, truly pioneering, of the notion that ensuring service life of structures is also a very important part of engineering. Its importance involves the Property, the designer, the contractor and the person in charge of the conservation. That novelty has been taken to the Committee of Bridges of ATC-AIPCR and to the Commission 4 of ACHE to the constitution of a mixed work group that lets to establish some rules that serve as a guide to designers, due to the lack of existing precedents. In the international sector it also starts to awake a great interest about this question. Thus, for example, Commission 5 of *fib* (Structural Service Life Aspects) is preparing a document in this regards by the TG 10 “Birth and re-birth certificates & through- life management aspects”.

In this article, the authors present the synthesis of the ideas developed in the work group of ATC and ACHE and that are rooted in the own definition of the “maintenance plan”, that is the set of tasks required to be identified in the design phase to assure a suitable maintenance that guarantees the service life defined by the Property. That happens because of defining the structure, its exposure conditions, the drainage system, the accessibility for the inspection and substitution of elements of shorter service life (support equipment, joints, etc.), the foreseeable deteriorations and everything serving the Property and the inspectors to focus the activities of inspection, maintenance and interpretation of the possible damages that could take place. This article also includes how these plans of maintenance must be fitted and coordinated in the general context of the bridges management system implanted.

Maintenance is not a smaller, secondary or merely cosmetic question. It is an essential activity to make sustainable constructions and efficient operation. It requires experience and a qualified engineering. It is a relatively new activity in the construction field, that has evolved a lot in the last years and that is foreseeably going to be developed even more in the next future.

1. PRINCIPLES AND CONTEXT

Spanish Standard EHE-08 [1], pioneer in this field, defines maintenance of a structure as "the set of necessary activities so that the level of performance for which it has been designed do not diminish, during its service life, below a certain threshold, linked to the characteristics of mechanical resistance, durability, functionality and, where appropriate, aesthetics". The code requires that, once the structure is open to service, the Owner may program and take effect the activities included in the Plan of Maintenance, in a coherent form according to the adopted criteria in the project. The new EAE-10 [2], devoted to steel structures, also coincide with the same layout.



Preventive Car Maintenance Check List

Vehicle System or Part	Diagram Ref. No.	Check Weekly	Check Monthly	Check Every 2 Months	Special Note	
Air Filter	5			X		Inspect and replace when dirty.
Antifreeze	1	X				Add 50/50% solution when needed.
Battery	8				X	Check with every oil change.
Belts	2		X			Inspect for slack between pulleys.
Brake Fluid	6		X			Add approved type when needed.
Engine Oil	4				X	Check level every other fuel fill up -- change every 3 months or 3,000 miles.
Exhaust	14				X	Have emissions checked yearly.
Hoses	2		X			Inspect for softness or bulges.
Lights	11				X	Keep spare bulbs and fuses in vehicle.
Oil Filter	4				X	Replace with every oil change.
Power Steering Fluid	9		X			Add approved type when needed.
Shock Absorbers	13				X	Replace when worn or leaking.
Tires	12		X			Inflate to recommended pressure level.
Transmission Fluid	3		X			Check with engine running; add approved type when needed.
Washer Fluid	7				X	Check every other fill up.
Wiper Blades	10				X	Replace yearly or when smearing or chattering.

Figure 1. The maintenance in the sector of the automobile or aviation, deeply-rooted long ago.

In this context, really unavoidable, of sustainability and global economy, it may be understood that maintenance is a preventive activity that detects, avoids or delays the appearance of problems that, otherwise, would have a very complicated and progressively expensive solution. In this sense, all the agents implied in the design, the construction and the exploitation of an infrastructure shall take into account the different phases of the life-cycle of structures, including the whole set of their life span. In addition, the different phases (design, execution and control, life span) cannot be considered totally independent, but interrelated. As a consequence, specific typical decisions of every project phase, such as the selection of materials, members' geometry and, where appropriate, equipment, joints, etc., must be taken into account carefully according to the maintenance strategy adopted [3], [4].

Thus, the Spanish structural standards are opened to the ignored (until now) temporal dimension of concrete constructions and their service period. As a matter of fact, little technical and normative attention for maintenance of constructions has been dedicated, which contrasts with the deserved recognition that maintenance has in so many different fields as automobile or aviation (figure 1). EHE-08 introduces, for the first time, rules about maintenance that are coherent with the treatment of durability and the service life; according also to the sustainability so fairly required.

This proceeding, that has been rather infrequent, has a logic which is hardly to be questioned. Figure 2 shows, in abscissas, the time whose origin is the moment at which the political decision of constructing is adopted. The following phases of design and construction are very important because they demand, among other things, a great investment, although its temporary extension, especially nowadays, is reduced to few months. To those design and construction phases, a great educational effort has been dedicated (it is what it has been taught at universities), standardisation (the structural codes are conceived to guide design and construction of new works, not to maintain the existing ones) and economic, but procedures or rules have not been established to comply with functionality requirement, structural and user's safety throughout life-span.

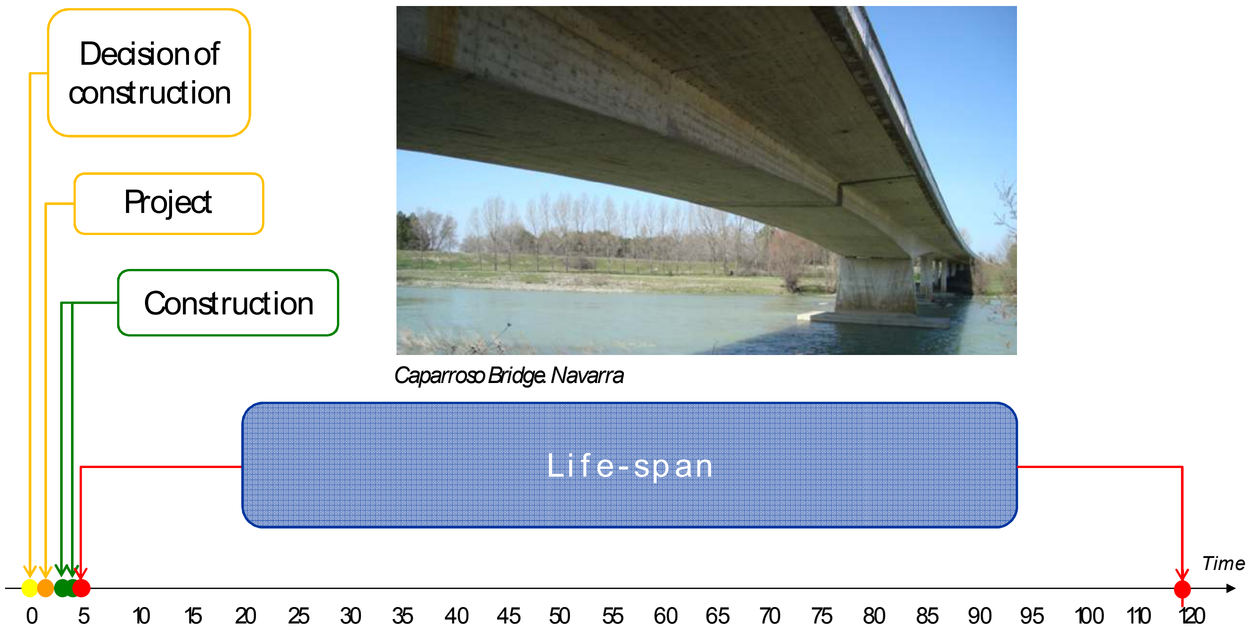


Figure 2. The phases of a structure over time.

Along its lifespan, the bridge will require a normal conservation, that it does not imply operations of rehabilitation beyond minor aspects. That period is due to satisfy and even to be extended if it is acted according to a correct policy of maintenance. These ideas, accepted commonly for airplanes, automobiles and electric home appliances, are valid also for bridges and surpass the mistaken cliché of which the bridges were constructed "for life". Although it is not well-known, it is important to emphasize that the Romans, who constructed magnificent bridges to give continuity to his magnificent road network, instituted the figure of the *Curator viarum*, person in charge of the maintenance of the roads and the bridges to which they gave support, which gives idea of the high importance of maintaining public works for that civilization.

This proceeding is classical in the field of the sanitary policy of the population (figure 3), insofar the application of preventive solutions, as hygiene, simple and economic therapy (comparable to the cleaning of water-drainages in the bridges and treatment of joints in bridges), gives as a result an increase of the life expectancy of the population. This example can explain the advantages of the preventive maintenance against the corrective attitude used up to present.

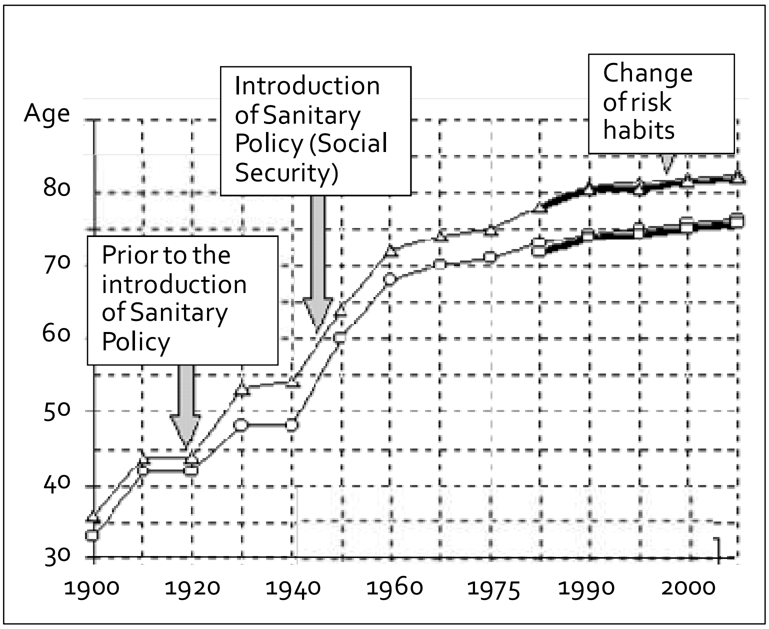


Figure 3. Evolution of the life expectancy in Spain.

Figure 4 shows a diagram that presents, in abscissas, the temporary axis from the end of construction and, in ordinates, the performance *R* offered by the structure and the loads and environmental aggression *S* acting over it, etc. The curves that conclude in point D correspond with a "normal" situation. The bearing capacity *R* (solid line) goes down as a result of the inexorable deterioration of the materials. Such degradation is slow at the beginning but it is accelerated more ahead. For example, steel corrosion and loss of cover are visible long time after the end of construction, being deterioration and loss of bearing capacity accelerated from then. Loads and environmental aggressiveness *S* (dotted line) grow, because both dead and live loads have been increasing, as well as environmental aggression (carbonation of concrete, chloride entrance, etc.). When both curves meet (point D) (the safety margin has been omitted, to clarity) the end of lifespan is achieved at age *t*.

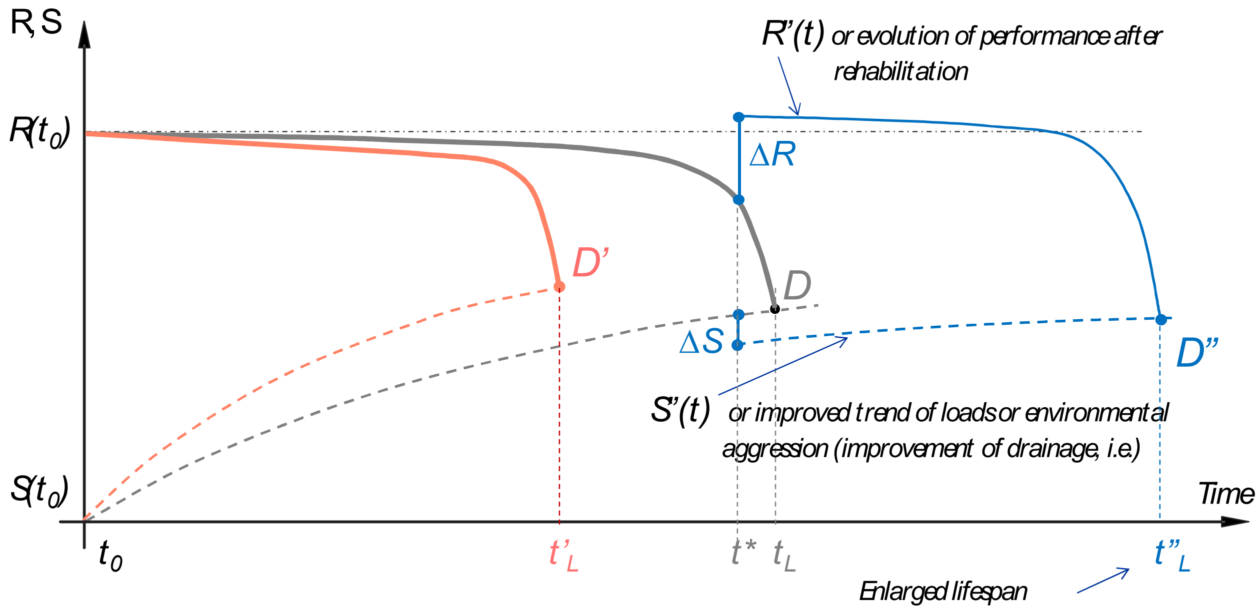


Figure 4. Evolution of performance *R* and load or environmental actions *S* over time

If curves meet in point D', reduced service life t'_L is attained because loads or aggressiveness increased or, perhaps, the structure did not benefit from a proper maintenance. If, in a certain moment *t**, wisely chosen, it is decided to act, a part, the totality or even more of the initial performance based capacity (ΔR) can even be recovered and, at the same time, part of the actions or aggressiveness (ΔS) can be reduced by, for example, improving the drainage system to keep water away (to improve the maintenance indeed). The end of service life will have been enlarged until t''_L. Therefore, a Bridge Management System is used indeed to determine in what state are *R* and *S* in a given moment *t* and, thus, to decide if is worthy to afford any corrective measure or if it can be delayed. Notice that maintenance is included in the management system of the structures, as indicated in figure 5 that shows a flow-chart that synthesizes the general process

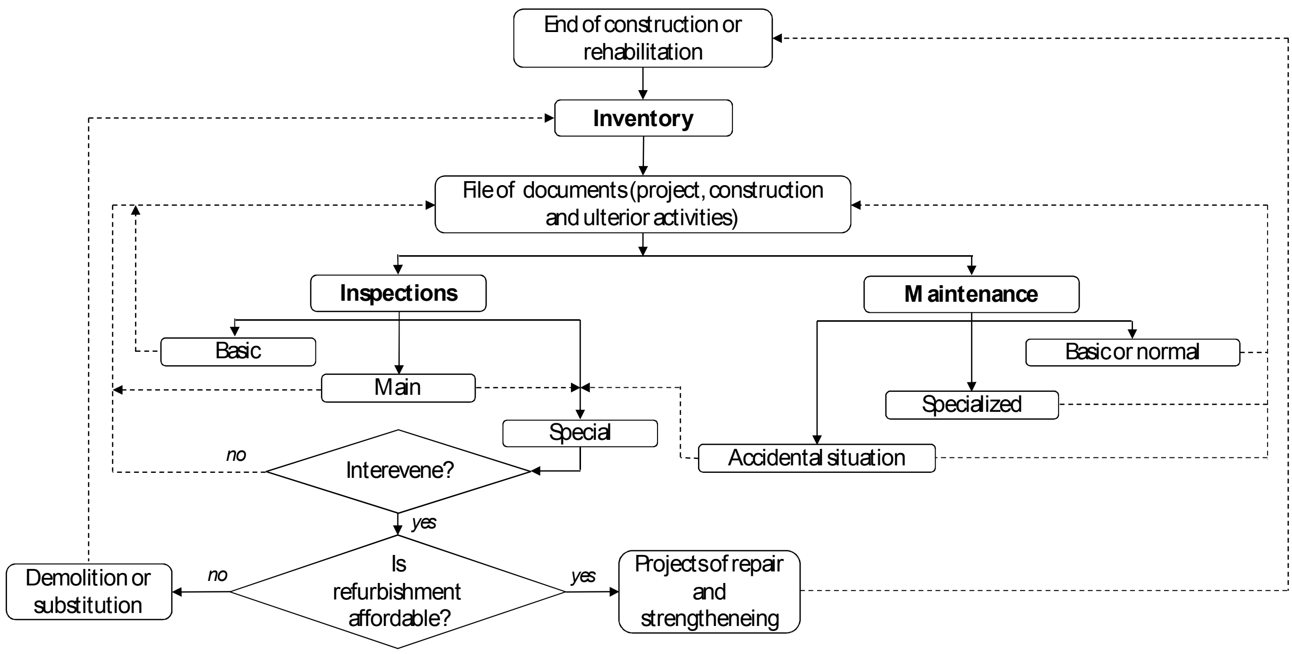


Figure 5. Flow chart showing the three basic elements of management of a set of bridges: up-to-date inventory, control and diagnosis inspections, as well as maintenance in its diverse levels.

Therefore, as a summary, it is important to notice about maintenance that:

- It has to be foreseen in the project, as established in the Spanish EHE-08 Standard.
- It has preventive character and is derived from the explicit incorporation of the concept of service life.
- It is developed according to a strategy defined in the project, starting from the identification of the foreseeable processes of deterioration
- Despite of that, it is evident that certain decisions taken during the construction and which were not contemplated in the project can affect in a very important way the maintenance of the structure, reason why it must be documented so that, at the end of the works, a Plan of updated Maintenance can be drawn up.
- The Owner is the one in charge of programming the maintenance and to arrange its completion.

Note that, in order for the structure to maintain its performance (bearing capacity, durability and functionality), it is essential the real knowledge of the structure finally constructed. In this sense, it is necessary to provide the Owner the as built project, considering the modifications of the project. For this reason, the maintenance plan must be considered as a “living document” that is, written up along with the erection process of the structure and must be kept together during its service life, modifying and updating in every action carried out on the structure.

2. PEOPLE IN CHARGE OF THE WRITING OF THE MAINTENANCE PLAN

According to the above paragraphs, the maintenance plan is a live document and must be updated throughout all the life of the structure. Three main phases are identified: design, erection and conservation.

Design Phase

The person in charge to draw up the Plan of Maintenance must be the author of the project, which is to be approved jointly with the rest of the project by the competent organ or the Property.

Erection Phase

Modifications of the original project that alter any aspects of it, as well as any incidence that might affect the future behaviour of the structure shall be registered. Thus, in the corresponding “as built” project, drawn up by the Director of the work, these circumstances will be included and a Plan of updated Maintenance will be written up.

Conservation Phase

In parallel to the inspection activities included within the Management System, also the activities of maintenance, preferably preventive, shall be registered. During this phase, the Owner (generally through the person in charge of conservation) will be the one in charge to maintain updated the Plan of Maintenance.

3. CONTENT OF THE MAINTENANCE PLAN

The implementation of the previous ideas may be carried out if a comprehensive and realistic Plan of Inspection and Maintenance is written. The following concepts are not intented to cover all possible situations. Special bridges (suspended or cable-stayed bridges, or refurbished bridges with special techniques, for instance), will require further details and procedures. The following paragraphs are prepared to provide a mainframe to help designers, supervisors and owners to prepare such a document.

3.1. Description of the structure

The bridge will be described so that people in charge of the maintenance of the bridge do not have to check the totality of the project to carry out their task. The following items shall be defined:

Location and overpassed obstacle

The structure will be identified by means of their location in the plan of the road establishing the mileage and the coordinates UTM in which its first abutment is located, and defining the obstacle or obstacles overpassed (railroad, rivers or creeks, roads, etc.), insofar as these aspects have incidence in the maintenance activity

Accesses

A location plane will include the ways or routes to reach the bridge, as well as those foreseen to facilitate the access to maintain the different zones of the bridge.

Geometrical and structural configuration

It refers (figure 6) to the overall length, the number and respective span lengths, cross section, height of abutments and piers, as well as to the structural typology. Obviously, project’s drawings may be used with this purpose. The functional characteristics of the bridge must also be indicated; if it is the case of a highway bridge, the number of tracks, shoulders and sidewalks, etc., with their dimensions will be also defined. Complementarily, it would be advisable to include traffic density and type of vehicles.

It is also necessary to make a description of the structural pattern of the structure: statically determined or undetermined, conceived torsion resistant mechanism, type of restraint in abutments or piers, fixed point in regard to thermal or rheological movements, considerations in regard to skew decks, etc. The load pattern assumed for design shall be explicitly considered.

Conditions of exposure

An extract of the climatic conditions considered in the project will be also presented, paying special attention to maintenance. For example, aspects as average precipitations and their seasonal variation, the annual temperatures maximum and minimum temperatures will be included. It is also important to describe the policy of applying de-icing agents to the platform

Description of significant elements for the conservation

Especially important are joints and bearing devices (figure 7). Regarding joints, number, position and types shall be recorded. For bearings, also types, the sizing criteria and, especially, details regarding the location of the elements foreseen in the project in order to substitute those devices shall be noted.

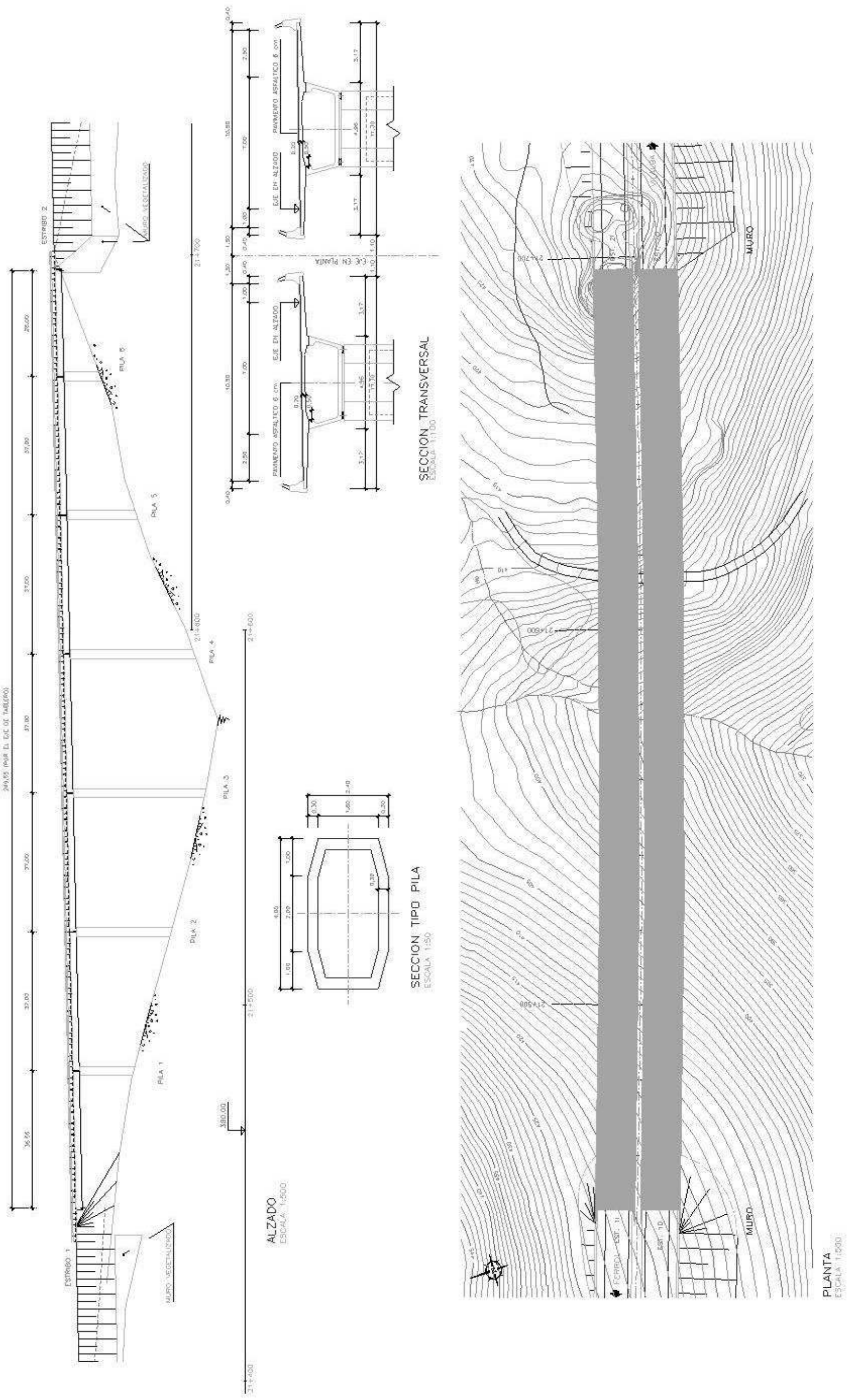


Figure 6. Example of geometric definition of the structure from the project.

It will also be defined, with the support of the plans, the drainage system, including the drainage of the platform, the existence of millraces, scuppers and gargoyles, as well as the presence of pipes as much in piers as in abutments. The definition of the system of drainage of the platform in the accesses to the structure will also be included.

Regarding parapets, the demanded level of containment as well as the definition of the system chosen, rigid or flexible will be shaped, including details of the anchors to the deck and how the continuity of the longitudinal system in the approach segments immediate to the structure has been contemplated. Waterproofing and pavement type shall be also defined, as necessary aspect for the maintenance and the management of the work.

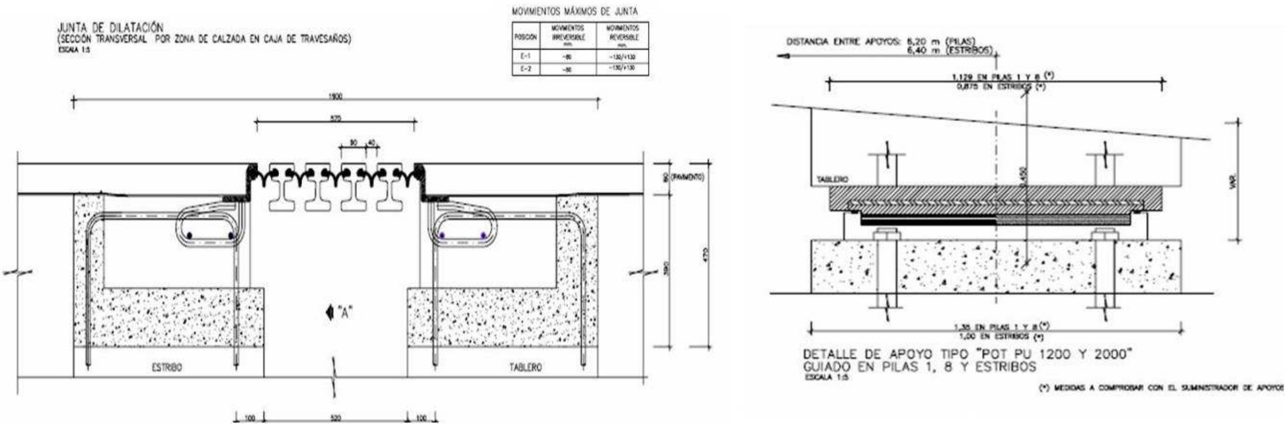


Figure 7. Example of definition of joints and bearings equipment.

With support on the project's drawings, the auxiliary facilities as illumination, brine diffusers, special water treatment plants on foot of slopes, devices to assure the durability conditions, i.e. systems of cathodic protection, shall be also fully described. In a similar manner, the presence of facilities as water or gas pipes, wiring of communications, etc. that could affect to the operations of inspection and maintenance of the structure shall be also accordingly documented.

3.2. Definition of the conditions of exposure and service life

It will also be established the class of exposure of each element of the bridge considered for the project, which is the base of the definition, amongst others factors, of the service life attributed to this element. In a special way, the Plan of Maintenance will include an estimation of the service life of those elements being part of the structure and whose service life is foreseeably shorter than the overall considered lifespan of the bridge. Therefore, as shown as a reference in table 1, the considered service life for joints, support equipment of parapets, drainage systems, waterproofing, pavements and elements of protection (anticorrosive paintings, treatments, anodes of sacrifice, etc.), amongst others, shall be also defined.

Table 1. Reference to service life of some bridge components

Components	Nominal lifespan
Pavements	8-15 years
Waterproofing	25 – 30 years
Painting and corrosion protection	10 – 20 years
Joints	15 – 30 years
Drainage equipments	5 – 15 years
Bearings	25 – 40 years

3.3. Definition of the critical points from the point of view of maintenance

The clue is to identify, according to the knowledge and experience of the designer, the points of the structure that are more susceptible to undergo damages or deteriorations. For example, a critical point can be the bottom of piers or abutments threatened by scour, insofar as a change of conditions of the channel contour could produce its undermining, or the existence of intermediate joints as shown in figure 8.

Figure 8. Example of intermediate support, with great difficulty of inspection.

During the construction and service phases, some other critical points could be identified as a result of some incident or ulterior installation of some devices (brine scatter, i.e.), during the exploitation phase, or some joints were suppressed (this aspect could imply other connotations, perhaps of structural behaviour.

3.4. Criteria of inspection

The definition of the inspection criteria will depend on the availability of a bridge management system (figure 5). If it exists, the Plan of Maintenance will be sent according to the management system indications. Otherwise, or if it is a singular structure, the additional necessary considerations will be established, including the regularity and the scope of inspection to be done.

In this sense, it is necessary to mention that most of the currently implanted Management Systems include three levels of inspection. The first one considers Routine or Basic Inspections, carried out frequently (twice a year, approx.), generally in coincidence with tasks of ordinary maintenance, by non specialized personnel, without auxiliary specific devices; that is to say, it is a simple visual verification of the state of the structure and its elements, focusing attention to the most relevant damages. The second level (Main inspection), more detailed, is carried out every five years, in general, and requires the qualified bid of engineers with the aid of some auxiliary equipment to proceed to a visual inspection of all the elements composing the bridge. Finally, Special inspections (third level), are those carried out to establish the state of a structure (level of security and prognosis of residual service life). They require participation of specialized personnel, special equipment and consists on reviewing the whole structure, surveying of it, taking samples and making bench tests. Also they can include tests of load of the bridge to verify their structural behaviour.

3.5. Definition of means of access

It is necessary to include in the Plan of Maintenance, the necessary means of access to inspect or to work on every element of the structure, as special platforms, interior of box cross sections, hollow piers, submerged foundations, etc.

3.6. Criteria of evaluation (acceptance thresholds)

These criteria must be objective and will alert that a certain structural or functional elements of the bridge could not have the predicted behaviour. These thresholds must be:

- Representative of the good or bad operation of the critical point to be evaluated.
- Measurable with quantifiable and independent magnitudes of the subjective judgment of the observer.
- Trustworthy, independent of the circumstances in which the evaluation takes place.
- Easy and economic to obtain.
- Preventive, that is to say, that indicates the beginning of the deterioration before the proximity of the structural or functional failure.

For example, some criteria of evaluation of piled foundations against the risk of undermining by scour could be as follows:

- Alert threshold of: the superior face is discovered of the foundation.
- Critical threshold: the undermining progresses up to discover a length of piles similar to considered in the hypotheses of calculation of the structure (should the designer indicate specifically which is this length).

Another example of acceptance thresholds of deformation of a support type pot will be as follows:

- Threshold of alert: in any point of the contact between the pot and the elastomer, the distance with the edge of the pot wall is inferior to 1 mm or a distance inferior to 1 mm between some of the metallic parts of the support exists.
- Critical Threshold: If any point of contact between the pot and the elastomer is just on the edge of the pot wall or exists contact between some of the metallic parts of the support.

Similarly, criteria of evaluation for the seats of the laying of foundations, the transitions at the abutments, the cracking in decks, the degradation or displacement in support equipment and the degradation of the joints can be established.

3.7. Criteria of substitution: specialized periodic replacements

Due to the fact that on the structure some elements with a service life inferior to the global one have been placed, it is necessary to define the way in which its substitution has been anticipated.

The most significant elements, with shorter lifespan than the overall structure, are the following: joints, supports, painting of metallic elements, platforms, parapets or railings, waterproofing of boards, firm and singular elements (stays).

The procedure to carry out the substitution may not be exhaustive if it a specific execution project is to be prepared, but the Plan of Maintenance must compulsory contain the necessary data so that the ulterior project of substitution can be written up without checking the complete project.

For example, in the case of bearing devices, it will be necessary to define aspects like geometry, configurations, slopes, operating service loads in the hoisting, considering the changes that could take place in evolutive bridges. Some aspects as layout of reinforcement in support areas will have to be considered, or those of the land in which auxiliary elements lean (figure 9).

Figure 9. Example of action of maintenance specialized for the substitution of support equipment.

It is advisable to emphasize that these periodic replacements are operations equivalent to a substantial part of the costs of conservation of the structures, reason why it is important to plan this operation properly.

3.8. Operations of ordinary maintenance

Apart from the periodic operations of replacement, it is necessary to take to end several normal operations of maintenance to maintain the bridge in a correct state of conservation, that is to say, to ensure a suitable level of proper service to the user and prolongs the durability of the different elements of the bridge, reducing therefore the operating expenses, as stated at the beginning of this article.

These operations, absolutely essential, are related with cleaning, as much of the platform as of the non structural elements of drainage and, as well as works of small repairing not having structural character that do not require neither a planning nor the intervention of specialized personnel for their execution. In this type of works are included punctual repairs of pavements, sealing of cracks, the milled and the located replacement of firm, the repair of sidewalks, the repair of small concrete scales, the repair of protection concrete lining, the located repair of metallic elements, the replacement or repair of constituent elements of the drainage system and precise repairs of elements damaged in traffic accidents.

Although these operations do not have a great technical complexity (figure 10), it is very important to complete them, especially those related to the cleaning of drainages, because on the contrary a water accumulation or spill takes place on elements that could shorten drastically their service life. Therefore, in this section it is necessary to define the main operations of conservation as well as their frequency.

Figure 10. Example of action of ordinary maintenance of cleaning.

3.9. Valuation of operations of maintenance

Finally it is considered of great importance to realize a valuation of all the operations described throughout the plan, periodic inspection, periodic specialized replacements and operations of maintenance, so that it is realistic and viable, avoiding in this way to set up a very demanding and preservative maintenance plan. In addition, with a valuation of the cost of maintenance of the bridge throughout all their life, it is possible to design structures in which the cost of all the service life and not only in the starting phases of project and construction is diminished, due to the fact that the cost overrun of a certain design can be justified if the same implies an important saving in the ulterior conservation of the structure.

4. REFERENCES

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