

New methodology for assessment of reinforced concrete structures with non-destructive testing

Nueva metodología de diagnóstico de estructuras de hormigón armado con técnicas no-destructivas

L. Ebensperger ^{1*}, J. P. Donoso ^{**}

* Construtechnik Ltda. – Santiago, CHILE

** BDL Soluciones Estructurales SpA – Santiago, CHILE

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Abstract

A Structures Assessment Methodology is presented, complementary to the Visual Inspection, which allows, through on-site non-destructive testing (NDT), to deliver as a result a comprehensive quantitative evaluation of the "Structural Health" of the different elements. This allows essential information to adjust maintenance cycles or make timely based decisions in critical situations, in order to guarantee future performance. The proposed methodology considers the execution of NDT to determine the state of the reinforcement, the characteristics of the concrete cover, and the presence of cracks. By means of the extraction of cores of smaller size (1") the ingress of carbonation or chlorides is determined. The results measured on-site are weighted to determine a Deterioration Index DI. The aggressiveness of the environment is included through an Environmental Exposure Index EEI. The incorporation of the results to the CTK-ConDiagO Model allows the combination of both indices, obtaining a Structure Global Deterioration Level SGDL, which measures the degree of damage determined at 6 levels. The proposed methodology is presented with the results of the study carried out on two specific bridges in Chile under different climatic conditions.

Keywords: Bridges, Reinforced Concrete, NDT, Assessment, Damage Level

Resumen

Se presenta una metodología de Diagnóstico de Estructuras complementaria a la Inspección Visual, que permite mediante la ejecución in-situ de ensayos no-destructivos (END), entregar como resultado una evaluación cuantitativa integral del "Estado de Salud" de los distintos elementos. Lo anterior permite contar con información fundamental para ajustar los ciclos de mantención o tomar decisiones a tiempo de situaciones críticas, con el objetivo de asegurar el desempeño futuro. La metodología propuesta considera la ejecución de END para determinar el estado de las armaduras de refuerzo, las características del hormigón de recubrimiento, y la presencia de grietas. Mediante la extracción de testigos de menor tamaño (1") se determina el avance de la carbonatación o cloruros. Los resultados medidos en terreno son ponderados para determinar un Índice de Deterioro ID. Los aspectos de agresividad del ambiente son considerados mediante un Índice de Exposición Ambiental IEA. La incorporación de los resultados al Modelo CTK-ConDiagO permite la combinación de ambos índices, obteniéndose un Nivel de Deterioro Global de la Estructura NDGE, el cual mide en 6 niveles el grado de deterioro determinado. La metodología propuesta se presenta con resultados del estudio realizado en dos puentes ubicados en Chile en condiciones climáticas diferentes.

Palabras clave: Puentes, Hormigón Armado, Ensayos No-Destructivos, Diagnóstico

1. Introduction

In the last decades, the operating occupancy rate of the structures has increased significantly, and consequently, the frequency and thoroughness of the scheduled maintenance, causing a greater deterioration of these structures than projected and increasing the probability of shutdowns due to force majeure.

For example, in Chile, road infrastructure is essential for the connectivity of the country. For this reason, more than 6,000 reinforced concrete bridges are part of this network. At present, the current methods for bridge assessment consider "depth" investigation levels, although different stakeholders consider the visual assessment as the base level for the subsequent decision-making process.

However, in many cases, this visual inspection does not provide enough parameters to accurately determine in which stage of its "Service Life" the structure is, thus making it difficult to decide on the appropriate repair or mitigation measures required for each case. (Figure 1) schematically illustrates the concepts associated with the Performance, Serviceability and Service Life and Residual Life of a structure and the necessary periods to perform maintenance.

¹ Corresponding author:

Construtechnik Ltda. – Santiago, CHILE

E-mail: luis.ebensperger@gmail.com



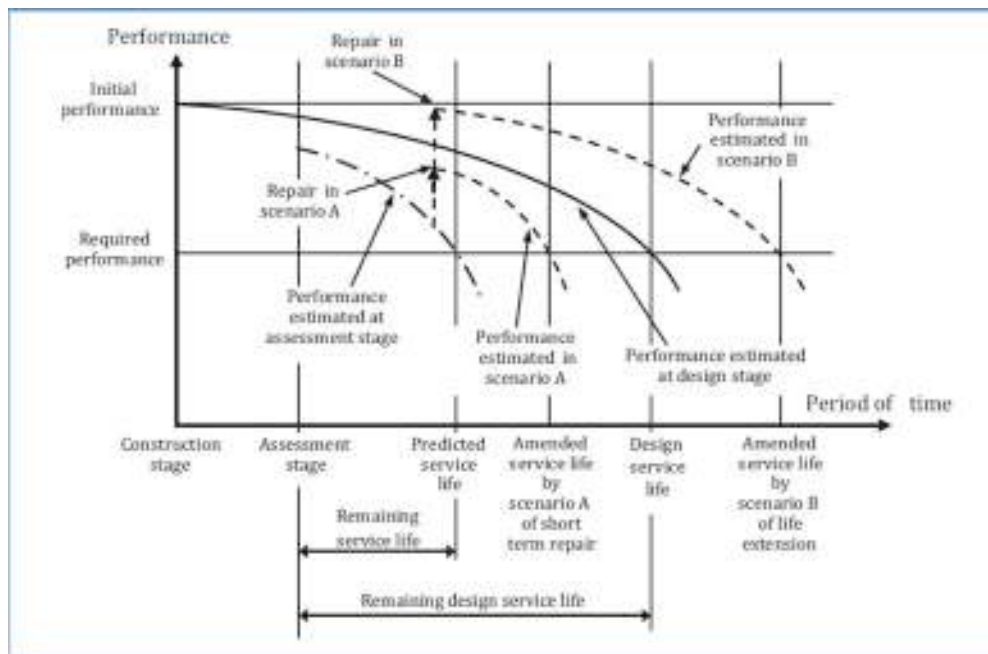


Figure 1. Level of Serviceability of a structure over time (adapted from ISO 16311, 2014)

In order to contribute with a new Assessment Methodology of Reinforced Concrete Bridges, a gap has been detected between the current inspection levels. Also, low penetration of non-destructive measurement (NDT) technologies has been detected. The recent technological development in the area of NDT allows access to a large offer from a technical point of view and accuracy in the reliability of the data delivered by the equipment.

In practice, this gap translates into an inefficient distribution of the resources available for maintenance or repair. Accurately positioning the structure in its timeline (service life) provides precision about the best time to perform maintenance or repairs and the resources needed to bring the structure back to the required level, respectively.

2. State of the Art

Worldwide, different organizations have presented their respective progress towards the standardization of Structural Assessment activities. Since 2007, the American Concrete Institute ACI, in the United States, has released three Guides with Recommendations. These guides cover the processes of "Evaluation of Concrete Structures Before Rehabilitation" (ACI, 2007), "Conducting a Visual Inspection of Concrete in Service" (ACI, 2008) and "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings" (ACI, 2013.) In these 3 cases, established guidelines, recommendations and instructions are provided to guide fieldwork in a standardized manner but do not include analysis concepts as such.

Also, the American Association of State Highway and Transportation Officials (AASHTO, 2011) prepared a comprehensive "Manual for Bridge Evaluation." This is a comprehensive document of the points to be followed when evaluating this type of structure. The manual has been developed to assist bridge owners, usually the State, or nowadays concessionaires, by establishing procedures for design review, inspection and evaluation practices. It is highly oriented to identify the conditions of stress and strength of the elements.

In 2014, the international standard ISO 16311 on "Maintenance and Repair of Concrete Structures" was released, providing standardized guidelines with general and specific principles that apply to all activities related to these issues. These guidelines consist of 4 parts, which are as described below:



- Part 1: General principles
- Part 2: Assessment of existing concrete structures
- Part 3: Design of repairs and prevention
- Part 4: Execution of repairs and prevention

(Figure 2) is a flowchart that summarizes the different aspects of the Assessment, including the determination of the Performance of the Structure, the execution of an Inspection, Risk Analysis, Structural Safety, Design and Execution of Repairs, among other aspects.

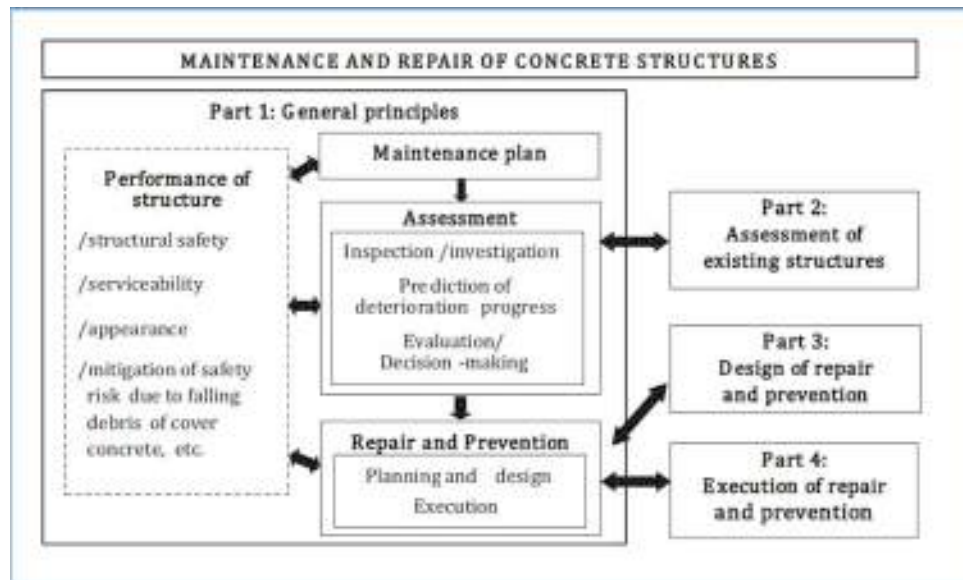


Figure 2. Flowchart of Maintenance and Repair Activities

Most recently, the Japan Concrete Institute (JCI, 2014) published new "Guidelines for Assessment of Existing Concrete Structures," which addresses the general requirements, methods, and procedures for the evaluation of structures, from buildings to industrial structures and bridges, including reinforced and prestressed structures, and rehabilitated structures. The main objective of this Guide is to provide directions for the evaluation of the reliability (confidence level) of an existing structure in relation to the performance required for its future use.

Through the definition of 3 Levels of Evaluation and 3 Degrees of Accuracy, associated to a Condition or Criterion to be evaluated, which at the same time is classified in 3 other Levels, the methodology provides an interesting mechanism to establish the current conditions of a structure, to compare them with the verification criteria.

Level I focuses on documentation review, technical specifications and a basic visual inspection. The prediction of future properties is made through design codes. On the other hand, Level II involves a detailed inspection with a limited number of samples and direct measurement with non-destructive and semi-destructive testing and prediction of material properties with core performance testing. This level considers subsequent structural reviews using current design codes and material property data measured on-site. Level III performs advanced numerical analysis as finite elements (FEM), establishing verification criteria according to the required performance by using the current and actual properties of the materials. These results can be compared through the code applicable at the date of construction or, ideally, with the design code in force at the design date.

(Figure 3) provides a simplified illustration of these different levels. Level I is developed with sufficient depth to identify whether the aspects associated with Serviceability, Durability and Structural Safety are in an intermediate position, or less/more unfavorable, to quickly define the condition of the structure under assessment and the need for intervention, which translates into:



- The current condition is acceptable.
- A follow-up is required.
- A Detailed Assessment (Level II or III) is recommended.
- Immediate action is required.

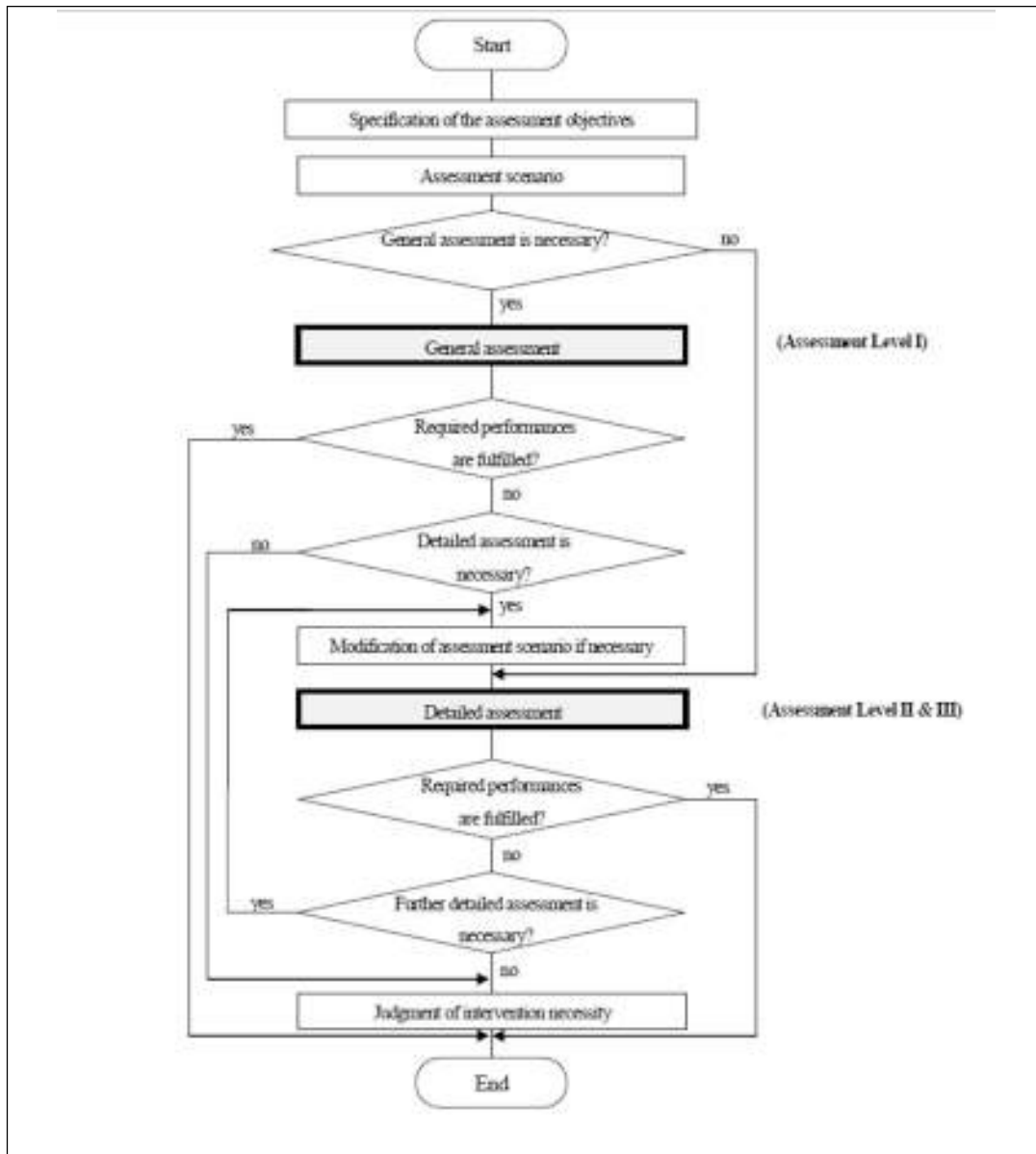


Figure 3. Assessment Flowchart according to JCI

Finally, it is important to mention the work carried out by a European interdisciplinary think tank partnered under a European Community Action (COST Action TU1406, 2019) to standardize at the European level the specifications for the Quality Control of bridge structures. The recommendations and guidelines defined are not mandatory but recommend and allow for a wide range of methodologies already in application in various bridge networks.



The multi-criteria analysis proposed in the Methodology provides Key Performance Indicators (KPIs), which are displayed in a "spider" chart (see Figure 4), where scale 1 represents the most favorable situation and scale 5 the least favorable. The defined classification is detailed as follows:

- **Reliability:** the likelihood that the bridge will be fit for purpose during its service life. It complements the probability of structural failure, operational failure or serviceability, or any other failure mode.
- **Availability:** the proportion of time that a system is in operating condition. It originates from planned maintenance interventions (e.g., additional travel time due to a traffic regime imposed on the bridge).
- **Safety:** related to minimizing or eliminating harm to people during the service life of a bridge.
- **Economy/Costs:** it is related to minimizing long-term costs and maintenance activities over the service life of a bridge. This factor does not include the user cost incurred due to detours and delays.
- **Environment:** it is associated with minimizing damage to the environment over the service life of a bridge.

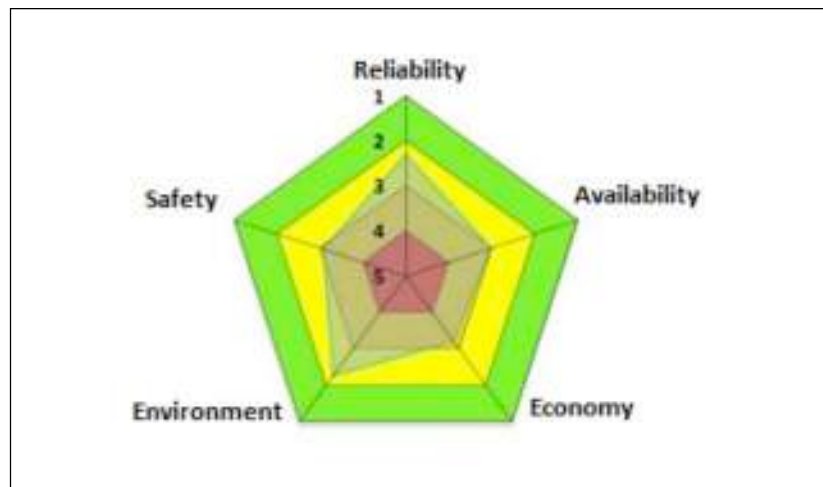


Figure 4. Chart representing the results obtained through the use of KPIs

In Chile, the "Highway Manual" (Ministry of Public Works, 2018) is applied. This document is updated annually according to the State of the Art. Volume 7 includes a chapter on Bridges and Structures, describing each of the tasks, scopes and deterioration that can be found inside bridges. It also describes working procedures for the repair of each of the damages found.

This Manual describes the Bridge and Structures Inspection procedure, indicating its objectives, which is to establish the serviceability and stability status of the structure based on the existing level of deterioration, through the generation of an inspection report that must be analyzed and reviewed by a specialist of the National Roads Department for its validation. These inspections should collect information regarding:

- Detection of damages due to environmental action, car accidents, vandalism and others.
- Updating of basic information on the characteristics of the work.
- Assessment of the deterioration level of the structure (quantification of subsequent works)
- Establishing the priority of actions to be taken
- Scheduling of resource allocation for necessary maintenance work.

In the field of structural maintenance, three levels of inspection are generally established:

- **Basic Inspection:** it is a visual inspection that can be performed by non-specialized personnel and is aimed at early detection of damage that may require urgent action.

- *Main Inspection*: although it also consists of a visual inspection, it is carried out by specialized technical personnel, ideally with knowledge in calculation and structural pathology. Therefore, it is a matter of collecting information on every deterioration present in the structure, assigning a cause to them, indicating the extent and severity of the damage.
- *Special Inspection*: it consists of the inspection by highly specialized technical personnel, carrying out all the additional work (sampling, tests, calculations, inspections by divers or mountaineers, etc.) necessary to obtain complete information to evaluate the condition of the structure and define the actions required to be carried out.

3. Discussion

Contrary to the ACI and AASHTO Recommendations, which focus on providing guidelines on the subject, the procedures developed by JCI and COST Action TU1406 provide an in-depth analysis of the complete process to be developed to determine the action to be taken according to the results obtained in the Assessment. On the other hand, the ISO standard orders and provides the framework for the maintenance processes to maintain the performance of a structure on the required serviceability levels during its Service Life, based on the assumption that a well designed and built concrete structure, with an adequate maintenance, should not require repairing works. The study shows that the Visual Inspection is present in all cases as the methodology to be used to start the Assessment of a structure, saving for the next stage—and only if required—a Detailed Assessment, which includes materiality tests. This allowed to conclude that it is necessary to concentrate efforts in determining the adequate development of the interrelation between the visual inspection and the non-destructive techniques considered to carry out an Assessment of a Concrete Structure, in order to obtain a simple but solid Assessment Methodology, to be applied from the first Stage.

The Evaluation or Assessment Methodologies of Reinforced Concrete Works seek to determine the "State of Health" of the component/ subcomponent under analysis and define an Action Plan to be executed according to the obtained result. Inspection levels classify the level of thoroughness of the current Assessment, ranging from a basic level, usually visual, to intermediate levels with destructive testing, up to detailed levels that include structural analyses that consider the current and expected properties of the work. Thus, the diagnosed condition may indicate that the current status of the structure is acceptable without major observations or risks, or it is necessary to make a Follow-up or Preventive Maintenance Plan to maintain the safety condition, or it is recommended to carry out a detailed evaluation that provides more information about the deterioration processes detected, and due to the effect of safety conditions, immediate actions must be taken.

In Chile, it is possible to observe that, although there is a standard and a characterized procedure to evaluate bridge damage, its nature is visual, qualitative and highly variable, depending on the professional in charge of the inspection. Special Inspections are performed when the level of damage detected is high, probably due to an important period of time without adequate control and with an expensive execution. The great challenge lies in eliminating the inspectors' subjectivity and standardizing the criteria for inspections throughout the country.

From a conceptual point of view, this situation gave rise to the need to work on a new Assessment Methodology, which could be executed in parallel with the Visual Inspection and provide quantitative data on the deterioration of the structure. Considering the experience of the authors in the performance of assessments of reinforced concrete structures through the use of non-destructive techniques and the incorporation of concepts related to the Durability of Concrete and the Useful or Residual Life of the Structure (Ebensperger and Olivares, 2017), the Methodology developed is presented below. The basic assumption of the project is to devise a simple Methodology, which incorporates the current technological development to determine the properties of concrete and steel and the behaviors linked to the environmental condition to which the structure is subjected.

Apart from that, the Methodology should be compatible with the existing methodologies and should be easily implemented within the usual inspection processes of public and private organizations. For this reason, the National Roads Department of the Ministry of Public Works (MOP) was invited to participate. This entity, through its Bridge Department, agreed to provide its sponsorship. Its experience and insight on these aspects were vital to the development of a useful tool. The authors presented the first advances of this project in 2019 (Ebensperger and Donoso, 2019) at the CONPAT 2019 Conference held in Mexico.



4. Concepts to Include in the Methodology

4.1 Non-destructive testing (NDT)

The different non-destructive testing techniques considered are briefly presented below, with photographs of each technique:

Inspection equipment based on magnetic pulses that provides immediate information on the location of reinforcing bars inserted in the concrete, allowing the detection of diameter, spacing and depth (cover thickness). (Figure 5)



Figure 5. FerroScan PS200 Equipment - Reinforcement location

Inspection equipment or scanner that has the latest portable Ground Penetration Radar (GPR) technology. It also detects nests, holes and cavities that are not visible to the naked eye and that are hidden inside structural elements (Figure 6)



Figure 6. FerroScan PS1000 Equipment - Reinforcement Information

The Schmidt Sclerometer or Schmidt Hammer approximately estimates compressive strength through correlation with calibrated tables. It is based on the resistance measured when giving a blow and recording the rebound. Values must be corrected in case of carbonation. (Figure 7)



Figure 7. Schmidt Hammer - Concrete Strength

This state-of-the-art equipment allows estimating the corrosion rate of reinforcement bars through a non-invasive approach, i.e., it is not necessary to physically connect to the steel bars. (Figure 8)

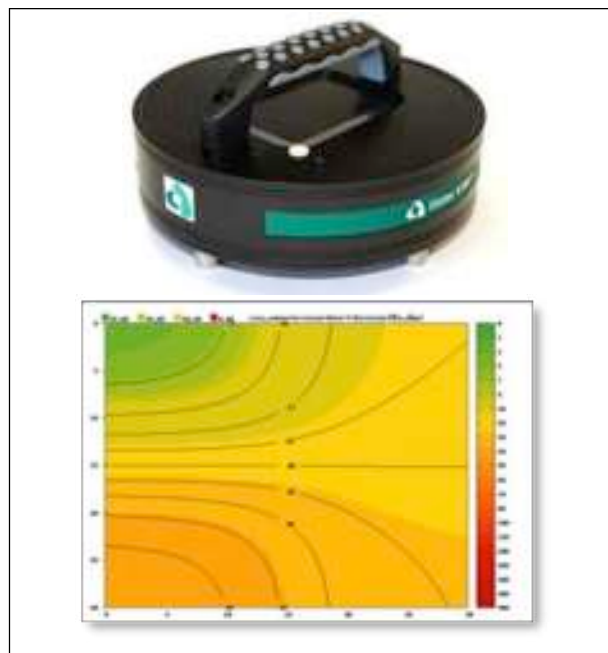


Figure 8. Giatec Icor Equipment - Steel Corrosion

The equipment has high precision sensors to measure:

- *Corrosion Rate of reinforcement bars*
- *Corrosion potential of reinforcement bars*
- *Surface Electrical Resistivity of concrete in situ*

Through the extraction of 1" cores, which are sprayed with a phenolphthalein solution or a silver nitrate solution at the time of extraction. (Figure 9)



Figure 9. Carbonation Depth and Chloride Penetration

The ultrasonic equipment allows in a simple way to estimate the depth when a crack is detected in the concrete. It requires a previous calibration on a nearby surface without cracks. (Figure 10)



Figure 10. Crack Depth

Equipment that measures three environmental factors of interest when performing in-situ tests: air temperature and humidity and CO₂ concentration level. (Figure 11)



Figure 11. Environmental Condition

Surface Moisture

Equipment that, based on the measurement of electrical impedance, determines the moisture level of the concrete cover using eight contact points. It is required to validate the Air Permeability measurement according to the associated standards. (Figure 12)



Figure 12. Surface Moisture

The ultrasonic equipment allows measuring the thickness of steel elements in an easy way. (Figure 13)



Figure 13. Steel Thickness



Through the creation of a vacuum on the concrete surface, this equipment measures the pressure increase occurring in a double chamber cell in a period of 6 minutes and according to the Swiss standard (Concrete Corrosion 261/1 Annex E, 2003). The rate at which this pressure increases due to the effect of atmospheric pressure is related to the permeability of the concrete cover. This methodology was developed for in-situ application and as a control of on-site concrete in terms of durability performance. It requires the measurement of batches composed of 6 measurement points. (Figure 14)



Figure 14. PermeaTorr Equipment - Air Permeability

4.2 Durability and Service Life

Considering the importance of this type of test to determine the properties and performance of concrete structures directly, some researchers focused their efforts on creating new tests that would allow relating the performance of structures against environmental aggressions with measurements performed in situ directly on the structure (most of the performance tests are conducted under laboratory conditions). The work carried out in the late '90s (Torrent and Ebensperger, 1993) was successful. In 2003 (Concrete Corrosion, 2003), the Swiss regulations included the Air Permeability test as a valid method to be specified in new structures, with a control in the finished work at an age between 28 and 90 days. These regulations were later updated in 2013 (Concrete Corrosion, 2020).

Subsequently (Torrent, 2015), the "Exp-Ref" Methodology was introduced. Using non-destructive measurements carried out on-site allows estimating the Service and Residual Life of concrete structures. The methodology is based on measuring the characteristics of the concrete cover in the finished work and comparing it to adverse environmental phenomena, such as carbonation or chloride ingress. The relationships found and internationally validated are detailed as follows:

Chloride ingress

$$VU = \alpha * \frac{c^2}{kT^3} + TP \text{ Chlorides} \quad (1)$$

CO₂ ingress – carbonation

$$VU = \beta * \frac{c^2}{[\ln(174+kT)]^2} + TP \text{ CO}_2 \quad (2)$$

- kT : Air Permeability [$10^{-16}m^2$]
- c : cover thickness [mm]
- α, β : factors dependent on the Environment type (EN206 Classes XC and XS)
- Tp : Propagation time after the Corrosion starts

Service Life Analyses consider that the starting point of corrosion of the reinforcement rebar corresponds to when the protective layer on the steel, which depassivates the reinforcement against corrosion ($pH > 12$), is reached by the carbonation front or chlorides, thus initiating the electrochemical corrosion process.

Therefore, the structure's durability is determined by the carrying capacity of the concrete cover to counteract the ingress of harmful agents and by the depth at which the reinforcement is placed. For this reason, the methodology is based on measuring two essential parameters: the permeability of this concrete layer and the thickness of the cover. Subsequent on-site verification of both parameters on the finished structure by measuring enough pairs of points to know the standard deviation of each measurement allows probabilistic estimates of the initiation of the steel corrosion process.

This Methodology has been included in the CTK-ConcreLife Model® (CTK, 2017). It allows the DESIGN of concrete for a particular Service Life, subject to different degrees of severity, either by the effect of chlorides or carbonation, and the subsequent CONTROL in the finished work. Figure 15 shows the relationship between Air Permeability and Cover Thickness obtained for a 50-year Service Life in a Carbonation environment condition. The red dot represents a defined thickness of $c=40\text{mm}$ and a Permeability $kT=0.25 \times 10^{-16} \text{m}^2$.

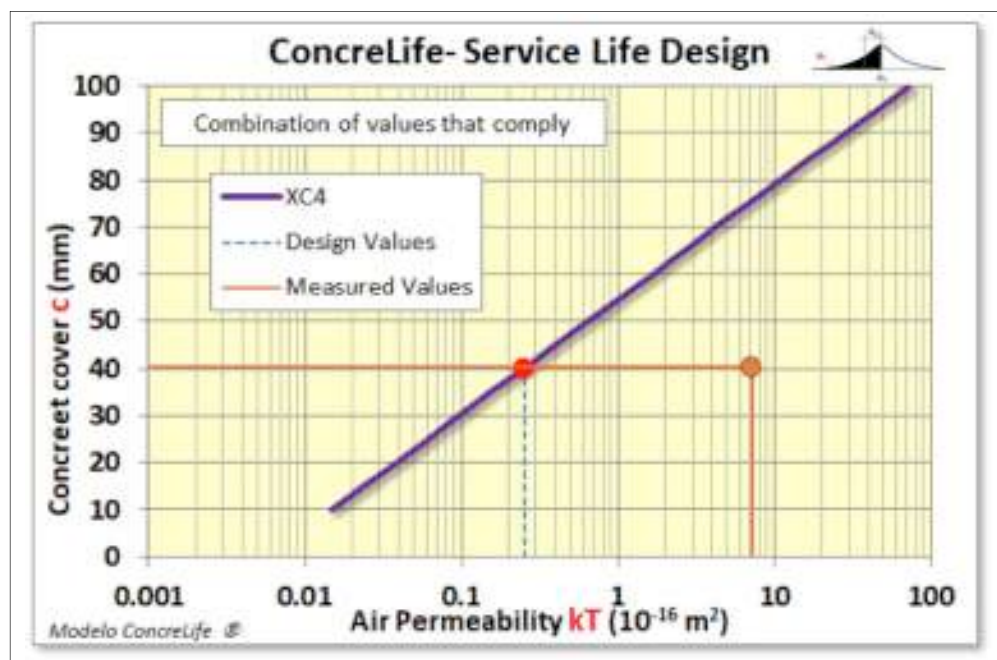


Figure 15. Relationship between Cover Thickness and Permeability for Class XC4 Environment

The area above the curve complies with the requirement of obtaining a Design Service Life of at least 50 years, a condition that is not met in this example when measuring in situ (orange dot with $c=40\text{mm}$ y $kT=7.20 \times 10^{-16} \text{m}^2$).

(Figure 16) shows the Probabilistic analysis of the same situation: the purple curve shows the DESIGN situation, corresponding to the red dot in Figure 16 with a 50% probability of corrosion initiation at 50 years (vertical green line). If it were desired that at this age, the probability of initiation would be only 10%, represented by the red curve, the Permeability value should be more demanding ($kT=0.14 \times 10^{-16} \text{m}^2$).

Finally, the dashed curve measured on-site as CONTROL indicates that at 50 years, the probability of corrosion initiation will be 77%. The 50% probability is expected at 43 years. If the measurement were performed at 10 years, the expected Residual Life would be 33 years.



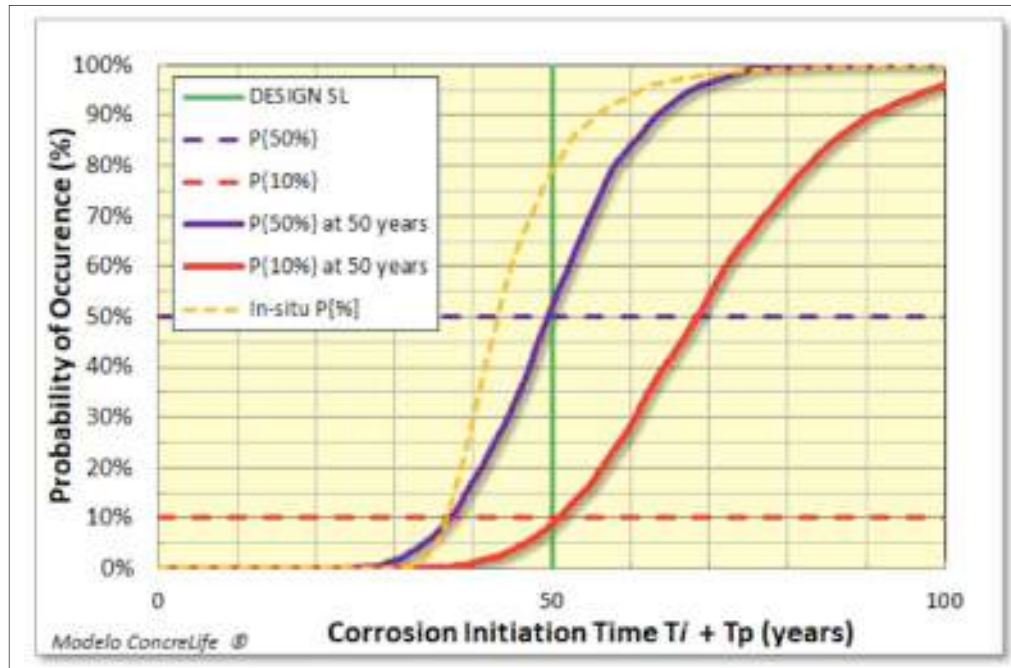


Figure 16. Comparison between Corrosion Initiation Probability by Design and actual Conditions measured in situ

A recent publication (Di Pace et al., 2019) mentions this Methodology as a Quality Control tool that provides a more realistic probabilistic evaluation of the Service Life of existing reinforced.

5. CTK-ConDiag® Comprehensive Methodology

5.1 Criticality Levels

The following indexes are defined for Deterioration and Environmental Exposure aspects:

- Deterioration Index, *DI*, is composed of 21 factors grouped into 6 concepts associated with Concrete Durability (Table 1)
- Environmental Exposure, *EEl*, is composed of 18 Exposure Classes grouped into 5 concepts (Table 2)
- Each factor is classified into 4 Criticality levels, according to (Table 1) and (Table 2):
 - Level 1: Low
 - Level 2: Medium
 - Level 3: High
 - Level 4: Critical

Table 1. Classification of Criticality Levels of Deterioration

Id	Property	Unit	DI = Deterioration Index			
			1 LOW	2 MEDIUM	3 HIGH	4 CRITICAL
Presence of Cracks						
1	Visual	-	no signs	with fissures	with cracks	gone through
2	Width	mm	< 0.05	0.05-0.30	0.30-1.0	> 1.0
3	Depth	mm	0	< c/2	<= c	> c
Chloride Ingress						
4	Chloride front	mm	0	< c/2	<= c	> c
5	Chlorides at the reinforcement level	concrete weight %	< 0.020	0.020-0.030	0.030-0.040	> 0.040
Carbonation Process						
6	Ambient Co ₂ level	mm	< 400	< 500	< 600	> 600
7	Carbonation depth	mm	0	< c/2	<= c	> c
8	Carbonation rate	(mm/√a)	< 4	< 7	<= 10	> 10
Steel Corrosion						
9	Visual	-	no signs	with stains	flacking	section loss
10	Steel rebar size	mm	> 25	25 - 18	18-12	< 12
11	Resistivity	Ωm	> 200	200-100	100-50	< 50
12	Corrosion rate	(µm/year)	< 10	10 - 30	30 - 100	> 100
13	Half-cell potential	mV	> -200	-200 -350	-350 -450	< -450
14	Mass loss	%	< 2	2 - 5	5 - 10	> 10
Concrete Strength						
15	Schmidt Hammer compression	MPa	> 45	> 35	> 25	< 20
16	Core compression	MPa	> 45	> 35	> 25	< 20
17	Ice/de-icing, air content	%	< 6	6 - 4	4 - 2	< 2
Concrete Cover						
18	Visual	-	no damage	wear	loss of material	spalling
19	Thickness	mm	> 65	60 - 40	40 - 20	< 20
20	Surface moisture	%	< 2	2-4	4-6	> 6
21	Air permeability	10-m	< 0.010	0.010-1.0	1-10	> 10



Table 2. Classification of Criticality Levels of Exposure

Class	Phenomenon	Environment Description	Level
XC1a	Carbonation	Dry	4
XC1b		Always humid	1
XC2		Wet, sometimes dry	2
XC3		Partly humid	3
XC4		Variable between humid and dry	3
XD1	Chloride De-icing Salts	Partly humid	2
XD2		Wet, sometimes dry	3
XD3		Variable between humid and dry	4
XS1	Seawater Chlorides	Saline air	2
XS2		Submerged	3
XS3		Variable between humid and dry	4
XF1	Ice/De-icing	Moderate saturation without salts	1
XF2		Moderate saturation with salts	2
XF3		High saturation without salts	3
XF4		High saturation with salts	4
XA1	Chemical Attack	Soft attack	2
XA2		Moderate attack	3
XA3		Strong attack	4

5.2 Deterioration Levels

The Structure Global Deterioration Level of the Structure is composed of six Deterioration Levels and is defined as $SGDL = \text{Average} (DI+EEI)$ according to (Table 3):

Table 3. Niveles de Deterioro Global de la Estructura NDGE

Level	Description	SGDL
I	No Deterioration	1.00 - 1.50
II	Minor Deterioration	1.50 - 2.00
III	Medium Deterioration	2.00 - 2.50
IV	High Deterioration	2.50 - 3.00
V	Very High Deterioration	3.00 - 3.50
VI	Critical Deterioration	3.50 - 4.00

6. Methodology Verification

Two applications of the Methodology in bridges are presented below:

6.1 Águila Norte Bridge

Route G-556, km 1, Paine, Metropolitan Region. It is located approximately 50 km south of Santiago in the Central Valley of Chile, in a dry Mediterranean climate. Bridge over the Angostura River, built in four spans, each with four prefabricated HA beams (Figure 17), supported on two central piers and two reinforced concrete abutments. Year of construction, 2010.



ENGLISH VERSION.....

The preliminary visual inspection showed that the structure has almost no damage and is in a good preservation state. The structure is relatively new (10 years), and the climatic conditions of the environment are not extreme in any of the aggressiveness parameters.

The element under study, the upper pier built in situ, showed no signs of corrosion or cracks. Despite the dry environment, the low CO₂ content measured showed low carbonation rates, with a depth of only 2 mm and a Carbonation Rate of 0.6 mm/√year. The use of low-diameter bars was identified as a weak point. In case of corrosion, these bars would be quickly affected. The Corrosion Rate was < 10 μm/year. The strength determined through the Schmidt Hammer reached 36 MPa. The cover thickness is adequate, with 40 mm; although the permeability of the cover was high, with $kT=7.5 \times 10^{-16} \text{ m}^2$. This structure element is classified with an SGDL = 2.38 at Level III.



Figure 17. Air Permeability Measurement with PermeaTorr equipment on Prefabricated Beam Flange



Figure 18. Corrosion Level Measurement with Icor equipment on the bottom surface of Prefabricated Slab



ENGLISH VERSION.....

6.2 Seminario Bridge

Seminario Bridge, Route G-98-F, El Quisco, Valparaíso Region, 200 m from the coast, is located in a maritime climate and subject to a constant sea breeze. Bridge over El Totoral Stream, built in four spans, each with two longitudinal steel beams, transverse reticulated steel bars supported on double central piers and two Reinforced Concrete abutments. Year of construction, 1964.

The preliminary visual inspection showed that the structure is in a good preservation state, except for the lower section of the pedestrian walkways and damage caused by run-off in the south abutment.

The element under study, the lower zone of roadways built in situ, showed corrosion signs. The corrosion rate was $72 \mu\text{m}/\text{year}$ (Figure 18). The CO_2 level measured in the environment showed high carbonation rates, with a depth of 29 mm and a Carbonation Rate of $3.9 \text{ mm}/\sqrt{\text{year}}$. As weak aspects, the use of low diameter bars was detected, which already showed a Corrosion Rate of $72 \mu\text{m}/\text{year}$. The strength determined through the Schmidt Hammer reached 28 MPa. The cover thickness is low, at 26 mm. This structure element is classified with an SGDL = 2.61 at Level I.

7. Final Comments and Conclusions

The proposed methodology seeks to be established between the Visual Assessment and Detailed Assessment levels. To this end, it will be necessary that the current parameters of the Visual Assessment are adequately weighted with the parameters provided by the non-destructive techniques. Three aspects were taken into account:

1. Contribution of the local experience and current parameters of an Initial Assessment.
2. Complementation based on international experience.
3. Incorporation of the use of Non-Destructive Testing, NDT.

The interaction between them—through the weighting of factors and probabilistic analysis of the results obtained in situ—allows reducing the gap described at the beginning of this document, providing relevant tools for the person in charge of the operation and "Service Life" of the structure such as:

- Projecting a Maintenance Plan according to the ACTUAL need of the bridge or structure.
- Determining within the Useful Life of the bridge the appropriate period for a Major Repair.
- Precisely defining the scope of Major Repair (elements and deterioration levels).
- Allocating resources to specific periods within the Service Life of the bridge, thus avoiding inefficient spending in early or late stages due to insufficient information

8. Acknowledgments

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