STUDY INTO THE DAMAGE TO VARIOUS CONCRETE BRIDGES DECKS WITH INTENSIVE WINTER MAINTENANCE

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ABSTRACT

This paper presents the detailed results of 21 special inspections on bridges of State Road Network, with regard to the study of the concrete slabs deterioration due to the freeze-thaw action and use of de-icing salts. All selected structures have concrete compression slab or concrete deck.

After preliminary visual inspection, potential measurements are performed in-situ following the PNE 112083 "Measurement of free corrosion potential in concrete structures", that provided qualitative assessment of the corrosion risk of the reinforcement. It was observed that the major slabs deterioration was not due to corrosion of the reinforcements, but concrete degradation; for this reason, this research has focused on the identification of chemical and physical mechanisms that may cause such deterioration in the concrete caused by freeze-thaw action and de-icing salts (mainly NaCl).

It was carried out a durability analysis for the concrete cores samples from the bridges, based on the following aspects: visual inspection, materials characterization (resistance – compression testing and in-situ ultrasound measurements- and compactness - porosity, density and absorption), aggressive chemicals study (carbonation, chlorides and sulfates) and microstructure study (RX diffraction, electron microscopy RX BSE-EDX).

Results clarify a little more, after this small sample, about the severity of this damage on the State Road Network, and let us to open a new line of laboratory research, focused on the freeze-thaw and de-icing salts damage on concrete about 20 years old, whose durability against the agents studied is significantly minor compared to current concrete.

1. INTRODUCTION. RESEARCH PURPOSE

This study aims to analyze the condition of low temperature and de-icing salt applied during winter road treatments, to the durability of concrete slabs or decks in the bridges on the State Road Network of a certain age, with the pavement as the only waterproofing system and with concretes with lower benefits than current ones.

For this purpose two sets of bridges were selected, one of them with structures presenting concrete deck durability problems due to different pathologies such as reinforcement corrosion, concrete degradation or existence of cracks, and the other set formed by structures that showed no disease, although weather conditions were similar.

According to information provided by different Conservation Areas, utilization data of de-icing salts indicate an important contribution to the decks that could range between the following values:

- In the structures on mountain passes as the N-502 in Avila or N-630 in Leon: in the winter period (November to April) the amount of salts extended on the deck was approximately 7 kg/m^2
- Other structures: the winter period is shorter and less intensive, ending in March, the average consumption of de-icing salts was about 2 kg/m^2.

With these data and taking into account that, in winter, the road temperature in the slab bridges area is less than road grading area, because of its greater exposure to environmental conditions (both lower and upper face) environmental exposure class of all structures included in the study is IIa + H or F, according to EHE-08. So all structures are located in a normal exposure class, high humidity, exposed to rain in an area with annual rainfall greater than 600 mm, and exposed to freezing and de-icing salts (in this sense, it gives a certain level of impermeability to the concrete slab or deck, as to be under the pavement).

Furthermore it is also intended to establish and validate a method of study and inspection, sampling and testing, to allow comparisons of damage and causes involved in determining the durability of the concrete decks or slabs on aging bridges, subjected to aforementioned adverse weather and with low or no waterproofing system. Those decks or slabs, as to be the most exposed elements to salts entry in ancient bridges, are at the first level of the study, prior to the recognition of other parts of the bridge.

2. BRIEF DESCRIPTION OF THE BRIDGES

To carry out this study, it was considered to select a set of 21 structures in different locations (Ávila, Albacete, Burgos, Guadalajara, León, Palencia, Teruel, Toledo and Valladolid). Among these locations, sampling and selection of bridges try to include as far as possible:

- Structures with different age
- structures in regions of different weather and therefore different frequencies of use of de-icing salts
- structures with different deck type

- structures with different slab condition (apparently healthy and damaged)

The following table and image show the location of the structures:

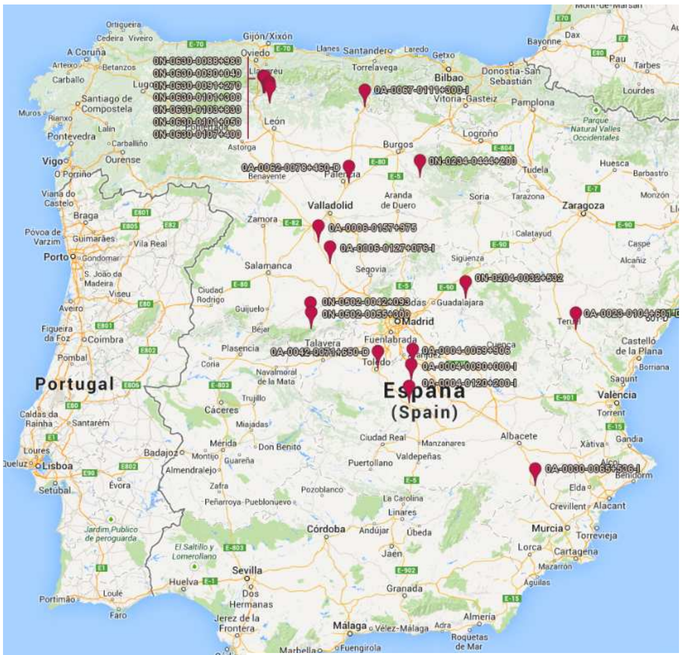

Figure 1 Location of bridges

Nº	Codigo	Carretera	PK	Provincia
1	0N-0502-0042+093	N-502	42+100	Avila
2	0N-0630-0088+980	N-630	88+890	León
3	0N-0630-0090+040	N-630	90+025	León
4	0N-0630-091+270	N-630	91+100	León
5	0N-0630-101+300	N-630	101+500	León
6	0N-0630-103+830	N-630	103+850	León
7	0N-0630-0107+400	N-630	107+890	León
8	0A-0067-0111+300	A-67	111+400	Palencia
9	0A-0004-0120+200-I	A-4	120+200	Toledo
10	0N-0630-101+050	N-630	101+100	León
11	0A-0004-0090+000-I	A-4	90+000	Toledo
12	0N-0234-444+200	N-234	445+150	Burgos
13	0A-0062-0078+460	A-62	78+400	Palencia
14	0A-0006-0127+076	A-006	127+180	Avila
15	0N-0502-0055+300	N-502	55+350	Avila
16	0A-006-0157+975	A-6	157+840	Valladolid
17	0A-0004-0069+906	A-4	69+906	Toledo
18	0A-0023-0104+601	A-023	104+750	Teruel
19	0A-0030-0065+536-I	A-30	65+600	Albacete
20	0N-0204-0032+532	N-204	32+532	Guadalajara
21	0A-0042-0071+650+D	A-42	71+500	Toledo

Structures are quite variable, regard to structural type, age, constituent materials and road type, although they can be grouped according to the factors listed above. Thus, we can distinguish the following groups:

A. Bridges of reinforced concrete beams of 1 span, supporting a 1 +1 lane road, built between 1965 and 1980.

Code	road	p.k	typology
0N-0630-0088+890	N-630	88+890	9 nerves
0N-0630-0090+040	N-630	90+025	7 nerves
0N-0630-091+100	N-630	91+100	5 nerves
0N-0630-101+300	N-630	101+500	14 beams + slab
0N-0630-103+850	N-630	103+850	14 beams + slab
0N-0630-101+050	N-630	101+100	slab

Figure 2 Bridges of type A

B. Bridges of reinforced concrete beams, multi-span, supporting a 1+1 lane road, built between 1965 and 1980

Code	road	p.k	typology
0N-0630-0107+400	N-630	107+890	3 spans: 6 beams
0N-0234-444+200	N-234	445+150	5 spans: slab+6 beams widening
0N-0502-0042+093	N-502	42+100	9 spans: 6 beams
0N-0502-0055+300	N-502	55+350	4 spans: 4 beams
0A-0067-0111+400	A-67	111+400	3 spans: 4 beams
0N-0204-0032+532	N-204	32+532	6 spans

Figure 3 Bridges of type B

C. Bridges of concrete slab type, multi-span, built between 1980 and 1995.

Code	road	p.k	typology
0A-0062-0078+400	A-62	78+400	3 spans continuous slab
0A-006-0157+975	A-6	157+840	4 spans continuous slab

Figure 4 Bridges of type C

D. Bridges of reinforced concrete, multi-span, supporting a highway of two lanes in each direction, built between 1990 and 2000.

Code	road	p.k	typology
0A-0004-0069+906	A-4	69+906	4 spans: 2 beams
0A-0004-0090+000-I	A-4	90+000	1 span: 6 beams
0A-0004-0120+200-I	A-4	120+200	8 spans: 8 beams
0A-0042-0071+650-D	A-42	71+500	9 spans: box section
0A-0006-0127+077	A-006	127+180	5 spans: 9 beams
0A-0030-0065+536-I	A-30	65+600	16 spans with 4 beams
0A-0023-0104+601	A-023	104+750	5 spans: box section

Figure 5 Bridges of type D

3. METHODOLOGY OF THE STUDY

In order to perform a comparative analysis of the results obtained in the different structures, a study methodology has been implemented, which allows a complete, consistent and detailed information about the damage to concrete bridge decks due to de-icing salts, regarding to reinforcement corrosion and concrete durability. A brief description of the methodology is described as follows.

3.1 Data Collection

The first step is to gather all information of the structure, about the structural characteristics, the environment where is located and winter road treatments used. It's convenient to include at least the following documentation:

- Code, inventory and inspections reports if any
- Geographic location
- Execution projects, including plans of structure and concrete type, dosages, additives, etc., primarily those used on the bridge deck
- Road layout over the bridge, in order to determine the exposure degree
- Local climatology
- De-icing salts data like composition, origin and use regimes

3.2 Visual inspection and testing level setting

This inspection is performed to establish the structures condition determining the presence or absence of any deterioration in the slabs of bridge decks, regarding to the concrete and reinforcement. Depending on the determined damages, the slab is classified as apparently healthy, with Level 1 for sampling and testing, or as LEVEL 2, which show damage or alterations.

3.3 Performing the sampling.

Depending on the level established from visual inspection, the sampling is done using the following guidelines:

• **LEVEL 1:** sampling provides only the establishment of three sampling points distributed on the slab as follows:

- T1: Right side next to abutment 1.
- T2: left side next to abutment 2.
- T3: deck center (both longitudinally and transversely).

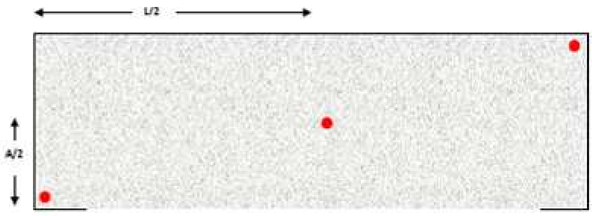

Figure 6. Level 1 sampling in slab

• **LEVEL 2:** sampling is more intense and the number samples depends both on the size of the slab and the areas of damage. At a minimum, depending on the deck size, the samples are located according to the following:

- T1: Right side next to abutment 1.
- T2: left side near abutment 2.
- T3: deck center (both longitudinal and transversely).
- T4: 1/4 to abutment 1 longitudinally and 1/3 of the left side.
- T5: longitudinally 1/4 to abutment 2 and 1/3 of the right side.

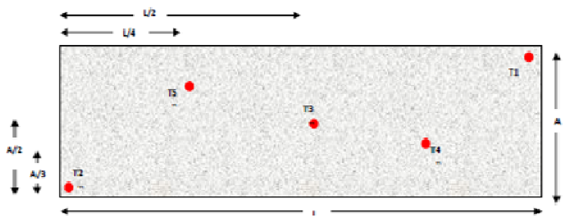

Figure 7. Level 2 sampling in slab < 1,000 m^2

Slabs area exceeding 1000 m^2:

In this case, locating witnesses, regardless of the spans or the deck length, the samples are located for each span in such a way that a sample is in the center (both longitudinal and transverse) and other one at the end (staggered), always locating two samples next to abutments.
In addition, in order to study the condition and parameters of the reinforcement, samples of about 1 m2 will be performed:

- For LEVEL 1: a single sampling.
- For Level 2: two samples, whose location will be representative of the damage detected.

Also will take samples of the de-icing salts used in the Conservation Centers involved.

3.4 Performing tests

The considered tests in this methodology are focused to determine possible alterations in both the concrete and the reinforcement, performing part of them in situ while others are performed in the laboratory.

For structures with **LEVEL 1** of sampling and testing, works to be performed are as follows:

- In-situ tests in the samples consist of:

  - Visual characterization of concrete
  - Status reinforcement (record appearance and corrosion potential and electrical resistivity of concrete)
  - Coating thicknesses
  - Revealed neutralization basicity profile (measured carbonation)

- In cores from rotating probe, the following tests are performed:

  - Visual characterization of the core : in all cores
  - Profile chlorides to 2 depths: in all cores
  - Analytical determination of sulfates, sodium and potassium: in all cores
  - Revealed neutralization basicity profile: in all cores
  - Determination the concrete compactness by testing porosity, absorption and density: in 1 of the cores extracted
  - Determination of cement: in one core
  - Determination compressive strength: in 1 of the cores extracted
  - Determination of micro-structural of the concrete by electron microscopy tests: in one core. This will also allow determining the possible presence of expansive type degradative processes (formation of ettringite and alkali-aggregate reactions, etc.)

For structures with **LEVEL 2** sampling and testing will be performed as described for level 1, increasing the number of samples in the following cases:

  - Determination of the concrete compactness by testing porosity, absorption and density: in half of the cores extracted
  - Determining compressive strength: in all cores
  - Determining micro-structural tests using electron microscopy in 2 of the cores

In the level are taken 2 samples of de-icing salts and analyzed the values of: chlorides, sulfates, sodium, Potassium, Magnesium, Nitrate, Nitrite and Calcium.

3.5 Work report

Once done all the work, the corresponding final report will include a description of the work performed and results obtained, including a summary table type, photo documentation and recommendations for repairs at each bridge.

4. DESCRIPTION OF TESTING CAMPAIGN.

Below is a brief description of the tests performed, the purpose thereof, as the results obtained in both level 1 structures (structures with no pathology) and level 2 structures (structures with pathology)

4.1 Visual characterization of concrete

Visual characterization of concrete is an important parameter since the presence of reinforcement seen with corrosion, cracks, moisture, efflorescence, etc. They are very useful data that can guide about the existing pathology at the bridge. However these qualitative data have to be confirmed with materials testing.

Figure 8. Structure nº 2; N-630, p.k 88

On the right image can be seen concrete of a beam with cracking, spalling, rust staining, and concrete precipitates, indicating about an important pathology.

The major damages found in analyzed bridges are humidities, exposed reinforcement, efflorescences, spalling and cracks, noting that concrete was in good conditions in the level 1 bridges analyzed (without knowledge of previous pathologies).

4.2 Status of reinforcements

Some of the most important data is to assess the state of passivation protection and reinforcement, since its oxidation leads to loss of bars section (see Figure 9), reducing the structural capacity of the bridge.

Figure 9. Structure nº 2; N-630, p.k 88

It can be determined by a destructive test like drilling the concrete cover until bars or using a non-destructive testing such as the measurement of the corrosion potential.

In this test the potential measurements were performed following the PNE 112083 "Measurement of free corrosion potential concrete structures", that provide qualitative information about the corrosion risk of bars because the potential variation along the structure may identify the presence of areas with and without corrosion. In this case measurements have been performed with a saturated copper electrode device (Cu/CuSO4 saturated), thus adopting the values shown in the first row of the table below.

Tabla nº 5. Criterios para el potencial de corrosión.

ELECTRODO	VALORES LÍMITE DE E_{CORR} PARA RIESGO DE CORROSIÓN		
	< 10 %	≅ 50 %	> 90 %
Cu/CuSO4 saturado	> -275 mV	-275mV <Ecorr < -425mV	< -425 mV
Calomelanos (ESC)	> -200 mV	-200mV < Ecorr < -350mV	< -350mV

Figure 10. Limit values for corrosion potential

Below are a series of figures with the potential maps performed.

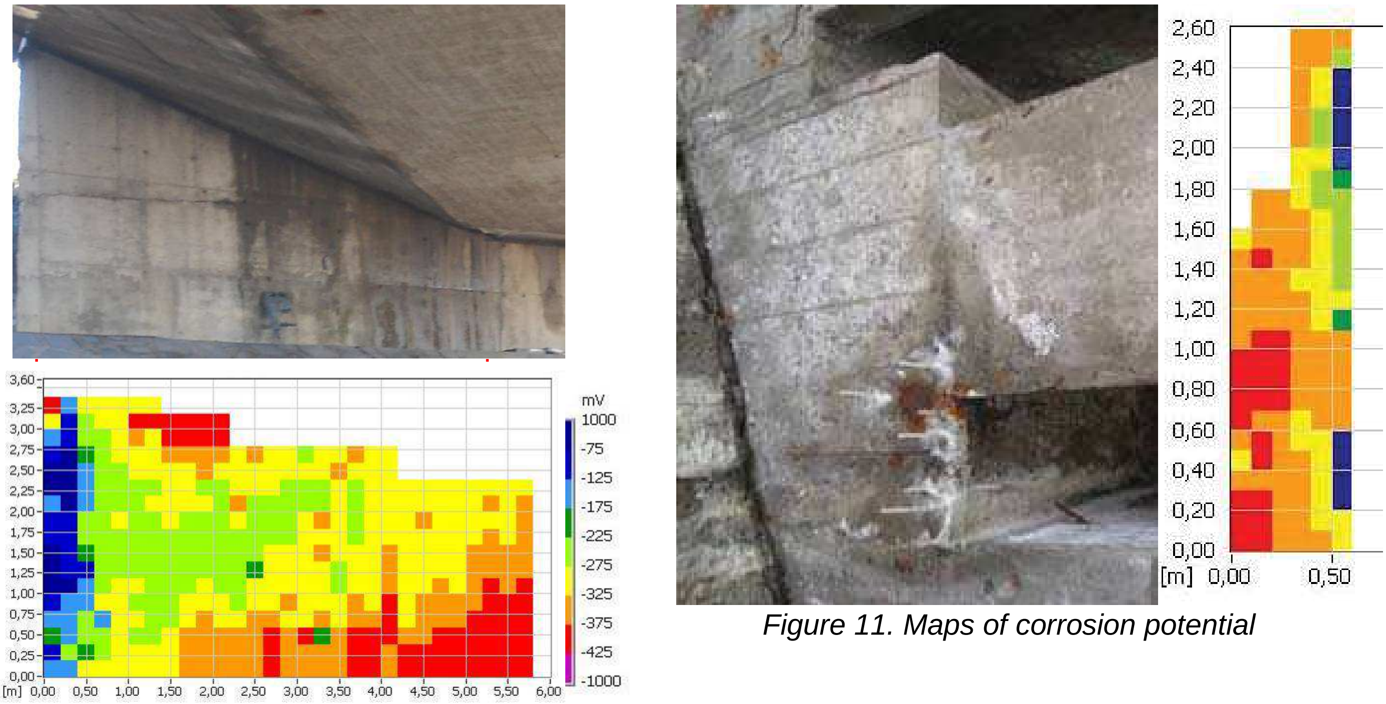

Figure 11. Maps of corrosion potential

As shown in the maps, there are areas with a high degree of corrosion risk even if it cannot be observed from the outside.

However, it's noteworthy that the research found some bridges that despite being in winter maintenance areas and having deteriorated concrete, reinforcements were in good condition both visual inspection and the corrosion potential was not very high, showing the existence of other types of concrete deterioration unrelated to oxidation of reinforcements.

4.3 Coating thicknesses and carbonation measurement

The goal is to determine the reinforcement protection against concrete carbonation, by applying phenolphthalein, following the UNE 112-011-94 standard. Depending on the color to take (colorless for pH less than 8, turning a red-purple as the pH rises), we can know the progress of carbonation front and if this has passed the coating thickness.

Test is performed in-situ in the samples executed and in the cores extracted.

From the results of this test in this study can be noted that the progress of carbonation at the top of the slabs is zero due to the protection of agglomerate layer, and the newest bridges and Level 1 bridges, with more compacted concretes, have less advanced carbonation, as it can be expected.

4.4 Determining concrete strength

Concrete strength is one of the basic parameters for its characterization, so in this study have been evaluated using two different but complementary techniques: accurate and destructive methods and other in-situ tests, with the advantage of being non-destructive and be applicable widely. Thus, the tests carried out were:

- Determination of compressive strength and modulus of elasticity of concrete cores, previously extracted with rotating probe
- Determining the ultrasound speed in-situ.

The results show that the obtained strengths, despite some large dispersions, are above the required and estimated values. Therefore there is no damage due to lack of resistance, in general, in the bridges analyzed..

4.5 Determining the compactness of concrete

In the same way that concrete strength is the key parameter for structural calculations, compactness is the critical parameter for durability, since a good compactness lower permeability and prevent aggressive entry from the outside.

To quantify the compactness of concrete, laboratory has determined the porosity, density and absorption of the various samples, prior to performing the compressive strength test.

In order to describe the ability of concrete against aggressive external agents, the most commonly values of porosity are:

- Porosity ≤: 10% good quality concrete and compactness.
- Porosity between 10-15%: moderate quality concrete.
- Porosity> 15%: poor durability concrete.

It’s noteworthy that most of the bridges have good and moderate quality concrete, although the values obtained are very heterogeneous, varying significantly between bridges of the same road, and without being able to establish a relationship between the porosity and the time when the bridge was built (for example, some newest bridges located in A-67 or A-23 have higher porosity than some bridges located in N-630). Yes it is noteworthy that in the latter, the N-630 bridges, there is a poor implementation of concrete slabs and abutments, with areas of concentration of gravel and low cement content, or lack of coating. Concrete beams have better quality and better executed. The abutments have little reinforcement, but are very susceptible to freeze-thaw damage in general.

4.6 Determining the chloride profile

This could be defined as the most significant test to determine the damage of the winter maintenance to bridge decks, as the most common deterioration mechanism is the increase of chloride in the concrete and the consequent reinforcement depassivation.

Since chlorides can come from outside (de-icing salts) or from inside concrete itself (additives or as a contaminant), the chloride content is calculated at two depths to determine if they come from external input or not.

In most structures was taken as allowable limit value prescribed by EHE-08.

4.7 Analytical determination of sulfate, sodium and potassium

In addition of the chloride content, has been analyzed the content of other aggressive agents for concrete, such as sulfates, which can lead to sulfate attack, and sodium and potassium, since a high concentration in concrete with a reactive aggregate can trigger an alkali-aggregate reaction.

Most bridges the sulfate content was less than 1.4% the weight of the concrete, with one punctual exception and two structures had values slightly above the Standard. In these cases was not found a pathology associated with sulfate.

Regarding the alkali content, that is superior to allowable limit in some structures, there being a possible pathology by alkali-aggregate reaction in some of them.

4.8 Determination of micro-structural concrete using microscopy tests

Microscopy tests are very important to confirm concrete degradation due to the presence of expansive compounds, primarily ettringite gel or alkali-aggregate reaction, but can salts appear as expansive Friedel's salt.

The test can determine the micro structural composition of the concrete, and the existence of micro-cracks in it.

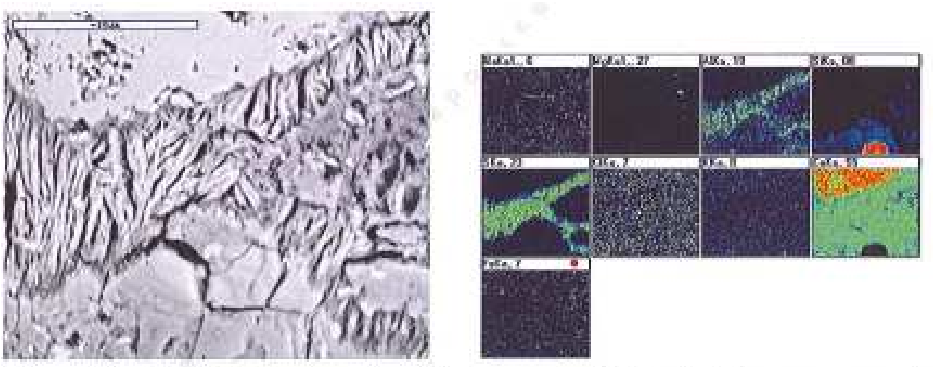

Figure 12. Microscopy: crystallization of ettringite in cracks and map elemental composition

Among the tests performed, it was determined the presence of ettringite and alkali aggregate reactions emerging into some of the structures.

5. **ANALYSIS OF VARIOUS BRIDGES**

Once the inspections and application of the methodology and tests indicated were performed, the next step is analyzing the problems detected, highlighting the following:

In the State Road Network, different zones are observed associated with various damage levels.

A first area on N-630. In this area, between Leon and the south face of Pajares, about 1200 meters above sea level, storms come from South to North, with minor slopes of the road on this stretch, and temperature variations between -15 and +15 over several months. In this section are located seven structures of the study (in the province of León), the **0N-0630-0107 +400** suffered a slab collapse in an area of about 1.5 m2 and was repaired. Other two structures are badly damaged, the **0N-0630-101 +300 and 0N-0630-103**+850. Other three structures have similar damage although less intense, **0N-+890 0630-0088, 0630-0090 0N- +040, 0630-091-0N.** At last, the **0N-+100 0630-101 +050** has less damage, curiously crossing the railway, no a watercourse.

The structures have similar typology except the one crossing the railway (slab type). Generally it can be stated that the top slab of decks have a poor execution (in-situ), probably about 25 N/mm2 strengths, somewhat higher than those abutments of a similar execution, 16 N/mm2. The abutments are no prone to corrosion (low reinforcement and high covers), but are more exposed to freeze-thaw effects. As for the nerves and beams, these are more resistant and they range from 25-36 N/mm2, with more careful execution. The drainage system is almost nonexistent thereof (in local roads drainage is based on runoff from the road itself). The waterproofing of the decks is also nonexistent (with a pavement layer about 8 cm). Importantly, the porosity of the concrete values range from 8 or 9 in nerves and slab, to 12 in abutments, with certain homogeneity.

At this conventional road section, it has been observed a large amount of chlorides in the slab, particularly in the edge and joint areas, also in nerves or beams under slab, especially in the edge beam and bearings areas. The abundance of these chlorides associated to inlets of water zones, indicates they probably came from the de-icing salts used during winter maintenance of the road.

Not appreciate significant presence of sulfates. As for carbonation, although in some structures is of limited importance, curiously in more intensely damaged (perhaps by the great height of the structure on the channel), in the other structures the carbonation is significant mainly in the nerves of the deck (close to the value of concrete cover). Carbonation of the upper face of the slab is zero in general. Corrosion potential measurement and concrete resistivity, detects very high risk areas associated with water inlets: edge zones, bearings on abutments.

Damages are similar, and focus on the existence of corrosion in localized areas of the deck, movement of water and concrete degradation in edge areas, elevations and localized in some abutments associated with freeze-thaw cycles, exacerbated by the de-icing salts used on the road. (To determine this, the General Road Directorate is carrying out a research in the Institute Eduardo Torroja based on the application of freeze-thaw cycles with and without salts in different conditions). This freeze-thaw damage is extensive, although

Figure 13. Damage at abutment and sidewall due to freeze-thaw cycles

not widespread, and can be seen in areas corresponding to accumulation of snow, or certain elevations (not always on the same side of the road, despite being the same stretch, associated with the same sunlight and shade), so it must have great influence the local microclimate of each bridge, and its implementation in the road.

Continuing with the rest of bridges, we have studied another 3 structures **0A+0004-0090, 0A-0004-0069+906, 0A-0004-0120+200 (province of Toledo)**, located in the A-4 between the province of Toledo and Ciudad Real. Here the rainfall is less than the anterior and thermal oscillation lower, ranging -5 to 18 degrees. The types are similar, straight deck of beams with compression slab. No waterproofing system is observed, outside the pavement. The estimated porosity for two of these structures ranges from 9 to 12. It was detected an important presence of chlorides, by sampling points in the PK 120, the beams and the cap of piers, therefore associated to water entry areas, and thus coming from use of de-icing salts. In the three bridges, sulfates were not detected. Regarding the corrosion potential, it was detected a high corrosion risk in the edge beams and pier caps of all structures.

Generally, the main damage is caused by water ingress and corrosion edge zones. No concrete degradation is detected.

The bridge **0A+400 0062-0078** (in the province of Palencia) is located in a similar climate to the previous rainfall (less than 600mm on average). It is a continuous concrete slab, of three spans and strength concrete ranges from 20-22 N/mm2 to 40N/mm2, but the average is about 9%. Chlorides or sulfates are not detected. Carbonation is low. Low corrosion potential, despite obvious water inlets were detected. In this case microscopy analysis detected micro cracking with ettringite crystallization product and alkali-aggregate reaction.

The major damage in this bridge is cracking of the deck both underside and edge of slab. It is in advanced stage and with presence of water.

The bridge **0N-0234-0444+200** (in the province of Burgos) is located in a climate of greater precipitation than the previous (over 600mm), is a bridge of 5 spans with ribbed slab and one side widening by 3 beams and compression slab. The concrete strength of the widening is slightly higher, around 27 N/mm2 with porosity of 8%, compared to the original concrete with 20 N/mm2 strength and porosity of 11%.

Chlorides were detected in the slab edge areas, across all deck, and in the edge beams. No sulfates detected. And high corrosion potential in the edge beams, being low in the remaining elements. Fundamental damages are associated with water circulation, with much localized corrosion on edges, pier caps and joints.

The structure **0A-0006-0157+975** (Valladolid), is located in an area of greater than 600 mm rainfall. The section presents 4 spans with continuous concrete slab type. The core strengths show values lower than expected, probably due to cracking damage. Porosity greater than 10% indicates that it is a concrete not adequate to maintain the durability of the structure. The progress of carbonation is practically zero in all samples. Generally, the chloride content of the samples is negligible.

No sulfates detected in the slab, but sulfate concentration detected in the abutment 2 is clearly high, and may be indicative of the presence of ettringite. In the microscopy test ettringite associated to micro fisuration was observed. The detected cracks may be due to combined action of ettringite and tensional state of the structure. In addition, products of alkali-aggregate reaction were detected in all samples, tough in an incipient state.

Regarding the bridge **0N-0502-0055+300** (Avila) is located in an area of high rainfall (>600 mm). The structure consists of 4 spans, with 4 beams with compression slab. No damages were detected in the concrete slab, although there were small white precipitation of salts in the pores. The chloride concentration is somewhat higher than prescribed by the EHE. The sulfate concentration is somewhat higher than prescribed by the EHE. Carbonation is null. The alkali content exceeds the requirements of the EHE. The microscopy analysis detects the presence of ettringite, no cracking associated.

0N-0502-0042 +093 (Avila) is located in the same area as the previous precipitation. It is formed by nine spans, with 6 beams and compression slab. Cracks are observed in the surface layer of the slab. By microscopy were observed crystallization of salts in pores and small halos surrounding some aggregates. Carbonation is null. High porosity. High chloride concentration. No substantial sulfate concentration. The alkali content exceeds the requirements of the EHE. Some areas associated with water circulation are highly prone to corrosion. Detection of products associated with alkali-aggregate reactions even in initial stage. Presence of ettringite, no cracking associated.

0A-0006-0127+076 (Avila), is located in the same area as the previous precipitation, although clearly located in a valley on the River Adaja. It consists of 5 spans with section of 9 beams with compression slab. Chloride contents are at or slightly above prescribed by EHD. There have been sulfate content exceeding the limit prescribed by the EHE. In all samples the progress of carbonation front is null.

As for damage, rust stains are seen on the wings of the beams, probably due to the lack of coating in these areas, which favors the appearance of corrosion processes. Not seen any manifestation of expansive reactions.

The bridge **0A-0111-0067+400** (in the province of Palencia) is located in a climatic zone of precipitation less than 600mm average. It is three span with cross section of 4 beams with compression slab. No damages were detected in the aspect that shows the concrete slab, with no symptoms suggestive of degradative processes. The porosity is high. The chloride concentration is high with respect to the requirements of the EHE. No substantial sulfate concentration detected. Carbonation is null.

In the structures 0A-0023+0104+601 (Teruel), **in 0N-0204-0032+532** (Guadalajara) **and 0A-0030-0065+536** (Albacete), no damages are detected in the slab concrete aspect, with no symptoms indicating any degradative process.

The following table provides an outline of the work of each bridge.

Nº	Code	environment	Porosity	Concrete degradation	Sulfate	Alkalis
1	0N-0502-0042+093	IIa, H or F	High	Slab: cracks in the surface layer	Concentration below EHE limit	Concentration exceeds EHE limit
2	0N-0630-0088+890	IIa, H or F		Concrete degradation in abutments and lateral walls, including a several cm loss of thickness		
3	0N-0630-0090+040	IIa, H or F		Concrete degradation in abutments and lateral walls, including a several cm loss of thickness		
4	0N-0630-091+100	IIa, H or F		Concrete degradation in abutments and lateral walls, including a several cm loss of thickness		
5	0N-0630-101+300	IIa, H or F		Concrete degradation in abutments and lateral walls, including a several cm loss of thickness		
					x	
6	0N-0630-103+850	IIa, H or F		Concrete degradation in abutments and lateral walls, including a several cm loss of thickness		
7	0N-0630-0107+400	IIa, H or F	Moderate to high		Concentration below EHE limit	
8	0A-0067-0111+400	Iib,F	High	No apparent degradation in the concrete slab	Concentration below EHE limit	
9	0A-0004-0120+200-I	IIb,F		Concrete degradation mainly in the exterior girders, pier caps and prefabricated fascia	Concentration below EHE limit	
10	0N-0630-101+050	IIa, H or F		Slab: some areas of the top face Abutments: in the lateral walls		
11	0A-0004-0090+000-I	IIb, F		Degradation of the cantilever beams		
12	0N-0234-444+200	IIa, H or F		Good durability condition		
13	0A-0062-0078+400	IIb +Qb, H or F	Low		Concentration below EHE limit	
14	0A-0006-0127+077	IIa, H or F		No apparent degradation in the concrete slab	Concentration slightly exceeds EHE limit	Concentration exceeds EHE limit
15	0N-0502-0055+300	IIa, H or F		No apparent degradation in the concrete slab	Slab: concentration slightly exceeds EHE limit	Concentration exceeds EHE limit
16	0A-006-0157+975	IIb, H or F	High		Slab: concentration below EHE limit Abutments: concentration exceeds EHE limit in abutment 2.	
17	0A-0004-0069+906	IIb,F		Cracks in the extreme of the beams		
18	0A-0023-0104+601	IIa, H or F		No apparent degradation		
19	0A-0030-0065+536-I	IIb,F		No apparent degradation		
20	0N-0204-0032+532	IIa, H or F		No apparent degradation		
21	0A-0042-	IIb		No apparent degradation		

	0071+650+D						

Chloride	Corrosion potential	Carbonation	Microscopy
Slab: concentration exceeds EHE limit	High potential corrosion areas	None	Ettringite detected and early stage of alkali-aggregate reaction
Beams: Exterior beams and the bearing areas of the rest of beams	High corrosion in exterior beams and in the bearing areas of the rest of the beams		
Slab: completely affected			
Abutments: Penetration about 15 cms			
Beams: Exterior beams and the bearing areas of the rest of beams	High corrosion in exterior beams and in the bearing areas of the rest of the beams		
Slab: completely affected			
Abutments: Penetration about 15 cms			
Beams: Exterior beams and the bearing areas of the rest of beams	High corrosion in exterior beams and in the bearing areas of the rest of the beams		
Slab: completely affected			
Abutments: Penetration about 15 cms			
Beams: Exterior beams and the bearing areas of the rest of beams	High corrosion in exterior beams and in the bearing areas of the rest of the beams		
Slab: completely affected			
Abutments: Penetration about 15 cms			X
			x
Beams: In all support areas for the beams and the lateral beams	High corrosion in exterior beams and in the bearing areas of the rest of the beams		
Slab: completely affected			
Abutments: Penetration about 15 cms			
Concentration exceeds EHE limit		None	Ettringite detected
Concentration exceeds EHE limit		None	
Pier caps: concentration exceeds EHE limit		Except local areas, the existent carbonation is not affecting the reinforcement	
Exterior piers: concentration exceeds EHE limit			
Slab: mainly in areas with low concrete cover	High corrosion in the slab	Low	
Very low concentration	High corrosion in the exterior beams	Concrete cover is slightly superior to carbonated thickness	
Beams: some of the exterior beams are affected			
Sidewalks			
Very low concentration		Very low	Ettringite detected and early stage of alkali-aggregate reaction
Concentration slightly exceeds EHE limit		None	
Slab: concentration slightly exceeds EHE limit		None	Ettringite detected but not associated to micro fisuration
Very low concentration		Very low	Ettringite detected and early stage of alkali-aggregate reaction
Beams: very low concentration	No active corrosion	Reinforcement is not affected	

6. **CONCLUSIONS AND RECOMMENDATIONS**

As a result of this study focused on the durability of concrete decks of bridges located in the State Road Network we highlight the following conclusions:

- In 8 structures (# 11, 13, 16, 17, 18, 19, 20, 21) a significant presence of chlorides has not been detected at concrete slabs. In the other structures, chlorides were detected mainly in the areas of water inlet: slab edges, edge beams and abutments. In some bridges, such as the N-630, in very adverse weather, there are damages of high intensity. This suggests that are linked to water intrusion from the road containing salts, associated to winter maintenance. There may be different types of damage related:

    - Reinforcement corrosion: generally, a significant increase of corrosion has not been detected for this reason. In all cases the slab carbonation, especially its upper face doesn't exist; first of all, due to the pavement protection, which is a strong physical barrier, due to insufficient sealing of the bridges studied.
    - Another type may be the increase of the degradation of the concrete slab or the abutments. Clear pathologies were observed due to freeze-thaw, spalling of several centimeters, linked to water inlet areas, thus subjected to the same temperatures and conditions without appreciable deterioration. Also associated with areas of greatest accumulation of snow and / or salt. The effect of salts surely accelerate the degradation process in an obvious way, and these aspect is being investigated by experts from the Highways Agency.
    - Finally, another aspect such as the compounds that can be formed by the inclusion of these chlorides in the damaged concrete; for this have also been conducted microscopy analysis, although new compounds have not been clearly found. This phenomenon will be studied more deeply in future.

- In some cases, high alkali content have also been detected, which can occur on one hand to the original content of cement employed and the other to the addition of sodium, as de-icing salt (NaCl).

- In the structures 13 and 16 shows extensive cracking sharply on the slab, which could be due to an intrinsic problem of the composition of the concrete itself, with formation of ettringite and aggregate-alkali compounds. The chlorides in this case have not been detected.

- Finally, it has validated the proposed methodology, and its application its proposed in most cases, so it can compared the damage and problems associated with the durability of concrete structures in severe weather areas and to analyze the impact of the de-icing salts.

- This work also considers establishing climatic zones with intense winter maintenance, and temperature and humidity conditions that are suitable for critical damage by freeze-thaw. In this sense the N-630 is confirmed as a possible section for a detailed study. In these areas should pay special attention to drainage and waterproofing systems.

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