Database of Durability and Anomalies of Concrete Structures: Records in Several Environmental Exposures

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ABSTRACT

The main objectives of the work presented are the definition and creation of an original generic structure for the Database of Durability and Anomalies of Concrete Structures and its filling with technical information that Teixeira Duarte has, resulting from the structural inspection works studied by the author. Each structure is introduced with generic references of framing, of description and technical data, namely: concrete characteristics; steel reinforcements and thickness of concrete cover; results of chemical and electrochemical tests; other observations and photographs.

The data and results analysis, and the interesting intersection of this information, are achieved through the development of a set of graphics. Unless special features, the results obtained in general, by processing and analysis of information, are in accordance with the expected pathology, given the use, the type of concrete and the class of environmental exposure of structures.

Key-Words: Concrete, Structural Inspection, Corrosion, Durability, Anomalies

1. INTRODUCTION

The elaboration of a "Database of Durability and Anomalies of Concrete Structures: Records in Several Environmental Exposures" arises from the author's will to deepen and consolidate her knowledge in this area, through the development of a compilation work and systematization of data and technical information that were scattered. It is the consolidation of knowledge gained over many years of professional experience in this area, compiling and systematizing technical information resulting from different studies of structural inspection and diagnosis, carried out in various types of concrete structures, in Portugal and abroad, with different environmental framings and in different situations.

1.1. CONTEXT AND OBJECTIVES OF THE WORK

The durability of structures is an issue that in recent decades has had an increasing relevance. The increasing of the building works, the high number of cases that showed poor performance of concrete structures due to the durability and the increasing of costs related to structural rehabilitation interventions, have highlighted the need to continue the ongoing research in this field and to disseminate in the technical community current knowledge concerning the performance of existing works.

In this context, it is important to develop a database on the durability of concrete structures, subjected to different exposure environments, identifying and characterizing the structural materials, the anomalies, the deterioration level and the time of its development, and also, where possible, recording information about the implemented intervention methodologies of rehabilitation/repair and eventually its performance.

The Database can be of great importance and usefulness to the technical community and can, certainly, contribute to the reduction of failures that often occur in rehabilitation interventions. It is intended to facilitate the organization and sharing of results and technical data, relating to the pathology of reinforced concrete, which were not obtained in laboratory, but in a wide range of examples of studies and interventions carried out in real existing structures, in the course of their service life.

2. STRUCTURAL INSPECTION AND TESTS

The test and structural inspection campaigns and visual inspection are part of the actions taken to evaluate the condition of a structure. To these actions are also associated others with the same goal: gathering information about the original project of the structure under study and about its construction and subsequent maintenance; evaluating the deterioration; and the assessment of structural safety.

The main objectives are: to define the type and causes of deterioration; setting the level of deterioration; the prediction of the evolution of deterioration; and evaluating the security level of the concrete structure.

The results and their analysis will define the type and methodology of rehabilitation intervention to perform in the structure, depending on the type and level of deterioration, of its use and of the costs involved.

3. STRUCTURE AND OPERATION OF THE DATABASE

The structure of the Database of Durability and Anomalies of Concrete Structures is designed in Excel, with the following objectives: allow any user greater ease of use and/or consultation; not link the work to any specific software for database management, avoiding incompatibilities and favoring versatility; allow to give a planned and simple basic table of data collection, whose information may be collected and transposed to create or load any other specific database.

Each Structure is inserted into the DB always maintaining its anonymity and also of the respective client of the work or intervention and of the study performed. The content entered in each field, with the information on the given data, is intended to be brief and indicating the values or most representative benchmarks for each Structure. The results of tests to be inserted in this DB are related mainly to concrete and reinforced concrete, and there are not recorded testing indicators and observations carried to other parts of the structure (metallic structure elements, wooden structures, etc.) or for evaluation of additional issues such as, for example, pull-out tests ("pull-off") to evaluate adhesion or others.

3.1. DATA AND RESULTS ANALYSIS

The data and results analysis in the sampling contained in the DB is carried out especially by developing a set of graphics that are associated with it. The data and indicators used in the statistical and comparative analysis, are those most relevant and also those that have most often results recorded in the sampling achieved in this version of the DB.

From the General Database was possible to create Partial Databases, restricting the study and analysis of the information collected and compiled, for a particular type of structure or for a given environmental exposure class. These Partial DBs function as reduced versions of the General DB and result of careful reduction of the total sampling of the General DB, limited to one type of structure or exposure class. In this sense, the work resulted in four Partial Databases, one for each of the main types of structures, more frequent and representative in the sampling in the General DB: DB for Piers and Jetties; DB for Buildings; DB for Bridges; DB for Reservoirs. And also the same for all three classes of environmental exposure, more frequent and representative in the sampling in the General DB: DB for the exposure class XC1; DB for exposure class XC4; DB for exposure class XS3.

With the presentation of these Partial DBs, it is intended, on one side, to go to the direct encounter of what may be the specific technical interest of certain users of the DB and, on the other, to add additional indicators and results, in the data and results analysis of the DB, specifically focusing on the main types of structures recorded and on the most significant environmental exposure classes, recorded in this sampling.

4. ANALYSIS OF RESULTS

By the work developed, in the due time available, it was possible to gather in the Database a sampling with information of 43 structures, presenting the main results achieved by that DB, demonstrating some observations of the developed analysis and appreciation.

The Database of Durability and Anomalies of Concrete Structures gathers in this sampling various types of structures, including 14 Buildings, 8 Bridges (maritime environment, on rivers and on roads), 6 Water Tanks/Reservoirs (high and buried), 5 Jetties and 3 Piers, 2 drinking water Pipes (high and buried), and also one Tunnel, one Automobile Silo, one Industrial Chimney, one Industrial Structure of Deposits Support and one Silo for cement.

As regards the environmental exposure classes represented by this sampling, it appears that most structures are in classes XC1 and XC4, of corrosion induced by carbonation, in dry or permanently moist environment and in cyclically wet and dry environment, respectively, and in class XS3, of corrosion induced by chloride from seawater, in tidal zone environment, surf and splashing. The remaining structures fall into the classes XC2 and XC3, of corrosion induced by carbonation, in wet environment, rarely dry and in moderately humid environment, respectively, and in class XS1, of corrosion induced by chlorides from seawater, in environment of exposure to air transporting sea salt but without direct contact with sea water. There is also a recorded structure in the exposure class X0, a tunnel, of simple concrete, or concrete without reinforcement, without risk of corrosion or attack.

The DB gathers structures located in various countries, predominantly in Portugal, with 32 recorded studies, and with 5 structures in Angola, 4 in Mozambique, one in Ukraine (a Silo for cement) and one in Brazil (a Pier).

With regard to the year of construction of structures, those where it was possible to obtain this information, were inspected the oldest built in 1912, two Jetties, in Mozambique, and the latest dated in 2008 and 2009, two Buildings, in Angola.

For the year of inspection of the structures, there are recorded in this sampling the data and the results of structural inspection campaigns and tests carried out between 1999 and 2015.

Of those structures with construction dated, those in which the inspection was carried out in a most advanced period of its service life are the Structures n. 16 and 17, the two Jetties, in Mozambique, of 1912, inspected in 2007, with about 95 years of existence at the time. On the other hand, those structures in which the recorded inspection took place less time after its construction are the Structures n. 24 and 25, the two Buildings, in Angola, built in 2008 and 2009 and inspected in 2014 and 2015, with about 6 years of use at the time.

4.1.1. CONCRETE STRENGTH CLASS

Analyzing all the records of concrete strength class, associated to the main structural elements inspected, columns, beams and slabs or walls, in all the structures, it appears the predominance of classes C20/25, C25/30 and C30/37 (see Figure 1). Also, in this overall analysis, there have been many records of concrete of classes C16/20 and C12/15. The remaining strength classes recorded are C35/45 and C40/50, with 3 and 4 examples, respectively, and C45/55, C50/60 and C55/67, with one example of each.

The same appreciation, made only for the tested samples of concrete in columns in DB structures, reveals that most corresponds to the class C16/20, C20/25, C25/30 and C30/37. For beams, most of the examples recorded in the DB correspond to the classes C12/15, C20/25, C25/30 and C30/37. Regarding the slabs and walls, according to the type of structure, the tested concrete is in its majority of classes C16/20, C20/25, C25/30 and C30/37.

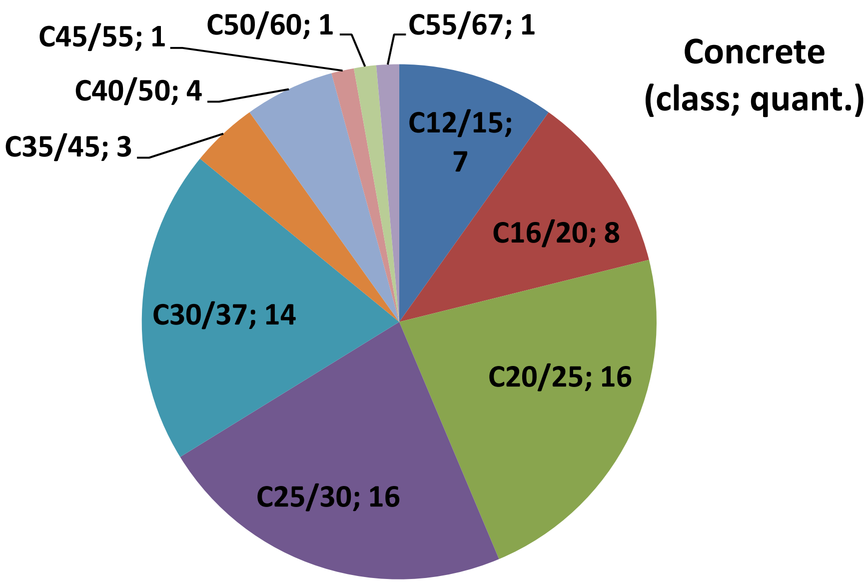

Figure 1: Total Graphic of Concrete Strength - General DB.

4.1.2. ELECTRICAL RESISTIVITY OF CONCRETE

In a total of 43 structures registered in the Database, only 9 have record of results of determining electrical resistivity of concrete tests. The values of electrical resistivity of concrete in this field of the BD are obtained from tests conducted in a Laboratory, on saturated samples of concrete, previously extracted from cores taken from the structure.

The highest average values are shown in Structures n. 6 (one Pier), n. 17 (one Jetty) and n. 43 (one Tank), respectively with 24.8, 31 and 30 kΩcm, indicating a low index of possible corrosion, ie, indicating weak susceptibility to the occurrence of significant corrosion in the steel reinforcements. The remaining average values range from 9 to 16 kΩcm, being indicators of a medium index of possible corrosion, lower or higher depending on the case.

4.1.3. CONCRETE COVER OF REINFORCEMENTS

Analyzing the total set of mean values, non-zero, of the thickness of the minimum concrete cover of reinforcement in concrete (average of minimum values of the cover on each test area), in mm, recorded for each of the main structural elements (columns, beams, slabs or walls), there may be verified the following (see Figure 2): the most of the covers have a thickness less than or equal to 30 mm; the maximum thicknesses of minimum cover, in this sampling, range from 50 to 85 mm, mainly occurring in columns and slabs or walls, as appropriate to the case; the maximum value of the minimum cover detected in columns of the inspected structures is 85 mm, in Structure n. 6, a Pier; the maximum value of the minimum cover detected in beams is 60 and 67 mm, in Structures n. 2 and n. 17, respectively, two Jetties; the maximum value of the minimum cover detected in slabs and walls is 80 mm, in Structure n. 40, a Building of one Industry.

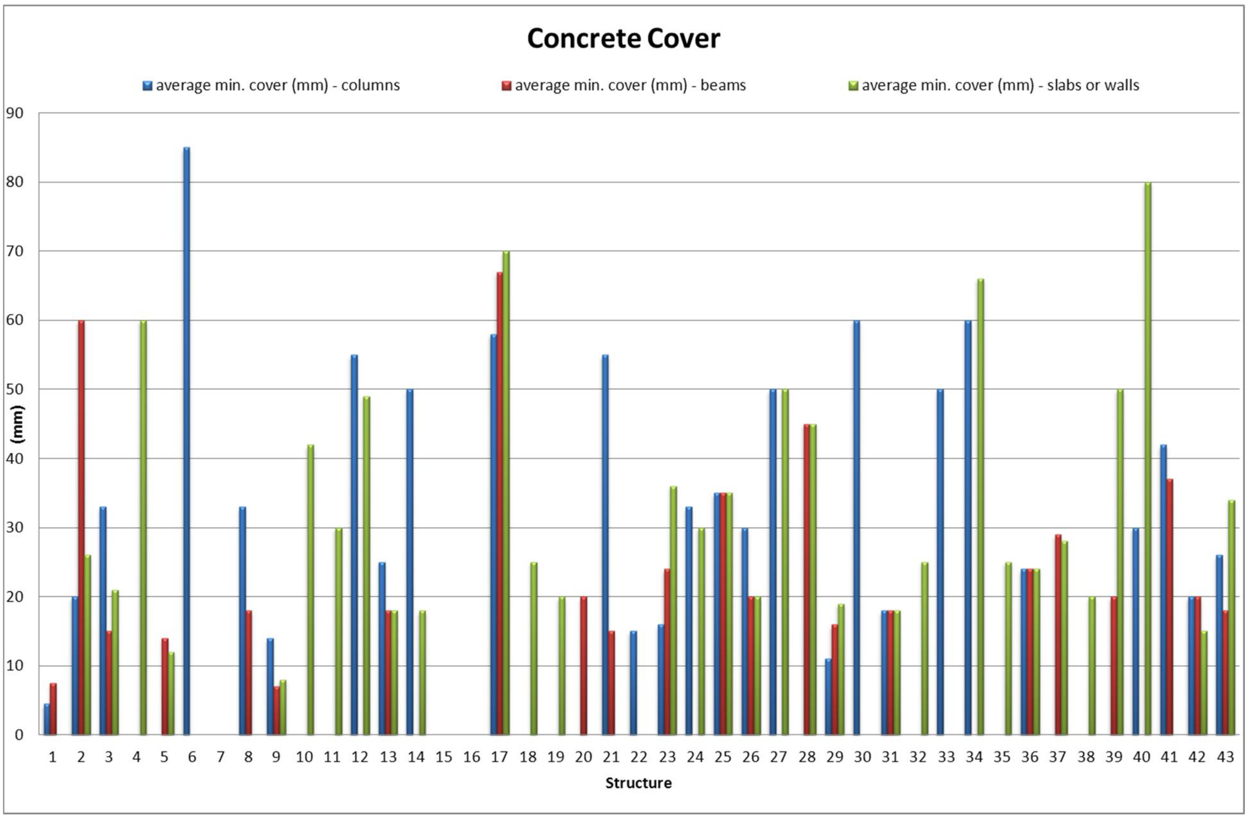

Figure 2: Graphic of Concrete Cover of Steel Reinforcements - General DB.

4.1.4. CARBONATION DEPTH IN CONCRETE

The analysis of the total set of mean values, non-zero, of the carbonation depth in the concrete, in mm, recorded for each of the main structural elements (columns, beams, slabs or walls) of structures in the DB, allows to observe that: the larger average depths of carbonation are registered in Structure n. 26, one Building; most of the results achieved is less than 20 mm (see Figure 3).

The joint analysis of the thickness of the concrete cover and of the carbonation depth, both in mm, recorded in columns, in beams and in slabs or walls, separately, allows appreciating the significance of the results obtained for each structural element. In the columns there are several case studies where the carbonation depth exceeds the thickness of the cover, representing risk of development of steel corrosion of reinforcements, namely in Structures n. 1 (one Buried Reservoir), n. 9 and n. 26 (both Buildings) and n. 43 (one Semi-buried Tank). For beams it is verified that the carbonation also exceeds the depth of the reinforcement in concrete, in Structures n. 9, n. 26 and n. 43. In the slabs and walls, as appropriate to each case, the carbonation detected reaches the depth of the reinforcement in Structure n. 18 (one Silo for cement) and exceeds this level in Structures n. 9, n. 26 and n. 42 (High Reservoir).

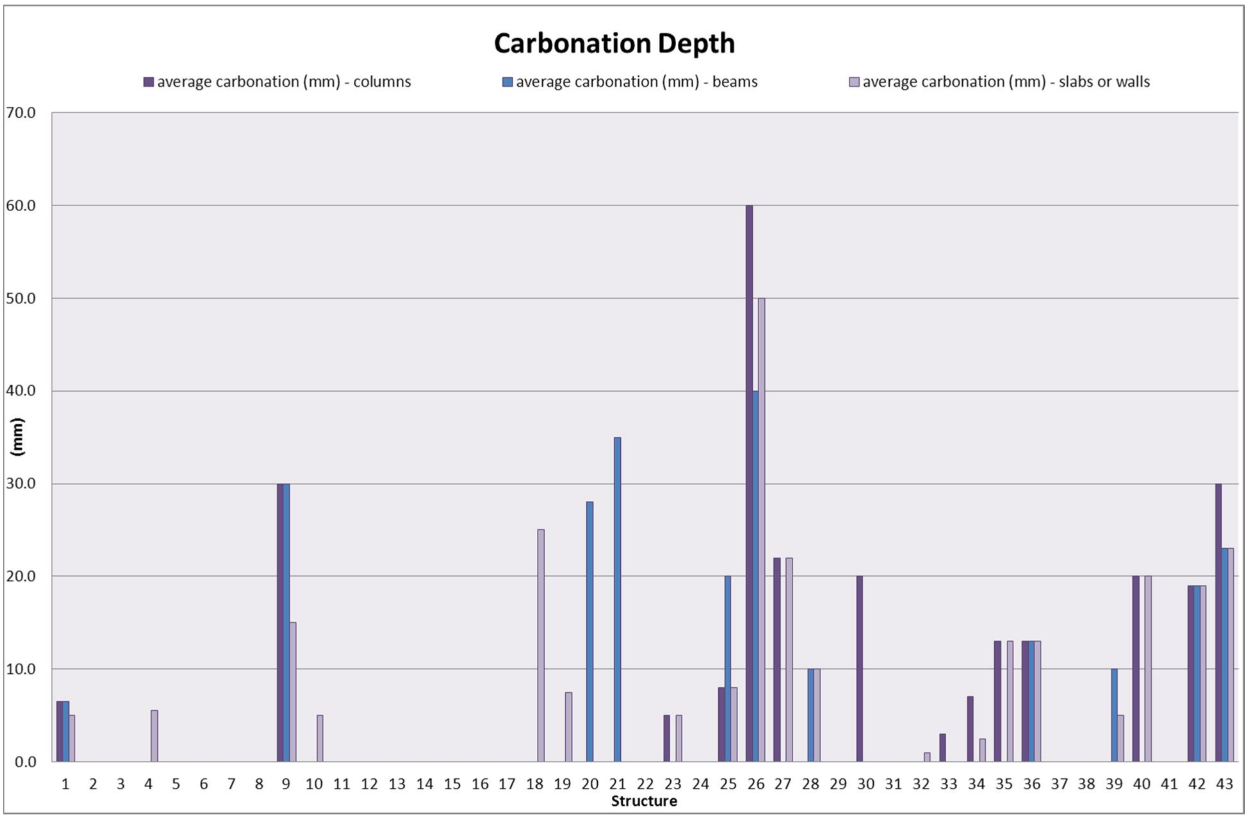

Figure 3: Graphic of Carbonation Depth in Concrete - General DB.

4.1.5. CHLORIDE CONTENT IN CONCRETE

As regards the analysis of the total set of non-zero maximum values of the chloride content in the concrete, in "% in concrete", recorded for each of the main structural elements (columns, beams, slabs or walls) of DB structures, it was found that: the maximum values occur in Structure n. 41 (one Jetty), with 2.0% in the beams and 1.0% in the columns; in the Structures n. 2 and n. 3 (two Jetties) also occur some of the higher values in this sampling, with 0.65% and 0.60% of Cl^- in the concrete mass.

The joint analysis of the maximum values of chloride content in concrete, respective depth of occurrence and the average thickness of minimum cover, recorded for each of the main structural elements (columns, beams, slabs or walls), allows to evaluate in which case studies the contamination is more severe and the depth of the high contents detected, in relation to the thickness of the cover, reaching or exceeding the level of reinforcement, indicating the development of corrosion of the steel (see Figures 4, 5 and 6). The main cases where a high chloride content occurs at a thickness that already reaches or exceeds the cover of the reinforcement are: for the columns, in Structures n. 2 and n. 3 (two Jetties) and in Structure n. 29 (one Pier) ; for the beams, in Structures n. 2 and n. 3, in Structures n. 5 (one Bridge), n. 28 and n. 29 (two Piers); and for the slabs or walls, as appropriate, the Structures n. 2 and n. 3, the Structures n. 28 and n. 29.

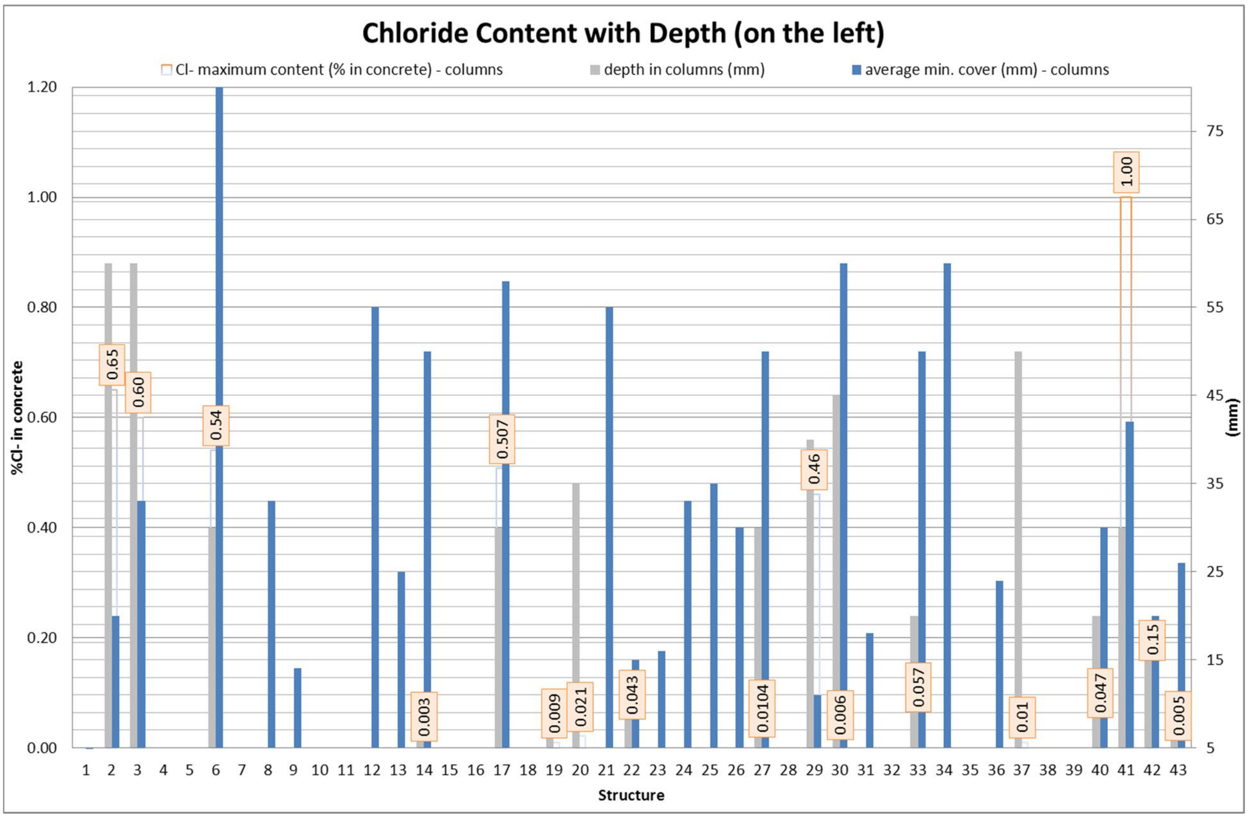

Figure 4: Graphic of Chloride Content in Concrete in Columns, with Depth and the Cover – General DB.

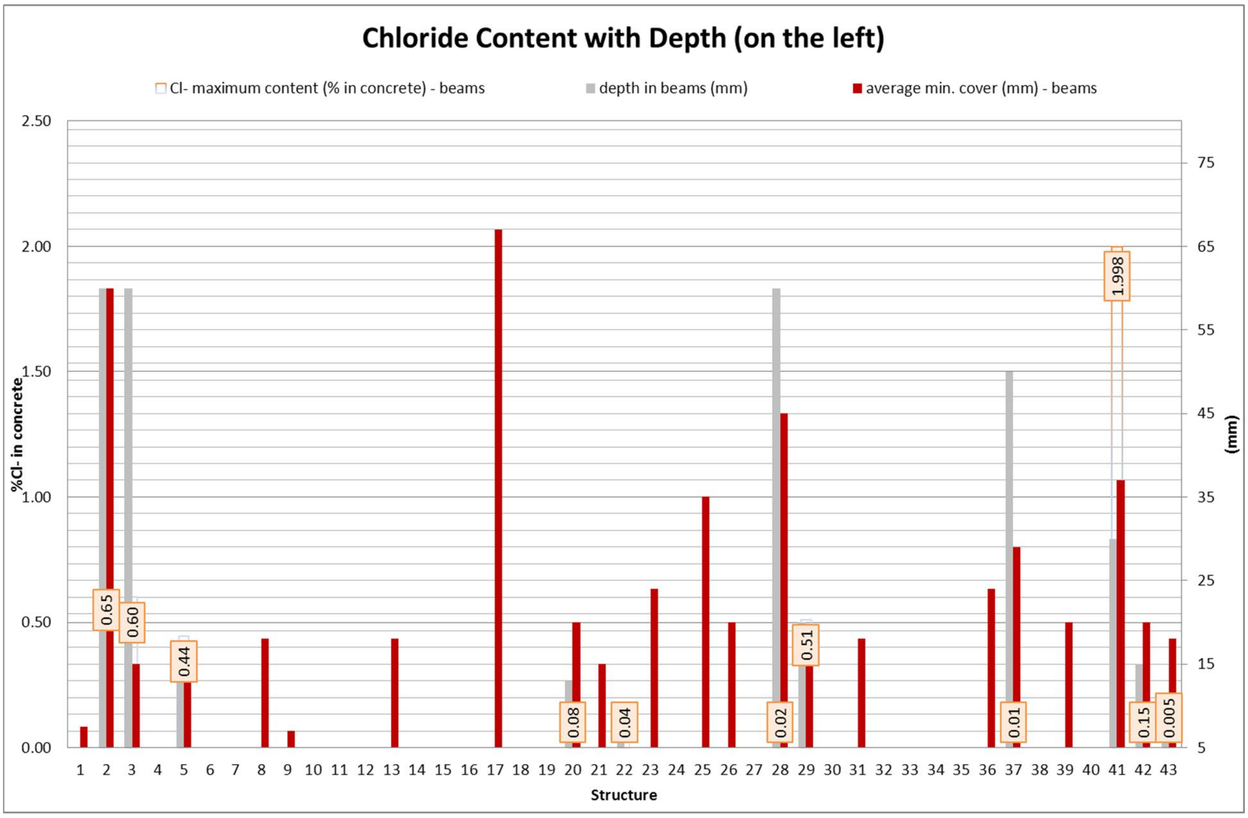

Figure 5: Graphic of Chloride Content in Concrete in Beams, with Depth and the Cover – General DB.

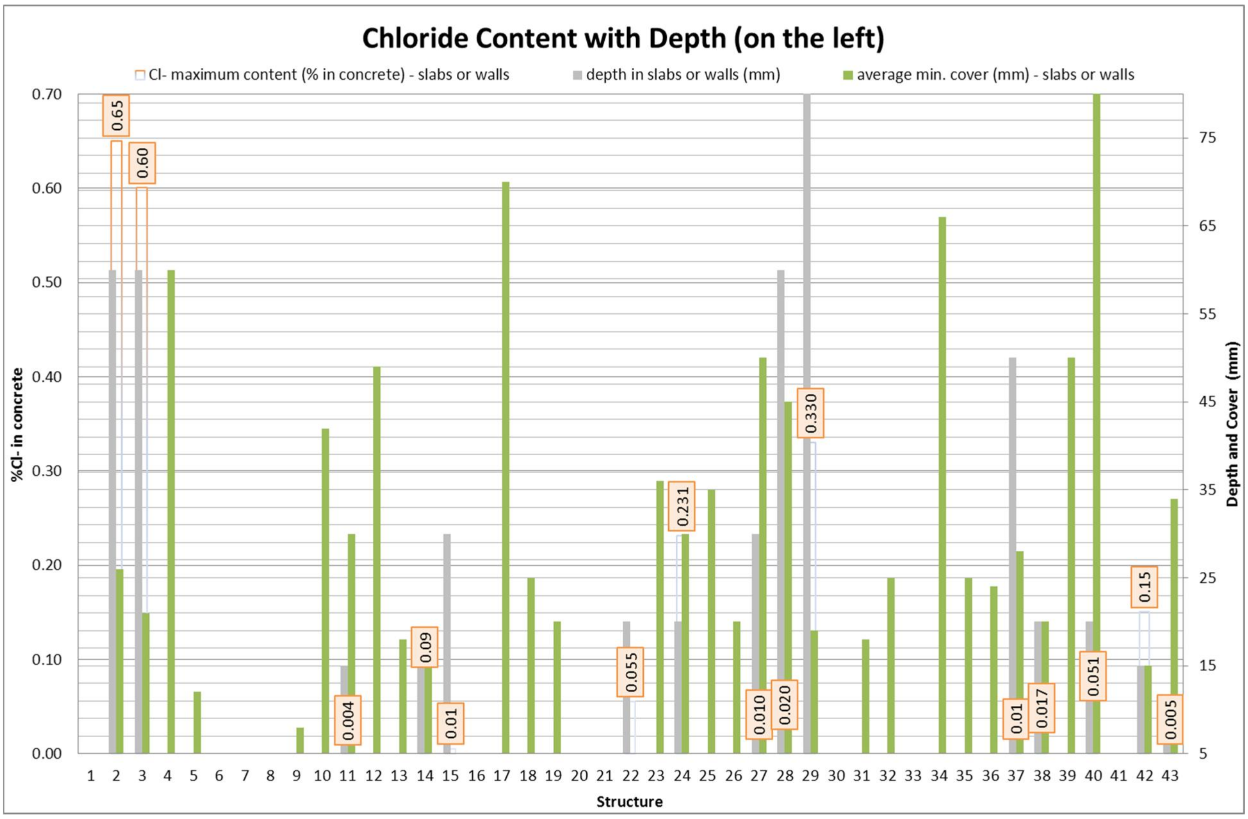

Figure 6: Graphic of Chloride Content in Concrete in Slabs or Walls, with Depth and the Cover – General DB.

5. CONCLUSIONS

As conclusions of the development of this work, besides the results obtained in the Databases and in its observation, it can also be referred the following:

- Unless special features of each case, the results obtained in general, by processing and analysis of information contained in the DB are, in most cases, in accordance with the expected pathology, given the use, the type of concrete and especially the class of environmental exposure of the studied structures;

- The creation of Partial DBs, dedicated only to a type of structure or environmental exposure class, has proved to be very useful in the data and results analysis process, allowing also to make a more directed information processing and directly oriented to the particular technical interest of who consults the DB.

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