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EARLY CONCRETE STRUCTURES AND POST-PATENTED SYSTEMS: LESSONS TO PRESERVE EARLY 20th HISTORICAL HERITAGE

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Abstract. *Reinforced concrete was introduced by patented systems into Spain towards the end of the 19th c. Early patents were effectively foreign trademarks, although Spanish engineers, architects and industrialists soon developed their own RC systems. Local builders would build structures with scarce little regard for calculated design and construction in the first decade of the 20th century. Nevertheless, as further knowledge was required, increasing research led to new RC standards in numerous countries, such as France and Germany. In the second decade of the 20th century, the use of patent systems declined. The teaching of RC started at the Spanish Civil Faculty where systems of scientific calculation were rapidly adopted, although no Spanish RC standard was drafted, unlike the situation in the leading European countries of that time. Hence, the RC structures that proliferated across Spain were mainly based on French or German standards. Spanish industrial activity began to develop in northern areas of the country where the use of new materials was pioneered over the following decades. Nowadays, some of those structures are listed heritage buildings. In this paper, some common features of 15 RC structures built between 1915 and 1936 are discussed, by focusing on their conservation problems. Preliminary structural reports from engineers, architects, municipal councils and, in some cases, the owners of the buildings are compiled with information on the pathologies affecting the buildings and analyses of* *structural morphologies, and steel and concrete strengths. The results of those studies are analysed, by connecting construction features with structural conditions, in order to gain a deeper understanding of their main characteristics and similarities. The findings will contribute to knowledge of heritage buildings, identifying key strategies for application in future rehabilitation works.*

1 INTRODUCTION

In the mid-19th c., the inventive idea of Reinforced Concrete (RC) emerged when metallic elements, usually steel bars, were first used to strengthen the concrete mass. Some pioneering inventors and the dates of their patents may be mentioned, such as Lambot, in 1855, and François Coignet, in 1852, in France [1,2]; Wilkinson, in 1854, in the U.K. [1]; and Hyatt [3], in 1878, and Ransome [4], in 1884, in the U.S. In modern Europe, Joseph Monier is considered the principal inventor of RC, patenting a construction system with a wire frame covered with layers of mortar in 1867.

In the last decades of the 19th c. and the start of the 20th c., the construction of RC structures rapidly spread, as their main advantages over the separate use of masonry and steel structural materials came to be widely acknowledged: high durability (at the time and very mistakenly considered "almost eternal"), monolithism, versatility, acceptable mechanical characteristics, and very especially fireproof [5-7]. Its proliferation, based on the many patents from numerous countries, led to the launch of RC 'multinationals' such as Hennebique (France) and Wayss & Freytag (Germany). There was a proliferation of patents both in the U.S. (Goodman, Goodbridge, Jackson or Kahn) and Europe (Blanc, Coignet, Cottancin, Bordenave, Matrai, etc.).

The inventors made perhaps excessive efforts to protect their patented systems. It was assumed that the system specifications had been included the calculation of RC structures (floors, beams and columns) for the implementation of detailed reinforcements with sufficient strength for each architectural feature. Nevertheless, there were many totally experimental patents with no real scientific basis, and even the patents that had a degree of technical support were reluctant to disclose the scientific basis of their claims. At the turn of the century there were some catastrophic structural failures: a pedestrian bridge in Paris (1900), the Zum Bären Hotel in Basel (1900), the roof of a Madrid reservoir (the Third Deposit) (1905), and buildings in Berne (1906), and Milan (1908).

In the last decade of the 19th century, research into RC concrete started to expand, and design requirements and calculation methods became freely available in published form. Research was available on concrete vaults, arches, slabs, and beams, and subsequently columns. Likewise, the first courses on the subject were launched at the "École Nationale des Ponts et Chausses", Paris, in 1897. All these factors –scientific research, structural collapses, and access to academic publications- finally led to the enactment of various national regulations that greatly enhanced RC structural safety: Switzerland in 1903 and 1909, Germany in 1904 and 1907, France in 1906, Italy in 1907, Austria in 1907, the U.K. in 1907 and 1911, Russia in 1908 and 1911, Denmark in 1908, and the U.S.A. in 1908 and 1910 [8]. The combination of national standards and open access to RC knowledge ended the payment of royalties linked to patents, leading to a new panorama for RC construction. Both, patented systems and patented free structures coexisted until WWI, although their demise after the first World War, saw the start of a new phase in its development based on knowledge and regulations.

Since the end of 19th c., RC structures have become a part of our Cultural Built Heritage. Its status as Heritage is a testimony to progress in science, economics, culture and society in its content, its technique, and its materiality. Its conservation and preservation contribute to our historical understanding of technological and social advances, as well as other events that may have occurred throughout that time [9]. This Heritage has invariably deteriorated, due to functional and typological obsolescence and irreversible modifications, inappropriate treatment, and inadequate conservation, often resulting in its abandonment and destruction. Its relevant innovative features for which it is recognized as Heritage clearly reflect the systems and materials used in its construction.

The first step for acceptable conservation, rehabilitation and maintenance is to gain knowledge of the construction techniques and the main features of the structures from that historical period. It should be focused on the targets for mechanical strength in compliance with the regulations at that time, especially in early RC structures, and durability of the concrete. Studies on structures built following patented systems are frequent [10-19], although structures built in the post-patent period are now becoming an interesting period of study too [20-26].

2 THE POST-PATENTED RC STRUCTURES OF SPAIN

In the last decades of the 20th century, the introduction of RC in Spain came later than in other European countries and was influenced by French patented systems. At the start of the 20th century, RC had become a relevant structural material, especially in civil and industrial constructions, still linked to patented systems up until around 1910. Whereas numerous Europeans countries enacted their own standards, structural safety regulations were unavailable in Spain until 1939 [27], the end of the Spanish Civil War.

From the point at which the patented systems had become obsolete at the end of 1910, up until 1939, the common references in Spain for structural concrete design and calculation were the French and the German standards [28]. Even though a Spanish Army standard was enacted in 1912, it was never applied in civil construction [29]. In fact, engineers based their RC design and calculations on foreign standards during the time between the end of the patent systems and the outbreak of the Spanish Civil War, assisted by the knowledge gained from their studies on RC, the first of which took place, in 1910, at the Faculty of Civil Engineers in Madrid.

The core industrial activity of Northern Spain, mining, ship building, and steel industries, pioneered the use of the new material, where most RC structures were built over the following decades. Numerous examples of RC constructions were built, although some have since been demolished, as a result of economic development and urban and social transformations. These lost examples of heritage were integral to the industrial and the social life of that day and age, and local government has now listed many remaining structures as heritage buildings that stand in testimony to that period of Spanish history.

Figure 1: Two examples of the buildings under analysis: a) Old Aquarium (San Sebastian), b) Villa Ducourau (Irun)

In this study, some common features of 15 RC structures built between 1915 and 1936 will be discussed: 10 from the second decade and 4 from the first decade of the 20th c., and 1 from 1936. All of them are listed heritage and none followed patented RC systems for their construction. Two examples are shown in Figure 1. A collection of 15 pathological structural studies are examined, developed by different architects and engineers as preliminary structural studies. Their common points are their construction in the period between the end of the RC patented systems and the outbreak of the Spanish Civil War, and their location in the Basque Country, north-western Spain.

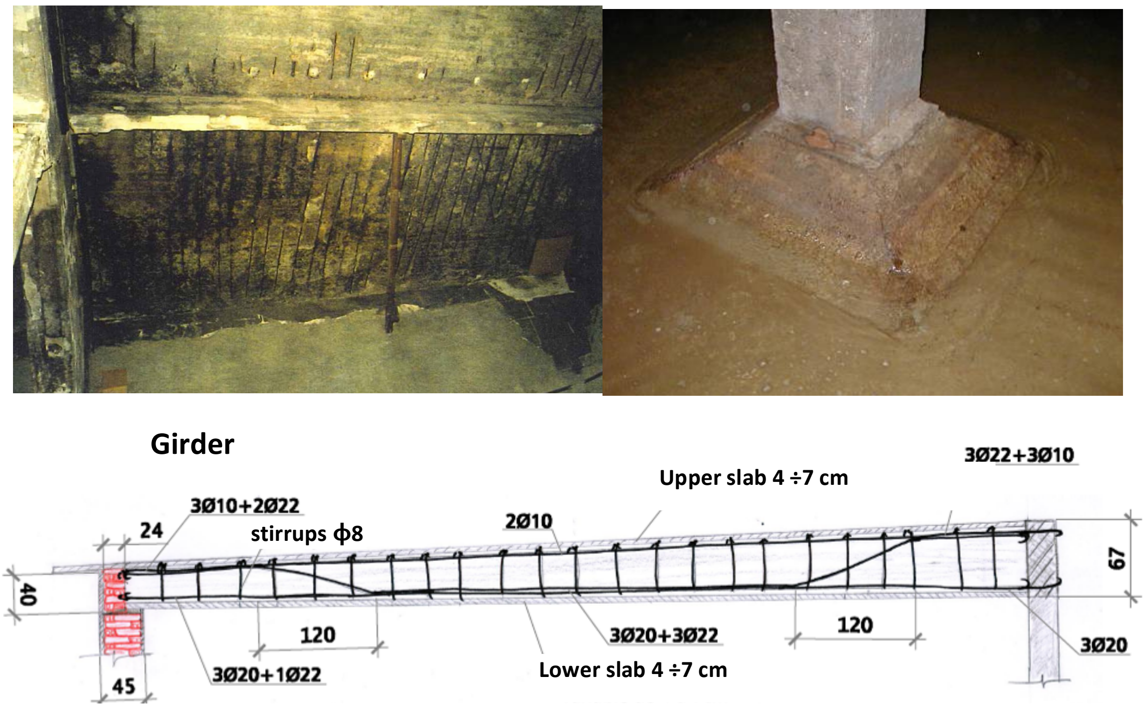

Figure 2: Usual structural layout: a) slab and narrow beams in structure Nr 3, b) trapezoidal foundation (structure Nr 2), c) beam reinforced scheme (structure Nr 6)

Also near all of then have similar structural schemes, with slabs, marrow beams, columns instead of walls and sometimes trapezoidal foundations (figure 2). The theoretical corpus for these studies had been researched in relation to each specific construction in an appropriate way attending to location, age and owner's requirements for building use and the proposed objectives. The scope of the studies may therefore vary, but the methodology used in all of the studies was similar. However, the range of tests and the depth of analysis were conditioned by the purpose that the property served. The most common test of the concrete structure was its compressive strength, although various studies included data from steel strength, steel cover, concrete carbonation depth and chloride ions in the concrete mass.

3.1 Durability

Nearly all the studies included visual inspections for signs of pathologies. Issues related to durability were mainly observed: parallel concrete cracking in longitudinal reinforcements and the appearance of corroded reinforcements, even with cross-sectional reductions, all caused by the corrosion of steel bars. The results are summarised in Table 1; Figures 3 and 4 shows typical structural damage. This pathology was found to affect more than 80% of the structures and can be considered a widespread problem. The remaining 20% included one partial study of a building focused on well-maintained interior parts of the buildings where no corrosion would be expected due to exposure to the interior environment.

Table 1: Main pathologies detected in 15 RC structures

Concrete cracking parallel to reinforcements	87%
Appearance of corroded reinforcements	80%
Cross sectional reduction of steel rebars	67%
Pitting corrosion	53%
Dampness	60%

Environmental exposure to chlorides had affected the structures by approximately 46%, followed by seawater from tidal surges, spray and splash (33%) and by airborne salts (13%), while others had been exposed to moderate humid. It is relevant that more than 50% of structures showed pitting corrosion, connected with corrosion induced by chloride ions in the concrete. The studies concluded that nearly all of them were of internal origin, mainly due to use of coastal sand in the concrete mixture, a frequent practice in coastal areas before 1936. Only one structure was affected by environmental exposure to chloride. The use of chlorides in concrete was not prohibited in Spain until 1973 [30].

Figure 3: Typical rebar corrosion: a) lower side of a slab (structure Nr 5) b) detail of pitting (structure Nr 4)

Information on the carbonation depths of 9 structures was also ascertained. These depths were very variable, between minimum values of 9 mm and maximums of around 160 mm.

Whenever both measures, concrete cover and carbonation depth, were taken, it could be checked that the carbonation depth always exceeded the reinforcement bar depth. An exception was noted in two tests from a column in one the structures, where the depth was close to zero. The zone was in the tidal range, and the water saturating the pores prevented the penetration of air inside. Nevertheless, the columns were highly affected by pitting corrosion.

Figure 4: Cross section reduction in column (structure Nr 15)

3.2 Concrete and steel features

Although precast concrete was available in the period under analysis, it was not common, and all the structures under study were cast in situ. Nearly all the studies included an analysis of the concrete strength of extracted cores, sometimes, combined with ultrasonic velocity pulse tests. The results are summarized in table 2. They show a very variable strength with no regularity: mean strengths of between 9 and 43 MPa and characteristic strengths of between 8 and 30 MPa. The remarkable differences between the mean and the characteristic strengths in each structure were due to the usual variability in concrete strengths. These variations were caused by the methods used in dosing (usually in volume), mixing (low mechanization), on-site transport, compacting (ramming, formwork by hand hammering or a slide bar), and curing [31,33]. Poor mechanical tools for compacting frequently led to the addition of extra water to ensure workability, increasing porosity and variability and worsening the durability of the RC components [10].

Table 2: Concrete strength of extracted cores (MPa)

Structure Nr	1	2	3[a]	4[a]	5	6	7	8	9	10	12	13	14	15
Mean Strength	23	19	15	31 19	23	27	43	9	15	15	25	17	19	24
Characteristic Strength	19	13	13 8	23 13	10	21	30	7	12	10	24	10	10	17

a: two batches were considered

Although ribbed bars were standard, even in proprietary systems, in the United States, smooth bars were used for reinforcing concrete in Spain [32]. A practice that was confirmed by the observations of the structural reports. There were fewer tests on the steel rebars than on the concrete. The results shown in Table 3 showed higher strengths than the values calculated for yield strengths of 220 or 240 MPa, which were considered at the end of the 20th c. for smooth bars.

There were some difficulties obtaining rebar samples, because larger diameter rebars were not used for testing, due to the damage that could have been caused to the structure. The possible rolling effect on yield and tensile strength could not therefore be verified.

Table 3: Steel strength (MPa) of tensile tests

Structure Nr	1	3	4	7	7
Diameter (mm)	15	8	18	8,1	10
Yield strength (MPa)	298	314	311	274	311
Tensile strength (MPa)	396	398	426	383	502

3.2 Condition

Finally, an assessment of the structural condition was completed. Four categories were defined, depending on the severity of the deterioration, which yielded the following results:

- 3 structures with very low levels of damage, including incipient cracking, due to steel bar corrosion.
- 2 with a few pathologies, but with little structural damage; cracking due to corrosion was noted.
- 5 with severe damage, including structural safety risks.
- 3 with very high damage and with very high levels risk for stability and structural safety, including partial collapse, total steel cross-sectional reduction and severely damaged columns.

There was insufficient information to assess the condition of 2 structures, because their pathological analyses were only partial building studies in well maintained areas.

Over 50% of all structures had high levels of damage, mainly with problems of durability linked to steel bar corrosion. High levels of damage due to chloride-ion penetration were noted, especially caused by marine sand used in the concrete mix. This condition had dramatic consequences for the buildings under analysis: 40% had undergone total or partial demolition, while 40% needed structural repair and strengthening.

12 CONCLUSIONS

After analysing the pathological reports on all 15 structures built between 1915 and 1936, from the end of the RC patented systems until the outbreak of the Spanish Civil War, the following conclusions can be presented.

- The concrete structures under study were designed following foreign standards until the Spanish standard was issued in 1939.

- Steel features were frequently not examined in the pathological reports, as their removal from the structure risked excessive damage. Where calculated values were needed, the features for smooth bars were taken from the literature. The test results were necessary, otherwise the mechanical features could have been underestimated.
- Concrete strength was very variable between structures and inside each structure. It was very common and was conditioned by dosage, mixing, *in situ* casting and compacting. Only two structures had characteristic strengths of under 10 MPa, even when variability reduced the characteristic strength. However, that conceptual difference was not common until the second half of the 20th century, after the period under analysis. The characteristic strengths must therefore be interpreted with caution.
- The structural condition of this group of structures had important consequences for their integrity and authenticity. Nearly 80% of them needed a complete structural intervention including total or partial demolition in 40% of cases.
- The damage was due to the combination of environmental exposure, low concrete cover and the influence of chloride ions that are the cause of steel reinforcement corrosion. An endogenous origin of chloride damage should therefore be investigated in structures near coastal areas.

The central message for the conservation of RC heritage is early and correct diagnosis for the provision of proper maintenance planning and to mitigate structural deterioration. A conservation strategy could include more specific dampness protection, and corrosion protection measures, such as cathodic protection, re-alkalinisation, and chloride removal.

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