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Structural Analysis of Historical Constructions

Anamnesis, diagnosis, therapy, controls

Koen Van Balen & Els Verstrynge
Editors

help open

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Early concrete structures: Patented systems and construction features

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ABSTRACT: Reinforced concrete structures came to Spain in the late-nineteenth century, somewhat after the development of this new construction material elsewhere in Europe. Their introduction was pioneered in industrialized areas, especially Northern Spain, under systems first patented in other European countries. Local constructors built structures under patents with little or no explanation for calculation, design and construction technique. Some of these buildings from the recent past are now listed buildings. This study centres on three construction projects under patented systems: Our Lady of "La Antigua", Orduña (Monier system), "La Ceres" flour mill, Bilbao, (Hennebique system) and Alhóndiga, Bilbao (Blanc system). Preliminary structural studies analyzed morphology, reinforcements, concrete strength and pathological processes in each structure. Results are compared with information taken from the patent systems in use at the time. This useful information on the structures, which may be expanded in future research, clearly describes the relationship between their theoretical specifications and the built reality.

1 INTRODUCTION

Reinforced Concrete (RC) was devised in the mid-nineteenth century as an inventive means of strengthening concrete, by placing metallic bars within the concrete mass. The origin of RC is linked to Joseph Monier, who patented a construction system for flowerpots with iron and cement in 1867; a starting point for what would eventually be his construction company. However, there were several earlier inventors, such as Lambot, who exhibited a "ferro-concrete" boat at the Universal Exhibition of 1855, and François Coignet, who built slabs using steel wrapped in concrete, in order to improve slab fire resistance (Coignet 1861), and Wilkinson, who employed metal wires and other profiles to build slabs, patented in 1854 (Collins 2004).

The leading players in the development of RC were industrialists and inventors. They focused on the protection of their patented systems and their economic profitability rather than on its scientific basis. The development and application of structural RC systems was therefore closely tied to the use of proprietary systems.

2 PATENTED SYSTEMS ERA

The proliferation of structural concrete was based on the patented systems up until WWI. Numerous patents had previously been published in both Europe and the United States: in the former, the systems patented by Hennebique, Cottancin, Coignet, Bordenave, Melan, Golding, Matrai, Koenen and Monier may be highlighted (Christophe 1902). The last-mentioned system became widespread in Central and Eastern Europe through the progressive developments by Wayss & Freytag, the German concessionaire. RC structures were therefore constructed with one of the various systems, trusting in its tried and tested reputation.

Several construction business models coexisted. The first was the direct exploitation of the patented system, as in the case of Monier in France. Another was through concessions, granting the right to apply the patented system and to provide consultancy services in the structural design phase. Monier successfully expanded this business model in central Europe. A third approach followed by Hennebique converted the business model into an early multinational. With its headquarters in Paris, it designed and calculated structural building projects in many parts of the world. A general agent in each country had the mission of marketing the patent, managing local concessions and calculating some projects. Pioneering figures in RC under the umbrella of the Hennebique company emerged in various countries: Mouchel in the United Kingdom, Pocheddu in Italy, Ribera in Spain, and Maillart in Switzerland.

The dominancy of patents gradually lost ground as a market mechanism and ended at some point around the start of WWI. The first signs of its demise appeared the compressed head and the tensile reinforcements. Likewise, in the Blanc system, also of French origin, the bending moment was distributed in the same way, but it established the position of the neutral axis at the centre of the rectangular cross sections and at two-thirds of the distance between the centre of the tensile forces and compression forces, in the case of the "T" beams (Marcos et al. 2010). The mechanical properties of both the steel and the concrete considered in the calculation are summarized in Table 4. (Blanc 1902a, Christophe 1902, El Cemento Armado 1901, Revista de Obras Públicas 1897a, b).

5 DISCUSSION

The main features of three early reinforced concrete Spanish structures have been presented. These structures were built with technical support from the patent and the expertise of the builder. The computational methods for these brands were "empirical", insofar as they had no theoretical grounding whatsoever. The arrangement of La Ceres steel reinforcements faithfully followed the Hennebique patented system. However, Orduña and Alhóndiga only partial match it. As may be expected, local builders and designers had to customize solutions to each particular structural case, because sufficient detail was unavailable from the patent. In addition, in the case of Orduña, decades had elapsed since the original Monier patent, and builders applied structural techniques that had considerably improved. Ribera incorporated these advances, applying not only his own proprietary solutions, but others based on Monier, Coignet, Dubois or Bussiron, in accordance with his criteria and experience (Ribera 1902).

The test results on the three buildings revealed design values higher than the patent values (mean concrete strengths of between 16 and 30 MPa compared with design values of between 2 and 4 MPa). This difference between steel design values and test results showed variable mechanical properties, especially with high-diameters bars. These values were not a problem at the time, although numerical evaluations using modern-day codes structure would be desirable. Steel tests on the ends of the diameters, particularly the larger one, are particularly interesting. The concrete in the Alhóndiga building showed a yield strength of below 200 MPa. Taking traditional calculation values for smooth steel, of about 240 MPa, it could represent an underestimation of 20%.

The variability of the results of concrete strength in each structure may be explained by the construction conditions of that period, including dosage per volume, water content, and poorly controlled landfill, compaction and curing (Hellebois et al. 2013). However, the mean strengths can be considered high, especially in cases of Alhóndiga and Orduña, at almost 20 and 30 Mpa, respectively. These results mean that early concretes cannot be associated with low-grade concretes. This is in line with other research developed on early concrete structures (Hellebois et al. 2013).

The greatest threat to these structures is durability, highly conditioned by the presence of chloride ions, detected in both structures. The problems of lack of covering and progressive carbonation depth, increased the severity of the situation. An explanation for the chloride presence in the concrete is found in the proximity to the coast and the use of marine sand. The presence of sea sand has been seen in other pre-Spanish Civil War structures in the same region up until 1940 (Marcos 2014).

The data on the three structures may be used to guide future works on early concrete heritage conservation to identify critical conservation issues to find remedies. At present, no maintenance is done on the Orduña monument and the continuous infiltration of water has not been restricted, so structural damage continues to increase.

The studies that have been conducted may also be used in future studies on heritage structures, complementing information on durability and material characterization.

6 CONCLUSIONS

After analyzing the pathological reports of three early reinforced concrete structures based on proprietary systems, the following conclusions are presented. Proprietary systems and their specifications were based on the original patent, but were always adapted to the structure and the work of local builders and designers. After all, the patent cannot be expected to correspond precisely to the built structure.

Steel-bar testing should include the range of diameters that are employed, in order to numerically evaluate a structure. This procedure ensures that the mechanical properties are not underestimated.

Early concrete from late nineteenth and early twentieth centuries cannot be identified as low strength concrete. The average strength values are, despite their high variability, well above design strengths in patented systems.

The combination of low covering, environmental exposure and the presence of chloride ions in two structures have led to very high levels of degradation. The reinforcement corrosion problems are the biggest threat to their conservation. Consequently, the tasks of conservation and maintenance should establish the cause of the pathology and provide proper maintenance, to mitigate structural damage and the future conservation of the heritage structure.

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