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ScienceDirect

Procedia Structural Integrity 5 (2017) 139–146

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Low durability of concrete elements due to steel corrosion – cases wherein the steel reinforcing bars acted as an internal clock bomb

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Abstract

Concrete elements are expected to resist any process of deterioration to remain its original form, quality and serviceability when exposed to its intended service environment. As the concrete deteriorates durability problems progressively develop leading to structural damage, which might put users in a potential danger. Concrete deterioration may be categorized into three categories of causes: physical, chemical, and mechanical, from which major durability issues come from steel corrosion as a result of combined effect of multi environmental factors. This work reports examples wherein the corrosion of the steel reinforcing bars severely affected the concrete element durability. Five examples wherein the steel reinforcing bars got prematurely corroded, acting as an internal clock bomb for concrete element durability, are reported. It is questioned if the steel reinforcing bars were structurally (un)necessary and if (in)appropriate construction practices were used. Alternative solutions for higher durability are proposed.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: Clock bomb, Corrosion, Concrete; Durability, Steel reinforcing bar.

1. Introduction

In today's society, there is a greater awareness of sustainability, whether economically or environmentally. Due to its characteristics, construction industry plays an important role on sustainability, wherein the concrete performance (mainly durability) is the key factor. Being aware that the production of 1 ton of clinker releases approximately 865

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2452-3216 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.082

kg of CO^2 owing mostly to chemical reactions and fuel consumption in cement production, it is undoubtedly essential to transform the concrete industry into a green industry, i.e. using concrete more efficiently.

In regards to a more efficient concrete application, nowadays more than ever before, constructors and owners are requiring materials that have to fulfill not only economic demands but also issues like productivity, durability, serviceability, quality and environment. Construction stakeholders are becoming aware that, for instance, in regarding to concrete the cost per m^3 is not the unique criterion to select the most profitable composition and that the acceptance criterion based on the resistance to 28 days is becoming obsolete. Factors like the concrete fresh performance and, especially, the cost per year of the life cycle of the structure are also highly valuable (Aitcin, 2000). In the 21st century, to ensure the sustainability of the construction industry, it is mandatory an increasing use of concrete with high efficiency (i.e. with high durability), as by increasing concrete durability, the amount of concrete is reduced by decreasing the number of applications and natural resources are saved.

Unfortunately, the Madeira Island is an example wherein the economic sustainability is being negatively affected by the low durability of its concrete infrastructures. In fact, numerous of concrete infrastructures constructed in the last 25 years are already presenting high deterioration levels. It is then important to understand why several concrete elements have such high level of deterioration. And, where errors were typically committed?

It is well-known that concrete constituent materials in Madeira Island are quite different than the one used to create standards. For instance, both gravel and sand are from volcanic origin and mostly crushed, consequently to reach a similar workability concrete compositions need higher water and sand contents that cause higher porosity, permeability and shrinkage and lower E-modulus (Maia, 2016). On the other hand, due to its geographical location, as an island, it is surrounded by the Atlantic Ocean which means that most of concrete infrastructure face severe environmental conditions during its service life – most of them are exposed to sea winds or even in several cases in they are direct contact with the sea. Therefore, several questions are arisen: (i) are standards entirely appropriate and/or are they being applied correctly in Madeira Island? (ii) are the usual concrete design/construction practices appropriate? To help to answer these questions this work identifies and reports five examples (all from the Madeira Island) of concrete elements wherein the steel reinforcing bars ('rebars') acted "as a clock bomb" due to its corrosion premature. It is questioned: why steel rebars were employed, if could be they dispensed; how steel corrosion deteriorated and affected the concrete element; what should be done to avoid corrosion and what would be an appropriate construction solution.

2. Steel corrosion in concrete

2.1. Corrosion process

Concrete deterioration may be categorized into three categories of causes: physical, chemical and mechanical, from which major durability issues come from steel corrosion as a result of combined effect of multi environmental factors, occurring when water and ions are able to penetrate into the concrete core. This penetration takes place when interconnections develop between isolated microcracks, visible cracks and pores. Therefore, deterioration is closely associated to cracking as well as to porosity, i.e. concrete durability is mainly related to concrete permeability. Being aware that steel corrosion is the dominant cause of premature degradation of reinforced concrete (Santos, 2014), first it important to understand the corrosion phenomenon.

Corrosion is an electrochemical process that results in a loss of function of the element since it produces a new and less desirable material (rust) from the original metal. It requires the simultaneous presence of moisture and oxygen to oxidize the iron in the steel to produce rust (Figure 1.a),b)). As rust occupies roughly six times the volume of the original material, when the process occurs inside of a concrete (steel reinforcing bars) stresses are generated and concrete cracks (Figure 1.c),d)). Consequently, permeability strongly increases, allowing the ingress in the concrete core of more corrosive species that increases corrosion that increases the concrete cracking, and so on. Thus, once corrosion begins in a steel rebar inside of a concrete the process quickly provokes concrete cracks which can appear just as a single crack (Figure 1.e)) or as spalling (Figure 1.f)) or as a delamination (Figure 1.g)).

In terms of chemical reactions, corrosion happens because at the surface of the steel, the major component (iron 'Fe') undergoes a number of simpler changes: $\{Fe \rightarrow Fe^{n+} + n \text{ electrons}\}$. Thus, the iron atom loses some electrons and become a positively charged ion allowing bonds to other groups of atoms that are negatively charged. The free electrons at the presence of water and oxygen creates the group OH^- by the reaction $\{O^2 + 2H_2O + 4e^- \rightarrow 4OH^-\}$ allowing