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Chloride penetration into concrete in an offshore platform-analysis of exposure conditions

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ABSTRACT

The chloride penetration in three different exposure zones (Atmospheric, Splash and Tidal) of an offshore concrete platform in the year 2000 and 2005 was analyzed. Chlorides profiles for different orientations of the analyzed structure were also obtained. The apparent diffusion coefficients and surface chloride contents of concrete specimens were determined by curve fitting of chloride profiles in chloride penetration models based in diffusion. Increase in the chlorides ingress with exposure time was verified and microclimatic factors such as exposure to wind and wetting and drying cycles were the main responsible for the behavior of obtained chloride profiles.

1. Introduction

The durability of reinforced concrete structures in marine environment has been investigated with greater intensity in these past decades due to several reasons. The intense urbanization in coastal areas is responsible for the presence of these structures in this region. Besides, studies show that many times the service life is compromised due to high aggressiveness in this environment (Castro-Borges et al., 2013; Fernández and Pardo, 2013; Ghods et al., 2005; Hirdaris et al., 2014). Finally, there is a growing need for the use of offshore concrete structures in developing countries, such as ports, oil platforms and airports.

The reinforced concrete structures present in marine environment are susceptible to reinforcement corrosion due to the presence of chlorides. The chlorides disposed in marine environment come mainly from seawater. Its contact with concrete structures can happen directly by seawater or through the marine aerosol. After contact, the chlorides are deposited on the surface of the concrete and can penetrate on it through different mechanisms, depending on the characteristics of materials and the environment in which it operates.

The chloride penetration occurs through the concrete pores, particularly by the transport mechanisms known as diffusion and capillary absorption. However, one must note that the greatest depths are observed where the mechanisms can act simultaneously (Liu and Shi, 2012; Song et al., 2004; Wang and Ueda, 2011). The absorption mechanism may be present along with the diffusion in some real environments. Although capillary absorption movement is fast, it is less favored by the discontinuous pore system in concrete (Liu and Shi, 2012); diffusion takes place in an aqueous medium. Therefore, both mechanisms act together mainly in the first layer of concrete, in zones subject to wetting and drying cycles (tidal zone for example). According to some studies (Song et al., 2004; Wang and Ueda, 2011), chloride penetration mechanism is dominated by diffusion in deeper depths where the indoor humidity is more stable.

Considering the quantification of chlorides ingress in concrete, in a practical way, the profiles obtained in existing structures adjusted themselves, in a satisfactory way, to the diffusion phenomenon (Medeiros et al., 2009; Ramli and Tabassi, 2012).

Due to different characteristics of attack, resulting mainly from different accesses of oxygen and humidity, the marine environment is divided in different zones of aggressiveness. These zones are segmented having the sea level as reference, and are defined as follows (Duracrete, 1999; Mehta and Monteiro, 2005):

Atmospheric zone – Concrete suffers the action from marine aerosol, however the structure is not affected directly by water splashes. The winds can carry the salts in the form of solid particles or as droplets of saline solution. The quantity of salt present decreases as a function of the distance from the sea, suffering influence of speed and prevailing wind directions. The

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main mechanism of degradation present in this zone is the corrosion of reinforcements by chlorides action and carbonation. The chloride penetration may be affected by carbonation in this zone and some studies (Demis and Papadakis 2012; Zhang and Zhao 2012) try to understand the interaction between carbonation and chloride penetration in concrete.

Splash zone – Zone immediately above the maximum level of intertidal variation. In this zone, the concrete is directly affected by water splash. The height of the splash zone is a function of the wave height, as well as of the speed and wind direction. The most significant damage found in this region is produced by reinforcement corrosion by chlorides. The splash zone is subjected to cycles of wetting and drying and this phenomenon becomes more significant as the water evaporates and the salt remains into the concrete. This region not only suffers an intense contamination, but is also supplied with sufficient amounts of water and oxygen so that the corrosion process develops.

Tidal zone – It is the concrete zone between the minimum and the maximum level of tides, governed by their variation. This region is also subjected to the wetting and drying cycles action. Degradation occurs due to the action of aggressive salts (chemical attack), reinforcement corrosion, waves' abrasive action and other substances in suspension, and attack of microorganisms.

Submerged zone – It is the region where the concrete is below the minimum tide levels, or permanently submerged. Degradation happens by the action of aggressive salts (example, sulfates and magnesium) and by the action of microorganisms. This type of exposure was not analyzed in this study because it is not considered as an attack of reinforcement corrosion caused by chlorides, since the difficulty of oxygen access restricts the corrosion rate to very low levels.

Ghods et al. (2005) consider that exposure zones play an important role in the service life design of concrete structures that should be concerned as a main input parameter in models. This means that in many cases, a model that is related to only one type of exposure zone relative to the chloride attack, should not be generally used. Thus, the expected life of a structure in a marine environment needs to be considerable different depending on the 4 exposure zones previously mentioned.

Although the importance of this article subject, it appears that there are few data in literature discussing the evolution of chlorides penetration with the time in a same real concrete structure. It is possible to understand that this data gap is due to the high degree of difficulty to access these types of structures, since often these buildings belong to private powers with restricted access.

Thus, it is observed that many papers periodically verify the ingress of chlorides in concrete specimens exposed to marine environment (Ghods et al., 2005; Moradllo et al., 2012; Peterson et al. 2013; Ramli and Tabassi, 2012; Wang et al. 2013). However, it is still unclear the representativeness of the acquired data in specimens when compared to real structures. It should be taken in consideration that an offshore structure, such as a concrete platform, generally has larger dimensions and are subject to a number of factors that are not accounted for in the concrete specimen.

In this context, this is an inspection work of a real reinforced concrete structure, and produced important data about a real building submitted to natural aging in marine environment. It can be compared to a specimen left in the environment for decades and with the possibility to be studied nowadays. However, a study like this has some difficulties that are inherent to a real structure. Unlike a laboratory study involving specimens molded to a particular study, in this case, there are many unknown variables at inspection time, such as: variation in the loading level of the structure, influence of different active microclimates, uniformity and proportioning in the concrete mixture, changes along the building, changes in cement and others. These difficulties make the inspection work more interesting, however more difficult.

Therefore, the aim of this paper is to verify the behavior and durability of an offshore platform built in Brazil through the verification of degradation levels presented by the platform and the evolution of chlorides penetration. For this, it will be taken in consideration tests performed in 2000 (Pereira, 2003) and 2005. The chlorides measured in profiles are compared with those obtained using a model for chloride ingress which is based on diffusion.

We recognize that the number of samples obtained is not extensive, making it difficult to perform more precise statements. For future work on real structures, it is recommended to carefully plan the local of samples extraction and the number of specimens required for a more complete approach. However, this study is relevant because gives guidelines that there is some influence of microclimate on chloride penetration, and therefore, opens an important field of study to draw attention to include these variables in models of service life. The aim of this article was not to show how to include these variables in the models, but to demonstrate, using data obtained in real structure, that microclimate is important (change the profiles of chlorides) and should be carefully studied and incorporated in the models.

2. Existing data platform

In this item, the data available in literature for the offshore platform considered in this paper were approached. In 2000, Pereira (2003) performed a series of tests in the platform. Among these tests is the determination of chloride concentration in different points of the platform. The main characteristics of the material constituting the platform and the environment surrounding it are presented next.

2.1. Features of the platform

The platform selected in the present study is located in the state of Rio Grande do Norte, north-eastern Brazil, at an approximate distance of 12 km from the coast. The structure was built in 1976 with

Table 1
Characteristics of the platform concrete. Adapted from Pereira (2003).

Cement type	Ordinary Portland Cement (OPC) – maximum C_3A content of 8%
Mean cement content (kg/m^3)	526.11
w/*b* ratio	0.42
Apparent density (kg/dm^3)	2.354
Total porosity (%)	11.34
Additives	Plasticizers and hardening retarders
Compressive strength (cylindrical specimens) (Mpa)	56.95
Minimum cover (cm)	4–5