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Assessment of service life models for determination of chloride penetration into silica fume concrete in the severe marine environmental condition

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HIGHLIGHTS

- Five year-old concrete jetties were investigated in various exposure conditions.
- The time of corrosion initiation were estimated by four service life models.
- Remarks on the diffusion coefficient and surface chloride are shown.
- Micro-environmental properties have great influence on chloride penetration.

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ABSTRACT

In the last decades, the Persian Gulf region has experienced significant development in marine construction. But many RC structures are showing signs of deterioration, mainly due to the chloride-induced corrosion of reinforcement. The aim of this study is assessment of basic parameters in long term chloride penetration in severe marine environmental condition. Therefore, five year-old concrete jetties were investigated depending on two parameters, (a) construction method: in situ and precast, (b) exposure conditions: atmospheric, splash and tidal zones. Also some accelerated durability tests were performed on standard samples having similar concrete mixture. Finally, theoretical chloride penetration profiles and corrosion initiation time were estimated by four service life prediction models. Experimental results showed all concrete properties are complying with relevant durability requirements and micro-environment characterization has great influence on chloride penetration. In addition, the obtained results from service life models showed the existence of various uncertainties in parameters of chloride penetration.

1. Introduction

Several factors affect on durability of reinforced concrete structures located in marine environments. However, numerous studies indicate that the predominant reason of reinforced concrete deterioration is chloride-induced corrosion. If the amount of diffused chloride ions on the surface of the reinforcing bar reaches the threshold value, the steel bars embedded in concrete undergo depassivation and corrosion initiates. With propagation of corrosion, the corrosion products can expand more than 5–6 times of intact reinforcement. Subsequently, concrete cover deteriorates by cracking, delimitation or spalling [1]. Although exposure conditions to which concrete structure is subjected in marine environment, plays an important role on the chloride penetration, there is not enough field investigation all over the world in order to quantify its effect on the rate of chloride penetration into concrete. The severe environments of Middle East, South Asia and other "hot belt" countries have shown themselves to be particularly harsh on concrete structures subjected to marine environments. Considering the location of structural elements in relation to seawater level, five exposure conditions could be introduced including splash, tidal, submerged, soil and atmospheric zones. In each of these zones, the mechanism of chloride penetration into concrete is different and is influenced by environmental conditions [2]. The previous studies [3,4] show that maximum amount of the diffusion coefficient of chloride ions (D) and the surface chloride content (C_s) are related to tidal and splash zones, respectively.

Castro et al. [5] studied chloride concentration profiles from field exposed concrete and revealed that the environmental conditions of the tropical marine climate in cylindrical concrete specimens promoted the formation of two zones: one internal that is always dampened and one external that is always wetting and

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drying. Costa and Appleton [6] exposed 54 concrete panels to marine environments for 3–5 years, and the study examined three concrete mixes and five exposure conditions (from the tidal to the atmospheric zone). It concluded that both the chloride diffusion coefficient and the surface chloride concentration were time-dependent, which has considerable implications in predicting the chloride ingress into concrete and the risk of rebar corrosion in concrete. Therefore, challenges are inherent in assessing concrete durability from its chloride diffusivity.

Through the use of concrete deterioration models, cost-effective decisions can be made concerning the appropriate time to repair or replace existing structures, and the most effective corrosion control strategies [7]. The effect of environmental conditions on the prediction of the models is one of the most important issues. Hence, regional investigations are necessary. This is particularly important in harsh environment such as Persian Gulf region where structures have been characterized by short service life spans compared to their counter parts elsewhere [8–10]. Recently, Ramezanianpour et al. [11] proposed a modified fib service-life design model for predicting the service life of reinforced concrete structures in the Persian Gulf environment.

The aim of this study is the assessment of the basic parameters in long term chloride penetration in the Persian Gulf marine environment. For this purpose five year-old concrete jetties located in the north–west of Persian Gulf were investigated considering two parameters, (a) construction method: in situ and precast, (b) exposure conditions: atmospheric, splash and tidal zones. Also some accelerated durability tests were carried out on standard samples having similar concrete mixture in the laboratory. Finally, theoretical chloride penetration profiles and corrosion initiation time were estimated and compared by four service life prediction models.

2. Description of structures and materials

The level of chloride transport may be varied to a large degree by the location of structure, the degree of exposure to chloride environment and weathering condition with regard to temperature and humidity. Therefore, the climate has a crucial impact on the rate of chloride transport. Song et al. [12] compared the chloride transport of concrete from three different latitudes: in the UK, Japan and Venezuela. Then they found that concrete structures exposed to a tropical environment are more susceptible to chloride attack, and concluded that the tropical climate is a worse condition for chloride ions penetration due to the high level of relative humidity, temperature and chloride concentration.

Table 1
Climatic features in BIK zone.

Feature	Amount	Unit
Average maximum temperature	35	°C
Average minimum temperature	12	°C
Absolute maximum temperature	50	°C
Absolute minimum temperature	6	°C
Average relative humidity	46	%
Absolute maximum humidity	96	%
Absolute minimum humidity	8	%
Yearly average of dusty days	87	Day

Source: I.R. of Iran Meteorological Organization website (www.weather.ir).

In this study, under investigated jetties are constructed in the latitude 30°, 25′ N and longitude 49°, 4′ E at a distance of 65 km from the mouth of Persian Gulf that is called BIK(Bandar Imam Khomeini) zone. These reinforced concrete structures were built in 1927–41 and were totally rehabilitated in 2004–07. Fig. 1 shows some pictures of location and present condition of investigated structures.

According to Table 1, the climatic conditions of the Persian Gulf region are characterized by high temperature with salt-laden humidity and large fluctuation in the diurnal and seasonal temperature and humidity. In addition to the severity of climatic conditions, the amounts of chloride and sulfate ions are higher than that found as the average of the Persian Gulf seawater. Semi-close nature of the region, type of ocean current system, high level of evaporation, not much of rainfall and not much freshwater inflow of rivers may be the main reasons for high salinity of the seawater in this region [13].

Based on the available official documents, investigated parts of structures have the same concrete mixture. The raw material characterization and concrete mixture features are reported as follows (see Table 2):

(1) Cementitious materials: the cement was type I(PM) blended cement from the Bushehr factory, conforming the ASTM C595 standard. In addition to the blended cement, silica fume was used containing 88.5% SiO_2 with pozzolanic activity index 103% and meets other requirements of ASTM C1240 standard. The chemical compositions of cement and silica fume are shown in Table 3.

Fig. 1. Location and present conditions of Eastern and Western jetties in BIK zone.