ESTIMATION OF SERVICE LIFE OF REINFORCED CONCRETE IN MARINE ENVIRONMENT OF SOUTHERN VIETNAM

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BẢN TÓM TẮT

Sự giảm tuổi thọ của kết cấu bê tông là kết quả tổng hợp của nhiều quá trình phản ứng vật lý cũng như hoá học. Những phản ứng này có thể là sự ăn mòn dưới tác động của axit hay bị kiềm hoá, sự tác động luân phiên của môi trường khô và ẩm ướt, giữa lạnh và nóng, v.v… Tuy nhiên, quá trình có tác động ảnh hưởng nhiều nhất vẫn là sự ăn mòn cốt thép trong kết cấu bê tông bởi sự thâm nhập của ion clorua. Chính vì thế, yêu cầu cần có một mô hình để dự đoán tuổi thọ của kết cấu bê tông gây ra bởi quá trình ăn mòn này là một đòi hỏi cấp thiết. Tuy nhiên quá trình rất phức tạp bởi nó tổng hợp xây dựng nên không chỉ từ lý thuyết mà còn có những quan sát từ thực tiễn, thí nghiệm. Bài viết này dựa trên những kiến thức có được từ những cuộc nghiên cứu có được của những người đi trước nhằm xây dựng một mô hình đơn giản phù hợp với điều kiện môi trường của Việt Nam để dự đoán tuổi thọ kết cấu bê tông dưới ảnh hưởng của quá trình ăn mòn cốt thép bên trong. Nhằm minh họa cho mô hình này, ví dụ về cầu Cần Thơ sẽ được đưa vào xem xét.

ABSTRACT

Deterioration and distress of concrete structures in service is a result of a variety of physicochemics processes. These processes include attack by acids or alkalis, cycles of wetting and drying, freezing and thawing, alkalis – aggregate reaction, etc. However among the most serious deterioration processes are those caused by corrosion of rebar. Moreover, up to date, the accurate service-life prediction of steel reinforced concrete structures is getting more and more attention. Needless to say, the most advanced models on durability of concrete are found in the field of chloride-induced corrosion. Conversely, a simple and ease to use approach from these models that can apply in practical conditions is an imperative. The current paper tries to apply available models with local environmental conditions in order to derive a practical model which is a combination of theoretical and empirical approaches. Furthermore, an application for Can Tho Bridge is also considered.

1. INTRODUCTION

The sea is a harsh environment. As man tries to trespass in this forbidding world, the sea will strive relentlessly to undo his handiwork. Any objects that he places in or even near the sea, the sea will attempt to devour. The deterioration of materials or structures in the sea may be brought about by the single or combined agencies of physical abrasion and chemical corrosion. So far, corrosion in concrete is a worldwide problem and a lot of money is spent each year on repair and replacement of reinforced concrete structures. Chloride induced corrosion is the major type of corrosion encountered in reinforced concrete.

Vietnam is a country with a very long coast line as well as a complicated rivers and streams system. With this kind of environment, the problem of steel corrosion needs to pay more attention. Furthermore, up to date, there are more and more bridges built such as My Thuan Bridge, Rach Mieu Bridge, etc. Therefore, an evaluation of the service life of these bridges is worthy and necessary for the maintain work. From this desire, an ease to use approach based on the mechanism of chloride diffusion process through inhomogeneous material is developed. There also present in the current paper some output results by using this approach.

2. MARINE ENVIRONMENT OF SOUTHERN VIETNAM

There are many marine environment parameters that influent the durability of concrete structure such as temperature conditions, humidity conditions, precipitation and surface condensation, running water, water pressure, chloride conditions and carbon dioxide conditions. The current case only takes into account the local parameters temperature conditions and chloride conditions. For the temperature conditions, according to research carried out by Penjan R. A. [1], the average temperature near the Mekong river mouth is about 29.5 Celsius.

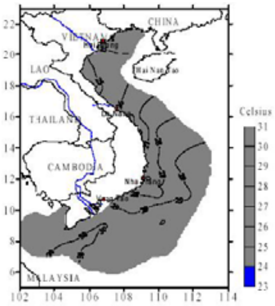

Fig.1 Ambient temperature

Regarding chloride condition, by investigating collected data of salinity from Gulf of Thailand stations and Mekong river mouth stations, Penjan R. A. concluded that salinity concentration of Mekong river mouth has an influence from Gulf of Thailand. Therefore, in the current paper, it is assumed that the chloride concentration of Mekong river mouth is equal to that of Gulf of Thailand and the chloride ion concentration Q_{Cl} is 24, 313 mg/l [2].

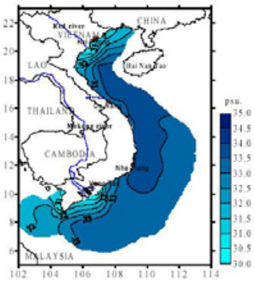

Fig.2 Salinity in seawater

3. CHLORIDE DIFFUSION PROCESS

Among diffusion, permeability and absorption, diffusion is the main process that governs the transmission processes by which chloride ions can transfer through reinforced concrete structures.

Regarding Browne [3], the service life of a concrete structure in marine environment normally consisted of two definite stages, the initiation period and the propagation period. The initiation period is the time during which changes, usually in interaction with the surrounding environment (chloride condition in the current case), in the concrete take place until, eventually, a limit is reached and damage begins to propagate. In the propagation period, the initiated damage continues to propagate (corrosion of steel in the present case), cracks are formed. In this paper, the service life is defined as the time from construction until the chloride content at the depth of rebar is high enough to initiate corrosion, and it is also the time for maintenance.

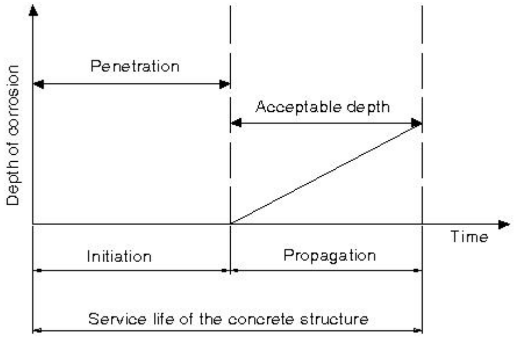

Fig.3 Browne model of service life of concrete structure

3.1. Initiation phrase

Since Collepardi [4, 5] reported his application of Fick's second law of diffusion, his assumption is used by many researchers with the purpose of predicting chloride ingress in concrete. According to Fick's second law, one dimensional mathematical model of chloride diffusion in isotropic medium is governed by the differential equation as follows:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (1)$$

Where: D = the diffusion coefficient measured

Since D is a function of time t, the solution of the diffusion equation (1) can be solved for a boundary conditions problem with constant initial chloride condition by applying the finite difference method.

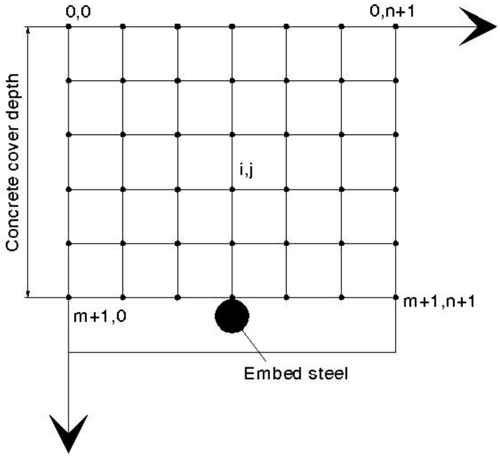

Fig.4 Finite difference method

3.2. Initial chloride concentration C_0

Initial chloride concentration is measured as the concentration at the surface of concrete within thickness of 0.5 in = 1.3 cm. With assumption that initial chloride concentration is constant and capillary pores in concrete are filled with sea salt completely, the percentage of initial chloride concentration on cement weight can be computed as follows:

$$C_0=\frac{V_C}{C}\times Q_{Cl^-} \tag{2}$$

Where: C_0 = initial chloride concentration

Q_{Cl} = quantity of chloride in sea water or river water = 2.4313 for current case.

C = quantity of cement per 1 m^3 of concrete

V_c = volume of capillary pores which can be computed as follows:

$$V_C=\left(w/c-0.382\times h\right)\times C \tag{3}$$

Where: w/c = water cement ratio

h = degree of hydration = $h_{max}e^{\left[-A(\ln t)^{-B}\right]}$

Where: h_{max} = 1 for w/c ≥ 0.39 & $\frac{w/c}{0.39}$ for w/c < 0.39

$$A = \text{constant} = -\frac{\ln(\frac{h_1}{h_{max}})}{[\ln 24]^{-B}} \tag{4}$$

$$B = \text{constant} = \frac{\ln\left[\ln(\frac{h_2}{h_{max}})/\ln(\frac{h_1}{h_{max}})\right]}{\ln\left[\frac{\ln 24}{\ln(2.5\times 365\times 24)}\right]} \tag{5}$$

$$h_1 = 0.48x\sqrt{w/c}\times e^{-\frac{E}{R}\left(\frac{1}{T}-\frac{1}{293}\right)} \tag{6}$$

$\frac{h_2}{h_{max}}$ = 1 for w/c ≥ 0.625 & 1.265x$\sqrt{w/c}$ for w/c < 0.625

E = energy of activation = 36,000 J mol^{-1}.

R = gas constant = 8.31447 J mol^{-1} K^{-1}.

T = absolute temperature Kelvin.

3.3. Chloride diffusion coefficient D

It is well-known that chloride diffusion coefficient D is a function of mix proportion, water cement ratio, temperature and time. Basically, chloride diffusion coefficient D is known that decreasing with time and it can be computed according to the work carried out by Takewaka K. el al [6] and Mangat P. S. [7] as follows:

$$D = D_{ref}\left(\frac{t_{ref}}{t}\right)^m \tag{7}$$

Where: D_{ref} = diffusion coefficient at referenced time t.

m = constant (depending on mix proportions).

For ordinary Portland cement with referenced time t = 28 days and referenced temperature T = 293 ^{0}K, the value of D_{ref} and m can be computed according to Kyle Stanish et al 2003 [8]:

$$D_{28}=1\times 10^{(-12.06+2.40\times W/C)} \tag{8}$$

$$m = 0.2 \tag{9}$$

Since the reference diffusion coefficient is measured at reference temperature T = 293 ^{0}K, it needs to be transformed to the local temperature conditions by applying Arrhenius equation as follows:

$$D = D_{ref}\left(\frac{t_{ref}}{t}\right)^m \times \exp\left[\frac{U}{R}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\right] \tag{10}$$

Where: U = activation energy = 36,000 J mol^{-1}.

R = gas constant = 8.31447 J mol^{-1} K^{-1}.

T = local absolute temperature Kelvin.

3.4. Threshold chloride

Threshold chloride is taken as the point at which the chloride content at the depth of reinforcement is high enough to start the propagation phrase. There is no fix value for the threshold chloride. Some values from literatures can be seen from table.1:

Table 1. Threshold chloride

Source	Threshold chloride
ACI 222	0.20
ACI 318	0.20
BS 8110	0.4
Australian codes	0.60
Norwegian codes NS 3420	0.4
RILEM	0.4

Note: Values specified by ACI 222 and BS 8110 are codal limits and not true threshold values for onset of corrosion.

4. APPLICATION

In order to make the application of the current approach more clearly, an application for Can Tho Bridge is investigated in order to get the estimated service life of the abutment wall of this bridge.

4.1. Background information about Can Tho bridge

Can Tho bridge is a new cable-stayed bridge of 500m main span with steel box girder in the central part of main span and prestressed concrete box girder in the remaining part of the structure. The 2.75km-long bridge spanning the Mekong River tributary links Vinh Long Province with Hau Giang Province, and have a 4-lane carriageway measuring 26m in width. It also has a clearance of 39 meters. Furthermore, when completed, Can Tho Bridge will be the longest cable-stayed bridge in Southeast Asia.

4.2. Input values

The input values for the case study Can Tho Bridge [9] are as follows:

Table 2. Concrete properties for abutment wall

Class of Concrete	E
Specified Strength (Mpa)	24
Cement Content (kg/m3)	350
w/c	0.55
Air Content (%)	3
Maximum Size Of Coarse Aggregate (mm)	20
Concrete cover depth (cm)	8

Table 3. Initial & threshold chloride concentration

w/c	0.55
Cement content (Kg)	350
Degree of hydration	1
Capillary volume for 1m^3 concrete (dm^3)	58.8
Initial chloride concentration	0.408
Threshold chloride concentration ACI 318	0.2

Table 4. Chloride diffusion coefficient for Ordinary Portland cement

w/c	0.55
Temperature Celsius	29.5
D_{28} (m^2/s)	$1 \times 10^{-10.74}$
m	0.2
Reference time (years)	0.077
Reference temperature (^{0}K)	293
Temperature (^{0}K)	302.5
Chloride diffusion coefficient	$D = 15.904 \times 10^{-11.74}\left(\frac{0.077}{t}\right)^{0.2}$

4.3. Output values

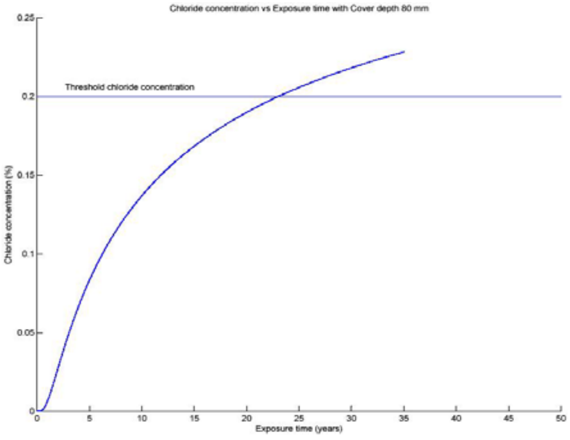

Fig.5 Chloride concentration vs. Exposure time at cover depth 80 mm

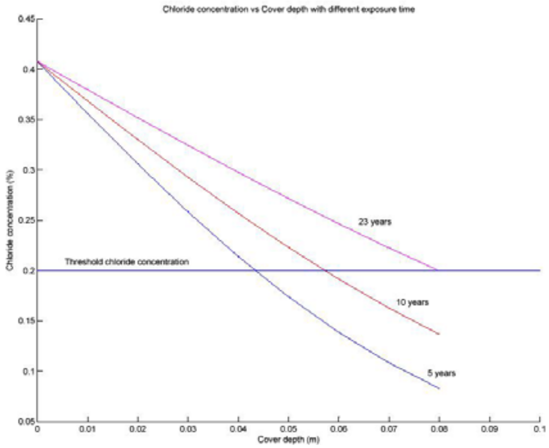

Fig.6 Chloride concentration vs. Cover depth with different exposure time

According to the above figures, it can be obviously seen that the time end of initiation phrase is 23 years. Therefore, the estimated service life of the structure is about 23 years. After this time, the structure needs to be maintained in order to continuous its service.

5. CONCLUSIONS

This approach can be applied for predicting the service life of other concrete structures with the same exposure conditions based on the input data of cover depth and concrete properties. On the other hand, the properties of concrete or cover depth can be designed in the way to obtain a certainly desired life-time of a concrete structure, for instance 100 years of service life. However, due to the simplification of the current approach which only takes into account the effect of chloride concentration conditions and temperature conditions, a further study is required to investigate this approach which other environmental actions, for instance humidity conditions.

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