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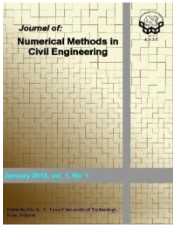

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The impact of environmental conditions of the Persian Gulf on the probability of chloride corrosion initiation in reinforced concrete structures

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Abstract:

According to the technical literature, the amount of chloride transported by air from the sea surface depends on the amount of salt in that area's seawater, the wind's speed and direction, and the distance from the sea. Accordingly, data on the highest annual wind speed and direction of the wind are collected in several reinforced concrete structures (RC structures) in southern cities near the Persian Gulf at different distances from the sea. In this paper, by applying probabilistic modeling and utilizing the Hasofer–Lind and Rackwitz–Fiessler (HL-RF) method of reliability by aligning the enhanced Colliding Bodies Optimization method (ECBO) algorithm, and utilizing the data from the National Meteorological Organization for concrete structures located in different distances with different speeds and directions of the wind from the Persian Gulf, the time of chloride corrosion initiation in reinforced concrete structures and the durability of these structures has been surveyed.

1. Introduction

The corrosion process of reinforcements in RC structures is complex to the extent that, in addition to the quality and properties of concrete, it is highly dependent on environmental and external factors [1,2]. Identifying the initiation of corrosion of reinforcements in RC structures holds crucial significance. Because after the corrosion initiation, damage and capacity reduction continue with great intensity [2,3].

The destructive impacts after the corrosion initiation have been mainly on decreasing the compressive strength of concrete, the load-bearing capacity of reinforcements in pressure and tension, and eventually, on reducing the load-bearing capacity of the structural members and the entire reinforced concrete structure and even under particular circumstances, it may lead to failure or obsolescence before the structural design period [4,5]. Given the uncertainty of many variables in influential factors and contributors involved in the chloride corrosion process, most investigations and regulations utilize reliability-based probabilistic methods to study the durability of concrete structures [6,7]. Using advanced meta-exploration methods, Shayanfar et al. examined the possibility of corrosion in RC structures with different structural quality and environmental conditions [8]. He carried out corrosion-related calculations according to Kaveh et al.'s research, which examines the reliability of structures [9].In Iran, marine conditions play a substantial role in the threat of RC

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structures due to chloride attacks [10, 11].In another study in the country's coastal areas, Shayanfar et al. compared the probability of starting corrosion in tidal and spraying conditions with variable mean values and standard deviation of the parameters affecting corrosion initiation [12, 13]. Chloride ions, diffused by the bursting of bubbles at sea level in the region's atmosphere, are transmitted far distances by wind [1, 10, and 14]. Although the ambient temperature can affect the amount of chloride in the area, the impact and intensity of that may require environmental testing and data [1]. The higher the wind speed in the regions, the more chloride is diffused to a greater distance [15]. Besides, the greater the distance from the sea, the lower the amount of chloride in the region [15, 16]. According to the Fitzgerald study in the spraying area, as the wind speed increases above 3 m / s2, the chloride levels in the more remote areas also increase [17].In this context, probabilistic methods have been utilized to determine the probability of corrosion occurring to predict the service life of RC structures [18-22]. Feliu et al. concluded that, by increasing the distance from the sea, numerous parameters such as wind conditions, waves, and hydrodynamic behavior of water levels affect the amount of surface chloride [23]. Alinaghimaddah et al. Considered the impact of corrosion at different distances from the sea by inspecting valid and different methods. However, in their work, the effects of wind speed and direction were not included in the analyses [24]. The effect of the amount of chloride transferred becomes significant when the wind speed exceeds 7 to 11 m/s [16]. In terms of chloride ion spraying area from marine areas, in addition to the effect of wind, which leads to the diffusion of chloride ions to farther distances, gravity is also effective as a barrier to transferring ions to remote distances [25-27].

Hasandoost et al. used Monte Carlo simulations to investigate the effects of corrosion in RC elements. In this regard, they studied the remaining area of reinforcements, changes in yield stress, ductility, and flexural capacity of RC beam sections under propagating corrosion. These changes were applied to a singly reinforced beam model, and its behavior at the flexural limit state was investigated. Results indicated that statistical dispersion in the remaining area of rebars and their yield stress increases over time. As a result of a decrease in yield stress, the balanced steel ratio in cross-section increases [28]. Jafary et al. predicted the starting time of corrosion using probabilistic and non-probabilistic methods. Corrosion initiation time has been investigated using Monte Carlo simulation probabilistically. They have also considered the effect of surface chloride concentration and the water-cement ratio. Calculations and results for corrosion initiation time based on various distances from the shore, water-cement ratio, and failure probabilities have been compared [29]. Zacchei et al. Have proposed a new multi-factor and multi-phase model to explain some of the effects on chloride surface concentration in the convection zone. They collected 136 values to identify the position and concentration of chloride at the boundary between the diffusion and convection regions. Advanced numerical solutions for space and time have also been developed. Results show that the error function-based solutions could underestimate the chloride concentration C for periods < 10 years and for concrete depths > 4.0 cm compared to the proposed model [30]. Valdes et al. Conducted a study of atmospheric corrosion of CT-3 carbon steel in the traditional coastal region of Havana. The primary purpose of classifying atmospheric corrosion according to carbon steel was the main metal material used in the construction industry. Monthly and cumulative behavior of steel corrosion rates, as well as factors affecting kinetics, were analyzed. The effect of climatic factors on chloride and sulfur compound deposition was also analyzed. The obtained results allow the appropriate selection of primary and secondary protection systems for the structures to be reconstructed and constructed in the study area [31]. Guerra et al. Investigated the atmospheric corrosion of exposed carbon steel in a tropical coastal region of Manabí, Ecuador. The samples were exposed to six outdoor exposures at different distances from the sea. The wind speed threshold was set to increase the chloride deposition rate. The interaction of the chloride deposition with the RH temperature complex and the wind velocity shows a statistically significant effect on the corrosion of the low-carbon steel atmosphere[32].To predict the onset time of corrosion, Hamidan et al. Considered the uncertainties in the parameters affecting the onset of corrosion. They concluded that the proposed method is beneficial in assessing the onset time of corrosion of RC structures, especially new structures[33].A study by Troung et al. Focuses on a definitive and probabilistic analysis of service life (or repair application time) for RC assets that have been repaired with chlorine attack techniques in severe marine environments exposed to chloride attack [34].

According to studies, most discussions have been about the probability of corrosion for structures in water, tidal, and splash zones. In the atmospheric zone, the simultaneous effects of wind speeds and directions in different regions with different distances from the sea on the probability of chloride corrosion occurrence at different distances from the sea are not considered. In this research, the wind conditions of the region in the southwestern regions of Iran in the north of the Persian Gulf have been gathered following the available data from the National Meteorological Organization. After conducting the compatibility test for the available data for the maximum wind speed values, the parameters related to this distribution and the mean and standard deviation values were determined. Considering the conditions in some parts of the Persian Gulf, the corrosion initiation process of reinforcement in RC structures is examined.

Furthermore, in most studies, Simulation-based methods are used, and some effects, such as the importance of each parameter, were ignored. By using the ECBO optimization method, we can compensate for this defect. So, reliability-based ECBO optimization is developed for this reliability-durability problem.

2. Corrosion process of rebar buried in concrete

The concrete environment is very alkaline due to the products of cement hydration, especially CaOH2 (pH between 12 and 13), which causes a thin layer of iron oxide to form on the surface of the rebar, preventing corrosion [30]. One of the most critical factors in eliminating this passive layer is the impact of steel corrosion on reinforced concrete members.

2.1 Corrosion model

Chloride ions in the corrosion initiation process do not bond or react. In other words, they act like catalysts, which means that they help break down the zinc oxide layer on the steel and speed up the corrosion initiation process. The penetration of chlorine ions causes local corrosion, also called Pitting Corrosion [30].

According to the technical literature, the diffusion of chloride ions into concrete follows the second Fick law, as follows [31]:

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

Crank's solution of the above equation with considering the boundary conditions, assuming that the first law of diffusion is valid and it is one-dimensional, the amount of chloride at depth x from the concrete surface at time t is obtained from the following equation [31]:

$$C(x,t) = (C_s - C_0)[1 - erf\,(\frac{x-\Delta x}{2\sqrt{D_{app}t}})] \quad (2)$$

In the above equation, C (x, t) is the amount of chlorine ion at time t and depth x of concrete, Cs is the amount of chloride concentration at the surface (that depends on the distance from the sea, wind speed, and direction), the erf(.) is error function or Gauss error function, D_{app} is the apparent chlorine diffusion coefficient in the concrete environment, t is time, x is rebar cover or concrete cover, is convection depth in case of the tidal zone. Since this study assumes that the buildings were built at a distance from the sea, the convection zone has been eliminated in the calculations. The amount of primary chloride in concrete, assuming proper quality control of construction, has not been considered in the calculations according to the references [21, 39].

2.2 The surface chloride (C_s) model

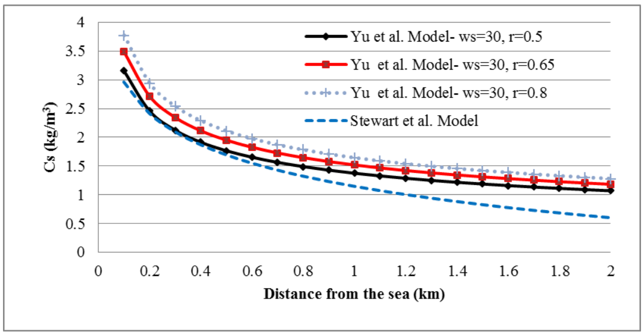
It has previously been mentioned that chloride ions are transported by wind to farther distances in coastal areas. It is estimated that winds can diffuse these chlorides up to 3 km and sometimes more [17, 23]. The focus of the spraying chlorides on the surface of the reinforced concrete members depends on environmental conditions, topography, wind speed, the structure's orientation, the desired concrete member, and the distance from the sea [32].In Equation 1, the value of the parameter C_s depends on the environmental conditions in which the structure is located. In this section, we will introduce two important relationships presented by researchers to investigate the effect of distance from the sea, wind speed, and wind direction on corrosion initiation time. Given the study of Yu-Chen Ou, the equation of calculating the value of Cswith considering the parameters of distance from the sea, wind speed in the environment, and wind direction are as follows [32]:

$$C_s = 0.988[1.29r(w_s^{0.386})(d_{s0}^{-0.952})]^{0.379} \quad (3)$$

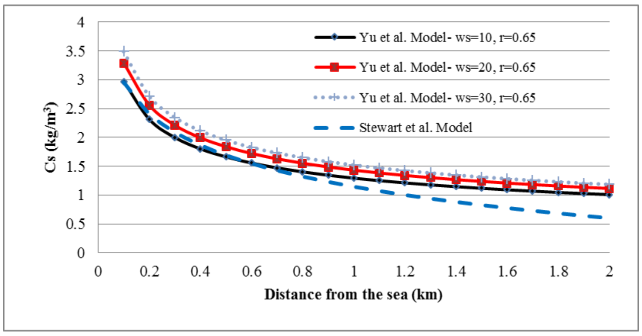
In the above relationship, w_s is the average wind speed in a period in terms of m/s, and d_{s0} is the distance from the desired point to the nearest sea in terms of kilometers. r is determined as the ratio of wind days per month from sea to coast according to Table 1. In Shayanfar et al.'s study, this amount was intended for 2-year data. Meanwhile, the impact of this parameter on the calculations was not included. [24]. Another relationship for C_s is introduced by Stewart et al. for distances between 0.1 km and 2.84 km as follows [21]:

$$C_s = 1.15 - 1.81\log_{10}(d) \quad (4)$$

In the equation above, d is the nearest distance from the sea in kilometers. Since this equation is provided for distances greater than 100 m to more than 2 km and at a distance of less than 100 m, surface chloride is considered constant. So, the relationship of Yu et al. at close distances to the sea (less than 100 meters) provides higher values, and from this distance onwards, it gets similar to Stewart's relationship. An overall comparison between relationships 3 and 4 provided by Yu and Stewart to estimate the surface chloride (C_s) at different distances from the sea is demonstrated in Figure 1.



a) The effect of wind direction changes on the surface chloride concentration



b) The effect of wind speed changes on the surface chloride concentration

Fig. 1: Comparison of the rate of chloride ion spread in Stewart and Yu relationships (with different parameters: wind direction and speed changes) at different distances from the sea.

As mentioned before, the cornerstone of the survey is based on the probabilistic study, and one of the parameters required to determine the values of probabilistic barriers and the type of probabilistic distribution is the surface chloride (Cs) parameter. The data associated with environmental conditions, including wind speed and direction, have been collected based on the information provided by the Meteorological Organization of Iran for the assumed environmental conditions in this study. In this survey, as opposed to C_s in equation 3, the formula compatible with the velocity direction and location based on the Yu and Stewart relationships was applied to see the impact of each parameter.

2.3 Statistical analysis of the conditions of the study area

Initially, the wind conditions of the region in the southwestern regions of Iran in the north of the Persian Gulf have been gathered following the available data from the country's meteorological site. For the maximum wind speed values, the parameters related to this distribution and the mean and standard deviation values were determined according to Table 1. Furthermore, in this survey, only winds that blow from sea to land are included in the calculations. Besides, recorded winds' highest speed was utilized each day [33].

Table 1: Maximum speed of the annual wind and wind direction towards the coast in different cities

Weather station	Distance from the coast (m)	Average velocity(m/s)	Standard deviation Speed (m/s)	The average number of days in a month	The standard deviation of the number of days
Assaluyeh	1600	17.83	3.83	26	4.65
Kharg Island	10	18.08	5.14	25.5	2.45
Bushehr	20	24.50	6.67	26.5	1.56
Coastal Bushehr	10	25.08	4.21	27	1.66
Bandar Deylam	1500	15.17	2.82	26.3	3.47
Bandar Deyr	300	21.33	2.9	26.5	1.41

2.4 Structural conditions

Because the chief aim is to survey the impact of distance, speed, and direction of wind according to the area in which the structure is built on the probability of corrosion occurrence, Table 2 applies the values provided in previous studies for the values of probabilistic distribution concerning the concrete cover, chloride ion diffusion coefficient, D, that represents resistance against penetration of chloride ion depend on w/c and critical chloride, C_{th}, that is required chloride for destroying the passive layer and corrosion initiation [18, 34].

Table 2: Probabilistic data for chloride corrosive conditions

Random variable	Average value	Coefficient of variation	Statistical distribution	References
C_{th} (kg/m^3)	0.9 kg/m^3 1.6(kg/m^3, Persian Golf)*	0.2	uniform	Stewart et al. [21] Ramezanianpour et al. [18]

D_{app} (mm^2/year)	40 mm^2/year	0.25	Lognormal	B. Saassouh& Z. Lounis-
	41 mm^2/year	0.75	Lognormal	Nogueira and Leonel [39]
	38.3(mm^2/year, w/c = 0.4)			Papadakis et al. [?]
Cs*	2.95 (kg/m^3)	0.5	Log-normal	Nogueira and Leonel [39]
	2.95 (kg/m^3)	0.75, 0.5	Lognormal	Stewart et al. [21]
	4.35(kg/m^3 , Persian Golf)*			Ramezanianpour et al.[18]
Cover (mm)	50, 40 mm	0.5	normal	Nogueira and Leonel [39]

* So evaluated RC structures built distant from the coast, tidal and splash zone not considered

** Effect of wind speed and direction and distance from the sea is taken against a constant value

3. The corrosion process of rebar buried in concrete

3.1 Corrosion model

Reliability analysis calculates the probability of failure according to a specific failure scenario, referred to as the limit state. The first step in assessing reliability is to determine random variables. In order to determine the randomness, a probabilistic distribution must be determined for all of these parameters. In this survey, probabilistic distributions related to each variable are provided based on laboratory surveys and research approved by researchers.

The subsequent step in this process is to define the desired failure mode and determine the function of the limit state g (x) for that mode. This function divides the space into desirable and undesirable areas. It is often prevalent to consider R=C_{th} as capacity and S=C(x,t) as demand. The performance function for failure mode is defined as follows [34]:

$$g(x) = C_{th} - C(x,t) \tag{5}$$

This study describes the limit state function to estimate corrosion initiation based on the equation below [22].

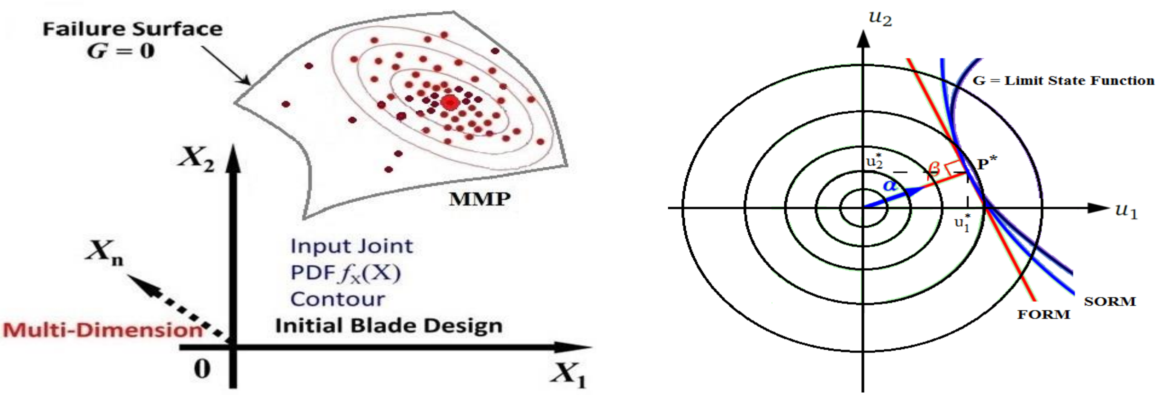
$$G = 0 \quad \rightarrow$$

$$C_{th} - 0.988[1.29r(w_s^{0.386})(d_{s0}^{-0.952})]^{0.379}\left[1 - erf\,\frac{\text{cover}}{2\sqrt{Dt}}\right] = 0 \tag{6}$$

In this case, C_{th} is the critical chloride value, and if the value of this function is G<0, the structure enters undesirable conditions. In this survey, the undesirable conditions are the elimination of the passive layer on the rebar and the initiation of the corrosion process. Based on FIB-Bulletin 65 [6], corrosion begins when the probability of corrosion initiation is nearly 10%. This value is used in some research, like [22], and is suggested by 50% in some articles [35].

3.2 Solution algorithm of Enhanced Colliding Bodies Optimization

In this method, the probability of failure in the n-dimensional state is calculated based on the theory of reliability with multiple integrals of the density of the common probability of variables in the range of improper performance. Due to the complexity of the solution of this multiple integral, different methods have been introduced and used to analyze the reliability and calculate the probability of failure. According to the (HL-RF) method definition, the reliability index (β), as shown in Figure 2, is equal to the minimum distance between the limit function and the coordinate origin in the standard normal space [41 and 42].



a) Real space

b) standard space

Fig. 2: Design point in real space and reliability index in standard space

For each response in the initial population that contains six parameters, five parameters out of six parameters are randomly selected. Then, these five parameters are converted to real coordinates based on distribution, the first and second moments of each variable from standard space to real space. Then, the sixth variable is calculated from the previous five converted variables based on the satisfaction of the limit state function (Equation No. 3). By doing this, it must be on the limit state function, and the initial answer selected is correct. Then, the reverse conversion process of the sixth variable is performed, and thus, six parameters that form a response (design point coordinates in standard space) are obtained. Accordingly, this response selection algorithm continues until the completion of the initial population. Then, the optimization and calculation of the most probable point (MMP) and the objective function (reliability index and thus the probability of corrosion onset) is performed. By doing this, all the answers in the constraints are valid, and there is no need for a penalty function.

Therefore, the stages of calculating the reliability index and determining the design point are optimization issues, and its mathematical form is expressed as follows [9].

$$\begin{aligned} &\text{find} \quad u=[u_1,u_2,\ldots,u_n] \quad u_i \in U \\ &\text{to minimize} \ : \ \beta(u)=\left(u^T u\right)^{\frac{1}{2}} \\ &\text{Subject to}: \quad G(u)=0 \end{aligned} \tag{7}$$

The u_i is the corresponding value of each parameter transferred to the standard normal space. By transferring variables to a normal distribution space and making them independent of each other, the probability of failure is calculated from the following equation:

$$P_f = \Phi(-\beta) \tag{8}$$

$\Phi(\beta)$ is the mass distribution function, and β is a reliability index. Due to the high power of meta-heuristic algorithms in solving optimization problems, the dimensions of the present problem not being large, and the function of the limit state related to finding the corrosion initiation, as well as the high processing capability of today's computers, the use of efficient meta-heuristic algorithms for assessing the probability of corrosion initiation occurrence is very beneficial based on the definition provided by the reliability Index by Hasofer–Lind and Rackwitz–Fiessler (HL-RF) method [41,42]. Meanwhile, the high accuracy of these methods in computing the design point results in finding valuable information about the impact and significance of each impact parameter on corrosion, which cannot be achieved through simulation methods. In this research, the Colliding Bodies Optimization Enhanced method, called ECBO for short, was utilized to find the design point and calculate the value of the reliability index [44].

CBO optimization is a population-based statistical optimization method developed by Kaveh and Mahdavi in 2014 [43].In this method, the object collides with another object, moving towards the minimum energy level.

CBO is conceptually simple and does not depend on any internal parameters. Each collision body (CB), Xi, has a specific mass defined as follows:

$$m_k = \frac{\frac{1}{fit(k)}}{\frac{1}{\sum_{i=1}^{n} \frac{1}{fit(i)}}} \quad , \quad k=1,2,\ldots,n \tag{9}$$

Which fit(i) demonstrates the value of the objective function CB, and n is the number of collision objects. In order to select a pair of objects for collision, CBs are stored in a decreasing classification according to their mass and are divided into two equal groups:(a) stationary group and (b) moving group [44]. Moving objects move toward stationary objects to improve their positions and drive stationary objects toward better positions. The following equations determine the velocity of stationary and moving objects before the collision (vi) and the modified velocity after collision (v'i).

$$V_i = 0, \text{i}=1,2,\ldots,\frac{n}{2} \tag{10}$$

$$V_i = X_{i-\frac{n}{2}} - X_i, \text{i}=\frac{n}{2}+1, \frac{n}{2}+2, \ldots, \text{n} \tag{11}$$

$$V_i' = \frac{(m_{i+\frac{n}{2}} + \varepsilon m_{i+\frac{n}{2}})V_{i+\frac{n}{2}}}{m_i + m_{i-\frac{n}{2}}} \qquad i = 1,2,\ldots,\frac{n}{2} \tag{12}$$

$$V_i' = \frac{(m_i - \varepsilon m_{i-\frac{n}{2}})V_i}{m_i + m_{i-\frac{n}{2}}} \qquad i = \frac{n}{2}+1, \frac{n}{2}+2, \ldots, \text{n} \tag{13}$$

$$\varepsilon = 1 - \frac{iter}{iter_{max}} \tag{14}$$

Hence, the new position of the particles, $x_{i\text{-new}}$, is calculated based on the new velocity obtained from the previous position of the particles. Kaveh and Ilchi have developed further explanations and the relationship details of this algorithm for the non-probabilistic problems [44].

4. Results and discussions

In calculations related to estimating the corrosion initiation time in this section, the nominal thickness of the concrete cover, chlorine diffusion coefficient, and other parameters, such as critical chloride, are assumed to be constant according to the values mentioned in Sections 2-3. Furthermore, the discussion of temperature on chloride diffusion equations has been overlooked because of the lack of straightforward relationships and the lack of local experiments.

4.1 The effect of increasing the distance on the probability of corrosion

In order to consider the impact of distance, given the cities under study, distances of 10, 20, 100, 300, 1000, and 1500 meters from the sea were considered. To examine only the effect of distance, other parameters affecting the diffusion of chlorides, such as speed and direction, were considered constant. Hence, the average values and standard deviations of 25 and 4 m/s were selected for velocity (V), and 26 and 3.5 days were chosen for the direction factor's average values and standard deviations, respectively. Determining the corrosion initiation in a concrete member is based on different sources equivalent to different probabilities.

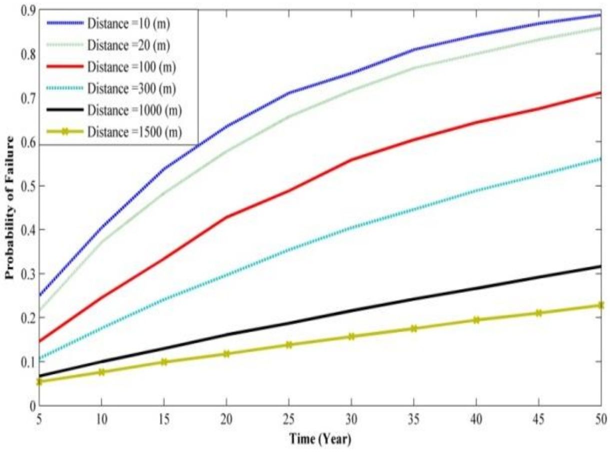


Fig.3: Changing the probability of corrosion at different distances from the sea over 50 years

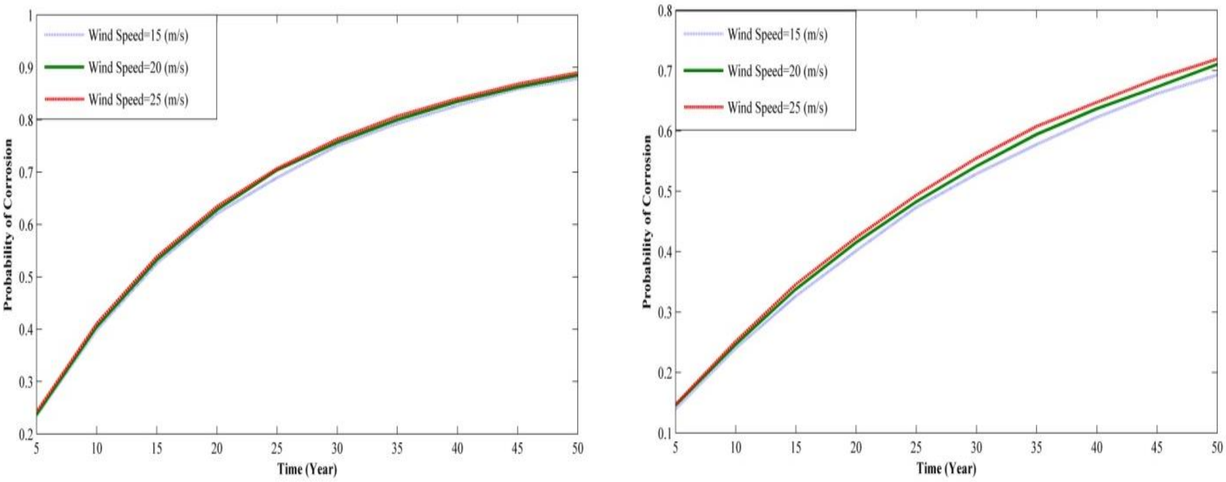
Based on Stewart's study and other research, in the first 100 meters, the probability of corrosion is the same for all structures, while it does not depend on the speed and direction of the wind. According to the Yu relationship, the closer we get to sea level, the higher the probability of corrosion occurrence in concrete members. According to the conditions considered in this study, according to Figure 3, the probability of corrosion initiation in the area far from the sea (atmospheric area) decreases after passing the distance of 1000 meters. If the other parameters are constant, it approaches the corresponding values at a distance of 1500 meters. The example of the most probable point (MMP) calculated in Real and standard space, reliability index, and probability of corrosion with this ECBO method for the years 40 and 50 are shown in Table 3.

Table 3: MMP, Reliability index, and probability of corrosion for some cases with ECHO

	MMP in Real and Standard Space				**Probabilistic Moment of Variable**			
Parameter	**40th year**	**40th year**	**50th year**	**50th year**	**mean**	**CoV**	**Distribution**	**unit**
Cth	0.916	0.067	0.931	0.129	0.9	0.19	uniform	Kg/m^3
D	29.221	-0.173	26.812	-0.302	41	0.75	lognormal	mm^2/year
wind Speed	24.353	-0.033	24.545	0.006	25	0.2	lognormal	m/s
r_wind direction	0.833	-0.025	0.832	-0.038	0.85	0.15	lognormal	-
distance	0.100	0.003	0.101	0.058	0.1	0.1	normal	km
cover	56.046	0.242	59.469	0.379	50	0.5	normal	mm
Reliability	**0.308**		**0.506**					
Pf	**0.621**		**0.694**					

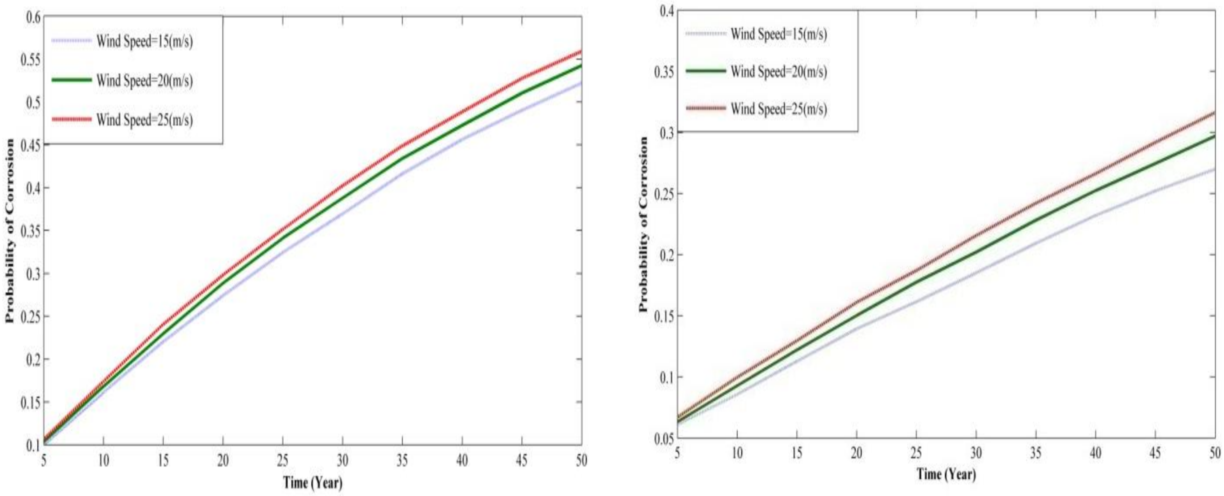
4.2 The effect of wind speed changes on the probability of corrosion occurrence

Other effective parameters for corrosion initiation, such as concrete cover, diffusion coefficient, and critical chloride, were selected according to Table 2 to consider the effect of wind speed at constant distances of 10, 20, 300, and 1000 meters. The effect of mean values and standard deviation of the direction, similar to paragraphs 4-1, was considered 26 and 3.5, respectively. Regarding velocity changes, wind speed varies in the region in two areas with the same distance (such as Kharg Island and Bushehr). Moreover, changes in weather conditions over time may bring about changes in wind speed in an area that could be considered in future research. The results of the analysis and calculations are presented in Figure 4. As the distance from the sea increases, the impact of wind speed on the chloride diffusion and the corrosion initiation also rises.



a- At a distance of 10 meters from the sea

b- At a distance of 20 meters from the sea



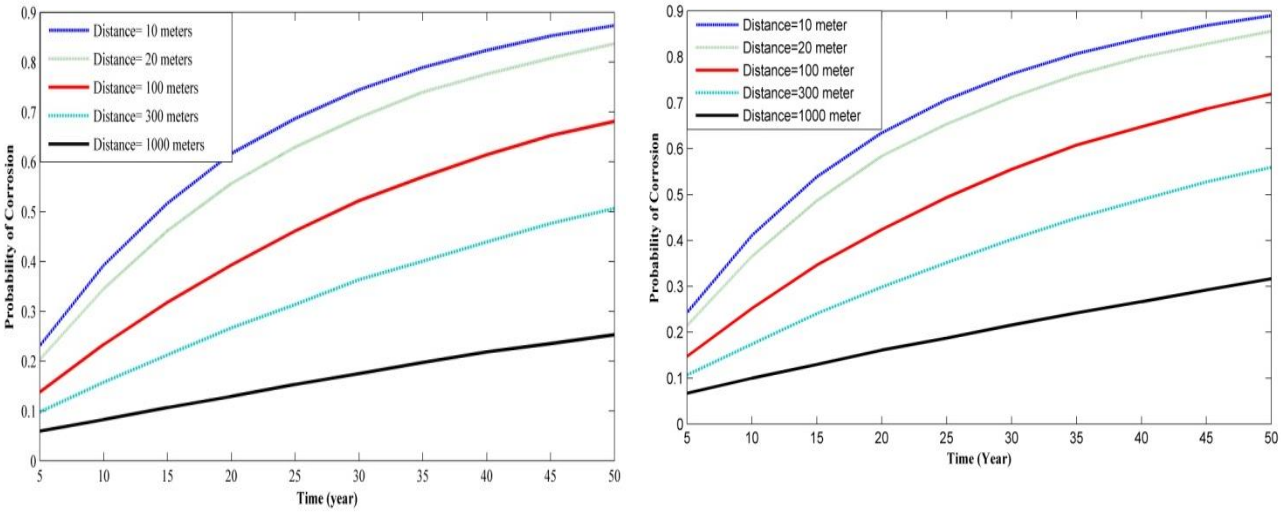
c- At a distance of 300 meters from the sea

d- At a distance of 1000 meters from the sea

Fig. 4: Changing the probability of corrosion at different wind speeds

4.3 The effect of wind direction changes on the probability of corrosion occurrence

Due to the changes in wind direction as a factor in increasing or decreasing the concentration of surface chloride, this parameter is considered a factor influencing the corrosion of buried rebars in concrete. Proper estimation of this parameter in the area to design the structure is crucial in terms of current conditions, climate change in the area, and the importance of the structure in terms of accuracy to find the answers. In this section, assuming the use of concrete coating parameters, diffusion coefficient, and critical chloride, which was explained in Section 4-1, at distances of 10, 20, 100, 300, and 1000 meters and for two wind speeds of 25 and 15 meters per second, the probability of corrosion initiation during the service life of the structure is shown for two different values of r in Figures 5 and 6.

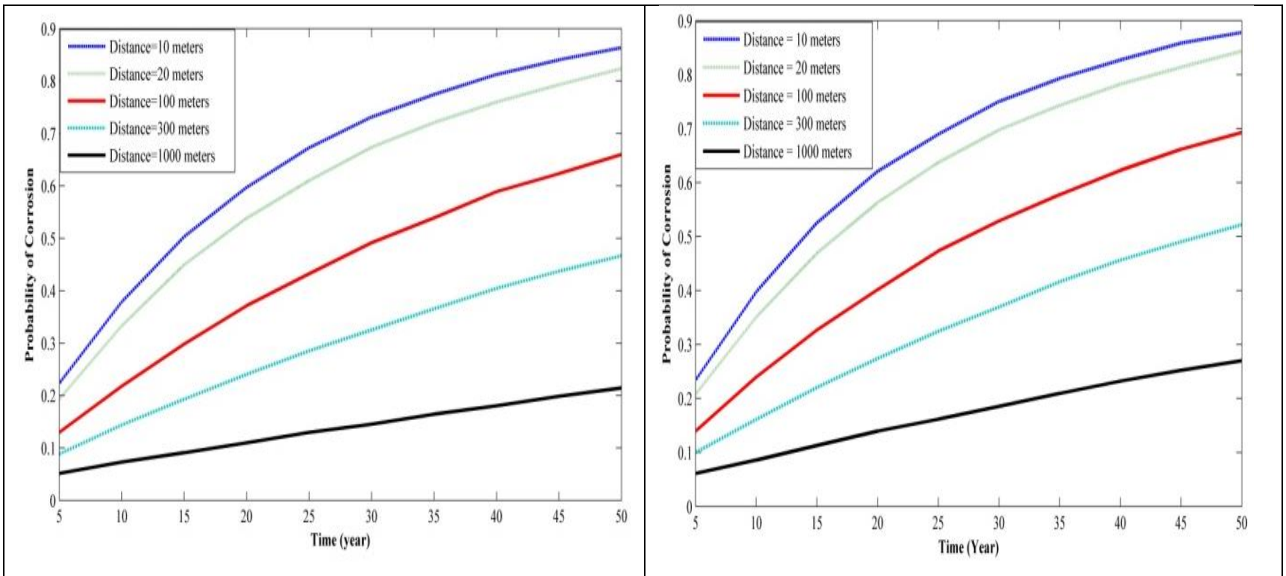


A- Wind effect coefficient(r) is 0.65

B- Wind effect coefficient(r) is 0.85

Fig. 5: Changing the probability of corrosion in different values of the wind direction parameter (wind speed 25 meters per second)

Comparing figures A and B, it can be concluded that the effect of directional change at close distances to the sea is not considerable, and the probability of corrosion in both structures is close. Even so, as the distance from the sea increases, the difference in corrosion initiation expands. For instance, at a distance of 1000 meters from sea level, for the conditions of the region with r = 0.65, the probability of corrosion initiation after 50 years is nearly 25%, whereas, for conditions with r = 0.85, this value reaches above 30%. Figure 6 indicates that when the wind speed in the area decreases. However, the reduction in the probability of corrosion initiation at longer distances (due to the speed reduction) is noticeable, and the ratio of change in probability of corrosion initiation for two wind directions is even slightly higher. For instance, at a distance of 1000 meters from sea level, the probability of corrosion initiation after 50 years is virtually 21% for region conditions with r = 0.65, while for conditions with r = 0.85, this value reaches 27%.



A- Wind direction coefficient(r) is 0.65

B- Wind direction coefficient(r) is 0.85

Fig. 6: Changing the probability of corrosion in different values of the wind direction parameter (wind speed 15 meters per second)

5. Conclusion

This study is about predicting the probability of corrosion of RC structures located at various distances from the sea. To do so, the ECBO optimization method was utilized along with some modifications to be applied in reliability calculations. Also, the effect of distance from the sea, wind speed, and direction on the probability of corrosion occurrence in structures of different importance was examined. After that, the probability of corrosion calculated by the Monte Carlo method was investigated. In this case, although probabilistic distributions are considered for all the parameters involved, the random variables considered for this study are wind speed, the horizontal distance from the chloride source, and the amount of surface chloride. The observations from this simulation demonstrate the following:

It should be considered that RC structures located in atmospheric areas, depending on their distance from the sea, can be exposed to different levels of chloride attack factors. In fact, the distance is the most crucial parameter in chloride reaching the surface of the structure, which has a substantial impact on the durability of the reinforced concrete structure.

In addition to distance, wind direction and speed effectively diffuse chloride ions. The wind effect coefficient rising from 0.65 to 0.85 at close distances from the sea does not lead to any noticeable change in the probability of corrosion initiation, and, the farther we go from the sea, the more likely it is that corrosion will begin. In this case, at a distance of 1000 meters, the probability of corrosion increases by 25%.As wind speed increases near the sea, there is no noticeable change in the probability of starting corrosion. However, as we go farther from the sea, the possibility of corrosion initiation will rise.

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