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Chloride Resistance of Concrete under Complex Stress and Environment

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Abstract

The presence of stress is shown to have a significant impact on chloride ions in concrete. Reinforced concrete is usually durable and cost-effective which has resulted in its widespread use for construction, however, the concrete subjected to environment and load has become increasingly apparently that attacked by aggressive agents such as chloride ion. In this study, the coupling influences are stress effects and environmental problems on the coastline concrete durability have been investigated. A series of cyclic of a wet-dry cycle and submersion tests were performed onto the stressed concrete to obtain an understanding of the physical mechanisms causing the accumulation of chlorides in the interior pores of concrete under different stress types and exposure environments, based on the same duration. Specimens were prepared and subjected to NaCl solution in a wet-dry cycle and submersion, the chloride in the tension zone is gradual with increasing the stress level, as well as the chloride ion in the wet-dry cycle, is increasing the number of cycles. The apparent diffusion coefficient of each specimen was calculated respectively, the profile of concentration at a different section of tension and compression zones were presented in influence factors of the number of cycles, the length of drying phase, and periodic wetting cycles with sodium solution was discussed. After employed Fick's second law, the results suggested D_a in a wet-dry cycle is much higher than the D_a in submersion zones.

Keywords

Concrete Durability, Chlorideion, Penetration, Wet Dry Cycle's Zone, Submerges Zone, Compressive Stress, Tensile Stress, Life Prediction, Micro-Structure

1. Introduction

The problem of chloride attack rises usually when the chloride doorway from the outside. This can be caused by seawater. Chloride can also be deposited on the surface of the concrete in the form of floating very fine dewdrops of seawater raised from the sea by turbulence and carried by the wind or of floating dust which consequently becomes wetted by precipitation [1]. This experiment is performed, and which is mostly designed to simulate the several problems coastal concrete structures that are facing with environmental and impact loads such as stresses and chloride erosion these two factors, may affect the concrete physical and chemical, which will be able to lead the concrete structure to fail [2]. Load effect is physical which may change the concrete, chloride resistance is altered when concrete meets some environmental problems such as seawater wet-dry cycles or submerged under seawater most of the time, and the chloride conveyance in concrete is a typical process of penetration in non-saturated concrete [3]. And it is assumed that the chloride ingress process is a combination of diffusion and conviction. For the environmental conditions of the marine structure, except for temperature, RH and chloride ion concentration, it is widely accepted that the zone suffering from the seawater drying-wetting cycle is the most hazardous part of steel corrosion and it has been regarded as the chief factor of the durability design [4].

It is worthwhile to study the mechanism of chloride penetration in the concrete structure under wet-dry cycles and submersion. The aim of this research is to investigate the effect of stress and environmental problems that subjected to the concrete structure with wet-dry cycle and submersion, based on this experiment results, the work to validate the applicability of Fick's second law describing the chloride profile in specimens that subjected to stress and environment effects. It is necessary to quantify the chloride penetration stress effect and environmental problems [5]. Chloride ions and other aggressive substances penetrate through concrete via different mechanisms depending on the driving force involved [6]. Diffusion, permeability, and absorption are the most well-known chloride transport mechanisms through concrete [7].

Other phenomena such as chloride binding can also influence chloride ingress. The stress level of concrete and the service environment determine the driving force and thus the mechanisms by which chloride penetrates into concrete [8]. Capillary absorption, hydrostatic pressure, convection and diffusion are the means by which ion can penetrate in concrete the most familiar method is diffusion the movement of chloride ion is a concentration gradient, for this to occur, the concrete must have continues liquid and there must be chlorideion concentration [9]. These condmechanism for the chloride ingress is permeation, driven by a pressure gradient, if there is an applied hydraulic head on one face of the concrete and chloride are present, they may permeate in the concrete. A situation where a hydraulic head is maintained on highway structure is rare; however, a more common transport method is absorption [10].

2. Experiment Design

This study is focusing on chloride resistance of concrete under compressive and tensile stress, to simulate the coastline area reinforced concrete structure which faces two severe problems leading concrete structure to fail. Numbers of beams are prepared, cast, and cured as standard (ASTM2002). Before the beams are immerse different stress level will be applied to the beams while some of them will leave as unstressed, for there as on that to purify the variance effects of the two conditions. Then the beams are placed into a 3% of NaCl solution in 90 days, the beams are loaded back to back, where it planned each paired specimens have a different environment, The upper specimen will meet the wet-dry cycle and the lower specimen expose the NaCl unabridged of the 90 days. After that interval, the specimens will take them off the containers, see in **Table 1**.

Then there will be a time for air-drying mostly at two days, and then it will use drilling machines (BOSCH GBH2-22) to attain some sample powder from the specimens for investigating chloride concentration profile. Subsequently providing the information from the powder study, it will show up to plot some graphs. Later it will calculate the apparent diffusion coefficient of chloride using for by error function of Fick's second law. This will provide the result of apparent diffusion and surface chloride concentration.

16 specimens of 100 × 100 × 500 mm were reinforced 1 × φ 10 mm hot rolled steel bar at the tension side with cover thickness 30mm were cast. Rectangular mold with a non-absorbent surface, sizeable enough to hold their shape during the molding of the specimen was prepared. The mold contains hard wooden and two white pipes that through the specimen and allowed that the bolts go through easily to connect the two specimens during the self-anchorage. All of the mixing and casting works were carried out in a standard laboratory. Each and every one of the test specimens cared with the axis of the mold vertical to avoid a sloping end in the hardened concrete. The entire casted specimens were kept under laboratory conditions 23-25˚C as shown **Figure 1**.

After 28 days, it was removed from the molds. Five sides of the specimen were coated with thick epoxy and protection was taken to ensure that no coating material gets onto the surface to be exposed, except the only side on the stress .It must be assured that the method of application and hardening prescribed by the supplier of the coating material is observed. Then two specimens were self-anchored mutually and loaded with different stress levels by tightening the two screws with dimensions of 12 mm both before 100 mm at the end of paired specimens. Just before the dry-wet cycle and submersion testing, the Compressive and tensile sides' surfaces of the specimens were uncoated with epoxy or anti-corrosion, which can ensure the chloride's ingress from the compression and

Table 1. Mix proportions (kg/m^3).

Grade	cement	Water	Sand	C/Agg	w/c	f_c at 28 day (MPa)
C25	509	220	562	1044	0.432	29.5

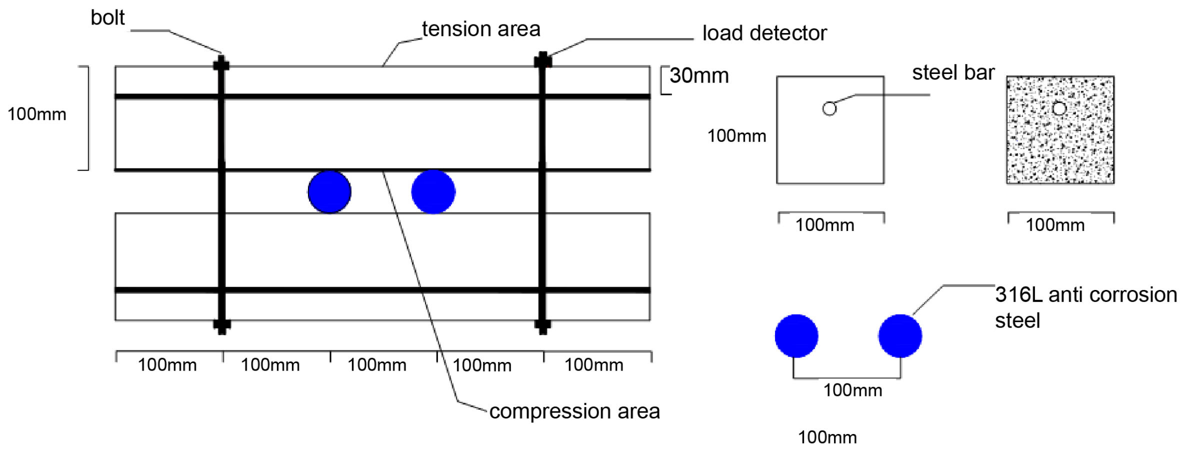


Figure 1. Paired beam with load detector and 316 L ant corrosion steel.

tensile surfaces. Then, as soon as the coating has hardened, the specimens were immersed in 3%NaCl solution. The solution of NaCl concentration must be checked at least before and after use and the temperature of the water was indoor temperature. In order to examine the effects load on the chloride penetration in concrete specimens. After the concrete cast, cured, and coated. To bring on chloride pathway in the concrete was subjected to different stress levels in various specimens. Total 16 reinforced concrete beams and 2 cubes were casted. 16 specimens were loaded various loads each 4 of them were loaded different load from, 0.1 ft, 0.3 ft, 0.5 ft, and 0.7 ft and two were unloaded cubes. Every specimen has a dimension of 100 × 100 × 500 mm and cubes 100 × 100 × 100 mm. The flexural stress section is the interval between two roller supports. The mid 100 mm of the specimen is the zone expected to obtain micro-pores structures.

The primary mechanism is diffusion. The main goal is to obtain information regarding the effect of the length of cycles and number of cycles on the degree of chloride ingress in concrete, the wet-dry cycle has the same time length, which means the wet stage lasting for 12 h/day and the air-drying stage lasting for 12 h/day. In the wet stage, both of the two beams of one set are submerged under salt solution, in the drying stage, the upper beam is exposed in the air, the lower is still in salt solution. In order to compare with the environment of marine concrete, the method of the dry-wet cycle was used. The first was done before cycles were started and placed into all the beams. The alteration was made later 59 days (total 90 days) for loaded and unloaded beams. And submerged beams were kept into the container for all 90 days compared with submerged specimens in marine concrete as shown in the below Figures 2-5. Similarly it can be seen the conditions of the specimens through the entire process as shown in Table 2.

90 days exposure of wet-dry cycle and submersion, the specimens were took out from the container and placed in a lab 2 days for air-drying. Formerly, the powder at concrete in stress sections were acquired by electric drilling with a

Figure 2. Paired beams before submerged.

Figure 3. Beams exposed into NaCl solution.

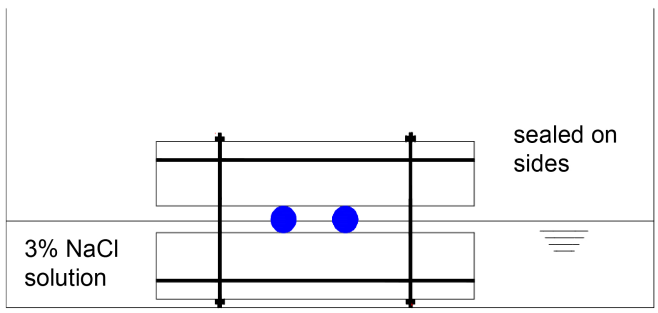


Figure 4. Low water level NaCl solution.

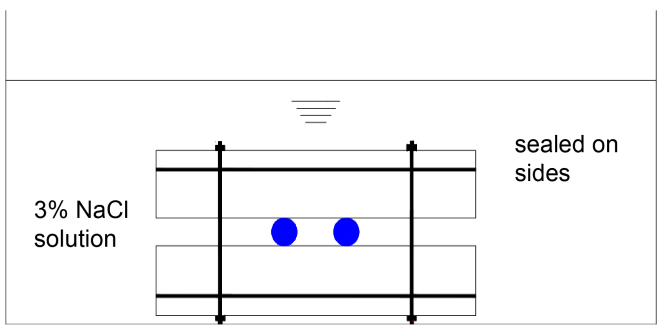


Figure 5. High water level of NaCl solution.

Table 2. Conditions of the specimens during the wet-dry cycle and submersion.

Beams	Load	Conditions	Stress type	Temperature
BEAM 1	0.1 f_t	Wet-dry cycle	Compressive	−8˚C to 16˚C
BEAM 2	0.3 f_t	Wet-dry cycle	Compressive	−8˚C to 16˚C
BEAM 3	0.5 f_t	Wet-dry cycle	Compressive	−8˚C to 16˚C
BEAM 4	0.7 f_t	Wet-dry cycle	Compressive	−8˚C to 16˚C
BEAM 5	0.1 f_t	Submerged	Compressive	−8˚C to 16˚C
BEAM 6	0.3 f_t	Submerged	Compressive	−8˚C to 16˚C
BEAM 7	0.5 f_t	Submerged	Compressive	−8˚C to 16˚C
BEAM 8	0.7 f_t	Submerged	Compressive	−8˚C to 16˚C
BEAM 9	0.1 f_t	Wet-dry cycle	Tensile	−8˚C to 16˚C
BEAM 10	0.3 f_t	Wet-dry cycle	Tensile	−8˚C to 16˚C
BEAM 11	0.5 f_t	Wet-dry cycle	Tensile	−8˚C to 16˚C
BEAM 12	0.7 f_t	Wet-dry cycle	Tensile	−8˚C to 16˚C
BEAM 13	0.1 f_t	Submerged	Tensile	−8˚C to 16˚C
BEAM1 4	0.3 f_t	Submerged	Tensile	−8˚C to 16˚C
BEAM 15	0.5 f_t	Submerged	Tensile	−8˚C to 16˚C
BEAM 16	0.7 f_t	Submerged	Tensile	−8˚C to 16˚C
BEAM17	0 f_t	Wet-dry cycle	0	−8˚C to 16˚C
BEAM 18	0 f_t	Submerged	0	−8˚C to 16˚C

Note: 1—wet-dry cycle means 12 hours of wet per day and 12 hours dry per day of being submerged per day; 2—Submerged: the specimens were submerged NaCl solution for 90 days; 3—Duration of this experiment is 90 days.

depth of 30 mm, perpendicular to the tension and compression zones. At each position, one sample powder was obtained for every 5 mm drilling depth.

For the constant drilling method, a length of colored duct tape was wrapped around each drill bit, as a result that the lower edge of the tape corresponded to the appropriate drilling depth to facilitate easy depth control. After each point was drilled, the hole was measured to ensure that the correct sampling depth was achieved. After the first hole was drilled, the concrete powder was collected in a plastic bag using a small brush and spoon. After the appropriate depth was attained, the test area was cleaned, and the sampling tools were cleaned to remove residual powder and prevent contamination between samples. Subsequent holes were drilled and sampled following the same procedure.

Subsequently all the samples for both the drilling and the powder collection were obtained, each specimen powder sample was examined. The sample was put into tested for 4.0 g of the extraction of specific water soluble solution, and then was shaken 10 minutes than the bottles of solution were remained for another 10minutes as the sample solution to sink.

3. Results and Discussion

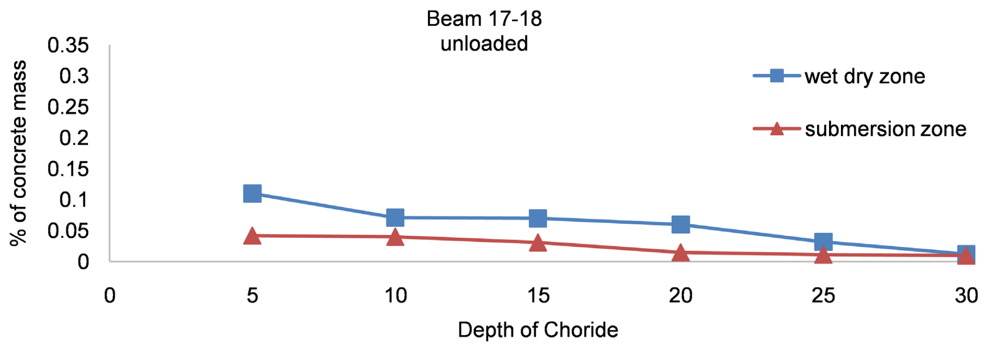
In this study, there are two different exposure environments, wet-dry cycle zone and submerged zone. The Cl^- transporting behaviors in the concrete in these two environments are fairly different accordingly as it can be seen the below **Figures 6 (a)-(I)**.

In wet/dry cycles, the chloride concentration in the concrete increases with increasing number of cycles, whereas it is approximately constant with time of exposure, when similar concrete mixes are immersed in 3% of NaCl solution. The effect of method of exposure in NaCl solution (*i.e.* total submersion or wet/dry cycles) on chloride penetration in concretes exposed to 3% salt solution for 90 days are shown. As can be seen, after 90 days of exposure, the chloride concentration profile is greater in concretes exposed to wet/dry cycles in NaCl solution than those immersed. Many more chloride ions entered the concrete under cyclic wetting and drying conditions than in a constantly saturated environment. For the samples under cyclic wetting and drying periods, when the spray ended, the surrounding environment became dry, and water then evaporated from the pores of the concrete. The rate to which the chlorides penetrate in the specimens depends on the duration of the wetting and the drying periods. As the specimens' remains wet, some salts migrated in from the concrete surface by diffusion. However, the wetting period was short, then the entered of salt water by absorption carried the salts into the interior of the concrete and much deeper concentrated during drying. Cycles of wet-dry increase the concentrations of chlorides ions, by evaporation of water. As well, for the submerged specimens, less chloride entered the specimens as the leading penetration mechanism was diffusion through the pore solution.

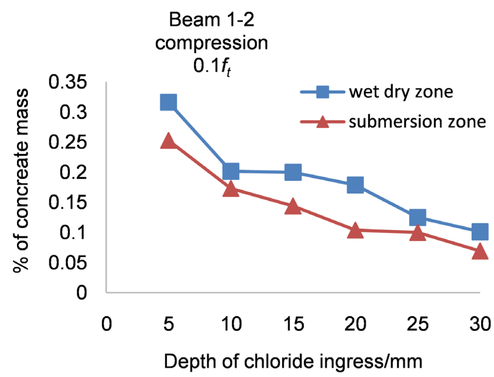
4. Conclusions

This research was focused the effects of stress and environment problems which affect coastline concrete structure that meets more problems in daily life, this study was prepared some specimens compared coastline concrete structure and salt solution simulated marine water. The outcome of this research shows some real data that illustrated problems of stress and environmental conditions. So the major findings of this study are following:

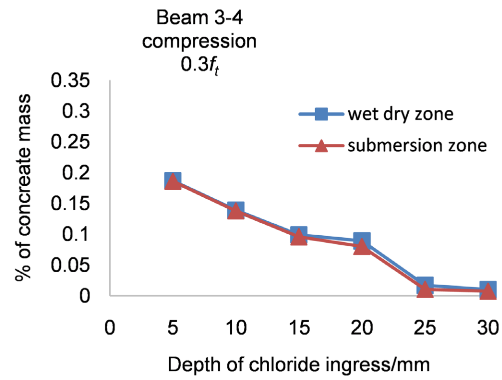
- The chloride concentration in concrete increased with stress level, when the stress level increased the chloride ingress in concrete also increased in tension zones, while the compression zone increased as the stress level of concrete decrease;
- Environment problems some specimens were submerged and some other specimens are wet-dry cycle, the chloride penetration in wet-dry cycle was much larger than the chloride in submersion specimens. It's clear there is huge significant in the environment problems.
- After used Fick's second law equation. It confirmed that apparent diffusion coefficient in tension zone is much larger than the compression zone, where the D_a in submersion area was less than D_a in wet-dry cycle area.


Beam 17-18
unloaded
wet dry zone
submersion zone
% of concreate mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of Choride

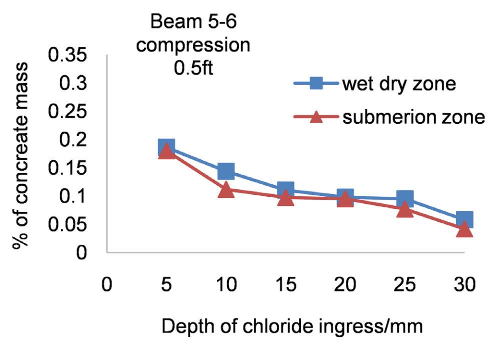
(a)


Beam 1-2
compression
0.1f_t
wet dry zone
submersion zone
% of concreate mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

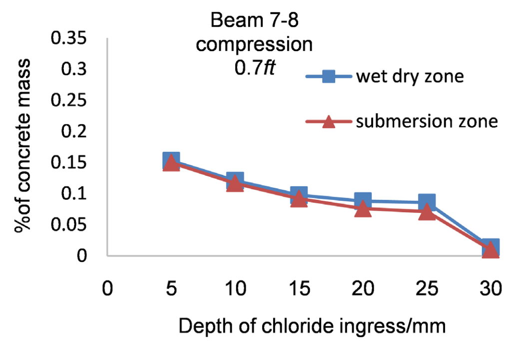
(b)


Beam 3-4
compression
0.3f_t
wet dry zone
submersion zone
% of concreate mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

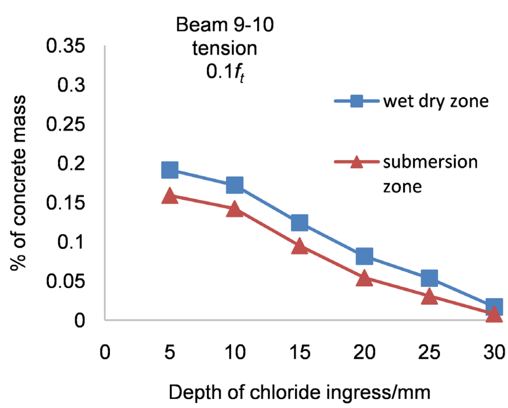
(c)


Beam 5-6
compression
0.5ft
wet dry zone
submerion zone
% of concreate mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

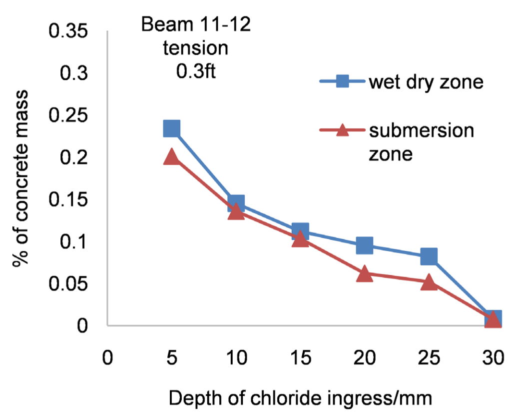
(d)


Beam 7-8
compression
0.7*ft*
wet dry zone
submersion zone
% of concreate mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

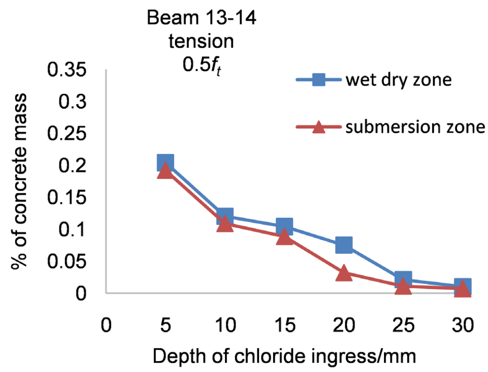
(e)


Beam 9-10
tension
0.1f_t
wet dry zone
submersion zone
% of concrete mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

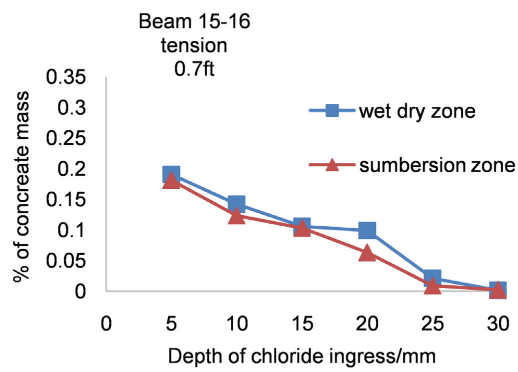
(f)


Beam 11-12
tension
0.3ft
wet dry zone
submersion zone
% of concrete mass
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Depth of chloride ingress/mm

(g)



(h)



(i)

Figure 6. Comparison of w/d vs. submersion. (a) Beam 17 - 18 unloaded; (b) Beam 1 - 2 Compression 0.1 ft; (c) Beam 3 - 4 compression 0.3f_t; (d) Beam 5 - 6 compression 0.5 f_t; (e) Beam 7 - 8 compression 0.7 f_t; (f) Beam 9 - 10 tension 0.1 f_t; (g) Beam 11 - 12 tension 0.3 f_t; (h) Beam 13 - 14 tension 0.5 f_t; (i) Beam 15 - 16 tension 0.7 f_t.

Based on comprehensive research, we can conclude that chloride ingress into concrete is a complex process which coastline environment is complicated by the wet-dry cycles experienced by concrete structure near to seawater. While there are numerous existing experimental or modeling studies related to the effects of stress and environment problems in concrete structure in coastline area. The measurement of chloride ingress into concrete is technically challenging. Furthermore, it is also difficult to assess the durability of reinforced concrete from its chloride diffusivity, partially owing to the heterogeneous nature of the concrete matrix.

In this study, there was some limitation that pushed off to go far and beyond, cycle circle was only 90 days thus it will be better to 1 year or more to obtain further results. Moreover, NaCl chloride was synthetic, however it can be used sea water.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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