ESTIMATION OF MARINE SALTS BEHAVIOR AROUND THE BRIDGE STRUCTURES IN INDIA

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ABSTRACT

A growing concern for better assessment of existing concrete structures has revealed a need for improved understanding of the structural effects of deterioration. The two most common causes of deterioration in concrete structures are freezing of the concrete and corrosion of the reinforcement. The aim of this study is to deepen the understanding of the structural effects of deterioration with special attention to the bond between deformed bars and concrete. The effects of freezing on the material properties of concrete and the bond behaviour of bars were investigated through experiments. A significant influence of frost damage was observed on the stress-strain response of concrete in compression, tensile stress-crack opening relation, and bond-slip behaviour. Based on this, a set of methods was introduced to predict the mechanical behaviour of reinforced concrete structures with a measured amount of frost damage. The methodology was applied to frost damaged beams using non-linear finite element analysis at the structural level. Service life prediction is becoming one of the major tasks in the design of concrete structures. The durability design must be based on consistent models that can describe the deterioration models more accurately. The development of chloride penetration models is essential for the assessment of the service life of concrete structures exposed to marine environment. Simple models are derived from Fick's 2nd law of diffusion are at present the best way to predict chloride penetration in practical situations. However these models need to be calibrated with experimental results.

Key words: *Concrete structures, corrosion, salt behaviour, strength and damages*

INTRODUCTION

A considerable percentage of highway bridges in coastal area of Andhra Pradesh are in a structurally/functionally deficient state due to aging, aggressive environments, and increased traffic load and volume. In 2010, about ¼ bridges in A.P were either structurally deficient or functionally obsolete. On a bridge structure, the substructure is one of the most vulnerable components to the routine application of deicing salts, repeated freeze-thaw cycles, and other damaging effects including environmental effects. Nevertheless, these deteriorating effects demand proper maintenance, repair and replacement techniques.

Reinforced concrete structures have proven to be vulnerable to the damaging effects of carbonation and chlorides which are born from seawater and dicing salts. The deterioration of concrete structures due to chloride-induced reinforcement corrosion is one of the largest contributing factors affecting the strength capacity of concrete piers. In a reinforced concrete structure, the concrete cover around the reinforcement provides protection to the reinforcement from environmental damaging effects. The corrosion of the steel reinforcement leads to concrete fracture through cracking and spalling of the concrete cover and most importantly a reduction in the concrete and reinforcement cross sections. As a result of the corrosion, the reinforced concrete pier experiences reduction in its strength and ductility, and this reduces the safety, serviceability and life of the concrete structure.

The effects of frost on material properties of concrete and bond behaviour of deformed bars were investigated through experiments. There is very little information concerning the softening behaviour of frost-damaged concrete in the literature; moreover, the limited available knowledge is not experimentally validated. The bilinear tensile stress-crack opening relation estimated through inverse analysis of wedge splitting test results is believed to be the only available estimation made from experiments. The principle of the methodology proposed for frost-damaged concrete is that the effect of frost can be modelled by adapting material and bond properties and by modifying geometry. Although suggestions for adjusting the material and bond properties of frost-damaged concrete have already been given by other researchers, their application to concrete beams in ultimate state has not been done before. The effect of reinforcement corrosion on the bond mechanism is studied in detail through experiments and analyses. A simple analytical model to predict the bond-slip behaviour for corroded bars is proposed; this is used as input for structural analysis to assess existing structures. A previously developed corrosion model on a more detailed level was extended to include the favourable effect of rust flowing through a crack. The fundamentals of the development are based on mass transportation, assuming that the volume flow of rust depends on the splitting stress around the corroding bar and the crack width. This method of describing the phenomenon has not, to the author's knowledge, been taken into account before. The eccentric pull-out tests carried out to study the combined influence of large corrosion penetrations and corroded stirrups are believed to be unique.

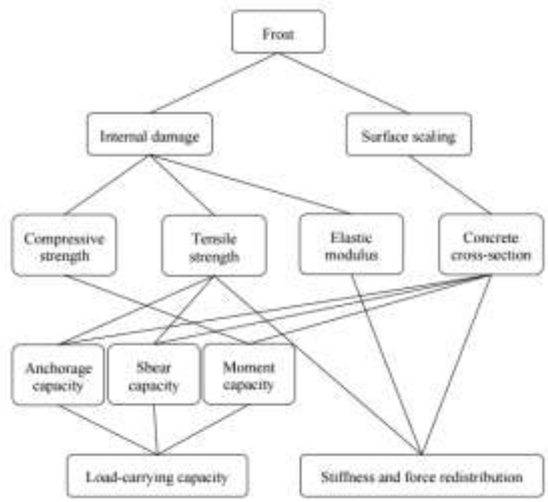


Figure: shows the methodology of load distribution

LITARATURE REVIEW

Problem is the production of a frost resistant concrete which has a good and stable air void system during transportation and handling of the fresh concrete. Extensive investigations of existing concrete structures with intentionally entrained air have revealed that no air was present or was inadequate by current standards (Klieger 1980, Manning 1989, Gjørv 1987). Even for a normal-strength concrete without the use of any super plasticizer, the production of a good and stable air void system may represent a problem, but in the presence of a super plasticizer, however, this may be an even more severe problem (Okkenhaug et al 1992). Therefore, much attention has been given in recent years to find out whether a frost resistant high-performance concrete can be produced without any air entrainment.

Both Okada et al. (1981), Foy et al. (1988) and Gagne et al. (1990) have reported a good frost resistance of non-air-entrained concrete with w/c ratios in the range of 0.25 to 0.35. Malhotra et al. (1987) who also tested a number of concretes with different types of cement and w/c ratios in the same range, concluded, however, that air entrainment was necessary for these concretes to be frost resistant.

Also for salt scaling, there are some conflicting results in the literature. Petersson (1984) reported that deterioration of high-strength concrete was small for the first 50 to 100 freeze– thaw cycles, while in the following 10 to 20 cycles, a very rapid deterioration with total destruction took place. However, both Foy et al. (1988), Gagne et al. (1990) and Hammer and Sellevold (1990) have shown that it is possible to produce high-strength concrete without any air entrainment which is resistant to salt scaling. These investigations included concretes with w/c ratios of up to 0.37 and testing of up to 150 freeze–thaw cycles.

Although the first durability problems caused by alkali-aggregate reaction (AAR) were observed on several Californian concrete structures and reported by Thomas Stanton already in 1940, it has taken a long time to recognize AAR being a general durability problem. Already in 1947 Mielenz et al. published a ”black list” of alkali-reactive aggregates and minerals. This form of degradation occurs when alkalis released from the hydrating cement react with aggregate containing reactive constituents. Gilliot (1975) suggested that AAR should be subdivided into the following three groups of reaction: alkali-silica reactions with siliceous aggregates (some cherts, opal, and siliceous lime stones), alkali-carbonate reactions with carbonate aggregates (some argillaceous dolomites) and alkali-silicate reactions (same as alkali-silica reaction except that the reactive constituent in the aggregate is silica present in the form of phyllosilicates).

Later on, several international publications have shown that even more stable silicious rocks can be alkali reactive, e.g. granite, quartzite, shist and sandstone. A list of reported alkali-reactive aggregates were published by Coull (1981) and by Dolar-Mantuani (1983). Since 1974, extensive international experience with AAR in concrete has been published in a large number of international conferences.

The AAR is influenced by a number of factors, DuraCrete (1998a):

• Constituent materials: This involves the properties of binders (equivalent alkali content, relative proportions of sodium and potassium and fineness), aggregates (reactivity, proportions and grading of the fine and coarse fractions, presence of salt impurities, alkali contributions from certain aggregates and porosity of coarse aggregates) and admixtures (AEAs, plasticizers and superplasticizers).

• Mix proportions: This involves the binder content, water content, w/c and the aggregate/binder ratio in the concrete.

• Exposure environment: This factor involves the availability of moisture and external chlorides, the temperature and alkali concentration effects.

• Structural loading: This factor consists of the magnitude and the nature of the structural loading.

• External and internal restraints: This factor is influence by the amount of reinforcement and the structural configuration.

Certain siliceous minerals from the aggregates react with the alkalis (Na2O, K2O) in cement forming a gel; an alkali-silica complex of variable composition. The clear alkali-silica complex may react with calcium ions originating from calcium hydroxide or other cement hydrates to form a white, opaque calcium silica or alkali-calcium-silica complex (Powers 1955). The product of the alkali-silica reaction absorbs water and increases in volume, and in this process changes from a hard solid to a softer gel and finally to a sol. As water is absorbed, the swelling reaction product (which usually appears as a while rim around the reactive aggregate) exerts a disruptive force on the surrounding cement paste and cracks it. As more water is absorbed, the crack is propagated into the mortar and becomes wider. The forces produced by many such swelling particles may interact and accentuate the propagation and widening of a crack (Vivian 1978). Cracking usually takes many years and is often preceded by pop outs and spalling on the concrete surface.

MATERIALS AND METHODS

CHLORIDE ION PENETRATION

Durable concrete is defined as having has the ability to withstand external effects, which may be mechanical, physical, or chemical, with minimal damage. Low permeability is key to long-term durability of concrete. Low permeability in high performance concrete provides protection against: damage due to freezing and thawing, alkali-aggregate reactivity, carbonation, acid attack, chemical resistance, sulfate attack, seawater exposures, etc. The work is taken in an extremely corrosive environment and care must be taken to ensure that any structural steel within the concrete is protected from chloride acid attack.

For this test, two 4 by 8 inch cylinders were cast from each mix design. The cylinders were removed from the molds after 24 hours curing under a plastic tent with wet burlap. The tent was used to maintain a relatively constant temperature and humidity of 68 degrees Fahrenheit and 60 %, respectively for the first 24 hours of curing. Upon removal from the molds, the specimens were partially cured by submersion in lime water followed by curing in a moisture cabinet until the 28th day of curing. The first phase of three mixes was cured for 22 days in the lime water before the specimens were placed in the standard cure moisture cabinet. The four mixes in the second phase were water cured for 6 days before the transfer to the moisture cabinet. It is essential for concrete structures to perform well not only within their specified mechanical requirements but also within their durability expectations. Very often the issue of durability is being overlooked since engineers make the assumption that strong concrete is also durable.

MATERIALS CEMENT: The cement in the concrete provides protection to the reinforcing steel against corrosion by maintaining a high PH in the order of 12.5-13 to the presence of $Ca(OH)_2$ and other alkaline materials in the hydration product of cement, and by binding a significant amount of total chlorides. OPC of 43 grades in one lot was procured and stored by air tight. The cement used was fresh, i.e., used within three months of manufacture. It should satisfy the requirement of IS 12262.

WATER: The Ordinary drinking water available at the construction laboratory was utilized for preparation of concrete for casting all specimens of this investigation. Ordinary water available is used for the curing purpose. The quality of water was found to satisfy the requirement if IS: 456-2000.

FINE AGGREGATE: Aggregates containing chloride salts cause serious corrosion problems, particularly those available near seas and those whose natural sites are in ground water containing high concentration of chloride ions. A fine aggregate got from the river is used for experimental purpose. Fine Aggregates clean from silt, organic material, salt and clay and it was clean and dry. It is of size retained in 1.2 micron sieve. Here fine aggregate is got from Krishna River.

Figure Shows the fine aggregate used for sample preparation

COARSE AGGREGATE: The coarse aggregate should be strongest and porous component of concrete. The coarse aggregate in concrete reduces the drying shrinkage and other dimensional changes occurring on account of movement of moisture. The Coarse Aggregates is clean and dry. The Maximum size of aggregate is 20mm. The coarse aggregate used passes in sieve 19 mm and retained in sieve of size 11.4 mm sieve. It is well graded (should of different particle size and maximum dry density and minimum voids) and cubical in shape.

Figure Shows the 20mm course aggregate

BULKING OF FINE AGGREGATE

• Table the representative of sample of sand, from the available lot at sight.

• Fill the graduated jar with sand up to certain weight compacting.

• Level the sand surface by gentle motion and note down this height.

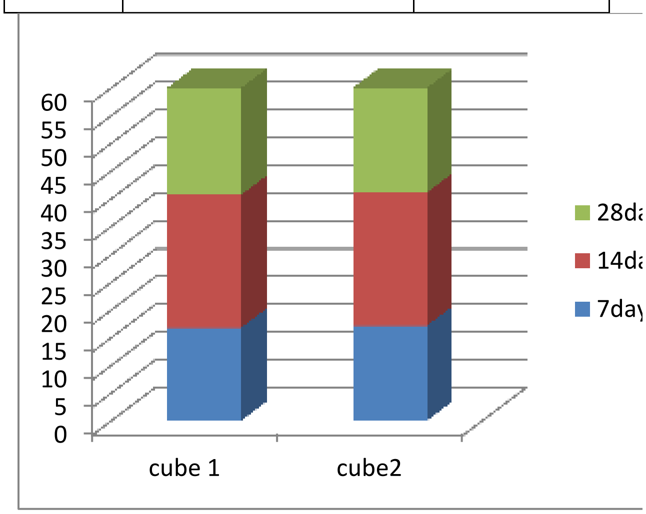
• Now pour the water into the graduated jar containing sand till the sample is submerged.

• Cover the jar with the disk and give some motion.

• The tamping rod should be moved through out into sample in the jar, so as to ensure to remove of entrapped air completely.

Table shows the properties of river sand

S.NO	PROPERTIES	VALUES
1	SIZE	Passing through 5mm sieve
2	FINENESS MODULES	2.62
3	SPECIFIC GRAVITY	2.78
4	WATER ABSORPTION	1.1%



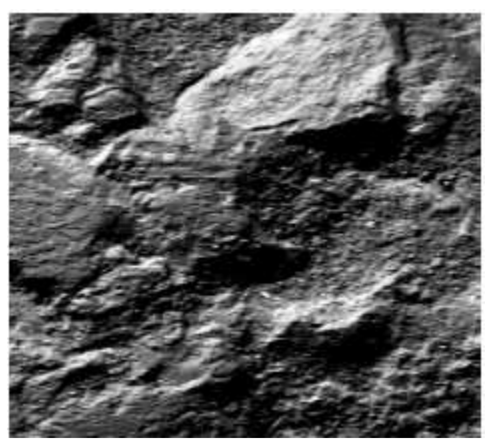
Graph shows the compressive strength values as per the results obtained

a) b)

Figure shows Carbonation test. a) Cut of cylinder. b) Acid-base indicator application.

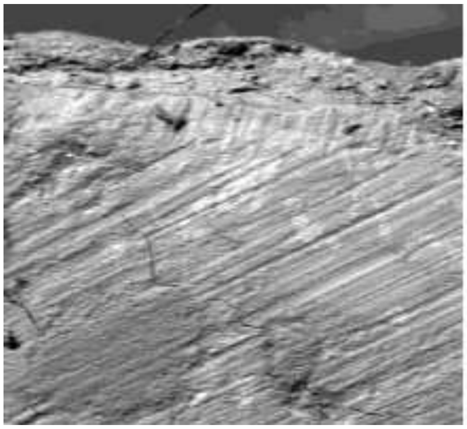
<u>SEM/EDS Analysis.</u>

On the other hand, a comparative mapping about the elemental distribution in concrete samples is presented in Figures 3 (Ca), 4 (O), 5 (Cl), and 6 (Mg).

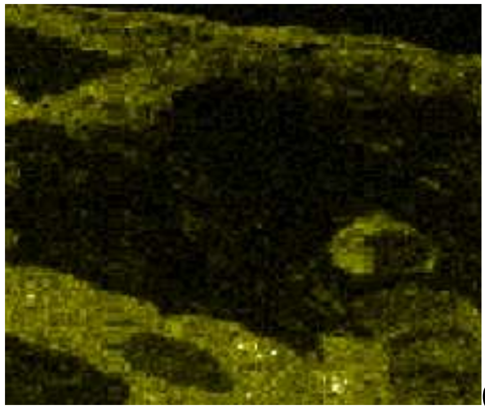


(a)


(b)


(c)

Concrete samples borders. a) ATM (130x), b) ALT (250x), c) IMM (1500x).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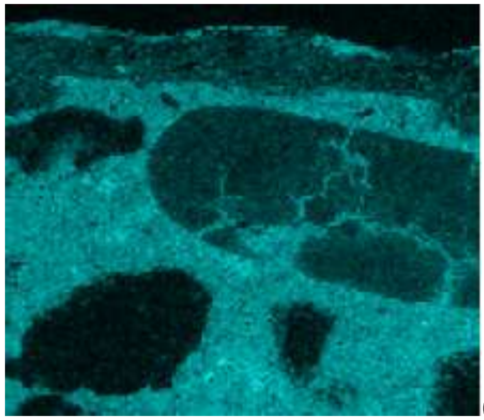
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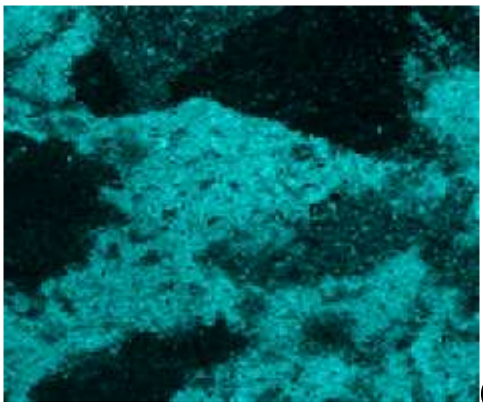
Calcium distribution at the borders. a) ATM (130x), b)ALT (250x), c) IMM (1500x).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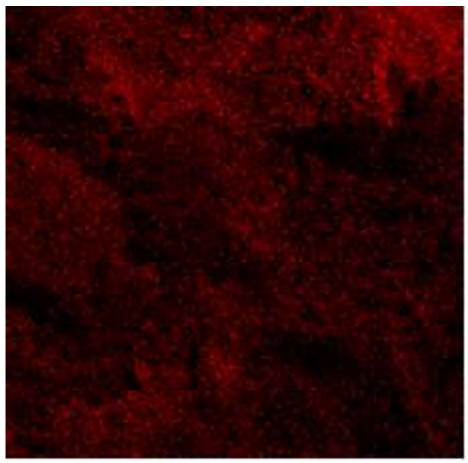
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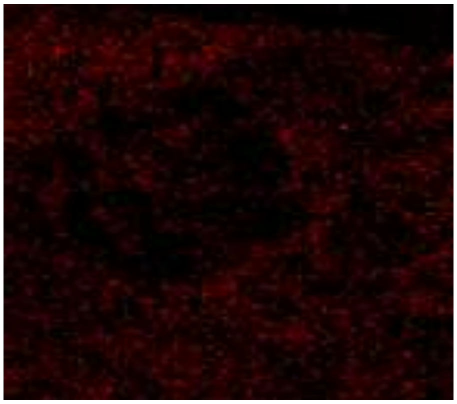
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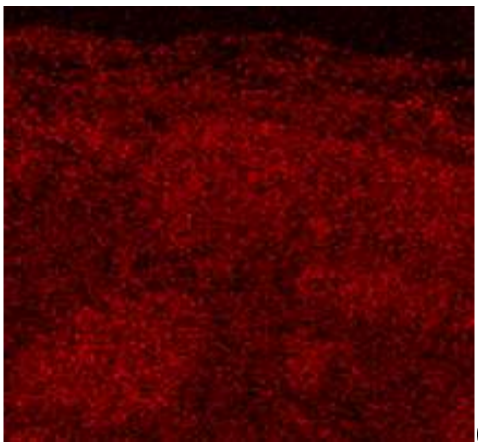
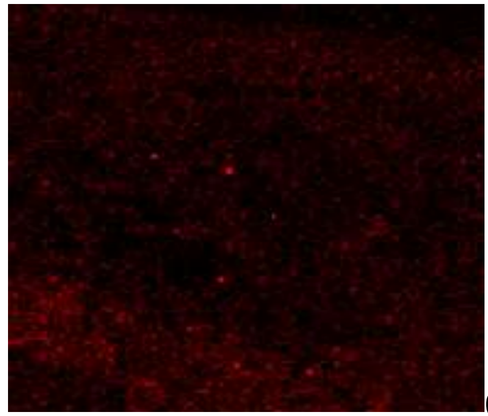

(c)

Oxygen distribution at the borders. a) ATM (130x), b)ALT (250x), c) IMM (1500x).


(a)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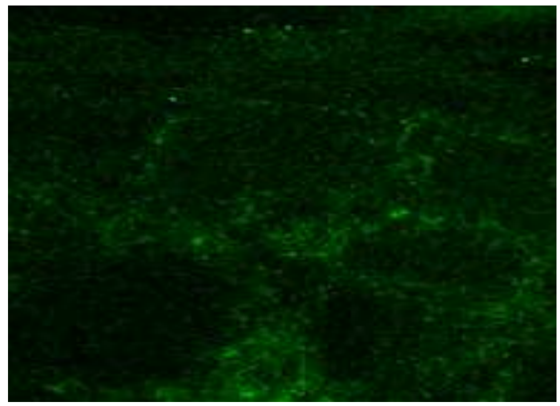
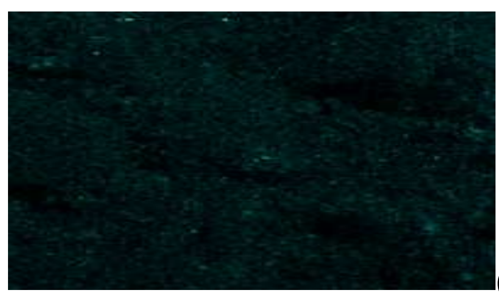

(C)

Chlorine distribution at the borders. a) ATM (130x), b)ALT (250x), c) IMM (1500x).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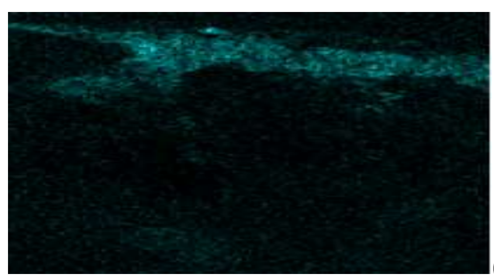
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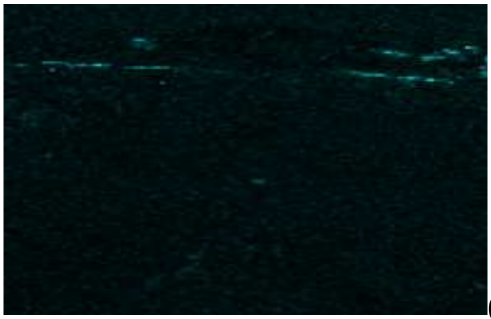
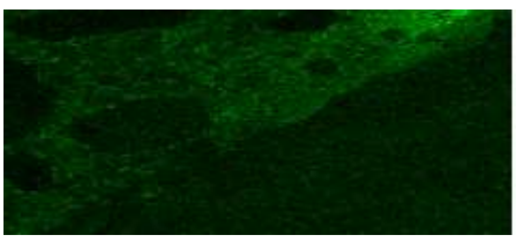

(c)

Magnesium distribution at the borders. a) ATM (130x), b)ALT (250x), c) IMM (1500x).


(a)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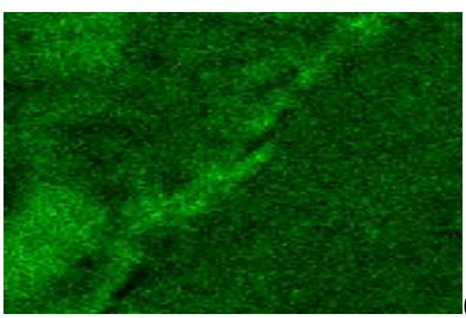
(c)

Chlorine distribution at concrete-steel interface. a) ATM (130x), b)ALT (110x), c) IMM (130x).

<u>Conclusions</u>

This study performed immersion test in a 5% NaCl solution considering the type of cement, the eventual admixing of fly ash and the water-cement ratio as major test variables in order to examine the characteristics of chloride ion penetration in NPP concrete structures. Especially, tests were performed for the case where carbonation is exerting composite action so as to secure basic experimental data concerning composite deterioration due to the effects of these variables.

It was observed that concrete cast and immersed in seawater for 24 days beyond the curing period increases its weight due to penetrating of marine salts and increases in compression strength beyond the strength of concrete cubes cured in fresh water. The fresh-salt water situation occurs when structures constructed in shores and in seas near shores. The marine salts penetrated in the concrete cause corrosion to the reinforcement and reduce the service life. To increase the service life the pH value of the concrete must be increased and preventive measures against corrosion of steel reinforcement must be taken. It is recognized that a dense and impermeable concrete can ensure long-term durability in harsh marine exposure conditions.

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