# CONCRETO EN AMBIENTE MARINO

por

Theodore W. Bremner

**Sinopsis**: Se revisa la historia de las estructuras marinas de concreto comenzando con los puertos romanos hasta las plataformas mar adentro de hoy en día y se evalúa su comportamiento en términos del grado en que hayan cumplido las expectativas del diseñador. El medio ambiente marino puede tener un efecto destructivo sobre el concreto y se discuten las diversas reacciones físicas, mecánicas y químicas en términos de los posibles mecanismos de deterioro. Se presentan las normas actuales para hacer al concreto resistente a las acciones destructivas y se discute su efectividad. Se dan ejemplos de estructuras que fallaron al no comportarse adecuadamente, se proporcionan las posibles razones para su pobre comportamiento y se presentan procedimientos para la reparación. Se describen los proyectos actuales que involucran los avances en la tecnología marina del concreto. Se enumeran las investigaciones que se están desarrollando en todo el mundo y se enfatiza la necesidad de coordinar internacionalmente un programa de investigación sobre el concreto marino.

**Palabras clave**: Concreto, marino, agua de mar, químico, deterioro, investigación, refuerzo, corrosión, álcali-agregado, abrasión, impacto, puzolana, ligero, expansivo, vesicular, barcos, puertos, muelle, desembarcadero.



# CONCRETE IN MARINE ENVIRONMENT

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Theodore W. Bremner

nopsis: The history of concrete marine structures is reviewed starting from the Roman arbors up to the offshore platforms of the present time and their performance is evaluated terms of how well they met the designers expectations. The marine environment can ave a destructive effect on concrete and the various physical, mechanical and chemical eactions are discussed in terms of possible deterioration mechanisms. Current code quirements to make concrete resistant to these destructive actions are presented and heir effectiveness discussed. Examples of structures that have failed to perform properly re given and possible reasons for their poor performance are given and repair procedures re presented. Current projects that involve advances in concrete marine technology are scribed. Research being done on marine concrete around the world is listed and the eed for an internationally coordinated research program for marine concrete is stressed.

eywords: concrete, marine, seawater, chemical, deterioration, research, reinforcing, orrosion, alkali-aggregate, abrasion, impact, pozzolan, lightweight, expanded, vesicular, hips, harbor, piers, wharf.

**Theodore W. Bremner**, Professor of Civil Engineering, University of New Brunswick, Fredericton, N.B., Canada, E3B 5A3. Dr. Bremner teaches undergraduate and graduate courses in materials and conducts research on lightweight concrete and on the performance of concrete in severe environments. His students are working in the areas of moisture mechanics, permeability of lightweight and normal weight concrete, effectiveness of epoxy-coated reinforcing steel in salt water and seawater, durability of concrete in seawater, chemical admixtures for concrete and resistance of concrete to freezing and thawing. Before returning to university, he was a structural design engineer. He acts as a consultant on the design, maintenance and repair of marine facilities.

## INTRODUCTION

Historians focus on disasters, wars and national calamities and spend scant attention on the successes of the working public especially if they are builders and especially so if the facility is a success. In ancient times ports were of great importance as most of the trade and communication was by sea and one of the best preserved is the Port of Cosa in Italy built about 200 B.C. The main feature of the harbor was the concrete piers, three of which are still visible above the water. The marine concrete served its function well until changing trade patterns two centuries later made it obsolete (1).

The piers at Cosa built by the Romans are believed to be the first known examples of harbors built using pozzolans. It seems they recognized early in the second century B.C. that pozzolans, a powdery volcanic ash, when mixed with lime and water, sets and endures when placed in seawater or fresh. Pozzolans, hydrated lime and water were used by the Cosa concrete engineers to form the matrix or binder that was combined with the particulate phase composed of limestone, tuff and amphora fragments to produce concrete. Over the years these massive blocks wasted away to some extent but nevertheless the structure is still useable at the end of the second millennium for its intended purpose if the need exists. Unfortunately some modern structures being attacked by seawater in a similar way have been known to require repairs before the facility was commissioned and others need continual maintenance to keep them in a serviceable condition. These processes of deterioration that affect both ancient and modern concretes will be examined and means of minimizing their effect will be discussed.

A further complication arose when steel was incorporated into concrete for marine work. Significant increase in structural efficiency was possible when the tensile forces could be assigned to this embedded steel but these more highly stressed structures developed a new form of deterioration - spalling of concrete cover over embedded steel. The material specialist in some aspects has yet to fully cope with this problem which has rendered seemingly elegant structures into ones that challenge our ability to maintain them in a serviceable condition.

In recent years new materials and procedures have been introduced that offer significant improvement both to the economy and to the performance of structures and those procedures and materials appropriate for marine work will be presented.



## NATURE OF MARINE EXPOSURE

### Effect of Geographic Location

The degree to which concrete remains durable depends on a number of factors including mix constituents, mix design, climatic conditions, exposure duration and workmanship. Of prime importance is geographic location as this influences whether or not the concrete will be subjected to cycles of freezing and thawing. Prior to the use of an air entraining agent, most of the concrete marine structures deteriorated rapidly from this effect. With a properly entrained air void system the concrete is immune to this type of attack and other forms of attack become of prime importance.

Temperature affects the reaction process in that increasing temperature results in increasing rates of chemical reaction between the seawater and the concrete; however some of the reaction products - gypsum in particular - are more soluble in cold water than in hot water. Also the cold seawater absorbs more oxygen and so can cause greater rates of corrosion of steel in submerged concrete. In general the maximum air temperatures in July are surprisingly similar at the major ports around the world. The wide variation in minimum January temperature at these various ports reflects the fact that deterioration from chemical interaction is very slow in the winter at some locations which means that exposure intensity is different but probably not substantially so from one marine location to another for the concrete exposed to the atmosphere.

What can be different is the temperature of the surface water which can range from 28°C at the tropics to -1°C in the polar regions (2). Useful design information about the effect of these temperature extremes on concrete can be obtained from work done by the U.S. Corps of Engineers at their two exposure sites for concrete on the east coast of North America (3). Their cold water site is at Treat Island, Maine near the Canadian-U.S. border where the temperature ranges from a low of 1°C in the winter to a high of 40°C in the summer. The warm water site is at St. Augustine, Florida, where the surface seawater temperature is 21°C year round. Chemical attack would tend to dominate in Florida while deterioration due to freezing and thawing would be the main factor at Treat Island for concrete specimens located at a midtide wharf. Summer air temperatures at Treat Island can approach extremes experienced at St. Augustine and concrete prisms at midtide level of size 250 mm square by 750 mm long reach ambient air temperature at the end of the dry period of the tidal cycle and therefore a chemical interaction between the seawater and the concrete also should be expected in northern waters as the concrete remains fully saturated during the period when the tide is low.

Nevertheless the potential for chemical attack is substantially less in cold regions than in tropical regions. Mean tidal range at Treat Island and St. Augustine are 5.5 and 1.4 m respectively. The wide variation in temperature between water and air plus the more rapid change in water level would make the thermal shock effect more severe in Treat Island as compared to St. Augustine. However the tendency for disruptive expansion to occur would be lessened at Treat Island by the increased solubility in cold water of some of the reaction products.

As shown previously, ambient air and water temperature plus local tidal ranges affect the concrete's interaction with seawater. Of lesser importance is the local variation in the chemical composition of the soup that constitutes seawater for a particular ocean body (4). However, the salinity and content of various salts in different seas vary as can be seen in Table 1 (5, 6). The salinity in seas with a small inflow of fresh water and high evaporation rates such as the Mediterranean and Dead Seas is higher than that of the oceans (5). Seas whose intake of fresh river water or snow and ice melt water is high, can have greatly reduced salinities. Local evaporation of sea spray plus possible contamination of the seawater with fish processing wastes can result in severe local concentrations of salts. In northern regions deicing agents such as sodium and calcium chloride can be used to deice concrete surfaces which will have disastrous results for marine structures already critically saturated with salt from spray.

In terms of aggressive attack of concrete by seawater it would appear that all concrete materials engineers concerned with the design and repair of marine facilities will be building in a soup that chemically tends to be more similar than different and that the maximum summer temperature also will tend to be similar. This allows some simplification in formulating international design codes in that design is normally based on the worst possible case conditions regardless of the geographic location of the structure. The only exception is that design codes recognize that in higher latitudes where freezing and thawing is likely to be a problem, air entrained concrete must be used.

**Zones of Reaction**

To illustrate the various zones of attack, reference will be made to one of the most common concrete marine structures which is cylindrical piles (columns) used to support a beam and slab deck. Such a structure can be seen in Figure 1. The numbers refer to areas and components most likely to deteriorate with the lowest number assigned to the area where deterioration is likely to become sufficiently severe to require attention first. The higher numbers reflect areas that are less likely to deteriorate and that may survive indefinitely without requiring repair. The zones and various deterioration mechanisms listed below are based on observations and testing of various types of structures in Canada and observations of a total of 11 international ports.

**Description**

**Zone**

A. Submerged Zone. Fully below the low tide level and continuously underwater and which usually is not affected significantly by the seawater.

B. Lower Tidal Zone. Between midtide level and low tide level with significant chemical attack possible at midtide level and with essentially no deterioration at low tide level.



C. Upper Tidal Zone. Between midtide and high tide level with significant deterioration in cold regions of concrete with an inadequate air void system. Chemical interaction between seawater and concrete has the most severe effect in this region. Also corrosion of steel reinforcement is evident at midtide level and becomes more serious above midtide level being especially severe at high tide level.

D. Splash Zone. From high tide level to a height above high tide level equal to the annual maximum wave height as measured from trough to crest. Deterioration due to freezing and thawing is usually maximum in this region. Minor signs of chemical attack from seawater are evident.

E. Atmospheric Zone. From the Splash Zone upward and being of greater effect where onshore winds are present. The effect is reduced going inland but still can have a significant effect in terms of chloride content of concrete at 1 km from shore.

The numbered components of the structure in Figure 1 are listed in Table 2 in descending order of those most likely to deteriorate and for each component the types of deterioration are listed in order of decreasing effect or decreasing probability of occurrence.

Within the five zones there can be microzones where deterioration patterns are significantly different. Generally on a wharf deck the top concrete surface tends to deteriorate to a significantly greater depth than does the underside which tends to be moist and where the diffusion of carbon dioxide is significantly lessened. The opposite occurs in bridge decks over seawater. Generally the underside of the bridge deck is much drier than the deck and the depth of carbonation on the bottom is usually twice that of the top. In general the second and third bays in from the front of the wharf will show greater corrosion damage than does the outer bay. Nevertheless sufficient chloride can be present from the seawater spray to cause the cover over the bottom layer of steel to fall off revealing a network of corroded steel reinforcement. Repairs to this type of structure are extremely difficult. Beams under the wharf that support the deck slabs are frequently the first to show deterioration. Salt water running down the face of the beams, evaporating and leaving the salt behind can account for exceptionally high levels of salt in very localized regions.

Marine concrete can be subjected to the same type of deterioration in all regions but the effects appear more pronounced in some zones. Alkali-aggregate reaction is usually evident first in wharf faces or parapet walls above high tide level. It usually is evident next on the top of the wharf deck. Based on experience in Atlantic Canada alkali-aggregate reaction has a much greater effect on highway bridges inland than it does on marine structures when the same materials were used in both instances. Apparently the salt water carries away the reactive compounds lessening the effect.

Abrasion of the concrete due to lateral transport of sand and gravel past the structure can have an effect especially at the splash zone and to a lesser extent below the water level. Damage due to hard berthing can also be a problem and damage of a purely mechanical nature is frequently evident and may be a greater indicator of poor seamanship than of poor concrete design and construction.

## Typical Deterioration Patterns

In cold northern waters, concrete structures of the type shown in Figure 1 have been known to exhibit scaling of the concrete deck with a veneer of concrete coming off the concrete surface in the first year. Also in the first year loads of concrete that failed to have an air-entraining admixture added to the mixture become evident and can result in complete disintegration of the concrete in several years. Current practice normally requires that every load of concrete be tested for entrained air and that the existence of an acceptable air void system be verified by testing the hardened concrete using candidate materials before construction starts. Nevertheless, many structures made without entrained air continue to serve a useful purpose in cold northern waters. Normally the part of the structure saturated and exposed to freezing and thawing will deteriorate on the surface first and then progress inward. The deteriorated form has the characteristic hour glass shape. It starts at midtide level and becomes more severe reaching a maximum at high tide level and decreasing at an increasing rate in the splash zone. Repairs can be surprisingly effective if all concrete showing freeze-thaw damage and areas likely to deteriorate in the foreseeable future are removed and replaced with air entrained concrete. Inevitably deterioration will eventually occur at the old to new concrete interface and this must be accepted as part of the ongoing maintenance process. In certain instances, particularly in small sections of concrete that can easily respond to temperature fluctuations, failure can be more dramatic with the concrete failing in mass rather than by progressive loss of a surface layer, and then repair and reinstatement on a local level will probably not be successful unless the as-yet-undamaged concrete can be encased with a structurally and thermally protective layer of significant thickness.

When freezing and thawing is not a problem the deterioration is a maximum at midtide and is symmetric above and below the midtide level proceeding at decreasing rates above and below midtide level and being negligible at high tide and low tide levels (7). In most instances where freezing and thawing are not a problem surface deterioration due to chemical attack is slow with trivial loss of surface mortar taking several decades. Polymer coatings can be highly effective in restoring the appearance of the structure and preventing future chemical attack (8).

Concrete below low tide level is surprisingly resistant to seawater. Some surface softening will occur in low strength concrete, however, this is not likely to be significant in concrete of a strength normally used for marine structures. Mehta and Hayes tested 67 year old concrete blocks ( 1 x 1.7 x 1.7 m) that initially had been partially submerged and then fully submerged at the San Pedro Breakwater in Los Angeles Harbour. Only the 20 MPa concrete showed any surface softening (9).



## DETERIORATION MECHANISMS

### Deterioration Mechanism for Plain Concrete

As was discussed previously, lack of resistance to freezing and thawing causes premature failure usually before the normal chemical interaction of concrete with seawater has taken place. Only in concrete exposed in regions where freezing and thawing is not a problem or where an effective air void system is present can the chemical interaction be evaluated. In concrete not at risk to freezing and thawing damage, the interaction with seawater involves various surface effects that are easily visible and result in a progressive roughening of the surface. Also elements in the seawater diffuse into the concrete and react with the hydration products. This according to Moskvin causes an initial densification and then an expansion that after many years of seemingly good performance produces a severely spalled surface (6).

Anderson examined concrete from the Bay of Fundy and from the English Channel using a scanning electron microscope equipped with energy dispersive x-ray equipment (10). He found that the chemical interaction zone was no more than 25 mm thick in good quality concrete even after five and six decades of exposure at midtide level. Also he found that specimens having severe surface deterioration still retained strength comparable to what would be expected if they had been continuously moist cured in fresh water.

The chemical reactions between marine concrete and seawater have been summarized by Regourd (11) who lists such reaction products forming as $MgSO_4$, $MgC1_2$ and $CaC1_2$ as being the dominant reactants coming from the seawater. The tricalcium aluminate ($C_3A$) is the main reactant with the seawater to cause expansion of the concrete. Also she notes that $CO_2$ cannot only react with the $Ca(OH)_2$ to produce a precipitate that acts as a coating similar to carbonation but also reacts with the ettringite ($C_3a.3\ CaSO_4.32\ H_2O$) to produce thaumsite ($CaCO_3.CaSO_4.CaSiO_3.15H_2O$). During the course of current research this latter product has been found in entrained air bubbles in large quantities which in turn renders air entrained concrete no longer air entrained and therefore vulnerable to damage due to freezing and thawing.

Surface expansion due to the growth of chemical compounds resulting from the reaction between the seawater and the cement paste occurs in the outer 25 mm layer of the concrete and must be considered a positive factor assuming that freezing and thawing resistance in not being degraded. Unfortunately concretes with otherwise good performance tend to shed a veneer of concrete about 25 mm thick after about 50 years exposure to seawater. Also workmen engaged in repair note a very dense surface layer that tends to be very strong but is only of limited thickness. During demolition this thin veneer tends to come off in slabs. This surface deterioration may be due to many causes and is deserving of further research.

A review of the test data from long term testing at the Technical University of Norway done over a twenty five to thirty year period and reported by Gjorv (12) revealed a significant increase in flexural strength with time up to 15 years at which time there was a regression of strength for concrete with high $C_3A$ contents. Apparently these chemical surface effects on the 40 x 40 x 300 mm and 100 x 100 x 750 mm had what appears to be an initial positive effect on the tensile strength until a system of fine cracks formed in the interior of the concrete that adversely affected the tensile strength (12).

The deterioration mechanisms noted above are not likely to have a significant effect on concrete of a water to cement ratio prescribed by most codes as the reactions are only of a surface nature and are dependent on the tricalcium aluminate content of the cement. By limiting this component the reaction can be controlled.

## Deterioration Mechanism for Concrete Containing Embedded Steel

Marine structures of all types that are of steel or have steel components are at risk from the rapid oxidation of the iron in the chloride laden seawater. Concrete is a protective material in which to encase steel in that an initial reaction takes place which rapidly goes to completion and forms a thin protective oxide layer over the steel. This protective whitish layer ($Fe(OH)_2$) can be readily seen by the naked eye. This protective layer can break down for one of two reasons, and the $Fe(OH)_2$ turns to $Fe(OH)_3$ and $Fe(OH)_3.3H_2O$ with a substantial increase in volume that results in the concrete over the steel being spalled off exposing the steel to direct corrosion from the seawater with a resulting loss of structural capacity.

The protective oxide layer can be maintained by keeping the pH of the concrete above about 11.5 which is not difficult if the concrete is wet as in the splash zone or below as seawater is normally deficient in $CO_2$ and it is the $CO_2$ gas which reacts with the $Ca(OH)_2$ to produce $CaCO_3$ which then lowers the pH and results in the protective layer being destroyed. Above the splash zone and particularly on the underside of marine decks where the structure is periodically subjected to salt laden moist air during storms followed by extended periods of exposure to dry air, the concrete will dry out, air will diffuse in and the concrete will carbonate rendering the pH less than 11.5.

The protective oxide layer can also be destroyed even when the pH is above 11.5 when chloride ions diffuse into the concrete from seawater, salt spray, and salt laden winds. Salt levels of 0.6 to 0.9 kg of Cl per cubic metre of concrete are normally the threshold level to cause corrosion to start. A combination of chloride levels above the threshold level plus carbonation provide especially severe conditions for concrete and the periodic nature of high wind speeds and high waves plus subsequent air drying accounts for most of the failures of concrete structures to perform their intended purpose. This applies only where distress cannot be attributed to poor workmanship, inadequately air entrained concrete in cold regions, inadequate structural design, and where concrete mix materials and mix proportions failed to meet current standards.



Corrosion of steel can be controlled by using one or more of the following approaches:

i improving the quality of the concrete;
ii using protective coatings at the concrete surface;
iii using a corrosion inhibiting admixture such as calcium nitrate;
iv using a coating at the steel/concrete interface as a barrier;
v suppressing the electro-chemical process of embedded steel by implementing cathodic protection.

The above five approaches are listed in order of decreasing ease of implementation and in increasing probable degrees of effectiveness given available technology.

Quality of concrete in this context means low permeability to chlorides and oxygen and in order to achieve this, researchers have dealt with such parameters as composition of cement, mix proportions, water to cement ratio and the thickness of the concrete cover. Unfortunately concrete capillaries vary from 15 to 1000 A° in diameter and chloride ions are less than 2A° in diameter and easily pass through concrete. Also concrete subjected to alternating conditions of wetting and drying in a marine environment provide conditions such that the chloride and oxygen ions will eventually permeate through relatively high quality concrete. Therefore enhancing the concrete properties to prevent corrosion of the embedded steel is not always economical or possible.

One of the most effective methods of improving the performance of concrete is to prestress it to prevent cracking. Unfortunately there have been problems with this technology in recent years where prestressing strands pass through ducts in the concrete. Apparently these ducts have been improperly grouted in many instances and the cables have corroded. Currently the UK Department of Transport is preparing a new standard for this work and until it is available they will not commission any new bridges using grout-duct post tensioning (13). The use of protective coatings has proved to be surprisingly effective based on coatings applied to unreinforced concrete prisms at Treat Island by the U.S. Corps of Engineers. A variety of polymeric coatings were applied and have remained intact for about a decade. Whether or not the coating is sufficiently crack free to hinder chloride diffusion is not known nor is it known if the coatings would be as effective at high tide level where corrosion is a major problem. An epoxy coating has been used on the King Faud causeway from Saudi Arabia to Kuwait in the splash zone for the main piers and has given good service. On test piles that were not coated, salt scaling has eroded the surface to a depth of 3 to 5 mm (14).

The third method listed; use of a corrosion inhibiting admixture, shows considerable promise provided that the concrete can be made sufficiently impermeable that the admixture, calcium nitrate, does not bleed out. Long term experience is lacking, but short term results are promising.

Coatings applied at the concrete/steel interface have been used for several decades, however recent incidents of failure have been reported. In 1986 the first reported signs of corrosion of epoxy-coated bars were observed in the Long Key Bridge Structure in

Florida which was built in 1979-1981. Further investigation revealed problems with other bridges built about the same time. Although some of the spalling of the cover over the reinforcement was in areas where the cover was inadequate the majority of the corrosion was observed in locations with up to 10 cm of sound concrete cover. In December 1988, the Florida Department of Transportation stopped specifying the use of epoxy-coated rebars in bridge substructures as they felt it would not provide suitable long term protection against corrosion in a marine splash zone environment (15). Nevertheless bars coated with fusion bonded epoxy and cast in concrete prisms and tested both in the field at Treat Island and in accelerated tests have demonstrated their ability to give significant improvement in performance over that of uncoated bars (16).

Suppression of the electro-chemical process by implementing cathodic protection has been demonstrated to be effective in parking garages and bridge decks but long term data on its successful use in marine structures is limited and its effectiveness to deal with the various exposure zones has yet to be established. Gerwick reported on a seawater cooling canal in eastern Saudi Arabia where sacrificial anode cathodic protection has been effective below and 1 m above water level (14).

In the question of corrosion of embedded steel in a concrete marine structure it is apparent that at best any one system, if employed properly, will give a useful service life. However, marine structures tend to have long term uses and a combination of two of the above listed protection methods would appear mandatory and that only the first method, improving the quality of concrete, enjoys full support of the engineering profession in terms of certainty of results and method of implementation.

## DESIGN CODES

Marine Structures are covered by general codes such as those formulated by technical associations like the American Concrete Institute and the Federation Internationale de la Precontrainte. Also there are various national codes written specifically for marine work. In recent years it has been the practice to write standards for specific applications such as for offshore (17), floating (18) and Arctic (19) structures.

The purpose of these codes is to assure that concrete does not fail based on the available information, and as information becomes available these design codes are revised. Generally they reflect the state-of-the-art at the time they are written and differences between various documents can be explained by noting the date of publication. A case in point is the allowable level of tricalcium aluminate ($C_3A$) in Portland cement for use in marine concrete. Before 1980 codes normally limited $C_3A$ to 5% or less as it is the primary reactant in the cement to cause expansion when in the presence of seawater (11). The $C_3A$ was later found to react favorably with the chlorides in the seawater producing an insoluble chloro-aluminate which in turn lowered the permeability of the concrete and also reduced the potential of the steel reinforcement to corrode (20). The 1989 Canadian Standard for Offshore Structures requires a tricalcium aluminate of "not less than 4 nor more than 10% by mass of the total cementing material used" (17). Gerwick, in giving an overview of his international experience, stated that "there is a growing indication that 10 to 12 percent may be optimum" (14). Formulation of standards and guides to good practice must be a continuing process if lessons learned from current laboratory research and field observations are to be incorporated into these standards in a timely way. Means must be found to have standards that are used internationally reflect the broad spectrum of local environmental conditions rather than reflect the conditions near the head office of the so-called international institutions. With globalization of trade this process will become less difficult with time as the major international financial groups have a vested interest that extends world wide.



## PERFORMANCE RECORD OF MARINE STRUCTURES

Marine structures are usually designed for a specific application for which they are deemed cost effective if they can be maintained operational for their financial design life with acceptable maintenance costs. Using this as a measure of their performance record concrete marine structures have been extremely successful with only a few structures requiring extensive maintenance to keep them serviceable. These problem structures usually involve either improperly understood technology such as the hollow-core piles for the Rodney Terminal in Saint John, New Brunswick, Canada (21) or the use of unsuitable materials such as seawater as mix water for heavily reinforced marine concrete as used in the middle east (22). In the former, the best minds of the day failed to anticipate the problems and in the latter the basic principles, known for decades, were ignored.

Marine structures used by the Allied and Axis forces during the last world war were almost without exception extremely durable and continue to act as an example of how concrete should perform. With the exception of the submarine pens in Trondheim, Norway, the structures have not found an alternative use and their good durability is in fact a disadvantage. Not so in most other concrete marine structures. Owners come and go but the marine commercial facilities endure continuing to meet the needs of successive owners. Usually bought for distressed prices they are modified to meet the new owner's requirements and frequently make business ventures viable that would not be so otherwise. A case in point is the non air entrained concrete wharf at Eastport, Maine, USA which was built in the 1920's by Continental Can, sold to various fish processing firms and then bought by Mearle Corporation for their fish scale business. Finally it was sold to a Canadian firm with the unlikely name of "Maine Pride Incorporated" who currently put it to good purpose in their salmon aquaculture business. Only limited areas of this non air entrained concrete wharf needed repairs at several times in its life but these were easily done at modest cost. Unfortunately one small part of the facility failed to receive timely repairs and collapsed; however, the remaining part has been revamped to meet current needs and serves its intended purpose admirably.

Most government and municipal marine wharves continue to be serviceable in spite of benign neglect. In Canada all wharves made prior to 1950 were non air entrained and most of them, in various states of distress continue to serve their intended purpose. The main reason for this is their massive nature in an environment where deterioration is a