THESIS

A STUDY OF THE DURABILITY OF CONCRETE IN SEA WATER

BY

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The Effect of Sea Water on Concrete.

The durability of concrete in sea water has been a very widely debated question from the time that disintegration of concrete in sea water first became evident. Numerous investigations and reports have been made of isolated structures in various parts of the country and from these, hasty conclusions have been reached which engineers, situated where different conditions prevail, have not been warranted in accepting. A few engineers have made investigations of a much wider scope and consequently their conclusions should be given greater weight.

Engineering literature is filled with examples of concrete structures that have failed in sea water whereas we have very few examples of satisfactory structures, so exposed. The reason for this is obvious. Structures that have failed attract attention but the satisfactory ones only excite a passing interest not sufficient to warrant an investigation to determine why they are satisfactory. Concrete is too well adapted to all marine construction to be discarded because of frequent failures. One example alone of a sea water structure which has given long, satisfactory, service is proof that concrete can be made durable in sea water and every effort possible should be made to determine what the qualities of that concrete are that have made it long lived and serviceable. When these qualities are determined and rules formulated that will insure their duplication in other structures under all conditions the problem of the durability of concrete in sea water will have been solved.

The writer realizing the value to the busy engineer of having, easily accessible the existing knowledge of the action of sea water on concrete, has read and compiled the available literature on this subject. The important points and conclusions of these individual articles have been correlated and incorporated into one set of general conclusions. Inasmuch as the articles read have covered reports of sea water structures all over the world it is hoped that the conclusions reached will be valuable to all engineers engaged in marine construction. However, no definite set of rules can cover all local conditions and it is very essential that the engineer thoroughly investigate such conditions before attempting construction work.

The following briefs of the articles read contain only that material which in the opinion of the writer has a direct bearing on the problem at hand. Not all of the articles read have been included in this compilation due to the fact that they covered exactly the same phases of the problem which were taken up by other articles. A reference to each article is given in order that the reader may have access to all of the details.

ENGINEERING NEWS - RECORD

Reference: What is the Trouble with Concrete in Sea Water?

Article I. By Wig & Ferguson. Vol.79, P.532

The authors examined concrete exposed to sea water in the U.S., Canada, Cuba and Panama and from this comprehensive study have attempted to make general conclusions which will guide contractors in building concrete structures in sea water. Wherever possible the specifications and photographs taken during construction were obtained and examined, and the men in charge of construction interviewed.

It was found in the case of one wall 12 years old that disintegration had started in the construction seams.

Article II. Vol.79, P.641

All concrete regardless of its quality, is subject to disintegration by the action of sea water after the surface has been appreciably abraded. The lime of the cement reacts with carbon dioxide in the atmosphere forming an insoluble lime carbonate which acts as a protective coating. The lime which is exposed by abrasion after the concrete has aged is in the crystalline form which does not react readily with CO_2 therefore a new protective coating cannot be formed and the lime is progresively dissolved until the cement is completely disintegrated. If this surface can be protected disintegration will not take place so readily.

Some time after the completion of a concrete sea wall on the Pacific Coast it was found that a section of it was too high so the top was lowered twelve inches. Where this removal was made the concrete had softened to a depth of ½ an inch but otherwise the wall, after seven years, is in good condition.

The laitance formed in sea-water concrete is partly cement rising to the surface and partly magnesia precipitated from the sea water. Extreme care should be used to remove this film before more concrete is laid because it forms an excellent point of attack for sea water.

In the design of sea-water structures all sharp corners and edges should be avoided for they offer excellent opportunity for abrasion.

Wooden jackets placed around piles protect them by preventing abrasion. The wooden jacket was removed from a plain concrete pile in the Bay of Fundy after 25 years of service and the form marks were still visible on the concrete. No softening had occurred. Where abrasive action is very severe a protective coating of granite should be used.

Article III. Vol.79 P.689

Even in first class concrete built in or near sea water a depth of 1 or 2 inches embeddment of reinforcing is not sufficient. Initial corrosion of reinforcement in concrete cannot be attributed to the use of salt water in mixing for most American structures have been built with fresh water. It was found in some cases that reinforcing embedded to a depth of 2½ inches in very good, dense, concrete had corroded, causing spalling of the concrete.

Electrolysis cannot have the weight generally attached to it for effecting reinforced concrete structures. If deterioration were caused by electrolysis, spalling would occur down to low water level, because at low tides the current could not leave the reinforcing until it reached this point. It is found that very seldom does spalling occur very much below high water level so that only in rare cases can spalling be attributed to electrolysis.

On one of the rivers emptying into the Atlantic there are more than 25 beacon lights extending past the point in the river where no brackishness can be determined in the water. None of the structures beyond the fresh water point show signs of deterioration but from the point where brackishness is just perceptible to the mouth of the river every one of the structures shows signs of deterioration, the deterioration being more marked as the brackishness increases. These were all built from the same materials at the same time, by the same contractor. Deterioration occurs invariably above the water line. Electricity is not used in or near the towers so electrolysis could not have taken place.

Cracks in concrete piles are not caused by shattering of the head during driving for the cracks do not as a rule extend to the head and the majority of piles are jetted.

Deterioration of piles can be prevented or retarded by using smaller diameter rods for reinforcing and embedding them deeper. As the bending stresses are not great above the water line, and here is where the spalling occurs, the piles may be so designed that the reinforcing may be bent in toward the center slightly below low water. Care should be taken not to over reinforce structures and if possible reinforcing should be eliminated entirely above low water level. Galvanizing the reinforcing above low water would also increase the life of piles.

Deterioration of reinforced concrete proceeds more rapidly in warm humid climates than in cool climates. Reinforced concrete deteriorates much more rapidly where plain concrete is the least affected by sea water action and vice versa.

Article IV. Vol.79 P.737

All well made Portland cements will resist disintegration in sea water if properly used. Providing the cement is properly manufactured one containing 8% of alumina will resist sea water action as well as one containing only 4%. Magnesia in cement is wholly inert to sea water and is one of the most stable elements of the cement. 3% to 8% magnesia is permissible. There is no definite relation between the properties of properly manufactured cement and the ability of concrete made from them to resist sea water action.

Sea water may be used in mixing plain concrete but reinforced concrete above high water level should be mixed with fresh water. The only effect noticeable in using sea water for plain concrete mixing is the increased laitance which forms consisting mainly of magnesium hydroxide precipitaded from the sea water.

Limestone which is a calcium and magnesium carbonate may be safely used as aggregate in concrete for these substances are very stable.

A number of sea water structures made with various waterproofing compounds showed no difference in appearance than those where no waterproofing had been used. Besides not being beneficial in keeping moisture out, the waterproofing weakens the concrete.

Article V. Vol.79 P.794

The character of the workmanship has an important bearing on the ability of concrete to resist the action of sea-water. In marine construction all joints should be made water tight to prevent leakage of the concrete and to keep the mortar from being washed out by action of the sea. A diver should be employed to carefully examine the forms below the water surface. All forms should be given a coating of kerosene or mineral oil. Fish oil is very deleterious to the concrete.

The materials should be combined to form the most dense concrete possible. This mixture should be determined by actual trial and not theoretically. Arbitrarily specified proportions are unscientific and should not be used but the proportions should be actually determined for the materials used. Frequent tests should be made as the work proceeds.

The amount of water used in mixing is of greater importance than proportioning of ingredients. If too little water is used the concrete is porous and the surface lacks smoothness and density, if too much is used the concrete is also porous and the surface chalky and weak. The correct consistency is one just dry enough to permit of light tamping but not so dry as to rerequire any great effort to bring water to the surface. For reinforced construction a slightly wetter consistency must be used. The use of excess water may reduce the strength as much as 50%.

The outboard section of one New England pier was constructed by an engineer who used a very dry consistency. Another engineer constructed the inboard section under the same specifications using the same ingredients, but a consistency which needed only slight tamping. After 10 years the outboard section needed extensive repairs and a sloppy consistency was used. These repairs have disintegrated to such an extent that more repairs are necessary whereas the inboard section is in very good condition after 15 years of service without any repairs.

Either too wet or too dry a consistency will cause failure. All concrete to be exposed to sea water should be thoroughly mixed.

It is very necessary that the concrete be very carefully placed, especialy when placed under water, and that all laitance be removed before resumption of work.

A large pivot pier, 18 feet in diameter, on the Atlantic Coast was built in water 45 feet deep. The original plan of construction, by the use of a coffer dam, had to be abandoned due to leakage. The material was then placed by bottom dump buckets. The laitance which formed during the night was not removed before proceeding with work the following day. Some years after the work was completed holes were drilled through the top of the pier to the bottom. Alternate layers of hard and soft materials were encountered; some of the soft layers being as much as 24 inches thick.

It is beneficial to have a mortar face richer than the than the body of the structure.

Joints should never occure in piles between the levels of high and low water.

Reference: Does Waterproofed Concrete Resist Sea Water?
By Toch Brothers
Vol.79 P.1212.

Cracking of beams and kneebraces occur in many localities other than along the sea coast and is due to stresses caused by temperature variations and has nothing to do with the imperviousness of the concrete.

In tests carried on by the U.S. Bureau of Standards it was found that the waterproofing compound Toxement decreased both the compressive and tensile strengths of concrete for all periods less than a year but tests at the end of a year showed that the strength was slightly increased.

Toxement decreases disintegration of concrete in sea water by decreasing the porosity.

Reference: More Comment on Behavior of Sea Water Concrete
A Discussion of Articles by Wig & Ferguson
Vol.80 P.264

Surface protections found on sea water concrete are carbonate of lime and carbonate of magnesia.

Porous mortar retains the salt in the pores as the water level lowers. This action is repeated with the rising and falling of the tide until there is a saturated solution acting in the pores of the concrete tending to disintegrate it.

The need for a non-porous concrete is more fundamental than the need for a protective coating of lime carbonate.

Reference: Are Spirally Wound Concrete Piles Safe in Sea Water.
By: A.C. Chenoweth
Vol.80 P.926

Premoulded concrete piles of the cast in the form type are effected by sea water and the elements, being cracked along the line of vertical reinforcement. Chenoweth Spirally wound concrete piles showed no signs of cracking or spalling after 10 years service.

Crystallization of salts occurs above the high water level.

Reference: Some Observations on Concrete in Sea Water in SanFrancisco Harbour.
Vol.80 P.575

The most important factors in the ability of concrete to resist sea water action are its density and imperviousness.

The protective coating of calcium carbonate, although insoluble itself, does not prevent the soluble hydrate of the interior coming to the surface and dissolving out.

For dense concrete this protective skin is very thin whereas for poor concretes it is very thick. The thickness of the calcium carbonate coating is a very good indicator of the density of the concrete.

This insoluble lime carbonate forms immediately and readily upon exposure to air or water regardless of the age of the concrete.

Surface frost action will disintegrate concrete and must be guarded against.

It is the increased density of the skin which protects the interior rather than the calcium carbonate coating.

Shock, shrinkage and temperature stresses produce hair cracks which ~~persist~~ permits salt air and moisture to reach the reinforcing, starting corrosion.

Reference: Spalling of Reinforced Concrete in Moist Location.
By F.E. Turneaure
Vol.80 P.46

The reinforced concrete tanks under the floor of the Hydraulics Laboratory of the University of Wisconsin contains only fresh water. Under the floor slab the reinforcing was buried to a depth of 1½ inches but after twelve years the concrete has spalled off exposing the badly rusted steel. In the walls where the reinforcing was spaced further apart spalling has occurred over the steel only. Rods similarly covered in other parts of the basement where there has been a free circulation of air have shown no tendency to rust and spalling has not occurred. There is no evidence of rusting or spalling on those parts of the concrete which are continually submerged.

Reference: Ocean Pier to be Scrapped because of Concrete Disintegration.
Vol.84 P.621

This article is a report on the Municipal Pier at Santa Monica, California, which was closed to the public in November 1919.

The piles were pre-cast on shore at an angle of 40 degrees with the horizontal and were sunk into place by jetting. The concrete would not compare favorably with present day standards but was a 1:2:4 mix with stone limited in size to 1 inch. Deterioration had taken place to a considerable extent after 8 years of service. The beach sand of which some of the piles were made contained particles of black shale which oxidized causing the concrete to spall. Joints had been made in a number of piles in such a position that when the piles were sunk the joints were located at about mean tide. Deterioration was due to the open, permeable concrete and probably to a slight extent to electrolysis.

Reference: Asphalt Coating for Exposed Steel in Waterfront Concrete.
Eng. News-Record
Vol.84 P.1075

Concrete beams along the SanFrancisco waterfront in which the steel is exposed have been under observation for two years without any appreciable increase in deterioration. The exposure of steel is all in the beams, practically none being found in the piles or floor slabs. For this reason it is thought that the deterioration was not due to the effect of sea-water but to the vibrations of locomotives passing over the structure. A protective coating of asphalt is being applied to the steel only, to prevent any further deterioration of the exposed metal.

Reference: Ocean Pier to be Scrapped because of Disintegration.
Vol.84 P.621

The piles of the Santa Monica pier, after eight years of service were so disintegrated between low and high water levels that they could be cut with a knife. The concrete in the piles were of a 1:2:4 mix. A high per centage of magnesia was found upon analysis.

The high percentage of magnesia found shows that disintegration had been going on for some time.

Cracks appeared to be over vertical reinforcement and above the elevation of mean tide.

Investigation by divers in 1920 showed that the piles had suffered very great deterioration under water.

Chemical disintegration took place under water or between low and high water levels. Cracking due to expansion of the reinforcing took place above high water.

The failure was due to permeability of the concrete.

Permeability may be caused either by the use of too much or too little water.

Reinforcement should be deeply imbedded.

The disintegrated concrete lost 23% of lime and gained 9.5% more magnesia in the form of the hydroxide, than the good concrete contains.

Reference: More Observations of the Effect of Sea Water on Concrete.
Vol.86 P.121

All of the piers from Santa Monica to Huntington Beach, on the Pacific Coast, were thoroughly examined and found to be in various degrees of preservation or disintegration.

Oil coating on piers possibly acts as a protection against sea water action.

Disintegration occurs between low and high water levels.

Cracking starts over the reinforcing and is indicated by rust marks. Usually the reinforcing was found to be embedded only to a depth of two inches or less.

Oil keeps all marine life and growth away from the piles.

Reference: Biological Action in Deterioration of Concrete in Sea Water.
By Baxeres de Alzugardy
Vol.86 P.910

Soon after a concrete structure comes in contact with sea water marine growth attaches itself to the surface, penetrating the softer part of the concrete material. Litchens, fungi, and algea are the starters of this destructive work. Some organisims can even bore holes in hard rock so that excellent openings are made for the attack of the chemical action of sea water. Other sea animals secrete solutions of hippuric and sulphuric acids, the latter causing active disintegration of the silicates and aluminates forming the cement elements of the concrete. This action is further aided by the mechanical forces exerted by the crystallization of salts in the pores.

There is no limit to the penetrating power of salts and other corrosive agents. These may progress from layer to layer causing final failure.

The penetration of oil in concrete is very good and serves as a protection against marine growth, and also against the destructive action of sea water.

Reference: Protective Coatings for Sea Water Concrete.
By Louis Ravier, Paris, France
Vol.86 P.566

At Boulogne-sur-Mer sea water concrete is covered with a thin coating of pure cement paste after which is applied two coatings of boiling coal tar, the second not being applied until the first is perfectly dry.

No trace of decomposition is observable in concrete treated in this manner after ten years of exposure to the sea water.

Reference: Too Great Concren over Sea Water Concrete.
By F.J. Litter
Vol.86 P.652

Concrete piles should cure on shore for four weeks before being put in the water.

None of the reinforcing or its fastenings should be within an inch and one half of the surface.

In hard material all concrete piles should be jetted. If a steam hammer is used in soft material the pile should be thoroughly cushioned.

Reference: Recommend Concrete for Ocean Structures
Vol.86 P.1032

The municipal bath house at Coney Island after ten years of exposure showed relatively little deterioration caused by corrosion of the steel and that was due to failure of following specifications in regard to minimum depth of reinforcing.

Slender pile frames of long, unbraced length, should not be built where they will be subject to the batter and vibration of the waves.

Reinforcing above mean low water should be embedded to a depth of three inches.

Reference: Water Content Affects Wear of Concrete Test Pieces.
By Dan Patch
Vol.86 P.373

A study of the latest inspection report of the test pieces placed in Boston Harbour by the Aberthaw Construction Co. indicates that the water content of concrete is important.

The best percentage of water for a mix to resist the action of the tidal water is from 9% to 10%.

The percentage of water to be used for a rich mix should be higher than that for a lean mix.

Reference: Two Concrete Piers
H.H. Braun
Vol.87 P.827

Two concrete piers, A and B, located in Manila Bay were built at the same time and under exactly the same conditions. The very best of concrete was used in both piers which are located about 1000 feet apart. Pier A is subjected to far heavier traffic than is pier B. After seven years of service pier A is in excellent condition while pier B is in an advanced stage of disintegration. When the reinforcement was sent out to the job it was found that it had been bent wrong. The superintendent on pier A stopped work and had the reinforcement bent right whereas the superintendent on pier B put it in as it was with the result that it was too close to the surface (from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inches) and was subject to the corrosive action of the sea water.

Also the superintendent on pier B pushed his mixer and supplies out on the new floor slabs within a day or two after they had been poured. Undoubtedly the vibration of the mixer opened fine hair cracks in the new concrete allowing salt air to penetrate to the steel.

Reference: Some Examples of Corrosion of Reinforcing Steel.
By F.P. McKibben
Vol.87 P.531

In a meat packing plant in Buffalo where the concrete was subjected to much salt and moisture the reinforcing had corroded flaking off the concrete to a dangerous degree. Some of the reinforcing had rusted entirely away. Alternating current electricity was used in the building which eliminated the chance for electrolysis.

The reinforcing in a concrete residence in the British West Indies was exposed in many places even in the interior of the house. All cracks were parallel to the reinforcing. Near the residence were a pavillion and a bridge in which the concrete in many places had been pushed off by the corrosion of the embedded steel. Alternating current was used in the residence but no electric wires were near the other structures. Salt water and unwashed sea-sand were used in the concrete.

The reinforcement in a railing near Nice, France, had corroded, completely destroying part of the spindles. The spindles rested on a concrete wall which permitted water to penetrate the horizontal joints, thus starting corrosion.

A great many structures in Atlantic City were very badly disintegrated by corroded steel. More than half of the structures carried no electric wiring and the rest used alternating current electricity. Electrical readings showed that electrolysis was not connected with the corrosion of the steel. The character of the fractures indicated that chemical action caused the corrosion.

Reference: Corrosion Due to Sea Water or Electrolysis
W.A. Snow
Vol.87 P.528

An article concerning the deterioration of reinforced concrete floor beams in a residence along the east coast of Florida.

The Protecting concrete was found flaked off in a great many places leaving the reinforcing steel exposed.

Upon investigation it was found that sea-water had been used in the original mixing. It was also found that direct current was used in the building and the lighting system was continually giving trouble.

Conclusions

The conclusions arrived at were as follows:

1. Sea water being used in the concrete mix accounted for the initial rusting of the steel.

2. The basement, ceiling, and walls being continually exposed to warm salt water vapor and not being damp-proof tended to increase the rate of corrosion.

3. Indications seemed to point to the fact that there were severe ground electrical currents in the building which probably passed through the reinforcing. Later evidence seemed to prove that current had passed through the reinforcing.

The concrete was of an average mix for that section which is somewhat softer than northern concrete.

ENGINEERING NEWS

Society Report

Vol.58 P.461

Concrete deposited in sea water as a rule disintegrates faster than that cast in the air and sunk into place. Disintegration may be prevented by coating surfaces corroded by ice action with cement mortar each spring. Bridge piers and abutments should be faced with granite ashlar from a little below low water level up.

Never mix concrete with water before placing for under water work; place it dry through chutes.

The cement for concrete placed directly in sea water should contain a low percentage of magnesia and not over 2% of sulphur trioxide. When using a tremic the first charge should be placed in the center and not near the forms for there is always washing of the first charge and this weaker material should not be near the surface. Calcium hydroxide being too heavy to float often forms on the surface and unless removed before more concrete is placed will cause a weak section. Disintegration takes place more rapidly in freezing weather.

Iron Ore Cement

By Wm. Michaelis, Jr.

Vol.58 P.646

Cement made of limestone and iron ore instead of limestone and clay effectively resists sea water attacks. It is a slow setting cement manufactured purposely for sea water work and attains a strength far in excess of ordinary Portland cement.

It differs from Portland cement in that the aluminates are replaced by calcium ferrites. It contains 70%-80% of active ingredients whereas Portland cement contains only 30%-40%. Mixed with plaster in any proportion it remains perfectly sound when exposed to the action of sea water of five times normal strength under a pressure of fifteen atmospheres-- conditions which destroy ordinary Portland cement within a few days.

The Decomposition of Concrete in Sea Water

Vol.60 P.392

For the past ten years iron ore cement has been used in marine construction in Germany with absolutely satisfactory results. Every test piece of concrete made with iron ore cement when tested in sea water concentrated up to five times and under pressures as high as twenty times atmospheric was in a state of perfect preservation even after tests carried on for several years. It was noted that the more severe the tests the greater was the strength of the test specimen afterwards.

The Fishery Harbours of Scotland

By John Taylor

Vol.67 P.671

Assuming first class concrete for sea water work there are still four great causes of disintegration; 1, vibration and shock; 2, temperature stresses; 3, freezing; 4, air compression and suction.

Vibration and shock are caused by the impact of the waves against the structure which will often amount to 1 ton or more per square foot. The one safeguard against this is to make the construction heavy enough to withstand it.

In large monolithic construction the expansion and contraction lengthwise is not the only effect of temperature changes. If a massive wall has been exposed to the hot rays of the sun until it has thoroughly warmed throughout and is then covered by a cool wave the surface responds almost immediately to the change in temperature tending to separate, as it contracts, from the warmer interior, along planes parallel to the surface. The surface between high and low water level is subjected to this action twice each day. This will account partly for the deterioration between these limits.

Water entering cracks formed by temperature stresses and freezing will tend to flake these surface layers off.

In sea work exposed to wave action there is air compression and suction in the cracks and voids at each impact of a wave. This repeated compression and suction has a tendency to loosen the individual grains of sand and rock.

In depositing concrete under water it should be mixed dryer than for above water construction and should be placed by means of skips of 2 ton capacity or larger for massive work.

Failure of Concrete Piles at Long Beach, Calif.

Vol.67 P.78

Concrete piles should never be placed in wooden forms from which the water cannot be pumped out. Two reasons for such a pile not being strong are; first, if located in a strong current the cement will wash out through the cracks in the form; second, there is not adequate chance for inspection.

Embedded Wood in Concrete

By C.G. Rupert

Vol. 64 P. 155

Wood should never be imbedded in concrete for it absorbs moisture and swells, thereby rupturing the concrete.

Reinforced Concrete in Hydraulic Works

By J.S. Sewell

Vol.67 P.1029

Two experimental slabs of reinforced concrete were made of identical composition except that one was mixed with sea water while the other was mixed with fresh water. They were then exposed to the weather on a roof in Washington, D.C., for some months at the end of which time the reinforcement in the sea water slab was badly corroded while there was no sign of corrosion in the slab mixed with fresh water.

Corrosion of Steel Rods in Reinforced Concrete by Salts

By C.P.Mayfield

Vol.67 P.258

Tests carried on by mixing different per-centages of Sodium and Calcium Chlorides in concrete surrounding reinforcing showed that the steel in concrete mixed with the salts corroded whereas that in plain concrete did not. This action is greater in a concrete of dry consistency than in one of wet consistency. The denser the aggregate the less the corrosion.

Destruction of Concrete Between Tides in Sea Water
Vol.68 P.262

In marine construction in Germany trass is added to the concrete which gives it great density and high initial strength.

French Tests on Oil Mixed Concretes
Vol.70 P.1228

Concrete mortars expand or contract according as they gain or lose in humidity independent of temperature changes and repetition of these movements will cause cracking.

The addition of a slight percentage of oil in mixing concrete decreases the permeability, especially of porous concrete but it also decreases the adhesive power of the mortar and the compressive resistance.

It is much more desirable to obtain an impermeable concrete by careful proportioning than by the use of any waterproofing.

Reference: Salt Water Causes Cracking Concrete in Philippines

By J.L. Harrison
Vol.76 P.1047

Samples taken regularly for the past two years, from reinforced concrete structures in the Philippines, which have shown signs of deterioration, revealed the presence of chlorine upon analysis. Chlorine is liberated by the salt from sea sands and ocean water used in mixing and reacts very readily with the steel reinforcement causing rusting. There are numerous structures which have given very satisfactory service. All of the structures in the latter case were made of very dense concrete.

The use of beach sand and beach gravel should be permitted only after thorough washing with fresh water. Sea water should never be used in reinforced concrete.

ENGINEERING RECORD

Reference: Action of Sea Water on Portland Cement
By J.M. O'Hara
Vol.61 P.677

Accelerated sea water tests were made at San Francisco on cement pats made from several brands of Portland cements.

The sulphur of the magnesium sulphate in sea water has a stronger affinity for calcium than for magnesium and the reaction products are magnesium hydroxide and calcium sulphate. This calcium sulphate further combines with the calcium aluminate which causes great swelling of the concrete and total destruction of all cohesion. The magnesium hydrate formed has a tendency to fill the pores of the concrete making it less pervious.

More than twice as much lime is set free by cement setting in sea water than in fresh water.

The sodium chloride of sea water is able to dissolve the calcium silicate of cement which is the main factor of final hardening and strength, thus causing the structure to be weakened.

Softening of concrete takes place only where there is an abnormal amount of sulphuric acid present and is the result of a reaction between the acid and a part of the lime of the cement.

Sea water has no apparent action on the ferric oxide of the cement.

Alumina is a harmfull ingredient of cement in sea water construction. It would seem that a cement in which most of the alumina was replaced by iron would be preferable for this type of work.

Reference: The Behavior of Hydraulic Compounds in Sea Water
By H. Burchartz
Vol.62 P.237

The Royal Testing Laboratory conducted a very exhaustive series of tests of concrete in sea water. The tests will eventually cover a period of 30 years. The results here given are of the first five year period.

Final strength of concrete in sea water is decreased by the addition of trass. The mixture with trass increase proportionally more in strength than those without trass;i.e. they reach their final strength sooner.

It is desireable in sea water work to use a very rich, dense, concrete.

The addition of trass to concrete reduces its density.

Reference: The Condition of Concrete Structures in Boston Harbor.
By S.C. Willis
Vol.64 P.371

After 17 years service the central pier of the Dover Street drawbridge had disintegrated to a depth of 1.38 feet. A one inch mortar facing was put on the pier at the time it was built but not until the main pier had fully set. Where this surface had not been disturbed it was yet very dense and hard. Undoubtedly there was little bond between the pier and the facing. Frost action accounts for a great deal of disintegration in some structures while in others the use of a dry mixture has permitted sea water to enter and "rot" the concrete.

Reference: How to Make Concrete Resist Action of Sea Water
By W.W. Pagon
Vol.73 P.702

1. Add trass (puzzolan) between the limits of 1 part to 1 part part cement and ½ part to 1 part cement.
2. Waterproof with substances that combine chemically with the free lime.
3. Use a rich mortar face.
4. Use cements low in lime, alumina and gypsum.
5. Use sharp well graded sand free from foreign particles.
6. Have no stones near the surface of the concrete.
7. Use sufficient fresh water to permit easy handling.
8. Use tight forms.
9. Reinforce the facing taking care that steel is deeply imbedded.
10. Do not place concrete in cold weather.

MISCELLANEOUS

Reference: Technologic Papers of the U.S. Bureau of Standards.
Number 12
November 1, 1912

The U.S. Bureau of Standards made very extensive tests of the effect of sea-water on concrete at Atlantic City, N.J. Tests were made using slag, natural and other sea-water cements. 8 inches by 16 inches cylindrical test pieces were made using 1 part cement, 2 parts Jersey sand and 4 parts of trap rock by volume. They were stored in a damp room for eight weeks and then immersed in sea-water where they remained until tested. A duplicate series was made and placed in fresh water. Two series of tension briquettes were also made of the various cements and after 24 hr. storage in moist air placed in sea-water and fresh water respectively. These briquettes were tested in periods ranging from 4 weeks to 2 years. A third series of briquettes was made and tested in the same manner using from 0.05 to 20.0% Plaster of Paris. Other briquettes were made of cement and standard Ottawa sand and immersed in ammonium carbonate for six days before placing in sea-water. Still other briquettes of mortar were made but this time ammonium carbonate was used in place of water for mixing. Finally two neat cement pats were made using a mixture of all of the cements used for the other tests. One was placed in sea-water and the other in fresh water. A quaking or mushy consistency was used in all mixtures.

When the cylinders were removed for testing they were cleaned of all foreign matter and very carefully capped with Plaster of Paris.

Results

Concrete placed under sea-water by a tremie showed less than 33% the compressive strength of concrete placed dry and immediately submerged.

Concrete allowed to set and harden for eight weeks before immersion showed more than 3 times the compressive strength of that placed through a tremie.

A few tests with reinforcement in the concrete showed that practically all of the metal within an inch of the surface was more or less corroded whereas that at a depth of two inches or more was unaffected.

Cylinders containing a high percentage of lime showed a much more rapid disintegration than those relatively free of lime. The compressive strength was also greatly reduced.

Concrete allowed to harden in fresh water before immersion in sea-water shows less retrogression of strength with age.

The mortar briquettes showed less evidence of sea-water action than the neat briquettes for all periods up to two years.

A slight percentage of ammonium carbonate increased the strength of the briquettes slightly for periods less than two years but the effect for greater periods was detrimental.

Carefully mixed Portland cement concrete when totally immersed was unaffected by the chemical action of sea-water during the two year period.

Neat briquettes of Portland cements of high iron content, and several of high and normal alumina content showed no marked difference in strength when exposed to fresh or sea-water for periods up to two years.

There was found to be no apparent relation between the chemical composition of a cement and the rapidity with which it reacts with sea water when brought into intimate contact.

The most soluble element of cement either in sea water or chemicals is the lime. If the lime is carbonated the cement becomes practically insoluble.

The magnesia present in cement was found to be practically inert.

The quantity of SO_3 present in cement affects its stability only by affecting its rate of hardening.

The sulphates are the most active constituents of sea water and are taken up by the cement. Their action is accalerated in the presence of chlorides.

Concrete was also tested in all of the important chemicals and compounds and it was found that almost any of the salts crystallizing in the pores will rapidly disintegrate any porous mixture.

Reference: Journal of the Franklin Institute
The Deteriorating Action of Salt and Brine on Concrete
By H.J.M. Creighton
Vol.184 P.689

In addition to the corrosion of iron through the action of brine, auto-electrolysis may occur, when the reinforcing is subject to dampness, on account of the presence of segregated impurities which are responsible for the differences of potential established in certain areas. These potential differences bring about a galvanic action which causes the iron to go into solution at certain points with the formation of rust.

Reinforced concrete, for this reason and unless absolutely impervious, will begin to deteriorate as soon as it comes in contact with sea water, for the rust, occupying a greater space than the metal, exerts an enormous expansive force which causes spalling of the concrete.

All waterproofing materials on the market will sooner or later hydrolyze, crack, or disintegrate.

The iron oxide adhering to the concrete which had spalled off was often as much as one eighth inch thick.

Salt should not be used in mixing concrete in freezing weather unless the structure can satisfactorily be kept waterproof for its remaining life.

Reference: Engineering
Ferro- Concrete Vessels.
Vol.103 P.381

An addition of 5 per cent of finely ground clay to a concrete mixture renders it more impervious to sea-water.

Deterioration is due to free lime combining with the magnesium sulphate in the water. Puzzolane cement is free from a surplus of lime and also has a surplus of silicic acid which is able to bind free lime. It is therefore much more stable in sea water than other cements.

The use of too much fine sand is very injurious to sea water concrete.

The protective measures to be followed are:

1. The use of rich mortar.

2. The use of cement with but little free lime, alumina, and gypsum.

3. The addition of puzzolane to fix the free lime.

4. The use of coarse sand.

5. The use of dense concrete.

6. Surface treatment.

Reference: Engineering
The Best Way of Protecting Reinforced Concrete from Marine Deterioration
Vol. 112 P. 73

Failures in marine structures are of four kinds:

1. Softening of concrete due to chemical action.

2. Scaling of concrete due to frost action.

3. Wear due to attrition by traveling shingle and stones.

4. Cracking due to rusting of reinforcement.

The softening of concrete can be prevented by making dense, impervious concrete.

A dense, impermeable concrete will not be affected by frost action if it is allowed to harden in air before being subjected to water.

A tough aggregate with large stones is effective in resisting the wearing action of moving stones.

To decrease the effect of rusting steel the work should hot be over-reinforced, the size of stones should be limited to $\frac{3}{4}$ inch, and the steel should be deeply imbedded in the concrete.

A coating of pure cement grout applied directly to the steel before the concrete is placed would prevent rusting without destroying the bond between the concrete and steel.

Concrete should be well mixed, stones and sand well graded, i.e. they should not be uniform in size but varying from coarse to fine. Neither too much nor too little water should be used as either extreme tends to produce a porous concrete.

Rather than use integral waterproofing an extra amount of cement should be added as this increases the impermeability without decreasing the strength.

Surface waterproofing with oil is good but should not be applied until the concrete has matured for some months.

Reference: Transactions of the A. S. C. E.
Results of Concrete Specimens in Sea Water at
Boston Navy Yard
By R. E. Bakenhus, Volume LXXXI, P. 645

The tests show that;

a) The effect of the proportions of the ingredients on the durability of concrete in sea water is very great.
b) In every case the specimen richer in cement is more durable than the corresponding leaner specimen.
c) Only specimens of 1:1:2 mixture appear in the first three classes.
d) In general dry mixtures are of the least value and wet or very wet mixtures decidedly improve the durability.
e) The two most durable specimens were those lowest in alumina content.

f) There is no apparent relationship of magnesia content to durability.

g) Hydrated lime has very deleterious effects when used in sea water concrete.

h) The addition of Sylvester wash is decidedly harmful.

i) The addition of 5% of clay to the cement had a beneficial effect.

The pile that resisted disintegration the most was made with German iron ore cement.

Discussion

Concrete in setting forms a surface which effectively resists sea water action but once this surface is broken deteriorationtakes place very rapidly.

Less laitance forms on concrete made with washed beach sand and gravel than with washed beach sand and broken trap rock with the dust screened out.

Examinations of structures on the Central Railroad show that fresh water structures do not disintegrate in comparison- with sea water structures which disproves the theory that disintegration is due solely to the alternate freezing and thawing of the concrete.

An addition of 30% of beach sand improved the strength of concrete as compared with concrete made from so-called perfect sand.

Rather than add 5% of clay it is better to add more cement which besides increasing the density makes a stronger concrete.

The stone used in sea water concrete should be chemically inert, insoluble, non-absorbent, and should present a surface to which the cement will adhere with the greatest possible strength. This would eliminate all round smooth sea stones, whole rock, sandstone, limestone, and other rocks of a sedimentary nature.

Coarse aggregate should not be allowed too near the surface for if the surface is chipped off accidentally or otherwisethe water can follow the joint between the concrete and surface of the stone where by freezing it can cause the concrete to scale off.

Reference: Transactions of the A. S. C. E.
Discussion on Pearl Harbour Dry Dock
Volume LXXX, Page 297

The time of mixing is very important. Although five minutes to a batch may seem axcessive it is far better to err on the safe side than otherwise.

Reference: Minutes of proceedings The Institute of Civil Engineers
Experiment Upon Mortar
By A. Poulsen Volume CC, P.409

The addition of puzzolana to concrete is beneficial because it contains active silicic acid which combines with the free lime of the cement thereby making it impossible for the lime to be replaced by magnesia which is one of the reactions tending to produce deterioration. In order to produce this silicate of lime it is necessary to add 15 pounds of active silicic acid for every 14 pounds of free lime.

The diatomaceous earth should be thoroughly dried and ground up with the cement clinker in order to be thoroughly effective.

SUMMARY

Due to the wide variance of local conditions throughout the United States it is impossible to formulate a complete set of rules which, if observed, will insure success in all marine construction. However there are a few general considerations, such as materials and workmanship, that are applicable to all cases and which must be strictly adhered to if success is to be attained.

The question of the endurance of concrete in sea water simplifies itself into one of density and composition. Unless marine concrete is very dense it cannot hope to be long lived. Too much dependence should not be placed upon theoretical proportioning of the ingredients to secure maximun density. Proportioning should be the result of actual tests carried out in the field. Prolonged and thorough mixing increases the density. Either too much or too little water causes the concrete to be porous. Spading increases the surface density. Integral waterproofing compounds should not be used for they weaken the concrete. Surface coatings of pure cement grout or certain oil products are effective as waterproofing.

Those rules which must be observed in all marine construction are as follows:

1. Sand and coarse aggregate must be well graded from the finest to the coarsest particles, too much fine material causes weakness whereas too much coarse decreases the density.

2. The stone of the coarse aggregate must be chemically inert, non-absorbant, insoluble, and hard. It should have a rough surface in order to increase its holding power.

3. The correct consistency is one which requires light tamp-

ing to bring the water to the surface.

4. Enough time must be allowed in mixing to permit of intimate admixture of all particles.

5. Surfaces must be thoroughly spaded.

6. All coarse aggregate must be kept well away from the surfaces.

7. For reinforced concrete:

   a. Beach sand and gravel may only be used after it has been thoroughly washed with fresh water.

   b. Never use sea water in mixing.

8. Reinforcement must be embedded deeply.

9. Small diameter rods should be used for reinforcement.

10. Great care should be taken not to over reinforce a structture.

11. Construction joints must not occur between the levels of high and low water whenever possible to prevent it.

12. Thoroughly remove all laitance.

13. Keep the form joints water-tight.

14. Inspect the work continually.

15. Employ only skilled workmen.

The conscientious application of these fundamental rules with a thorough knowledge of and regard for local conditions will result in permanent marine construction.

It has been found beneficial to make a rich mortar face when such face can be cast monolithic with the rest of the structure. It is also better to allow concrete to cure in the air before immersion in sea water when the design will permit. Surfaces subjected to abrasion by floating ice and debris should be protected by a granite facing or wooden jacket. The danger from abrasion is reduced by eliminating sharp corners and edges in the design.

European engineers add puzzolan to sea water concrete with very beneficial results. Puzzolan contains a high percentage of silicic acid which combines with the free lime of the cement thereby eliminating one of the factors in the deterioration of concrete in sea water; for, free lime is displaced by the magnesia of sea-water, in the form of the hydroxide, which occupies a larger volume than the lime. This increase in volume exerts a force tending to rupture the concrete. It would be of great value to the engineering profession if some means could be found in this country of supplying, commercially, the silicic acid needed to combine with the lime.

Another much debated question, which the writer would like to see answered experimentally, is the advisability of waterproofing the reinforcing by galvanizing or painting it before placing in the forms. It has been suggested that applying a coat of pure cement grout to the steel would sufficiently protect it without destroying the bond between it and the concrete.

There is very little definite knowledge concerning the action of sea water on concrete and it is only by exercising the greatest possible diligence and care that the engineer can hope to attain success in marine work.