surface phenomena. The exception is when the alkalis in the cement react expansively with the aggregates and this can, at least in Atlantic Canada, cause serious problems with the structures after about three decades of service. Although no testing of these structures appears to have been done below low tide the problem might be less here as cracking although severe in the splash zone becomes less apparent at low tide.

The offshore structures located between Norway and Scotland used to extract oil from the sea bed have been in place for over two decades and have performed exceptionally well (23). Equally well performing but less well known are the concrete platforms in the Gulf of Mexico. Some of these have been in place for over four decades. Many of them are made from lightweight concrete and demonstrate the good performance likely to be obtained with this material. Mather (24) reviewed the literature on the first two marine structures (now over 75 years old) made from lightweight concrete - the "Atlantis" and the "Selma" and noted the good performance of these ships. Recently Hoff (25) reported on a comprehensive series of tests on lightweight concretes that are relevant to marine structures.

Many examples of good long term performance exist for marine concrete. The exceptions are few and can be attributed to many reasons including the fact that unique designs were attempted for which all factors were not taken into account. Even in these rare cases the structure can, in most instances, be made serviceable as was Rodney Terminal and the non air entrained wharf at Eastport.

CONCLUSION

Marine concrete structures have proven to be both so versatile and durable that they can serve in the most severe climatic conditions in the world. Instances of poor performance are so few that the public normally expects extremely long term service. This means that the structure may be asked to serve several uses during its long service life and this presents a special challenge to designers to produce a structure that will have minimum maintenance costs. Our current concern with how best to build durable marine structures focuses attention on those aspects most needing investigation, and the problems with the corrosion of steel embedded in concrete is probably the one most in need of action. Because corrosion is influenced by the presence of flexural cracks it would appear desirable to do testing of stressed beams in seawater in both cold and hot climatic conditions. A research program to address this problem is now being implemented at Treat Island and in Florida and also possibly at a coastal site in Mexico. Because these tests must run for several decades, considerable care is needed to make sure that the test frames and instrumentation will have the necessary long term stability. Work to validate the testing equipment and procedures is now essentially complete and full scale beam tests are scheduled to start in the Fall of 1994.

The performance of structures is influenced, according to Skalny, "... by our education system, quality of research and development, knowledge transfer, quality of workmanship,

onomic factors such as life cycle costing and research funding ..." (26). To cover this the level Skalny suggests, warrants a study on an international bases that covers the spectrum of human expectations with respect to marine concrete and discussions ng these lines perhaps should start at this conference.

REFERENCES

McCann, Anna Marguerite. "The Roman Port of Cosa". Scientific American, Vol. 258, March, 1988. pp. 102-109.

Gross, M. Grant. "Oceanography". Charles E. Merril, Columbus, Ohio, 1984, pp. 56.

Cook, Herbert K. "Experimental Exposure of Concrete to Natural Weathering in Marine Locations". Vol. 52, ASTM, 1952, pp. 1169-1180.

Gaythwaite, John. "The Marine Environment and Structural Design". Van Nostrand Reinhold Company, London, 1981, pp. 264.

Buenfeld, N.R. and J.B. Newman. "The Permeability of Concrete in a Marine Environment". Magazine of Concrete Research, Vol. 36, No. 127, June 1984, pp. 67-80.

MOSKVIN, V.M. "Concrete and Reinforced Concrete Deterioration and Protection". translated by V. Kolykhmatov, Mir Publishers, Moscow, 1980, pp. 314-316.

Mehta, P.K. "Durability of Concrete in Marine Environment - A Review". Performance of Concrete in Marine Environment, V.M. Molhotra ed., ACI Special Publication SP-65, 1980, pp. 1-20.

Al-Rabiah, A.R., R. Baggot and Rashieduzzafar. "Construction and Durability Considerations for King Kahl Causeway - A Case Study". ACI SP-65, pp. 705-734.

Mehta, P.K. and H.H. Haynes. "Durability of Concrete in Seawater". Journal of the Structural Division, Vol. 101, No. ST8, Proc., August 1975, pp. 1679-1686.

Anderson, Brent R. "Seawater and Its Effect on Concrete Durability". MSc. Thesis, University of New Brunswick, April 1986, 177 pp.

Regourd, M. "Seawater Attacks on Concrete, Precautionary Measures". Centre d'Etudies et de Recherches de L'Industrie des Liants Hydrauliques, N. Ref: MR.FL. 01953, Paris, January 3, 1984, pp. 13.

Gjorv, O.E. "Long-Time Durability of Concrete in Seawater". ACI Journal, January 1971, pp. 60-67.

13. "Prestressed Concrete Bridge-Tendons", FIP Notes 1993/1, pp. 18.

14. Gerwick, Ben C. "International Experience in the Performance of Marine Concrete", FIP Notes, Quarterly Journal of the Federation Internationale de la Precontrainte No. 1, 1991, pp. 11-15. Also published in Concrete International, May 1990.

15. Smith, L.L., Kessler, R.J. and Powers, R.G., "Corrosion of Epoxy-Coated Rebar in a Marine Environment", Transportation Research Circular Number 403, March 1993, pp. 36-45.

16. Erdogdu, Sakir and Bremner, Theodore W. "Field and Laboratory Testing of Epoxy-Coated Reinforced Bars in Concrete", Transportation Research Circular Number 403, March 1993, pp. 5-16.

17. "Concrete Structures", prepared by Technical Committee on Offshore Concrete Structures". Published by Canadian Standards Limited, 178 Rexdale Boulevard, Rexdale (Toronto), Ontario, Canada M9W 1R3, 1989, pp. 33.

18. "Design and Construction of Concrete Ships". Published by the Federation Internationale de la Preconstrainte and available from the Institute of Structural Engineers, 11 Upper Belgrave Street, London, SW1X 8BH, U.K. 1986, pp. 12.

19. "State-of-the-Art Report on Offshore Concrete Structures in the Arctic". Published by the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, Michigan 48219, USA, 1985, pp. 117.

20. Rasheeduzzafar, Al-Saadoun, S.S., Al-Gahtani, A.S. "Reinforcement Corrosion-Resistance Characteristics of Silica - Fume Blended - Cement Concrete", American Concrete Institute, Materials Journal, Vol. 89, Number 4, July-August 1992, pp. 337-366.

21. Khanna, J., Seabrook, P., Gerwick, B. Jr., and Bickley, J. "Investigation of Distress in Precast Concrete Piles at Rodney Terminal, Saint John, New Brunswick", in Performance of Concrete in Marine Environment. V.M. Malhotra ed. ACI SP109, 1988, pp. 277-320.

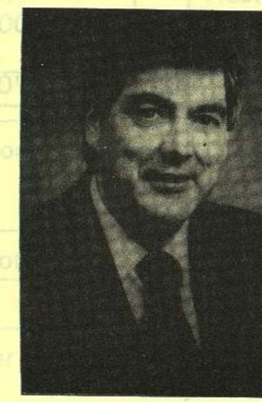
22. Figg, J.W. "Rusting Reinforcement - the No. 1 Problem of Concrete Durability", Concrete, May 1980, Vol. 14, No. 5, pp. 34-36.

23. Hoff, George C. "The Challenge of Offshore Concrete Structures", Concrete International, August, 1985, pp. 12-22.

24. Mather, Bryant. "Concrete in Seawater", Concrete International, March 1982, pp. 28-34.

25. Hoff, George C. "High Strength Lightweight Aggregate Concrete for Arctic Applications - Part 1 and 2", ACI, SP-136, T.A. Holm and A. Vaysburd ed., 1992, pp. 1-175.

26. Skalny, Jan P. "Concrete Durability - An Issue of National Importance", Kathe and Bryant Mather International Conference, American Concrete Institute, John M. Scanlon ed., SP-100, Vol. 1, 1987, pp. 265-280.



Theodore W. Bremner,
Professor of Civil Engineering,
University of New Brunswick,
Fredericton, N.B., Canada

Table 1. Concentration of Major Ions In Seawater Concentration (mg/ℓ)

Ion	Form	Atlantic	North Sea	Persian Gulf	Baltic Sea	Caspian Sea
Chloride	Cl^-	20 000	16 850	23 000	3 960	4 173
Sodium	Na^+	11 100	12 200	13 100	2 190	2 482
Sulphur as Sulphate	SO_4^{2-}	2 810	2 220	4 000	580	2 349
Magnesium	Mg^{2+}	1 410	1 110	1 480	260	570
Calcium	Ca^{2+}	480	430	500	50	270
Potassium	K^+	400	550	670	70	66

Table 2. Components Most Likely to Deteriorate and Component Deterioration

Number	Component (in decreasing order of most likely to deteriorate)	Cause for individual component deterioration (in decreasing effect or decreasing probability of occurrence)
1	Upper Tidal Zone Support	Freezing and thawing, chemical reaction between seawater ad concrete causing dissolution or disruptive expansion
2	Wharf Face	Mechanical damage, alkali-aggregate reaction, corrosion
3	Deck Slab (Top)	Plastic shrinkage cracking, freezing and thawing, alkali-aggregate reaction, corrosion
4	Deck Beams	Freezing and thawing, corrosion
5	Lower Tidal Zone Supports	Chemical reaction between seawater and concrete causing dissolution and disruptive expansion
6	Deck Slab - Soffit	Freezing and thawing, corrosion
7	Back Wall	Corrosion, freezing and thawing
8	Buildings On or Near the Wharf	Corrosion
9	Structures Away from the Sea	Corrosion
10	Submerged Zone Supports	In exceptional circumstances - surface softening due to destructive interaction between seawater and cement paste matrix. Usually found where concrete has been placed improperly underwater and the cement past fraction has segregated from the fine and coarse aggregates.

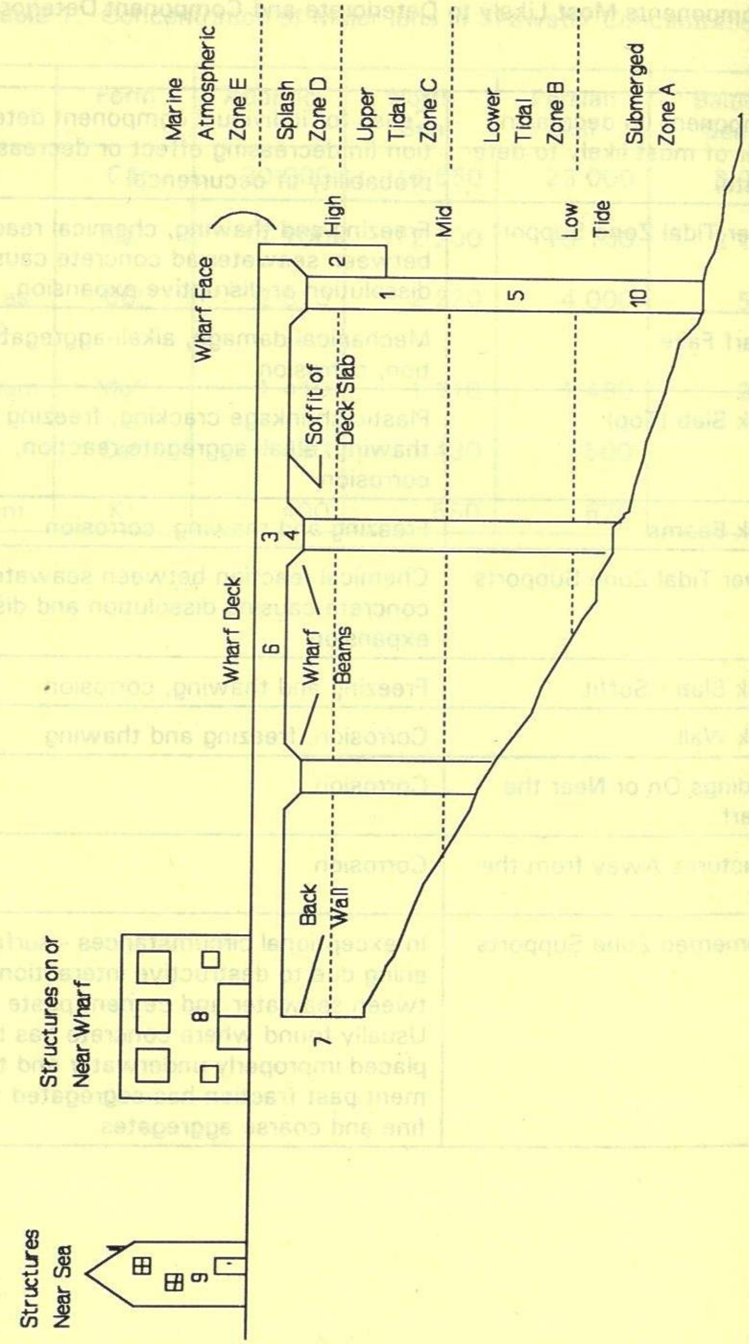


Figure 1. Concrete Structural Elements of a Harbor Structure