PROTECTION AGAINST DETERIORATION OF MATERIALS AND STRUCTURES IN THE OCEAN ENVIRONMENT

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Summary

Research results on the durability, deterioration, and protection of marine structures and materials such as used in waterfront construction are reviewed. Chemical, physical, biological, and mechanical attacks on oceanside manmade facilities and life support systems and their prevention are presented. Case studies of structural failure due to natural and manmade causes, such as storm waves, tsunami, and blast-generated waves, are discussed. Results of full-scale research programs in the field and of scaled model tests done by research laboratories are included.

1. Introduction

The use and protection against deterioration of materials in the ocean has been a field of endeavor and of great concern to humans from early times. Ocean navigation, from the times of the Phoenicians to modern-day intercontinental shipping, naval activities from the era of the Spanish Armada to the peacekeeping fleets of today, ports and docking establishments from the earliest extent around the perimeter of the Mediterranean Sea to the global distribution of great harbors, all bespeak vast efforts to combat massive environmental attack on shipping, docking facilities, and materials.

A large variety of life-supporting structures are situated along the coastline, the nearshore on and off the continental shelves, at islands, and in the deep oceans of the world, including polar regions. These structures and the fixed equipment associated therewith support trade, human habitations, energy sources, defense, and safeguarding and rescue operations. Within continental (and offshore island) limits, their ownership and upkeep belong to the countries in whose territorial waters they are located. Beyond that zone, any activities belong to the deep ocean's domain common to all nations and, apart from localized salvage and rescue operations, mineral and fossil fuel prospecting and recovery, and research, there is no appreciable permanent construction .

The following types of life support system construction are found along continental shores and offshore islands: harbors, piers and docks, bridges, tunnels, seawalls, jetties, wharves, breakwaters, tanker terminals, offshore drilling platforms, anchorages and moorings, runways, canals, seawater intakes and effluent disposal pipelines, transocean communication cables, seawater conversion plants, nuclear power stations, tidal and storm-surge barriers, dredging and coastal protection operations, and spacecraft launching platforms .

All the works and activities named above have to rely on sound design and construction principles for their successful performance as life support systems. The choice and upkeep of appropriate materials will determine their survival against the elements in the ocean environment. Experience and research that have gone into the selection and treatment of materials for ocean engineering have led to the formulation of standards for acceptable practice, which will be further discussed in this article.

The materials involved range from rock, sand, coral, and cement for mass concrete construction and mass-placing in breakwaters, groins, sheet-pile jetties, and so on; to steel and other metals for concrete reinforcement, containers, anchorages, and cabling; to rubber, plastics, and bitumen for liners and seals; to wood for pilings, piers, decks, and floating docks.

In the maintenance requirements of these, the following classifications of materials will be considered:

- suitability, choice, and durability
- preservation and replacement

Detailed accounts of systematic testing done by port authorities and navies around the world are listed in the Bibliography. The principal areas of research and development of materials for marine use and their preservation and maintenance are reviewed here. A review is also given of research results on the direct attack by waves on waterfront structures.

2. Materials of Construction

Three categories of construction materials will be considered for applicability to ocean/coastline structures and equipment (apart from rock, sand, fascine and bitumen, coral, and so on, as used in groins and breakwaters): wood, metals, concrete. These are used roughly for temporary, semipermanent, and enduring construction purposes, respectively.

2.4. Wood (Timber)

Samples of various kinds of wood and types of treatment of timber have been subjected to long-term exposure in the ocean environment for determining durability. Wood (timber) is used for various reasons—availability, low cost, light weight, and ease of manufacture—and is mostly for temporary applications, such as piling at harbor piers, jetties, and wharves. The longer such wooden constructions can be made to last, obviously the more cost effective wood will be as a construction material in the offshore zone.

Wood is, however, subject to deterioration caused by marine organisms, notably *Teredo* (“shipworm”), *Limnoria,* and *Martesia*. Certain kinds of woods are far more durable than others, e.g., greenheart and redwood versus pine, oak, and ash. Studies undertaken over several decades at the US Naval Civil Engineering Laboratory, Port Hueneme, California (US NCEL), have established valuable results regarding the attack by various marine organisms on different kinds of wood (timber) and the means of partial protection afforded by impregnation with preservative chemicals such as creosote, bitumen, and creosote-coal tar solutions (see section 3.1).

2.5. Steel and Other Metals

Far more durable than wood (but much more expensive) are steel and other metals (such as cast iron, copper, brass, bronze, aluminum, titanium) as is evidenced from historical comparison with the wood-hulled ships from the seventeenth century onward, later with copper-clad hulls, and with the steel-hulled ships of the twentieth century and the titanium-clad spacecraft. For deep-ocean construction, different types and grades of steel and stainless steel have been investigated and tested for all purposes, such as cables, anchorages, and fasteners, in tests done at the US NCEL.

- *Submerged test units.* Samples were placed on deep-ocean test racks, on which they were supported by porcelain insulators (to prevent cathodic corrosion due to stray electrical currents originating between varying electrochemical potentials) and then submerged to depths of between 700 m and 1800 m for periods of up to several years. By recovering the test racks at intervals, examining, weighing, and inspecting the samples, the findings as to their corrosion and hence durability were obtained (see section 3.2).
- *Material exposed at deep ocean sites.* The location of steel/metal constructions relative to the sea surface and the sea bottom is another key

factor in their durability. Tests at US NCEL established that the intertidal zone (i.e. the sea surface and a few meters above it) is the most aggressive zone, due to continuous wetting and drying, salt spray, and marine growth. The zone at the ocean bed, and a few meters below it, is also very aggressive to metal (steel) structures due to abrasion and erosion by currents and sediments.

Warm seawater temperatures are more corrosive than cold temperatures; higher dissolved air content is more aggressive than lower dissolved air content; water in motion is more abrasive than quiescent water.

The rate of corrosion is not constant with time and also varies from metal to metal, e.g., the rate of corrosion reduces with time (in years) for steel and increases with time for aluminum. Titanium is generally highly resistant to corrosion, but is expensive. Certain maraging stainless steels are resistant to corrosion and are somewhat less expensive. Cast iron is highly corrosive and not recommended. Lead is not corrosive and is useful as deadweight. Coatings (epoxy, paint) are effective in shallow near-surface depths, but not in the spray zone or in the deep ocean (where pressure causes blistering of the coating). Steel sheet piling is corroded most in the intertidal zone and at the sea floor (see section 3.2).

2.6. Concrete

The ingredients of concrete are sand, rock, cement, and water. In ocean construction, the presence of salt ions, mainly $Na^{+}Cl^{-}$ or common salt, can affect the quality of concrete if seawater is used for mixing. Exposure to salt spray in overwater construction was found to be beneficial to the strength of mass concrete, but detrimental to reinforced concrete, as corrosion of the steel results in volume increase of the reinforcement, so that subsequent spalling and breakup of the concrete will occur (see section 3.2).

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Biographical Sketch

J.M. Jordaan participated from 1963 to 1965 in ocean-related research programs at the US Naval Civil Engineering Laboratory, Port Hueneme, California, US, as a hydraulic research engineer. He lectured in hydraulic and ocean engineering at the Universities of Hawaii and Delaware from 1965 to 1969; and in hydraulic engineering at the University of Pretoria, South Africa, on a part-time basis from 1989 to 1998.