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# Combined protective action of barnacles and biofilm on concrete surface in intertidal areas

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## HIGHLIGHTS

- Barnacles and bacterial film help improving chloride resistance in concrete.
- Without bacterial film and barnacles, chloride penetrates faster.
- The chloride ion is traced by chloride migration test and EPMA (SEM-WDX).
- Weathering damage to plain concrete is marginal during the initial 40-day exposure.

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## ABSTRACT

This study investigated the effect of biofilm and barnacles on the surface of concrete. The specimens were set in an intertidal environment and divided into two study groups: one whose bacterial film was removed, and the other whose bacterial film was left intact. The chloride migration test and EPMA (SEM-WDX) were used as the study methods. The findings suggest that barnacles pose no threat to concrete. On the contrary, barnacles and biofilm were found to improve concrete durability by attaching to the surface of the concrete and sealing underlying microcracks. Further, chloride diffusion rates were lowered due to crack-closing.



## 1. Introduction

Marine growth is inevitable and needs to be considered in the design and maintenance of offshore platforms and offshore structures. Despite the fouling behavior of marine growth, some researchers have suggested that certain intertidal species such as barnacles and bacterial films extend concrete life [1–5]. Further, low-tidal zones experience significant chloride ingress [6]. Should barnacles and biofilm have a protective effect on the surface of concrete, they could be widely applied because they are abundant in the ocean. To date, the combined bio-protective effect of barnacles and biofilm remains unclear, and this raises the complexity of determining the factors that contribute to concrete durability. In consideration of the above, this topic merits investigation. This research contributes knowledge mainly regarding the effects of barnacles and bacterial film (Fig. 1) especially during the initial period when the marine growth does not fully occupy the structural surface. The utilization of marine growth as an additional bio-coating could be an alternative solution to destruction of same. This research focuses on the use of natural marine bio-protection on concrete structures by taking advantage of existing local habitats. Possible beneficial outcomes include maintenance-cost savings, long-term sustainability, and a more healthy coastal ecology through reduced use of environmentally toxic antifouling materials.

Biogenic crusts of barnacles have been found to improve concrete durability against chloride attack [4,5], while the giant Pacific oyster, *Crassostrea Giga*, has been shown to have a similar surface-coating effect [7]. Further, such biogenic structures have been observed to stabilize surface temperature and protect substrates

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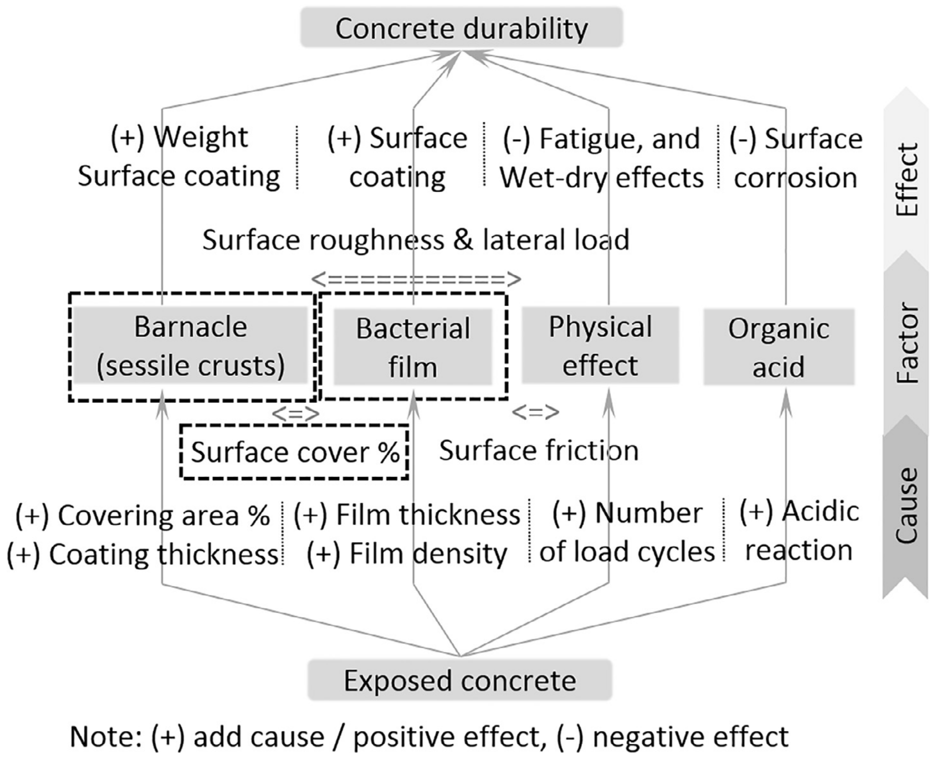


**Fig. 1.** Cause-effect diagram for maritime concrete taking into consideration the effects of biological, physical and chemical factors on the surface of concrete.

from weathering erosion and sunlight [1,3,8,9]. Moreover, their heat-proofing effect has been found to work slightly better in cold climates [10]. Similarly to barnacles, bacterial films acting as an additional micro-protective layer also help separate concrete and free chloride ions in seawater, thereby preserving the alkaline condition in the cement matrix [2].

Bacterial film begins colonizing the surface area at first, and the rate of increase of the bacterial population depends on many factors including types of bacteria, climate and weathering, temperature, seawater salinity, and plankton nourishment [2,11]. Next, barnacle cypris larvae, swimming in search of a suitable substrate and guided by biochemical cues [12], start forming permanent attachments, preferring in particular biofilm-covered surfaces [11,13,14]. Highly textured substrates tend to recruit a high number of settlements [15–19]. As cypris larvae metamorphose to a juvenile state, the biofilm starts decreasing and is eventually replaced with barnacle footprints [20,21]. The footprints of different barnacle species are not exactly identical, but barnacles are made up of between 30.8% and 48.8% of calcareous compounds, and several protein-based tissues [22,23]. About 40 days after initial settlement, barnacles start secreting stronger adhesive materials that make them harder to detach [24,25]. The mortality rate of the intertidal barnacle is surprisingly high due to predators, surface heat, area competition, and water temperature. Previous studies postulated that only approximately 20% of barnacle settlements survive and are able to reach a full-growth state by six months [26–28].

This study aimed to investigate the effects of biofilm and sessile crust on the concrete surface. It appears that these marine organisms provide combined protection against chloride attack. The surface condition and concrete permeability were checked using an electron probe microanalyzer integrated with wave dispersive X-ray spectroscopy (EPMA (SEM-WDX)), and the chloride migration test. The results obtained support the use of bio-protection by taking advantage of existing local marine habitats.

## 2. Material and methods

To verify the presence of bacterial films on the concrete surface, we compared two types of surfaces: surfaces with both sessile crust and biofilm, and surfaces from which biofilm removal through gentle brushing was attempted (rarely affecting the sessile crust). The brushing visually removed dirt and slightly brightened the surface, yet we were unable to confirm the actual impact to biofilm without proper microscopic investigation. The surface conditions in both cases were checked by EPMA (SEM-WDX). Further, the chloride migration test was conducted to investigate the rate of chloride ingress in concrete with marine growth.

### 2.1. Site information

The Yokosuka shoreline, in the southern part of Kanagawa Prefecture, has highly diverse fauna and flora and is home to many intertidal habitats that teem with algae, barnacles, mussels, blowfish, and crab. The blue mussel (*Mytilus edulis galloprovincialis*) and buckshot barnacle (*Chthamalus challeneri*) are among the dominant macrofauna species [29,30]. The selected site is a concrete jetty supported by steel columns and has a steel platform close to the tidal level. The mean sea level corresponds with the bottom flange of the steel girders that support the platform. According to the Japan Meteorological Agency, the range between the highest and the lowest tides in Yokosuka is approximately 2 m. During the high tide, the steel platform is entirely underwater. A layer of soil sediment is also present at the bottom and the water temperature during the summer period ranges between 23.4 °C and 29.7 °C. Information on the chemical composition of the seawater, the bacteria types, and the dominant marine species is provided in Fig. 2. The concrete specimens were placed in plastic mesh boxes and hung under the steel girders. All samples were set at 40 cm below mean sea level.