ECO-ENGINEERING SOLUTION FOR NATURE-BASED SHORELINE PROTECTION AT THE PORT OF SAN DIEGO (USA)

Jorge Gutiérrez[1], Tomer Tagar-Hadary[2], Yaeli Rosenberg[3], Maayan Neder[4], Philippe LeBlanc[5]

[1]Head of Engineering, ECOncrete, Tel Aviv, Israel, jorge@econcretetech.com
[2]Head of Operations, ECOncrete, Tel Aviv, Israel, tomer@econcretetech.com
[3]Head of Biology ECOncrete, Tel Aviv, Israel, yaelir@econcretetech.com
[4]Marine biologist, ECOncrete, Tel Aviv, Israel, maayan@econcretetech.com
[5]Business Development Manager, ECOncrete, Tel Aviv, Israel, phil@econcretetech.com

ABSTRACT: The Port of San Diego (Port) partnered on a pilot project with ECOncrete Tech Ltd. (ECOncrete), a company developing bio-enhancing concrete technology and ecological structural solutions, to demonstrate an innovative approach of building resilient coastal infrastructures. The goal of the pilot project was to provide an ecologically enhanced armor layer for shoreline protection, while creating well-defined local ecosystems that mimic natural rock pools. The unique partnership between ECOncrete and the Port resulted in a holistic project design to address not only the structural and coastal engineering requirements for shoreline protection and stabilization, but also the need to promote native marine habitats, increase biodiversity and restore local coastal ecosystems. As part of the pilot project, ECOncrete will be conducting ecological and structural monitoring every six months for two years. The project was launched in 2021 and the results from the first biological monitoring event showed development towards a richer and more diverse community, compared to adjacent control rocks. The pilot project demonstrates that Ports, with the use of innovative technologies and materials, can achieve both structural and ecological goals when designing coastal infrastructure. The resulting shoreline protection design is a single-layer armor structure composed of interlocking units of bio-enhancing concrete, with multidirectional characteristics, and water retention elements.

KEYWORDS: Eco-engineering, innovation, nature-based design, bio-enhancing, concrete

1. COASTAL RESILIENCY INNOVATION

Building climate resilient coastal infrastructure require innovative design considerations beyond the mandatory industry standards. In recent years, there has been a growing interest to integrate nature-based structural solutions into the designs of coastal and marine construction projects (Sella et al. 2021, Bridges, 2021; Bouw and Eekelen, 2020; De Vriend et al., 2014). Coastal and marine engineers are exploring how natural processes and eco-engineered technology can provide management and design solutions to resolve the degradation and/or vulnerability of coastal and marine structures.

In 2016, the Port of San Diego (Port) in California, launched a Blue Economy Program to seek innovation to address Port environmental and coastal resiliency challenges. The program allows the Port to partner with innovative companies in testing new technologies and approaches to help bridge the gap between sustainability and coastal development. In 2019, under this program, the Port partnered with ECOncrete Tech Ltd. (ECOncrete) to demonstrate a new and innovative design of ECOncrete's coastal armor unit element, the Coastalock. The Coastalock was eco-engineered by ECOncrete as an alternative for the traditional coastal armor structures to address the structural requirements for coastal infrastructure, while promoting local biodiversity and ecosystems. The Coastalock is designed as a single-layer interlocking armor unit, with the ability to create and mimic different natural habitats, often missing from artificial structures. Each armor unit is designed with multidirectional characteristics and a complex surface to generate different habitats and ecological niches (Figure 1), and are manufactured using a bio-enhancing concrete admixture, which assists settlement of local marine organisms and increases compressive strength.

Figure 1. Schematic representation of the COASTALOCK units showing the different orientations and habitats

The Coastalock units allow for a regular placement in a single layer armor which enhances hydraulic stability. It serves as a replacement for traditional riprap to provide ecological armoring and shoreline stabilization while creating well-defined local ecosystems that mimic natural ecosystems and habitats. The Coastalock units create water-retaining elements, overhangs, holes, caves and different orientations, which are absent in most urban waterfronts.

ECOncrete has pioneered the development of ecological structural solutions for coastal and marine construction (Sella et al., 2022; Perkol-Finkel et al., 2018; Perkol-Finkel and Sella 2015; Sella and Perkol-Finkel, 2015;] Perkol-Finkel and Sella, 2014). The core elements of ECOncrete technology is a suite of science-based bio-enhancing concrete admixtures, complex surface textures, and 3D nature-inspired designs that act in synergy to increase the ecological value of coastal and marine infrastructure. ECOncrete's technology complies with industry standards and can be seamlessly integrated into maritime projects by local contractors.

2. NATURE-BASED SHORELINE PROTECTION

The International Union for Conservation of Nature (IUCN) defines nature-based solutions as actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefit. When applied to coastal engineering, this concept translates into developing nature-inspired structural solutions, working with, not against, nature in coastal infrastructure. New ecologically engineered technologies such as the Coastalock unit, provide solutions to adapt the design of climate-resilient and sustainable coastal infrastructures.

The Port partnered with ECOncrete to test the potential of the Coastalock as a bio-enhancing shoreline protection solution. The primary goal of the pilot project was to provide an ecologically enhanced armor layer for shoreline stabilization that provide structural, ecological, and community engagement benefits, including the promotion of marine organisms and restoration of local ecosystems.

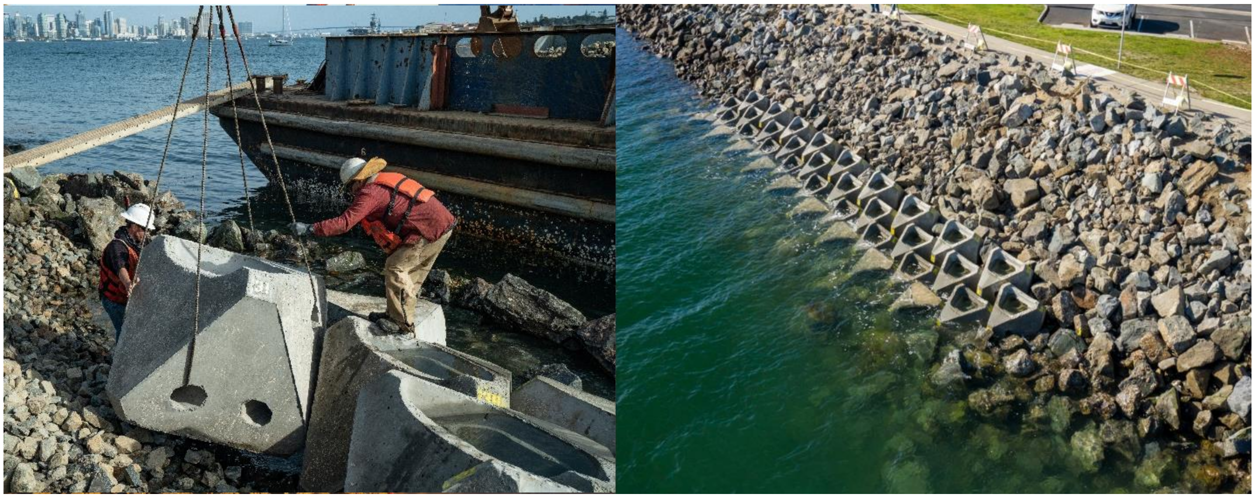

Figure 2. Coastalock installation at Port of San Diego, California, US

A total of 74 Coastalock units were installed during February-March 2021, replacing existing rock revetment in two different locations along San Diego Bay Harbor Island Park shoreline, next to the international airport of San Diego. During the two-year pilot project, ECOncrete is conducting ecological and structural monitoring every six months.

2.1 Monitoring Results

The results from the first biological monitoring event, in November 2021, eight-month post-deployment, showed a diverse community that has developed on the Coastalock units, including many sessile species, mobile invertebrates, and different fish species. In addition, on the Coastalock unites a diverse algal community was noticed including 13 species, composed of green, red, brown, and coralline algae while on the control rocks the algal community comprised nine species and was dominated by an invasive red alga (Figure 3,4). Already at 8 months post deployment (MPD), a significant difference was observed in the averaged species richness and diversity that developed on the outer surface of the Coastalock units compared to the control rocks ($P<0.05$). Yet, the populations observed within the cavities of the Coastalock units did not show a significant difference compared to the control rocks (Figure 5).

Although the control rocks on site were deployed decades ago, while Coastalock units were only deployed eight months at the time of sampling, a similar trend was observed in species richness and diversity on both the control rocks and the ECOncrete Coastalock units. The results of the 8MPD sampling indicate that a different community structure is found at the control and the treatment sites, shifting from a dominant invasive red alga at the control rocks, to a diverse algal benthic community on the Coastalock units. Furthermore, the addition of a new complex habitat able to support a diverse algal community has resulted in an enhancement of the recruitment of several invertebrate species at the Coastalock units compared to the control rocks. The most prominent example is the high numbers of juveniles of A. californica nudibranch, which can grow only on Ulva sp., which was more abundant in the Coastalock units. Additional biological monitoring is planned for mid-Spring 2022

Figure 3. Biological development enhanced by the Coastalock armor units, 6 months post deployment

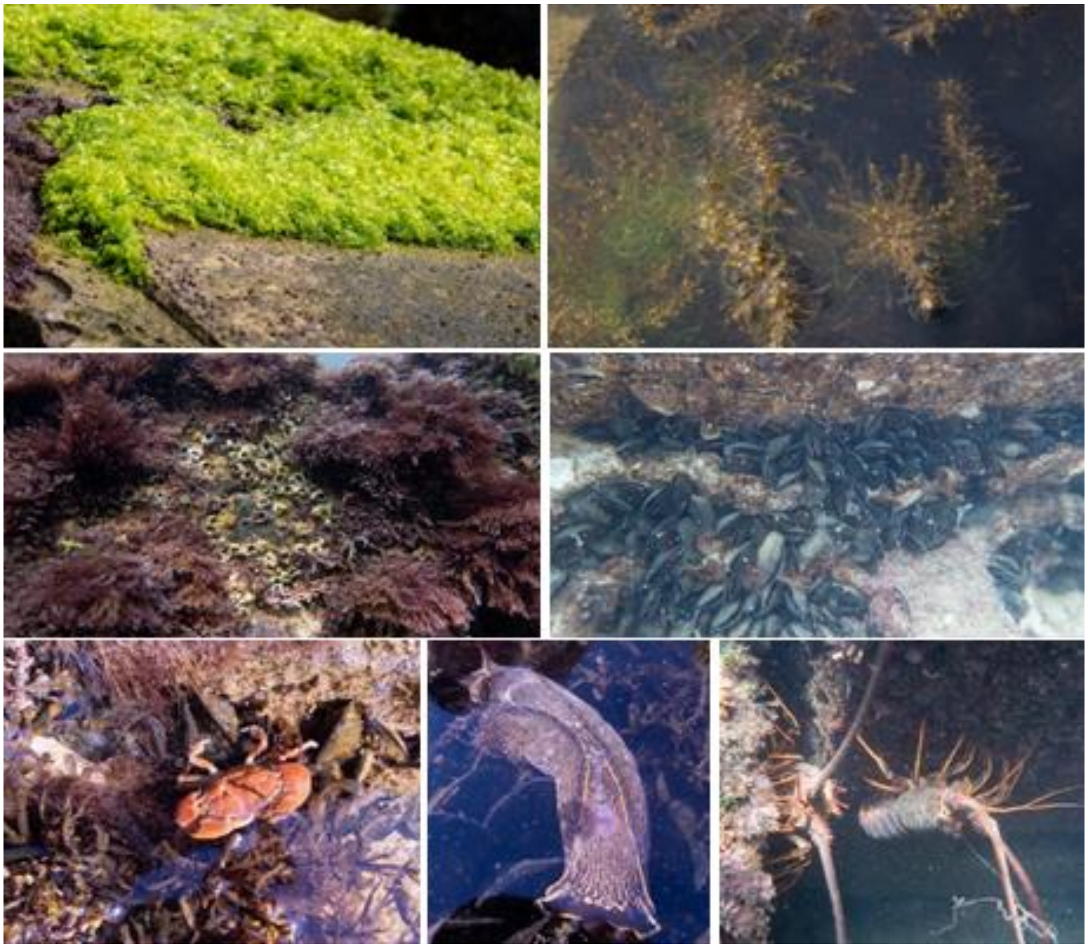

Figure 4. Examples of the biological development that covers the Coastalock units 8 months post deployment; encrusting Ulva sp. (top-left), the brown algae Sargassum muticum (top-right), the red algae Asparagopsis armata and barnacles (middle-left), clusters of Mytilus sp. bivalves (middle-right), the crab Cancer productus (bottom-left), the nudibranch Navanax inermis (bottom middle) and the spiny lobsters Panulirus interruptus (bottom-right).

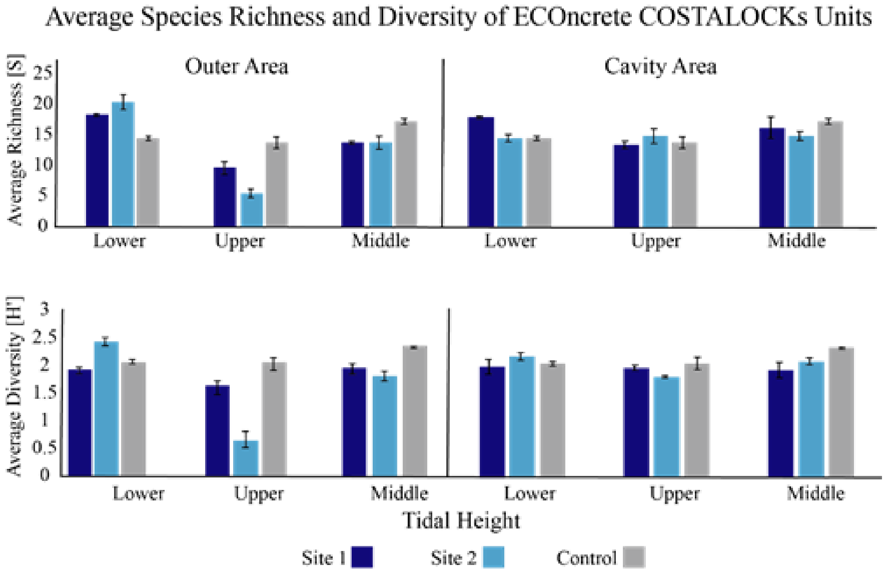

Figure 5. Differences in univariate parameters (species richness [S]- top row, and species diversity [H']- bottom row) between two sites of ECOncrete Coastalock (site 1- dark blue bars, site 2- light blue bars) deployed at three different tidal heights, and the control rocks (light gray bars), eight months' post-deployment. Error bars represent standard deviation.

2.2 Biological Benefits

It is well known that artificial systems are different from natural systems and the reduced environmental heterogeneity of artificial environments is thought to be one factor explaining the lower epibiotic diversity in artificial structures. The artificial surfaces of most coastal defenses lack habitats that can be found on natural rocky shores; thus, many species that use these habitats are absent from artificial shoreline protection structures. The ecological value of shorelines that have been altered to create new hard substrata, therefore, appears to be lower and the expansion of artificial structures can even lead to genetic diversity loss at regional scales.

Many studies have shown the effectiveness of simple ecological engineering methods that result in the enhancement of native biodiversity on artificial structures. This can be achieved by creating habitat complexity on artificial structures in the form of surface roughness, cervices grooves, and pits, deployment configuration, and tidal height position. Bio-enhanced shoreline protection structures could lead to greater habitat complexity and greater species richness.

The enhancement of marine life results in the development of a "biological crust" on the concrete that is formed by engineering species like oysters, serpulid worms, barnacles, and corals that deposit calcium carbonate (CaCO3) skeletons onto hard surfaces. The crust serves as an active carbon sink as carbon is assimilated into the skeletons of these organisms in a process called biocalcification. In addition, this biogenic calcitic crust protects the concrete structure and potentially reinforces it. This form of bioprotection can reduce the magnitude and frequency of structural maintenance, which translates into improved ecological stability (reduced anthropogenic intervention), as well as a higher return on investment (reduced maintenance costs).

2.3 Structural and Operational Benefits

The structural performance of the Coastalock units will be evaluated during the one-year post-deployment event. The structural monitoring protocol includes the physical condition of individual Coastalock units, the condition of the structure as a whole (e.g., sliding, sinking, or displacement) and the surrounding project area (toe, left and right flank, and upland areas).

The Coastalock armor layer provides several operational benefits as well. Coastalock units are placed in a single layer armor with a regular placement. This means that the placement of the units is straightforward and clear to all the site crew, including the crane operator and the supervisor of the works. Therefore, no discussion about whether the unit is correctly placed or not takes place. Furthermore, a regular placement accelerates the placement process and reduces the placement times as well the general timeframe of the construction which results into cost savings.

Coastalock armor units can be placed in steep slopes such as 2V3H and 3V4H that would increase the interlocking between the units. A steep slope also leads to a smaller structure footprint (therefore smaller invasion of a marine space and associated marine habitats) and savings of materials when compared to a gentler slope that is designed for rock or other artificial units.

2.4 Hydraulic Performance

In collaboration with the Hydraulic Engineering Laboratory of the Delft University of Technology (TU Deft), 2D physical model tests are currently underway to gain insights on the hydraulic performance of the Coastalock single armor layer. The aim is to investigate the limits of the application of the unit on sloping structures and define the hydraulic stability parameters of the unit for its specification. The 2D model tests are allowing to investigate the hydraulic stability through the placement of the units with different layer configurations and orientations on a sloped structure against different wave action configurations (Figure 6). The results will allow for the characterization of the hydraulic parameters that will serve to specify future prototype application design of the Coastalock armor units.

Figure 6. Coastalock 2D Physical model tests in TU Delft

3. REFERENCES

Bouw, Matthijs Bouw and VAN EEKELEN, (2020). Building With Nature - Creating, Implementing And Upscaling Nature - Based Solutions. EcoShape, NAi Booksellers 2020

Bridges, T. S. (2021). International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Center.2021

Coombes, Martin A, et al. (2017). "Cool barnacles: Do common biogenic structures enhance or retard rates of deterioration of intertidal rocks and concrete?" Science of the Total Environment 580 1034-1045. Elsevier, 2017

De Vriend, Huib and VAN KONINGSVELD, Mark and AARNINKHOF, Stefan. (2014). "Building with nature": The new Dutch approach to coastal and river works. ICE Proceedings Civil Engineering. 167. 18-24. 10.1680/cien.13.00003.

Firth, L. B., et al. "Between a rock and a hard place: environmental and engineering considerations when designing coastal defence structures." Coastal Engineering 87 : 122-135. 2014

Perkol-Finkel, , Shimrit, and SELLA, Ido (2014). "Ecologically active concrete for coastal and marine infrastructure: innovative matrices and designs." From Sea to Shore–Meeting the Challenges of the Sea: (Coasts, Marine Structures and Breakwaters 2013). ICE publishing, 2014.

Perkol-Finkel, , Shimrit, and SELLA, Ido (2015) "Harnessing urban coastal infrastructure for ecological enhancement." Proceedings of the Institution of Civil Engineers-Maritime Engineering. Vol. 168. No. 3. Thomas Telford Ltd, 2015.

Sella, , Ido, and PERKOL-FINKEL, Shimrit (2015) "Blue is the new green- Ecological enhancement of concrete based coastal and marine infrastructure." Ecological Engineering 84. 260-272. Elsevier, 2015.

Sella, Ido (2022), et al. "Design, production, and validation of the biological and structural performance of an ecologically engineered concrete block mattress: A Nature-Inclusive Design for shoreline and offshore construction". Integrated environmental assessment and management 18.1: 148-162. 2022