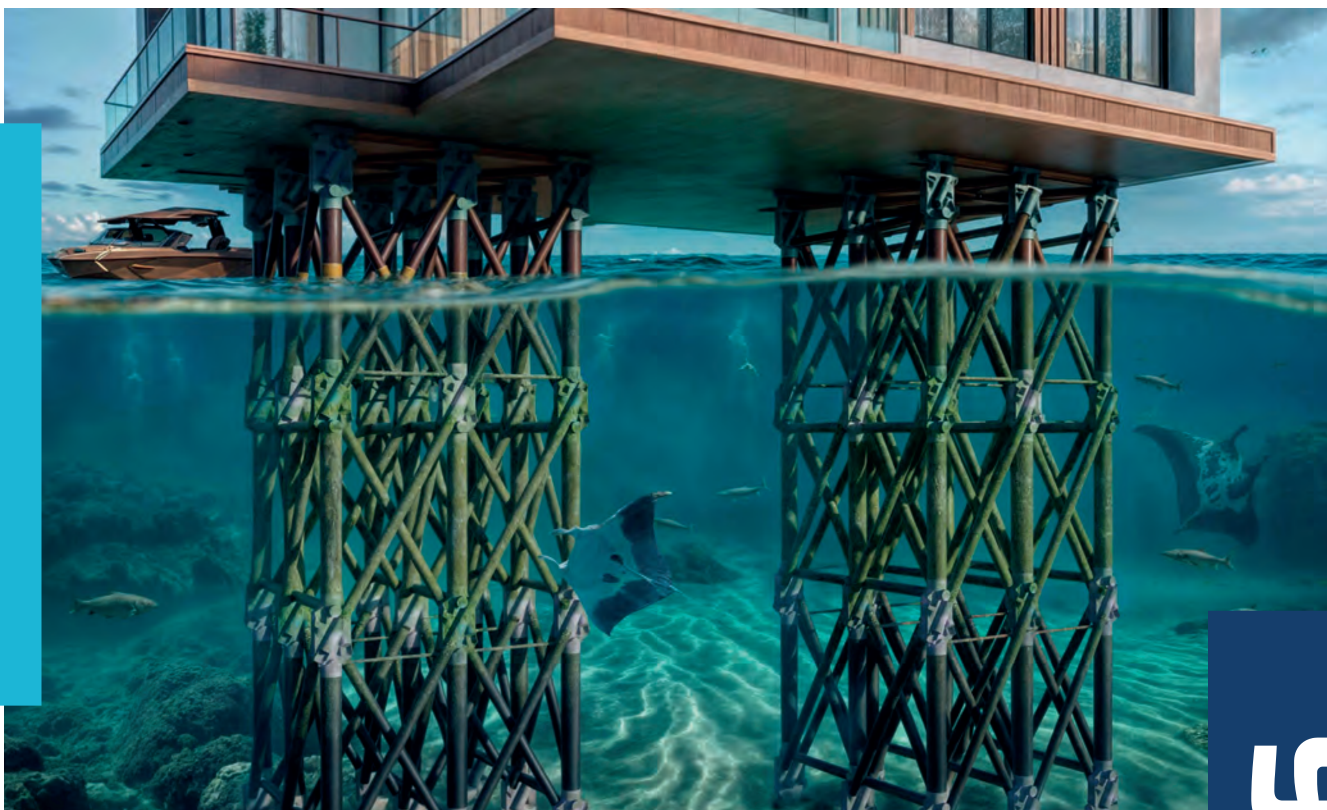
HYDRANTULA TECHNOLOGY OVERVIEW:

AN INNOVATION FOR COASTAL CONSTRUCTION



Technical brief
for coastal research teams

2026

1 OVERVIEW OF THE HYDRANTULA TECHNOLOGY

HYDRANTULA is an advanced technology for building permanent marine concrete structures using **modular non-removable formwork** made of plastic pipes and fittings. In practice, HYDRANTULA structures are **reinforced concrete 3D frames** cast directly **underwater or in the tidal zone** inside a pre-assembled plastic “skeleton”.

The system was originally developed for piers, jetties, retaining structures, near-shore platforms and houses on water. A light 3D lattice is assembled onshore from plastic nodes and HDPE pipes, then installed on the seabed and filled with concrete pumped from the bottom up. Water is displaced from the closed cavities, and after hardening the concrete forms a robust monolithic frame inside the plastic shell.

HYDRANTULA permanent formwork **competes directly** with piles, sheet piling, concrete pontoons and aluminium deck structures. Its key advantage is that it **dramatically lowers the cost and complexity of building 3D marine concrete frames**, bringing such designs from the world of oil & gas megaprojects into reach for mid-sized developers, marinas and residential coastal projects.

2 PRODUCT DESCRIPTION

2.1. System concept

HYDRANTULA develops, manufactures and sells **permanent (non-removable) formwork** for casting concrete underwater or in the tidal zone. The ready-to-cast formwork consists of:

- **Original connecting elements (fittings / nodes)** — proprietary plastic joints with multiple ports for pipes;
- **Beams made of standard HDPE plumbing pipes,** cut to length on site;
- **Rebar and micro-fibre concrete,** sourced locally as standard bulk products.

In other words, HYDRANTULA sells the technology and the specialized fittings; pipes, reinforcement and concrete are procured on the local market.

HYDRANTULA product lines cover a wide range of coastal tasks: foundations for houses over water, shore protection, retaining walls, slipways and mooring ramps for small boats, garages and lifts for vessels, and waterfront walkways. The eight product series together cover up to **90% of typical coastal construction tasks.**

2.2. Key patented innovations

The system is based on a family of patented design concepts and components:

1. Fitting system and modular nodes

- Traditional 3D steel frame joints are expensive, because each angle and geometry requires custom fabrication.
- HYDRANTULA replaces steel or aluminium nodes with polyethylene fittings produced by rotational moulding (rotomolding), allowing almost any angle between pipe ports (0°-80° with any azimuth). Metal fabrication cannot realistically compete at this level of geometric flexibility.
- The angular range of 0°-80° between any two pipe axes at a given port covers the full geometric family of diagonal bracing and non-orthogonal space frame configurations. For orthogonal frames - where pipes must meet at 90° — HYDRANTULA resolves this through a normal plastic sleeve, orthogonal layouts are therefore fully achievable within the standard fitting range.

2. Binary Socket

- Creating separate fittings for every possible angle and orientation would result in thousands of SKUs. HYDRANTULA solves this through the Binary Socket concept.
- Each fitting is manufactured with a set of potential ports. On site, installers use a crown drill to open only those sleeves that are needed for a given node; unused ports remain closed.

- This allows a single universal fitting to replace multiple "left/right/top/bottom" versions, simplifying logistics and inventory.

3. Side offset geometry and buildability

- At a 3D node, the axes of pipes should theoretically converge in one point. With large pipe diameters that is impossible — pipes physically collide.

- HYDRANTULA introduces side offset geometry, slightly shifting pipe axes so they bypass each other. This avoids collisions, allows more compact fittings and significantly improves buildability of complex 3D frames.

4. Co-axial sockets and through-pipes

- Thanks to side offset, some sockets are co-axial, allowing full-length pipes to pass through fittings without cutting.

- With sleeves and anti-bell structures, large frame "planes" can be pre-assembled, which simplifies construction and improves concrete performance during pouring.

5. GrooveLock / Camlock compatibility

- HYDRANTULA fittings incorporate adapters for standard GrooveLock and Camlock systems.

- Concrete is pumped into the frame under pressure from the lowest point, with no free-air pouring, resulting in denser and more durable concrete in harsh marine environments.

6. Pull rods and manifold innovation

- HYDRANTULA is the first formwork system to systematically incorporate composite pull rods engineered to resist dynamic loads typical for marine environments.

- Modular fittings evolved into manifold hubs capable of managing multiple parallel pipe feeds — forming robust concrete “walls” useful for shoreline protection, erosion control and terraced beaches.

7. Off-the-shelf tools and skills

- The system uses standard HDPE plumbing pipes and welding tools: socket/butt fusion machines, handheld extruders, etc.

- No proprietary tools are required, and an existing global workforce trained in HDPE pipe welding can assemble HYDRANTULA with minimal additional training.

2.3. Assembly and underwater concreting

1. Onshore assembly (≈90% of work)

- An empty formwork is fully assembled onshore as one rigid 3D frame.

- Pipes are cut to length, connected to fittings by butt/socket welding or mechanical fasteners, and reinforced by inserting steel or composite rebar inside the pipes at this stage.

2. Transportation and installation

- The assembled frame is transported by crane, truck or barge to the installation site.
- Depending on reinforcement type, the frame may float for some time (composite rebar) or sink immediately (steel rebar).

3. Concrete placement

- A concrete pipe or hose (DIN 125/100) is connected to the GrooveLock / Camlock port of one fitting at the lowest point of the structure before lowering it into the water.
- Concreting is carried out underwater. Concrete is pumped from bottom to top, displacing water inside the formwork and minimizing air pockets and segregation.
- The formwork is not fully watertight but holds concrete well enough for a controlled displacement of water.

2.4. Quality assurance during concrete placement

Controlled bottom-up pumping through a single GrooveLock/Camlock port provides a primary level of quality assurance. Air displacement and void control are managed through a dedicated procedure: small-diameter holes are pre-drilled at the upper sections of pipe members prior to or immediately after concrete placement begins. As concrete rises from the bottom, entrapped air escapes through these holes. Each hole self-seals naturally when the concrete front reaches it - coarse aggregate in the mix bridges the opening and plugs it without any intervention. A hole that has sealed confirms that the concrete column in that member has reached the hole elevation; a hole from which air continues to escape indicates an unfilled zone and allows remedial pumping before the concrete sets.

This self-sealing mechanism provides a distributed, zero-cost quality indicator across the entire frame without requiring dedicated instrumentation. Standard practice additionally includes:

- **monitoring pump pressure and flow rate** throughout the pour to detect blockages or unexpected resistance;
- **verifying concrete consistency** (slump or slump flow) at the pump inlet **before each pour**;

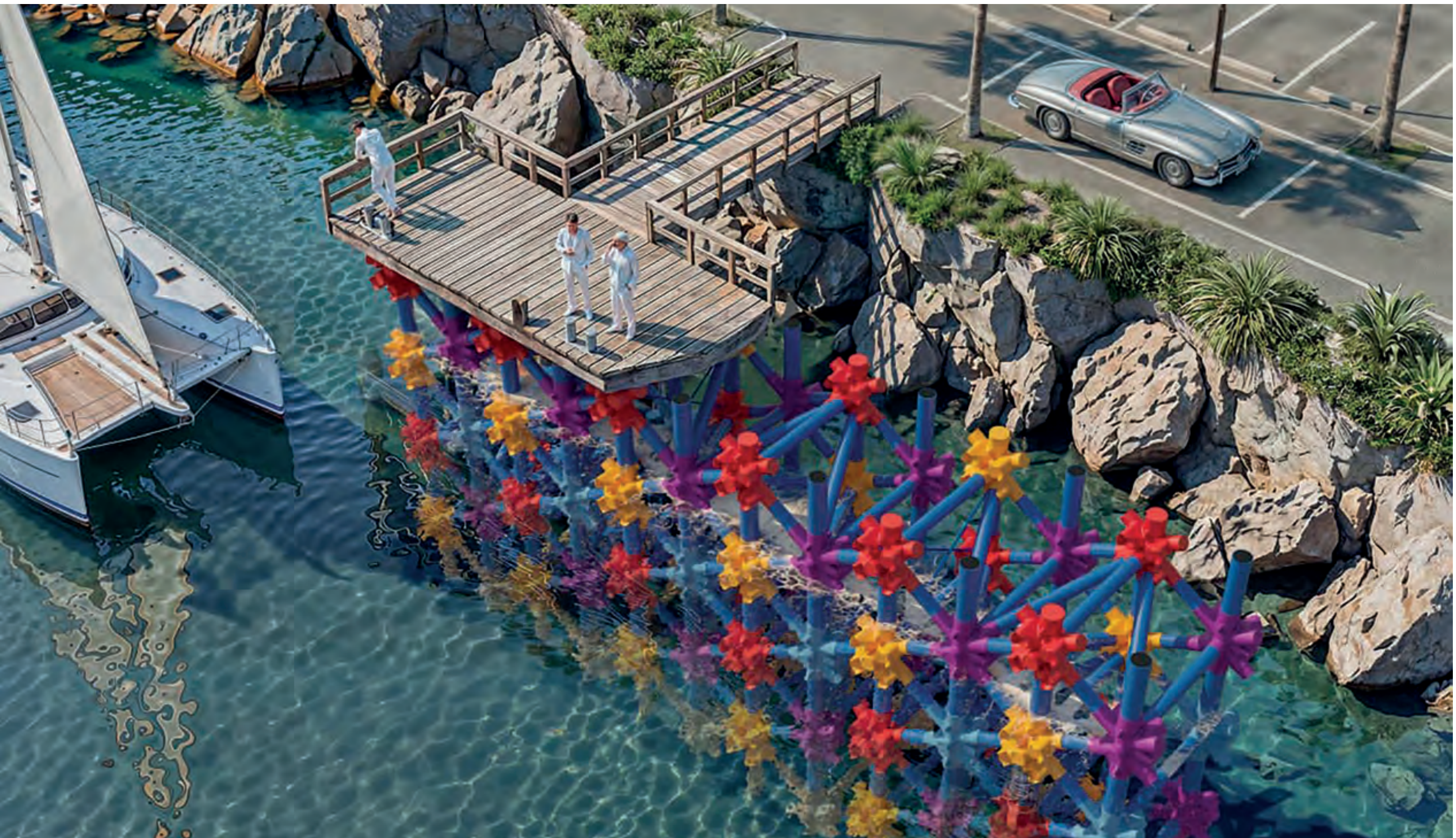
- retaining standard cube or cylinder samples from each pour for **28-day compressive strength testing;**
- **post-installation inspection by diver** to confirm the absence of visible unfilled zones at the structure perimeter.

Where project specifications require higher assurance, non-destructive testing of completed members — including impact-echo or ultrasonic pulse velocity methods adapted for HDPE-enclosed sections — can be specified. This is recommended for structurally critical members and for first installations in any new geographic market.

- After curing, the result is a monolithic reinforced concrete frame enclosed in a plastic shell: **a permanent, corrosion-resistant structural element designed for decades of service in marine conditions**.

2.5. Materials and logistics

- Up to 99% of components are plastic; the heaviest empty element weighs only about 25 kg, which simplifies manual handling and logistics.
- Pipes can be pre-cut before delivery; fittings are compact and transportable on pallets over long distances.
- There is no **need to purchase heavy concrete pumps or HDPE welding machines** specifically — they are widely available for rental, and their cost is only a small fraction of the normal cost of crane barges and marine construction equipment.



2.6. Concrete mix requirements

Concrete used in HYDRANTULA frames is pumped under pressure from the lowest point of the structure, displacing water from within the closed formwork. This placement method imposes specific requirements on mix design:

- **Workability:** the mix must be self-consolidating or near-SCC in consistency (slump flow typically 550-650 mm) to ensure complete filling of all cavities without vibration;
- **Mix class:** minimum C35/45 (characteristic cylinder / cube strength) is recommended for marine exposure; C40/50 is preferred for aggressive tidal and splash zone conditions;
- **Exposure class:** XS2-XS3 per EN 206 / SS EN 1992-1-1, depending on tidal regime and chloride exposure;
- **Cement type:** sulphate-resistant or blended cements (GGBS, fly ash) are preferred to reduce heat of hydration and enhance long-term chloride resistance;
- **Micro-fibre reinforcement:** glass fibres or stainless steel macro-fibres are used to reduce plastic shrinkage cracking during curing and improve post-crack toughness and ductility;
- **Water-cement ratio:** not to exceed 0.45 for submerged and tidal zone applications.

Standard concrete supply, pumping equipment and mix design expertise are available in all major coastal construction markets. Specific mix design should be verified and adapted to local cement sources and environmental exposure by a qualified structural or materials engineer.

2.7. Terraced and manifold configurations

Beyond single-module frames, HYDRANTULA's manifold hub fittings enable a distinct structural typology: terraced multi-row arrays designed for shoreline protection, beach stabilisation and ecological enhancement.

In this configuration, multiple frame modules are arranged in stepped horizontal tiers descending from the shoreline into deeper water. Each tier partially attenuates incoming wave energy before it reaches the next, creating a distributed dissipation profile rather than concentrating loading on a single defence line. Key characteristics of terraced configurations:

- **Wave energy dissipation:** the open lattice geometry allows water to pass between tiers, converting wave energy into turbulence rather than reflecting it.

Reflection coefficients are substantially lower than for solid walls or armoured revetments, reducing toe scour and secondary erosion;

- **Sediment dynamics:** permeable multi-tier structures promote natural sediment deposition in the sheltered zones between rows, potentially supporting beach recovery and seagrass establishment over time;
- **Ecological value:** the stepped geometry creates a vertical habitat gradient - subtidal, intertidal and splash zones are all represented within a single structure, supporting diverse communities of organisms at different tidal elevations;
- **Scalability:** the number of tiers, tier spacing and individual module dimensions are continuously adjustable to match site bathymetry, wave climate and design objectives.

Terraced configurations are one of the most distinctive capabilities of the HYDRANTULA system and are not readily achievable with conventional pile-and-deck or monolithic wall approaches. They represent the primary structural typology proposed for hybrid coastal protection and eco-shoreline applications.

3 TECHNICAL CHARACTERISTICS

3.1. Load capacity and structural behaviour

HYDRANTULA frames form **spatial (3D) trusses** with high stiffness and load-carrying capacity. Because the structure is fully three-dimensional and can be multi-storey, it:

- resists lateral wave and current forces, uplift and variable cyclic loads;
- distributes loads over a wide footprint on the seabed, reducing bearing pressure and settlement risks;
- provides three-dimensional load redistribution and redundancy under lateral, uplift and cyclic actions; resistance to multidirectional wave loading is achieved by the spatial frame action, while directional stiffness and strength depend on the specific geometry, symmetry, bracing layout, support conditions and installation mode.

For structural design purposes, the HDPE shell should be treated primarily as permanent formwork and a protective outer barrier. The principal load-bearing function is provided by the reinforced concrete core and internal reinforcement.

The use of **pull rods** and continuous through-pipes creates redundant load paths and enhances resilience against fatigue and shock loads typical of marine environments.

3.2. Soil conditions and slopes

HYDRANTULA can be installed on various seabed types: sandy, silty or rocky. Wide "skids" or base beams at the lowest level spread loads across the seabed. On sloped bottoms, certain series (e.g. H1 and H2 variants) include **height-adjustable columns**, allowing the frame to be levelled without excessive site preparation.

Some series are adapted for **free-standing installation** ("FreeStand mode") — the frame rests on the seabed without rigid anchoring, relying on its own weight and footprint. Where required, vertical columns can serve as guides for screw piles or anchors, combining free-standing and fixed support modes.

FreeStand mode requires careful site assessment in two respects. First, sliding and overturning stability under lateral wave and current loading must be verified by calculation, accounting for wave period, water depth, frame geometry and the weight of the concrete-filled structure. For most filled configurations the self-weight provides adequate resistance, but exposed sites with energetic wave climates or strong tidal currents require explicit stability checks.

Second, seabed scour beneath the base beams must be evaluated. Where current velocities or wave-induced bed shear stresses exceed the critical threshold for the local sediment, progressive undermining of the structure's footprint is possible. Mitigation options include scour protection aprons (rock, gravel mat or geotextile), increasing base beam footprint area, or transitioning to a partially anchored configuration using the integral column guides provided in certain series. Site-specific hydraulic modelling or reference to established scour prediction methods (e.g. EurOtop or Manual on scour at bridges and other hydraulic structures) is recommended for exposed FreeStand mode.

3.3. Depth range

HYDRANTULA series cover the following characteristic depths:

- **H1** — single-storey series for very shallow water;
- **H2 / H4** — configurations for depths up to approximately **5-6 m**;
- **H5** — deeper-water options with multi-storey frames for depths around **8-12 m**, and in some designs up to ~15 m.

Multi-storey capability is a key differentiator: vertical stacking of truss layers provides stiffness and height without excessive member sizes, making it suitable for much of Singapore's nearshore zone (<10 m).

3.4. Durability in marine environments

- **Plastic shell:** The HDPE outer layer protects concrete from the external environment for decades, shielding it from abrasion, direct saltwater contact and freeze–thaw cycles where applicable.
- **Corrosion**: resistant to electrochemical corrosion; alkaline durability of GFRP rebar in concrete depends on the specific material system and proper selection for alkaline service conditions.
- **Ice resistance:** The system is designed to tolerate freezing waters and pack ice; while that is less relevant for tropical Singapore, it indicates robustness under harsh mechanical contact loads.
- **Service life:** Product materials and design service life target of 60+ years, based on material performance data for HDPE in marine environments; long-term verification ongoing.

3.5. Equipment and workforce

- **Assembly uses commonly available equipment:** drills, crowns, HDPE welders, optical levels, manual extruders, circular saws.
- Construction equipment is limited **to cranes, a concrete pump and standard concrete trucks.**
- Most assembly operations can be performed by **ordinary construction workers or plumbers trained in HDPE welding;** no divers or offshore-class crew are necessary for the bulk of works.

3.6. Regulatory and standards pathway

HYDRANTULA frames are reinforced concrete structures and fall within the scope of standard structural engineering codes. The technology does not require new regulatory categories; rather, it is designed to be assessed under existing frameworks applicable to permanent marine structures:

- **Structural design of the concrete core and reinforcement:** EN 1992-1-1 (Eurocode 2) and EN 1992-2 (concrete bridges and civil structures), as adopted locally — in Singapore, SS EN 1992 and BCA structural Eurocodes apply;
- **Marine durability and exposure classification:** EN 206, EN 1504 series;

- **HDPE pipe materials:** ISO 4427 / EN 12201 (PE pipes for pressure applications); welding procedures per DVS 2207-1 and DVS 2208-1;
- **Geotechnical assessment of seabed bearing capacity and scour:** EN 1997 (Eurocode 7), supplemented by site-specific geotechnical investigation.

Where national building authorities require project-specific structural assessment for novel construction methods, HYDRANTULA's primary load-bearing mechanism — the reinforced concrete core — is directly calculable under standard codes. The permanent HDPE shell does not introduce regulatory ambiguity, as it is treated as non-structural formwork for code purposes (see Section 3.1).

Regulatory pre-consultation with BCA or the relevant authority is planned to agree the assessment basis before detailed design.

4 COMPARISON WITH CONVENTIONAL COASTAL SOLUTIONS

Below is a structured comparison of HYDRANTULA with the main competing methods in shoreline and marine construction: reinforced concrete piles, concrete pontoons, steel/aluminium structures and monolithic concrete walls.

4.1 Benchmarking dimensions

1. Construction method and logistics

HYDRANTULA	up to 90% of work is done onshore and in dry conditions, with only installation and concrete pumping performed in the water
Piles	require pile driving or drilling, heavy barges, vibratory hammers, underwater works
Pontoons	prefabricated floating units towed and moored; relatively simple, but not fixed foundations
Steel/aluminium	factory-fabricated frames installed on piles or heavy concrete blocks; require qualified welders and anti-corrosion treatment
Monolithic concrete walls	usually demand cofferdams and dewatering — often up to 60% of budget goes to temporary works (cofferdam construction and removal) for challenging tidal sites

2. Cost and labour

HYDRANTULA	low capex for marine equipment; uses rental HDPE welding tools and standard concrete pumps instead of expensive crane barges. Labour costs are reduced because work is relatively simple and dry
Piles and monolithic structures	high marine labour and equipment costs
Pontoons	moderate capex but higher lifecycle costs due to maintenance and limited service life
Steel/aluminium	high material and fabrication costs, plus ongoing corrosion protection

3. Environmental footprint

HYDRANTULA	lattice frame is **transparent to waves** and does not cause strong changes in currents or seabed erosion. It does **not increase turbidity** significantly because concrete is poured inside closed formwork from bottom to top. Over time, HYDRANTULA acts as an **artificial reef** — beams and nodes become habitat for marine organisms, increasing biodiversity
Piles and monolithic structures	relatively low physical footprint but noisy and disruptive during installation (underwater noise)
Pontoons	shade the water surface and may interfere with water exchange; do not promote reef-like growth
Steel/monolithic walls	reflect wave energy, often increasing scouring and erosion in front of the structure; construction processes commonly stir up sediments and impact water quality

4. Speed of construction

HYDRANTULA	fast deployment because onshore assembly and underwater concreting avoid cofferdam cycles
Piles and monolithic	sequential, weather-dependent operations; time-consuming
Pontoons	quick to install but shorter life cycle

5. Flexibility and scalability

HYDRANTULA	modular system; dimensions are continuously adjustable by changing beam lengths while maintaining aspect ratios. One basic fitting set can form many different layouts
Piles and monolithic structures	each structure type usually demands project-specific detailing and custom fabrication
Pontoons	
Steel/aluminium	

5 BENEFITS FOR COASTAL AND WATERFRONT PROJECTS WORLDWIDE

Coastal erosion, sea-level rise and storm surge affect over 600,000 km of developed shoreline globally. At the same time, the market for conventional marine construction — piles, cofferdams, sheet piling and prefabricated pontoons — is constrained by high equipment costs, specialist labour requirements and growing environmental regulation. HYDRANTULA addresses this gap, offering a combination of **engineering robustness, environmental compatibility and constructability** that is deployable across a wide range of coastal climates and regulatory environments.

5.1. Suitability for shallow coastal waters worldwide

The majority of shoreline protection and waterfront infrastructure globally is located in water depths of less than 10-12 m. This includes recreational beaches, tidal estuaries, lagoons, river deltas, coral atoll shores, and the nearshore fringes of port cities. HYDRANTULA's depth range – up to 10-12 m with multi-storey configurations – and its ability to rest directly on the seabed without deep pile foundations make it applicable to:

- nearshore and beach protection structures in tropical, subtropical and temperate climates;
- coastal park and promenade revetments along urban waterfronts;
- foundations for small jetties, ferry landing stages and recreational piers;
- fringe infrastructure at land reclamation projects;
- tidal inlet and river-mouth protection works.

Height-adjustable columns and adaptable geometry compensate for seabed irregularities – whether sand, silt or rock – without intensive dredging or site preparation. This is relevant for developing markets where site preparation equipment is scarce or expensive.

5.2. Onshore assembly and reduced dependence on marine equipment

In most coastal jurisdictions, crane barges, jack-up platforms and offshore marine crews represent the dominant cost driver in conventional marine construction. HYDRANTULA's onshore-first approach fundamentally changes this equation:

- approximately 90% of fabrication work is completed on land, in dry conditions, using locally available labour;
- the assembled frame is installed as a complete unit, reducing the number of vessel mobilisations;
- for shallow-water and near-shore installations, a land-based crane can launch frames directly from the shoreline, eliminating the need for a crane barge entirely.

This cost structure is advantageous in high-cost maritime markets (Northern Europe, North America, Australia) and equally valuable in emerging coastal economies where offshore-class equipment is simply not available or affordable. The same construction logic works in a Norwegian fjord, a Caribbean island and a Southeast Asian archipelago.

5.3. Quiet installation and reduced community impact

Pile driving generates sustained underwater impulsive noise, with peak levels that frequently exceed regulatory thresholds for marine mammals, fish and diving birds. In many jurisdictions – including the EU (Habitats Directive), USA (MMPA), Australia and Canada – this triggers mandatory noise impact assessments, exclusion zones and seasonal construction windows that add months to project timelines.

HYDRANTULA does not require pile driving or heavy vibro-equipment. As a result:

- underwater noise levels during installation are substantially lower, reducing permitting risk in ecologically sensitive areas;
- vibration transmission to adjacent structures – relevant for historic waterfronts, densely built harbour fronts and sensitive infrastructure – is negligible;
- work can often proceed in proximity to residential areas, recreational beaches and marine protected areas without triggering noise threshold exceedances.

This characteristic is commercially significant in jurisdictions where underwater noise regulation is tightening: the EU Marine Strategy Framework Directive, OSPAR, and comparable national frameworks are progressively lowering acceptable disturbance levels for offshore and nearshore construction.

5.4. Alignment with nature-based and hybrid coastal solutions

Across Europe, North America, Australasia and Southeast Asia, national coastal strategies are converging on a common position: hard engineering alone is not sufficient, and nature-based or hybrid solutions must be incorporated wherever site conditions permit. HYDRANTULA is structurally compatible with this paradigm:

- the **permeable lattice** allows waves, currents and sediment to move through the structure, avoiding the stagnant backwater zones and scour patterns associated with solid seawalls and revetments;
- rough concrete surfaces protected by the HDPE shell provide colonisation substrate for algae, corals, oysters, mussels, barnacles and other organisms, progressively converting the structure into a functioning artificial reef habitat;
- frames can be configured as **terraced or stepped arrays**, matching the geometry used in living shoreline, eco-seawall and reef restoration programmes.

These properties make HYDRANTULA directly relevant to funded research and pilot programmes in the EU (Horizon Europe, LIFE), USA (NOAA, USACE), UK (UKRI, Environment Agency) and multilateral development bank portfolios targeting climate-resilient coastal infrastructure.

5.5. Reduced turbidity and environmental disturbance during construction

Conventional «wet» construction methods – cofferdam installation, underwater concrete pouring, sheet pile driving – disturb seabed sediments and introduce cement fines into the water column. In areas with sensitive benthic habitats (coral, seagrass, oyster beds) or where suspended sediment concentrations are regulated, this constitutes a major permitting barrier.

HYDRANTULA's closed-formwork, bottom-up pumping method addresses this directly:

- there is no leakage of cement fines into the water column during placement;
- cofferdam construction and associated dredging are avoided;
- sediment resuspension during installation is limited to the mechanical footprint of frame placement;
- the risk of smothering sensitive benthic habitats in the construction zone is substantially reduced.

This is a meaningful advantage in regulated coastal environments globally – from Mediterranean Posidonia seagrass meadows to Indo-Pacific coral reef margins and North Atlantic kelp forest zones.

5.6. Aesthetic and urban-integration advantages

Coastal cities globally are increasingly treating their waterfronts as public amenity, tourism and economic development assets. Massive concrete seawalls and rock armour revetments are visually incompatible with high-value waterfront redevelopment programmes.

HYDRANTULA plastic shells can be manufactured in a range of colours and surface finishes, enabling visual integration with urban waterfront design schemes. Combined with the slender geometry of spatial trusses – as opposed to massive gravity blocks – this enables:

- lightweight-looking promenades, viewing platforms and water terraces on urban waterfronts;
- visually differentiated eco-piers and recreation structures in coastal park settings;
- reduced perceived bulk of protective infrastructure along historically sensitive or tourism-facing shorelines.

This characteristic is relevant for waterfront regeneration projects across Europe, the Gulf, Southeast Asia and coastal resort developments globally.

6 POTENTIAL APPLICATION DOMAINS

HYDRANTULA is applicable across a broad range of coastal engineering programmes, from research pilots to full-scale protective infrastructure. The following domains represent the primary areas where the technology offers a differentiated value proposition relative to conventional alternatives.

1. Shore protection and hybrid breakwaters

- Semi-submerged truss breakwaters attenuating wave energy in exposed and semi-exposed coastal settings while maintaining water exchange, sediment continuity and ecological connectivity.

- Combination with rock armour, mangrove fringe planting or artificial reef modules to create hybrid systems studied under local wave climates and tidal regimes.

- Applicable to open coast erosion control, harbour entrance protection and coastal infrastructure defence in tropical, temperate and arid coastal zones.

2. Eco-shorelines and living seawalls

- Structural backbone for stepped eco-shorelines in coastal parks, port redevelopment zones and reclamation fringe treatments.

- Investigation of how lattice geometry, surface texture and substrate orientation influence marine colonisation rates, species diversity and long-term ecological function.

- Relevant for urban waterfront programmes in the EU, UK, Australia, Singapore, Hong Kong, the Gulf states and the eastern and western seaboards of North America.

3. Foundations for jetties, platforms and aquaculture infrastructure

- Seabed foundations for pedestrian piers, water sports facilities, small-boat docks and ferry terminals, with direct lifecycle cost comparison against pile-supported decks and floating pontoons.

- Stable platforms for nearshore aquaculture infrastructure – fish cages, shellfish longlines, seaweed cultivation – in sheltered bays and straits, exploiting the frame's internal cavities for piping and utilities.

- Particularly relevant for island states and archipelago nations where conventional marine construction supply chains are long and expensive.

4. Pilot and demonstration installations

- Instrumented pilot segments at coastal protection, beach rejuvenation and port regeneration sites, monitoring wave attenuation performance, scour behaviour and biological colonisation over multi-year periods.

- Test beds for validating structural design models, hydraulic performance parameters and environmental impact assessments under real-world conditions in different metocean environments.

- Suitable for integration into national or regional coastal research programmes, providing technology validation data that satisfies both engineering and environmental regulators.

5. Lifecycle and end-of-life studies

- Verification of deconstruction claims: obsolete or damaged HYDRANTULA structures can be removed without leaving protruding piles, submerged metallic debris or residual contamination, reducing end-of-life liability – relevant to project financiers and environmental regulators alike.

- Assessment of plastic component recyclability and fitting reuse potential in the context of circular economy frameworks (EU Taxonomy, ISO 14040 LCA, EPD programmes).

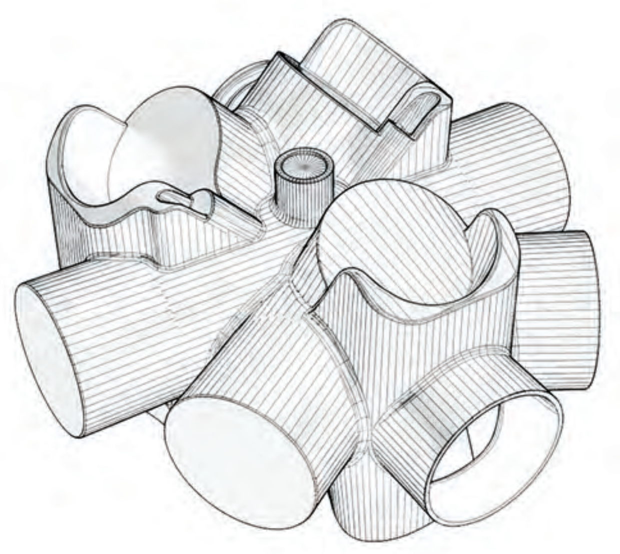
- Comparison of whole-life carbon and embodied energy against conventional coastal structure typologies, using established LCA methodology.

7 CONCLUSION

HYDRANTULA is a **modular, low-impact and durable** technology for underwater concrete structures that directly addresses several challenges in Singapore's coastal protection and waterfront development:

- It shifts most work onshore, reducing marine construction risk and cost.
- It enables robust 3D concrete frames in shallow and mid-depth waters without massive cofferdams or intensive piling.
- It aligns with hybrid and nature-based coastal strategies by allowing water and life to flow through, and by functioning as an artificial reef over time.
- It integrates with existing industrial standards (HDPE pipes, GrooveLock/Camlock fittings, standard pumps and tools), facilitating local adoption.

HYDRANTULA offers a **promising platform for research and pilot projects** in climate-resilient, ecologically sensitive coastal infrastructure. Systematic evaluation under Singapore's specific conditions could unlock a new class of shoreline structures that are both technically effective and environmentally regenerative.



MATERIAL DATA SHEET

ANNEX №1

Structural Components: HDPE Pipes and LMDPE Fittings for Marine Construction

Document No: HYD-MDS-001 **Revision:** 1.0 **Date:** May 2026 **UEN:** 202600937R

1. Scope and Application

This Material Data Sheet covers the two primary structural materials used in Hydrantula permanent formwork systems for marine and coastal construction:

Component	Material	Application in Hydrantula System
Pipes (beams)	HDPE PE100 (High Density Polyethylene)	Structural frame beams; permanent formwork enclosure; rebar conduits
Fittings (nodes)	LMDPE - ETILINAS LL3840UA by PETRONAS Chemicals Group Berhad	3D frame nodes; manifold hubs; concrete distribution connectors

Both components function as permanent (non-removable) formwork. After concrete placement, the plastic enclosure remains in place as a protective outer barrier, shielding the reinforced concrete core from direct saltwater contact, abrasion, and freeze-thaw cycles.

Note: This MDS covers material properties only. Structural design of the concrete core is to be carried out under EN 1992-1-1 / SS

2. HDPE PE100 Pipes (Structural Beams)

2.1. Material Classification

Parameter	Value / Reference
Material designation	PE100 (High Density Polyethylene)
Applicable pipe standard	ISO 4427 / EN 12201 (PE pipes for pressure applications)
Minimum Required Strength (MRS)	10.0 MPa (PE100 classification per ISO 9080)
Welding procedures	DVS 2207-1 (butt fusion); DVS 2208-1 (socket fusion); handheld extruder welding
Supply form	Standard HDPE plumbing pipes, cut to length on site

2.2. Pipe Sizes and SDR Series Used in Hydrantula Assemblies

OD (mm)	SDR	Wall thickness (mm)	PN (bar) @ 20°C	ID approx. (mm)	Typical use
125	13.6	9.2	16	106.6	Modular retention wall members
140	17	8.3	12.5	123.4	Frame, diagonals, sledges
160	21	7.7	10	144.6	Frame, diagonals, sledges
200	26	7.7	8	184.6	Frame, diagonals, sledges
225	26	8.7	8	207.6	Load bearing columns; primary members
250	33	7.7	6.3	234.6	Load bearing columns; primary members
280	33	8.6	6.3	262.8	Load bearing columns; primary members

Wall thickness calculated as OD / SDR. PN rating applies to water at 20°C per ISO 4427. For structural (non-pressure) beam use, SDR designation is used primarily to define wall thickness and cross-sectional moment of inertia, not pressure rating.

2.3. Key Mechanical and Physical Properties - PE100

Property	Value	Unit	Test Standard
Density	950 - 960	kg/m³	ISO 1183
Tensile strength at yield	≥ 22	MPa	ISO 527-2
Elongation at break	≥ 600	%	ISO 527-2
Flexural modulus (short-term)	≥ 900	MPa	ISO 178
MRS (long-term hydrostatic strength)	10.0	MPa	ISO 9080
Vicat softening temperature	≥ 120	°C	ISO 306
Service temperature range	-40 to +60	°C	ISO 4427 / EN 12201
UV stabilisation	Carbon black, ≥ 2% by mass	-	EN 12201-2
Chemical resistance - seawater / chlorides	Excellent	-	ISO 175
Electrical conductivity	Non-conductive	-	-
Design service life (marine environment)	≥ 60	years	EN 12201 / DVGW

Property values represent minimum specification requirements for PE100 per ISO 4427 and EN 12201. Actual values for any specific pipe supply should be confirmed from the pipe manufacturer's product data sheet for the relevant production lot.

3. Reinforced Concrete Core

The principal load-bearing element of any Hydrantula structure is the reinforced concrete core cast inside the permanent HDPE/LMDPE formwork. The plastic shell functions as non-structural formwork and a protective outer barrier; structural design is based on the concrete core and internal reinforcement in accordance with EN 1992-1-1 / SS EN 1992 (Eurocode 2).

3.1. Concrete Mix Requirements

Parameter	Requirement	Reference
Minimum concrete class	C35/45 (marine exposure); C40/50 preferred for tidal / splash zone	EN 206 / SS EN 206
Exposure class	XS2 (submerged) to XS3 (tidal / splash zone)	EN 206 / EN 1992-1-1
Workability (placement method)	Self-consolidating (SCC); slump flow 550-650 mm	EN 12350-8
Maximum water-cement ratio	≤ 0.45	EN 206 Table F.1
Cement type	Sulphate-resistant or blended (GGBS, fly ash) preferred	EN 197-1
Micro-fibre reinforcement	Glass fibres or stainless steel macro-fibres; reduces plastic shrinkage cracking and improves post-crack toughness	EN 14889
Placement method	Bottom-up pressure pumping via GrooveLock / Camlock port; no free-air pouring	Hydrantula construction procedure
Quality control sampling	Standard cube / cylinder samples per pour; 28-day compressive strength per EN 12390	EN 12390-3

Specific mix design must be verified and adapted to local cement sources and environmental exposure by a qualified structural or materials engineer. Standard concrete supply and pumping equipment are available in all major coastal construction markets.

3.2. Internal Reinforcement

Hydrantula structures use Glass Fibre Reinforced Polymer (GFRP) rebar exclusively. Steel reinforcement is not used in any Hydrantula configuration.

Parameter	Requirement
Material	Glass Fibre Reinforced Polymer (GFRP)

Parameter	Requirement
Tensile strength (ultimate)	600 - 1000 MPa (grade-dependent)
Elastic modulus	40 - 55 GPa
Density	~2.0 g/cm³ (approx. 25% of steel)
Corrosion resistance	Fully corrosion-resistant in marine and chloride-rich environments; no electrochemical degradation
Concrete cover requirement	Cover requirements are not driven by corrosion protection; governed by bond and fire resistance only
Electrical conductivity	Non-conductive; no galvanic interaction with seawater or adjacent metallic elements
Buoyancy effect during installation	GFRP-reinforced frames are buoyant prior to concrete fill; controlled ballasting or staged filling required during submersion
Applicable standards	ACI 440.1R (Guide for FRP rebar); fib Bulletin 40; CSA S806; CNR-DT 203

Rebar is inserted into pipe members during onshore assembly, prior to frame sealing. Pull rods - GFRP tension members engineered to resist dynamic marine loads - are incorporated as a standard feature of the Hydrantula connection system, providing additional redundancy under cyclic wave loading.

4. LMDPE Fittings / Nodes - ETILINAS LL3840UA

4.1. Material Identification

Parameter	Value
Trade designation	ETILINAS LL3840UA
Manufacturer	PETRONAS Chemicals Group Berhad (PCGB), Kuala Lumpur, Malaysia
Material type	Linear Medium Density Polyethylene (LMDPE)
Processing method	Rotational moulding (rotomolding)
Processing temperature	200°C - 300°C (mould-dependent)
Supply form	Pellets, 25 kg bags
Quality system	ISO 9001:2015 (Cert. No. AR1560)

4.2. Key Properties

Property	Value	Unit	Test method	Notes
Nominal density	938	kg/m³	ASTM D 1505	
Melt Flow Rate (I2, 190°C/2.16 kg)	4.0	g/10 min	ASTM D 1238	

Property	Value	Unit	Test method	Notes
Melting point	124	°C	ISO 3146	-
Crystallization point	111	°C	ISO 3146	-
Tensile strength at yield	21	MPa	ASTM D 638	50 mm/min, Type IV
Tensile strength at break	18	MPa	ASTM D 638	50 mm/min, Type IV
Elongation at break	800	%	ASTM D 638	High ductility
Flexural modulus	800	MPa	ASTM D 790	-
Charpy impact strength	12	kJ/m²	SO 179 Type 1 Notch A	-
Surface hardness	60	Shore D	ASTM D 2240	@ 23°C
Heat deflection temperature	70	°C	ASTM D 648 Method B	-
Vicat softening temperature	120	°C	ASTM D 1525	1 kg, 50°C/hr
ESCR (Environmental Stress Crack Resistance)	> 300	hours	ASTM D 1693	100% Igepal, Cond. B, F50
UV stabilisation rating	UV8	-	-	High UV stabilizer loading

4.3. Regulatory Compliance - ETILINAS LL3840UA

Requirement	Status
US FDA 21 CFR 177.1520 (food contact)	Compliant
EU Commission Regulation No. 10/2011 (food contact)	Compliant
REACH / RoHS / SVHC	Compliant
HALAL certification	Certified
ISO 9001:2015 quality management	Certified (Cert. No. AR1560)

5. Marine Durability and Environmental Performance

Performance criterion	HDPE PE100 Pipes	LMDPE Fittings (LL3840UA)
Seawater / chloride resistance	Excellent - chemically inert to seawater and chlorides	Excellent - non-reactive in marine conditions
UV resistance	Carbon black stabilised (≥ 2% by mass, EN 12201)	UV8 rating - high stabilizer loading
Biofouling	Non-toxic, does not leach plasticisers or biocides	Non-toxic, supports marine colonisation as artificial reef over time
Ice / freeze-thaw resistance	Excellent; designed for -40°C service	Good; service temperature range covers freezing conditions

Performance criterion	HDPE PE100 Pipes	LMDPE Fittings (LL3840UA)
Electrochemical corrosion	None - dielectric material	None - dielectric material
Abrasion resistance	Good - hard outer surface (HDPE)	Shore D 60 - adequate for marine contact loads
Design service life (target)	≥ 60 years in marine environment (material basis)	≥ 25 years (rotomoulded LMDPE; ongoing long-term verification)

6. Applicable Standards Reference

Standard	Scope
ISO 4427 / EN 12201	PE pipes for water supply and pressure applications - material specification and testing
ISO 9080	Determination of long-term hydrostatic strength (MRS) of thermoplastic piping materials
DVS 2207-1	Welding of thermoplastics - heated tool butt welding of pipes and fittings
DVS 2208-1	Welding of thermoplastics - machines and devices for heated tool butt welding
EN 206 / SS EN 206	Concrete specification, performance, production and conformity
EN 1992-1-1 / SS EN 1992	Design of concrete structures (Eurocode 2); applicable to concrete core design
EN 1997 / SS EN 1997	Geotechnical design (Eurocode 7); applicable to seabed bearing and scour assessment
ISO 9001:2015	Quality management system - applicable to PETRONAS LL3840UA supply

Property values for HDPE PE100 represent standard minimum specifications per ISO 4427 / EN 12201. Values for ETILINAS LL3840UA are taken from PETRONAS Chemicals Group Berhad Product Data Sheet (Rev. September 2020). Hydrantula PTE LTD makes no independent warranty of material properties beyond those stated in the respective manufacturer's documentation.

CARBON FOOTPRINT ASSESSMENT

ANNEX №2

Modular Coastal Structure (HYDRANTULA) vs Conventional Coastal Solutions

1 PURPOSE AND ENGINEERING CONTEXT

The objective of this assessment is to quantify and compare the embodied and life-cycle carbon footprint of a modular coastal structure based on Hydrantula technology against two functionally equivalent conventional solutions:

1. Steel coastal structural frame
2. Reinforced concrete underwater support structures

The assessment is framed for coastal protection and load-bearing applications under typical Singapore coastal conditions and aligned with MPA coastal engineering evaluation logic, where lifecycle performance, constructability in marine environments, and environmental impact are key decision parameters.

The calculation explicitly supports:

- comparative option assessment,
- early-stage engineering feasibility,
- ESG and sustainability screening.

2 FUNCTIONAL UNIT AND DESIGN BASIS

2.1 Functional Unit

The functional unit is defined as:

One structural segment providing equivalent coastal protection and structural performance per one linear meter of shoreline, designed for a minimum guaranteed service life of 60 years, under the same hydrodynamic loading conditions.

This definition aligns with standard coastal engineering comparison practices (PIANC WG reports, CIRIA C683/CUR manuals), where solutions are normalized per linear meter of coastline or per equivalent hydraulic performance.

2.2 Design Wave Condition (Reference)

For normalization and comparability, the following design wave condition is adopted as a reference envelope (not a project-specific extreme):

- Significant wave height, Hs: 2.5 m
- Peak wave period, Tp: 7-9 s
- Water depth at structure toe: 5-7 m
- Design return period: 50 years

This corresponds to conservative sheltered-to-semi-exposed coastal conditions typical for:

- reclaimed shorelines,
- port perimeters,
- urban coastal protection works in Singapore waters.

The key requirement is functional equivalence, not identical geometry.

3 SYSTEM BOUNDARIES AND METHODOLOGY

3.1 Life Cycle Assessment Boundary

The assessment follows ISO 14040 / ISO 14044 principles with the following boundaries:

- A1-A3 - Raw material extraction and material production (cradle-to-gate)
- B - Operation, maintenance, repair over 60 years (engineering-based estimates)
- C - End-of-life demolition and material handling (engineering estimates)

Explicit exclusions at this stage:

- Transport to site
- Installation activities

This exclusion is deliberate and conservative, as marine installation typically penalizes conventional solutions more heavily. These impacts can be added later without altering the relative conclusions.

3.2 Data Sources and Indices

All carbon intensity values are based on:

- industry-average EPD ranges,
- ICE Database v3.0,
- World Steel Association data,
- PlasticsEurope Eco-profiles,
- fib Model Code references for reinforced concrete.

No proprietary or unverified datasets are used.

4 STRUCTURAL CONFIGURATIONS AND MATERIAL QUANTITIES

4.1 Hydrantula Modular Structure (Reference Segment)

- Concrete infill: 7 m3
- HDPE/LLDPE structural shell: 1.0 t
- Composite reinforcement (GFRP): 0.25 t

Concrete density: 2.2 t/m3

This segment provides the required stiffness, mass, and geometry to resist wave loading and soil interaction equivalent to conventional solutions.

4.2 Steel Coastal Structure

- Structural steel mass: 8.0 t

Includes primary members only. Corrosion protection is addressed in lifecycle adjustment.

4.3 Reinforced Concrete Supports

- Two supports, each 2 x 3 x 3 m
- Total concrete volume: 36 m3
- Steel reinforcement: 120 kg/m3
- Total reinforcement mass: 4.32 t

This reflects typical underwater gravity or semi-gravity supports used in coastal and port infrastructure.:

5 CARBON INTENSITY FACTORS (A1-A3)

Material	Carbon Intensity	Source
Concrete (CEM I equivalent)	0.30 t CO2 / m3	ICE / fib
Structural steel	1.9 t CO2 / t	worldsteel
HDPE / LLDPE	1.35 t CO2 / t	PlasticsEurope
GFRP composite	4.0 t CO2 / t	Conservative literature range

Note: The composite factor is intentionally conservative and reflects resin-dominant scenarios. Real GFRP values are often lower.

6 EMBODIED CARBON CALCULATION (A1-A3)

6.1 Hydrantula

- Concrete: 7 x 0.30 = 2.10 t CO2
- Polymer shell: 1.0 x 1.35 = 1.35 t CO2
- Composite reinforcement: 0.25 x 4.0 = 1.00 t CO2

Total A1-A3: 4.45 t CO2

6.2 Steel Structure

- Steel: 8.0 x 1.9 = 15.2 t CO2

6.3 Reinforced Concrete Supports

- Concrete: 36 x 0.30 = 10.8 t CO2
- Reinforcement: 4.32 x 1.9 = 8.21 t CO2

Total A1-A3: 19.0 t CO2

7 LIFE-CYCLE ADJUSTMENTS (60-YEAR SERVICE LIFE)

7.1 Hydrantula

Engineering considerations:

- No corrosion mechanisms
- No cathodic protection
- No repainting
- Modular replacement without demolition

Estimated adjustment:

- +10-15%

Total lifecycle footprint: ~5.0 t CO2

7.2 Steel Structure

Engineering considerations:

- Recoating every 12-15 years
- Local steel replacement
- Energy-intensive demolition

Estimated adjustment:

- +45-60%

Total lifecycle footprint: ~22-24 t CO2

7.3 Reinforced Concrete

Engineering considerations:

- Crack injection and patch repairs
- Potential strengthening
- Demolition and concrete crushing

Estimated adjustment:

- +25-35%

Total lifecycle footprint: ~24-26 t CO_2

8 NORMALIZATION PER LINEAR METER OF COASTLINE

When normalized to **1 linear meter of shoreline** under the same design wave condition:

Solution	CO_2 over 60 years (t/m)	Relative Index
Hydrantula	~5	1.0
Steel	~23	~4.6
Reinforced concrete	~25	~5.0

This normalization is consistent with MPA coastal option screening logic.

9 REDUCTION OF DREDGING AND MARINE WORKS

9.1 Engineering Basis

Traditional coastal structures typically require:

- seabed excavation,
- leveling and foundation preparation,
- temporary cofferdams or stone bedding,
- extended marine equipment presence.

Hydrantula introduces:

- reduced foundation footprint,
- distributed load transfer,
- wave-transparent geometry,
- no deep excavation or piling in many configurations.

9.2 Carbon Implications

Published ranges (PIANC / CIRIA):

- Dredging: 5-15 kg CO_2 per m^3, depending on method
- Marine equipment operations: high fuel intensity per hour

Typical reduction potential:

- 30-60% reduction in dredged volume
- significant reduction in barge and crane time

Although excluded from the base calculation, inclusion of these effects would further widen the carbon gap in favor of Hydrantula.

10 ENGINEERING CONCLUSIONS

1. Under conservative, science-based assumptions, Hydrantula demonstrates a **4-5 times lower carbon footprint** than conventional coastal solutions over a 60-year design life.

2. The advantage is driven by:

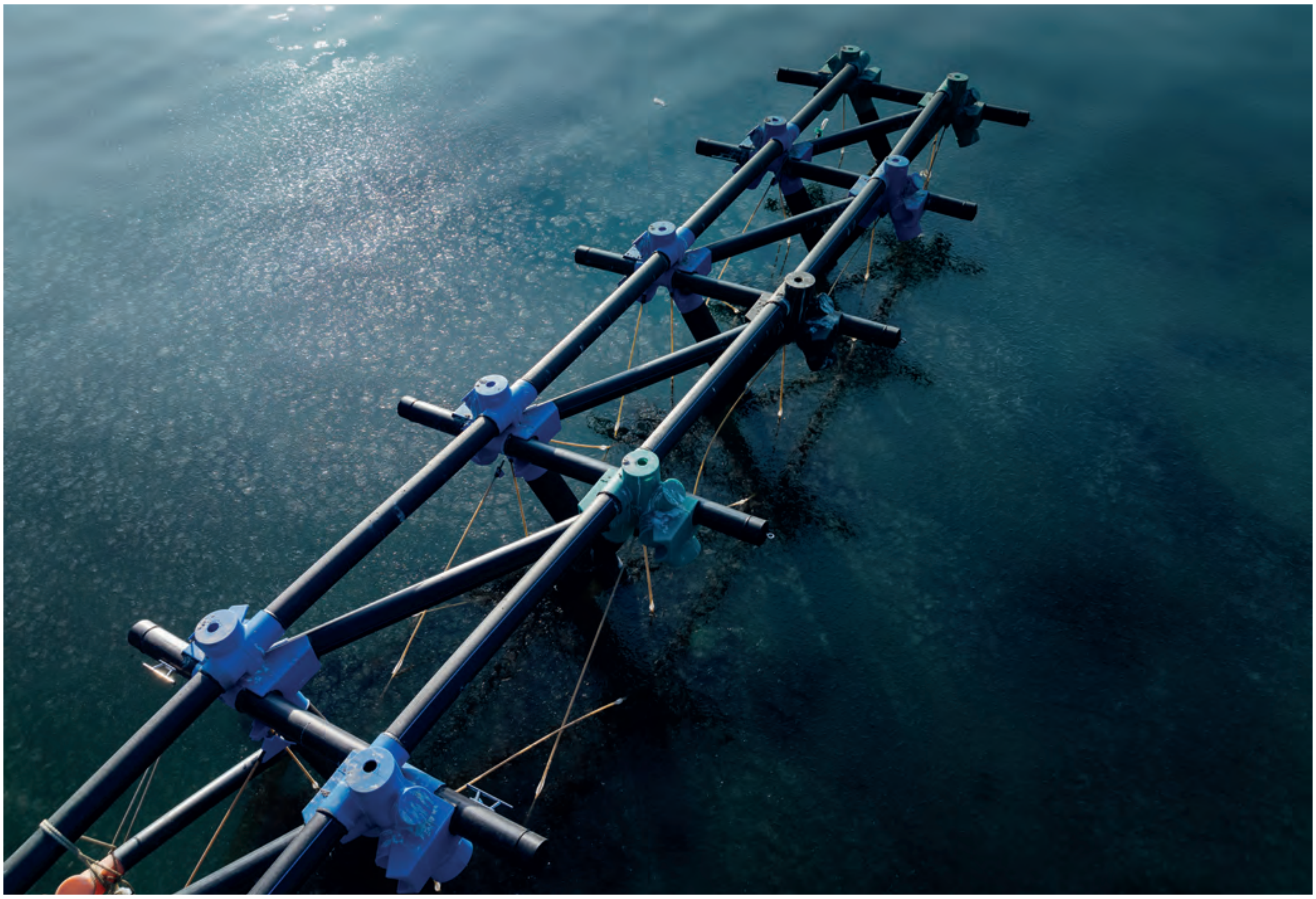
   a) material efficiency,
   b) elimination of corrosion-driven maintenance,
   c) modularity,
   d) reduced marine works.

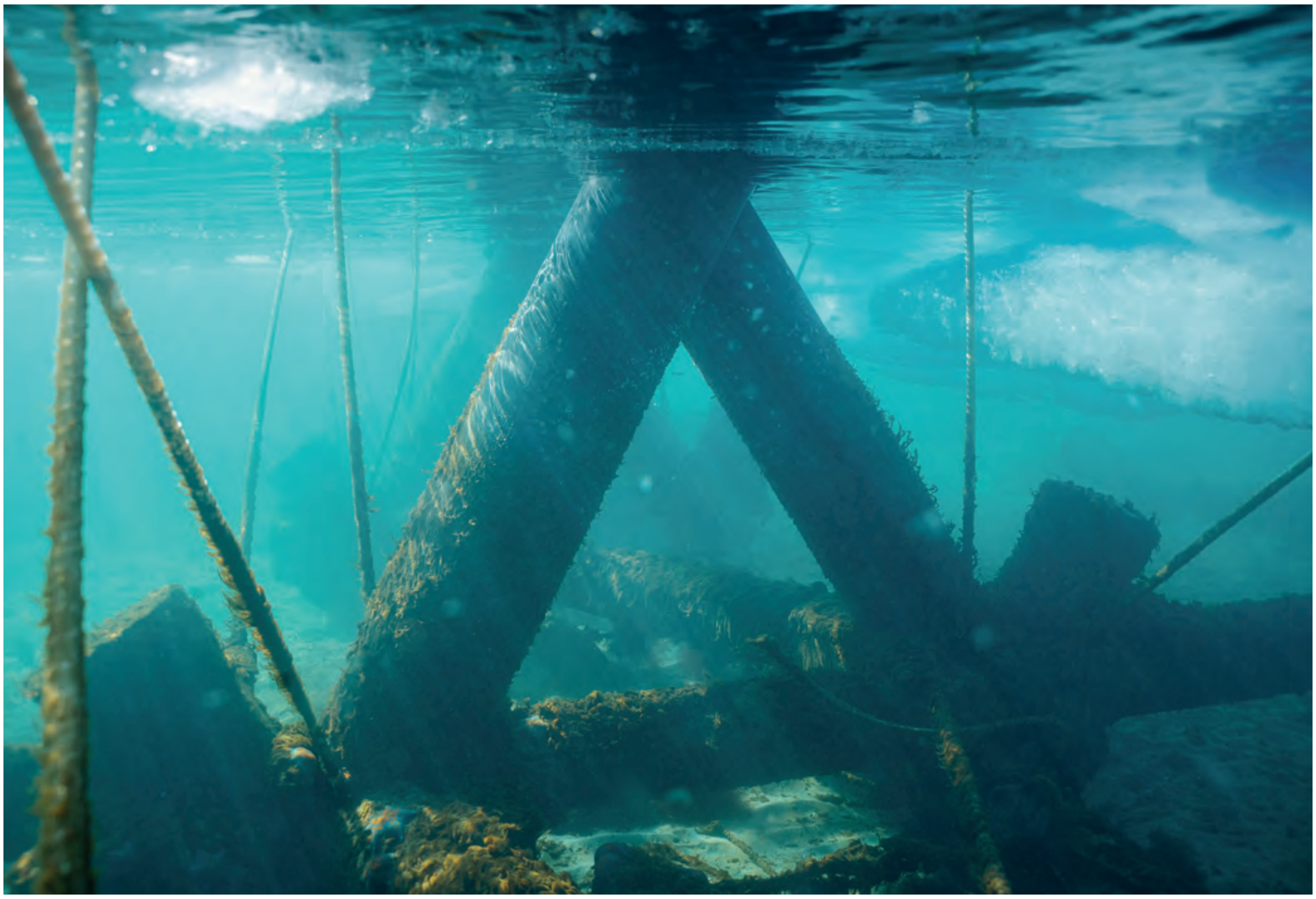
3. The conclusions are robust to sensitivity analysis and remain valid across:

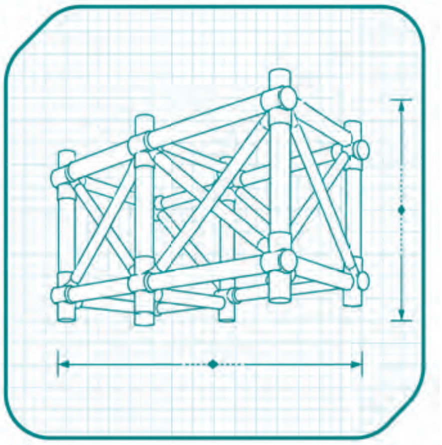
   a) alternative cement blends,
   b) recycled polymers,
   c) regional electricity mixes.

4. From an MPA coastal engineering perspective, Hydrantula aligns with:

   a) lifecycle-based asset evaluation,
   b) reduction of marine construction impacts,
   c) long-term sustainability objectives







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