MARITIME SOLUTIONS FOR A CHANGING WORLD

#177 - AUTUMN 2025

TERRA ET AQUA

BLUE CARBON
An opportunity for the waterborne transport infrastructure sector

YOUNG AUTHOR AWARD
Study of blunt chisel geometry on cutting forces

IADC SAFETY AWARD

SHOWCASING SAFETY INNOVATIONS IN THE DREDGING INDUSTRY

CUTTING EDGE

This year's IADC Young Author Award was presented to Rick van de Wetering for his contribution to the paper presenting the linear rock cutting setup to study cutting forces of blunt chisels. Read the full article on page 32.

CHANGING OF THE GUARD

As the dredging industry continues to evolve, we find ourselves at the intersection of innovation, sustainability and safety. This issue reflects that balance, showcasing not only technological advancements but also the environmental and human considerations that shape our sector.

We begin with a timely feature on blue carbon and the role our industry can play in protecting and restoring these critical ecosystems. As climate change mitigation becomes more urgent, the waterborne transport infrastructure sector has a unique opportunity – and responsibility – to contribute meaningfully. This article dives into how strategic dredging and coastal development projects can enhance carbon capture while promoting ecological resilience.

Safety, as always, remains at the core of what we do.

This issue highlights the submissions and winner of the IADC Safety Award 2025, offering insights into the innovations and initiatives that are raising the bar industry-wide. From new procedures to transformative tools, these efforts serve as a reminder that safety is not just a requirement, but a culture.

In our technical section, we spotlight this year's IADC Young Author Award winner, Rick van de Wetering, whose research into the cutting forces of blunt chisels promises to inform future equipment design and operational efficiency. Supporting emerging talent remains a priority for IADC and we are proud to showcase the next generation of dredging innovators.

In other innovations, IADC is launching the Responsible Marine Solutions: DFSI website – an exciting new hub for everything related to sustainable dredging. Building on the *Dredging for Sustainable Infrastructure* book and *DFSI Magazine*, this dynamic platform brings the philosophy to life online. With real-world case studies, fresh insights and practical guidance, it breaks down complex topics into clear, engaging content. Centred around six core principles, from nature-based solutions to energy transition, it's designed for everyone so whether you're a young professional new to the industry or a local authority representative, this is your go-to source for learning about responsible marine solutions.

This issue also marks a significant moment for our community as we prepare to bid farewell to René Kolman, our long-serving Secretary General, who will retire this November. René has been a guiding force for IADC for 17 years, championing industry standards, sustainability and collaboration on a global scale. His leadership has helped shape the organisation into what it is today and his legacy will undoubtedly endure. On behalf of the entire IADC community, we extend our deepest gratitude and best wishes for this next chapter.

We hope you find this edition insightful and inspiring as we continue building a smarter, safer and more sustainable dredging industry.

Frank Verhoeven
President, IADC

> IADC is launching the Responsible Marine Solutions: DFSI website – an exciting new hub for everything related to sustainable dredging.

SUBMISSIONS FOR THE IADC SAFETY AWARD 2025

When individual employees, teams and companies view everyday processes and situations through a continuous lens of safety, they can each contribute to making all aspects of operational processes, whether on water or land, safer. For this year's Safety Award, IADC's Safety Committee received 14 submissions. Each one is assessed on five different categories; sustainability; level of impact on the industry; simplicity in use; effectiveness; and level of innovation.

Affirming the importance of safety

Dredging activities can be risky operations with hidden dangers among heavy machinery. In response, the dredging industry proactively maintains a high level of safety standards. A representative of contractors in the dredging industry, IADC encourages its own members, as well as non-members participating in the global dredging industry, to establish common standards and a high level of conduct in their worldwide operations.

IADC's members are committed to safeguarding their employees, continuously improving to guarantee a safe and healthy work environment and reducing the number of industry accidents and incidents to zero.

Recognising advancers of safety

IADC conceived its Safety Award to encourage the development of safety skills on the job and reward individuals and companies demonstrating diligence in safety awareness in the performance of their profession. The award is a recognition of the exceptional safety performance demonstrated by a particular project, product, ship, team or employee(s).

No submissions were received this year for the safety award granted to a supply chain organisation active in the dredging industry. This concerns subcontractors and suppliers of goods and services. In total, 14 submissions were received for the dredging contractor safety award. Each one aims to improve routine processes and situations encountered in the dredging industry.

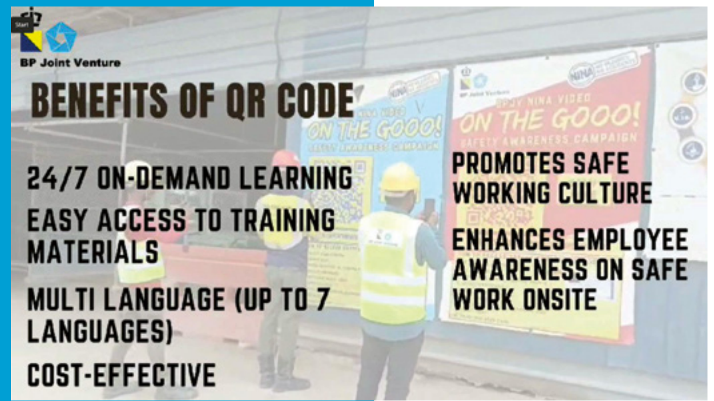
Dredging contractor submissions

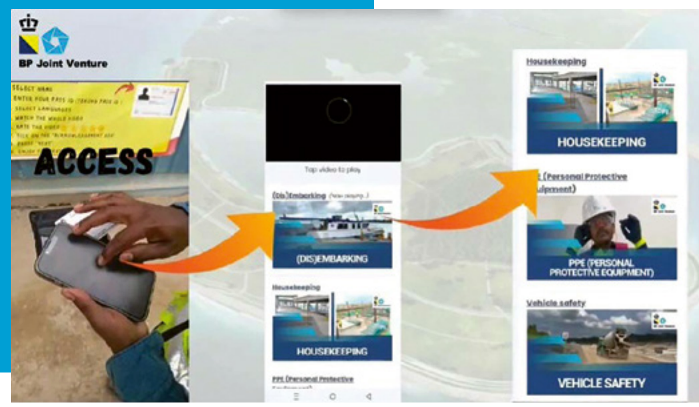
"NINA SAFETY VIDEOS" FOR INTERNATIONAL WORKFORCE BY BOSKALIS

Boskalis is using "NINA safety videos" tailored to its multinational workforce involved in a polder reclamation project. Recognising the large workforce that comprises of diverse linguistic and cultural backgrounds, the safety training videos are specifically designed to deliver important information directly to workers' devices, ensuring they can access training at any time and from any location on the project site.

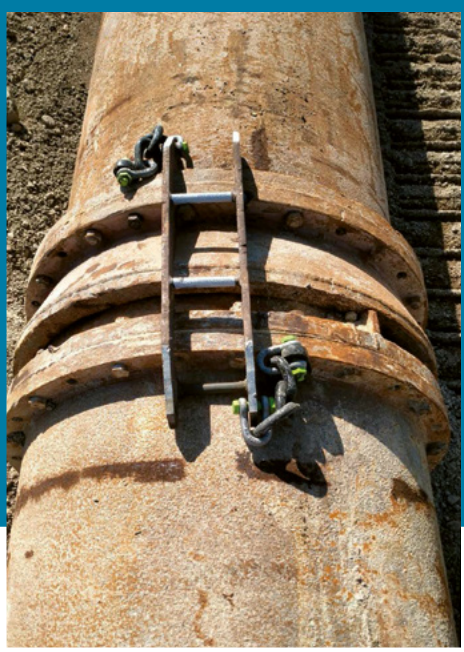
This approach has enhanced the efficiency of the conventional training process, eliminating the need for in-person sessions and onsite translators. Integrating multilingual support and culturally relevant content into each video, Boskalis ensure that every team member receives clear, understandable and engaging training. This enhances safety compliance across the workforce but also fosters a safer working environment by accommodating the unique learning paces and styles of its international employees.

The ease of access and portability of the training videos have shown to be highly effective in sustaining high safety standards while simultaneously improving efficiency and promoting inclusivity. This innovation of marrying technology with practical application can fulfil the dynamic requirements of today's diverse teams working on complex large-scale projects.





BRACKET FOR QUICK FIT PIPE CONNECTION BY JAN DE NUL



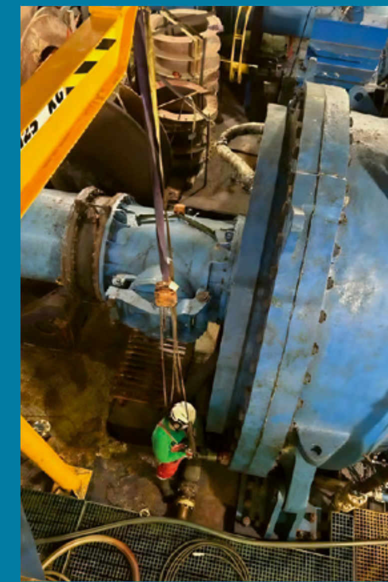
In many reclamation projects, bolting landline pipes is not always feasible due to time constraints or the continuous discharge process of the dredger. In such cases, push pipes are used as an alternative. However, these connections are more susceptible to separation under pressure, especially when there are nearby vibrations during the start-up of the discharge process or when there is a bend behind the female quick fit. To help mitigate those risks, Jan De Nul has designed a bracket to improve the security between the male and female quick fit connection on landline pipes.

The design consists of two parallel steel plates with openings that fit the quick fit connection, allowing the bracket to rest securely and stably on the pipe. To improve safety, the bracket is attached to the pipes using chains. This ensures that, in the event of sudden release of tension, the bracket remains secured and does not pose a risk to personnel nearby.

ZERO BALANCER FOR HAND TOOLS BY DEME

Zero balancers are mechanical devices designed to suspend tools, equipment or parts, making them feel weightless for the operator. They are widely used in industrial settings to enhance efficiency and reduce operator fatigue.

DEME has employed these tools for their many benefits, which include: reduced operator fatigue – by neutralising the tool's weight, spring balancers reduce strain and fatigue for the operator; enhanced safety – they promote a safer work environment by preventing tools from being accidentally dropped or damaged; and increased efficiency – workers can handle heavy tools with ease and precision, improving productivity.



INNOVATIONS WORKING IN CONFINED SPACE OF DOUBLE BOTTOM DREDGING TANKS BY PENTA-OCEAN

Cassiopeia V is a cutter suction dredger featuring a specialised double bottom tank configuration designed to house critical hydraulic lines. Unlike conventional vessels where such tanks are typically used for ballast, Cassiopeia V's tanks are narrow, compact and congested, necessitating frequent crew access for inspection, maintenance and repairs. These entries are particularly hazardous due to poor ventilation, structural movement during dredging operations (hogging and sagging) and recurring hydraulic leaks that may leave residual oil vapours, even after standard gas-free checks.

To address these challenges, Cassiopeia V implemented a custom-modified confined space safety system. The solution features a multi-user industrial breathing apparatus with extended air supply hoses, enabling multiple crew members to work safely within the tanks without the physical burden of bulky self-contained breathing apparatus (SCBA) units. This system significantly improves mobility, comfort and endurance while ensuring a continuous supply of breathable air in enclosed spaces.

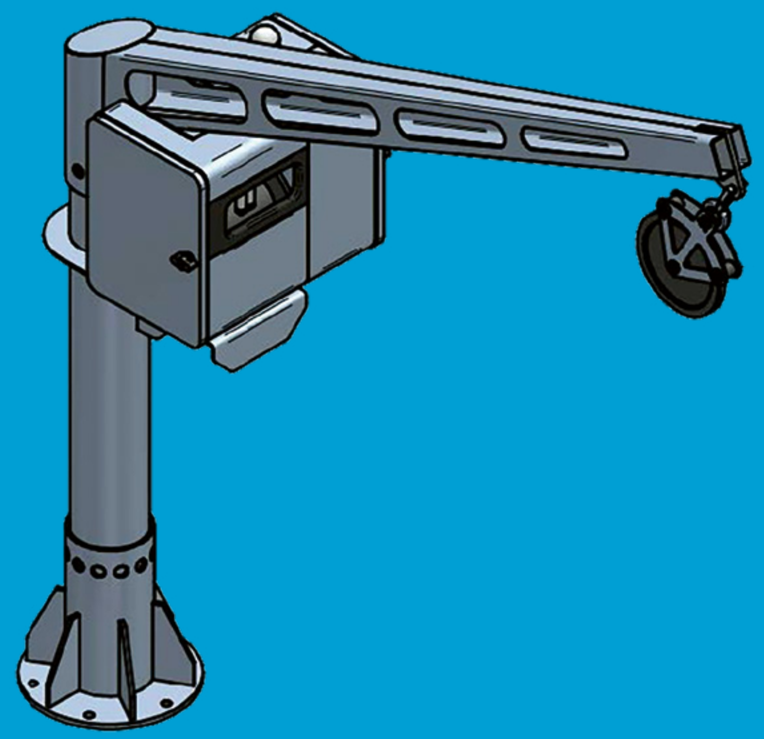
This vessel's specific solution has enhanced confined space safety, minimised operational risks and improved crew confidence. It serves as a strong example of how targeted innovation can address practical safety challenges and raise the standard for enclosed space operations in the dredging industry.

FORWARD DUMPING METHOD FOR ARTICULATED DUMP TRUCKS BY BOSKALIS

The forward dumping method for articulated dump trucks (ADTs) is a groundbreaking safety innovation developed and implemented by Boskalis that sets a new industry standard for how material is moved and discharged in reclamation and dredging operations. This method challenges decades of convention by eliminating the need for reversing during dumping activities. Instead, the ADTs are directed to drive forward over previously deposited, compacted material and discharge their load in a controlled, linear movement.

This operational shift is deceptively simple, but its impact is transformative. It eliminates a major source of incidents, increases production, reduces mechanical wear and removes the need for ground personnel near heavy equipment. The Forward Dumping Method is a no-cost, high-reward innovation and one that is immediately scalable across projects globally.

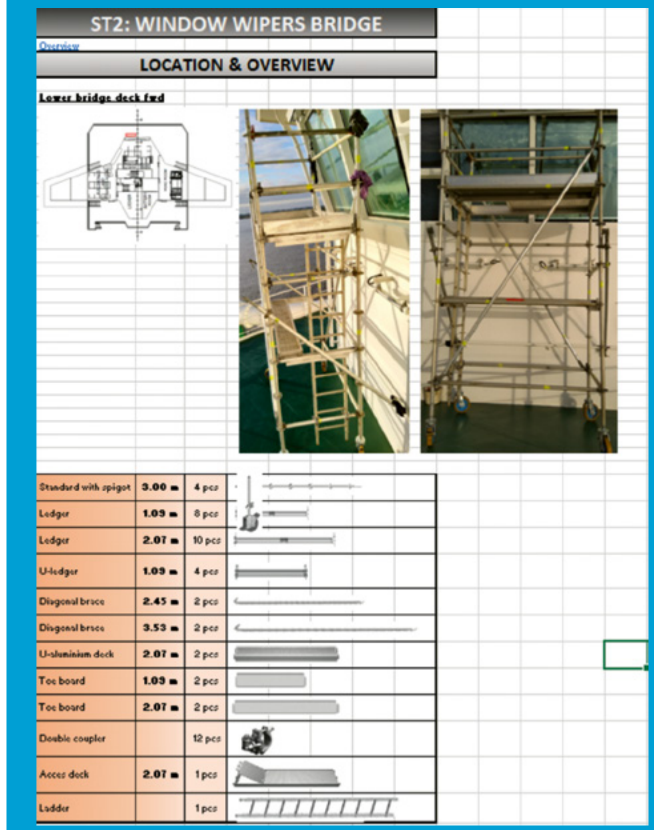
At its core, this method is a perfect embodiment of the NINA (No Incidents – No Accidents) values – it does not rely on behaviour-based compliance but builds safety directly into the design of the task. It does not manage risk, it erases it. It turns one of the most hazardous daily activities on site into a non-event.



MODULAR SOUND VELOCITY PROFILE WINCH BY JAN DE NUL

On trailing suction hopper dredgers (TSHDs) operating offshore without a floating auxiliary plant (FLAP), bathymetric surveys must be conducted on board. A critical part of this process involves regularly collecting sound velocity profiles (SVP), which requires deploying a probe into the water, allowing it to sink to the seabed and retrieving it to gather data. Across the industry, this task is still typically performed manually, exposing operators to significant safety risks, such as falling overboard when leaning over railings, rope entanglement leading to hand and leg injuries or burns, the danger of being pulled overboard if the rope becomes caught in the propellers and physical strain from repetitive tasks in awkward positions.

To address these challenges, Jan De Nul – together with Seatec – developed the modular, electrically driven SVP winch, also known as the Seatec Lier 113. This innovation offers a safer, more ergonomic solution by automating the launch and recovery of the probe, removing the n eed for manual handling near the vessel's edge. Its lightweight, modular design makes it easy to assemble, move between vessels after use, while the integrated spooling system ensures smooth, tangle-free cable handling throughout the operation.



ST2: WINDOW WIPERS BRIDGE

Overview

LOCATION & OVERVIEW

Lower bridge deck fwd

Standard with spigot	3.00 m	4 pcs	
Ledger	1.09 m	8 pcs	
Ledger	2.07 m	10 pcs	
U-ledger	1.09 m	4 pcs	
Diagonal brace	2.45 m	2 pcs	
Diagonal brace	3.53 m	2 pcs	
U-aluminium deck	2.07 m	2 pcs	
Toe board	1.09 m	2 pcs	
Toe board	2.07 m	2 pcs	
Double coupler		12 pcs	
Acces deck	2.07 m	1 pcs	
Ladder		1 pcs	

SHIP SPECIFIC SCAFFOLDING BOOK BY DEME

Whenever a vessel constructs a unique, complex or challenging scaffolding setup that has not been built before, it is documented in the scaffolding book. This avoids having to reinvent the wheel each time as crew can simply refer to the ship specific scaffolding book.

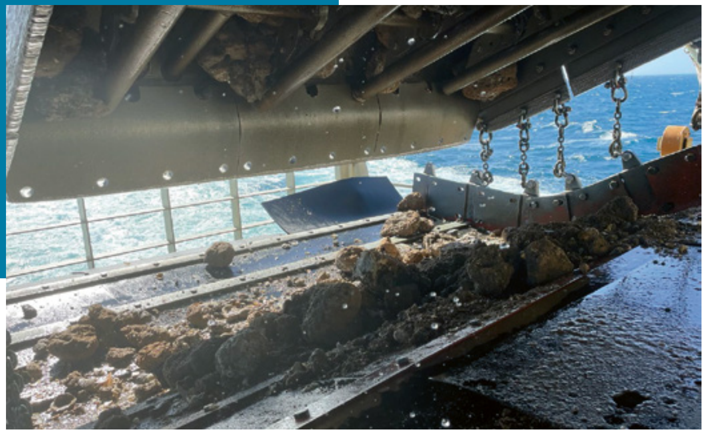
Each entry includes clear, high-quality photos of the completed structure together with a detailed list of all the scaffolding components used. In addition, helpful tips and tricks for handling specific features are also included. Having this information recorded and easily accessible allows everyone to understand the requirements and assembly process in situ.

By using the scaffolding book, crew are better prepared for upcoming jobs, allowing them to quickly and accurately rebuild the same setup when required. It not only saves valuable time but also ensures consistent safety standards across all teams and preserves knowledge even when crew members change.

SELF-CLEANING DRAG HEAD BY BOSKALIS

From a safety perspective the elevated position of a drag head on the inboard gantry cradle poses inherent safety risks when attempting to remove rocks and debris from within the drag head. The practice encourages personnel to work near or under suspended loads and contradicts established safety guidance. Particularly in environments where rock or debris is prone to becoming lodged in the drag head, the risk to crew members is notably elevated.

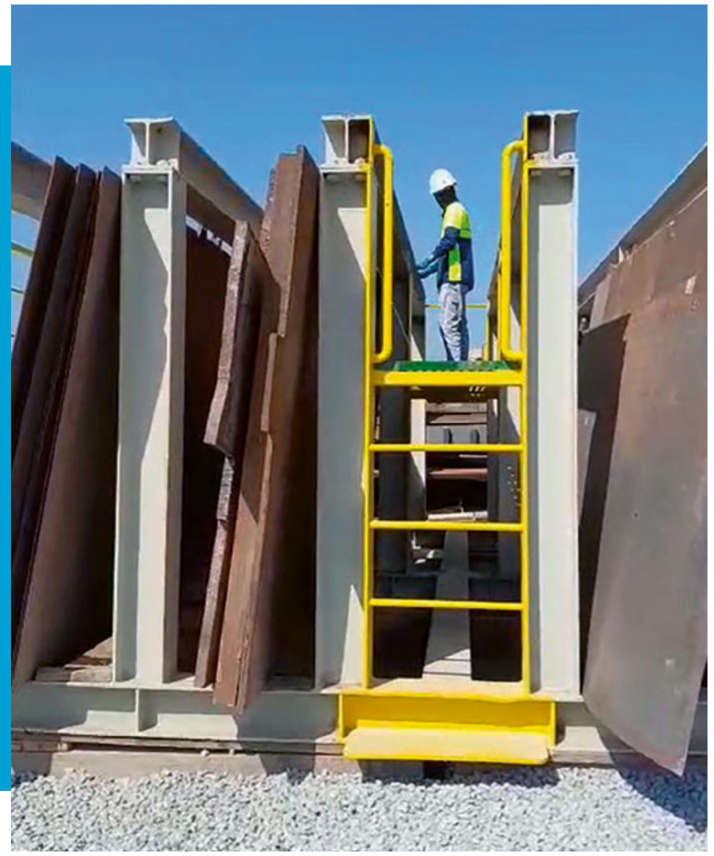
Boskalis' self-cleaning drag head features a movable grid that supplements the fixed steel grating, which prevents large debris from entering the drag head. When blockages occur, the movable part of the grid can be activated remotely, temporarily increasing the grid aperture – both during dredging operations and while the drag head is stored on deck – facilitating the dislodging of obstructions without requiring manual intervention. This advancement not only reduces risk to personnel but increases productivity as blockages can be actively removed.



SAFE STORAGE OF METAL PLATES IN WORKSHOP BY JAN DE NUL

Metal plates, commonly used for repairs, maintenance and equipment fabrication in the dredging industry are stored in designated racks at Jan De Nul's worksites. Safe access to the hoisting points on top of these big metal plates during storage and removal is both challenging and time consuming.

To address this safety risk, the workshop crew came up with the idea to fabricate ladders with railings to provide safe and easy access, and a platform with anti-slip features that can be installed in between the plate racks. Positioned 145 cm above ground level, the platform is fully enclosed between the racks, ensuring full compliance with industry best practices for working at height. The design also optimises space, which is a highly desired feature on dredging vessels with congested deck areas.

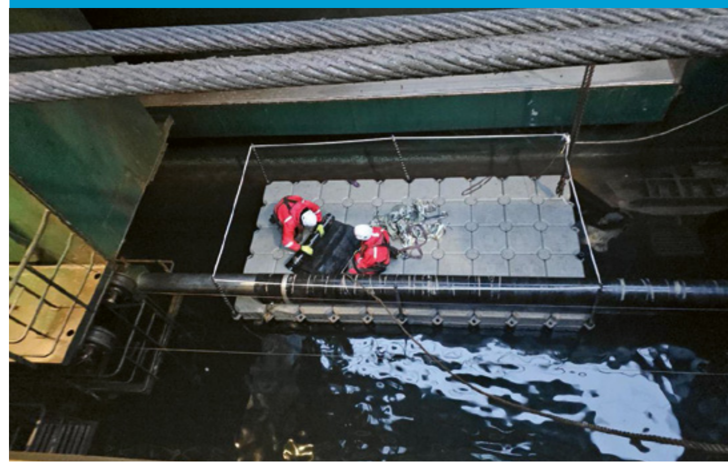


BARGE WASHING PUMP BY DEME

A common problem in backhoe dredging is dealing with an accumulated dredged material on barge passageways. After dredging is completed, normal practice is for the backhoe to take water into the bucket several times to clean up the spilled material. This is both time and fuel consuming, can add extra water in the hopper and is not efficient when dealing with sticky material.

To solve this problem DEME installed a barge washing pump on one of its backhoe dredgers. The barge washing pump is operated at the end of dredging while the barge is still being loaded. Once dredging is completed, the deck wash is also finalised and the barge can unmoor and cast off.

The installation has several benefits: it reduces production delay and improves fuel consumption while also eliminating exposure of crew to slips, trips and man overboard (MOB) hazards from manually cleaning the passageway.



MODULAR PONTOON FOR WORKING IN A SPUD WELL BY DEME

For works in the spud well of one of DEME's cutter suction dredgers, the challenge was to execute the work in a safe way. Before, when works had to be carried out on the cylinder and other structures in the spud well, there was nothing in place to work safely. Small inflatable boats had to be used or the crew sat on the top of the structure wearing personal fall protection. Either way, it was not easy to execute the works.

To solve this problem, DEME introduced a modular pontoon. The result is a stable work platform with railings, which reduces the risk of falling into the water. It means crew are able to work ergonomically and incur less muscular stress when working from other structures that require personal fall protection to be worn.

RECLAMATION PIPE GASKET REDESIGN BY VAN OORD

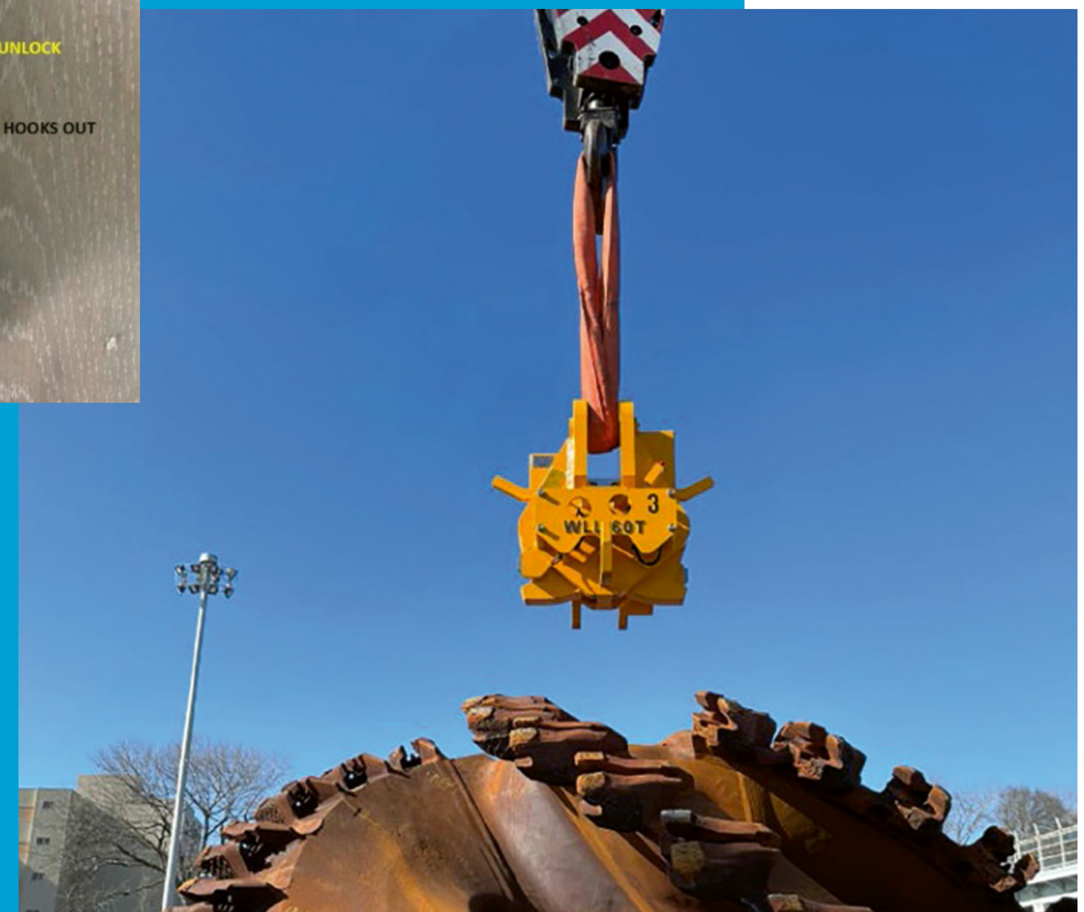
When connecting flanges of reclamation pipes, a gasket must be placed in between to seal the gap. The traditional type of gasket requires personnel to position the gaskets on the flange, keeping them in position with the openings aligned, while making the flange connection. This process carries the risk of finger injuries, due to the closeness of working to the flange.

Reclamation workers shared their concerns and came up with a design to reduce this risk. By adding "ears" to the gasket, the dimensions of which were designed to allow for easy handling, also while wearing gloves, it allows personnel to keep their fingers further away from the flanges while connecting the reclamation pipes. Therefore, reducing the risk of possible finger injuries.

PEDESTRIAN CROSSING LIGHTING SYSTEM BY JAN DE NUL

Jan De Nul presents a pedestrian crossing system that utilises lighting to improve safety on dredging and reclamation sites. The system works by projecting illuminated stripes directly onto the ground, which can include surfaces such as sand or gravel, defining pedestrian crossing zones and making them highly visible, especially during hours of darkness.

The improved visibility ensures that both pedestrians and equipment operators can clearly identify crossing areas, reducing the risk of accidents. The system can include an additional projector to signal the crossing to pedestrians, further emphasising the designated walkway. This crossing system complements other safety measures, such as stop signs and call buttons, creating a more consistent and noticeable safety zone for all individuals on site.



REMOTELY OPERATED LIFTING KEY BY DEME

On a rock dredging project, the damage to cutterheads is considerably high requiring them to be replaced and repaired. One of DEME's cutter suction dredgers has 14 different cutterheads, averaging a weight of 41 tonnes without teeth. Switching out cutterheads requires frequent lifts and in the past the rigging of these lifts was performed with chains around the blades of the cutter or with manual lifting keys.

However, this means it was always required for workers to climb on top of the cutterhead to connect and disconnect the lifting key or chains. And since the cutterheads of one of DEME's cutter suction dredgers is more than 3 metres in height, this makes the task even more risky. Therefore, a vertical lifting key that is remotely controlled was developed. With the aid of this equipment, working at height risks are eliminated and cutterhead lifts can be performed without any incident in a safer and more effective way.

BLUE CARBON – AN OPPORTUNITY FOR THE WATERBORNE TRANSPORT INFRASTRUCTURE SECTOR

Many ports and harbours operate in and around marine coastal habitats, such as tidal marshes, mangrove forests and seagrasses. Many of these marine coastal habitats are considered blue carbon ecosystems, which play a crucial role in capturing carbon. This article examines how waterborne transport infrastructure impacts blue carbon ecosystems, reviews current mitigation strategies and suggests integrated approaches for sustainable coexistence. We emphasise the importance of collaboration among marine transport authorities, environmental managers, scientists and engineers to protect these essential carbon sinks while supporting the sector's economic contributions.

Ports and navigable waterways are pivotal to global trade but often are situated in and around marine coastal habitats, such as maritime forests, salt marshes and seagrasses – collectively known as blue carbon ecosystems. Blue carbon ecosystems (BCE) can sequester carbon at rates orders of magnitude greater than terrestrial ecosystems and are key components of the carbon mass balance in coastal environments, playing a vital role in long-term carbon management (McCleod et al., 2011). Protecting, restoring and managing BCE can help reduce the risks and impacts of a changing environment. These habitats also serve as natural infrastructure, reducing flood risk and associated vulnerabilities while providing multiple co-benefits through habitat enhancement including food provision, livelihoods and cultural services (Friess et al., 2024).

The World Association for Waterborne Transport Infrastructure (PIANC) recognises how effective management of coastal ecosystems is relevant to port, harbour and waterway assets and operations. Coastal and estuarine flood protection, beneficial use of dredged materials and the development of sustainable infrastructure are examples of the interface where navigation interests and opportunities for effective BCE management coincide. For these reasons, PIANC launched a Working Group on blue carbon whose objective is to define blue carbon and describe its relevance to waterborne transport infrastructure (WTI).

This article explains how navigational infrastructural elements relate to and affect blue carbon, and how holistic sediment management can support BCE

> "We need to work with nature, not against it."
> – Sir David Attenborough

management and improvement, leading to more resilient ecosystems. The decision-making process on how best to conserve and promote BCE, particularly at the intersection of WTI development and nature, is motivated by a range of experts and project influencers, including:

- Port authorities, navigation and river authorities and commissions, and terminal operators.
- Regulators, government agencies and elected officials.
- Project designers, contractors, ecologists, civil engineers, planners and landscape architects.
- Environmental stakeholders, NGOs, public interest groups and other waterway users.

Background

Sediment is a crucial part of aquatic ecosystems, forming the foundation for natural habitats and playing a vital role in sequestering and storing carbon. Blue carbon ecosystems absorb carbon through natural processes, such as sedimentation of organic-rich particles, photosynthesis, plant growth and decay, the partial decomposition of organic matter and the accumulation and burial of plant detritus (Figure 1). Short term carbon storage happens continuously at the sediment surface, while buried sediment and organic material contribute to long-term (permanent) carbon storage if left undisturbed. Estimates indicate that some mangrove forests and coastal wetlands are thousands of years old (Friess et al., 2019; Mangrove Action Project, 2016), representing long-term carbon storage and making them essential to the carbon mass balance in aquatic environments (Kristensen et al., 2025).

Coastal ecosystems, especially BCE, have become vital resources for reducing natural hazard risks, with the capacity to sequester carbon from the atmosphere orders of magnitude faster than land-based habitats per unit area. Seagrass meadows, for example, demonstrate remarkable carbon sequestration capabilities – they hold 11% of the organic carbon in oceans while covering only 0.1% of the world's seafloor (NOAA, 2025). Therefore, these ecosystems not only support biodiversity but also capture carbon while enhancing coastal resilience and reducing natural hazard risks (Figure 2).

Many ports and harbours operate in and around these marine coastal habitats. Coastal, estuarine and riverine flood protections, beneficial use of dredged materials and the development of new sustainable infrastructure are examples of the interface where navigational interests and opportunities for effective BCE management coincide. PIANC's Environmental Commission (EnviCom) develops guidance to illustrate how the effective management of coastal, marine and freshwater ecosystems is relevant to port and waterway assets and operations. Relevant PIANC guidance documents prepared by EnviCom Working Groups (WG) are available free to members at www.pianc.org and include:

- Beneficial use for sustainable waterborne transport infrastructure projects (WG 214), 2023.
- Carbon management for port and navigation infrastructure (WG 188), 2019.
- Applying working with nature to navigation infrastructure projects (WG 176), 2018.
- Dredged material as a resource: options and constraints (WG 104), 2009.
- Ecological and engineering guidelines for wetlands restoration in relation to the development, operation, and maintenance of navigation infrastructures (WG 07), 2003.

In November 2022, PIANC and EnviCom hosted a webinar titled "A market approach to blue carbon and opportunities for waterborne transport infrastructure", building on the WG188 report on carbon management. The webinar examined market-based opportunities related to managing blue carbon resources. It also emphasised the limited current understanding of blue carbon concepts and their importance to the WTI sector. A blue carbon WG was therefore timely and PIANC EnviCom established WG256 to define blue carbon and explain how blue carbon is relevant to WTI.

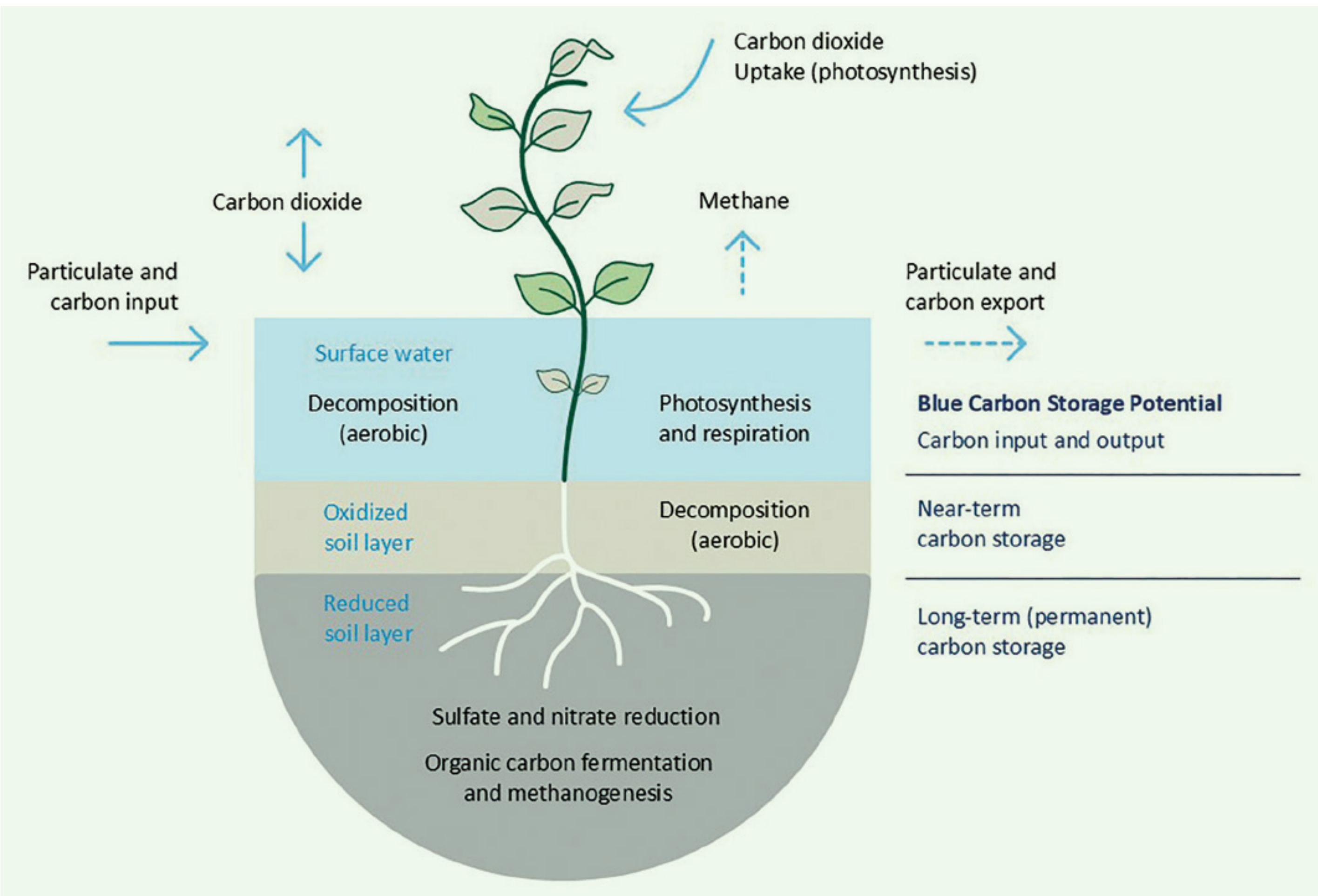


FIGURE 1

Carbon cycle in blue carbon environments (adapted from Kayranli et al., 2010).

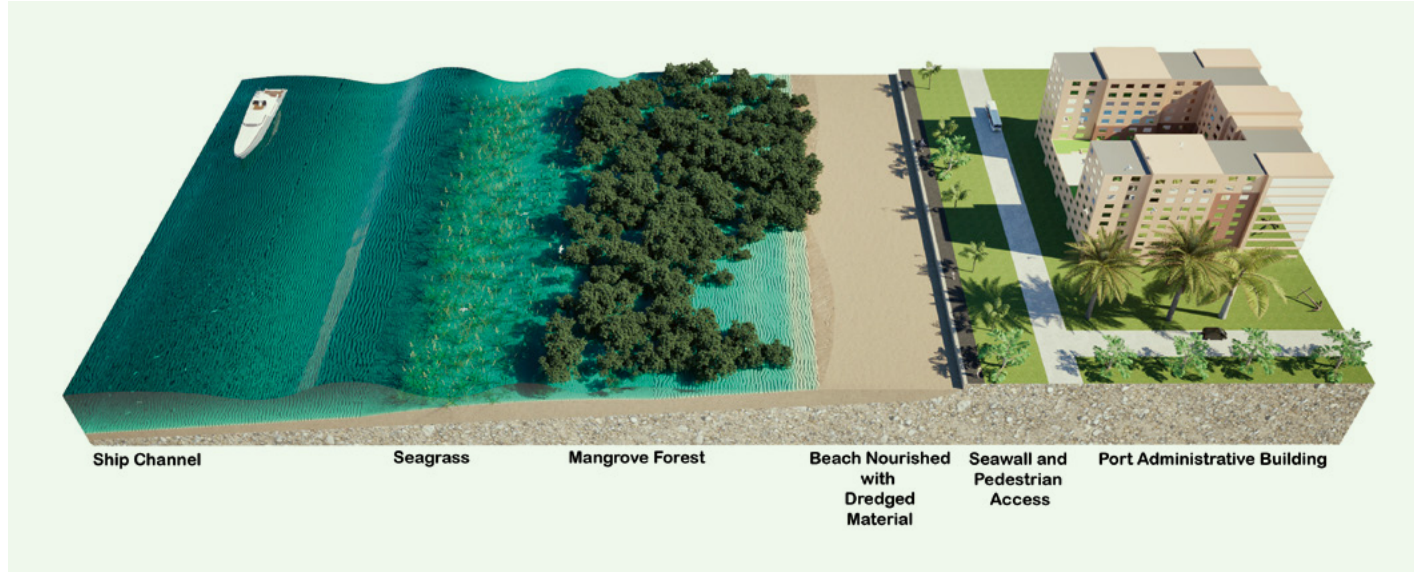


FIGURE 2

Blue carbon ecosystems helping protect the nearshore environment from coastal storms. Render © Jeff Houghton, Ramboll.

Defining blue carbon

Blue carbon refers to the carbon stored in coastal and marine ecosystems. Mangroves, seagrasses and saltwater marshes capture, store and sequester carbon dioxide (CO_2) in plant and sediment rhizome biomass, forming the basis of BCE. When mangroves, seagrasses and saltwater marshes are lost, the carbon they have long stored is released into the atmosphere as CO_2 through oxidation, while the capacity of these habitats to sequester carbon in the future is diminished, if not lost entirely. What makes these marine coastal ecosystems important is their ability to store carbon continuously and indefinitely, for as long as the ecosystems remain intact.

Carbon markets

Carbon markets play an essential role in the management and conservation of BCE. Carbon markets provide financial incentives for the preservation and restoration of BCE by assigning a monetary value to the carbon sequestration capabilities of these ecosystems. These markets create a blue carbon economy that encourages stakeholders to invest in BCE conservation efforts (Pendleton et al., 2012).

Carbon markets generally require that BCE projects demonstrate "additionality" to support the establishment of project-specific carbon credits (Michaelowa et al., 2019). The 1998 United Nations (UN) Kyoto Protocol defines additionality as "reductions in emissions that are additional to any that would occur in the absence of the certified project activity" (Houston et al., 2024; UNFCC, 1998).

Protecting BCE is essential and can be leveraged in carbon markets where existing BCE is at risk. The REDD+ framework was established to protect existing habitat in

NOAA (2025) defines blue carbon as the "carbon captured by the world's ocean and coastal ecosystems".

IPCC (2021) defines blue carbon as "biologically driven carbon fluxes and storage in marine systems that are amenable to management" and include "rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses."

FIGURE 3

Young mangroves are being used in the Boquilla Nature Reserve in Puerto Rico to restore native habitats, increase biodiversity and reduce shoreline impacts from storms. Photo by Burton Suedel.

developing countries – REDD stands for "reducing emissions from deforestation and forest degradation" and + stands for additional habitat activities that protect the climate, including sustainable management, conservation and enhancement of ecological carbon stocks (UN-REDD Programme, 2025). Under the REDD+ framework, developing countries can receive credit for emission reductions when they reduce habitat losses. Notably, REDD+ credits are not available in countries where BCE habitats already are protected. In Australia, for example, additional credit is not gained by "protecting" mangroves, which already require protection by law.

Carbon markets can be used to finance restoration and conservation projects through the sale of carbon credits generated from blue carbon projects. These credits are sold to entities looking to offset carbon emissions, creating a revenue stream that supports environmental sustainability (Duarte et al., 2013). By participating in carbon markets, BCE receives recognition and resources for its role in reducing atmospheric carbon, thereby contributing to global resilience to natural hazards (Murray et al., 2011). Participation in carbon markets requires rigorous monitoring and carbon-sequestration verification processes, which drives scientific research in understanding and measuring BCE. The Nature Conservancy (2024) provides a summary table of coastal wetland methods to calculate blue carbon credits. This paper does not summarise methods to quantify and verify BCE carbon storage.

While BCE, especially mangroves, seagrasses and salt marshes, are all highly efficient carbon sinks, other ecosystems (e.g., macroalgae, unvegetated tidal mudflats, coral reefs and ocean sediments) also serve as lesser or unknown carbon sinks (Howard et al., 2023). To date, carbon trading has targeted mangroves, seagrass and salt marsh BCE, while carbon metrics for other marine emerging environments (e.g., macroalgae, benthic sediments and mudflats), continue to be developed and may become actionable in the future (The Blue Carbon Initiative, https://www.thebluecarboninitiative.org).

Carbon sequestration potential in blue carbon ecosystems

BCE captures CO_2 by sequestering the carbon in biomass and in underlying sediments (Figure 2), which includes natural organic carbon along with decayed biomass and detritus. In marine environments, sulphate reducing bacteria slow biodegradation and limit methanogenesis and methane release to the atmosphere. These processes form the basis for long-term carbon storage in marine coastal ecosystems. In freshwater environments, anaerobic decay and methane and CO_2 production can reduce long-term and permanent carbon storage, though even in freshwater environments long-term carbon storage (termed teal carbon) is possible (Kayranli et al., 2010).

- **Mangroves** are intertidal forests known for trapping sediments and organic carbon. Mangroves shrubs and trees grow in coastal saline or brackish waters, primarily in equatorial climates and along coastlines and tidally influenced rivers (Figure 3). Mangroves are not solely equatorial and exist in temperate zones as well. The Blue Carbon Initiative estimates mangroves are being lost at a rate of 2% per year. Meanwhile, carbon emissions from mangrove deforestation account for up to 10% of emissions from deforestation globally. Global efforts to protect and restore mangrove forests have reduced mangrove loss rates from ~2% annually in the late 20th century to <0.4% annually in the early 21st century (Friess et al., 2019).
- **Seagrasses and seagrass meadows** are underwater ecosystems formed by seagrass and other marine plants found in shallow coastal waters and brackish estuaries. Seagrasses are submerged flowering plants that produce seeds and pollen and have roots and rhizomes anchored to the seafloor. According to The Blue Carbon Initiative, seagrasses cover less than 0.2% of the ocean floor and store roughly 10% of the carbon buried in ocean sediments each year. The Blue Carbon Initiative estimates that seagrasses have lost more than 30% of their historical global coverage and are being lost at a rate of 1.5% per year.
- **Salt marshes** are tidal wetlands that accumulate organic-rich peat layers, sequestering carbon over centuries. Salt marshes appear in the coastal intertidal zone and are regularly flooded by diurnal tides. Salt marshes (Figure 4) are populated by salt-tolerant plants that support the stability of coastal and estuarine environments. In addition to their long-term carbon storage capability, they play a vital role in the aquatic and terrestrial food webs and deliver nutrients to coastal waters. Tidal marshes have lost more than 50% of their historical global coverage and are being lost at a rate of 1 2% per year (The Blue Carbon Initiative).

Blue carbon ecosystems also have the unique advantage of accreting vertically in response to rising sea levels.

Blue carbon ecosystems also have the unique advantage of accreting vertically in response to rising sea levels providing they have

FIGURE 4

A salt marsh fringe near the Port of Virginia container terminal protects land-based infrastructure from storm impacts. Photo by Burton Suedel.

sufficient sediment supply (Mcleod et al., 2011). The sediment carbon sinks in these environments increase over time, greatly extending their longevity.

Sediment beneficial use can be used to enhance these processes, especially in degraded habitats subject to erosion, subsidence and habitat loss where the addition of dredged sediment can help maintain sediment elevations and healthy wetland habitat and aquatic ecosystems (Berkowitz et al., 2021, 2022a, 2022b; Bridges et al., 2021; Suedel et al., 2024). Mangroves, seagrasses, and wetlands continue to be at risk due to increasing seawater temperatures and sea level rise, increasing storm intensities, and anthropomorphic pressures including nearshore developments, thus limiting their ability to adapt and defend coastal environments against high-energy natural hazard events (Ondiviela et al., 2014).

Oceans absorb about 31% of the CO_2 emissions released to the atmosphere (NOAA, 2025). While coastal habitats occupy less than 2% of the total ocean area, they account for about half of the carbon stored in ocean sediments (The Blue Carbon Initiative). Table 1, adapted from Mcleod et al. (2011), shows the blue carbon sequestration potential for mangroves, seagrass meadows and saltwater marshes compared to carbon sequestration in terrestrial forests. Globally, there are between 36 and more than 100 million hectares of BCE, but this coverage is only a small part of what existed historically and is frequently threatened by population growth and other coastal development pressures. The total annual carbon storage potential in blue carbon habitats ranges from approximately 60 to 204 teragrams carbon (Tg C, or 10^{9} g C), while the annual carbon storage capacity of terrestrial forests is approximately 194 Tg C (Table 1).

The intersection of blue carbon and waterborne navigation infrastructure

Understanding the relationship between the WTI sector and BCE is essential for developing sustainable coastal management practices. Ports and navigation infrastructure that operate in marine coastal environments may be in proximity to coastal habitat where blue carbon resources (recognised or unrecognised) exist. While port and navigation operations can negatively impact BCE, thoughtful and proactive management practices may be used to protect and even enhance blue carbon resources. Such operations may include the coastal, estuarine and riverine flood protection measures and the beneficial use of dredged material (Suedel et al., 2024).

Opportunities for the WTI sector to protect, mitigate or enhance blue carbon resources include:

- Achieving net zero carbon emissions for WTI and new development projects.
- Aligning sediment beneficial use practices with habitat restoration and enhancement goals, and enhanced resilience to natural hazards.
- Restoring and enhancing habitat mitigate new development impacts to the environment.
- Applying Working with Nature and Nature-based Solutions (NbS) in operating or managing WTI.
- Creating and supporting community engagement with BCE.

Over the past decade, the US Army Corps of Engineers (USACE) and PIANC have advanced sustainability thinking with such concepts as Engineering With Nature® (https://ewn.erdc.dren.mil) and using Nature-based Solutions (Bridges et al., 2021). PIANC (www.pianc.org) developed the Working with Nature philosophy for WTI projects to advance coastal resiliency and habitat creation. In Europe, Ecoshape (www.ecoshape.org) has advanced the Building with Nature paradigm to integrate NbS into WTI projects. Collectively, these nature-based initiatives have been leveraged to promote habitat improvement and coastal resiliency, from altering the surface or texture of submerged structures and thus creating or expanding aquatic habitats, to using natural infrastructure systems, such as islands, marshlands and mangroves to protect WTI and local communities from severe weather events.

While nature-based initiatives can be incorporated at any project stage, they are best considered early in project planning when flexibility is greatest. By maintaining a committed and proactive approach from a project's start to finish, opportunities to support a blue carbon economy can be maximised, and importantly, frustrations, delays and unforeseen costs can be minimised.

Beyond improving sediment and habitat management, nature-based initiatives can be leveraged to optimise environmental conditions and optimise BCE. This involves first and foremost avoiding or minimising BCE losses and secondly using sustainable engineering design and project planning to restore and create new BCE. Meeting these objectives requires careful project planning and implementation, ecosystem and performance monitoring, and adaptive management. Adaptive management recognises that navigation projects rely upon learning and adaptation to optimise project outcomes, including reducing energy use and protecting the environment.

Waterborne transport infrastructure sector's alignment with blue carbon

Illustrative renderings were developed to identify potential applications of nature-based initiatives in a hypothetical port scenario showing a conventional port (Figure 5A) and the same port incorporating multiple BCE features (Figure 5B), aiming to gain a more comprehensive understanding of the opportunities to enhance, restore or create BCE and to integrate BCE into WTI planning.

Comparison of Figures 5A and 5B highlight the multiple opportunities to incorporate infrastructure-related features into the design of a new or existing port located at the land-sea interface. The incorporation of BCE into WTI creates opportunities to increase the carbon storage capacity of the port while promoting biodiversity, plant and wildlife habitat, ecosystem services for public use and reduced risks to port/harbour assets by using these systems to absorb high intensity, natural hazards. Blue carbon ecosystems can be implemented in ways that incorporate engineering, economic, social and environmental benefits while minimising costs and burdens to port operations. Such opportunities exist in both the land- and sea-related environments that complement existing and future WTI.

The tidal prism and nearshore environments are areas where BCE can be enhanced, restored or created (King et al., 2022). Figure 5B shows how BCE can be implemented to complement conventional structures, such as breakwaters and jetties, where natural infrastructure features can be integrated into the design, contributing to more sustainable multiple lines of defence to reduce flood risk while promoting safe navigation. Nature-based designs also can enhance the environmental benefits of hardened structures. When considering the repair or modification of existing structures, natural infrastructure features can be integrated into the design to create hybrid solutions that include niches for enhancing habitat value that contribute to BCE while supporting WTI infrastructure requirements (Bridges et al., 2021; King et al., 2022).

Port navigation channels requiring maintenance to support port activities offer unique opportunities to use dredged material beneficially. Navigation channels can be

HABITAT	GLOBAL COVERAGE	ANNUAL CARBON STORAGE POTENTIAL	
		(MG C/HA/YR)	(TG C/YR)
Blue carbon habitats			
Mangroves	15 million ha	2.36 ± 0.39	31 to 34
Seagrass meadows	18 to 60 million ha	1.38 ± 0.38	24 to 83
Saltwater marshes	2 to 40 million ha	2.18 ± 0.24	5 to 87
Terrestrial forests			
Temperate	1.4 billion ha	0.05 ± 0.01	53
Tropical	1.9 billion ha	0.04 ± 0.005	78
Boreal	1.3 billion ha	0.046 ± 0.02	63

Mg = megagram or 103 kg; Tg = teragram or 109 kg

TABLE 1
Blue carbon storage metrics (from Mcleod et al., 2011).

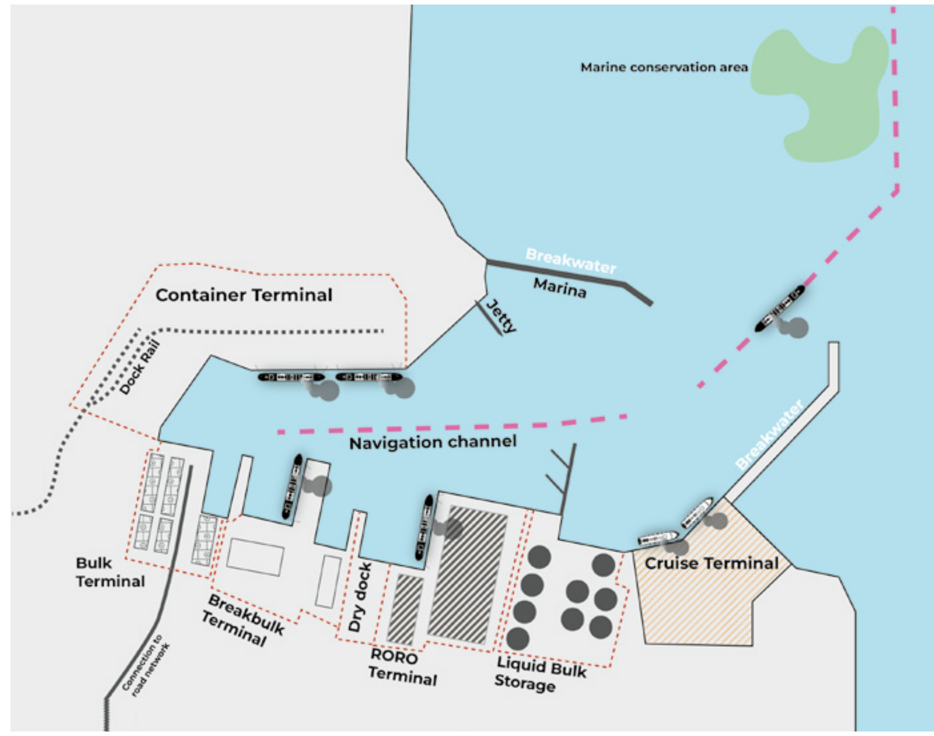


FIGURE 5A
Hypothetical port infrastructure showing typical land-sea-related assets, representing a conventional port lacking features contributing to a blue carbon economy. Rendering by Steven Bailey.

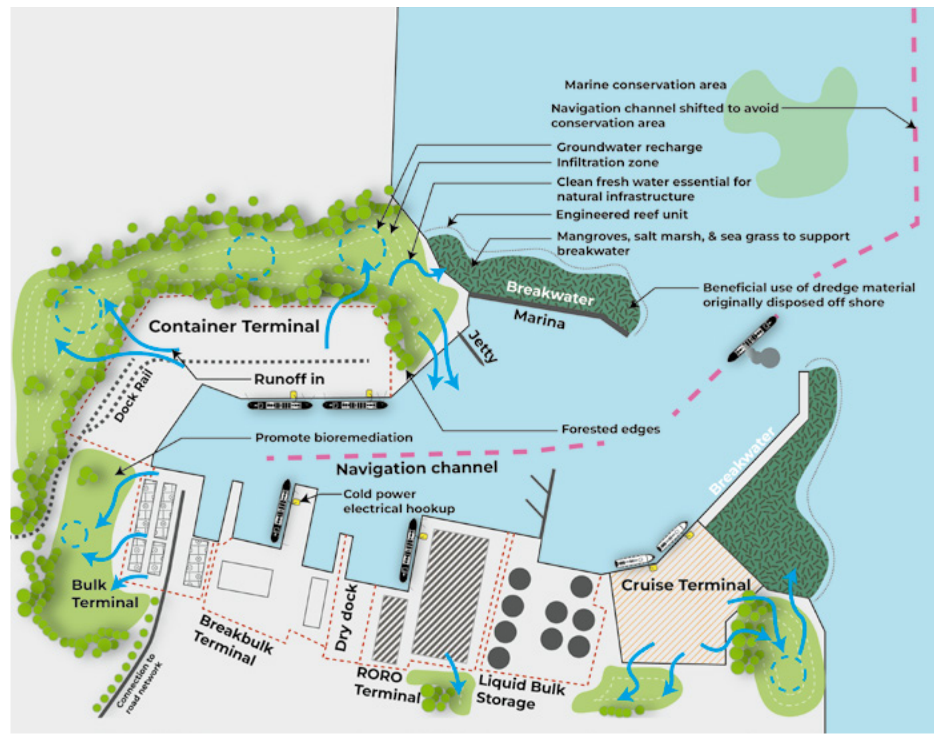


FIGURE 5B
Hypothetical port infrastructure showing typical land-sea-related assets, representing a port with multiple examples where natural infrastructure features are incorporated to promote BCE assets into the port's design. Blue arrows indicate direction of water flow. Rendering by Steven Bailey.

oriented or shifted to reduce their impacts on sensitive marine environments. Dredged sediment considered suitable for beneficial use can be placed in ways to support BCE by enhancing submergent or emergent wetland habitats (Figure 5B). Such features, when designed with intent, can serve to reduce wave energy and erosion potential while providing ecosystem services. To the extent that these BCE features attract native species and marine wildlife, such habitats serve recreational, economic and other co benefits (Grothues et al., 2025).

Hybrid structures such as engineered artificial reef modules can be used to increase the habitat value of infrastructure elements that require more hardened materials to be effective. While not considered meaningful contributors to blue carbon, such structures can be used to reduce wave energy on BCE such as seagrasses while promoting sedimentation landward of existing reefs (Watanabe and Nakamura, 2018) and reducing the vulnerabilities of BCE structures to natural hazards (Storlazzi et al., 2025).

Management of upland infrastructure and habitat features to further support BCE

Other features illustrated in Figure 5B include those that can reduce the vulnerability of ports to flood risk and other natural hazards, and when combined, contribute to multiple lines of defence for increasing coastal resilience. The Nature Conservancy (2024) identifies the following project activities that contribute to blue carbon:

- Avoiding habitat loss.
- Restoring tidal connectivity.
- Rewetting drained organic soils.
- Restoring sediment to sediment-starved wetlands.
- Improving water quality.
- Replanting vegetation.

While upland features are not blue carbon systems, they can work with offshore blue carbon systems to enhance flood resiliency and can be used to integrate habitat features with port infrastructure. Natural infrastructure features such as earthen berms constructed to reduce flood risk or to mitigate noise can be designed as multipurpose structures that include low-maintenance native plant habitat and walking trails. Selectively, those same plants can serve as soil engineers to stabilise berm slopes to help reduce erosion.

Upland habitat features also promote freshwater rain infiltration to groundwater and subsequent groundwater migration to offshore BCE that depend on freshwater input (Santini et al., 2014). Bioswales can be constructed at street level and planted with low-growing native grasses and other vegetation features to reduce flooding and

FIGURE 6

Coastal birds on recently placed dredged material at Horseshoe Bend on the lower Atchafalaya River, Louisiana that was strategically placed to use the river's energy to transport this material downriver to shape the island's development. Photo Burton Suedel.

FIGURE 7

Ocean-side established marsh habitat created in 1976 with dredged material placement and beach nourishment efforts at the Apalachicola Bay, Florida beneficial use site. Photo Nathan R. Beane (2019).

enhance groundwater recharge around parking lots, buildings and along roadways. Plant species selection considerations include species that are native and adapted to the region, provide wildlife habitat and food production, uptake stormwater pollutants and offer historical and cultural significance (Gaskin and Thomas, 2025). Pervious pavers can be used to promote additional groundwater infiltration, further enabling groundwater recharge.

Overall, natural infrastructure materials can be used to enhance the overall engineering, environmental and flood risk management benefits of WTI projects by reducing erosion, flood risk and the project's carbon footprint. Sediment forms the foundation for nearshore aquatic habitat and dredged sediment can be used to supplement natural sedimentation processes forming a foundation for BCE and supporting upland habitat.

Utility infrastructure also plays a role in carbon management, as the installation of shore power (Figure 5B) can reduce carbon emissions and local air pollution associated with ships docked at port. Combined, these "green" features collectively contribute to sequestering carbon, contributing to reduced WTI carbon emissions.

Waterborne transport infrastructure sector contributions to blue carbon

While the potential physical impacts of the WTI sector to BCE are well understood, much less has been reported on the potential opportunities to protect and enhance BCE in the WTI sector. Here, we provide examples that link a key aspect of the WTI sector and the beneficial use of dredged material, to serve as a foundation for BCE and carbon storage.

The USACE navigation project on the lower Atchafalaya River in coastal Louisiana is an example of sediment beneficial use to create BCE in a brackish, estuarine environment. Tidally influenced, Horseshoe Bend Island was created through multiple strategic placements of dredged material over a 12 year period, using the river's energy to shape the placed material to form the island (Figure 6). Foran et al. (2018) reported carbon sequestration results associated with wetland habitat created on the 35 ha Horseshoe Bend Island. Since 2018, Horseshoe Bend Island has nearly doubled in size and is approximately 60 ha.

Foran et al. (2018) reported emissions reductions due to a shortened navigation channel of 1.13 km (0.7 nautical miles) and lower rates of shoaling resulting in reduced dredging requirements and safer vessel transits. Horseshoe Bend Island sequesters an average of 5,220 kg of carbon per year. The shortened navigation channel reduces annual emissions by approximately 186 million metric tonnes of carbon dioxide equivalents based on the amount of fuel saved per trip and the number of trips made each year by commercial tugs and ships.

Other ecosystem services associated with Horseshoe Bend Island include increased habitat value for flora and fauna, reduced dredging costs and nutrient sequestration, which in turn reduces the nutrient load delivered to the Gulf of Mexico where hypoxia is an ongoing concern (Foran et al., 2018). The results of this innovative project demonstrate reductions in carbon emissions

FIGURE 8

Established woody plant community and sandy beach created in 1975 with dredged material placement and beach nourishment efforts at the Buttermilk Sound beneficial use site at the mouth of the Altamaha River near Brunswick, Georgia. Photo Nathan R. Beane (2019).

from reduced commercial vessels transit distances, less frequent dredging (reduced dredger-associated emissions) and BCE on the newly created island.

Berkowitz et al. (2021; 2022a, b) conducted ecosystem and engineering benefits assessments of six dredged material habitat improvement projects that were constructed more than 40 years ago, documenting the long-term benefits of dredged material beneficial use. Four of the projects were in marine/estuarine coastal environments where post-construction beneficial use monitoring data were available for comparison to natural reference locations (Figures 7 and 8). As part of the assessment, soil samples were collected and analysed for multiple physicochemical characteristics, including loss on ignition for percent organic matter (LOI) and total carbon measurements, both relevant for assessing blue carbon benefits. The results of the four projects consistently showed improvements in soil physicochemical properties with age, including increased carbon content. The LOI and total carbon concentrations increased over time and, in most cases, approached the values observed in reference locations. This trend demonstrated that carbon is accumulating in the beneficial use sites (Berkowitz et al., 2022a). However, the amount of soil carbon in the beneficial use sites was lower than values reported at natural reference locations – even decades after project implementation and even when habitat characteristics and vegetation composition showed significant similarities with undisturbed areas. These results align with findings from others reporting blue carbon accumulation in created coastal marshes (Yu et al., 2017; Abbott et al., 2019).

Overall, results showed that 40 years after construction, the four study sites maintained the soil physical substrate necessary to support healthy plant communities and ecological functions of their respective habitats (Berkowitz et al., 2022b). Carbon sequestration and other benefits were achieved without post-construction management or intervention. Collectively, using dredged material for habitat restoration demonstrates the potential for novel nature-based applications for the WTI sector to contribute to BCE.

Conclusions

While there is growing evidence for the benefits of blue carbon in marine coastal environments, few studies have reported on the intersection of the WTI sector and blue carbon resources. Known adverse impacts associated with WTI projects include carbon emissions from the world's dredging fleet, the release of carbon when BCE bottom substrates are disturbed by dredging activities and the loss of BCE when new ports and other WTI projects are constructed around existing habitat. Yet the beneficial use of dredged material, especially material removed from navigation channels, has received scant attention for its potential for providing opportunities to enhance, restore and create BCE.

In established ship channels, sediment beneficial use can offer an opportunity to increase WTI contributions to BCE (Figure 8). Sediment beneficial use offers several advantages: 1) it can create or enhance habitats; 2) it promotes resource circularity within the tidal prism or watershed; and 3) it reduces the release of CO_2 by limiting the oxidation of organic carbon in dredged sediment. While sediment removal over short periods contributes less to carbon storage, deepening or widening channels can significantly reduce BCE by disturbing aged substrates with long-term carbon storage. Sand, silt and clay suitable for beneficial use should be relocated to promote BCE and to contribute to long-term carbon storage. Disposal of dredged material offshore releases stored carbon and reduces potential benefits, as it only aims to remove sediment from the channel.

While the economic situations of developed countries and countries in transition are quite different, the opportunities to leverage natural processes and to integrate nature into WTI planning are universal. Greater focus must be applied to impacts on BCE, which intrinsically supports marine coastal habitat. New infrastructure developments are expected to yield the most benefits during a project's early development stages when integrated with existing habitats and avoiding habitat loss. Greater understanding of the natural processes affecting a project and how natural processes can be integrated into project designs reduces environmental and social risks associated with coastal development.

Two approaches should be at the forefront of WTI project design concepts to protect BCE and generate carbon credits: 1) how best to protect existing habitat; and 2) how to promote and create new habitat. The integration of nature-based initiatives with WTI projects can be leveraged to enhance existing environments, hence the "with nature" aspect of these initiatives.

All WTI projects have environmental impacts, which should be offset by enhancing and creating new habitats. The increased use of carbon trading models facilitates the use of blue carbon to meet or offset mitigation requirements. Sediment beneficial use and nature-based initiatives can be employed to create new BCE. Practitioners are encouraged to understand how BCE is traded in voluntary carbon markets and how to leverage carbon markets for blue carbon habitat investments. Blue carbon projects must protect existing habitats and demonstrate "additionality" when establishing project-specific carbon credits (Michaelowa et al., 2019).

PIANC EnviCom WG256 is developing guidance to promote these concepts. The guidance will define blue carbon and explain its relevance to WTI. The WG is gathering and reviewing information about international blue carbon initiatives, both in relation to WTI and, where relevant, other marine and coastal sectors including nature protection. The guidance will identify and present examples (case studies) that turn theory into practice. These case studies will include not only designed and implemented blue carbon projects but also examples showing evolving standards and markets.

The current information suggests that meaningful opportunities exist for the WTI sector to increase its contribution to blue carbon. However, significant gaps remain in our understanding of how blue carbon-related WTI activities can be implemented. Addressing these gaps will become increasingly important in the future due to the vulnerability of ports and other marine infrastructure facilities to natural hazard extremes. Blue carbon offers an opportunity to contribute meaningfully to BCE while simultaneously achieving a more sustainable, resilient and less vulnerable WTI sector.

> **"To restore stability to our planet we must restore its biodiversity, the very thing we have removed…. The greater the biodiversity, the more secure will be all life on Earth, including ourselves."**
>
> **– Sir David Attenborough**

Summary

This article examines the crucial role of blue carbon ecosystems (BCE) – mangroves, tidal marshes, seagrasses – in capturing carbon in marine environments and the role of waterborne transport infrastructure (WTI) to protect and restore BCE. Blue carbon ecosystems are vulnerable to pressures from WTI, such as ports and shipping lanes. We explore the impact of port activities on BCE and review current mitigation strategies, emphasising integrated approaches for sustainable coexistence. Working with Nature and sediment beneficial use can be leveraged through collaboration among marine transport authorities, environmental managers, scientists and engineers to protect these essential carbon sinks while supporting economic contributions from the WTI sector.

Blue carbon environments are essential to sustaining the marine coastal environment. They sequester carbon while also creating essential habitat for fish and wildlife. They also help reduce flood risks and associated vulnerabilities to nearshore communities and can be used to help protect ports and other WTI facilities from floods and high-energy events by absorbing wind and wave energy. While the creation of BCE can help protect our coastal communities, the loss of BCE risks exacerbating the potential for harm.

Carbon markets play an essential role in the management and conservation of BCE - they provide financial incentives for the preservation and restoration of BCE by assigning a monetary value to the carbon sequestration capabilities of these ecosystems. These markets are designed to encourage stakeholders to invest in BCE conservation efforts.

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Victor is a civil/environmental engineer with 30 years of experience in sediment risk management. His expertise encompasses site characterisation, site remediation and the fate and transport of bioaccumulative organic pollutants and metals. Through his involvement with PIANC, Victor has pioneered efforts in Working with Nature, sediment beneficial use and habitat restoration. He focuses on innovative restoration approaches that enhance coastal and environmental resiliency while promoting habitat uplift. Victor is nationally and internationally recognised as a subject matter expert in sediment remediation and has published more than 60 peer reviewed articles, book chapters and guidance documents. He is the US Representative for PIANC's Environmental Commission.

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VAN OORD'S AWARD-WINNING RECLAMATION PIPE GASKET REDESIGN

Sometimes a small improvement can have a huge impact. Van Oord's new reclamation pipe gasket design significantly reduces the risk of potential finger injuries with an easy to implement and cost-effective solution. The design was chosen as the winner of IADC's Safety Award 2025.

Design innovation

When connecting the flanges of steel reclamation pipes, a paper gasket is placed in between to seal the gap. When using traditional gaskets, workers had to hold the gaskets in place, creating a potential risk of finger injuries. With Van Oord's redesign of the gaskets to add "ears", personnel are now able to keep their fingers further away from the flanges, therefore significantly reducing the risk of finger injuries while connecting reclamation pipes.

For each 12-metre section of reclamation pipe, a gasket must be placed. With kilometres of reclamation pipes being connected annually by the global dredging industry, this small change in design can have a huge impact in reducing the risk for personnel involved in this activity.

The new gaskets were developed after reclamation workers at Van Oord shared their concerns and ideas for improving the issue. After a few hours of brainstorming and development of the new design, the new gasket was created.

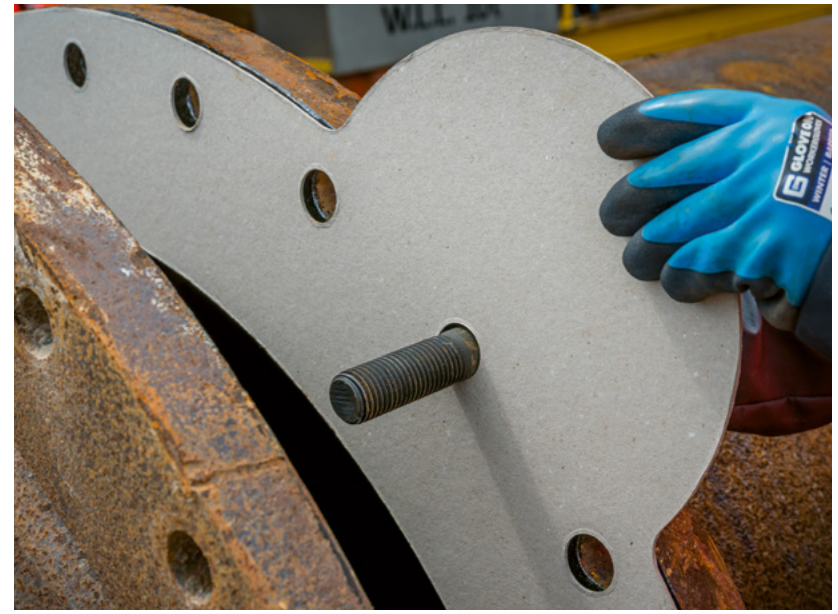
The type of gasket has remained the same, as only a small change in design was required. Therefore, it is easy to implement and use on reclamation pipe connections around the world. Van Oord opted for a design with three "ears" allowing for easy handling, even while wearing gloves.

Van Oord provided their supplier of the gaskets with the specifications of the new design, who ordered the knife required to cut the new gaskets. Once the knife was available, the supplier was able to deliver the gaskets quickly, as fast as traditional gaskets.

Simple and cost effective

Although the solution may be simple, its impact is considerable. The new design substantially reduces the risk of possible finger injuries, which can result in lost work time and even permanent disability. Another strength of this innovation is that the new gasket design can be easily implemented in a cost-effective manner by other dredging companies, improving safety for reclamation workers around the world.

This solution is a great example of the importance of creating a culture of safety. By empowering colleagues to speak up and voice their concerns, and listening to their ideas for improvement, we can all benefit.



LABORATORY SETUP TO STUDY CUTTING FORCES OF BLUNT CHISELS

Dredging of rock using a cutter head as found on a cutter suction dredger will become increasingly more important as drilling and blasting is often prohibited. Understanding the cutting process and resulting forces on the chisels can lead to improved design and operational efficiency. The majority of experimental and numerical work performed considers rock cutting with an unworn or sharp chisel, often omitting the normal force. This article presents the linear rock cutting setup developed by Royal IHC to study the effect of a worn or blunt chisel geometry on the cutting forces, with the emphasis on the normal force.

In the dredging industry, mechanical excavation is frequently employed for the removal of various soil types. A prominent example of mechanical excavation is a cutter head used by a cutter suction dredger (CSD) as shown in Figure 1A and 1B. While applicable to the full range of soil types, the CSD is particularly noted for its proficiency in rock cutting. Generally, mechanical excavation can effectively be used to dredge rocks with unconfined compressive strengths (UCS) up to approximately 50 MPa (PIANC, 2016). For greater rock strengths, drilling and blasting is utilised to pre-fracture the rock mass (Pettifer and Fooks, 1994). However, contemporary practices recognise the potential safety hazards and environmental concerns associated with drilling and blasting of (very) strong rocks (50-200 MPa), leading to regulatory prohibitions (Bach, Nielsen and Bollwerk, 2017).

Consequently, there is an increased focus on the potential application of a cutter head in strong rock, where two major, dependent challenges are chisel breakage and chisel penetration. To understand the balance, let us consider a cutter head and its operational conditions.

A cutter head contains five main elements (see Figure 1B). The arms, back ring and hub are often casted separately and welded together to form the cutter body. On the arms of the cutter body, adapters are placed that function as a holder for exchangeable chisels. The chisels are held in place within the adapter using a locking mechanism.

FIGURE 1

Royal IHC build CSD Hussein Tantawy (A) and Royal IHC cutter head (B).

To withstand the cutting forces in rock, chisels have a tapered design. As the chisels are subjected to abrasive wear (Verhoef, 1997), their length decreases over time. This length is known as the wear length and is defined between the tip of a new chisel and the wear mark indicator. Due to this tapered shape, the cross-sectional area of the chisel tip increases as a function of the wear length, generating a wear flat area. The existence of the wear flat area reduces the stresses at the chisel tip by changing the tip profile from an edge to a plane. This is known in the industry as a "blunt" chisel and results in an increased resistance to penetrate the rock mass. The wear flat area in combination with the operational conditions of the dredger determine the penetration behaviour.

During rock excavation, the cutter head is typically rotating at 15 to 30 RPM, resulting in a circular chisel trajectory and an angular velocity $(\boldsymbol{V_\omega})$ (Figure 2A and 2B). As cutter heads have increased to approximately 4 metres in diameter, tangential velocities have raised increased up to 7 metres per second (m/s). Next to the rotational velocity, a horizontal swing velocity $(\boldsymbol{V_s})$ is present due to the swinging motion of the dredger. The swing velocity is often found to be in between 10 and 20 metres per minute (m/min). The addition

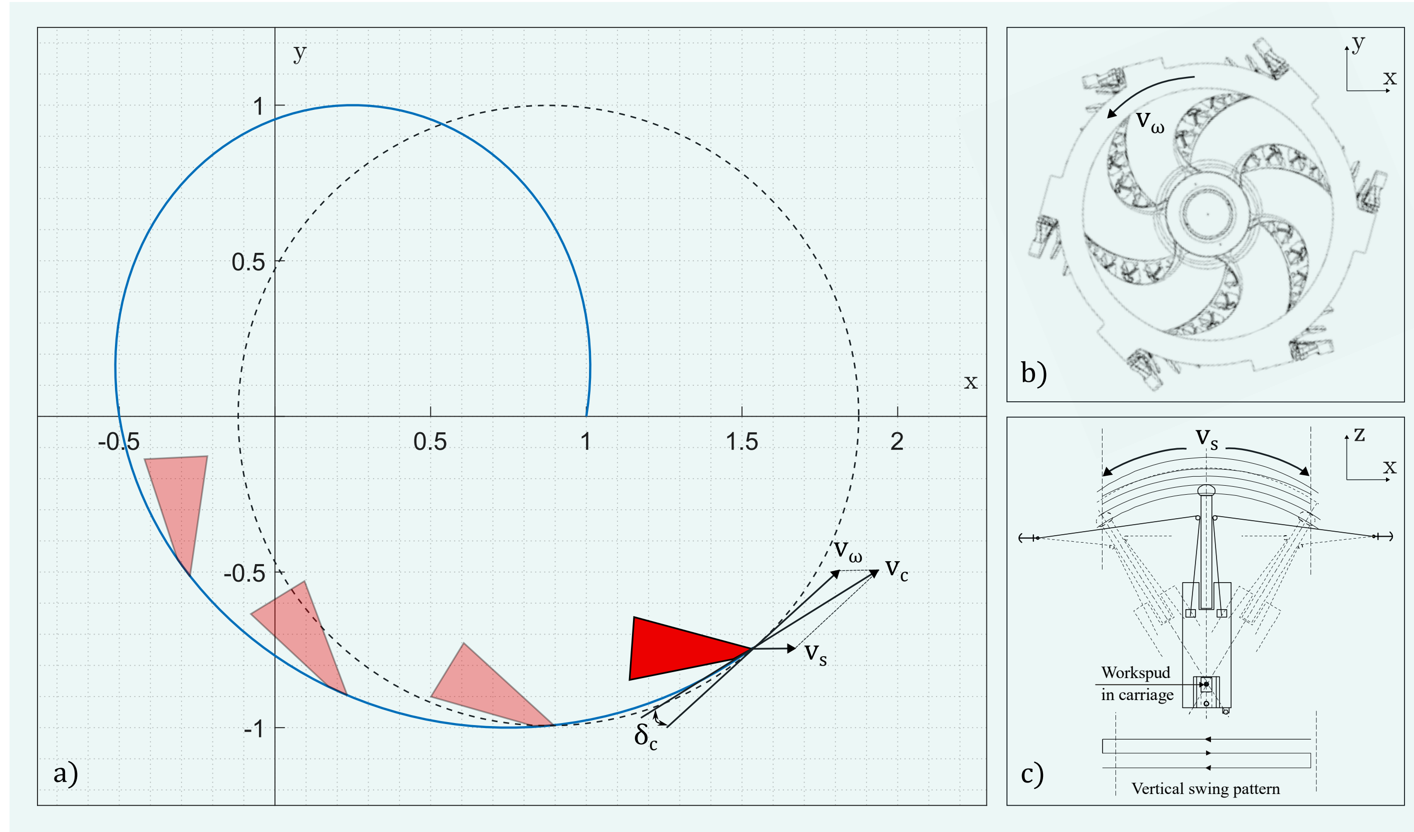


FIGURE 2

Chisel trajectory (A), rear view cutter head (B) and working principle CSD (C).

of this horizontal velocity component changes the trajectory from circular to helical (see Figure 2A and 2C) and results in the total or cutting velocity $(\boldsymbol{V_c})$.

Due to the difference between the angular velocity $(\boldsymbol{V_\omega})$ and the cutting velocity $(\boldsymbol{V_c})$, an angle δ_c is found. This angle determines the difference between the chisel static angle (circular trajectory) and the chisel dynamic angle, due to the addition of the swing motion. Although the swing velocity is an order of magnitude smaller than the rotational velocity, the difference between the static and dynamic angles can theoretically be up to 4 degrees. Note that this difference is dependent on the chisel location and corresponding trajectory. The dynamic angle equals zero when the angular velocity $(\boldsymbol{V_\omega})$ and the swing velocity $(\boldsymbol{V_s})$ are aligned, i.e. when the cutting velocity $(\boldsymbol{V_c})$ is exactly horizontal and has a maximum when both vectors are perpendicular.

The size of the wear flat area combined with the dynamic behaviour of the chisel directly affects the penetration in the rock mass and the cutting forces. Although this principle is known in the industry, little is known about the influence of a wear flat area in combination with the dynamic angles on the magnitude and direction of the cutting forces on the chisels. Some experimental work was performed where a blunted chisel (tip radius) was used to linearly cut dry coal (Daziel and Davies, 1964). It was found that the addition of a tip radius affects the normal force (F_n) to such an extent, that its magnitude can be similar to the cutting force (F_c) (see Figure 4). As the cutting force is also affected by blunting, the ratio average cutting force to average normal force $(\overline{F_c}/\overline{F_n})$ is often used to compare different chisel geometries. For a sharp chisel, a ratio of $\overline{F_c}/\overline{F_n} \approx -10$ was found. This results from a dominant cutting force and slightly negative normal force when the chisel is sharp, meaning that the chisel will be pulled deeper into the rock. For the blunt chisel a ratio of approximately 1.6 was found for different radii (Evans, 1965).

Detournay and Defourny (1992) published the start of a phenomenological model using a polycrystalline diamond compact (PDC) bit in a drilling application based on a suggestion of Fairhurst and Lacabanne (1957). The phenomenological model that is postulated includes cutting the rock (similar to sharp tools) and frictional contact underneath the tool due to the addition of a wear flat. Experimental observations using PDC bits with a rotational velocity and a rate of penetration suggested that a boundary layer of failed rock is formed underneath the wear flat area (Glowka, 1987). A schematic representation of this process is given by Dagrain and Richard (2006) and Helmons (2017) and is amended to a chisel (shown in Figure 3).

Although the process described is governed by different kinematics and tool geometry, it is expected that this phenomenon will play an important role in understanding the physics while cutting rock with a blunt chisel. This currently is insufficiently understood.

As dredging is most often executed below the water table, saturated rock conditions should be considered. Saturating the rock sample can have physico-chemical effects (Helmons et al., 2016) reducing the mechanical properties such as the tensile strength (TS) (Wong and

Jong 2014), UCS (Zhou et al., 2016) and chipping efficiency (Bejari and Hamidi, 2023), and therefore cannot be neglected.

This article describes the experimental setup designed and built at the Royal IHC laboratory to study the effect of a blunt chisel geometry on the cutting forces with the emphasis on the normal force. The setup aims to cover novel subjects, such as saturated rock conditions, relatively large cutting depth with respect to the tool width and a wear flat area in combination with a negative clearance angle and positive rake angle. Three comparable experiments are shown where the accuracy and repeatability of the setup are discussed. Subsequently, two preliminary experiments are shown where the cutting and normal force of a sharp chisel are compared to those using a blunt or worn chisel geometry.

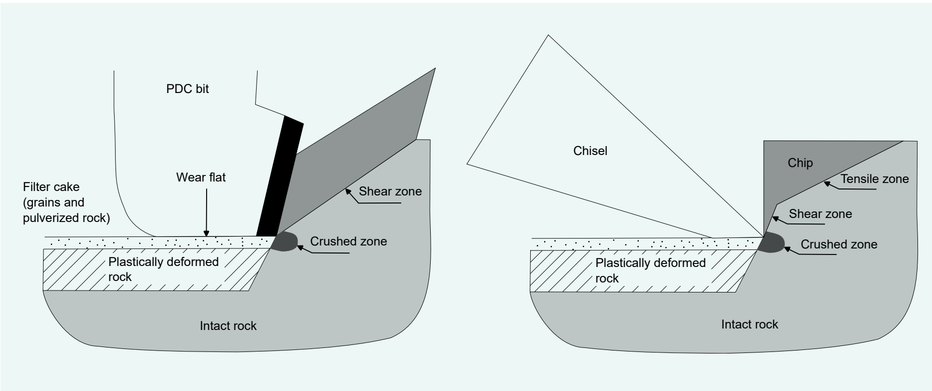


FIGURE 3

Phenomenological model rock cutting using a PDC bit and chisel (after Dagrain and Richard, 2006).

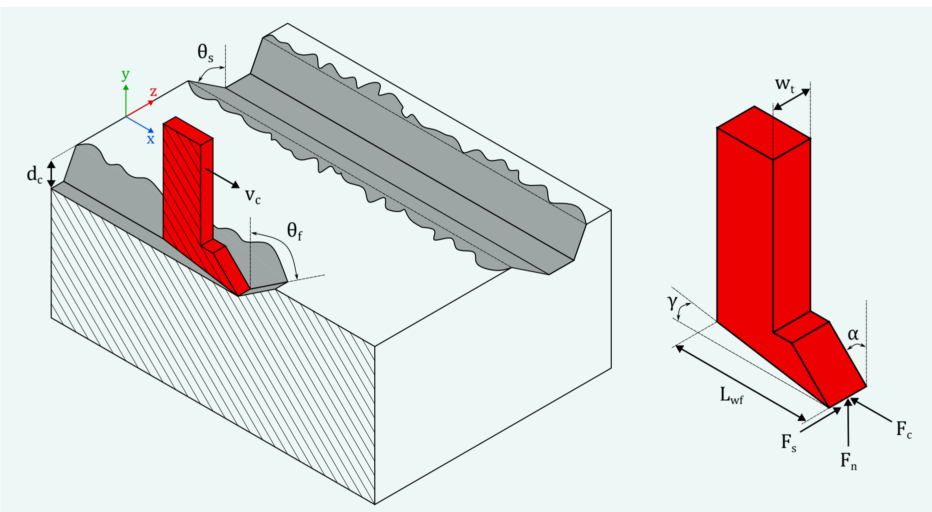


FIGURE 4

Schematic representation of a simplified chisel and unrelieved linear cutting experiment.

Chisel nr.	Width (mm)	Depth (mm)	Rake angle (degree)	Clearance angle (degree)	Wear length (mm)
1	10	10	30	5	30
2	10	10	30	-4	10

TABLE 1

Chisel properties.

Methodology

To study the cutting forces of a blunt chisel cutting rock, the chisel used during the experiments was simplified such that the parameters of interest can be incrementally varied. A schematic representation of a simplified chisel is shown in Figure 4. Here, w_t is the width of the chisel, α the rake angle, γ the (back) clearance angle and L_{wf} the wear flat length. The chisel as shown in Figure 4 is known as an unworn or sharp chisel. Although similar experimental setups have a chisel that follows a circular trajectory (Barker, 1964), it was decided to simplify the motion of the chisel to a linear trajectory. This reduces the overall complexity of the experimental setup and allows for a rigid and steady state measurement of the cutting forces.

Considering Figure 4, the cutting force (F_c) is defined as the reaction force on the chisel in opposite direction of the cutting velocity (V_c). The normal force (F_n) is defined perpendicular to the cutting velocity in the vertical plane and the side force (F_s) perpendicular to the cutting velocity in the horizontal plane. A schematic groove during an experiment (cross-sectional view) is shown where the forward breakout angle (θ_f) and the cutting depth (d_c) are indicated. The cutting depth is defined as the distance between the free surface of the rock sample and the tip of the chisel. Furthermore, a typical result of an unrelieved linear cutting experiment is shown where the side breakout angle (θ_s) is indicated.

Linear rock cutting setup

The linear rock cutting setup (LRCS) was designed and custom-built in the Royal IHC laboratory (see Figure 5). In our setup, it was chosen to drive the chisel by a hydraulic cylinder, simplifying testing on saturated and submerged rock samples. The hydraulic cylinder has a stroke length of 1180 mm and a pulling force capacity of approximately 5 tonnes. The cylinder is attached to a hydraulic power unit (HPU) that is capable of driving the carriage to a steady state cutting velocity in the range of 0.01 to 0.23 m/s (force controlled).

The rock sample is placed in a basin that allows for full submersion and contains a clamping frame to fix the rock sample to the basin (elements 3 and 4 in Figure 5, respectively). The maximum dimensions of the rock sample are 1100 x 300 x 300 mm. To eliminate any relative displacement between the rock sample and the chisel other than the cutting velocity, braces are installed on both sides of the basin in the direction of the cutting velocity.

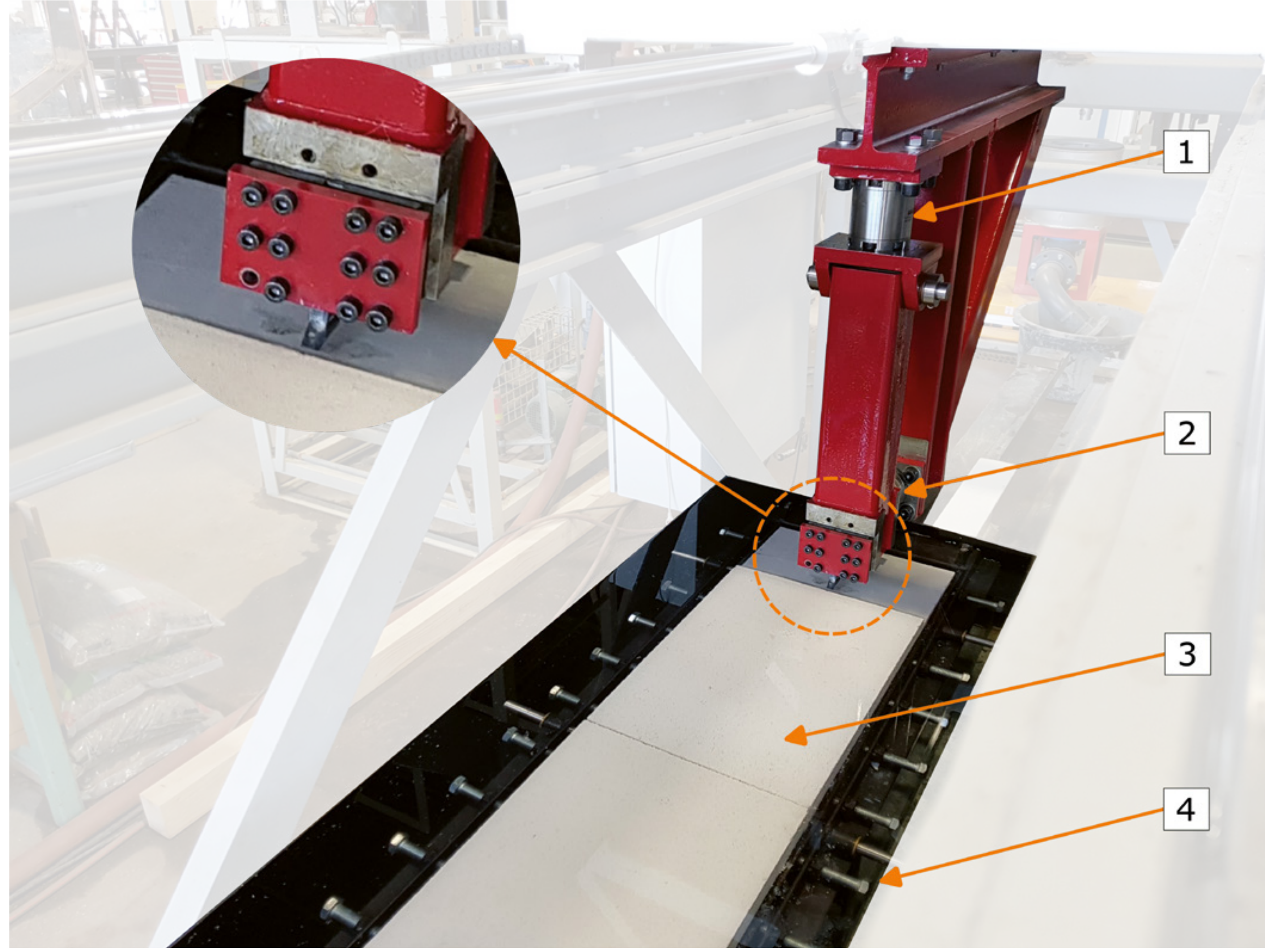


FIGURE 5

Linear rock cutting setup at the Royal IHC laboratory: vertical load cell (1); horizontal load cell (2); rock sample (3); and basin including rock sample clamp (4).

Instrumentation

The chisel is placed in the measuring section of the LRCS. As shown in Figure 5, the section contains two 6-degrees of freedom (DOF) loadcells. Both ME-Meßsysteme loadcells (type K6D68) have a nominal capacity of 10 kilonewtons (kN) in F_z (side force), 10 kN in F_y (normal force) and 20 kN in F_x (cutting force) direction. The nominal moment around all axes is 500 Nm. The unique feature in this design is the decoupling of the two loadcells. The chisel is mounted through a hinge to the vertical loadcell, decoupling it from the horizontal loadcell mount. This configuration allows for direct measurement of the cutting force as well as relatively large normal forces, which is the focus of this study. The chisel holder currently allows chisels with a width of 10 and 20 mm, but it can be modified to allow any chisel geometry of interest.

For these experiments a cutting velocity of 0.15 m/s was employed. The velocity is determined by the first derivative with respect to time of the cutting distance, taken from a pull-wire potentiometer during every experiment. To ensure sufficient resolution for all sensors, all measurements are recorded at 1 kilohertz (kHz). Additionally, two cameras are installed to record the cutting process from the top and from the side. The resolution of both cameras is 1920 x 1080 pixels and the frame rate is set to 30 hertz (Hz).

Chisels and mechanical rock properties

The LRCS allows for a parametric study of the chisel geometry and material properties. The chisels used in this research both have a width of $w_c = 10$ mm and a rake angle of α $\alpha = 30°$ (as shown in Table 1). The clearance angles used are $\gamma = 5°$ and $\gamma = -4°$ (see Figure 4). These angles are taken as a subset of a full experimental matrix. All chisels are made from hardened steel to prevent abrasive wear during the experiments. Although the geometry of the chisels is made to emulate a

Exp. nr.	Rock sample	Rock type	Rock family	Chisel nr.	UCS ± sd (MPa)	BTS ± sd (MPa)
1 & 2	**Ytong 1**	**Limestone**	Synthetic	1	**2.83 ± 0.03**	**0.60 ± 0.06**
3	**Ytong 2**	**Limestone**	Synthetic	1	**2.87 ± 0.10**	**0.59 ± 0.05**
4	**Savonierres**	**Limestone**	Sedimentary	2	**3.70 ± 0.01**	**0.60 ± 0.017**

TABLE 2

Experimental program and rock sample properties.

blunt chisel as found during dredging operation, additional wear during an experiment would be an uncontrollable variable and is outside the scope of this research. Additionally, all chisels in this research were used only once.

Two types of rock samples were used during this work. First, three comparable runs were conducted using Ytong – a synthetic limestone (aerated concrete), which was obtained at the local hardware store. The second rock sample used in this study was ordered from a quarry and is known as Savonierres limestone.

The physical and mechanical properties of these rock samples are evaluated by means of drilled cores and following the ASTM standards for rock testing (ASTM D2938-95 1995, ASTM D3967-95 1995, ASTM D4543-08 2008). A hydraulic compression tester was used to determine the UCS and the indirect or Brazilian tensile strength (BTS). Because the cores were saturated during testing, the force control was set to 0.05 kN/s. The mechanical properties of these rock samples are shown in Table 2.

Experimental protocol

Prior to every experiment, the rock sample is submerged for at least 24 hours to ensure full saturation. Then, the rock sample is transported to the basin at the LRCS. Here, the rock sample is positioned such that it is levelled in both longitudinal and transversal

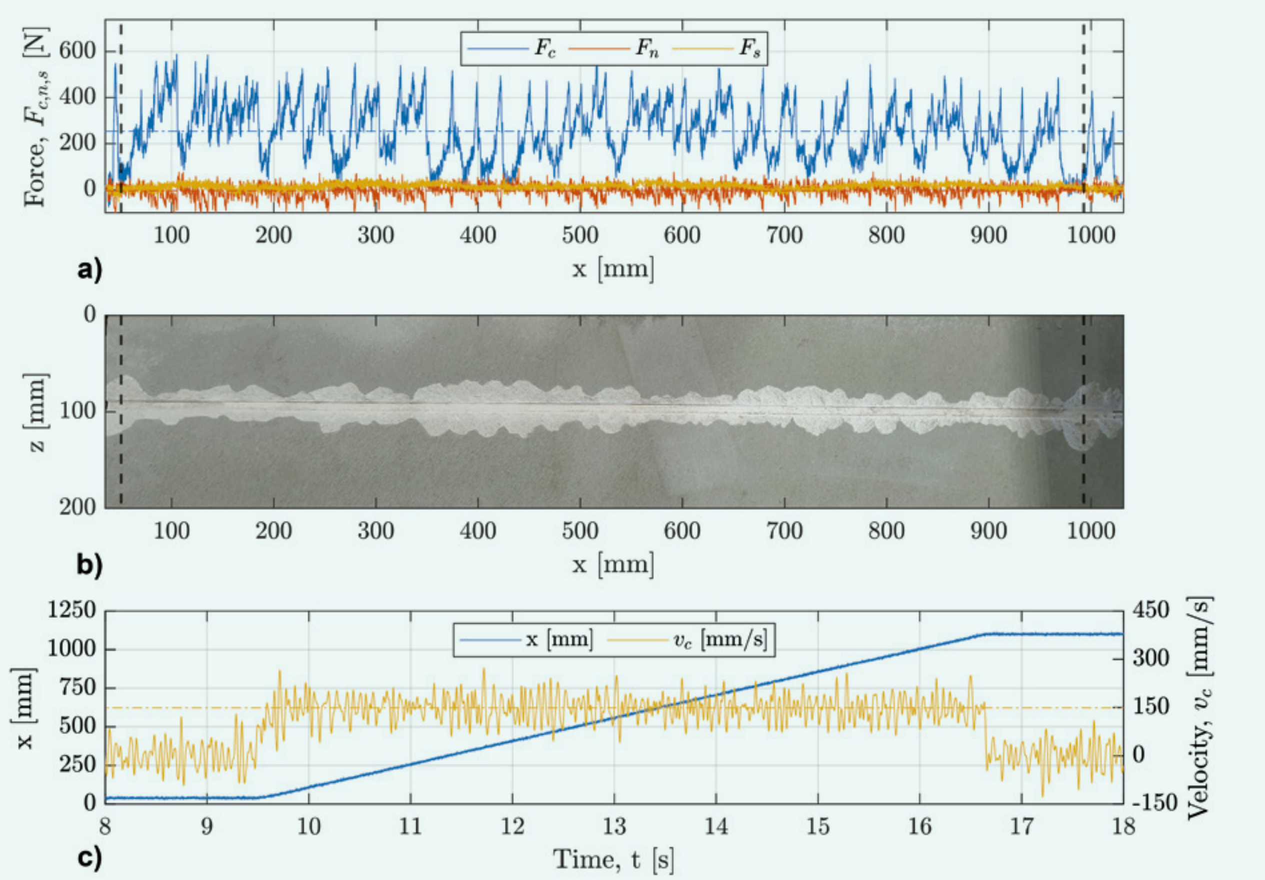


FIGURE 6

Linear rock cutting experiment nr. 3: raw data (A); cutting groove (B); and cutting distance measurement and resulting velocity (C).

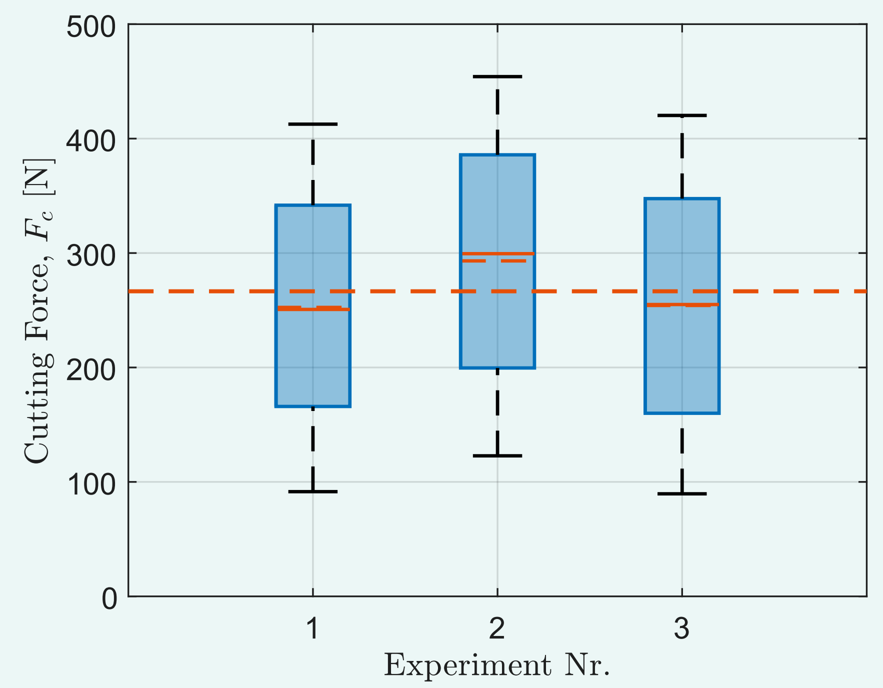


FIGURE 7

Repeatability LRCS

The linear rock cutting setup was designed and custom-built in the Royal IHC laboratory.

directions with respect to the LRCS, and the clamping bolts are tightened. Care is taken to not overtighten the clamping bolts to avoid inducing a confining pressure on the rock sample. Subsequently, the basin is filled with water and the chisel is installed. During installation, the cutting depth (d_c) is set using an analogue hand caliper. This depth is defined as the distance between the tip of the chisel and the top of the rock sample.

The depth of cut is kept constant over the total cutting distance, i.e. the cutting velocity (V_c) is set to be parallel with the rock sample surface. This is a simplification with respect to the practical application where the cutting depth varies from zero to $V_s/RPM * n$ or vice versa, dependent on the direction of swing with respect to the direction of rotation (overcutting versus undercutting). Here, n is the number of arms on the cutter head. Furthermore, the chisel is always positioned in the center of the rock sample to ensure an unrelieved cut.

As shown in Table 2, the tested rock samples have similar mechanical properties, allowing for direct comparison of the results. Note that all mechanical properties were taken as the average from two measurements. After the chisel installation, the carriage is carefully positioned such that the chisel tip touches the rock sample in order to minimise the impact force at the start of an experiment. After pressurizing the HPU, the chisel motion is initiated and stopped by an operator using a manual start/stop switch.

Results

A typical result of a linear cutting experiment is shown in Figure 6. In Figure 6A, the cutting force (F_c), normal force (F_n) and side force (F_s) are plotted against the travelled distance through the rock sample in x-direction. It can be clearly seen that after initial contact $(x \approx 40$ mm$)$, the cutting force increases significantly and a typical sawtooth pattern is generated, indicating a brittle failure mechanism (Verhoef, 1997). This behaviour results from the generation of rock chips during the cutting process. The normal force is related to the cutting force but shows a negligible increase. More precisely, it is found that the average normal force is slightly negative. This is a result of the tool tip temporarily loosing contact with the bottom of the groove as a rock chip is released from the mass. At this instance, partially due to the rake angle of the chisel, the normal force can be directed downwards, causing it to be "pulled into" the rock mass. As chisel 1 was used during the experiment shown in Figure 6, this is to be expected. Finally, the side force measurement is shown to remain approximately zero over the total distance. Due to the linear motion of the chisel and constant depth of cut this measurement confirms that the chisel and rock sample are properly aligned with respect to the LRCS.

Furthermore, two vertical dashed lines are shown. These vertical lines indicate the cutoff distance from initial contact of the chisel with the rock as well as the cutoff distance from the chisel exiting the rock sample. Because a steady-state cutting process is required to determine the statistics during an experiment, these so-called "break-in" and "break-out" distances were calculated by defining a threshold force value that is an order of magnitude larger than the noise of the signal. The data points between these initial cutoff distances are used to compute the mean cutting force, after which the vertical lines are shifted one data point inwards, effectively shortening the steady-state section where a new mean cutting force is computed. This process is repeated until the difference between subsequent mean cutting force values equals 0.1 N. The statistics are then determined using the datapoints in the steady-state section of the measurement.

After the experiment, the resulting groove is cleaned by carefully removing the released rock chips (Figure 6B). The width of the groove is found to be significantly wider than the chisel width due to the side breakout angle (θ_s) (Roxborough, 1973). The collected rock chips and resulting groove can be used in a later stage to determine a particle size distribution (PSD) and specific energy. Finally, the displacement measurement is shown in Figure 6C. The experiment is

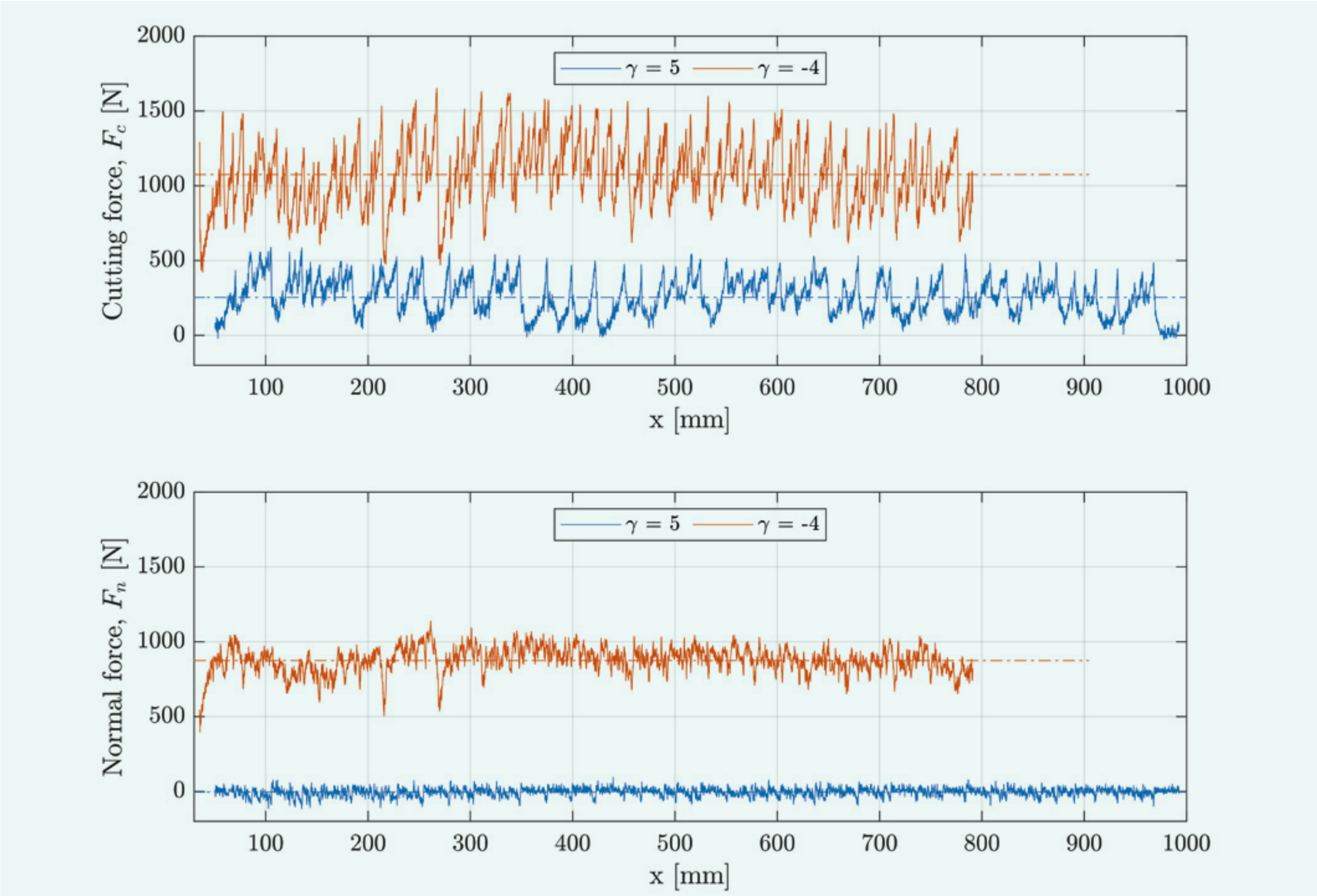


FIGURE 8

Effect of chisel wear (negative clearance angle) on the cutting and normal force.

characterised by a steady slope that leads to a constant cutting velocity of 0.15 m/s.

Setup performance

Three identical experiments (as shown in Table 2) were performed using Ytong limestone in order to address the repeatability of the setup. The results of these experiments are shown in Figure 7 using a box plot. Each of these experiments showed similar features as those described in Figure 6, where the cutting force was dominant, the normal force on average slightly negative due to the rake angle in combination with a sharp chisel geometry and the side force remained approximately zero.

Throughout the three experiments, it can be seen that the size of the boxes is very similar. The upper and lower length of the whiskers is found to be similar for the three experiments as well, indicating similar variability. Lastly, the overall mean of the cutting force was computed and determined to be $\overline{F}_c \approx 266$ **N.**

Another interesting finding is that the mean and median per experiment are approximately equal. This indicates a symmetrical distribution of the data, which physically means that the rock cutting process and thus behaviour is spatially consistent. To achieve this, the rock sample properties must be spatially consistent as well, indicating that this synthetic limestone might be considered homogeneous.

Preliminary results on the effect of clearance angle

Finally, the effect of chisel wear is addressed by changing the clearance angle (γ), while all other variables are kept constant (see Table 1 and 2). During the experiment a characteristic sound and vibrations were noticed, indicating that the cutting process was not as smooth as in the previous experiments. The resulting cutting and normal force as function of the cutting distance x are shown in Figure 8. Note that the length of the rock sample used for the worn chisel experiment $(\gamma = -4°)$ is approximately 800 mm length, 200 mm shorter than the rock sample for the sharp chisel geometry $(\gamma = 5°)$.

Comparing the cutting forces for the sharp and worn chisel geometry it is found that the difference between local minima and maxima is larger for the worn chisel. This, however, is expected to be caused by the ductility number $(m = UCS/BTS)$ that is slightly different for the two rock samples (Verhoef, 1997). Furthermore, it can be seen that both the cutting force as well as the normal force are increased due to the wear flat being in contact with the rock sample. Analysing the average cutting force to average normal force ratio for the sharp chisel yields $\overline{F}_c/\overline{F}_n \approx -55$, due to the cutting force being dominant and the normal force being slightly negative. In this case, the angle of the total cutting force can be considered zero, i.e. in line with the cutting velocity. The addition of the wear flat being in contact with the rock sample results in this ratio yielding $\overline{F}_c/\overline{F}_n \approx 1.23$. This shows that the angle of the total cutting force is no longer zero but approximately 39°. This trend corresponds well with the findings of Dalziel and Davies (1964). Because the UCS is slightly larger for the Savonierres limestone (~22%), the increase of the normal force between the two experiments cannot be directly compared, but it does indicate that the presence of a wear flat area, including a negative clearance angle of only 4°, results in a significant increase.

Analysing the normal force for the negative clearance angle test, it is found that the fluctuation in force is less than the cutting force. While it is expected that the cutting force is mainly dominated by a brittle failure mechanism, the normal force resulting from the rock sample being compressed at the bottom of the chisel is dominated by a cataclastic ductile failure mechanism (Detournay and Defourny, 1992; Cools, 1993; Verhoef, 1997). The continuous crushing action underneath the wear flat could explain the apparently higher frequency in the normal force measurement.

Conclusion

In this article, the LRCS that was designed and build at the Royal IHC laboratory is presented. This setup allows for a parametric study of the chisel geometry and rock sample properties. Using two, decoupled 6-DOF sensors, cutting and normal forces can be measured up to 20 kN, using chisel of 10 and 20 mm wide and a velocity range of 0.01-0.22 m/s. The maximum rock sample geometry allowed is 1100 x 300 x 300 mm.

Conducting three comparable experiments using a sharp chisel geometry in Ytong rock samples (synthetic limestone), resulted in the average normal force being slightly negative and the average side force remaining approximately zero. The cutting force was concluded to be similar throughout the three experiments with respect to the mean, median and the variability. From these findings it was concluded that the setup performs as expected.

Altering the chisel geometry by introducing a wear flat area in combination with a negative clearance angle resulted in a significant increase in the normal force while the cutting force was less affected. This finding was in good agreement with results found in literature and led to the conclusion that the measuring section is properly designed.

FIGURE 9

The Young Author award was handed over by IADC's Director Arnold de Bruijn (right) to Rick van de Wetering for his contribution to the paper "A laboratory scale linear rock cutting setup to study cutting forces of blunt chisels". The Young Author Award is granted at industry-leading conferences with 2025's winning young author selected from the proceedings of the 24th WODCON Congress, held from 23-27 June 2025 in San Diego, USA.

Summary

This article explains the linear rock cutting setup designed and built at the Royal IHC laboratory to study the effect of a worn or blunt chisel geometry on the cutting forces, with the emphasis on the normal force. To test the repeatability and accuracy of the setup, three comparable experiments were conducted using a sharp chisel. From the resulting cutting forces it was concluded that the setup performed as expected as the recorded cutting force was within 16% throughout the three experiments using synthetic limestone. Furthermore, the normal force was found to be slightly negative, effectively pulling the chisel into the rock. This corresponds with findings in literature. Finally, an experiment was conducted where a worn chisel geometry was used, resulting in an increased cutting force, but a significantly stronger increase in the normal force. This implies that the normal force is strongly dependent on wear and cannot be omitted when cutting rock with a chisel.

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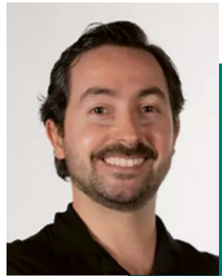
Rick is a research and development engineer at Royal IHC and a part-time PhD candidate of Offshore and Dredging Engineering at the department of Maritime and Transport Technology, Delft University of Technology, in the Netherlands. He specialises in excavation technology for the dredging and wet mining industry. Rick's research focuses on the physics involved while mechanically excavating soil or rock, combining experimental and analytical techniques into applicable models.



Dr. Miguel Angel Cabrera

Miguel is an assistant professor of experimental soil mechanics at the Geo-Engineering department of Delft University of Technology where he works on the physical modelling of land instabilities and soil-structure interaction systems. His research in geomechanics focuses on complex, multiphase, geophysical and environmental flows, and interaction systems between soil and fluid. To this end, Miguel develops and uses a combined approach of physical modelling, advanced measurement techniques and numerical modelling.

Dr. Mario Alvarez Grima

Mario is principal research and development specialist at Royal IHC with over 30 years of experience in geo-engineering. He specialises in process modelling for dredging and wet mining, combining analytical, numerical and AI methods with lab and field data. He holds a PhD from Delft University of Technology on AI applications in geo-engineering and has led multidisciplinary projects on rock cutting and dynamic soil-structure interaction. Mario has published extensively in international journals and conferences.

Frits Hofstra

Frits is a senior specialist at Royal IHC on the interface between dredging technology and mechanical engineering. He has worked on slurry transport in pumps and drag heads, focusing on material transport and the resulting loads on the systems. Currently Frits' research focuses on mechanical excavation of soil and rock for the dredging and wet mining industries and methods for the improvement thereof.

Dr. Rudy Helmons

Rudy is an associate professor in Offshore and Dredging Engineering at the Department of Maritime and Transport Technology, Delft University of Technology. His research focuses on physical processes related to dredging and seabed mining, including mechanical and hydraulic excavation, hydraulic transport and sediment dynamics. Rudy has been involved in several deep-sea mining projects and has a solid background in mechanical engineering and fluid mechanics.

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UPCOMING COURSES AND CONFERENCES

Dredging and Reclamation Seminar

17-21 November 2025
Holiday Inn Atrium
Singapore

About the seminar

Since 1993, the IADC has regularly held a week-long seminar developed especially for professionals in dredging-related industries. These intensive courses have been successfully presented in the Netherlands, Singapore, Dubai, Argentina, Abu Dhabi, Bahrain and Brazil. With these seminars, IADC reflects its commitment to education, encouraging young people to enter the field of dredging and improving knowledge about dredging throughout the world.

For whom

The seminar has been developed for both technical and non-technical professionals in dredging-related industries. From students and newcomers in the field of dredging to higher-lever consultants, advisors at port and harbour authorities, offshore companies and other organisations that carry out dredging projects. Attendees will gain a wealth of knowledge and a better understanding of the fascinating and vital dredging industry.

In the classroom

There is no other dredging seminar that includes a workshop covering a complete tendering process from start to finish. The in-depth lectures are presented by experienced dredging professionals from IADC member companies. Their practical knowledge and professional expertise are invaluable for in the classroom-based lessons. Among the subjects covered are:

- the development of new ports and maintenance of existing ports;
- project development: from preparation to realisation;
- descriptions of types of dredging equipment;
- costing of projects;
- types of dredging projects; and
- environmental aspects of dredging.

Site visit: seeing is believing

Practical experience is priceless and it sets aside this seminar from all others. There will be a site visit to a dredging project or yard of an IADC member to allow participants to view and experience dredging equipment first-hand to gain better insights into the multi-faceted field of dredging operations.

Networking

Networking is invaluable. A mid-week dinner where participants, lecturers and other dredging employees can interact, network, and discuss the real, handson world of dredging provides another dimension to this stimulating week.

Certificate of achievement

Each participant will receive a set of comprehensive proceedings and at the end of the week, a certificate of achievement in recognition of the completion of the coursework. Full attendance is required to attain the certificate.

Costs

The fee for the week-long seminar is EUR 3,100 (out of scope EU VAT). The fee includes all tuition, proceedings, workshops and a special participants' dinner, but excludes travel costs and accommodations. We can assist you in finding a hotel or accommodation.

For more information and how to register visit https://bit.ly/Seminar-SGP25

Dredging for Sustainable Infrastructure Course

18-20 November 2025
Holiday Inn Atrium
Singapore

How to achieve dredging projects that fulfil primary functional requirements, while adding value to the natural and socio-economic systems. This is just one of the questions addressed during the 3-day course that is based on the philosophy of the book, *Dredging for Sustainable Infrastructure*.

Experienced lecturers will describe the latest thinking and approaches, explain methodologies and techniques, and demonstrate through engaging workshops and case studies, how to implement the information in practice.

During the course, participants will learn how to implement the sustainability principles into dredging project practice, through answers to the following questions:

- What is the role of dredging in the global drive towards more sustainable development?
- How can water infrastructure be designed and implemented in a more sustainable and resilient way?
- How can the potential positive effects of infrastructure development be assessed and stimulated as well as compared with potential negative effects?
- What equipment and which sediment management options are available today?
- A brief introduction to the question, "What knowledge and tools are available to make sound choices and control a project?"

Register for the course at https://bit.ly/DfSI-SGP25

Enhance your skills and contribute to sustainable development!

RESPONSIBLE MARINE SOLUTIONS: DFSI

Introducing a new web resource on sustainable dredging

Readers of this magazine will know that one of the main missions of IADC is to promote the Dredging for Sustainable Infrastructure (DFSI) philosophy. In 2018, experts in marine technology, from dredging companies to academia, worked together to produce a book by the same name. The publication presents state-of-the-art guidance to achieve dredging projects that fulfil their primary functional requirement, while adding value to the (natural and socio-economic) system. In 2024, the new *DFSI Magazine* was launched as a further step in the promotion of the DFSI philosophy. Now, IADC is taking another step in this journey with the launch of a new online resource – the Responsible Marine Solutions: DFSI website.

The aim of this new website is to be the "go-to" source of information on all things related to sustainable dredging. The design has been created to be user-friendly, clear and accessible to a wide audience; breaking down what we really mean when we talk about sustainable dredging projects. It includes key insights from the book and will be regularly updated with case studies, news items and publications.

While the *DFSI Magazine* uses the chapters of the DFSI book to form the theme for each issue, the new website is based around six core principles of DFSI: nature-based solutions, ecosystem services, stakeholder involvement, energy transition, adaptive management and innovation, equipment and technology..

The new DFSI website will also serve as a valuable resource for anyone new to the industry – whether you're a student, a local authority representative, or simply someone passionate about sustainability.

So go visit www.sustainabledredging.com and don't forget to follow IADC on social media to find out when the latest content is out!

Ecosystem services
Generating services from nature for humans

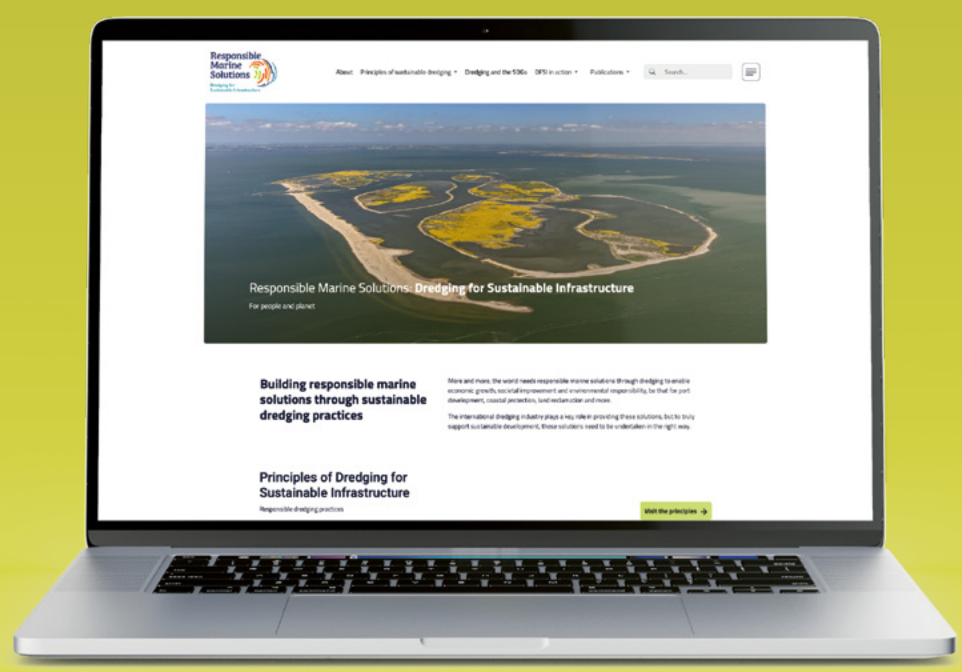
Nature-based solutions
Sustainable projects through the inclusion of nature

Stakeholder involvement
Understanding all sides of the story

Adaptive management
Sustainable through adaptability

Energy transition
Reducing emissions through cleaner energy in operations

Innovation, equipment and technology
Evolving, modernising and innovation



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