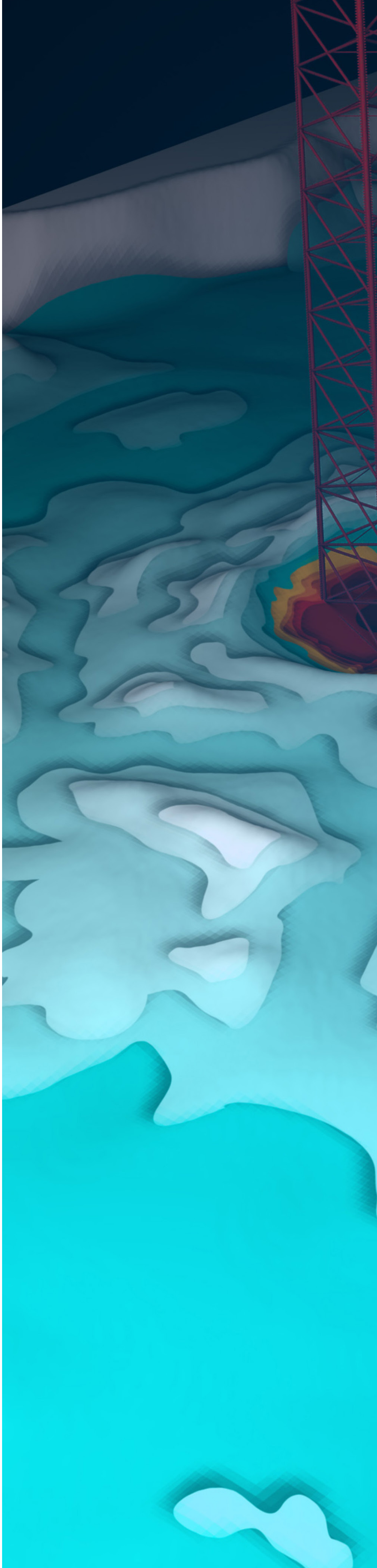
Rock solid challenges: how jack-ups are adapting to tougher seabeds

Beyond the sandy soils of the North Sea, a new generation of offshore wind projects faces a tougher test: rock-hard seabeds. Meeting this challenge calls for cutting-edge engineering, smarter digital tools and a deep understanding of how jack-ups interact with the seabed beneath them.



The shift to new offshore frontiers

As offshore wind expands beyond the familiar waters of the North Sea, developers are entering new regions, each with their own unique environmental and seabed conditions. From the rugged coasts of the North Atlantic to Japan's deep bays and Australia's continental shelves, these new frontiers hold immense promise for renewable energy. Yet beneath the waves lies a less visible challenge: hard seabeds and rocky foundations that test the limits of jack-up vessels. The combination of greater water depths, dynamic sea states and harder seabeds adds significant complexity to offshore wind construction.

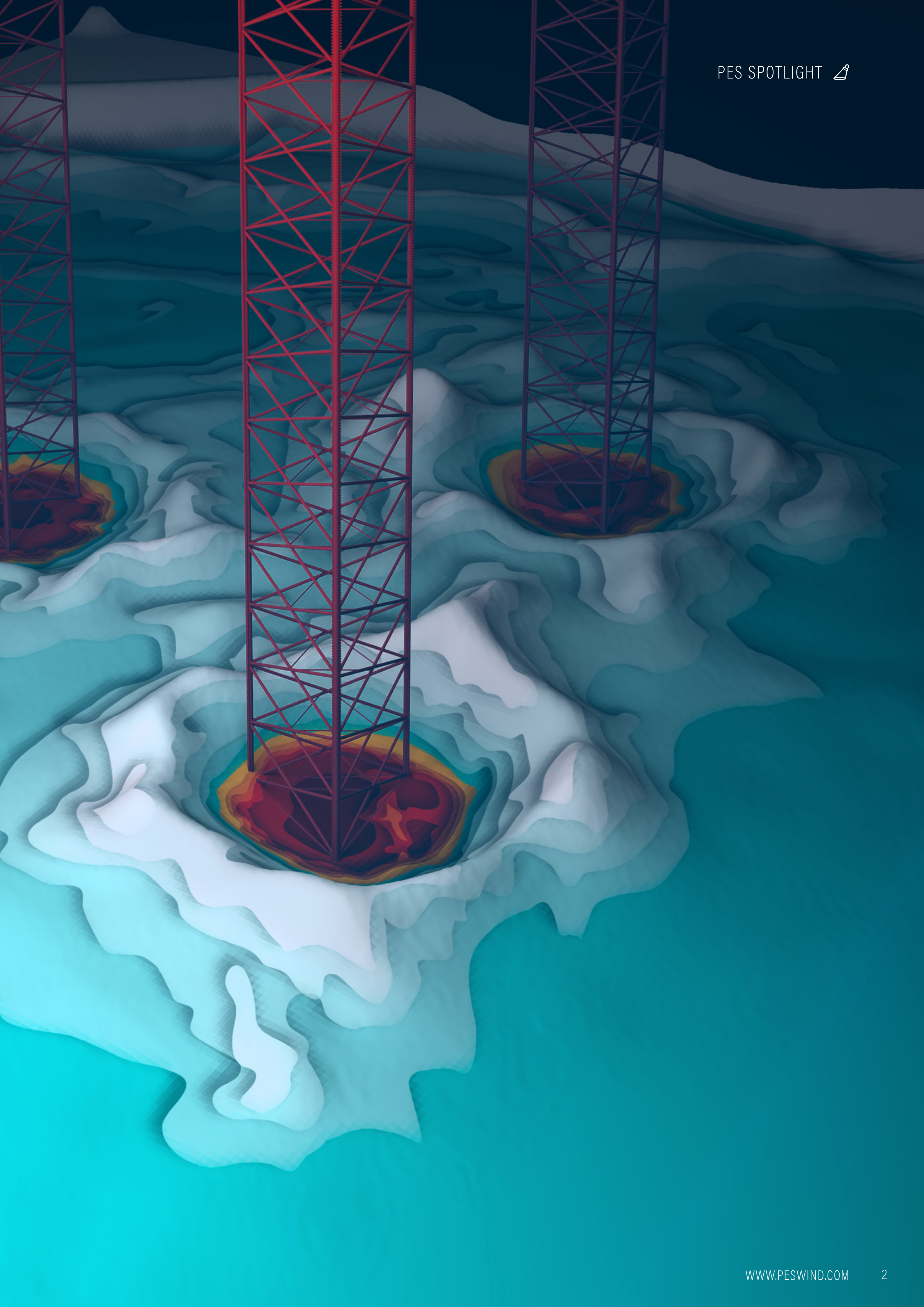
Companies such as GustoMSC, with long-standing experience in jack-up design and engineering support, play a key role in enabling this transition. As offshore wind moves into uncharted territory, success increasingly depends on translating practical knowledge into innovative engineering solutions, helping the industry adapt safely and efficiently to the tough realities of hard soil and rock.

Whereas North Sea projects deal mainly with cohesive and granular soils, many of these new sites present dense glacial tills, coral limestone, or even exposed bedrock.
Jack-ups lower their legs onto the seabed to perform installation operations. These new seabed conditions present new operational challenges.

Installing on hard seabeds

A jack-up installation might appear simple on paper: the vessel arrives on site using its own propulsion and dynamic positioning system, lowers its legs until the spudcans, or the footings, touch the seabed, and then jacks up to a safe elevation above the waves.
In practice, this sequence is a finely balanced dance between structure, sea, and soil. In soft soils, the spudcan penetrates smoothly, distributing loads across a broad area. But in hard soil, or worse, on solid rock, the story changes dramatically.

The spudcan's first contact with the seabed can trigger sudden peak loads that reverberate through the entire system: legs, leg-to-hull structure, and the jacking system. These impact loads, if not carefully managed, risk structural overstress or even damage.



Moreover, rocky seabeds often combine hardness with unevenness, ridges, slopes, or cavities that introduce eccentric loads and sliding risks. A spudcan might land on a sloped surface, threatening horizontal movement or loss of stability.

On sites with long-period swell waves, installation becomes especially challenging. The swell wave periods can excite the vessel at its natural frequency, often in roll or heave, leading to resonant motions and high-energy impact loads when the spudcans make contact with the seabed.

To manage these risks, jack-ups typically operate under stricter installation limits in long-period wave conditions. In reality, units encounter complex sea states, a mix of wind-driven and swell waves of varying periods, which further complicates operations. Working near these limits demands that onboard personnel fully understand the vessel's installation limits and continuously evaluate the associated risks during each phase of the operation.

Operating with minimal penetration

Once installed, jack-ups operating on hard seabeds face another set of engineering and operational challenges. Limited or no penetration means that the contact pressures between the spudcan and seabed are concentrated over smaller areas, increasing the risk of local structural damage.

The absence of embedment also reduces foundation rotational stiffness, the seabed's ability to resist tilting or rotation of the jack-up structure. This stiffness is crucial for maintaining the integrity of the hull, legs and jacking system, particularly under storm conditions.

In shallow waters, where breaking waves impose significant horizontal loads, low penetration further increases the risk of sliding. On rock, where frictional resistance is inherently low, even small lateral forces can become critical.

And then there's scour, the erosion of material around the spudcan caused by waves and currents. On hard soils, scour can remove what little supportive sediment exists, further reducing stability.

Still, not all aspects of hard seabeds are unfavorable. Rock offers exceptionally high bearing capacity, meaning there's no risk of the spudcan sinking or uneven settlement. Earthquake behavior on hard foundations also tends to be favorable, as higher frequency vibrations reduce resonance risks for the jack-up structure.

Engineering insight: from simulation to site support

Understanding and mitigating these challenges starts long before a jack-up arrives offshore. Site-specific foundation investigations, usually carried out for permanent structures like monopiles or jackets, also provide valuable data for jack-up assessments.

Expert engineers at GustoMSC use these inputs to run advanced time-domain simulations that model how the jack-up

Shimizu Corporation's Blue Wind, a GustoMSC-designed SC-14000XL wind turbine installation vessel, operating off Japan's coast

behaves under combined wave and soil interaction. These models incorporate the dynamic behavior of key components, such as spudcans, legs, jacking systems and leg-to-hull structures, to predict impact loads, structural stresses and safe operating envelopes.

Extensive simulation studies allow engineers to define installation limits and operational guidance tailored to specific sites. The results aren't just theoretical: they form the basis for clear, practical recommendations to onboard teams, defining safe weather windows, jacking speeds and allowable sea states.

Digital tools: learning faster, operating smarter

As operations become more complex, digitalization bridges the gap between rigorous engineering design and operational excellence in the field.

By integrating sensors and data acquisition systems onboard, operators can monitor how the jack-up actually behaves during installation, measuring leg loads, hull motions and seabed reactions in real time. These data streams can then be compared with engineering models, helping teams understand deviations, validate assumptions and improve accuracy for future campaigns.

For GustoMSC, the future of safe, efficient jack-up operations in challenging environments lies in smart digital solutions that merge simulation, monitoring, and decision support. The ability to visualize and predict loads dynamically enables faster learning across the industry.

Design evolution and collaborative development

Some sites may require physical mitigation measures such as seabed preparation, dumping gravel or crushed rock to create a more uniform surface, or adapting the spudcan design itself.

GustoMSC has explored alternative spudcan geometries that distribute loads more evenly or incorporate damping features to absorb impact energy. In parallel, research teams are refining dynamic modeling techniques to better simulate how every component, from gearboxes and motors to load control systems, responds under hard-soil conditions. These improvements have already shown measurable benefits in predicting and mitigating peak loads.

Equally important is the collaborative effort behind these advances. By working closely with operators, classification societies, and other industry partners, GustoMSC aims to help harmonize standards and develop best practices that reflect the realities of operating in new offshore environments.

Looking ahead: engineering beyond the North Sea

As offshore wind continues its global march, hard soils and rocky seabeds will become increasingly common. The lessons learned in Japan, Australia or the US will soon feed back into global design standards, shaping how the next generation of jack-ups are built and operated.

This evolution underscores the value of engineering expertise and adaptability. By combining advanced simulation, digital monitoring, and practical field experience, the offshore wind sector is learning how to manage the challenges of hard foundations, ensuring safe and efficient operations, worldwide.

The transition from designing for familiar North Sea to engineering for the world's divers seabeds marks an exciting phase for the industry. Through continued collaboration and innovation, offshore wind is proving that even the hardest ground can provide a strong foundation for future growth.

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