Optimizing Offshore Wind Infrastructure

A Numerical Study of Skirted Foundations under Dynamic Loading

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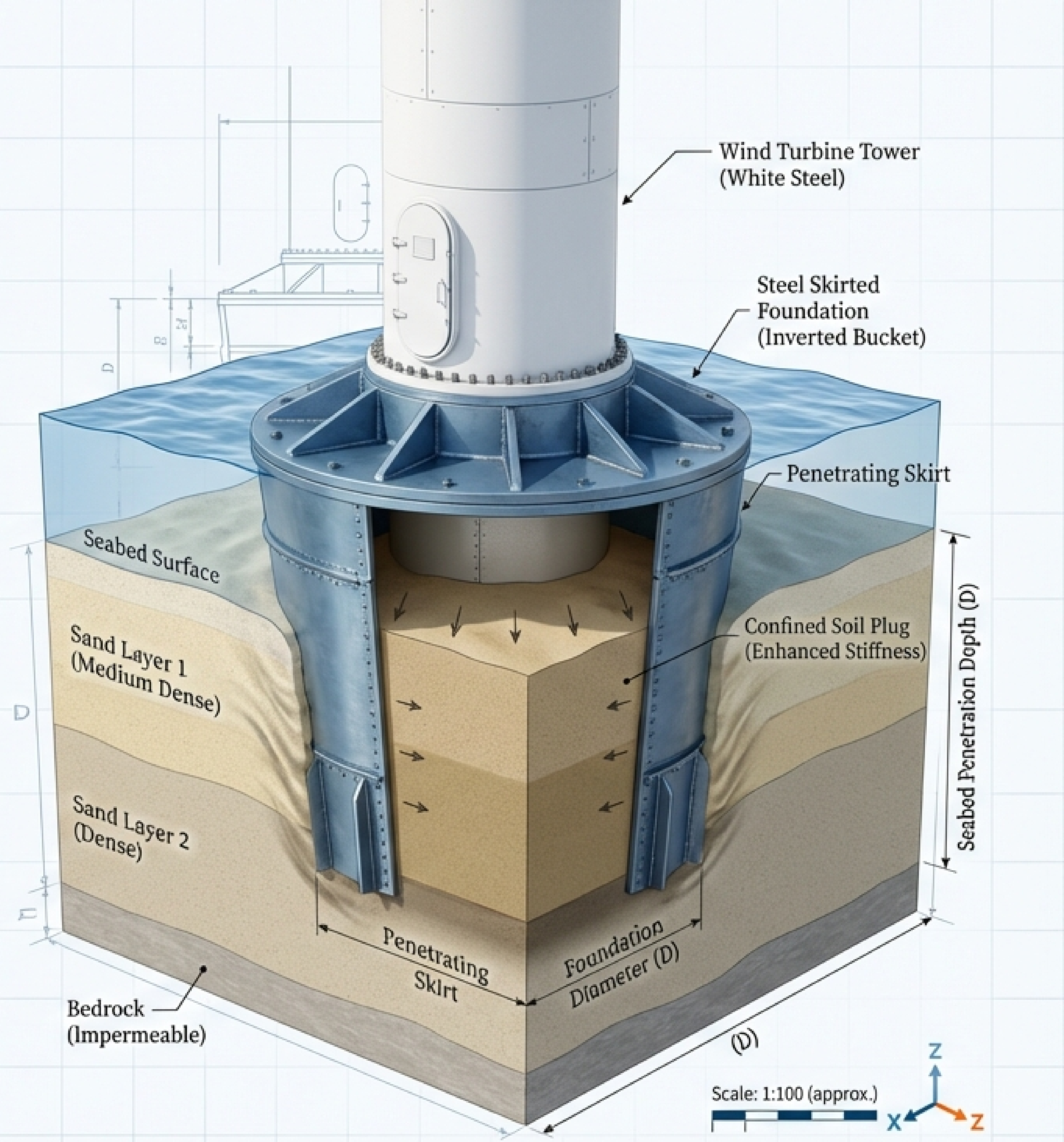
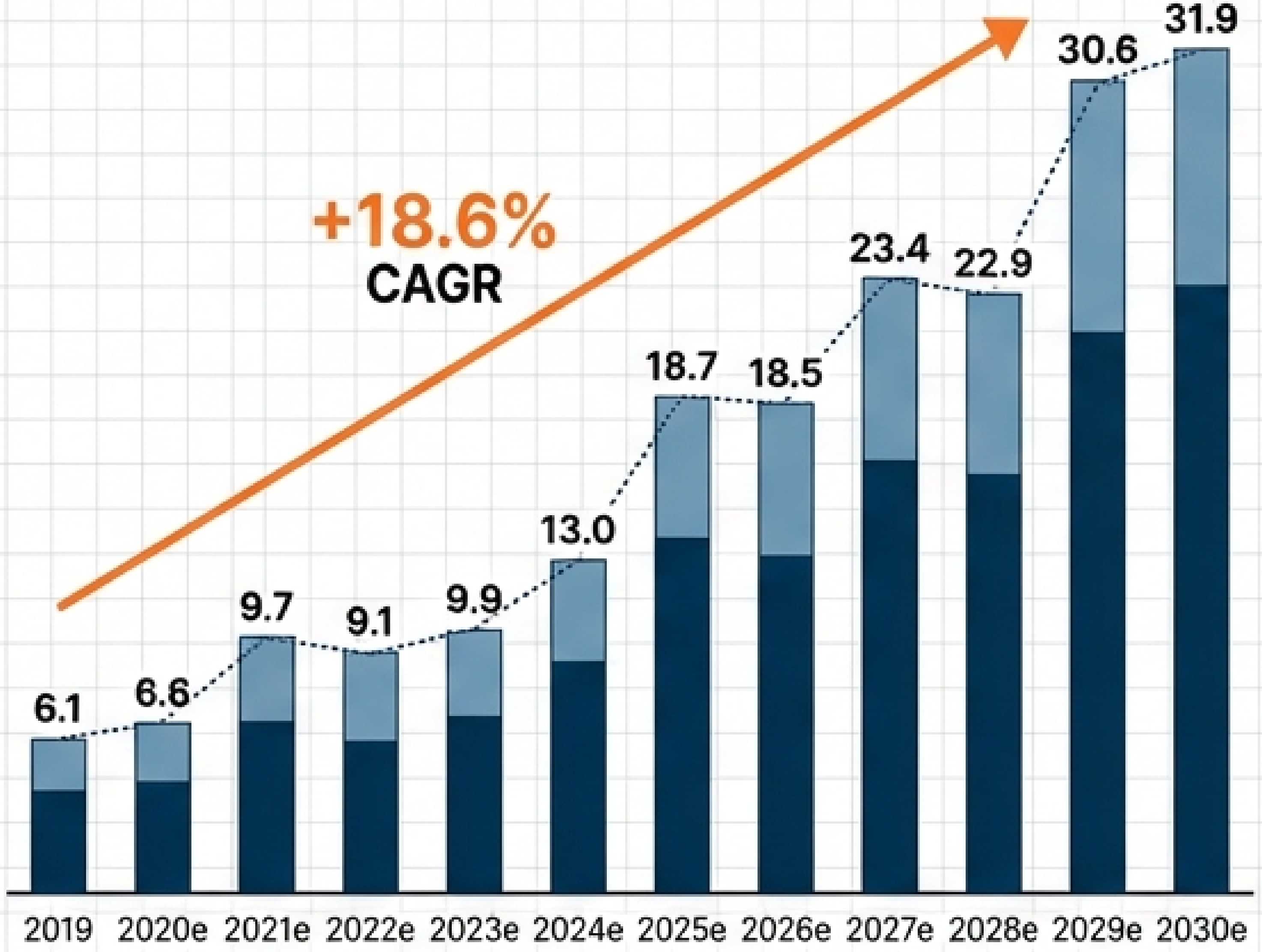


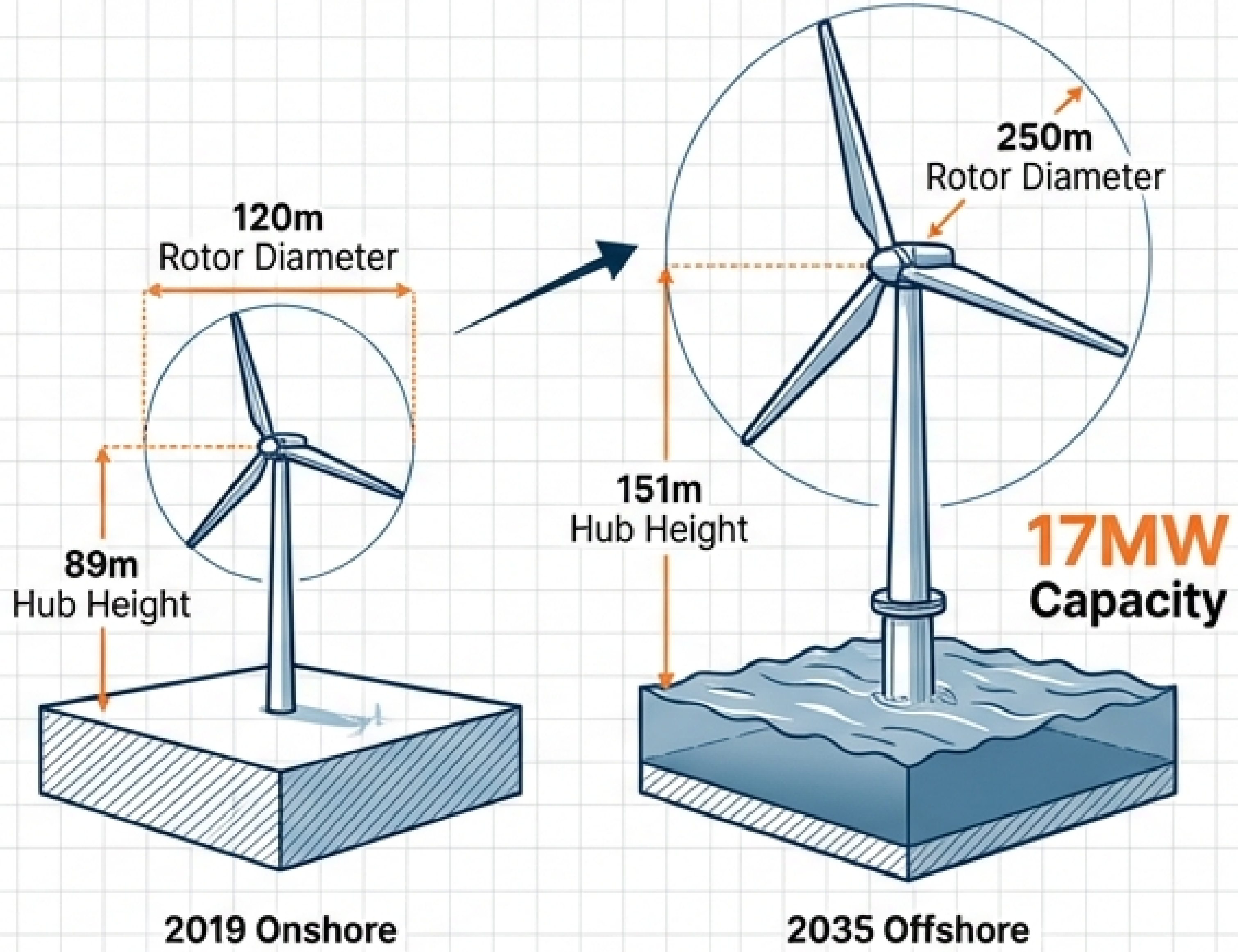
The Global Shift Toward Offshore Energy Capacities

Global Offshore Wind Installations (GW)



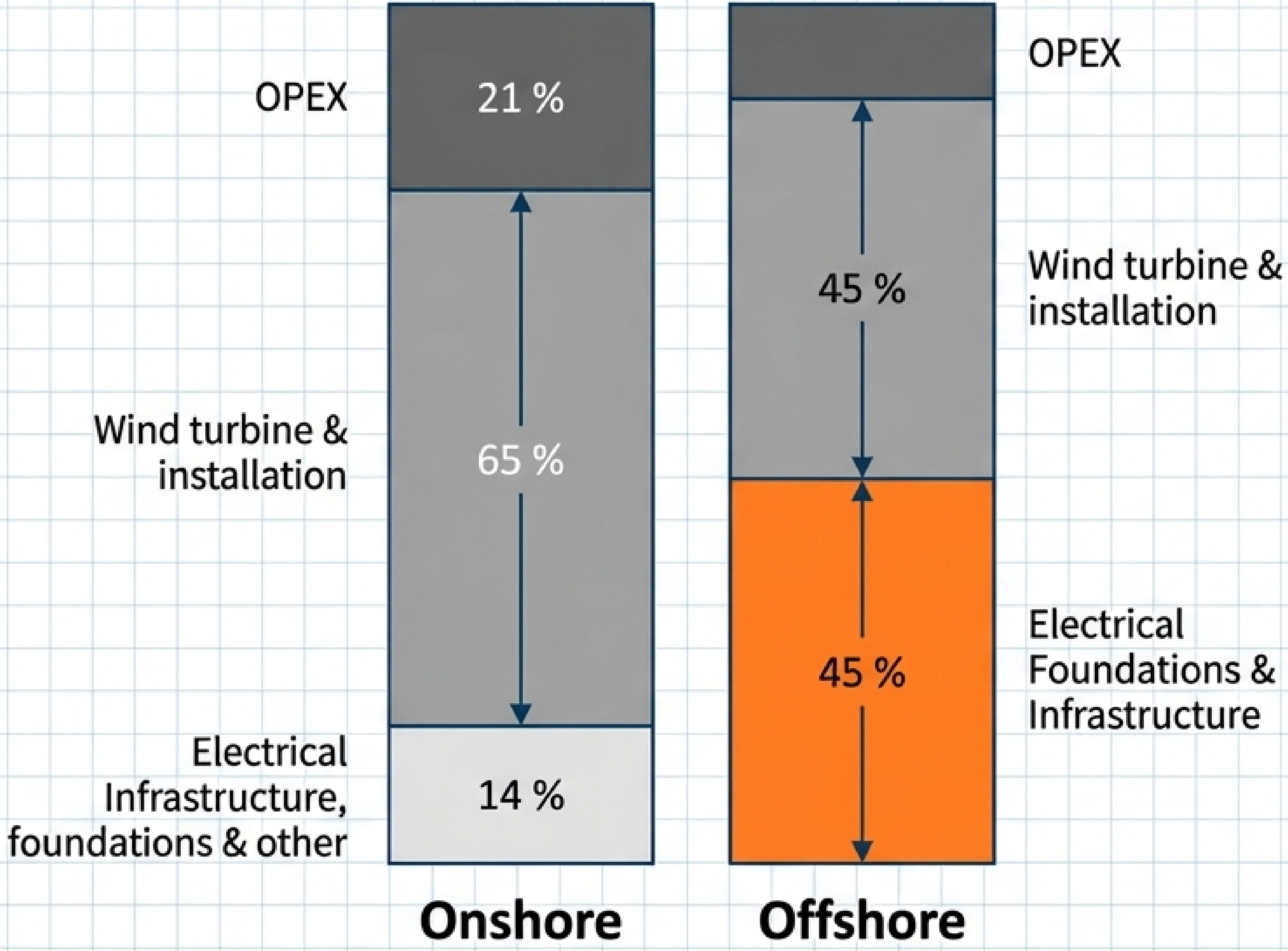
Exponential market growth driven by higher offshore wind speeds and reduced visual impact.

Technological Scale: Turbine Size & Capacity



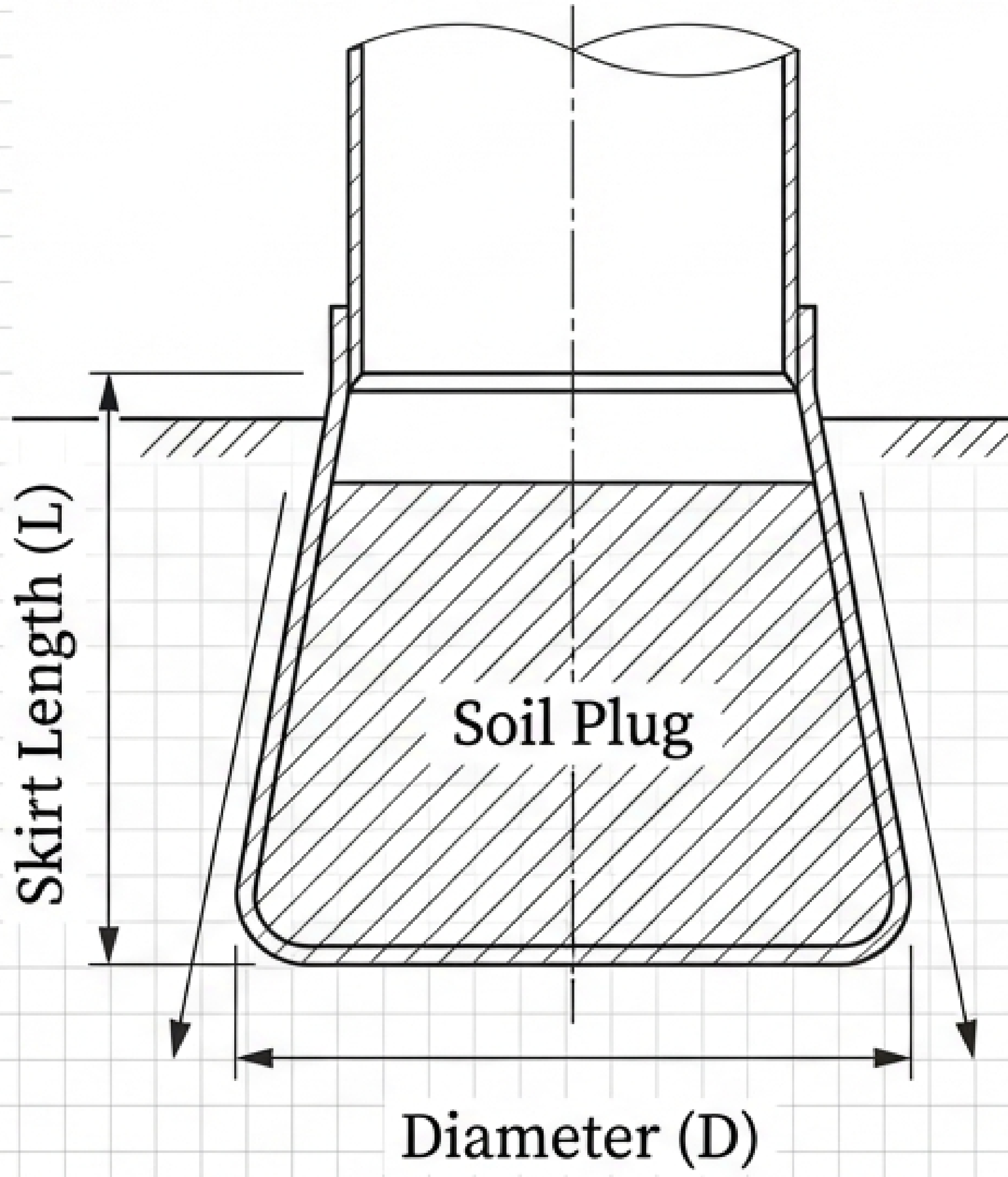
Offshore turbines are scaling rapidly: 17MW capacity projected by 2035.

Foundations Dictate the Economic Viability of Offshore Projects

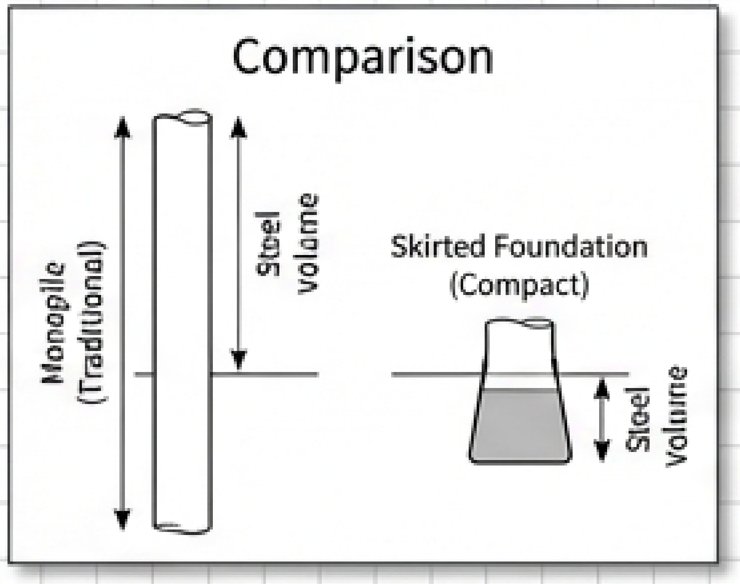


- **Key Insight:** In offshore projects, foundations and infrastructure account for ~45% of total CAPEX.
- **The Challenge:** Deep water (>40m) exponentially increases the complexity and steel volume required for traditional monopiles.
- **Implication:** Cost optimization of the foundation is the primary lever for project feasibility.

The Skirted Foundation: A Smarter Geotechnical Solution

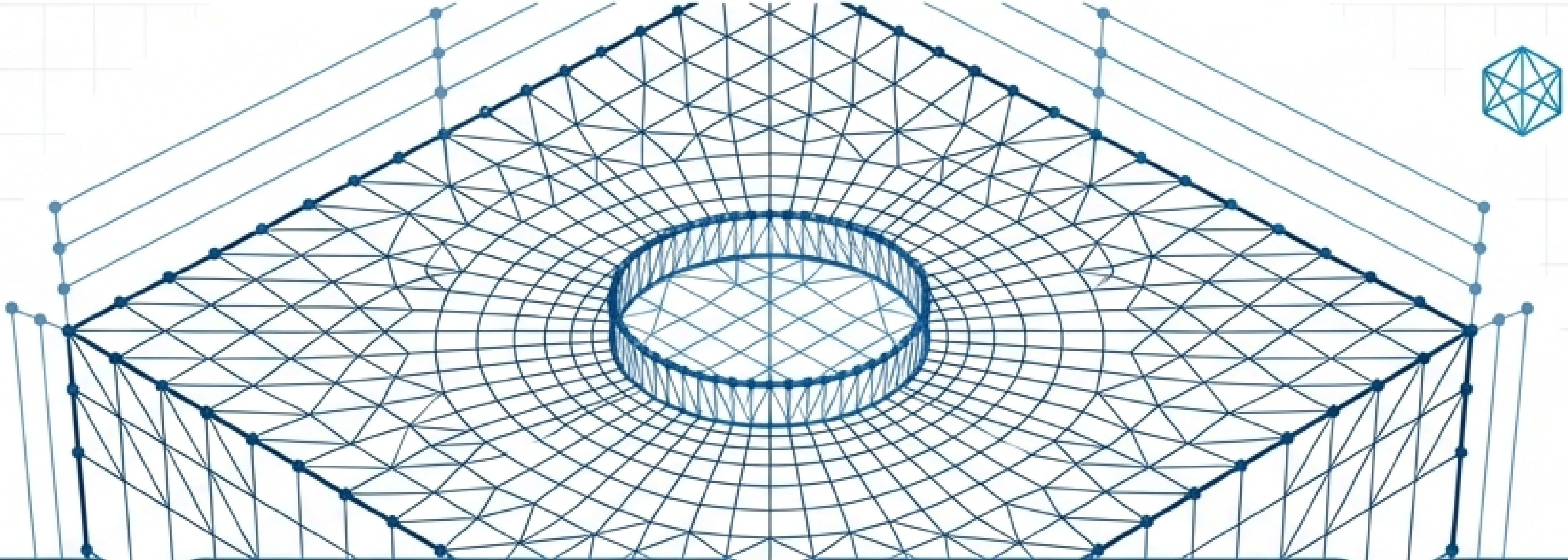


- **Definition:** Inverted bucket shapes that penetrate the seabed using suction or weight. Classified as 'Skirted' when L/D ≤ 0.5.
- **Advantages List:**
  1. **Material Efficiency**: Uses up to 50% less steel than traditional monopiles.
  2. **Installation**: Suction-assisted penetration eliminates heavy pile driving noise and vibration.
  3. **Mechanism**: Confines the soil plug to transfer loads to deeper, stronger layers.



Research Methodology and Simulation Scope

PLAXIS 3D
Connect Edition V21



Tool

PLAXIS 3D Connect Edition V21

Loading

Combined Static (V) + Dynamic (H, M) loading simulating Wind & Wave impact.

Environment

Analysis of Offshore (Dense/Medium Sand) vs Onshore conditions.

Geometry

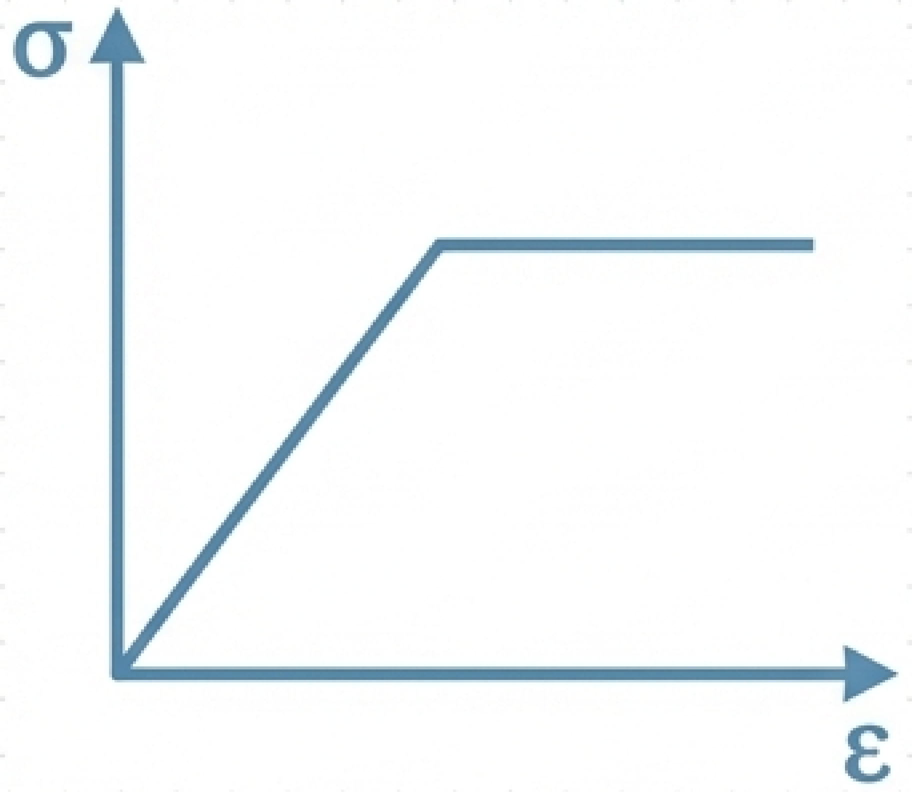
Parametric study of Skirt Length (L) and Diameter (D).

Validation: Results cross-referenced with field tests from Frederikshavn and Sandy Haven.

Advanced Constitutive Modeling of Soil Behavior

Mohr-Coulomb (MC)

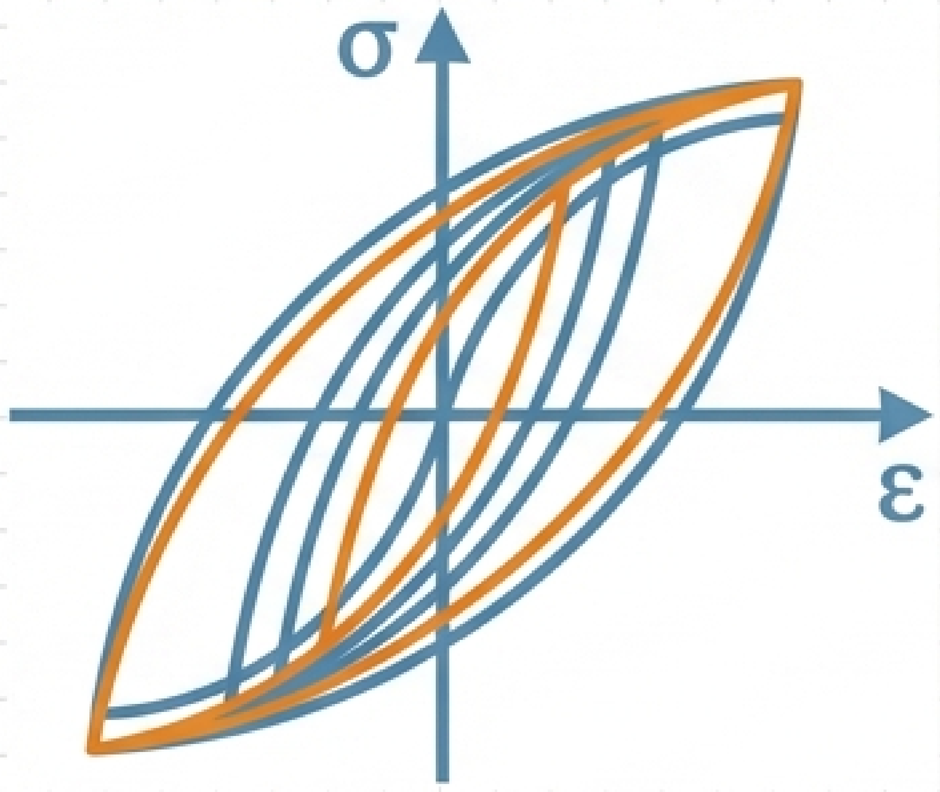
Linear elastic-perfectly plastic. Used for initial baseline approximations.



Hardening Soil Small-Strain (HS-Small)

Captures stress-dependent stiffness and damping of sand under cyclic loading.

Why It Matters:
Essential for predicting fatigue and vibration in dynamic offshore environments. Simpler models underestimate settlement risks.



This study utilizes the HS-Small model to guarantee high-fidelity prediction of Soil-Structure Interaction (SSI).

Calibrating for Real-World Geotechnical Profiles

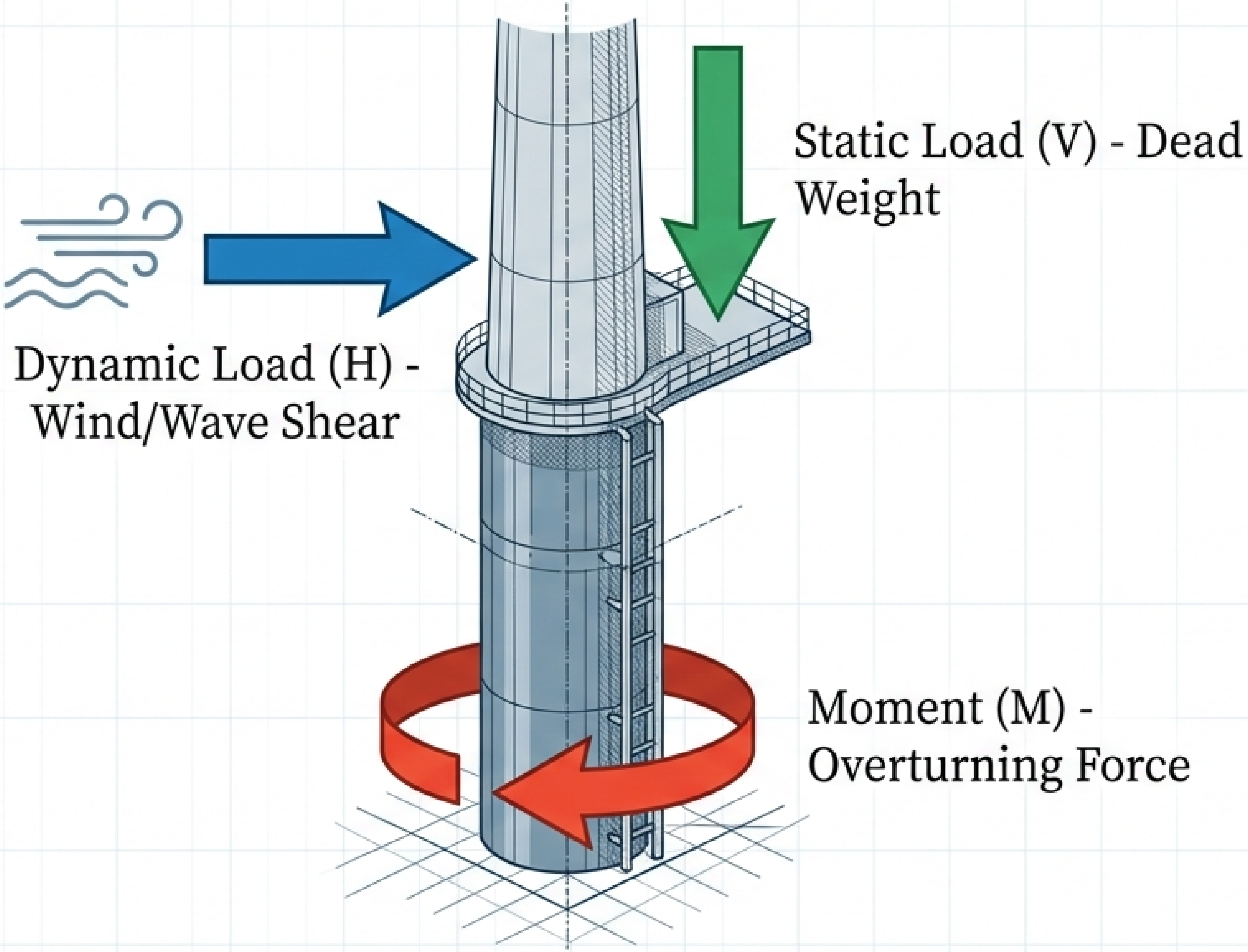
Soil parameters derived via back-calculation from large-scale field experiments (Houlsby & Byrne, 2000; 2005).

Relative Density (Dr) = 90%. High bearing capacity.

Relative Density (Dr) = ~50%. Weaker soil conditions.

Calibrated for Dr = 30%, 50%, 75%.

Simulating the Dynamic Ocean Environment



The Loading Matrix

Analysis of Combined V-H-M Loading

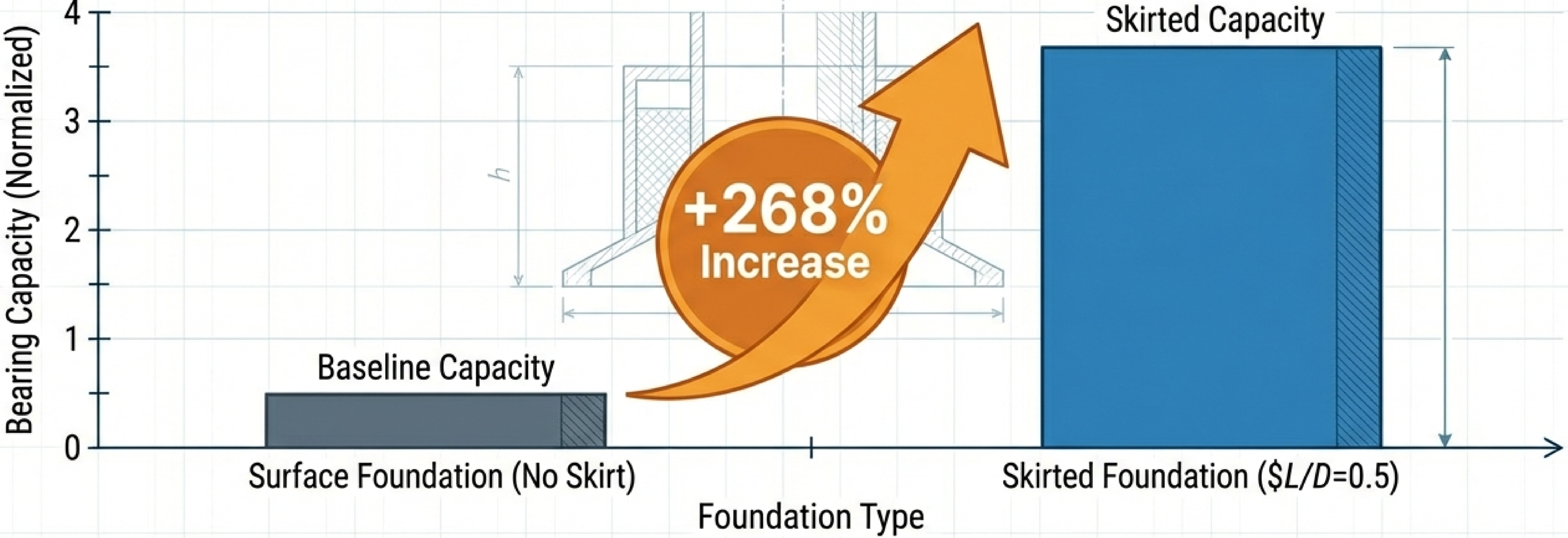
Regulatory Standards

- IEC 61400 (Wind Turbine Design)
- DNV-OS-J101 (Offshore Standards)

Limit States Analyzed

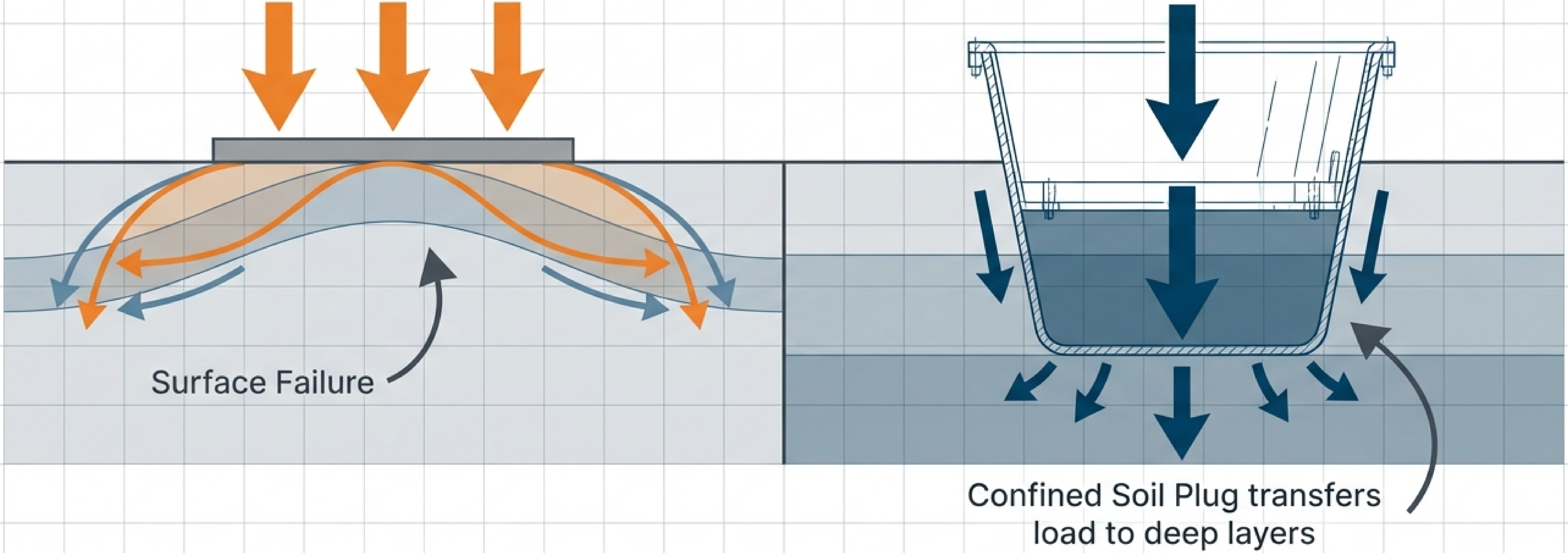
- **ULS (Ultimate Limit State):** Safety against catastrophic failure.
- **SLS (Serviceability Limit State):** Operational deformation limits.

Result: Massive Increase in Bearing Capacity



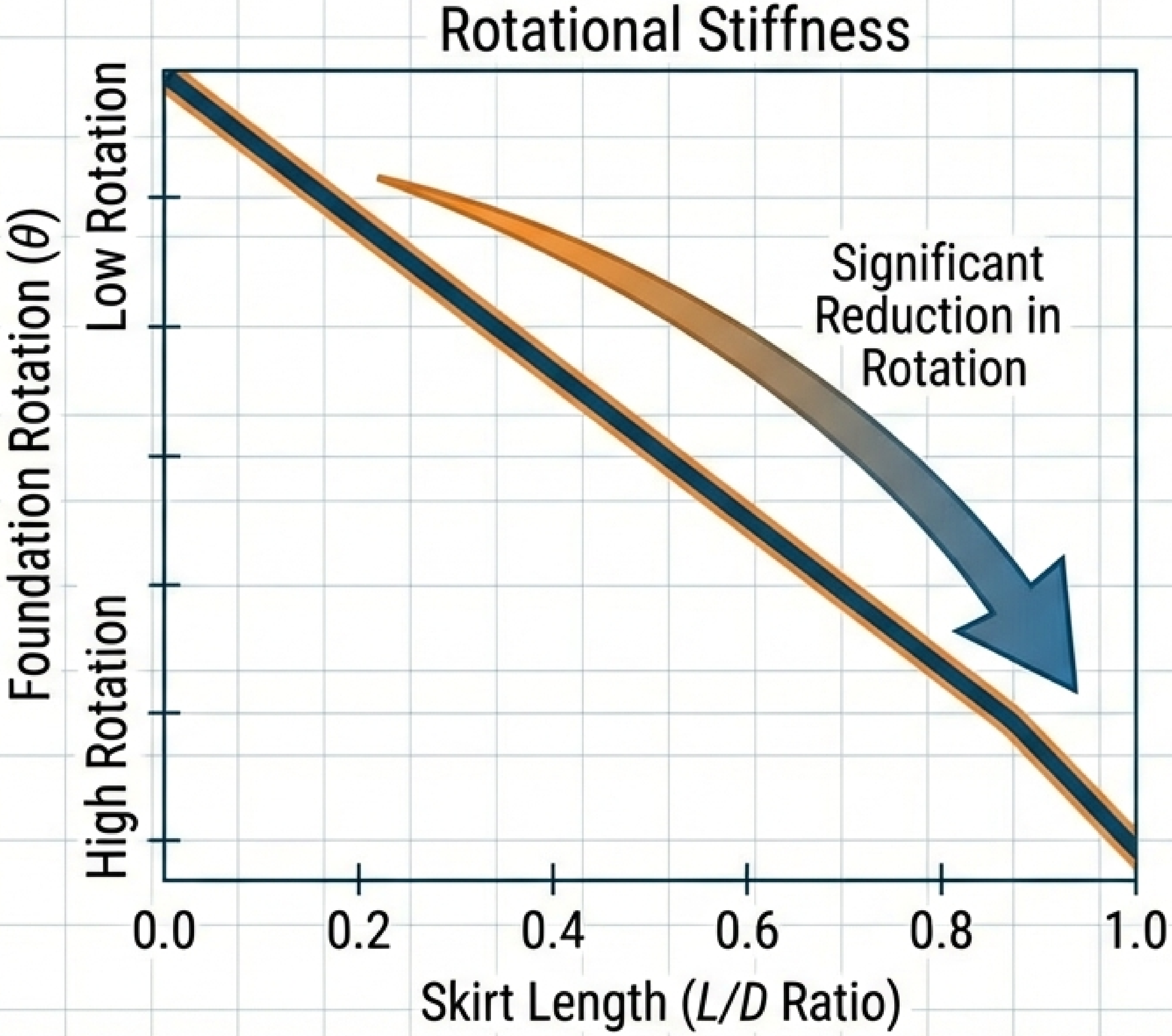
- **The Core Finding:** Adding a skirt with a length-to-diameter ratio of just 0.5 nearly quadruples the bearing capacity.
- **Implication:** Deeper skirts allow smaller diameters to support heavier 6MW+ turbines.

Controlling Settlement via Soil Confinement

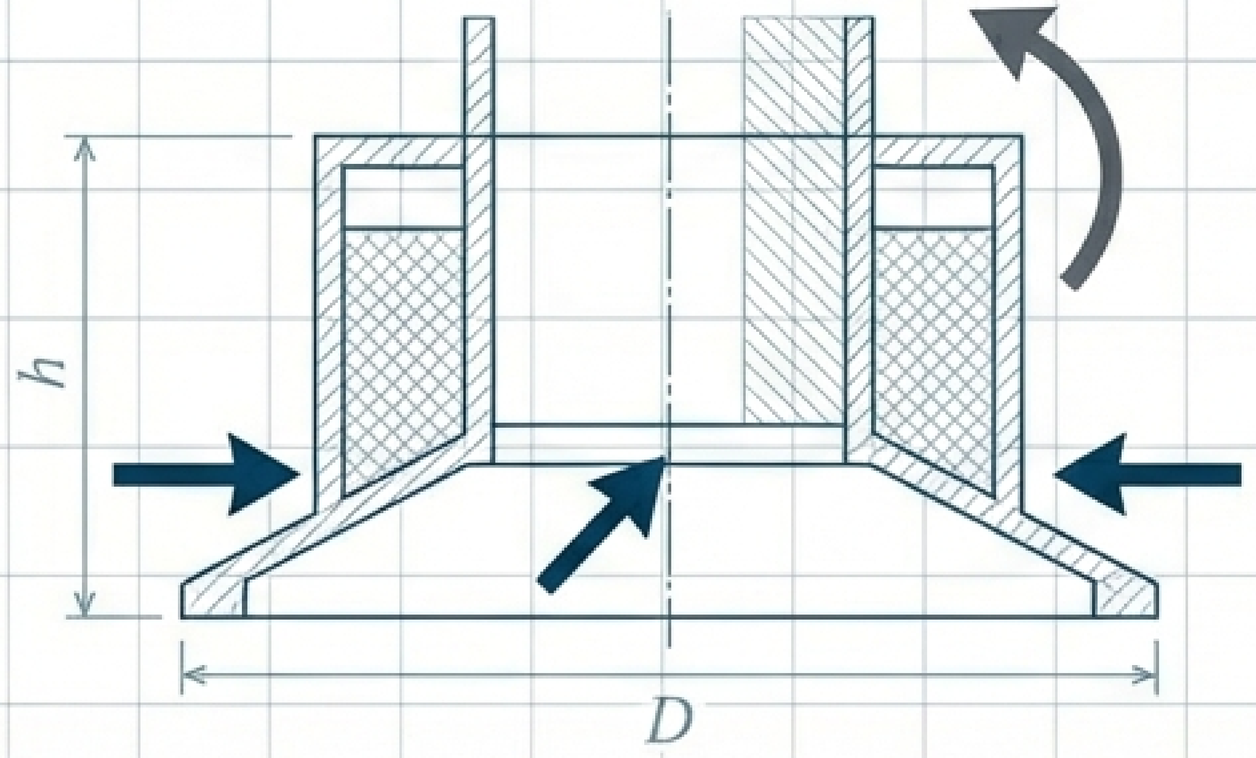


- **Mechanism:** The soil plug acts as a rigid body, bypassing weak surface layers.
- **Result:** Significant reduction in permanent settlement under dynamic wind/wave cycles, ensuring the tower stays level.

Resisting Overturning Moments and Rotation



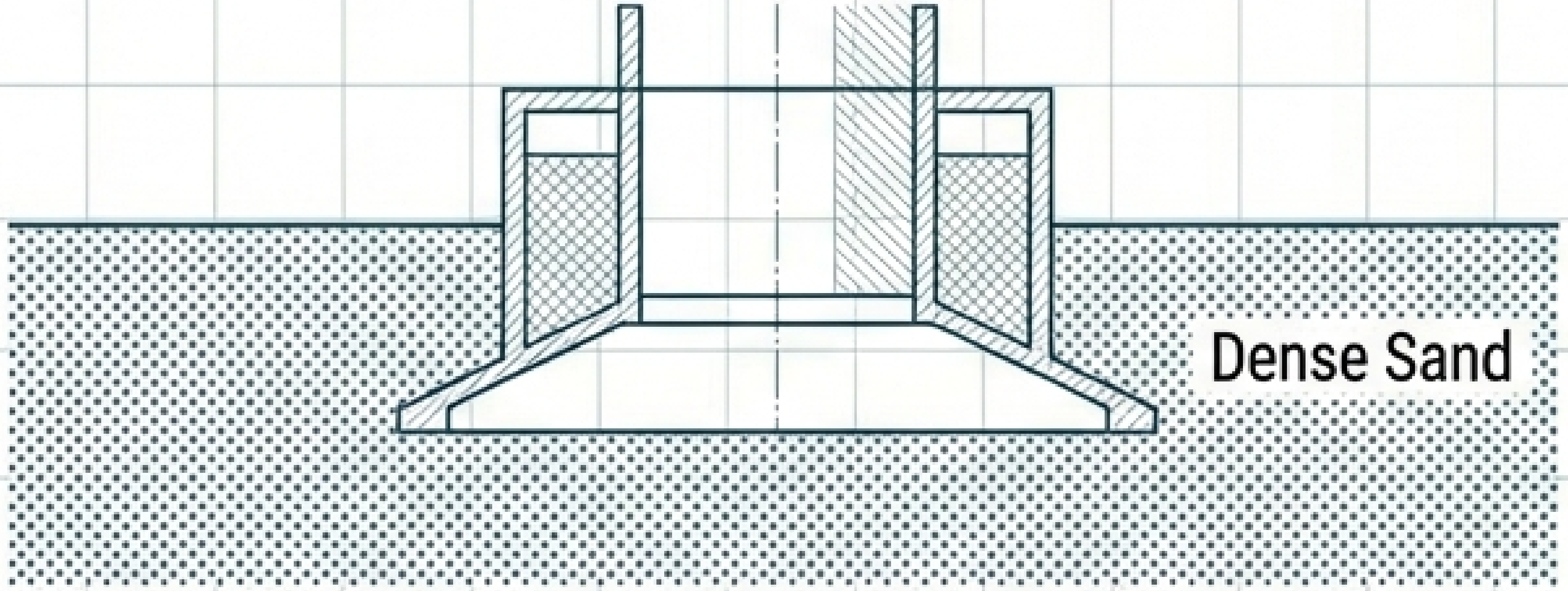
- **The Challenge:** Tall turbines create massive lever arms, leading to high overturning moments.
- **Finding:** Skirts drastically reduce rotation. This prevents structural fatigue and emergency shutdowns during high wind events.



Performance Across Varying Soil Densities

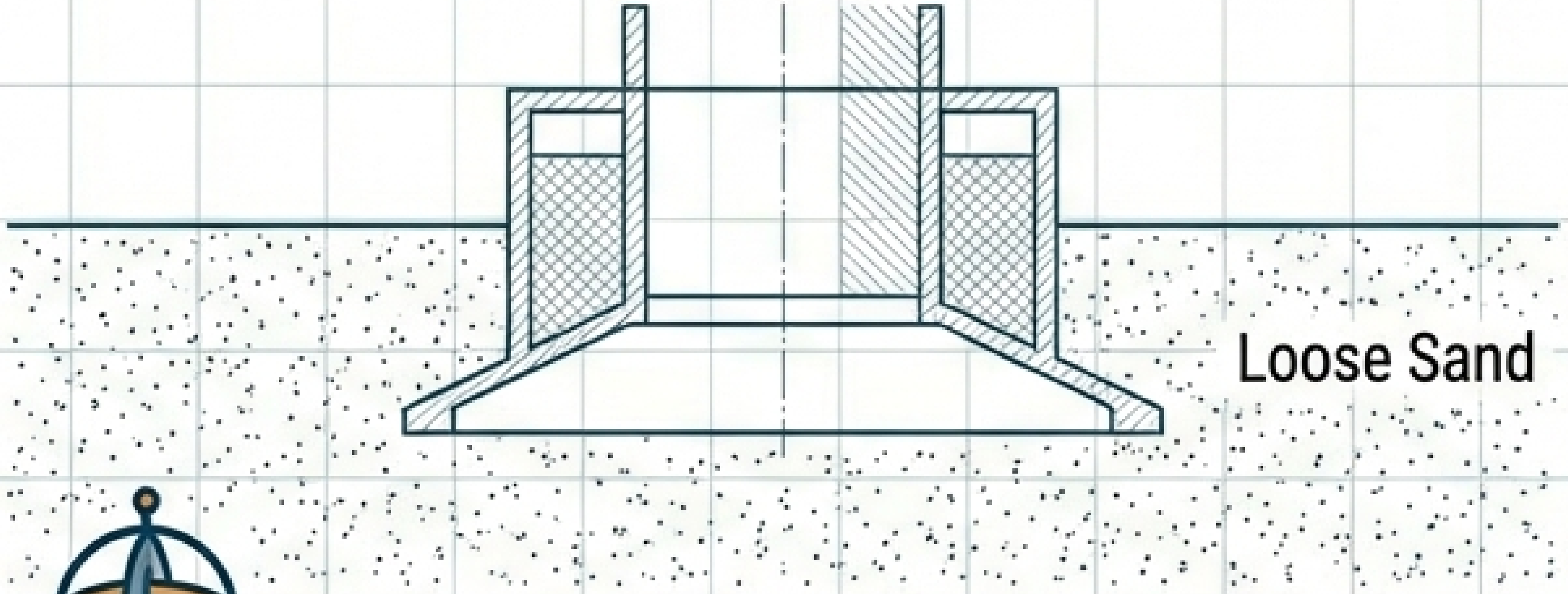
Comparative Matrix

Dense Sand (D_r =90%)



Highest Absolute Capacity.

Loose Sand (D_r =30-50%)

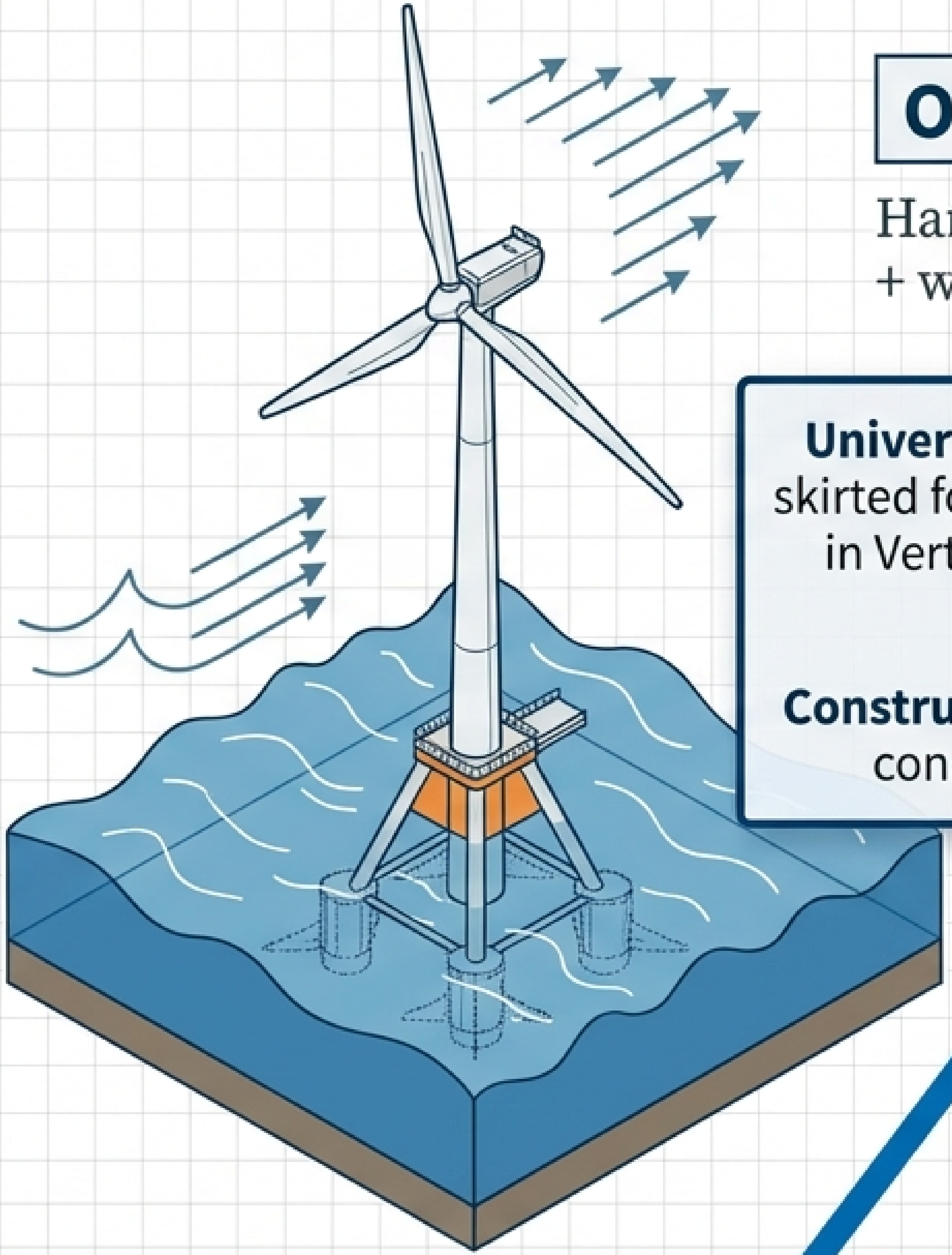


Highest Relative Improvement.

Skirted design stabilizes loose soil that is otherwise unsuitable for construction.

- **Key Takeaway:** This technology unlocks new sites with weaker topsoil for wind farm development, eliminating the need for expensive ground improvement.

Versatility: Onshore vs. Offshore Applications

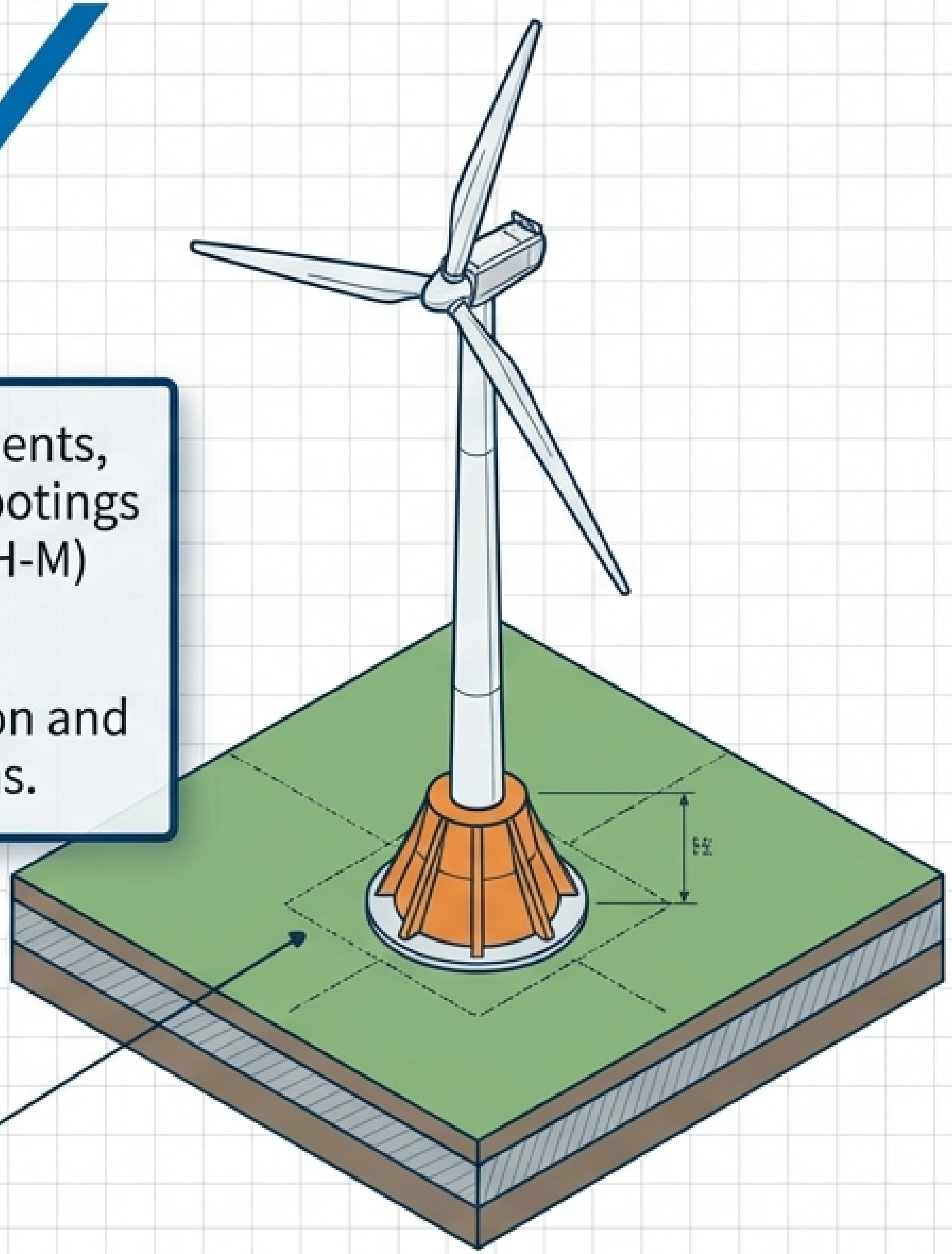


Offshore

Handles complex wave + wind shear.

Universal Advantage: In both environments, skirted foundations outperform surface footings in Vertical, Horizontal, and Moment (V-H-M) loading capacity.

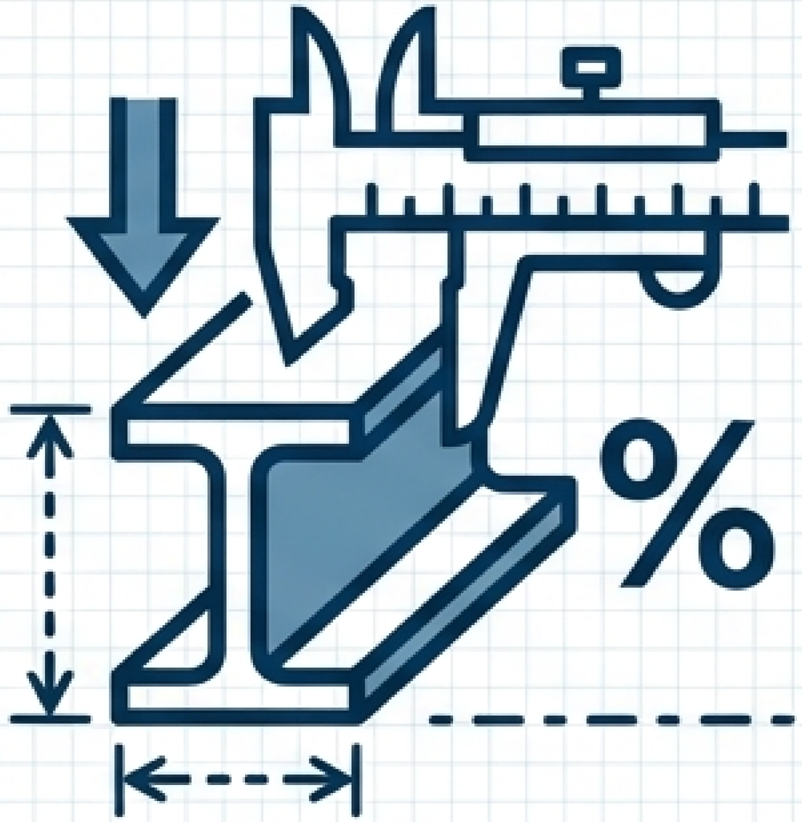
Construction Benefit: Reduces excavation and concrete volume for land-based farms.



Onshore

Replaces massive concrete gravity blocks.

Engineering Implications and Economic Impact



Material Efficiency

Steel Savings: 3.7x capacity increase allows for lighter, optimized designs compared to monopiles.

Enhanced Safety

Reliability: Advanced HS-
Small modeling confirms higher safety margins than previously predicted.

Sustainability

Carbon Footprint: Less steel and concrete directly translates to lower embodied carbon in construction.

Validating the Future of Wind Infrastructure

Summary

- 1. **Capacity:** Skirts increase bearing capacity by >268%.
- 2. **Stability:** Mitigates settlement and rotation under dynamic V-H-M loads.
- 3. **Economy:** A robust, material-efficient alternative to Monopiles.

Final Verdict

As turbines move into deeper waters, the efficiency of the foundation determines project viability. Numerical analysis confirms that skirted foundations provide the necessary robustness for the next generation of renewable energy.