



Illustration by Josh Bauer/NREL



Summary of Existing Foundations, Installation Methods, and Effects

U.S. Offshore Wind Noise Reduction Workshop

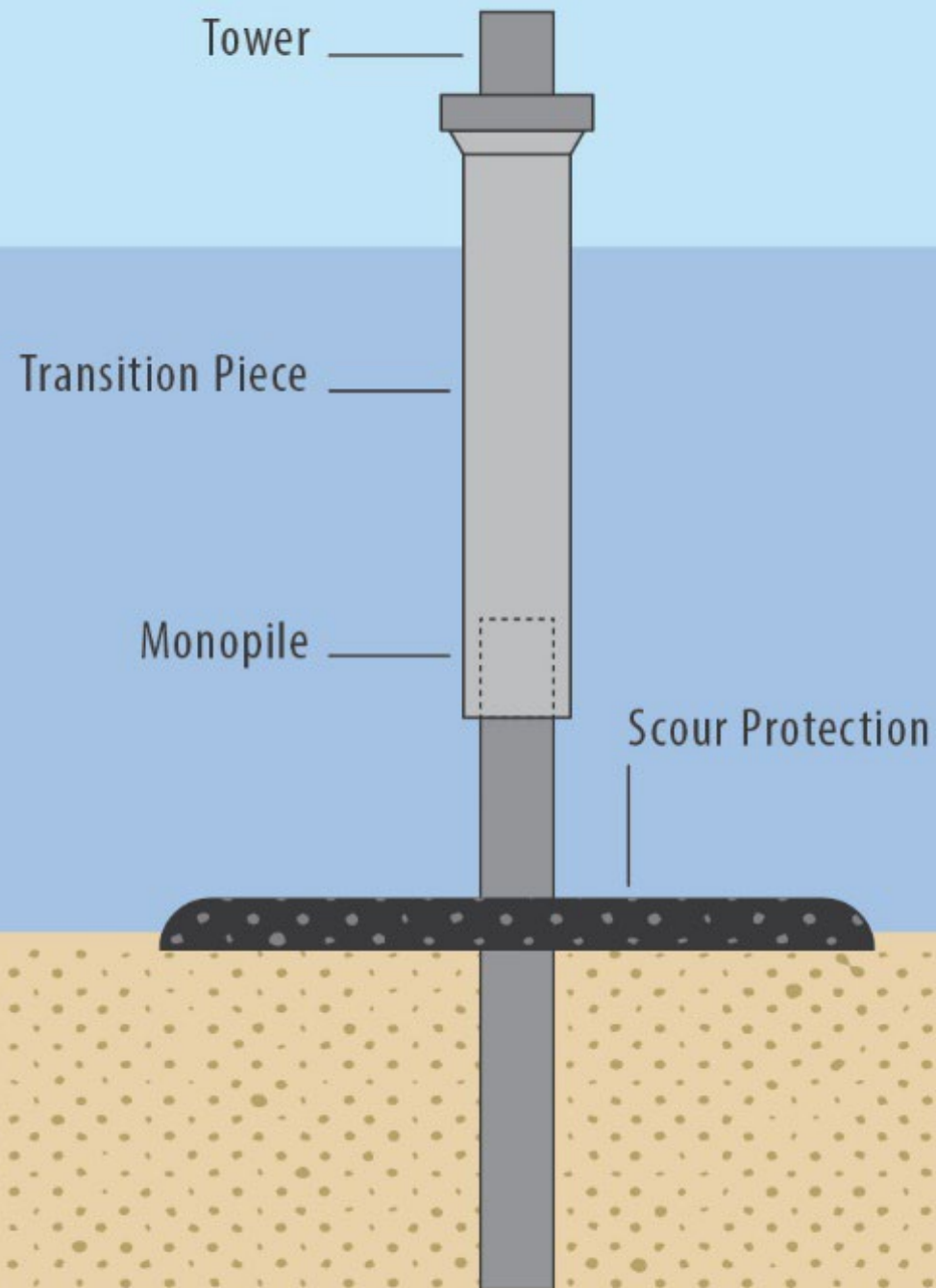
National Renewable Energy Laboratory (NREL) & Pacific Northwest National Laboratory (PNNL)



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Monopile Foundations



Description

- Single, large-diameter, steel pipe pile driven into the seabed
- Current designs include steel monopiles up to about 10 m (33 ft) in diameter
- Feasible in waters up to ~60 m (200 ft) deep

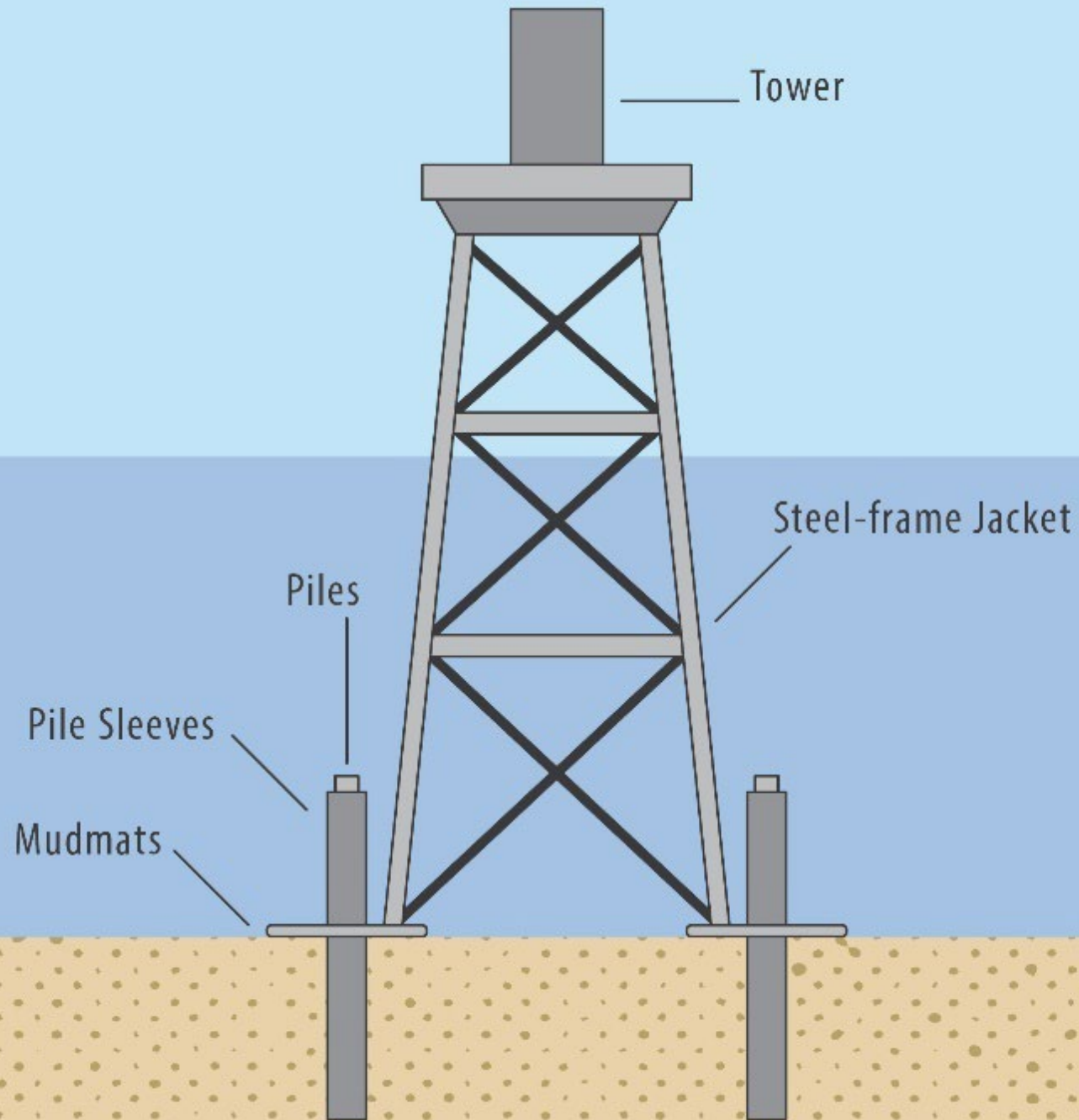
Installation

- Usually installed with pile-driving hammers or vibratory methods, although sometimes drilled

Acoustic Effects

- Installation noise may harm or displace marine animals.
- Impact pile driving creates the largest effects. Effects from vibratory pile driving or drilling would be smaller.

Jacket Foundations



Description

- Lattice-truss structures similar to the designs of many offshore oil platforms
- Usually four-legged, with tubular legs at the corners and smaller-diameter horizontal cross pieces and diagonal struts

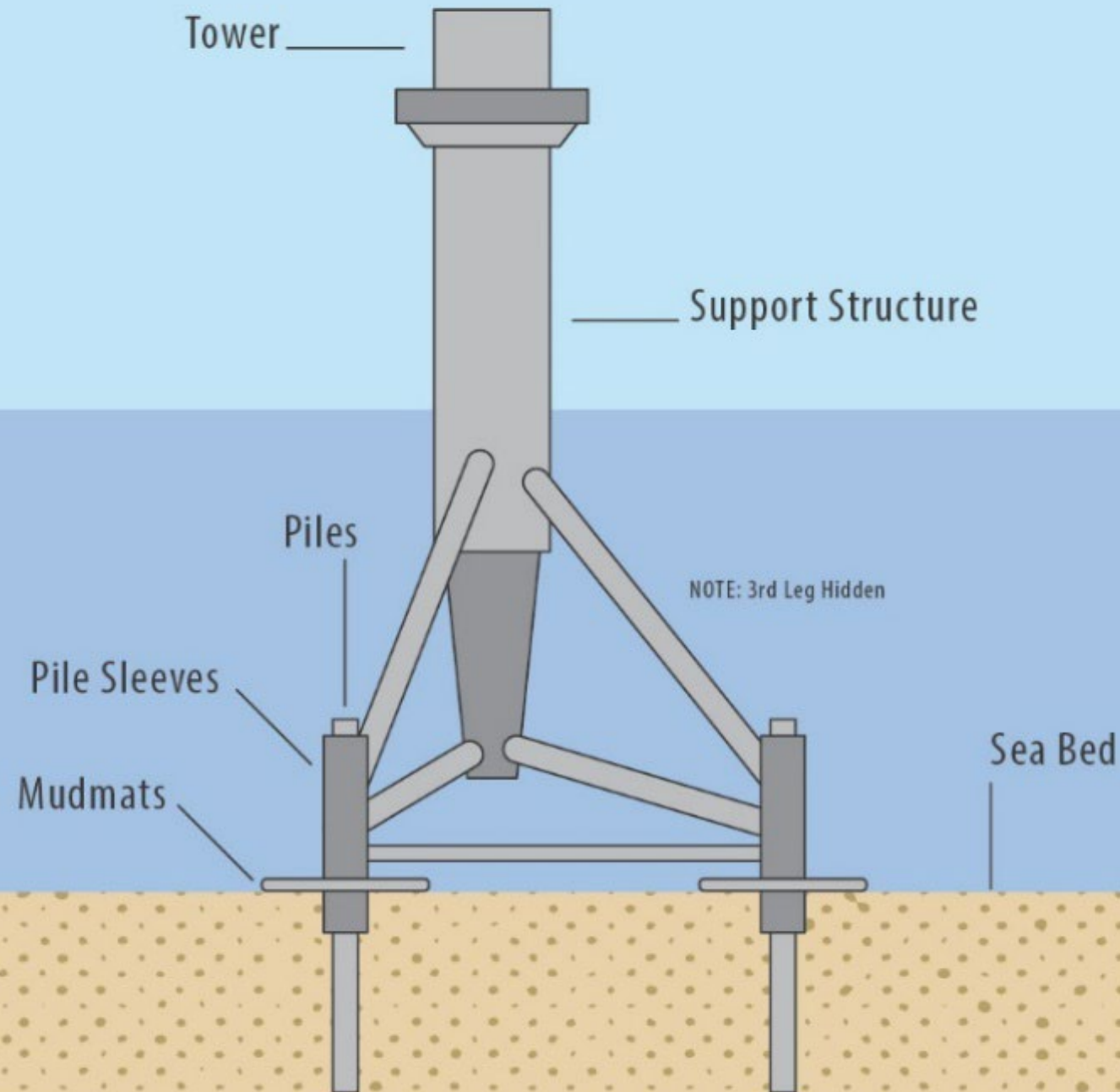
Installation

- Jacket anchored to the seabed with piles
- Piles may be driven before placement of the jacket using a template on the seabed, driven through the tubular jacket legs, or installed through external pile guides

Acoustic Effects

- Similar effects to monopile though the spatial scale of effects would be smaller.

Tripod Foundations



Description

- Tetrahedral (pyramid-shaped) space frame constructed from tubular steel members
- Cylindrical central column similar to a monopile, but it does not enter the seabed

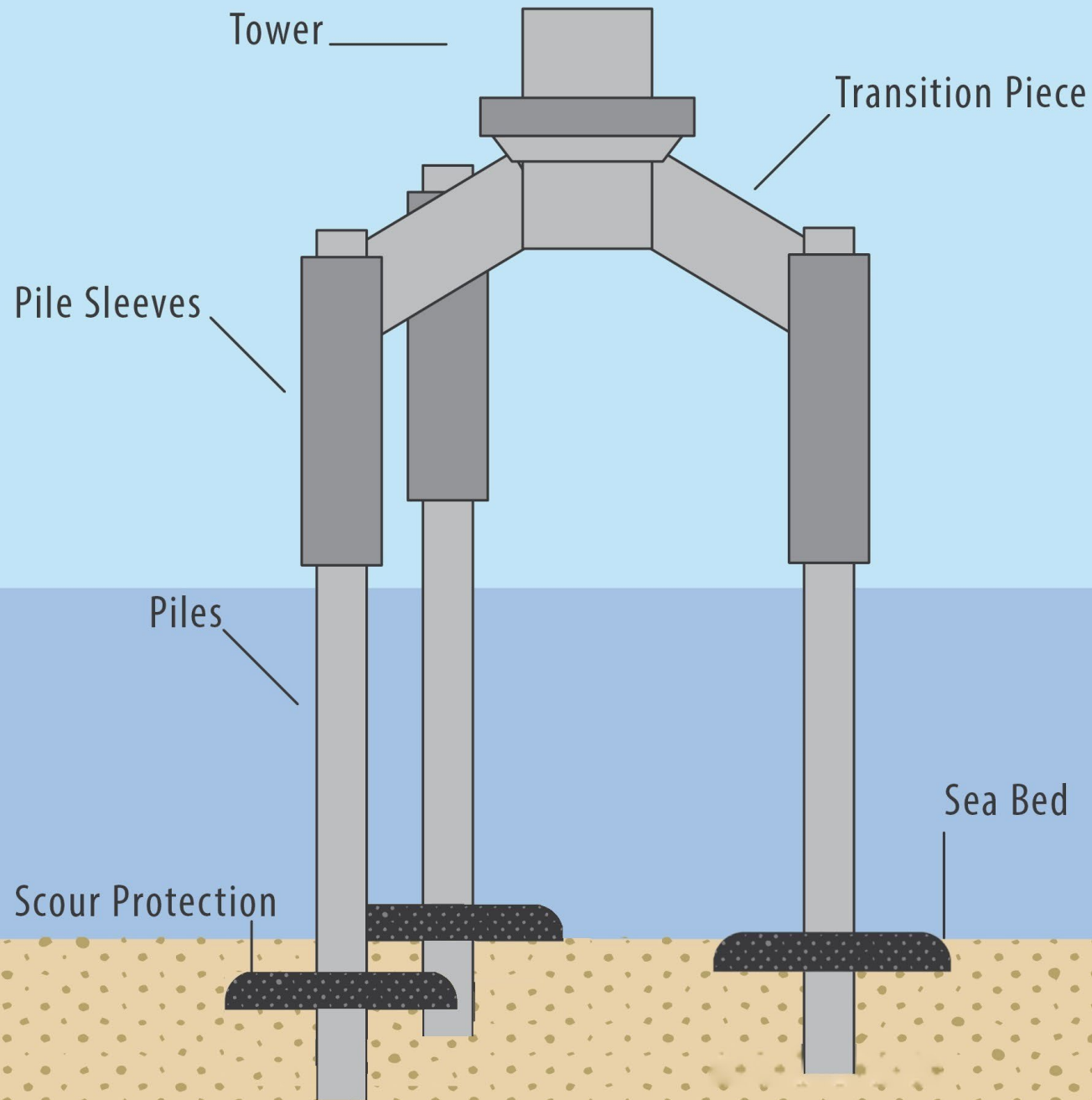
Installation

- Tripod anchored with piles or suction caissons at the corners of the triangular base

Acoustic Effects

- Piling has similar effects to monopiles though the spatial scale of effects would be smaller.
- Suction caissons cause minimal acoustic effects, relative to impact pile driving.

Tri-pile Foundations



Description

- Three cylindrical pile legs that connect to a transition piece above the waterline, forming a space frame that supports the wind turbine tower and turbine

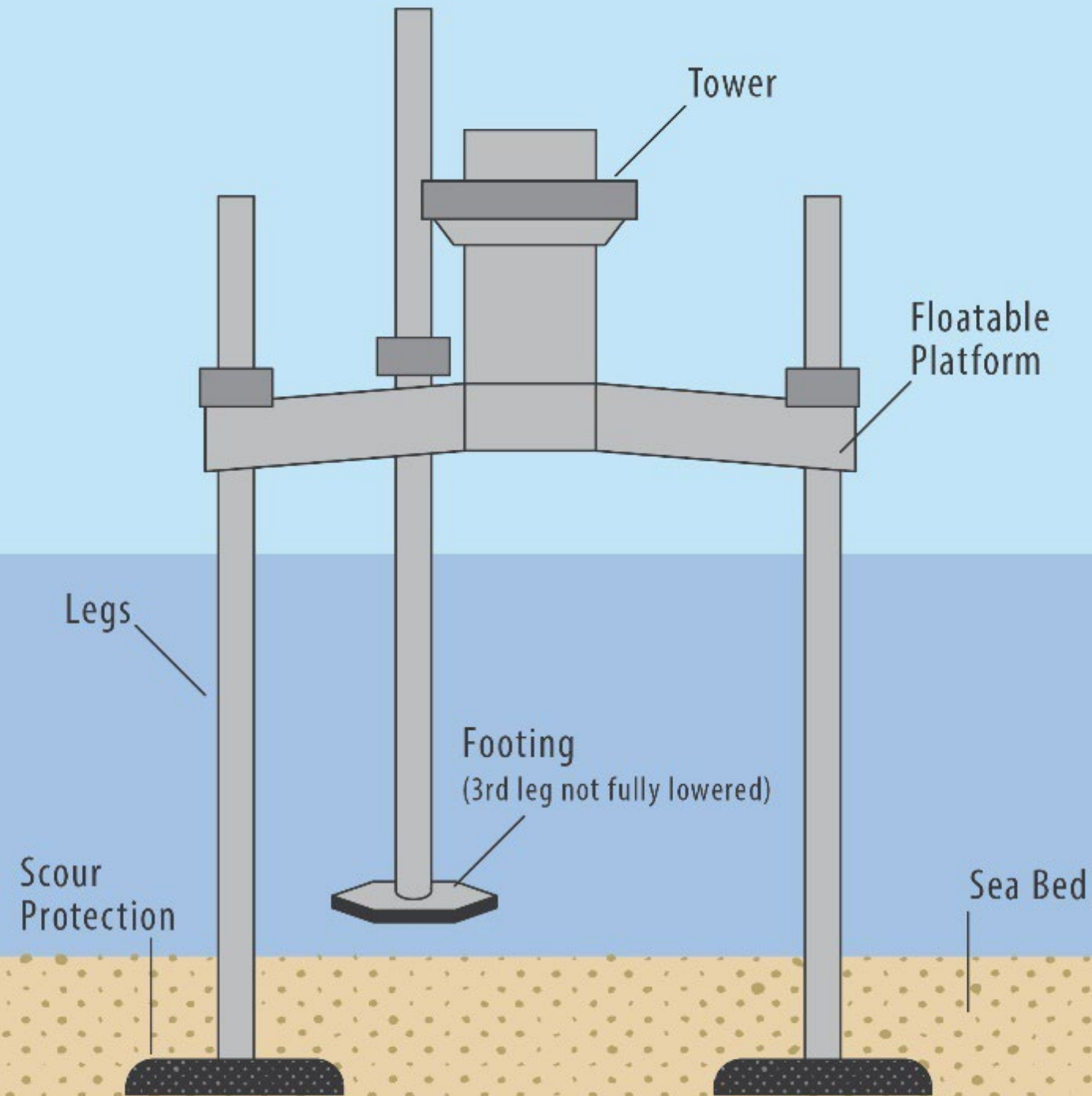
Installation

- Three foundation piles are hammered or vibrated into the seabed using a guide frame to maintain proper alignment to set the transition piece atop the piles.

Acoustic Effects

- Piling has similar effects to monopiles though the spatial scale of effects would be smaller.

Jack-Up Foundations



Description

- Floatable platform with three or four legs that can be raised and lowered relative to the platform

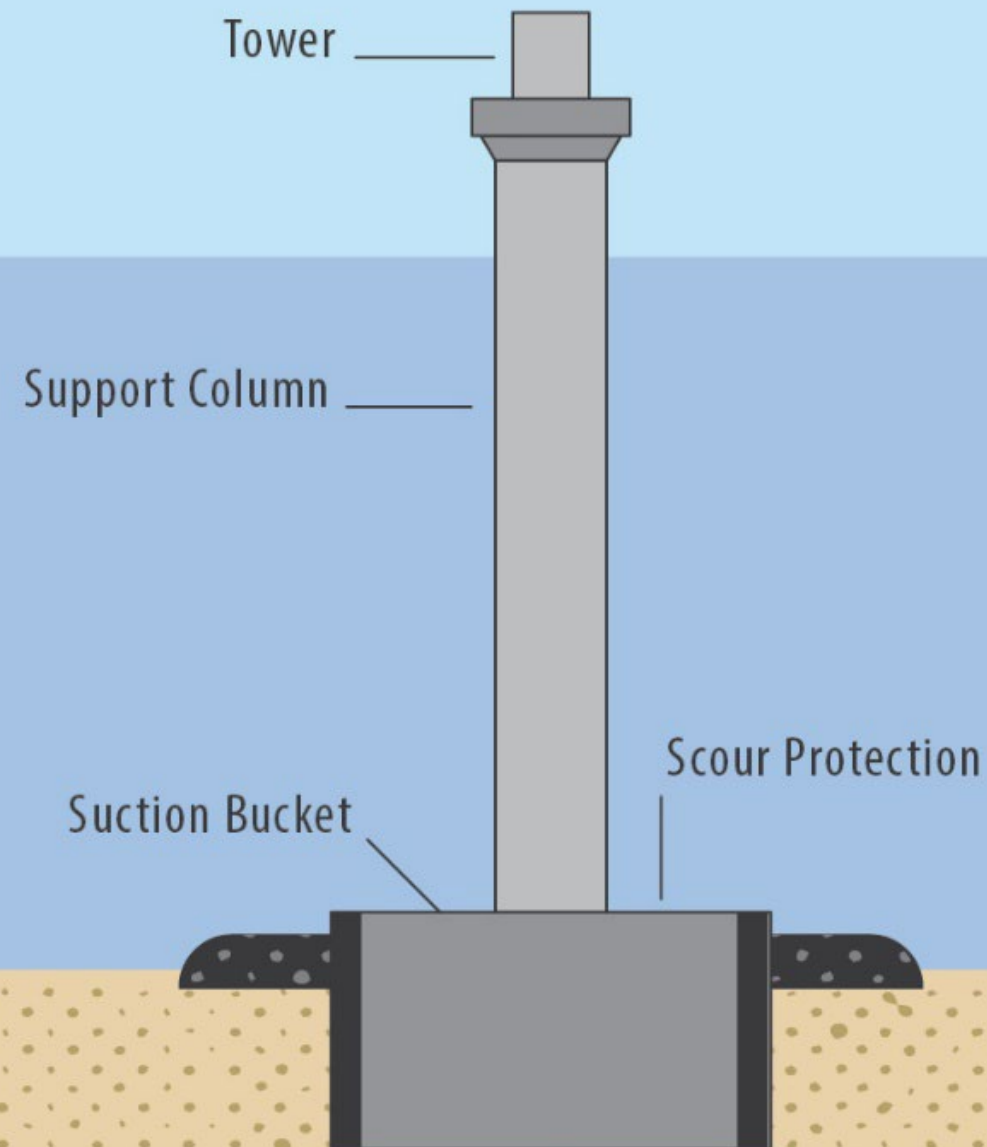
Installation

- The jack-up legs are lowered to the seabed
- The hull is jacked-up above the water surface

Acoustic Effects

- Jack-up foundations cause minimal acoustic effects, relative to impact pile driving

Suction Bucket Foundations



Description

- In its simplest form, a suction bucket foundation is a cylinder with an open bottom and a closed top.

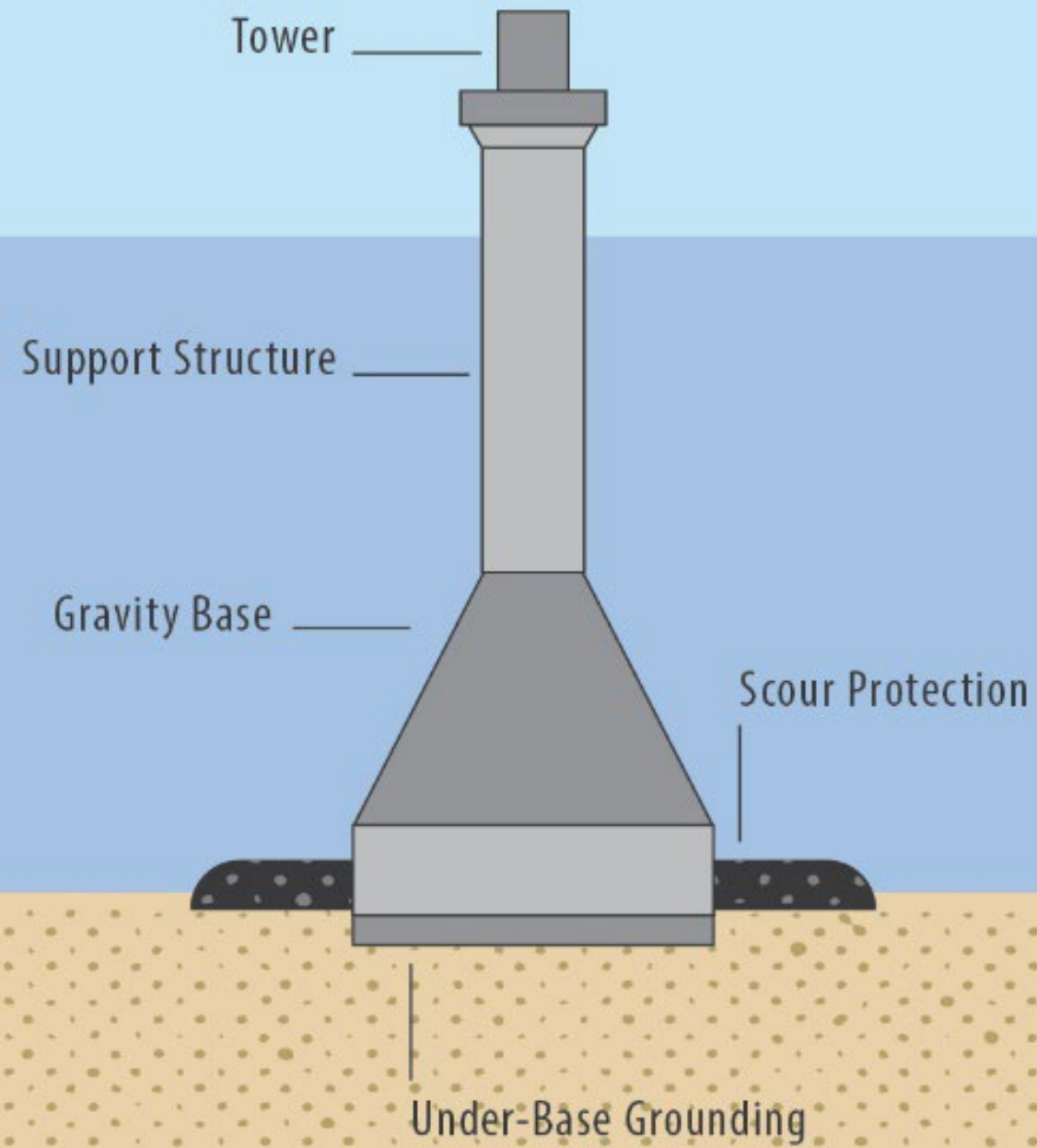
Installation

- Lowered to the seabed through controlled flooding until the suction bucket begins to penetrate the seabed
- Subsea pumps create a pressure differential by pumping water out of the suction bucket and forcing it deeper into the seabed.

Acoustic Effects

- Less effects than monopiles due to less noise inducing activities during installation.

Gravity Foundations



Description

- Gravity foundations, also known as gravity based structures (GBS), are structures with wide, heavy bases that sit on the seafloor and support the cylindrical central column.
- Most commonly made of reinforced concrete, but steel designs are also used.

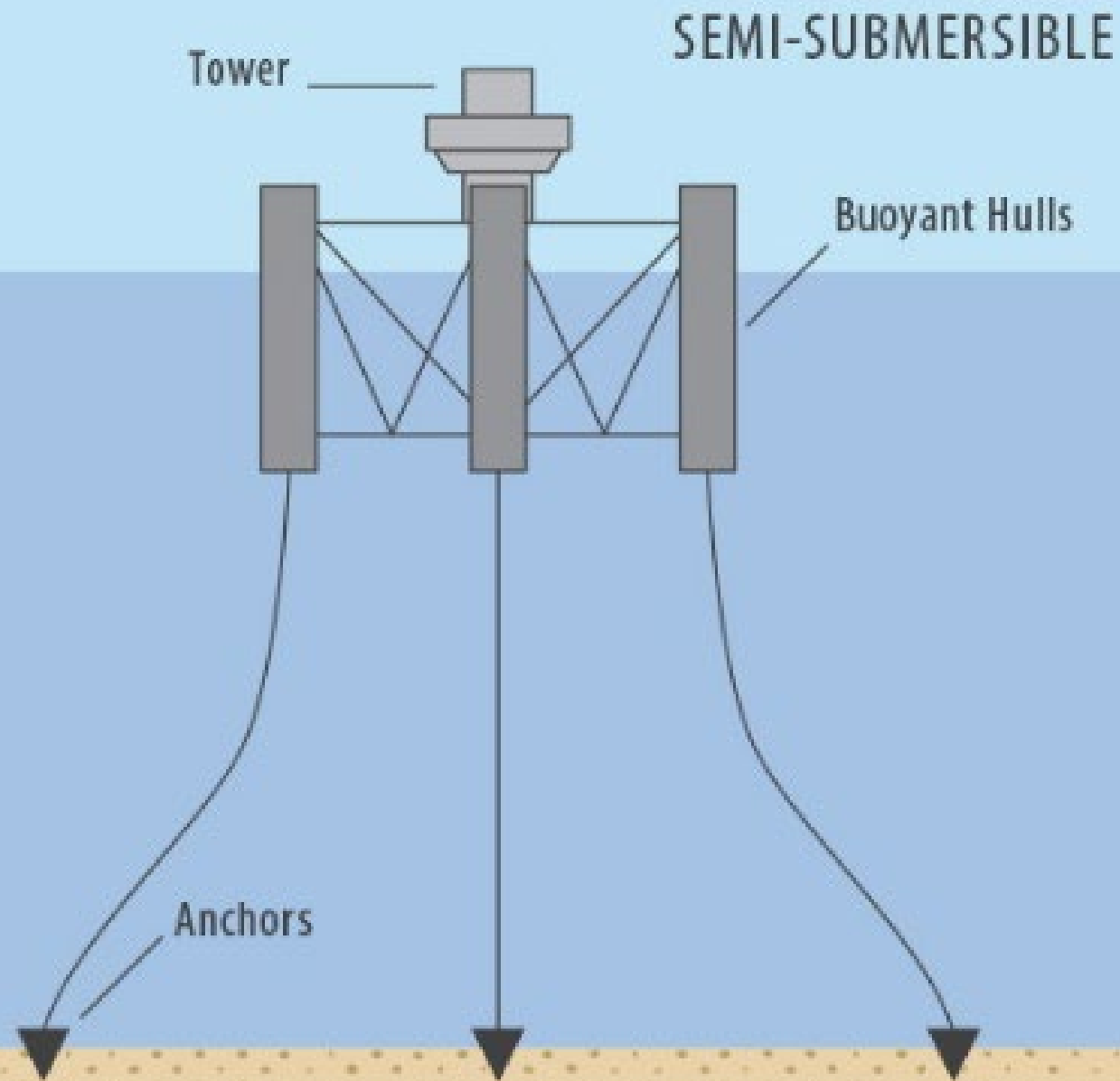
Installation

- Often require seabed preparation to create a flat and level area for the base.
- Seabed preparation may involve dredging or the buildup of a level gravel pad.

Acoustic Effects

- Less intense effects than pile driving but seabed preparation requires much more time.

Floating Foundations



Semi-submersible

Description

- Made of multiple hulls or submerged columns connected by braces with sufficient buoyancy to cause the structure to float and resist overturning

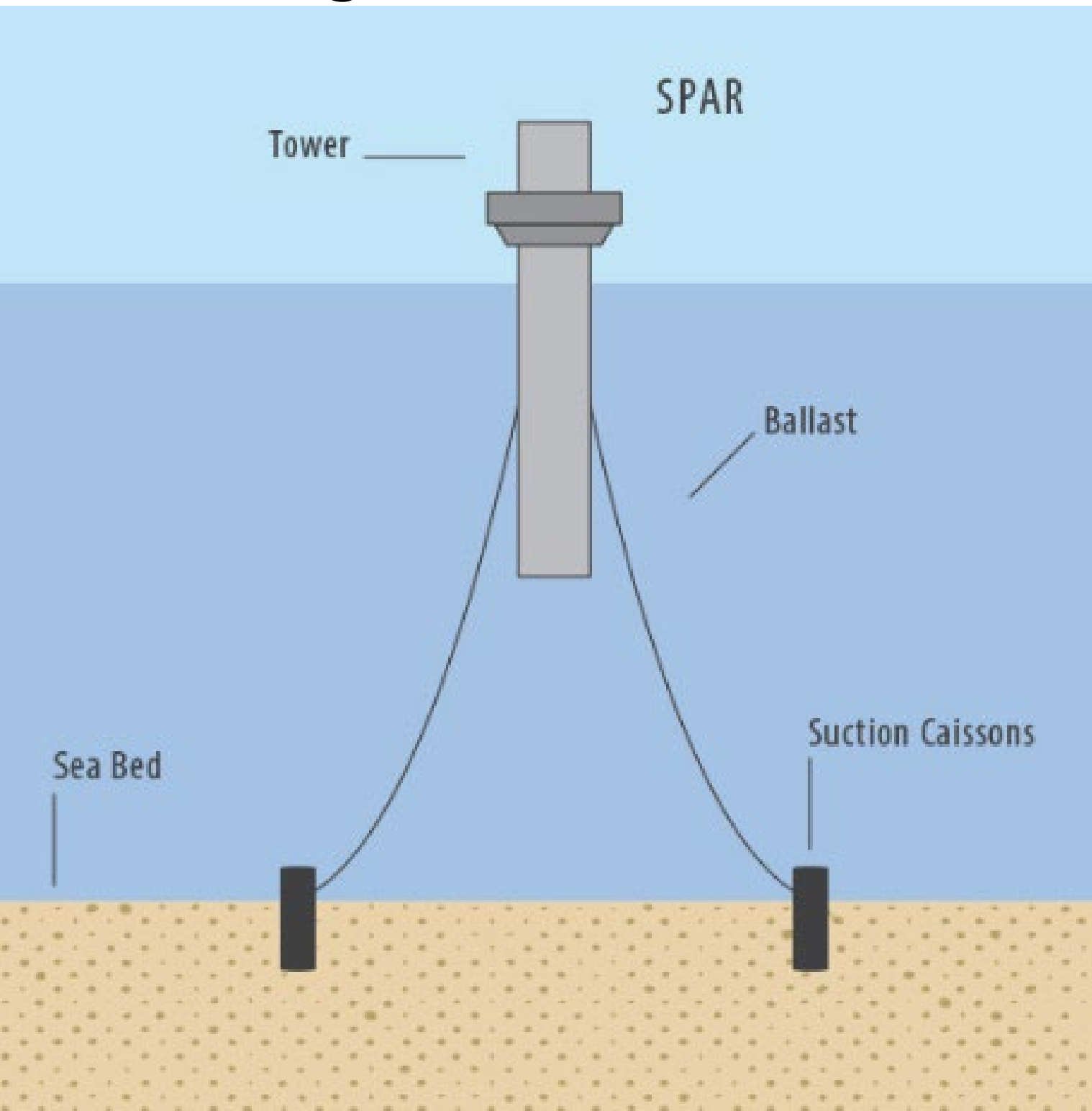
Installation

- An anchoring system is required primarily for station keeping.
- Anchors may be deadweight anchors, drag anchors, dynamically embedded anchors, driven piles, or suction caissons.

Acoustic Effects

- Smaller effects than monopiles if installed by piling (much smaller piles); less effects if installed by deadweight anchors, drag anchors, dynamically embedded anchors, or suction caissons.

Floating Foundations



Spar (or Spar Buoy)

Description

- Spars have a single ballasted cylinder that supports the tower and extends well below the waterline.

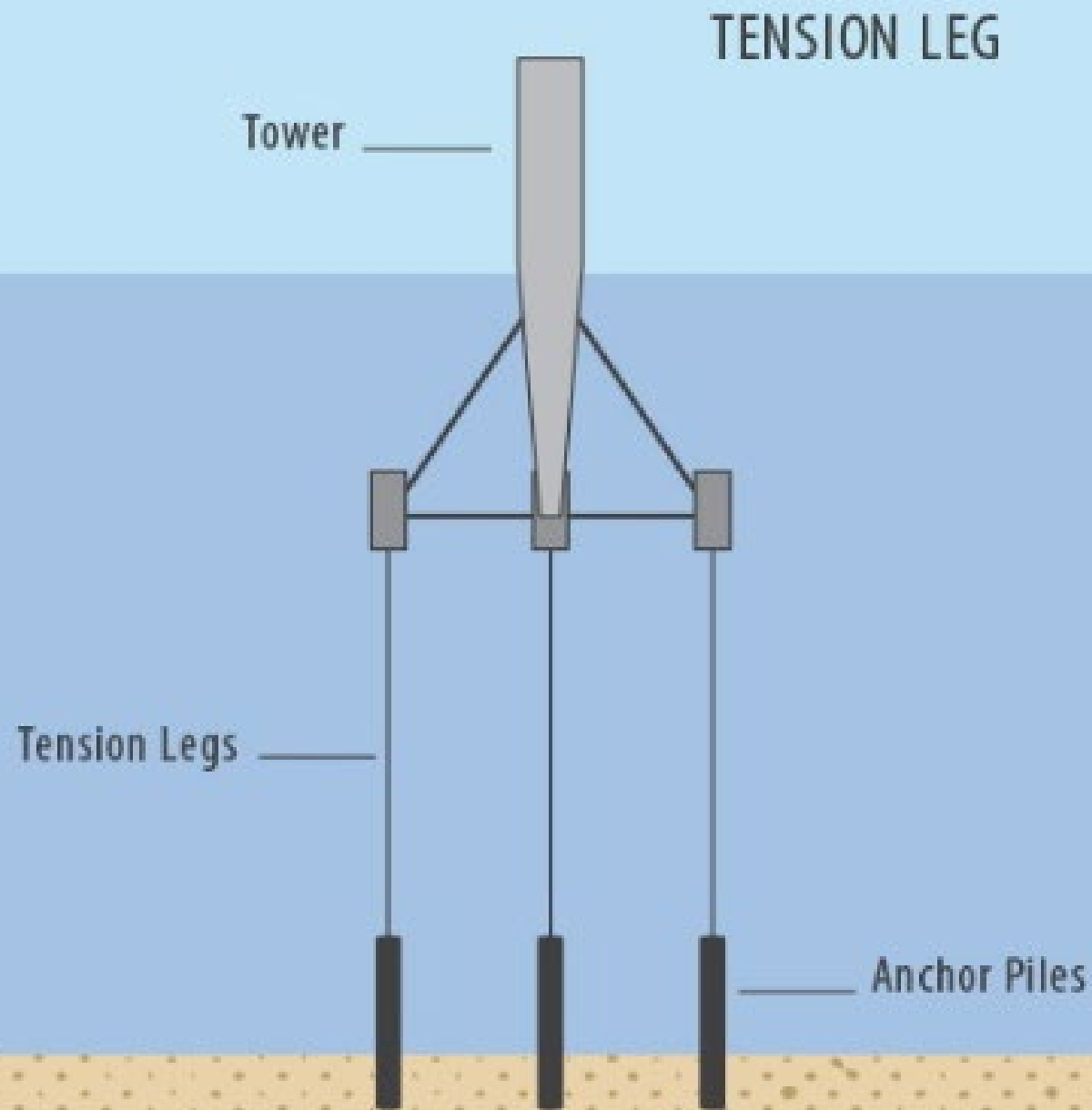
Installation

- An anchoring system is required primarily for station keeping.
- Anchors may be deadweight anchors, drag anchors, dynamically embedded anchors, driven piles, or suction caissons.

Acoustic Effects

- Smaller effects than monopiles if installed by piling (much smaller piles); less effects if installed by deadweight anchors, drag anchors, dynamically embedded anchors, or suction caissons.

Floating Foundations



Tension Leg Platform (TLP)

Description

- TLPs are buoyant multihull steel floating platforms.
- Moored to the seafloor by vertical tendons or tension legs to minimize vertical movement of the structure

Installation

- Most often anchored with piles or suction caissons for their greater and more reliable pullout resistance, compared to other anchors.

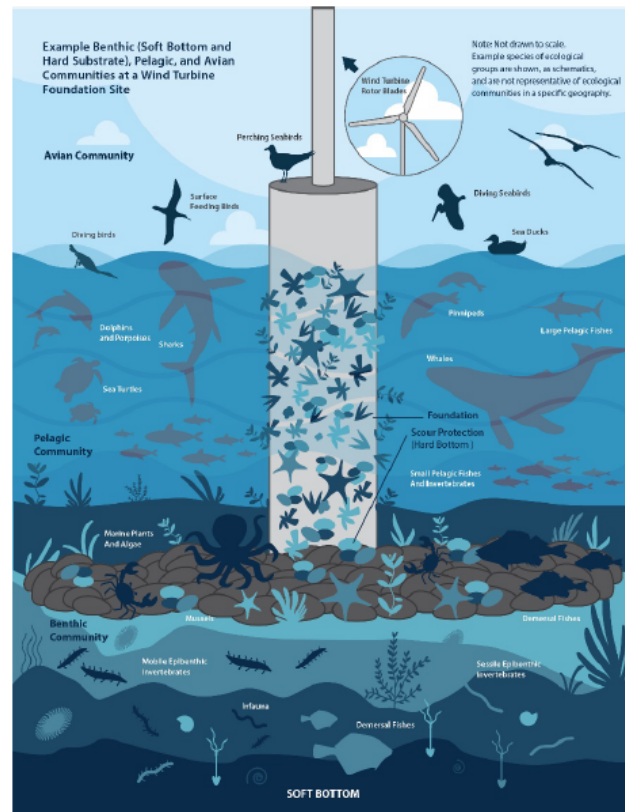
Acoustic Effects

- Smaller effects than monopile if installed by piling (much smaller piles)
- Suction caissons cause minimal acoustic effects, relative to impact pile driving.

For More Information

OCS Study
BOEM 2021-053

Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations



U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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<https://www.boem.gov/sites/default/files/documents/environment/Comparison-Environmental-Effects-Different-OWT-Foundations-2021.pdf>





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