Technologies for Offshore Structures in Extreme Environments

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frontier |ˈfrɑnˈti(ə)r| noun

• the extreme limit of settled land beyond which lies wilderness
• the extreme limit of understanding or achievement in a particular area

from the *Oxford English Dictionary*
Frontier areas in oil and gas

Unconventional

Arctic

Deepwater

Heavy Oil

Source: API
Why operate in frontier areas?

- Global energy demand will be about 30 percent higher in 2040 compared to 2010
- Through 2040, population and economic growth drive energy demand
Where is the demand coming from?

- OECD energy demand remains flat even as GDP nearly doubles
- Non OECD energy demand rises by nearly 60% to 2040
How are we meeting the demand?

- Oil and natural gas meet approximately 60% of the energy demand in 2040
  - Total from fossil fuels is approximately 80%
- Wind is the fastest growing energy source (900% increase from 2010 to 2040), but by 2040 wind/solar/biofuel meets only 4% of total demand
Engineering challenges in the Arctic

- Mobile pack ice and icebergs
- Severe storms and waves
- Prolonged darkness
- Earthquakes (some areas)

- Sensitive environment
- Low temperatures
- Remote location
- Permafrost
Sakhalin Island

The cold currents which wash both sides of Sakhalin flow down from the northern islands, where even at the end of summer there are ice floes. The eastern bank, being more open to the currents and icy winds, takes the full brunt of the buffeting. Here nature is absolutely grim.

*The Island: A Journey to Sakhalin* by Anton Chekhov

- Sea ice present 6-7 months/year
- Seismically active
Arkutun-Dagi platform

- Located 25km offshore in 35m water depth
- Concrete gravity-based structure (GBS) with integrated topsides
  - GBS caisson: 130m × 100m
  - Topsides weight: 50,000 te
  - 10 stories tall (top of quarters)
- GBS constructed hundreds of miles away and towed to site
- Topsides constructed separately and mated to GBS onsite
Resisting Ice Loads with a GBS

- Ice loads are horizontal loads that can be up to 50% of the structure’s weight.
- A GBS resists horizontal loads by virtue of its own massive weight:
  - Concrete
  - Solid ballast
  - Water ballast
GBS construction

Construction in drydock
GBS construction

Nearshore construction while moored & floating
GBS construction

Topsides mating (max hydrostatic pressure)
GBS construction

Tow to field
GBS construction

Installation
Seismicity at Sakhalin
Basics of base isolation

Conventional:
Structures absorb earthquake’s energy through inelastic action (damage) at controlled locations

Base Isolated:
- Superstructure is “isolated” or decoupled from the substructure or foundation
- A flexible interface elongates the natural period of the structure, leading to reduced accelerations
  - Interface must be designed to accommodate large displacements and provide restoring force
Friction Pendulum Bearing (FPB)

- Mid 1980’s - FPBs first used onshore for seismic isolation of buildings
- Mid 2000’s - First FPB application offshore, Shell Lunksoye-A and Piltun-B concrete GBSs (Sakhalin-2)
- Present – EM use on Arkutun-Dagi (Sakhalin-1)
  - Entire topsides (50,000 te) supported on 4 bearings
  - Largest gravity loads ever
    - 2x Shell’s platforms
    - 100x ‘typical’ onshore
Probabilistic seismic design factors

Basic Design Equation

\[ \frac{\gamma}{\lambda} D \leq \phi C \]

Median response in 7 EQ
Required Capacity

Demand (Load) Factor
Capacity (Resistance) Factor

- Designing for multiple hazards requires designing to a consistent target reliability for each hazard
- Required capacity ‘C’ is the response having probability of exceedence of 2% in 50 years (with a specified confidence level)
  - Different factors for FPB displacement, member forces, etc.

Design Factors for each response parameter

\[ \gamma = \exp \left( \frac{k}{2b} \beta_D^2 \right) \]
\[ \phi = \exp \left( - \frac{k}{2b} \beta_C^2 \right) \]
\[ \lambda = \exp \left[ k \left( \beta_{UT} - \frac{k}{2b} \beta_{UT}^2 \right) \right] \]
Key Takeaways

- Meeting the future needs for global energy demand requires the Oil and Gas Industry to operate in frontier areas
  - Geographic frontiers
  - Technological frontiers
- The Arctic is an important frontier area with large potential to help meet future energy needs
  - USGS estimates that 25% of the world’s remaining undiscovered hydrocarbon reserves are in the Arctic
- Heavy, gravity-based structures are used offshore to resist ice loads
- Specialized protective devices have been used to reduce earthquake acceleration demands on topsides facilities
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