Virtually every structure is supported by soil or rock.

Those that aren’t either fly, float, or fall over.

- Richard L. Handy, 1995
The Offshore Industry
Historical perspective

• First well drilled out of sight of land in 1947 in 6.0m w.d.
  Today, we are drilling in 3000m
• First offshore platform installed in 1947 in 6.0m
  Today, platforms are installed in depths exceeding 2500m
• World’s tallest structure was installed offshore in 1979 in 114m
  Today, a fixed platform stands in excess of 550m
• First subsea tree installed in early 1960’s in less than 90m
  Today, subsea trees are installed in over 2750m

The Offshore Industry - India
Historical perspective

• Offshore Oil & Gas Exploration
• Sagar Samrat - Jack up Rig
• Commercial find – Mumbai High – Western Offshore India
  First offshore platform – NA Platform 1977
• Eastern Offshore India
  Subsea Structures in 1200m water depth KG Block
Offshore Geotechnical Activities at IITD
Historical perspective

- Thermal conductivity of marine soils
- Engineering properties of Carbonate soils
- Engineering properties of Corals and carbonate clays
- FEM code – Wave Induced Soil Movements
- Marine Anchors
Offshore Structures
Bottom supported structures

- Jacket
- Jack-up rig
- Gravity base
- Compliant Tower

Spud can 14~22m dia.

Offshore Structures
Floating structures

- Tension Leg Platform (TLP)
- Semisubmersible
- SPAR
- FPSO
What makes offshore very different?

Site investigations: Extremely expansive, hire costs – several millions of dollars (Suitability of vessel to operate in the given environment, opportunity costs)

Soil Conditions: Unusual, various types (particularly – Carbonate/Calcareous, Corals)

Applied Loads: Large, high component of environment loads, large lateral loads as compared to weight of structure Loads - Static, Cyclic, Dynamic, Transient

Design modifications: During construction – generally not possible, Remedial measures – very expansive, incur severe cost penalties

Installation: Logistics – Marine spread, weather window, magnitude

Expect the Unexpected

“...as we know, there are KNOWN KNOWNs:

there are things we know.

We also know there are KNOWN UNKNOWNS:

that is to say we know there are some things we do not know.

But there are also UNKNOWN UNKNOWNS:

the one’s we don’t know we don’t know.”

Former U.S. secretary of Defence Donald Rumsfeld
Soil Types – Offshore Environment

Gulf of Mexico - Soft Clays, delta area – Wave induced soil movement & slope failures, Pile-soil set up

North Sea – Stiff to Hard Silty, Bouldry Clays (OC Clays) – Pile driving problems

Middle East – Cemented Sands, Calcarenite, Hard Clays, – Pile refusal, Pile relaxation, pile acceptance

Australia – Carbonate soils – Low capacity, remedial measures

Brazil – Dense Sands

Western Africa – Stiff to Hard Clays (NC To OC Clays)

South China Sea – Soft Clays/ Dense Sands

India Western Offshore – Calcareous/ Carbonate, Corals - Soils (High Spatial Variation), shifting sands, hard clays, soft soils

India Eastern Offshore – Very Soft to soft Clays (U/C to NC Clay) Deltaic regions - Collapsible, Wave induced soil movements & slope failures

Offshore Structure Foundation Types

Deep Foundations or Pile foundation

Shallow foundation
Gravity based structure
Jacket – Bucket Foundations
Hybrid Structures
Tension Leg Platform (TLP)

Anchoring system
TLPs
FPSO
FPS
SPAR

Jacket Structures
Tension Leg Platform (TLP)
Compliant Towers

General multi-footing Structures
Spud can

Anchoring system
TLPs
FPSO
FPS
SPAR
### Jacket Installation

![Jacket Installation Images]

### Pile Foundations for Jacket Structures

- Usually open ended steel pipes
- Variable wall thickness
- Variable strength
- Long deep penetrations
- Single pile or pile group per leg

**Typical properties of offshore piles**
- Diameter: 610 to 3000 mm
- Variable wall thickness: 16 to 95 mm
- Variable strength: 245 to 350 MPa
- Long deep penetrations: 30.0m to 150.0m
- Installation in number of sections or single length

**Typical loads**
- Axial: 10 to 100 MN/pile
- Lateral: ~1 to 5 MN/pile
Pile Installation

• Impact Driven Piles
  Pile Driving – Impact Hammers
  - Steam Hammers
  - Hydraulic Hammers
  - Diesel Hammers
  Pile Driving – Vibratory Hammers

• Drilled & Grouted Piles

Pile Installation through Jacket Legs

Main Piles
  • Through jacket legs
  • Driven by hammer
  • Secured by welding shims to jacket legs & if required secured also by grouting the annulus
Pile Installation through Skirt Sleeves

- Through Sleeves
- Driven with underwater hammer or chaser pile
- Secured by grouting the annulus

Pile Installation – Drilled & Grouted
Drilled & Grouted Piles

Likely use of drilled & grouted piles

Very Stiff to Hard clays
Cemented soils
Calcareous soils

Possibility of refusal at shallow depths

Diameter 24 in to 120 in
Length 100 ft to 500 ft
Oil Well Conductors
- 18 in to 26 in
- more than 1500 ft

Installation Problems
Gravity Based Structures (GBS)

Malampaya GBS
Foundation loads

- Self weight of structure and foundation system
- Wind, wave and current forces acting on substructure (H,M)
- VHM foundation loads
The Maureen Alpha platform is a steel gravity base structure with a weight of 112,000 ton, height of 241 meters and steel skirts for penetration into the seabed.

On June 27, 2001 the gravity based Maureen Alpha Platform, located in the Maureen Field at the U.K. Continental Shelf Block 16/29a, was successfully removed and towed to the western coast of Norway for demobilization and possible re-use.
Bucket foundations

Jack-up Rig
Jack-Up Hazards

- Seabed obstructions metallic or otherwise
- Leg penetration, raising the hull + preloading
- Buried items anchors, pipelines
- Seabed irregularities footprints pockmarks, reefs, pinnacles
- Seabed inclination
- Buried inclined hard layer
- Adequate leg length
- Rapid leg penetrations
  - Punch-through
  - Geo-hazards (mudslides, mud volcanoes, seismic activity, faults etc.)
  - Gas pockets / Shallow gas
  - Drilling control flushing in conductors – poor cement : gas
  - Scour
  - Storm vertical settlement and sliding
    - Unit removal
    - Leg extraction difficulties

Punch through Failure

- Punch-through failure during preload
- Punch-through failure due to storm overloads
Scour around jack-up footings can increase punch-through risk

Historical Back Ground
Compliant Towers – Piled, Articulated, Guyed

- A compliant tower is similar to a traditional jacket platform and extends from surface to the sea bottom.
- Unlike jacket platforms, a compliant tower is designed to flex with the forces of waves, wind and currents.
- The first tower emerged in the early 1980s.
- Compliant towers are designed to sustain significant lateral deflections and forces, and are typically used in water depths ranging from 1,500 and 3,000 feet (450 and 900 m).
- At present the deepest is Petronius in 535 m of water.
Floating Structures - Anchoring Systems
Drag Anchors

High Holding Power Drag Anchors
Anchor Handling Tug (AHT) in Action

Plate Anchor Types

Drag Embedment  Direct Embedment (SEPLA)
Drag Embedment

OMNI-DIRECTIONAL DENLLA - 14m²

Dimensions in millimetres

SOFT CLAY
A: Deployment B: Installation
C: Forward WDL Mode D: Recovery (unstoppaged)
E: ROOR Mode (for Omni-Directability)

SAND & STIFF CLAY
A: Locked Down Deployment / Installation / Recovery

Part-I Foundation Concepts

January 31, 2014
Drag Embedded Vertically Loaded Anchors

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower weight.</td>
<td>Requires drag installation, keying &amp; proof testing; limited to bollard pull</td>
</tr>
<tr>
<td>Smaller: fewer trips to transport full</td>
<td>of installation vessel.</td>
</tr>
<tr>
<td>anchor spread to a site.</td>
<td>Requires 2 or 3 vessels &amp; ROV.</td>
</tr>
<tr>
<td>Well developed design &amp; installation procedures.</td>
<td>No experience with permanent floating facilities.</td>
</tr>
<tr>
<td></td>
<td>Difficult to assure installation to, and orientation at, design penetration</td>
</tr>
</tbody>
</table>

Suction Anchors

- Stiffened cylindrical shell
- D: 2.5-8.0m  L: 5-20m
- Open base and enclosed top.
Group Suction Anchors
## Suction Anchors

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple to install accurately w.r.t. location, orientation &amp; penetration.</td>
<td>Heavy; Derrick barge may be required.</td>
</tr>
<tr>
<td>Leverage design experience with driven piles.</td>
<td>Large; more trips to shore to deploy full anchor spread.</td>
</tr>
<tr>
<td>Well developed design &amp; installation procedures.</td>
<td>Requires ROV for installation.</td>
</tr>
<tr>
<td>Anchor with the most experience in deep water for mooring MODUs and</td>
<td>Requires soil data from advanced laboratory testing for design.</td>
</tr>
<tr>
<td>permanent facilities</td>
<td>Concern with holding capacity in layered soils.</td>
</tr>
<tr>
<td></td>
<td>Lack of formal design guidelines.</td>
</tr>
<tr>
<td></td>
<td>Limited data on set up time for uplift.</td>
</tr>
</tbody>
</table>

### Suction Embedded Anchors (SEA)
SEA opening trajectory
1. Embed SEA using suction follower
2. Release rigging
3. Open SEA by reversed suction process
4. SEA ready for use
Holding Capacity of SEA

- **SEA Capacity**
- High capacity vs. own weight ratio (100:1)
- Independent on load angle

Follower + SEPLA Anchor (Suction Embedded Plate Anchor)
Suction Embedded Plate Anchors (SEPLA)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses proven suction caisson installation methods.</td>
<td>Proprietary or patented installation.</td>
</tr>
<tr>
<td>Cost of anchor element is the lowest of all deep water anchors.</td>
<td>Installation time about 30% greater than for suction piles/ caissons &amp; may require derrick barge.</td>
</tr>
<tr>
<td>Provides accurate measure of penetration &amp; positioning of anchor plates.</td>
<td>Requires keying &amp; proof testing: limited to bollard pull of installation vessel; also requires ROV.</td>
</tr>
<tr>
<td>Design based on well developed design procedures for plate anchors.</td>
<td>Limited field load tests and applications.</td>
</tr>
<tr>
<td></td>
<td>Limited in numbers to MODU only.</td>
</tr>
</tbody>
</table>
Deep Penetrating Anchor (DPA)
(Torpedo Anchor)
(Dynamically Penetrating Anchor)

Dynamically Penetrating Anchor Installation

13–15 metre-long 80–110-ton anchor
Dynamically Penetrating Anchor

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple to design: Conventional API RP 2A pile design procedures –</td>
<td>Proprietary or patented.</td>
</tr>
<tr>
<td>calculations readily accepted by certification agencies.</td>
<td>No experience outside Brazil.</td>
</tr>
<tr>
<td>Simple &amp; economical to fabricate.</td>
<td>Lack of documented installation &amp; design methods</td>
</tr>
<tr>
<td>Robust &amp; compact design: handling &amp; installation simple and economical</td>
<td>with verification agencies.</td>
</tr>
<tr>
<td>using 1 vessel and No ROV.</td>
<td>Verification of verticality.</td>
</tr>
<tr>
<td>Accurate positioning with no requirements for specific orientation and</td>
<td></td>
</tr>
<tr>
<td>proof testing during installation.</td>
<td></td>
</tr>
</tbody>
</table>

Driven Anchor Piles
Part-I Foundation Concepts

Seabed Pile Driving Frame & Underwater Hammer

Foundations for offshore wind farm structures

- Shallow Foundations
- Mono Piles
- Bucket Foundations
- GBS
- Jacket Structures
  - Piles
  - Shallow
- Floating - Anchored
Questions

These presentations are for the purpose of generating awareness in the field of Marine Geotechnology and Foundations for Offshore structures with no commercial intent.

Reference:
The list below is not exhaustive.

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Thank you for your attention