GOOD TECHNOLOGY, BAD SEABEDS & UGLY LOADS

Reliably Anchoring FLNGs in Cyclone Alley

Ben Holland

Senior Geotechnical Engineer - Fugro AG

Safety Moment

www.youtube.com/user/drunkarmyguy

Topics

- FLNG
- Metocean Assessment
- Mooring Design
- Seabed Conditions
- Anchor Options
- Closing Remarks

Topics - FLNG

- **FLNG**
- Metocean Assessment
- Mooring Design
- Seabed Conditions
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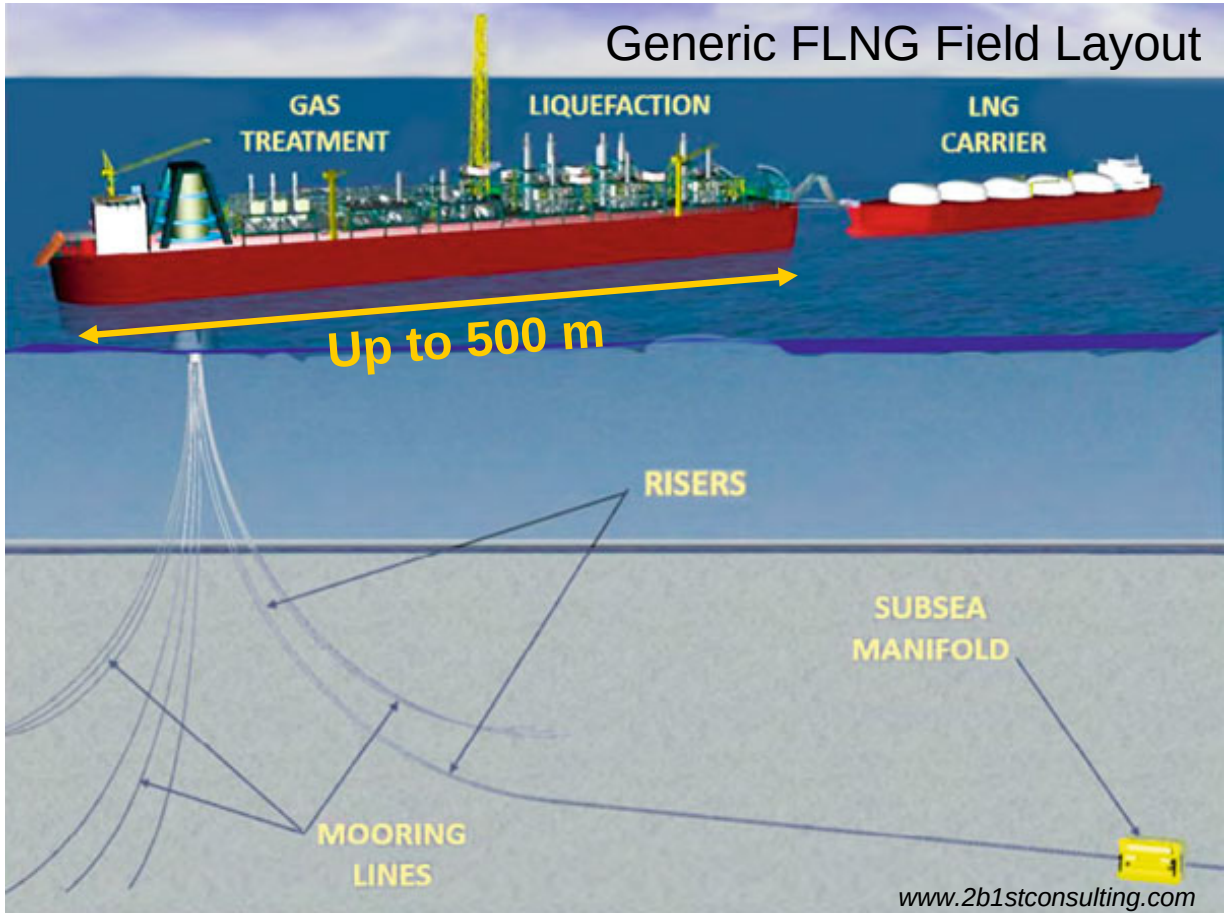
FLNG Vessels

- They are BIG!
- Up to:
  - 500 m Long
  - 100 m High
  - 75 m Wide
  - 600,000 ton
- Permanently Anchored
  - No running away from cyclones
  - Survivability design of anchors
  - Can't risk breaking the mooring



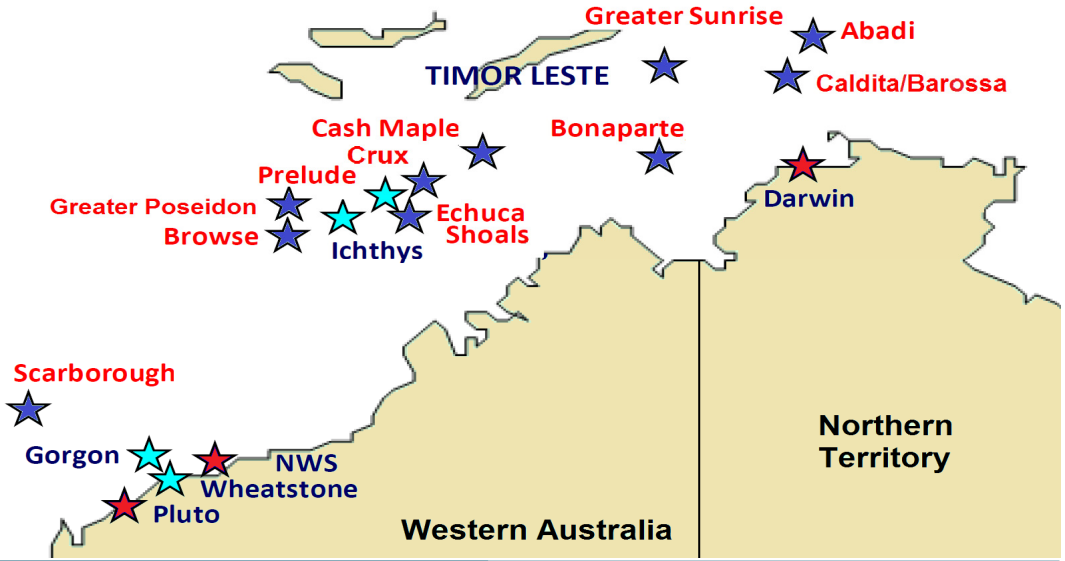
FLNG Prospects in the News

Australia

- **Prelude FLNG**
- Browse FLNG
- Scarborough FLNG
- Bonaparte FLNG
- Greater Poseidon FLNG
- Caldita/Barossa FLNG
- Cash Maple FLNG
- Sunrise FLNG
- Crux FLNG

Asia

- **Malaysia FLNG: Petronas**
- Abadi FLNG
- Malaysia FLNG 2: Petronas
- PNG FLNG



Topics – Metocean Assessment

- FLNG
- **Metocean Assessment**
- Mooring Design
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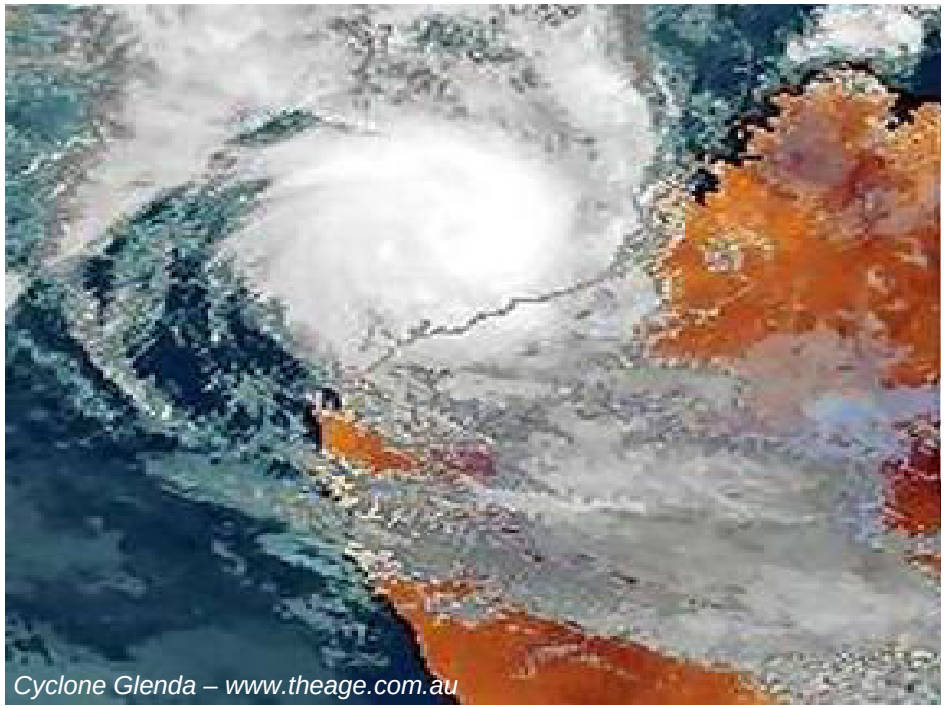
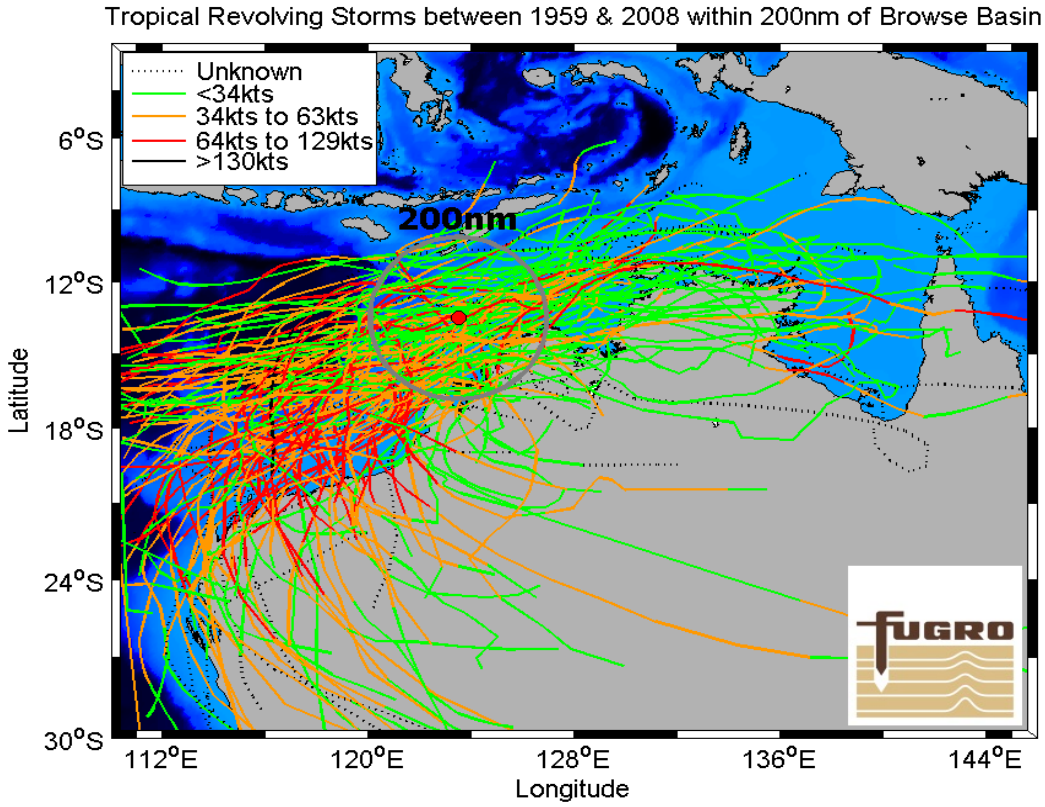
Metocean Conditions

- Cyclone Prone Region
  - High density of sever tropical cyclones pass along the NW of WA.

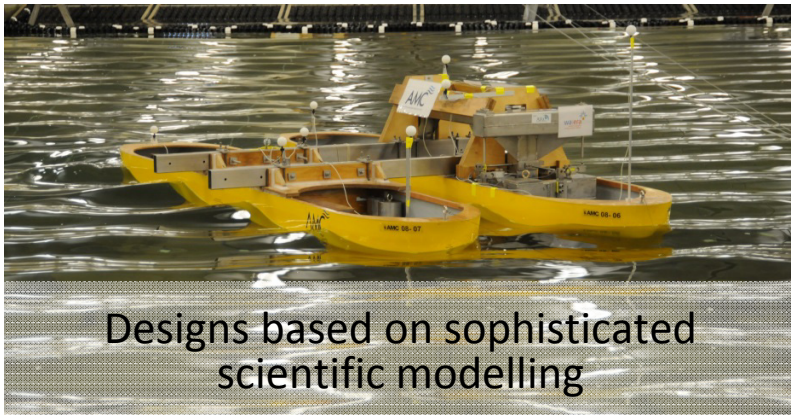




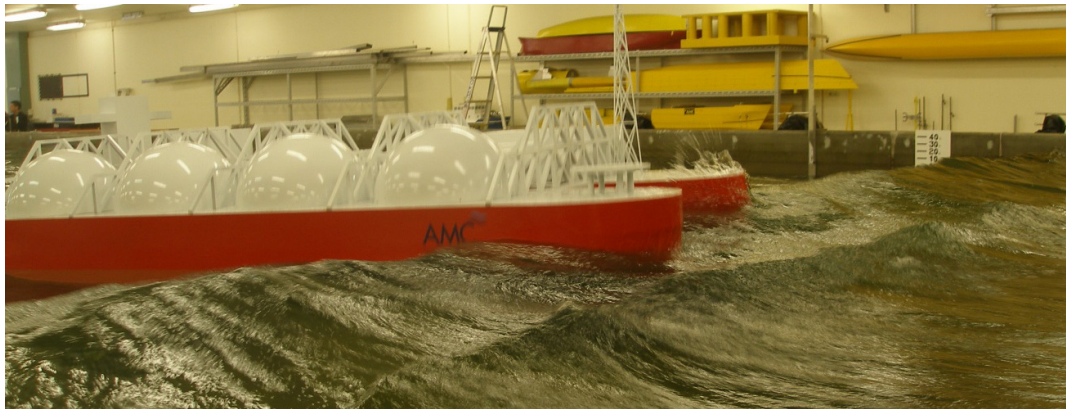
Metocean – Model Tank Tests

- Designed to successfully operate in and survive the severest seastates on the planet

Designed to remain stable and safe in unaligned and highly complex wind, waves and currents



Designs based on sophisticated scientific modelling



GasCat images shown with thanks to the technologists at Woodside Energy and the Australian Maritime College.

Metocean – Model Tank Tests

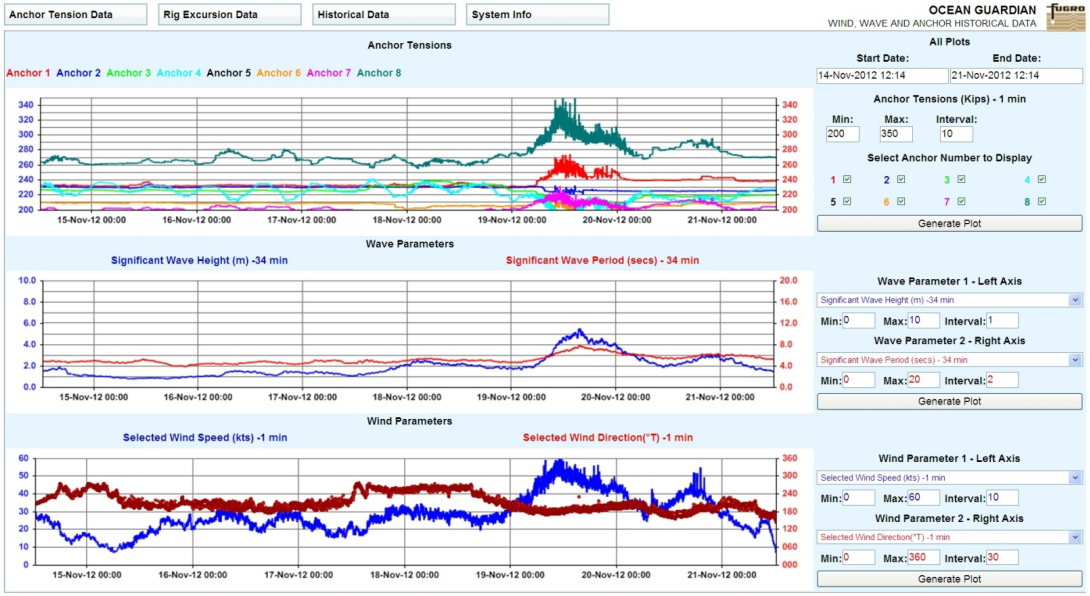
GasCat images shown with thanks to the technologists at Woodside Energy and the Australian Maritime College.

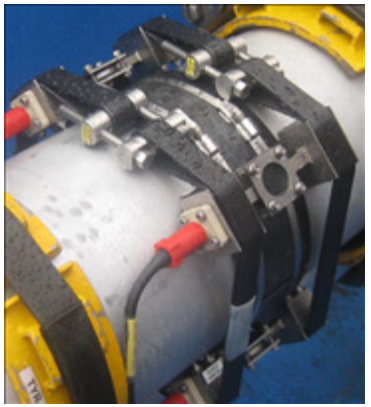
Metocean – Picture the Loads

- Unrestrained vessels will undergo significant motions during storms.
- Significant loading of the mooring system to mitigate the vessel motions.

Metocean Measurement

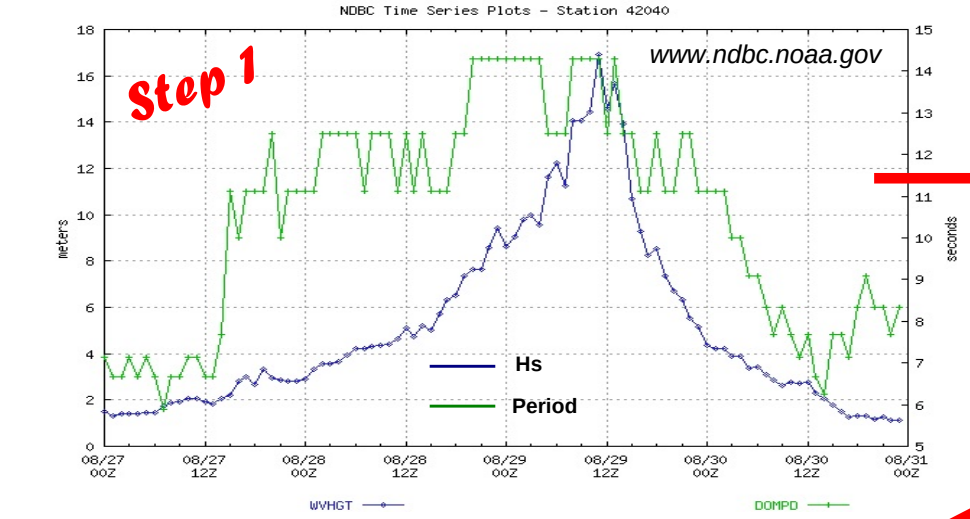
- Recording of metocean conditions over an extended period
  - Wind, wave, current & sea level
- Metocean measurements used to model a design storm
  - Modelling assumptions drive the severity of the design storm
- Real-time monitoring for FLNG vessel operation and fatigue analysis

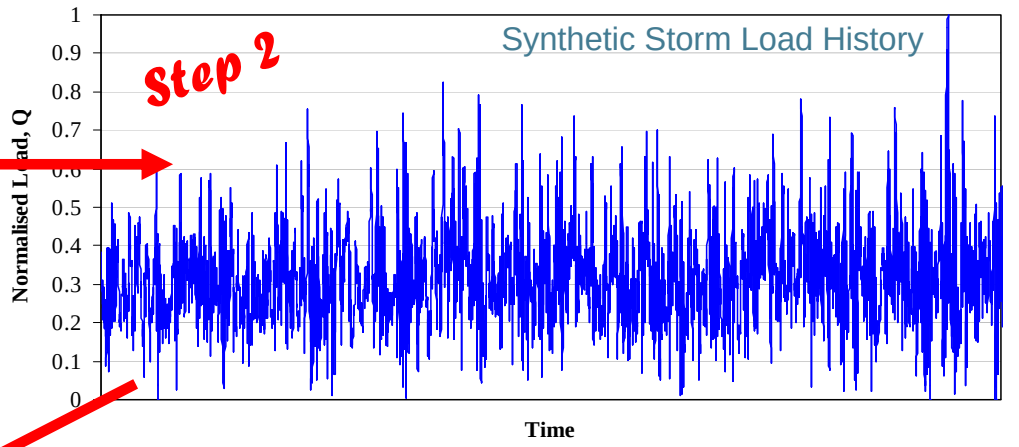


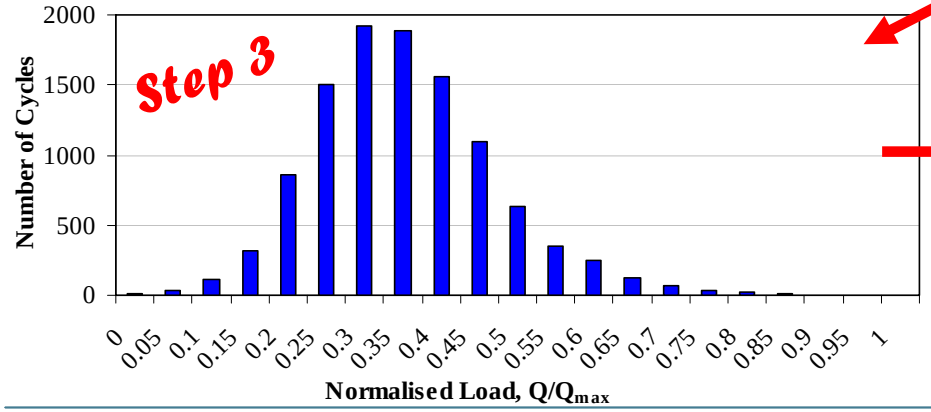


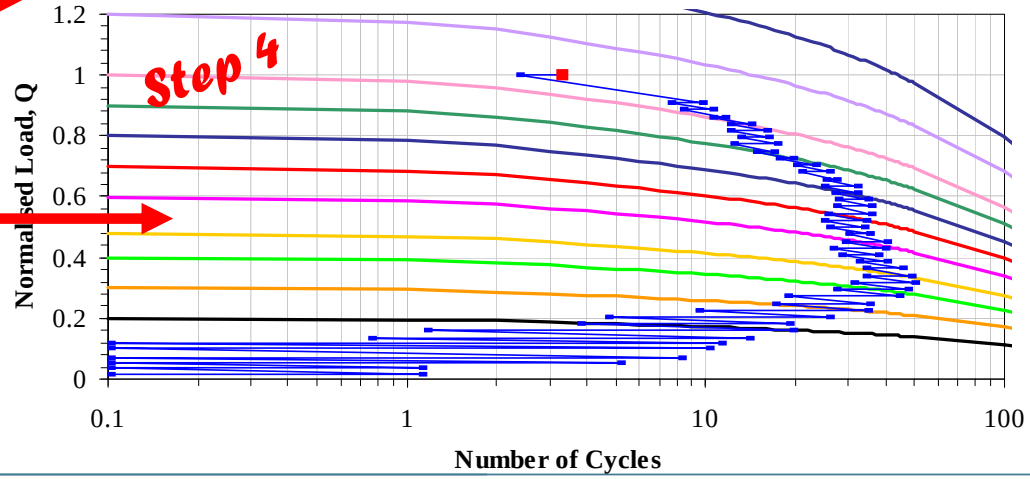
Metocean Loading

- Metocean data is used to develop mooring line loads







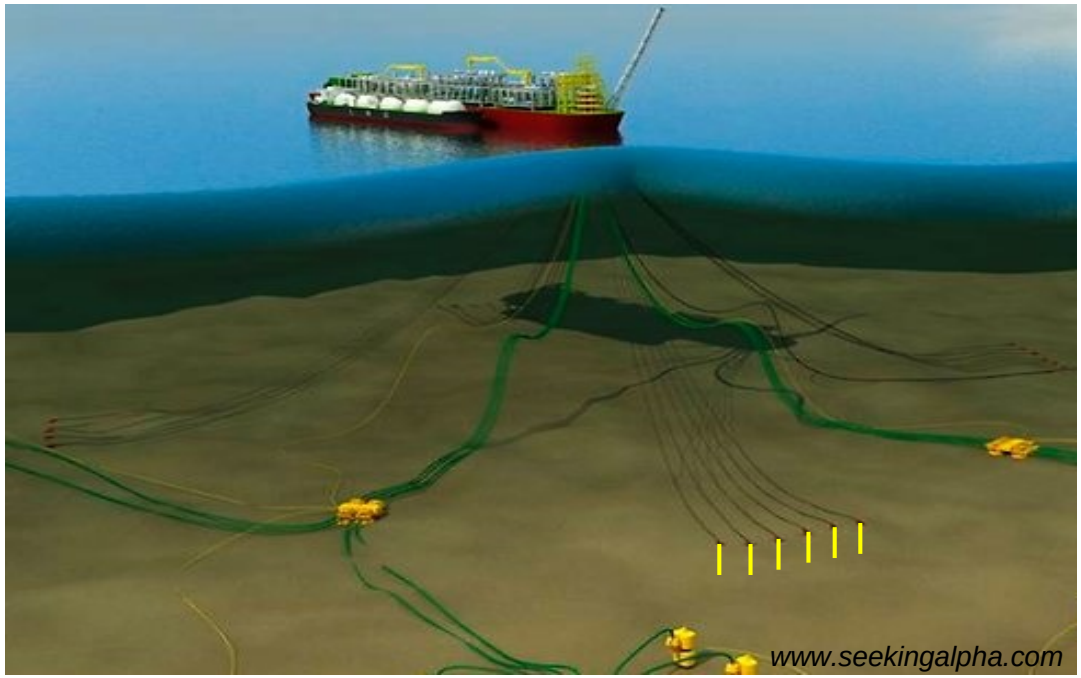


Topics – Mooring Design

- FLNG
- Metocean Assessment
- **Mooring Design**
- Seabed Conditions
- Anchor Options
- Closing Remarks

Mooring Systems

- Turret designed to weather vane to dominant loading direction.
- Catenary Mooring system
  - No load on the anchor during calm weather.
  - Chain load generally horizontal at mudline.
- Taut Mooring system
  - Generally loaded during calm weather at some angle.
  - May require large ballast to resist long term uplift loads.



Mooring System

Up to 2 km Mooring Radius in water depth ~300m

Beatty Park

DNA Tower

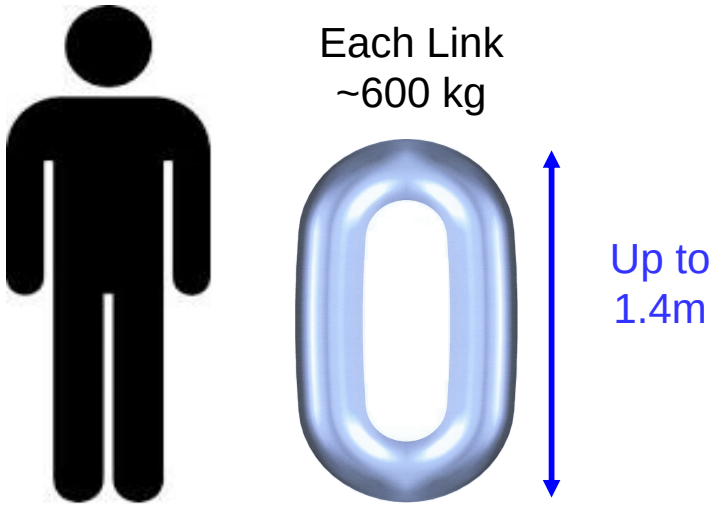
WACA

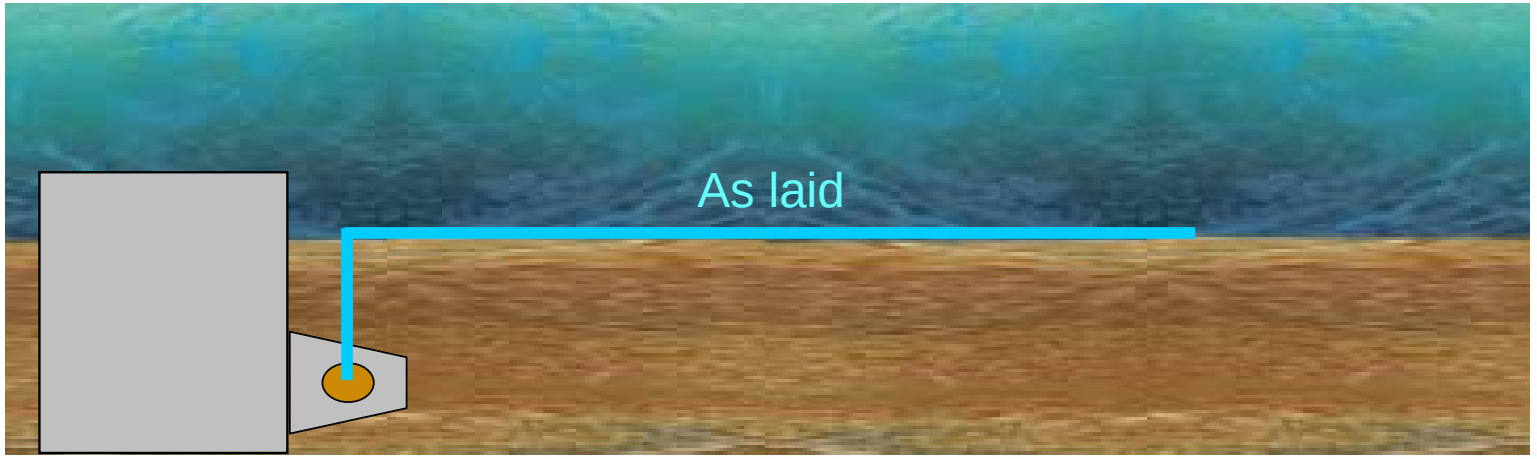
Windsor Hotel

Array of 12 to 32 anchors in 3 to 4 anchor clusters

Mooring Lines

- Combination of anchor chain and wire to resist massive static and dynamic tensions
- Pre-load & storm loading of mooring line
- Chain Slack induced when anchor line cyclically loaded during storm
  - Limited chain adjustment means padeye displacement must be controlled





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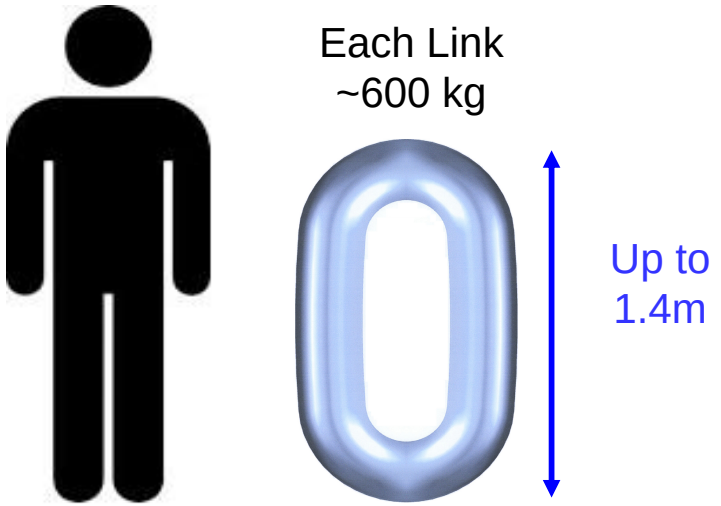

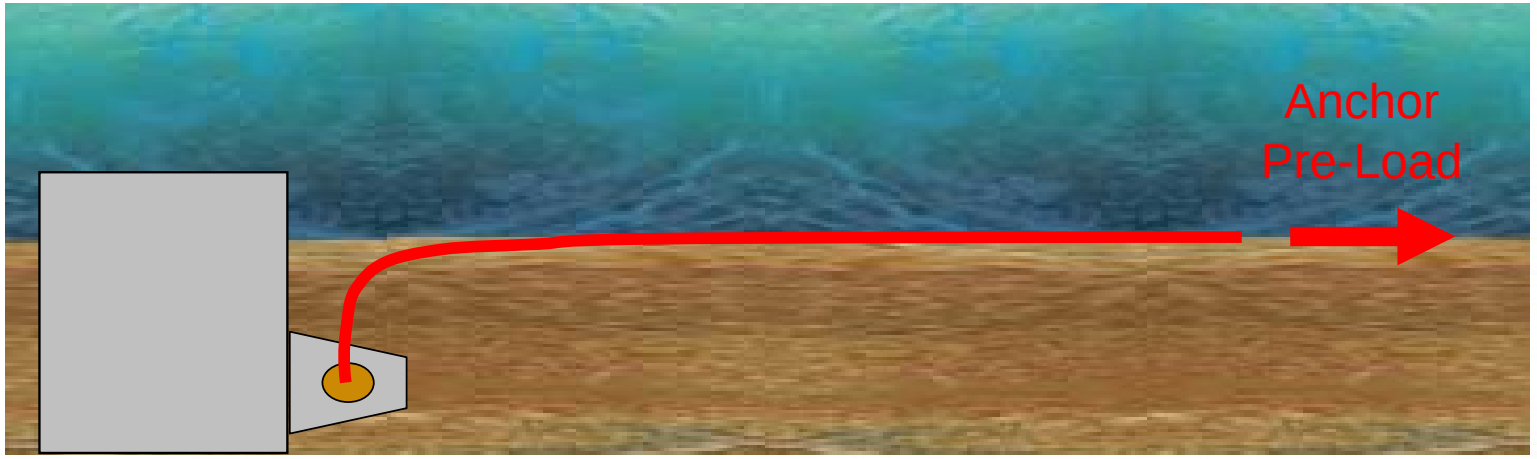

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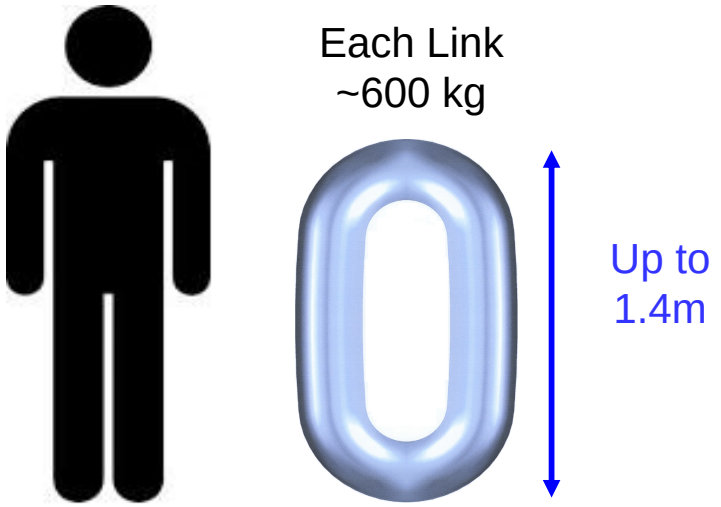
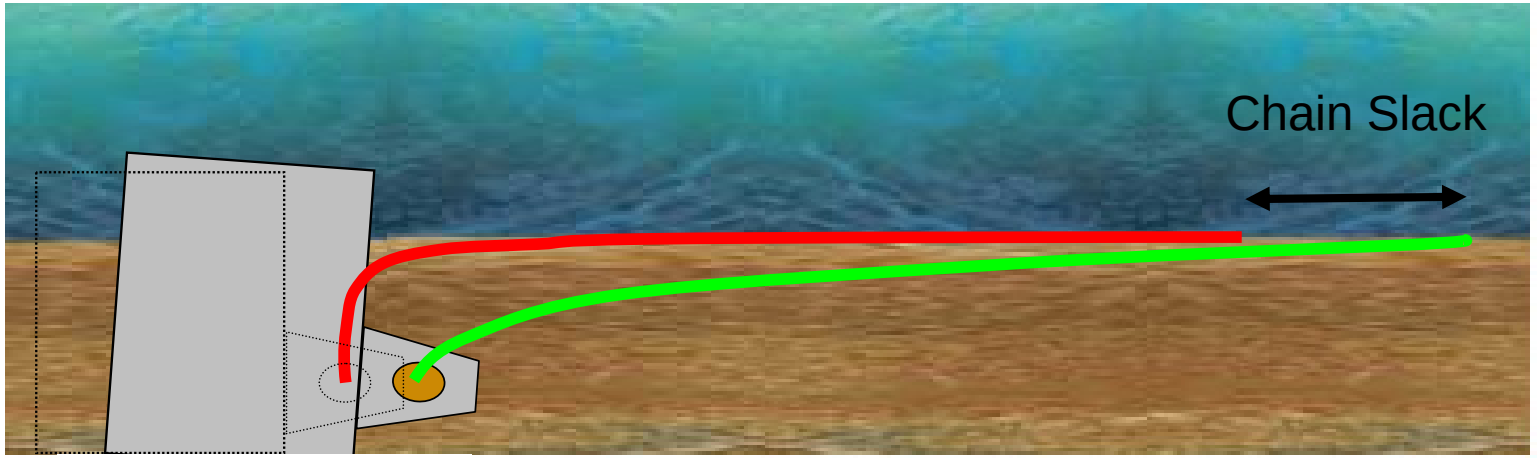




Anchor Load Cases

- Operation (1 or 10 yr), Extreme (100 yr) & Survivability (10,000 yr) cases
  - Metocean Conditions drive the survivability design case
  - 10,000 year storm – Factor of Safety for survivability = 1.0
  - Large lateral loads for survivability case – Up to 2,500t

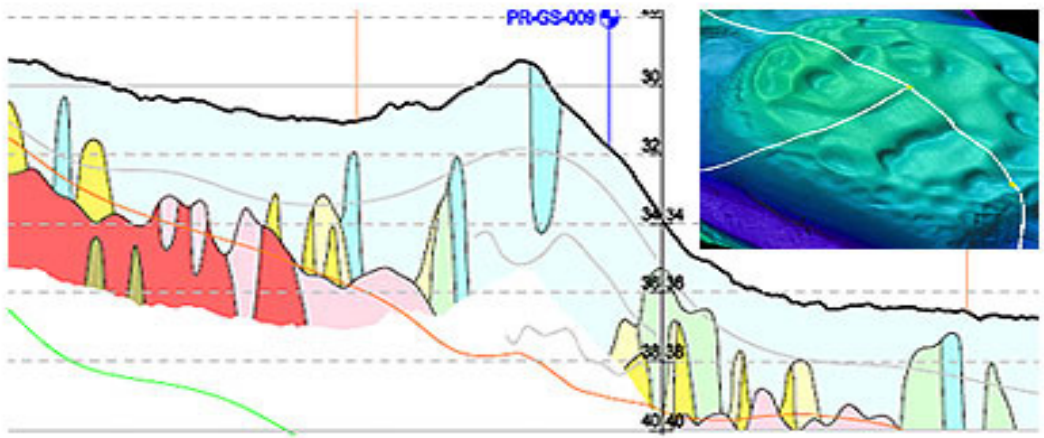
- Anchors generally designed for survival condition where some movement can be tolerated but failure is catastrophic.
  - Hydrocarbon leaks
  - Infrastructure damage

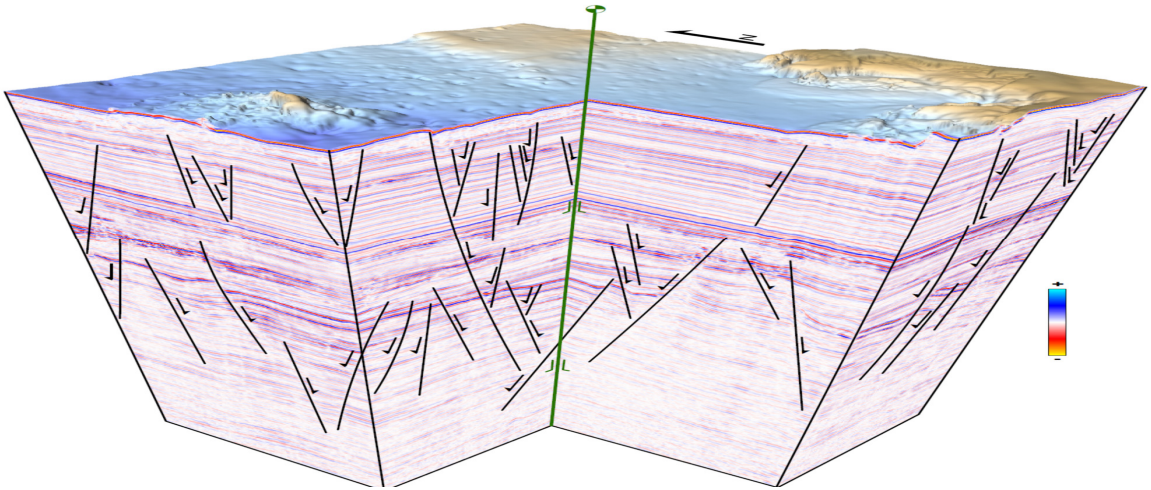
Topics – Seabed Conditions

- FLNG
- Metocean Assessment
- Mooring Design
- **Seabed Conditions**
- Anchor Options
- Closing Remarks

GeoHazards

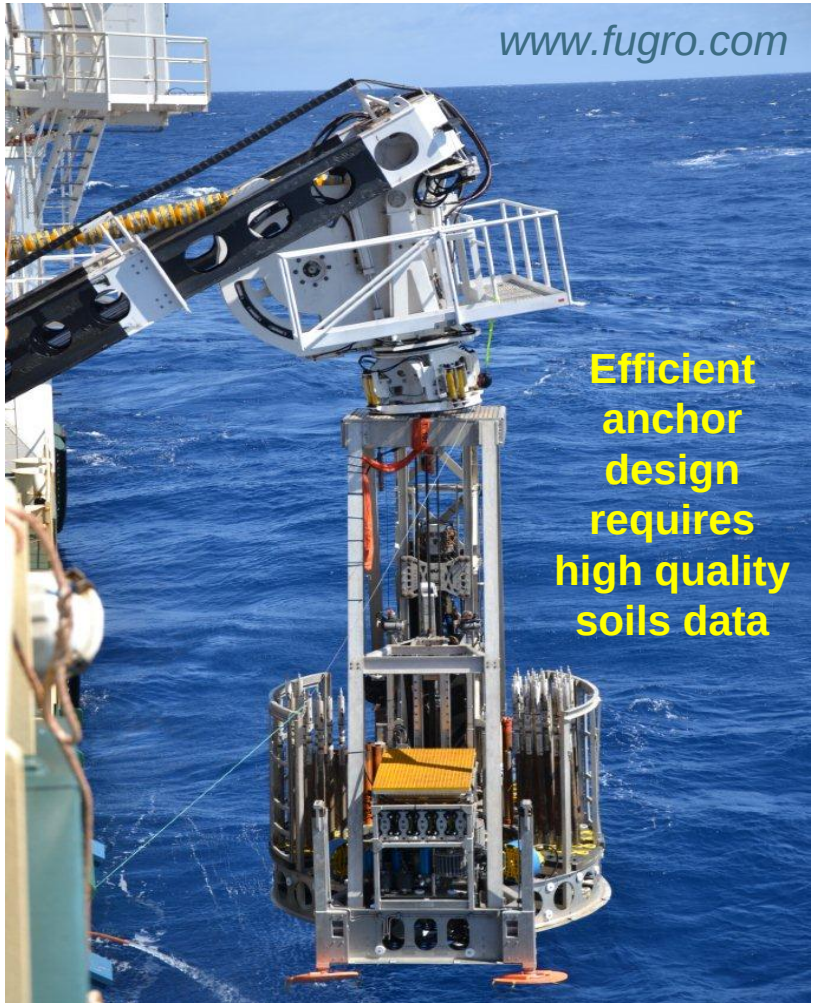
- Many GeoHazards present off the NW coast of WA
  - Seismic activity/ faulting
  - Slope failures
  - Seabed features/ sand waves
  - Shallow gas/ pockmarks
  - Sediment mobility/ Scour
- Integrated approach to site assessment
  - Geophysical
  - Geological
  - Geotechnical





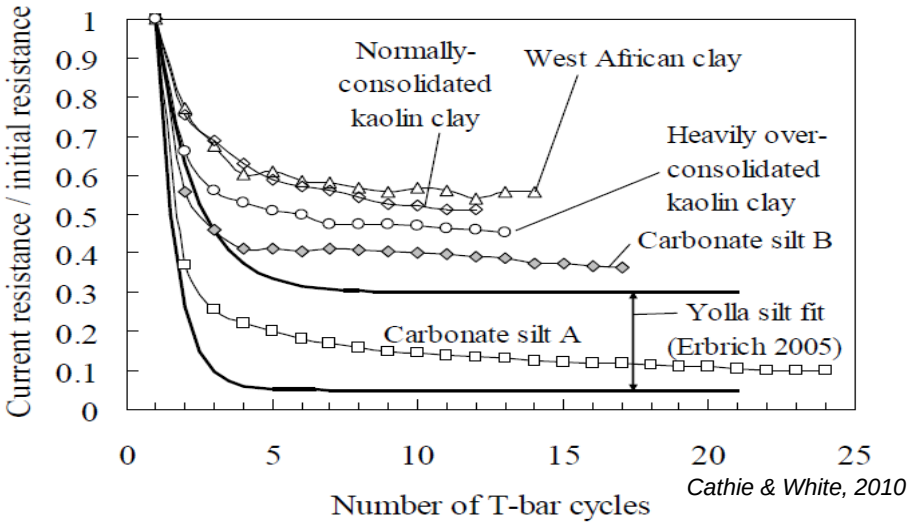
Seabed Sampling

- Often FLNG sites are undeveloped and in deepwater.
- Soil variability leads to a need for high quality soils data at each anchor cluster location.
- Conventional geotechnical drill ships
  - Ideally suited for shallow water & deep sampling
  - Longer pipe run times in deep water
- Seabed drilling equipment
  - Can be more efficient in deepwater and for shallow sample depths



Soil Characteristics

- North West of WA typically characterised by carbonate soils:
  - Fragile, angular and hollow grains
  - Potential for severe cyclic degradation
  - Potential for high compressibility
- In deep water very soft muddy silt sediments are found near the surface.
  - Often normally consolidated
  - Grain crushing and water release
  - Liquefaction



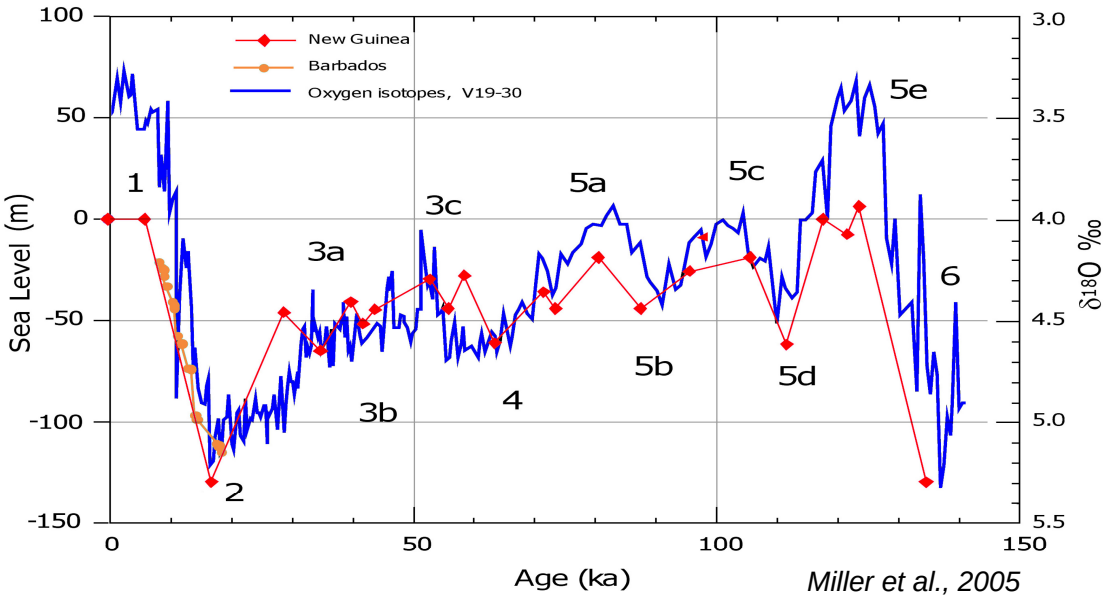
Cathie & White, 2010

Soil Characteristics

- Hard layers are seen at shallower water depths
  - Sea level rise and fall over time leads to exposure and cementation
  - Hard layers create geotechnical design challenges for anchors

Calcarenite

Sand/Silt



Miller et al., 2005

Topics – Anchor Options

- FLNG
- Metocean Assessment
- Mooring Design
- Seabed Conditions
- **Anchor Options**
- Closing Remarks

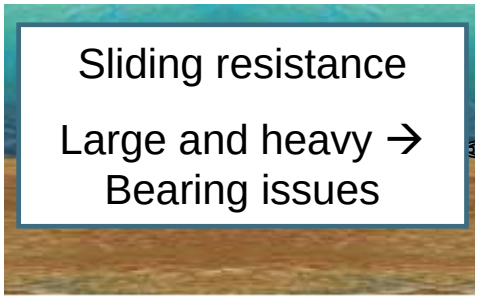
Anchor Options

Piles

Focus on these two anchor designs

Suction Caissons

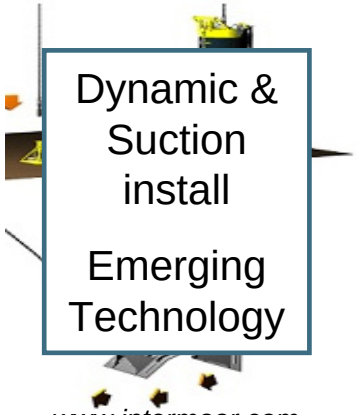
Gravity Anchors



Sliding resistance

Large and heavy → Bearing issues

Plate Anchors



Dynamic & Suction install

Emerging Technology

www.intermoor.com

Dynamic Anchors

Large uplift loads

Chain slack in catenary system

Drag Anchors

Capacity issues with standard anchor sizes

Chain Slack

Anchor Requirements

- Storm load capacity
  - Lateral and axial
- Operation Capacity
  - Settlement / creep
- Displacement limits
  - Lateral and axial
- Structural capacity & fatigue design
- Verification of novel components
- Fabrication
- Transport
- Installation
- Commercial & schedule impact

Often the anchor design requirements are conflicting.

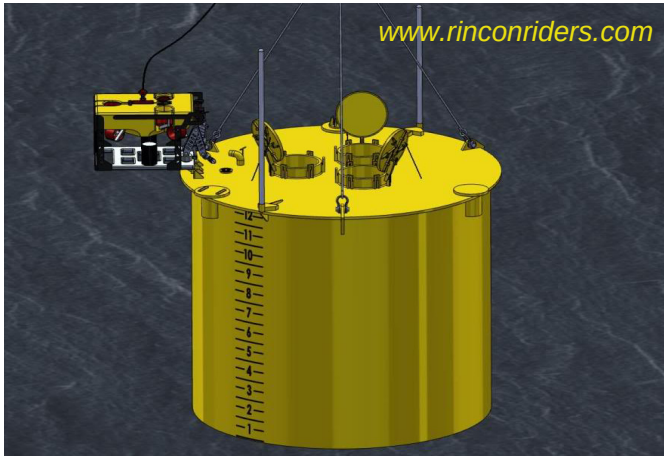
Integrated Design Approach:

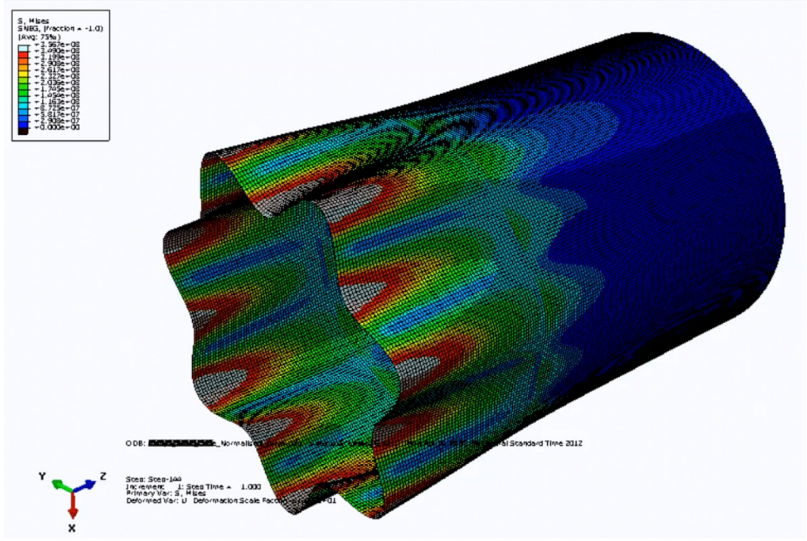
- Geotechnical Designer
- Structural Designer
- Naval Architects
- Installation Contractor
- Client

Requires novel designs and innovative installation procedures.

Suction Caissons

- Large, Heavy Caissons
  - 15 – 40 m long
  - L/D ~ 1 – 5
  - ~ 500 – 800t
- Best suited to soft deepwater sediments
- Transport & handling issues
- Geotechnical Design Issues:
  - Suction requirement
  - Seepage flow and plug failure
  - Buckling during installation
  - Hard or sand layer refusal
  - Deeper padeye requirement than piles → chain slack





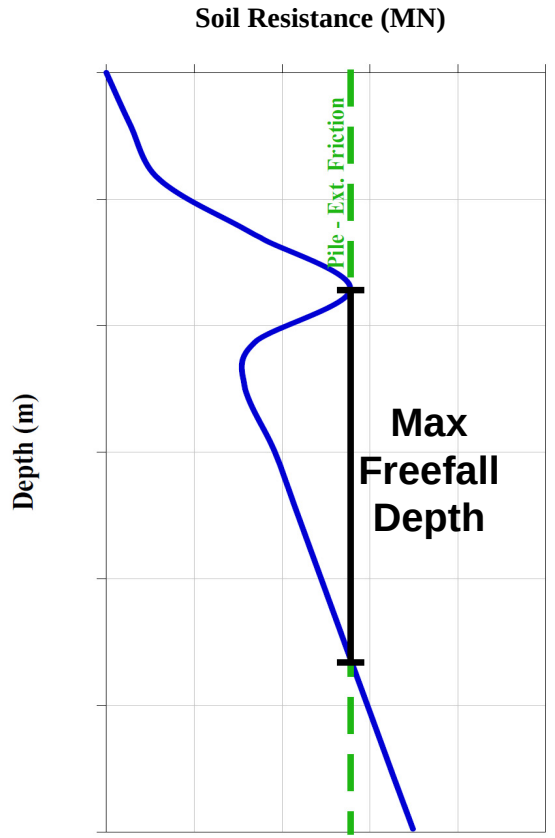
Anchor Piles

- Large, Heavy Piles
  - 40 – 60m long
  - L/D ~ 10
  - ~ 500 – 800t
- Driven or Drilled & Grouted Installation

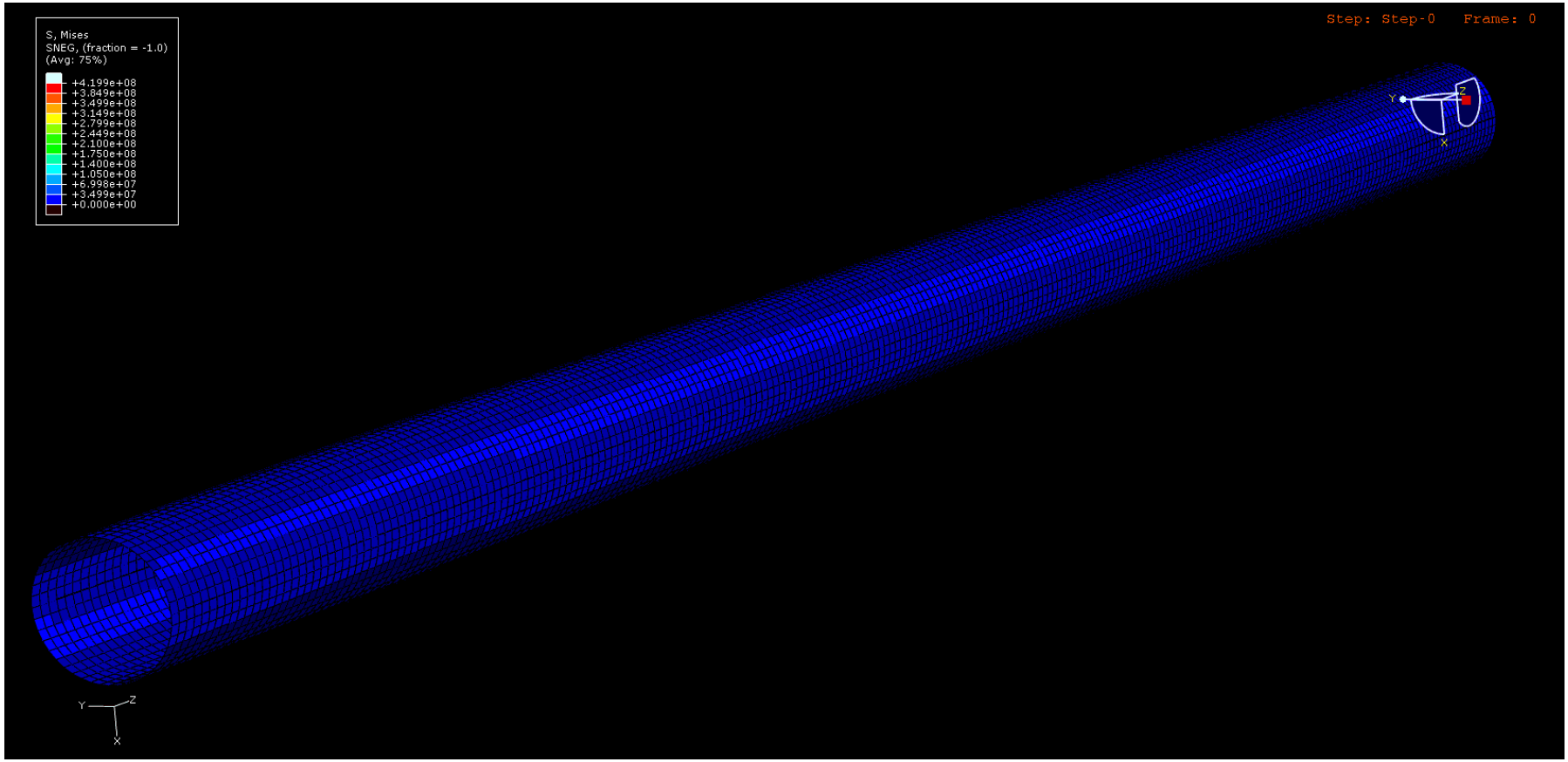
Anchor Piles

- Large, Heavy Piles
  - 40 – 60m long, L/D ~ 10, ~ 500 – 800t
- Driven or Drilled & Grouted Installation
- Geotechnical Design Issues:
  - Soil blowout
  - Venting – conflicting design requirements
  - SWP stick-up stability
  - Axial capacity – freefall, bearing elements
  - Driveability, refusal, driving fatigue
  - Buckling
  - Hole Stability, grouting, shaft friction

Photo Courtesy of ConocoPhillips



Buckling Analyses



Erbrich et al., ISFOG 2010

Pile Freefall

www.youtube.com/user/leoaushv, www.youtube.com/user/jackodiver

Topics – Closing Remarks

- FLNG
- Metocean Assessment
- Mooring Design
- Seabed Conditions
- Anchor Options
- **Closing Remarks**

- **Mooring an FLNG in the North West presents a number of challenges for the design team**
- **Unique and Challenging Seabeds**
  - Can be accurately characterised with high quality data
- **Massive Vessels Anchored in Treacherous Sea States**
  - Metocean conditions govern the design anchor loads
- **Novel Anchor Designs**

Thanks to colleagues at:

FugroAG **FugroGEOS**

Advanced Geomechanics

Thankyou to SUT Perth for the opportunity to present

SUT Society for Underwater Technology