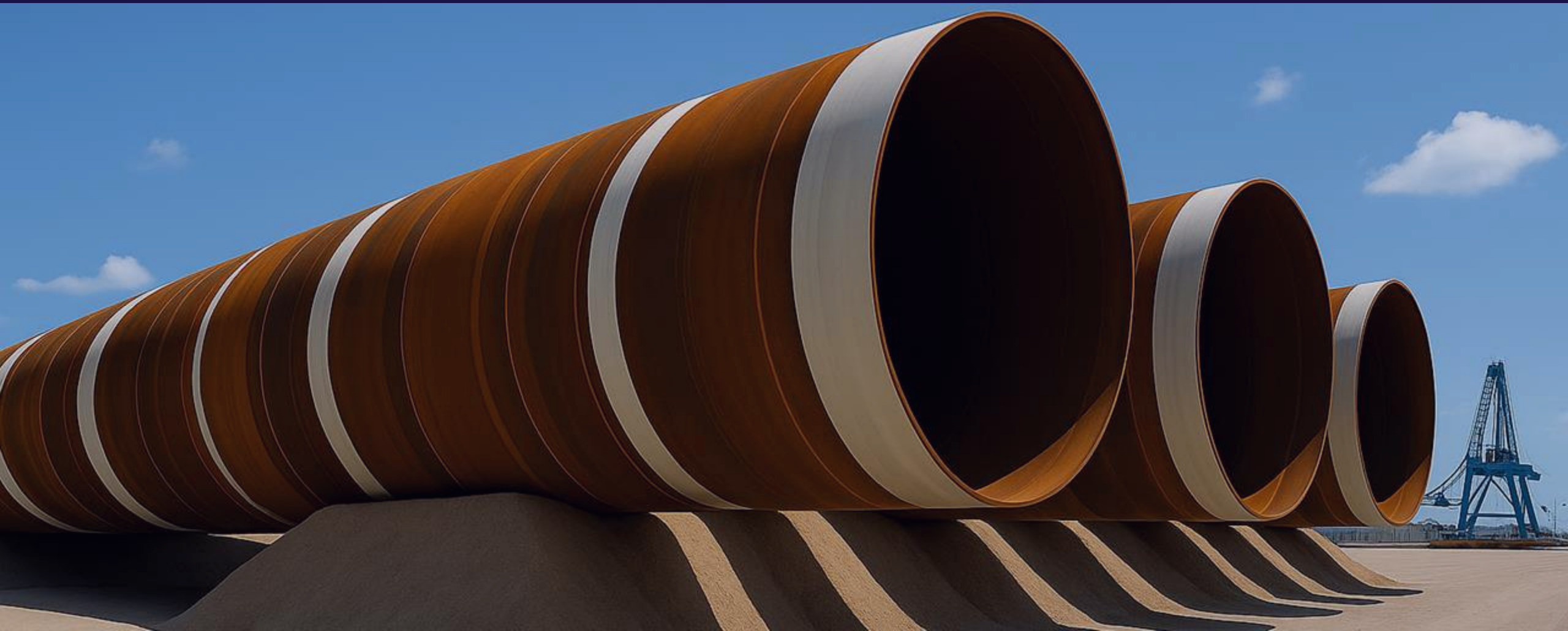
EMPIRE engineering

XXL Monopile Storage on Sand Berms: Worth a Rethink?

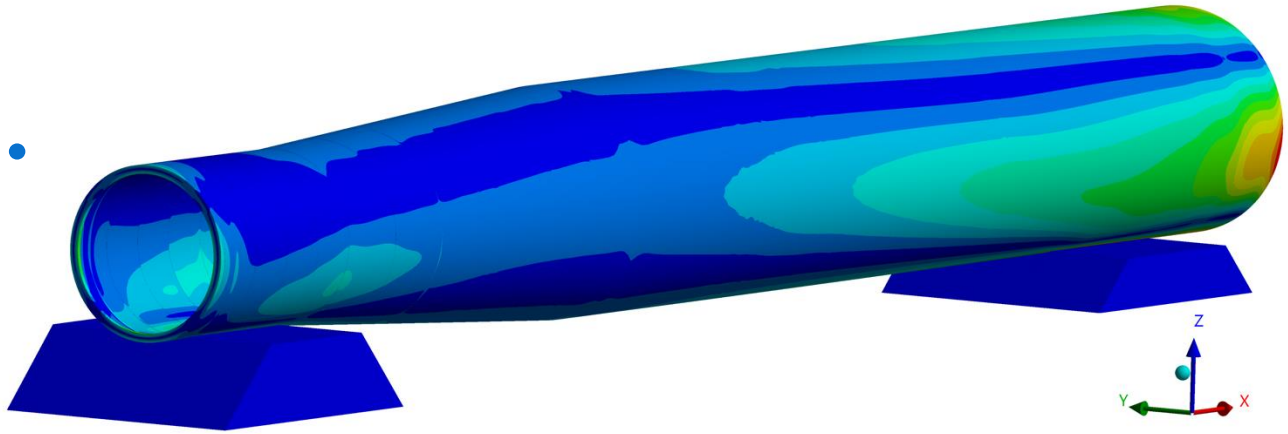


Sand Berm Storage

- Low cost
- Short construction time
- Provides flexibility
- “Tried and tested”

What could go wrong…right?!

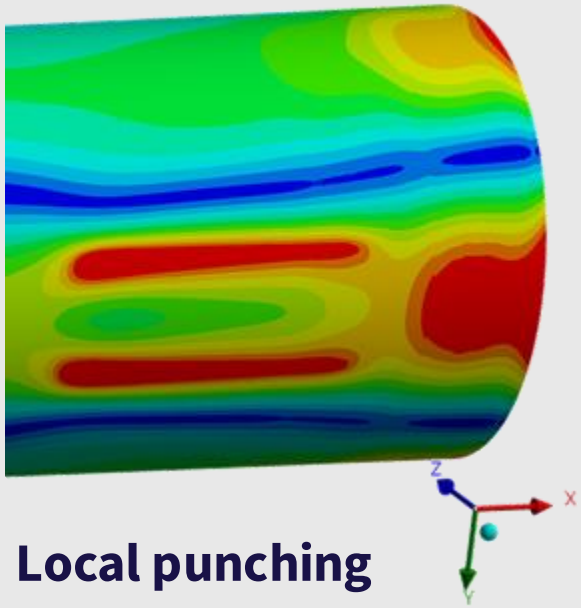
Let’s look at the stress…



FEA analysis performed incorporating nonlinear Mohr-Coulomb material model for sand, accounting for shear failure at stress levels above material cohesion.

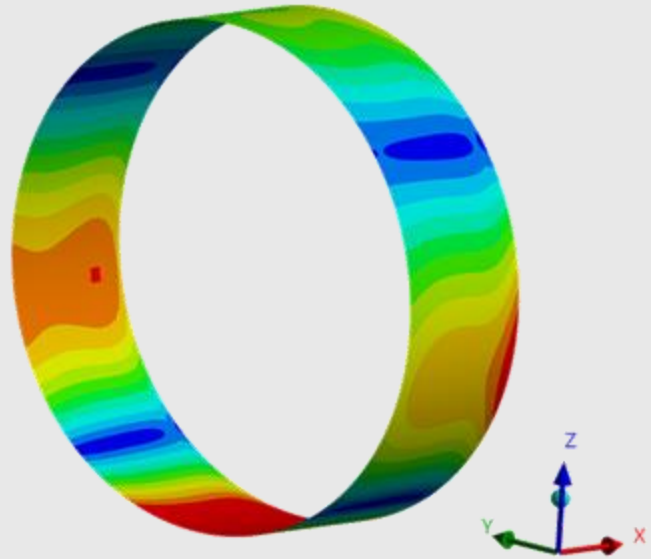
High stress regions are observed, driven by two separate phenomena:

- **Local punching** at the berm contacts
- **Ovalisation** of the cans under self-weight.



Local punching

- Small contact areas
- Localised stress concentrations

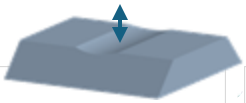


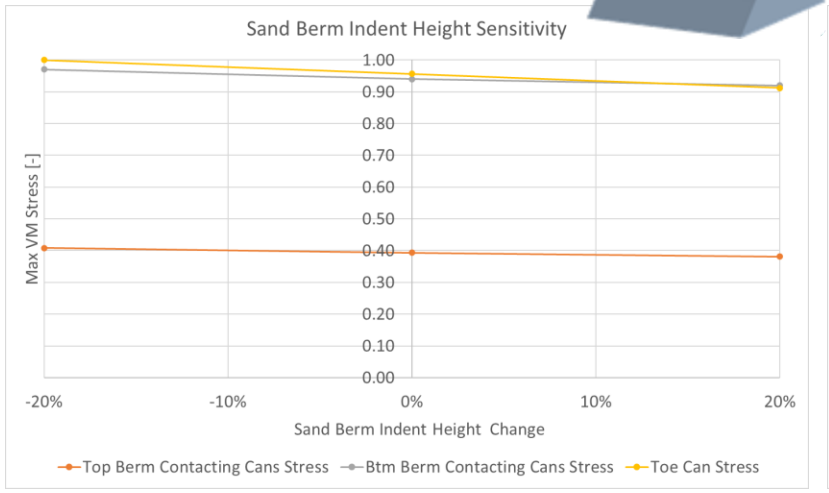
Ovalisation

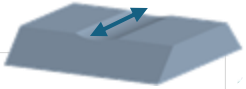
- Sand berm indents provide limited constraint against ovalisation
- Tension / compression stress patterns

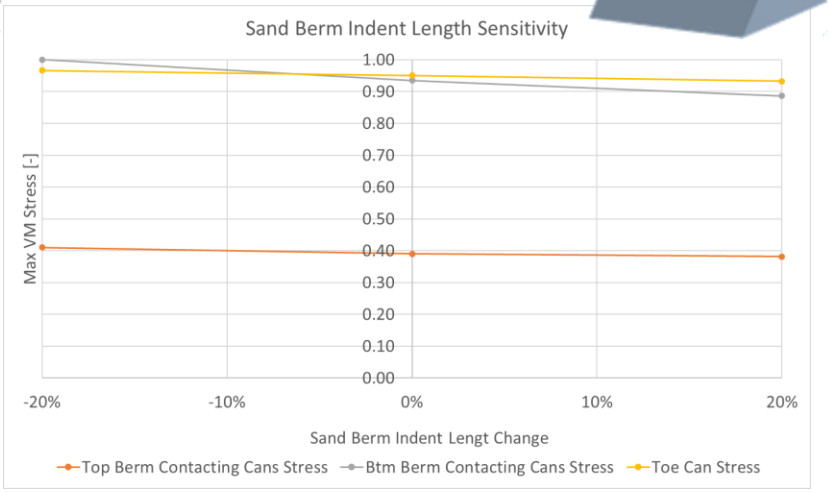
Analysis insights

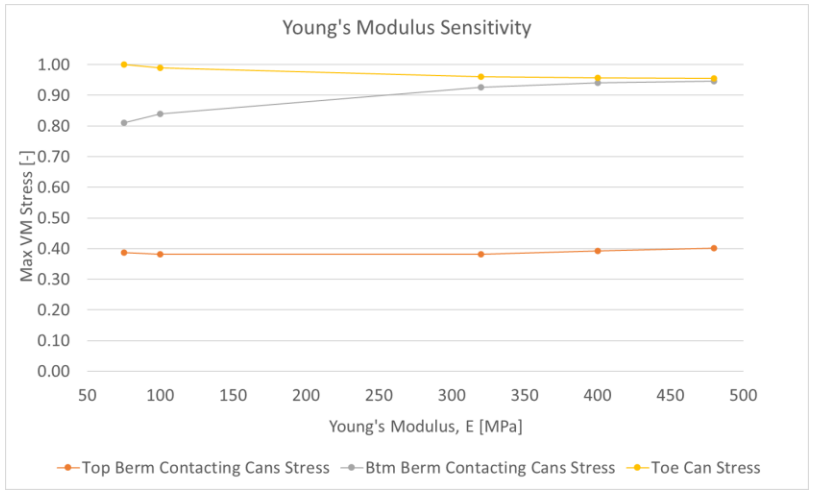
- **High stresses** and **large deflections**.
- Some **stress sensitivity** to sand berm geometry and materials.
  - ➢ Increasing berm indent height by 40% >> 10% max stress reduction.
  - ➢ Increasing berm indent length by 40% >> 10% max stress reduction.
  - ➢ Approaching 0 cohesion increases ovalisation stresses significantly.
  - ➢ Reducing sand berm stiffness reduces punching stresses but increases ovalisation stresses.
- When applying reasonable geometrical constraints **significant stress reduction is not seen**.

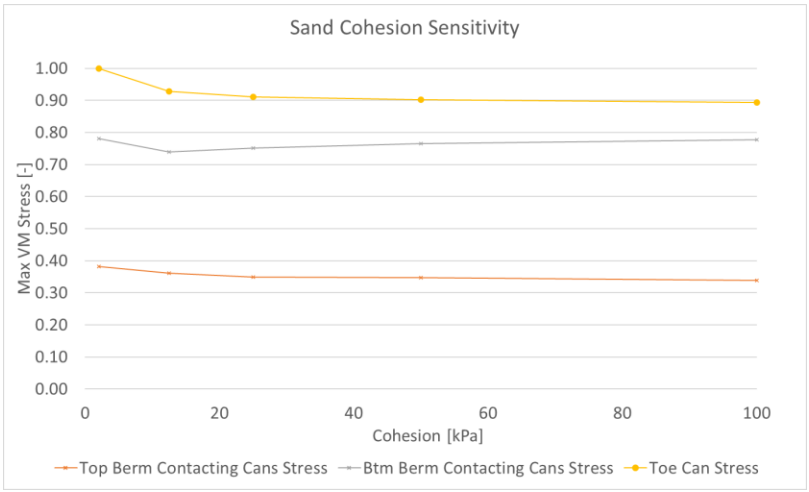












Inherent uncertainty

- Significant difficulty obtaining material data for sand berms.
- Sand berms may not be constructed with a single material and geomechanical properties can vary significantly.
- Material behaviour is nonlinear and difficult to capture accurately as compromises are made to gain numerical stability.
  - ➢ Detailed material behaviour is typically analysed using 2D geotechnical FEA but here the monopile response is not considered.
  - ➢ Idealisation of the berms for full 3D analysis is required.

This would all be “fine” if we weren’t seeing high stresses!

Let’s consider future monopile obesity!

As monopile waistlines continue to grow does monopile storage on sand berms become unfeasible?

Case study

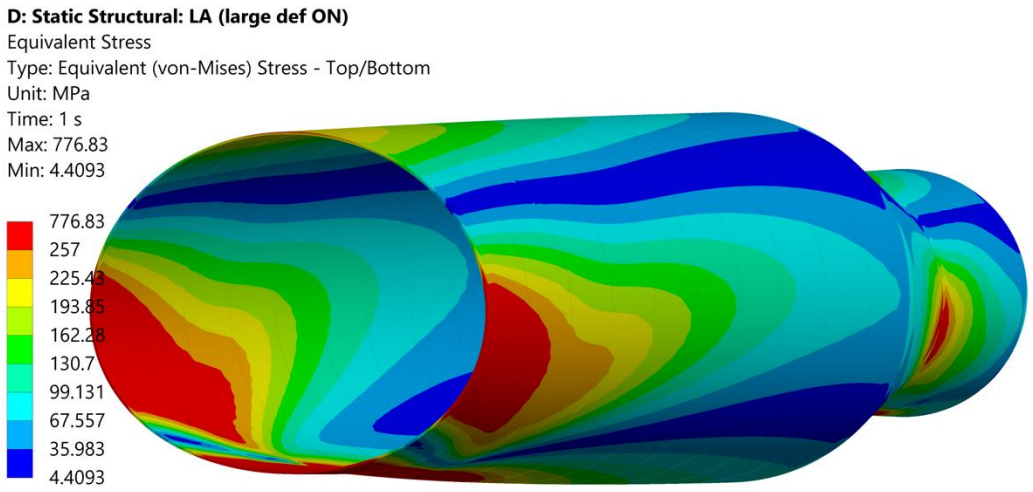
CWHI Qinzhou yard’s publicised capacity

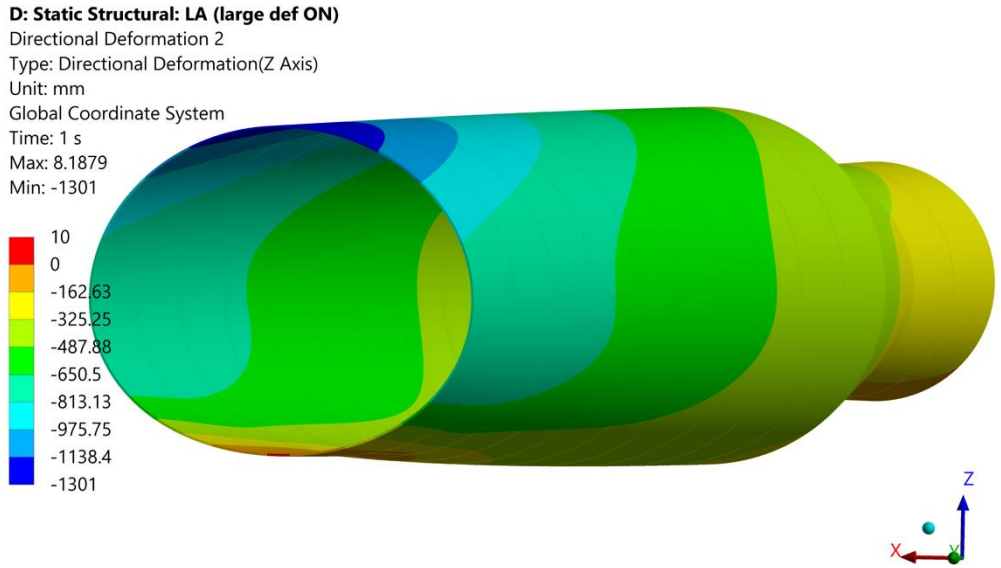
- A maximum outer diameter of 15m
- A maximum net weight of 4500 tonnes

Inputs and methodology

- Max monopile D/t of 140 and sand berm indents of 10m length with 30° span angles.
- Net weight applied directly. Material uncertainty factor of 1.15 applied and ULS load factor of 1.2 applied to gravitational load as per DNV.
- 3D FEA analysis with sand berms modelled as equivalent spring boundary conditions based on previous sensitivity analysis.

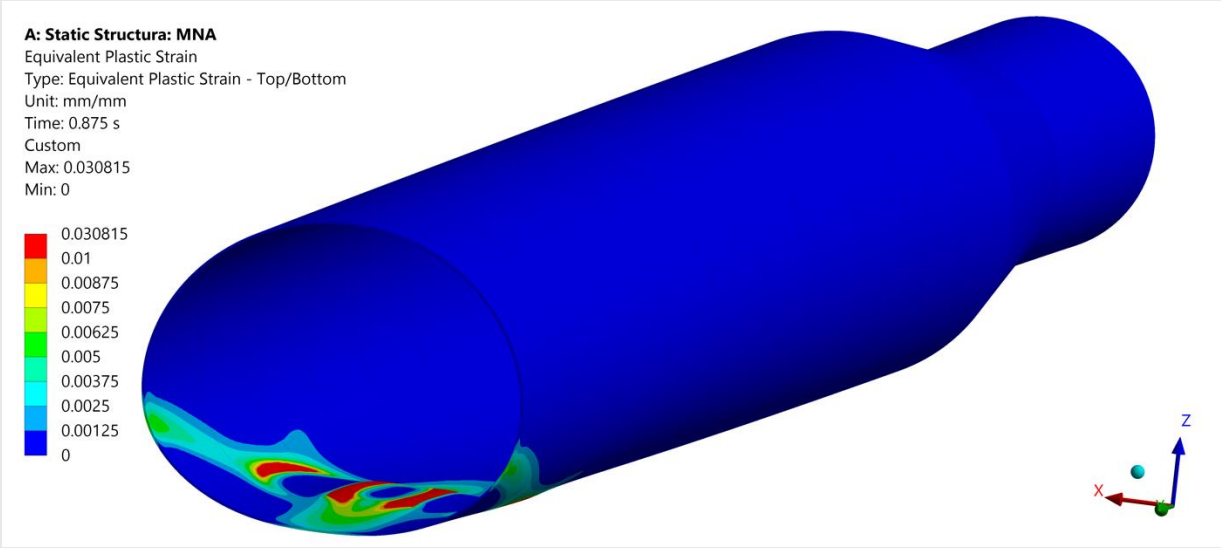
Results using linear elastic steel material





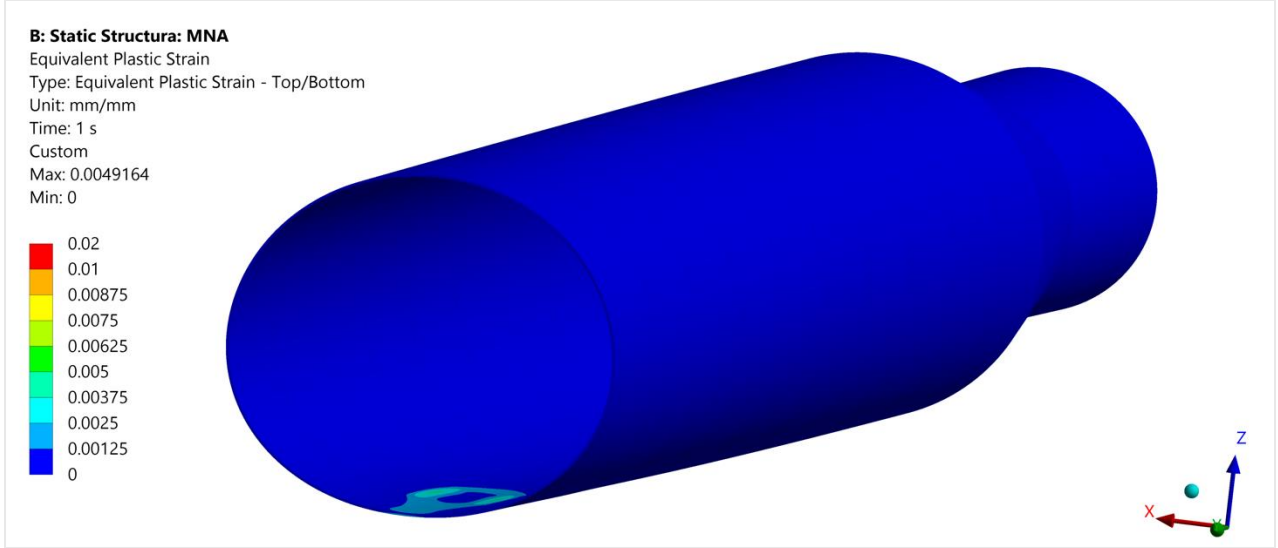
A ULS factor of 1.2….That still seems like a lot!

Results using nonlinear elasto-plastic steel material



Plastic strain with ULS factor of 1.2

(95% complete before collapse and divergence)



Plastic strain with ULS factor of 1.0

(100% complete simulation)

5.9.8.2.2 For loads and load effects that are well controlled a reduced load factor γ_f = 1.2 may be used for the G and Q loads instead of 1.3 in load condition ULS-a.

Guidance note:

Examples where γ_f = 1.2 may be applicable are:

- External hydrostatic pressure caused by an accurately defined water level.
- Loads due to an accurately distributed (i.e. static determinate) well defined self-weight.
- Functional loads accurately defined (limited) by the maximum (possible) capacity of equipment.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

So….do we have our heads stuck in the sand?

- It may seem like a standard low risk operation but as MPs continue to grow in diameter, structural high stresses become apparent when assessing using DNV standard practice.
- We see cases in which sand berm storage results in higher stress levels than those observed during transportation in cradles.
- Mitigating high stresses isn't easy with sand berm design alone and anti-ovalisation tools may become standard practise.
- Modelling and material uncertainty shouldn't be ignored but including a material uncertainty factor seems to be sufficient.
- We recommend ensuring the monopiles have been analysed for sand berm storage operations and not to rely on applying fabrication yard experience of sand berms to the next generation of large diameter monopiles.

In short, no, I think we are some way off seeing big structural integrity issues caused by storing monopiles on sand berms, but it is certainly a higher risk operation than commonly thought.