• Background to flexible lines

• Mechanical behavior of Flexible vs Steel.

• Why flexible buckling is important

• Flexible buckling in project cycle

• Design of flexibles against global buckling and mitigation techniques

• Case Studies

• Conclusions and learned lessons
Background to Flexible Lines

**When?** Just over 71 years ago – Operation Pluto saw the installation of the first flexible pipeline in support of D-day landings.

17 off 3-inch and 2-inch lines extending more than 500 miles across the English Channel.
What is a Flexible Flowline

Conventional Configuration

Different layers of different materials that act together and allow for unique behavior.

- **Internal carcass** – for prevention of collapse
- **Internal liner** – primarily an internal fluid barrier
- **Pressure armour wires** – provides pressure containment
- **Tensile armour wires** – sustaining tensile loads and internal pressure
- **Outer sheath** – resists mechanical damage and prevent seawater ingress.
The mechanical behaviour of Flexible flowline is widely different than steel.

- Significant variation with pressure and temperature
- Significant variation between different layer arrangements
- Significant variation with wall status
- Low non-linear bending stiffness
- Lower axial stiffness
- High expansion under pressure and temperature
Mechanical Behaviour of Flexible Flowlines vs. Steel Axial And Bending Stiffness
Mechanical Behaviour of Flexible Flowlines vs. Steel Expansion Coefficients

Temperature Expansion Coefficients

Pressure Expansion Coefficients
Why Flexible Buckling is Important

On seabed flexible flowlines on the seabed generally do not buckle due to the following reasons:

• Low bending stiffness – easy to move on the seabed

• Comparably lower EAF for same size rigid line with same conditions (especially if high temperature)

However, the requirement of fishing protection in shallow waters would mean that burial/rockdump is to be placed. Therefore, the cover would need to be designed to limit lateral/vertical movement whilst ensuring the following:

• No localisation of movement that may violate flexible minimum bending radius

• The protection specification is not violated by flexible movement.
Global Buckling Design in Project Cycle

**Concept/Pre-FEED**
- Cost Benefit Analysis
  - Protection Philosophy (Cost benefit Analysis)
  - Protection Requirements

**FEED/Detailed Design**
- Predictive Global Buckling Analysis
  - Minimum Depth of Cover/Rock Blanket Height
  - Rock Tonnage Estimation
  - Practicality of Pre-Pressurisation Technique

**Execution**
- OOS Analysis
  - Final Rockdump Schedule
  - Verification of as-Built Status
Design Considerations:

- Identify design Load Cases based on installation and commissioning sequence;
- Flexible wall status for each of the design load cases;
- Flexible non-linear behaviour;
- Flexible limiting criteria (MBR/ compression limit).
Pre-Pressurisation Technique: An approach where flexible is pressurised prior to trenching/rockdump. This results in locked in tension which helps reducing the compressive effective axial force under design conditions.
The flexible is pressurised up to leak test pressure on the seabed prior to trenching and backfilling. The following are the key considerations must be addressed during the design stage:

• The integrity of the flowline when pressurised on Seabed.

• Pressurisation on the seabed is likely to result in tight curvatures which must be manoeuvred by trenching tool. Therefore, tracked tools are probably more appropriate.

• The depth of the trench shall be sufficient to restrain the flowline after depressurisation to avoid surfacing.
The flexible is pressurised up to leak test pressure on the seabed prior rockdump. The following are key considerations that must be addressed during the design stage:

- The integrity of the flowline when pressurised on seabed.
- Pressurisation on the seabed is likely to result in tight curvatures. Rockdump shall be sufficient to restrain the lateral movement following depressurisation.
- Locked in tension shall be carefully evaluated during predictive stage. No overestimation.

Surface Lay and Rockdump Considerations
Case Study 1
Surface Lay and Rockdump

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<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Oil Production Flowline</th>
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<tbody>
<tr>
<td>Inner Diameter</td>
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<tr>
<td>Design Pressure</td>
<td>Barg</td>
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<tr>
<td>Design Temperature</td>
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<td>60</td>
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<tr>
<td>Length</td>
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<tr>
<td>Pressurisation Pressure</td>
<td>Barg</td>
<td>399</td>
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• Installed on Seabed.
• Pressurised to 400 barg.
• Pipeline significantly mobilised under pressure at multiple locations.
• Rockdump to nominal for protection.
• Depressurise under rock – flowline cannot be restrained due to soft soil.
• High potential of cyclic movement under design conditions.
• Risk on pipeline integrity (localisation of curvatures) along with severe disturbance of protection cover.
• Limitation applied on number of cycles associated with stringent inspection survey requirements

Challenges:
• Very Soft Seabed
• Very Fast Track Schedule
• Limited Weather Window
## Case Study 2

### Trench and Backfill

<table>
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<th>Parameter</th>
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<tr>
<td>Design Pressure</td>
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<td>Length</td>
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<tr>
<td>Pressurisation Pressure</td>
<td>Barg</td>
<td>242</td>
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</table>

- Installed on Seabed.
- Pressurised to 242 barg.
- Pipeline mobilised under pressure at multiple locations, mobilisation assessed and matched predictions of predictive design. No integrity or trenchability issues.
- Pipeline backfilled to an average of 1 m DOC.
- Depressurised.
- Survey showed minimal movement of pipeline following depressurising highlighting the success of pre-pressurisation technique.
- The approach eliminated the requirement of any rockdump resulting in a considerable saving to the project.

### Challenges:
- Fast Track Schedule
- No – As-laid data (prior to pressurisation)
Conclusions, Recommendations & Learned Lessons

- Global buckling is important to be addressed as early as concept stage to ensure robust and economical design.
- Early engagement with flexible manufacturer during tendering phase to minimise flexible axial strain (i.e. effective axial force).
- Pre-trench pressurisation is generally effective however must confirmed by predictive analysis.
- The non-linearity in flexible behaviour should be captured in the analysis. Over conservatism sometimes renders no solution.
- Understanding of flexible mechanical properties under cyclic behaviour is important in of an undesirable unrestrained scenario.
- It is beneficial to survey the flexible straight after lay (prior to pressurisation) to double check the effectiveness of pressurisation technique.
- It is imperative that the global buckling analysis (especially during the execution phase) is reflective of the offshore sequencing and operation and analyses shall be performed at each step of analysis as follows:
  - Following pipelay and prior to pressurisation. This will confirm the integrity of pipeline when pressurised and ensures no scenario of localised imperfection.
  - Following pressurisation and prior to rockdump. Identify rock requirements after rockdump to restrain the pipe.
  - Following rockdump. Ensures that design rock requirements are met and the pipe is safe to operate.
Thank you