ODA FLEXIBLE WATER INJECTION PIPELINE EXPERIENCE

Ullandhaug

4/12 - 2019

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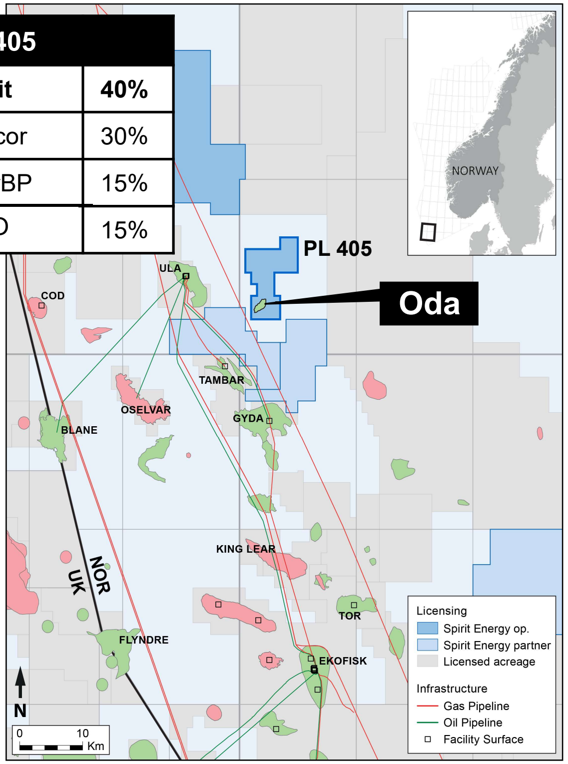
Oda
Small
Smart
Simple

AGENDA

- Oda project introduction – Spirit Energy
- Oda Water injection pipeline – incident and investigation results – Spirit Energy
- Experiences from contractor – Subsea 7
- Taking learnings forward – Spirit Energy

Oda field and development timeline

PL 405	
Spirit	**40%**
Suncor	30%
AkerBP	15%
DNO	15%



- License Awarded Feb 2007
- Oda discovered Oct 2011
- Concept selected Oct 2015
- PDO submitted Nov 2016
- PDO approved May 2017
- Production start **March 2019**

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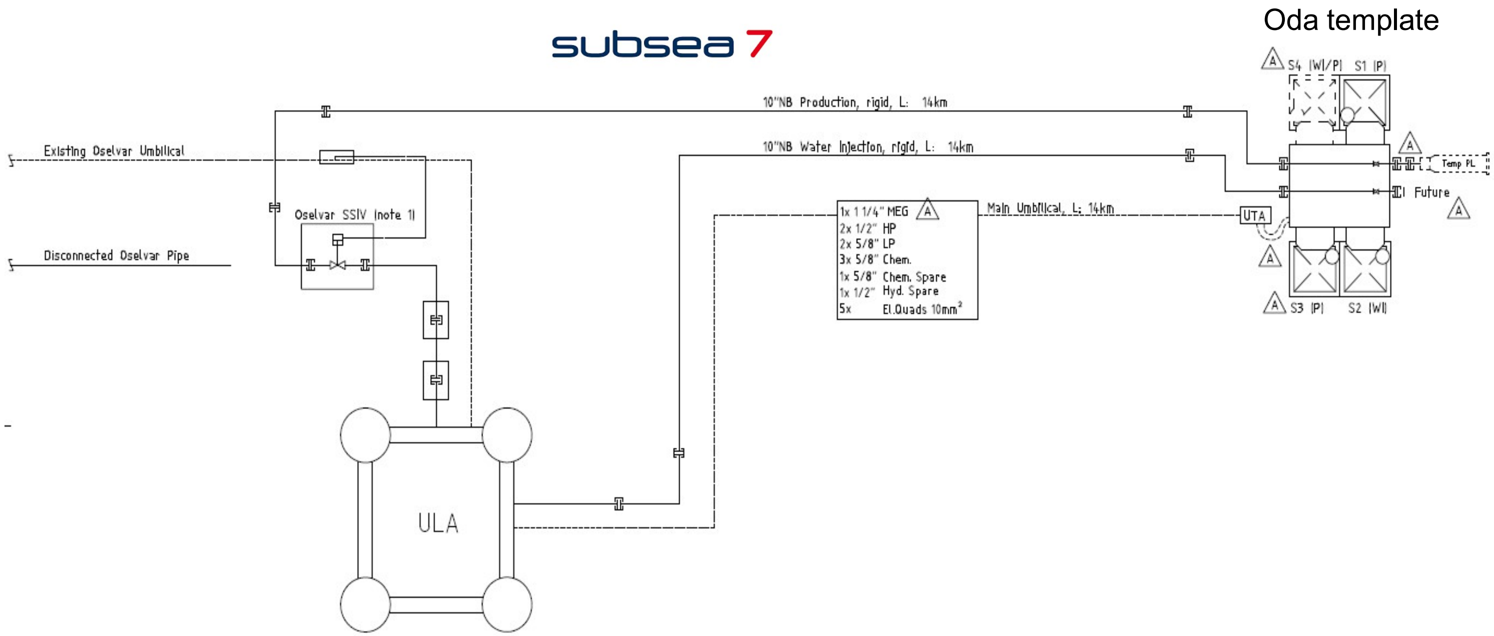
Oda Field Overall Layout



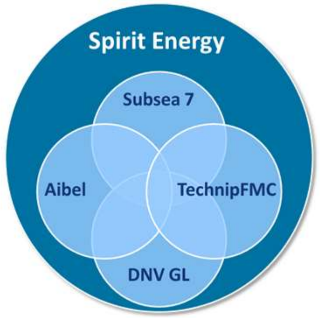
Oda Project Summary

- Excellent HSE record – Safety first at Oda

- First oil achieved 16th March 2019
  - 5 months ahead of PDO date

- Cost is estimated to be about 17% below PDO

- Successful collaboration with the supply chain – SPA model



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21.01.19
23.59HRS

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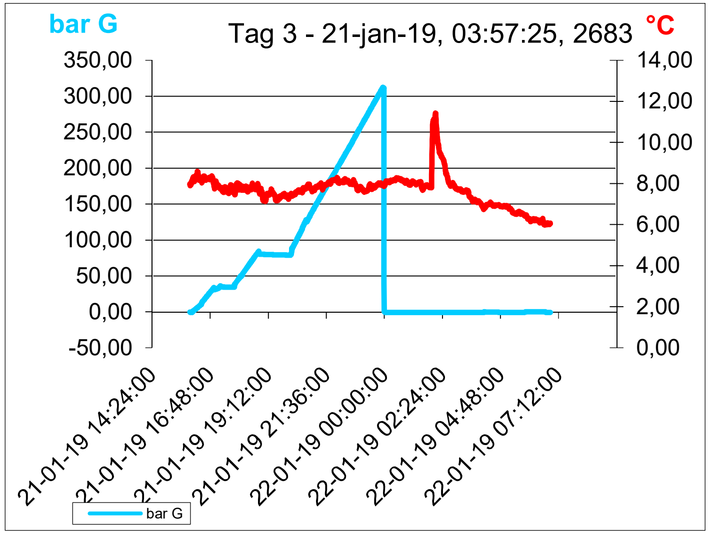
21.01.2019 @2359 - Loss of Pressure

- During system strength testing of the water injection flexible pipeline from Ula platform to the Oda manifold 21.01.19, an abrupt drop in pressure was noted from 312 barg to 0.5 barg in a few seconds

- At this point 16.8m^3 of water had been pumped into the pipeline in addition to the pre-flooded volume. Pressure loss occurred at ~85% of design pressure.

- For reference and clarity:
  - Design Pressure – 365 Bar G
  - Strength Test Pressure – 474 Bar G (1.3 x design - completed successfully during FAT at factory)
  - Target System Strength Test Pressure – 401 Bar G (1.1 x design)



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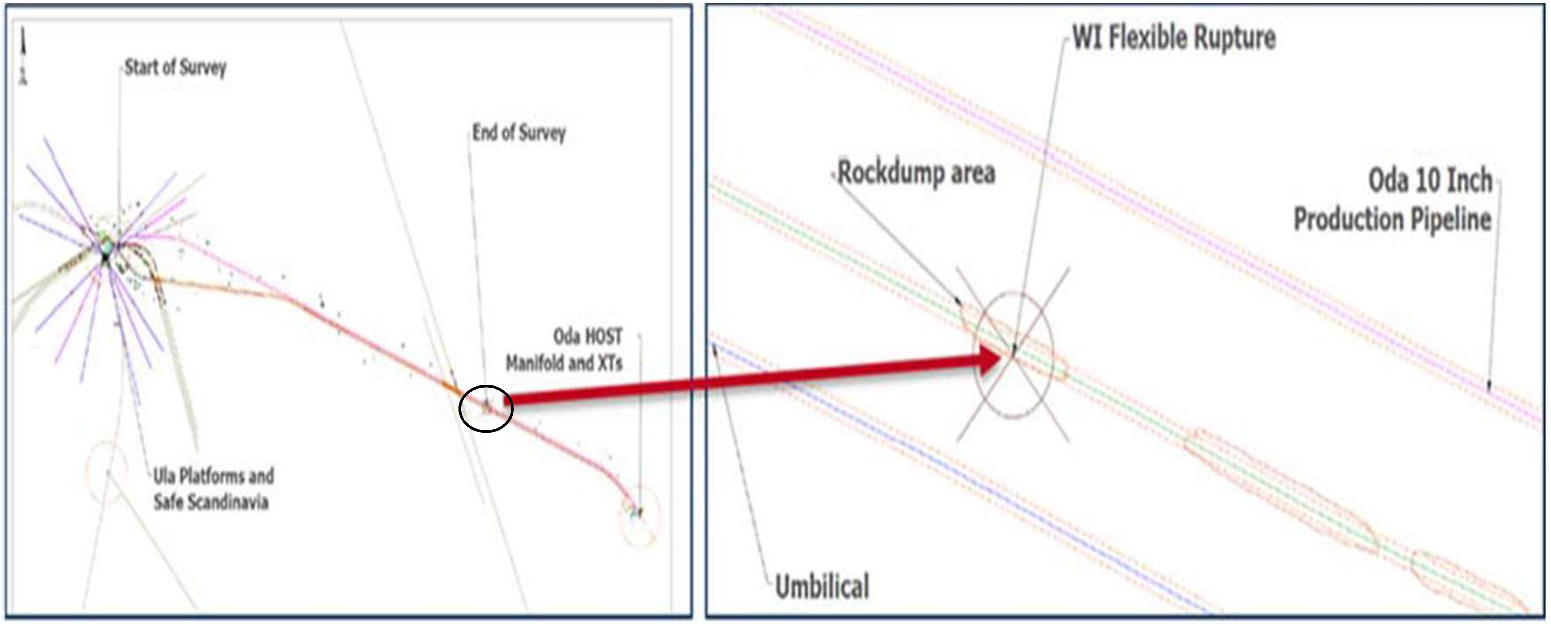
22.01.2019 @20:40 Visual inspection WI pipeline KP 9.811



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Major Consequences

The consequence of the failed WI flexible was significant, however no HSE impact:

- Impossible to repair failed flexible pipeline -> installation of new WI pipeline found to be the preferred option.

- Delayed pressure support into Oda reservoir resulted in curtailment of oil production

The industry categorises a water injection pipeline as **low safety class**, with a low consequence of failure.

Oda WI experienced a 10^{-4} probability failure

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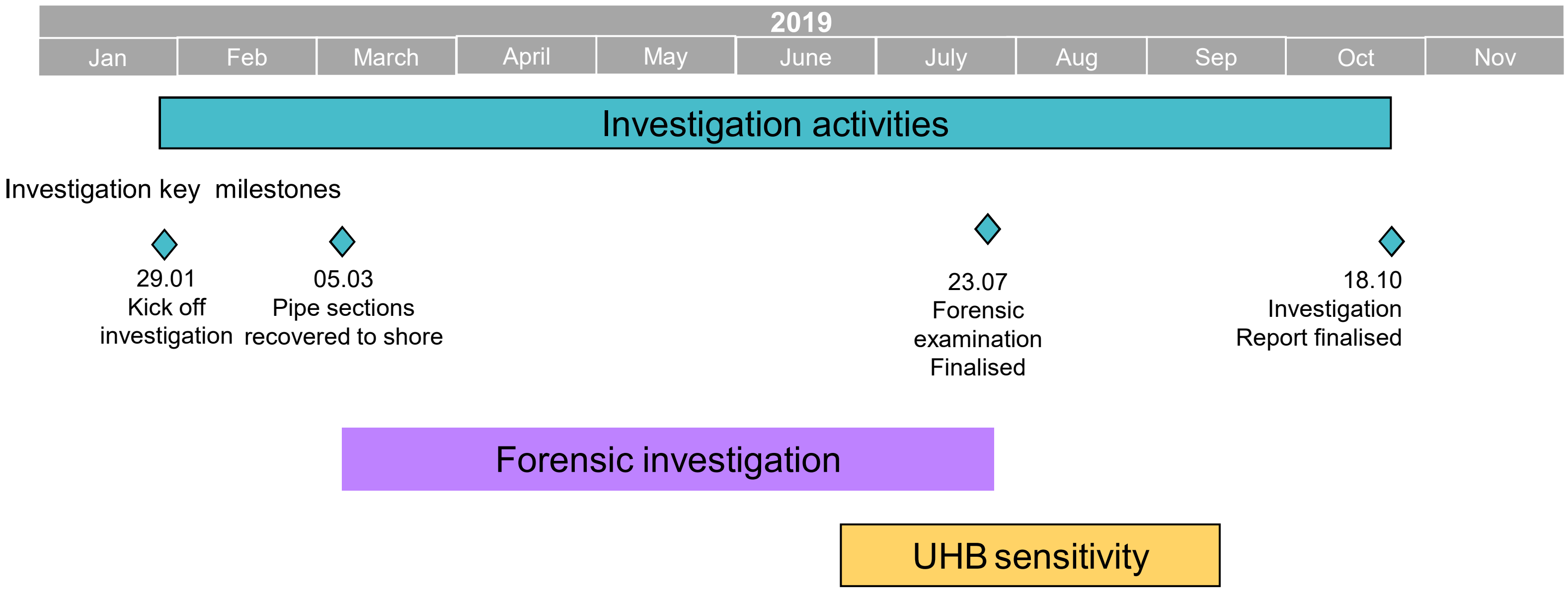
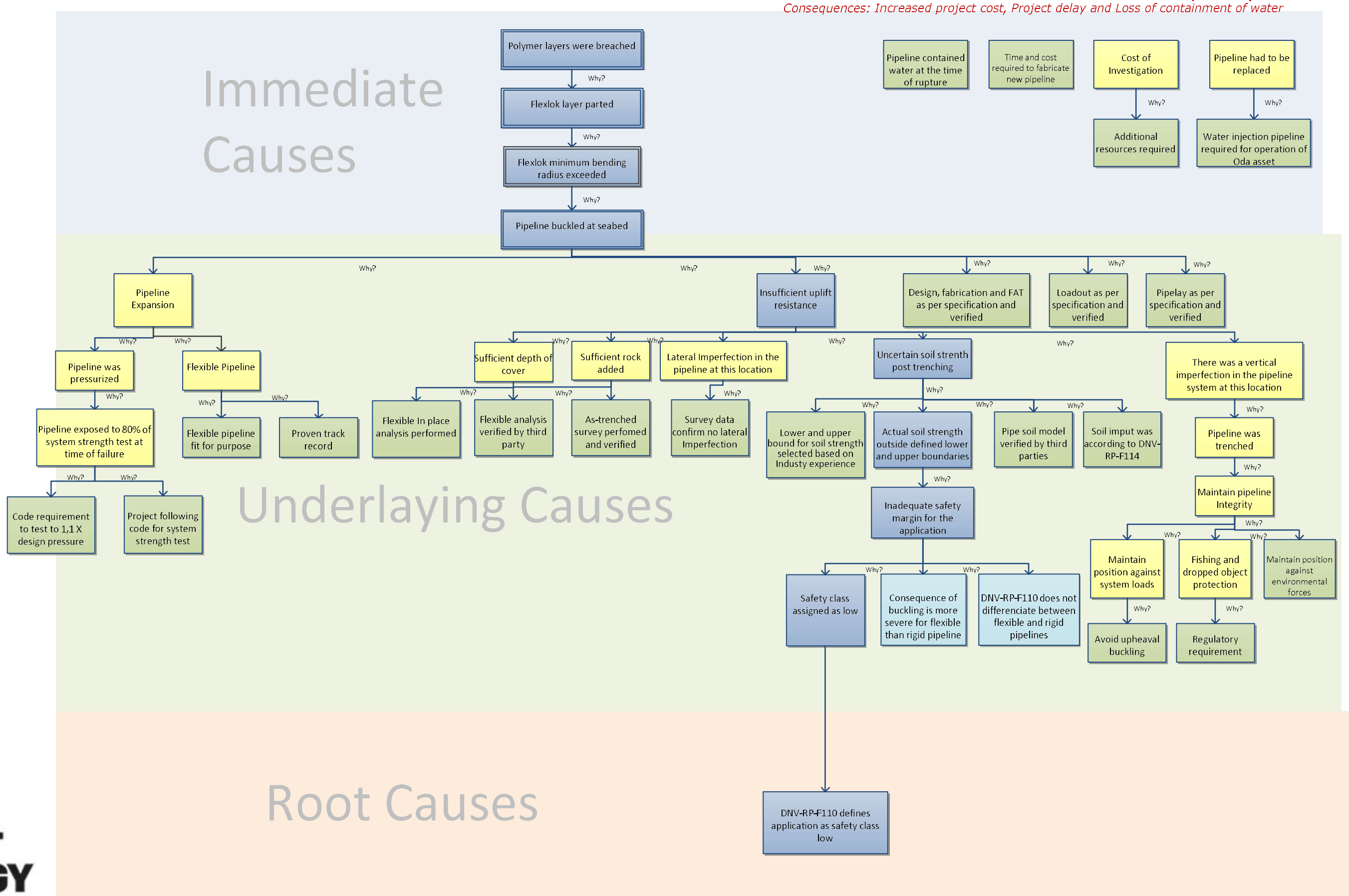
29.01.2019 - Started independent investigation



Root Cause Analysis

Incident Statement: Pipeline rupture
Consequences: Increased project cost, Project delay and Loss of containment of water



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Initial Investigation Findings

- The investigation found no evidence of a manufacturing defect or pre-existing damage from installation

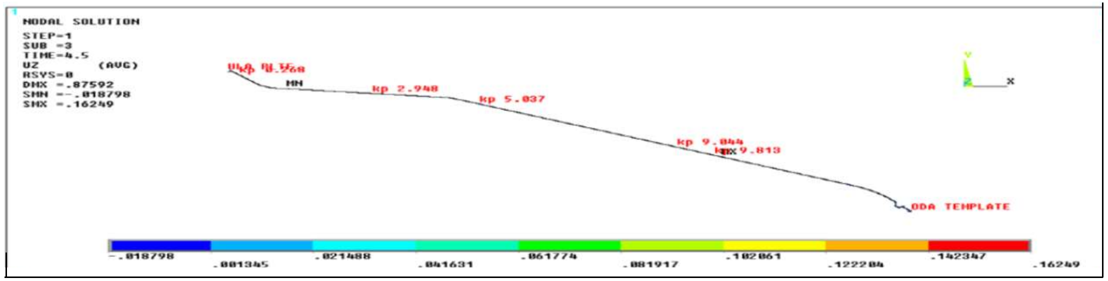
- The rupture and loss of containment was caused entirely by the buckling of the pipeline

- The investigation found that the pipeline (including trenching, backfill and SRI parameters) was designed in accordance with accepted industry practice and relevant Codes and that the parameters associated with those standards were met offshore

UHB sensitivity analysis – post incident

- As part of the investigation Spirit Energy has verified through independent models that there is no reason not to trust the FE models used for UHB.

- Sensitivity analysis with substantially weakened soil, the Oda WI flexible will fail first at the kp 9.814 which corresponds to the actual failure location



- Insufficient uplift resistance
- Insufficient soil cover strength and an inadequate safety margin
- The safety factors applied to the parameters (set within the Code) are marginal for this particular case (a WI pipeline during system strength testing)

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Investigation Findings – Existing WI flexible pipelines

Based on the investigation it can be concluded that there is no reason to have concern with existing flexible water injection pipelines in operation within the industry (passed system strength test which is worst case load condition)

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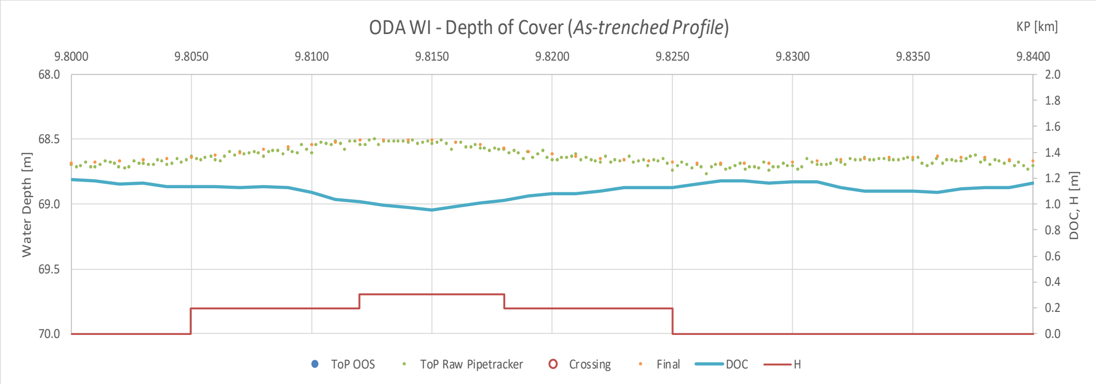
UHB design and Burial conditions

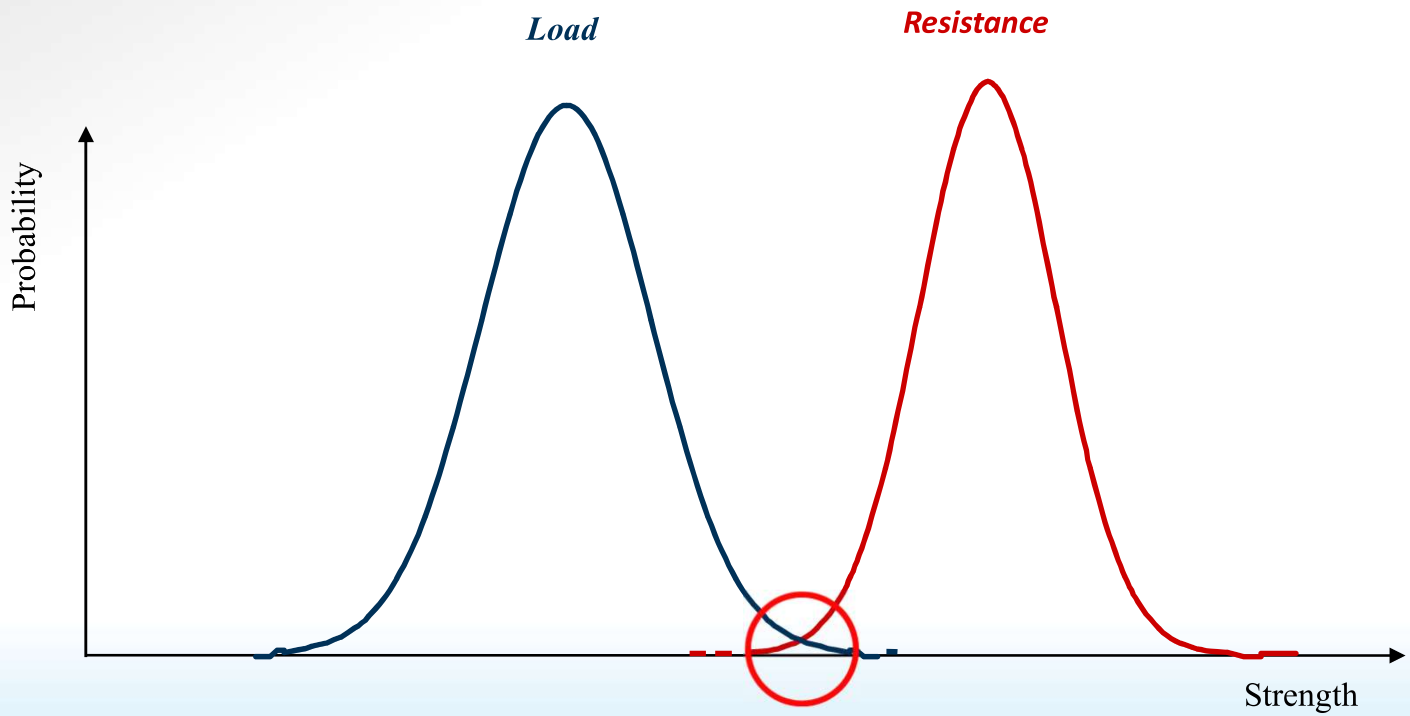
- Pipe profile, depth of backfill cover and SRI



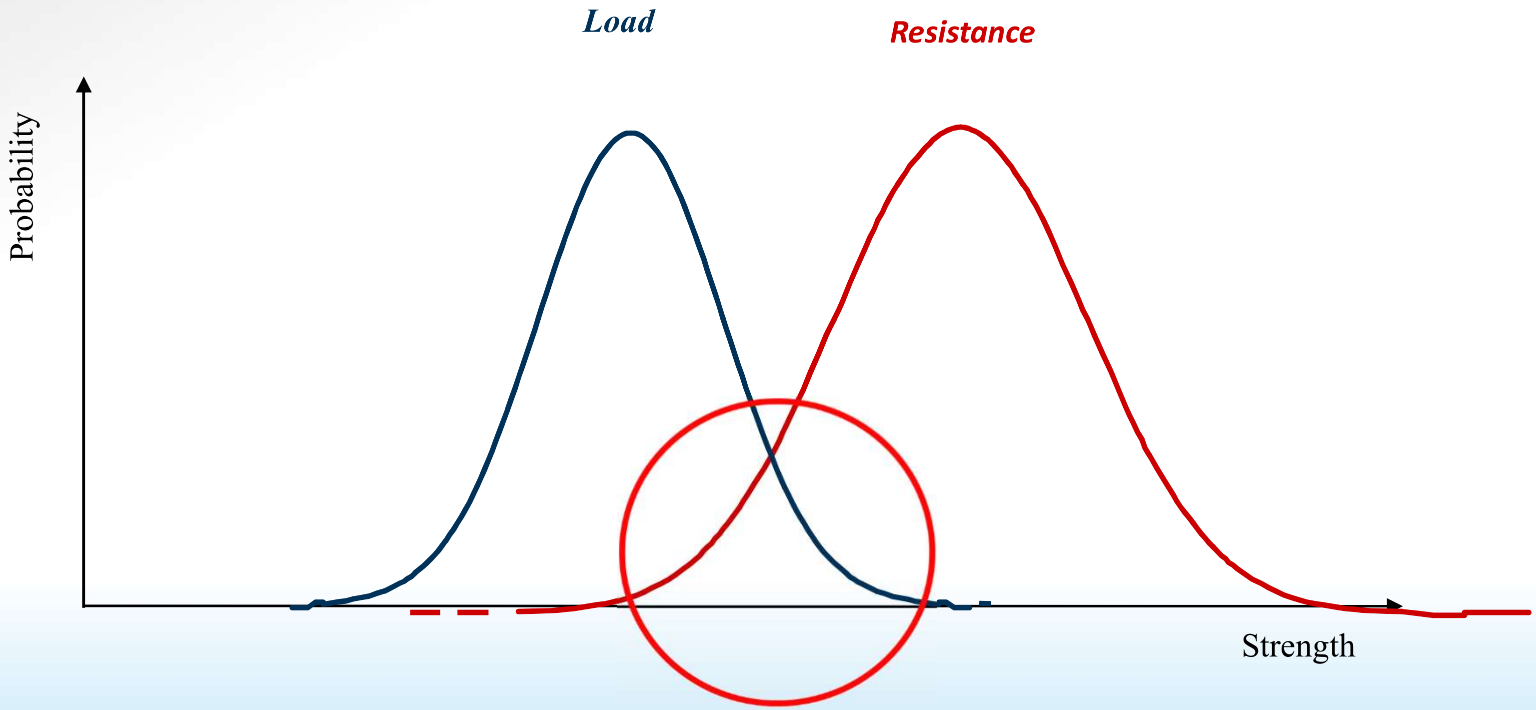
- As per design, the cover requirement was 1.2m ToP (0.9m soil backfill + 0.3m Spot Rock Dump) – Design according to DNVGL RP-F110
- The actual soil backfill cover was 1.08m (average) with an additional ~0.4-0.5m of spot rock dump

- *But the pipeline still failed – why?*
- *The failure was detrimental !*

Load and Resistance - Theory



Load and Resistance – Actual?



Main UHB uncertainties

For a rigid pipeline, the main uncertainties for UHB design (which are the basis for the design safety factors) are:

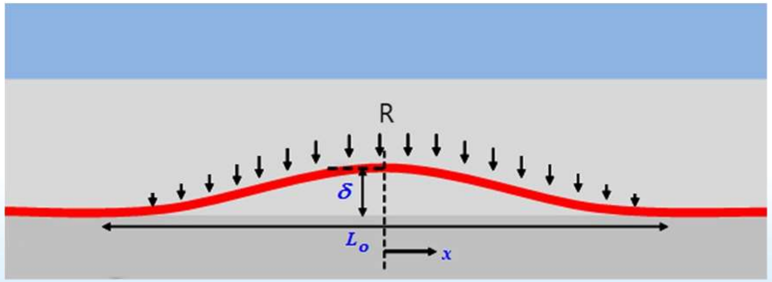
- **Vertical profile** (imperfection height), and associated survey accuracy;
- **Cover height**, and associated survey accuracy;
- **Cover strength** (geotechnical properties)

The remaining uncertainties relate to the pipe force and resistance, which again stem from the pipe's mechanical properties and dimensions, which have a significantly lower variability than for a flexible pipeline.

Additional uncertainties for flexible pipe

For a flexible pipeline the above uncertainties still apply, **but in addition**, the following parameters will also contribute:

- Pipe axial stiffness and associated axial force
- Pipe bending stiffness
- For a flexible pipe, a larger portion of the resistance is from the soil, compared to a rigid pipe, where the bending stiffness provides a significant contribution. As the soil uplift resistance is one of the main uncertainties (see above), there is a larger uncertainty in the overall resistance for a flexible pipeline than a rigid pipeline.



Example

- Required uplift resistance vs pipe bending stiffness

Pipe type	Required Uplift Resistance (N/m)		Ratio
	B-stiffness 100%	*B-stiffness 60%*	
Rigid pipe	3160	7150	1,26
Flexible pipe	2680	5010	0,87

Recommendations

- A comprehensive review of the UHB design requirements applicable to flexible flowlines should be performed (specifically relating to the differences when compared to a rigid pipe applications). In the meantime, there are two main recommendations that should be noted:
  - Since the **consequence of upheaval buckling** evidently can be detrimental to a flexible flowline, a higher safety class (i.e. lower failure probability) should be evaluated for future installations.
  - The design against UHB for a flexible pipe has additional uncertainties compared to the rigid pipe. In addition, as the UHB resistance for a flexible flowline is more dependent on the soil than for a rigid flowline (less contribution from the pipe bending stiffness), the total uncertainty increases. An increased safety margin should be considered for future designs.

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Next step

- Spirit Energy has initiated a study with DNVGL to further understand the challenge and reduce the probability of UHB of flexible pipelines

- Expectation is to finish the study with DNVGL Q1 2020.

- DNVGL will recommend a way forward on how to establish relevant recommendations and requirements to better control the UHB risk of flexible pipelines

THANK YOU FOR THE ATTENTION!