OIL & GAS

Reliable subsea gas transport; the history and contribution of DNV GL-ST-F101

Pipeline Safety Philosophy

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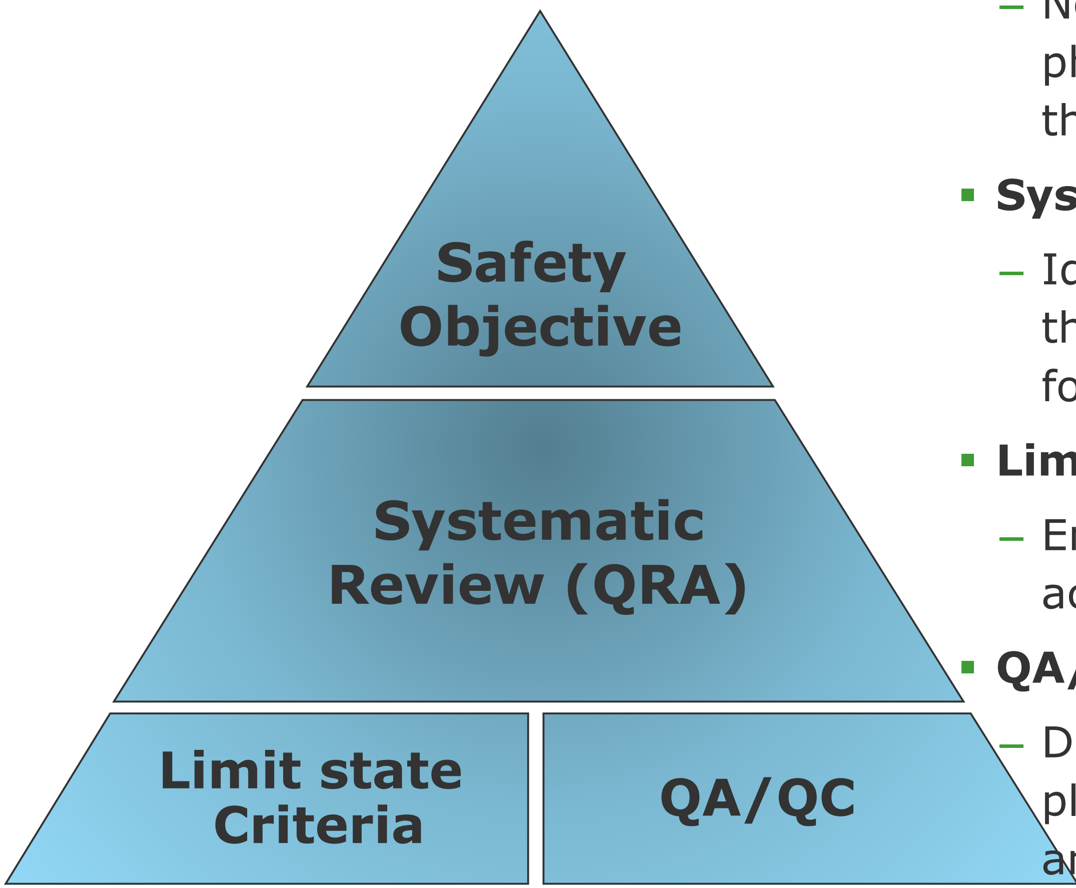
SAFER, SMARTER, GREENER

Safety Philosophy, challenges and risks

Safety Philosophy Structure



- **Safety Objective**
  - No single failure; a consistent safety philosophy has to be implemented as the DNA of the project organisation
- **Systematic Review**
  - Identify critical aspects or scenarios through a QRA and have special focus on these
- **Limit state criteria**
  - Ensure a consistent robustness across all structural design scenarios
- **QA/QC**
  - Design factors can never take the place of good quality and is therefore an equally important "brick" in the foundation of the safety philosophy

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The Nominal Probability of Failure
Where did it come from?

Table 2-5 Nominal annual target failure probabilities per pipeline vs. safety classes[5)]

Limit State Category	*Limit State*	*Safety Classes*			
		Low	*Medium*	*High*	*Very High[4)]*
SLS	All	10^{-2}	10^{-3}	10^{-3}	10^{-4}
ULS ALS	Pressure Containment[1)]	10^{-4} to 10^{-5}	10^{-5} to 10^{-6}	10^{-6} to 10^{-7}	10^{-7} to 10^{-8}
ULS FLS[2)] ALS[3)]	All other	10^{-3}	10^{-4}	10^{-5}	10^{-6}

1) The failure probability for the pressure containment (wall thickness design) is one to two order of magnitudes lower than the general ULS criterion given in the Table, in accordance with industry practice and reflected by the ISO requirements.

2) The failure probability will effectively be governed by the last year in operation or prior to inspection depending on the adopted inspection philosophy.

3) Nominal target failure probabilities can alternatively be one order of magnitude less (e.g. 10^{-4} per pipeline to 10^{-5} per km) for any running km if the consequences are local and caused by local factors.

4) See Appendix F Table F-2.

5) The target shall be interpret as "probability that a failure occurs in the period of one year".

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What the ridiculously small failure probability targets really are

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10^{-6} and all that: what do failure probabilities mean?

Professor Andrew Palmer, The Journal of Pipeline Engineering, 4Q2012

I tried to make sense of that number; “Did you say 1 in 10^5?”
“That’s right; 1 in 100000”
“That means you could fly the shuttle every day for an average of 300 years between accidents – every day, one flight, for 300 years – which is obviously crazy”
“Yes, I know”, said Mr Ullian

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Imagine….

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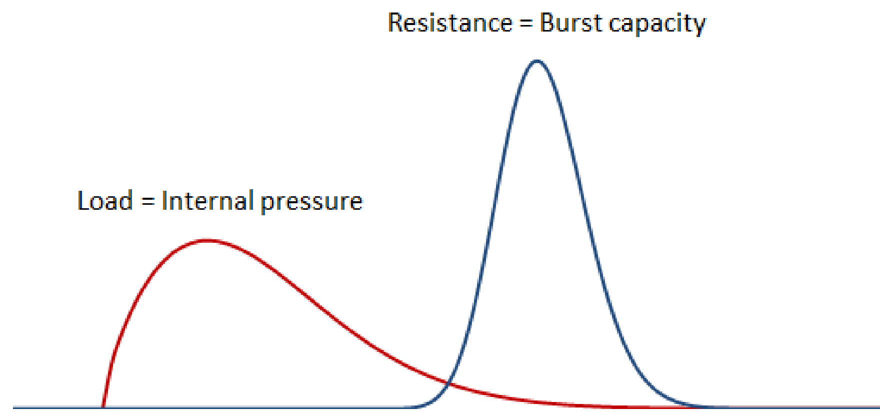
Limit State Design

- Limit state design
  - This implies that we check each failure mode.
  - So, why can we not just state:

Load < Capacity

Limit State Design

- Uncertainties
  - Load and capacity varies
  - Burst capacity and pressure varies…
- A certain spacing between the two distributions is therefore required which will give us a certain failure probability
- The spacing can be described by
  - Characteristic capacity
  - Characteristic load, and
  - Safety factor



$P_i \times \gamma < p_{cap}$ for some γ

- For defined Characteristic Load and Capacity we can select a γ that gives us a certain failure probability

- What should the safety factor be?

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Learn from history...

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Traditional design

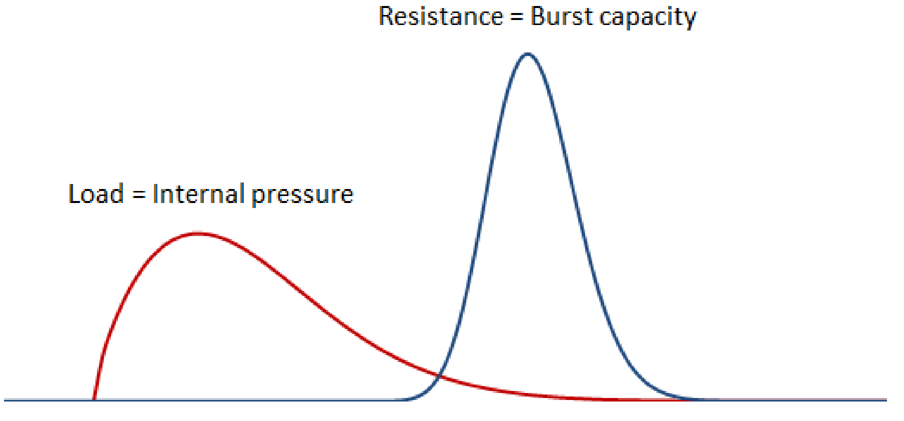
- Pressure vessels were first introduced in a large scale by use of the steam engine
- By the 1880's, exploding boilers in the US, had caused 50,000 deaths and 2 million people were being injured annually in a national population of 50 million.
- An initiative to establish a pipeline standard was taken in 1915
- A draft issued of ASME standard B.31 was launched 1925/ First revision 1935

- This was based on some fundamental elements that still apply:
  - It requested the pipeline to be pressure tested. It expressed this pressure as a fraction of the Barlow hoop stress times the yield stress. This fraction was 0.9.
  - It required that the design pressure should be a fraction of the test pressure; 0.8. And the factor of 0.72 was born.
  - It required a lower fraction where the consequences were more severe. I.e. it had some inherent risk principles.

Traditional design

- Has the pipeline history
  - Been to conservative?
  - Shown too many failures?
  - Been ok?

- Given that the pipeline history has shown to give an acceptable track record, how shall we select safety factors for the future and for other failure modes?



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Failure probability

- Maybe, we could define a probability of failure?
  - How should an acceptable probability of failure be determined?

- There are two (at least) ways of determining this;
  - Look into the implied failure probability in the used design criteria
  - Look into the failure statistics

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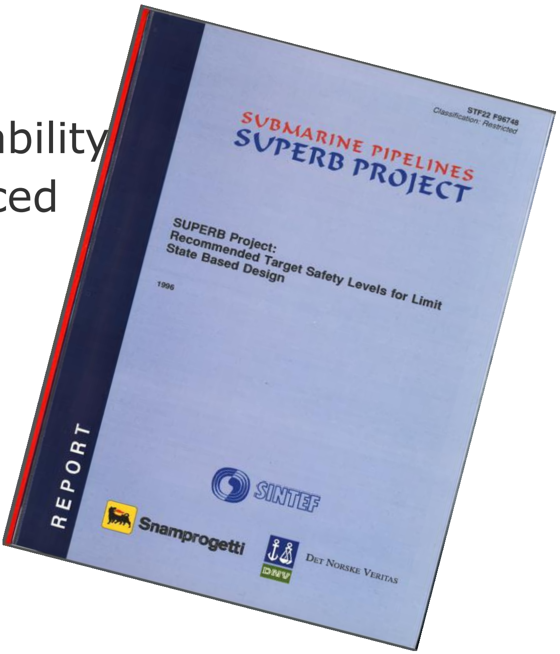
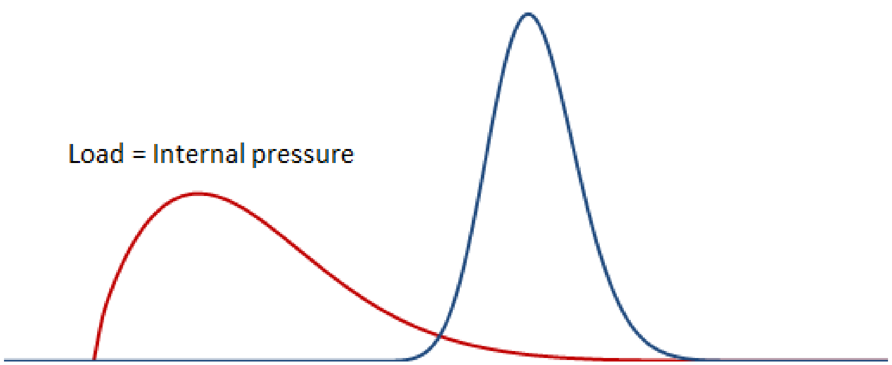
The Nominal Probability of Failure
Where did it come from?

- One could calculate the inherent (implied) failure probability of the design criteria that gave rise to todays experienced failure probability
- This was the basis for the work performed within the SUPERB project, a JIP in the first half of the 1990'ies.





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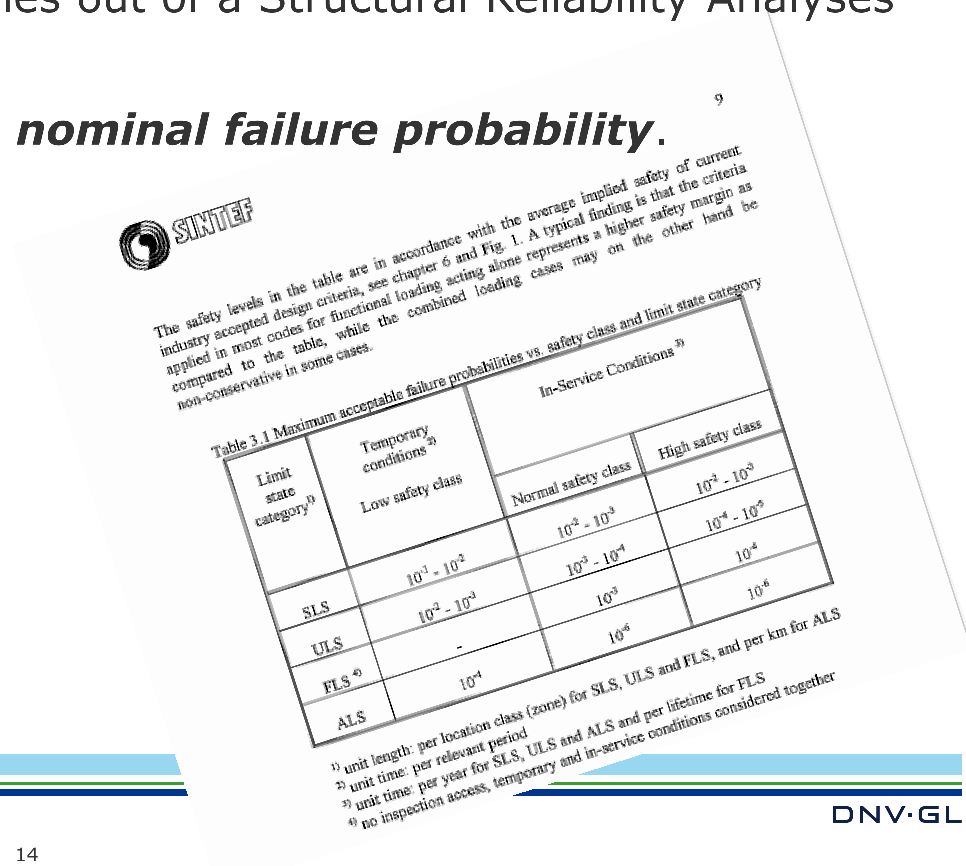
The Nominal Probability of Failure
Where did it come from?

- The SUBERP project studied design criteria that had been used during the last 50 years.
- Any new criteria should reflect the same level of safety.
  - Safety in this context was interpreted as the failure probability, for pipelines with similar consequences, that comes out of a Structural Reliability Analyses (SRA) of the design criteria used.
  - This probability is referred to as the ***nominal failure probability***.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The safety levels in the table are in accordance with the average implied safety of current industry accepted design criteria, see chapter 6 and Fig. 1. A typical finding is that the criteria applied in most codes for functional loading acting alone represents a higher safety margin as compared to the table, while the combined loading cases may on the other hand be non-conservative in some cases.

Table 3.1 Maximum acceptable failure probabilities vs. safety class and limit state category

Limit state category[1]	Temporary conditions[2] Low safety class	In-Service Conditions[3] Normal safety class	In-Service Conditions[3] High safety class
SLS	10^{-1} - 10^{-2}	10^{-2} - 10^{-3}	10^{-2} - 10^{-3}
ULS	10^{-2} - 10^{-3}	10^{-3} - 10^{-4}	10^{-4} - 10^{-5}
FLS[4]	-	10^{-3}	10^{-4}
ALS	10^{-4}	10^{-6}	10^{-6}

1) unit length: per location class (zone) for SLS, ULS and FLS, and per km for ALS
2) unit time: per relevant period
3) unit time: per year for SLS, ULS and ALS and per lifetime for FLS
4) no inspection access, temporary and in-service conditions considered together

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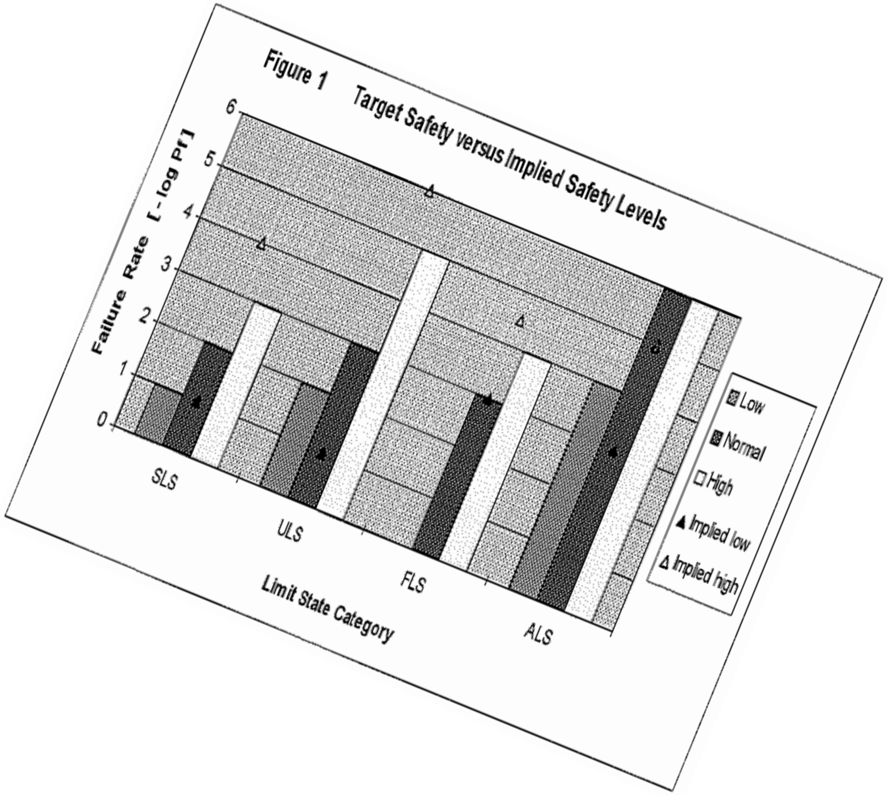
The Nominal Probability of Failure
Where did it come from?

- The Superb work resulted in:
  - 10^{-3} – 10^{-6} For severe failure modes
  - 10^{-4} – 10^{-10} For pressure containment

- Failure statistics shows:
  - 10^{-2} – 10^{-3}

- Why this difference?



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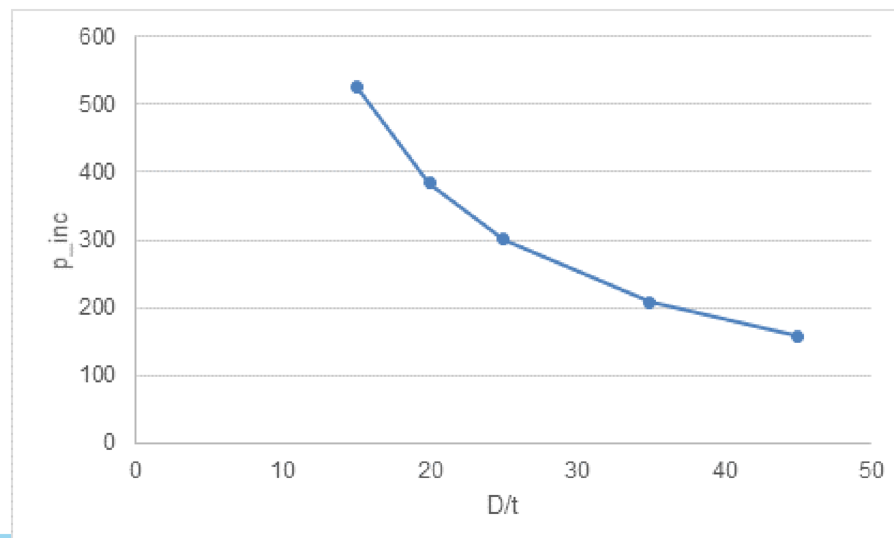
The Expected Probability of Failure
Why does failure happen?

- One pipeline was severely damaged by an anchor
  - Anchors were not expected there in 215 m water….
- One pipeline broke when a trawl got stuck at a flange
  - The flange was specified to be protected by gravel in the design….
- Another pipeline broke when a trawl got stuck at a flange
  - This was inside trawl free zone…
- One pipeline bursted after three years service
  - Was specified to be been cleaned, inspected and inhibited but was not….
- One pipeline experienced upheaval buckling in a depression
  - The survey for gravel determination was based on top of pipe…
- One pipeline was decided to be taken out or service
  - And was not…
- ….and so on….

Pipeline Safety Philosophy

- Most failures are not due to:
  - Erroneous input
  - Poor implementation of design assumptions
  - …

- Almost never due to design failures
  - Which it should not - given these ridiculously low failure probabilities…



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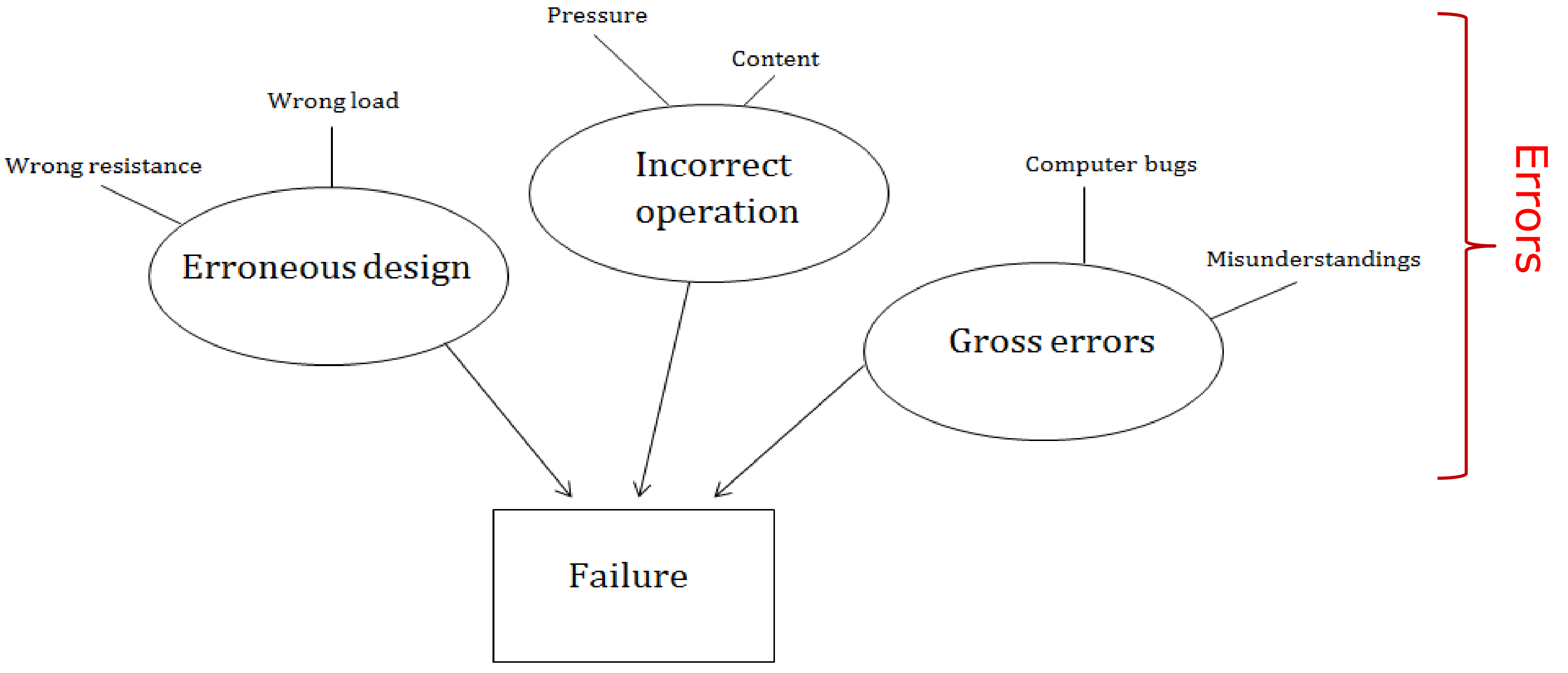
What does “nominal failure probability” mean?

- It is not only parameter and model uncertainty that contribute to failure …



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What does “nominal failure probability” mean?

$$PoF_{\exp} = P(Failure|E) \cdot P(E) + P(Failure|\overline{E}) \cdot P(\overline{E})$$

$P(Failure|E)$ is the probability of failure when an error has occurred.

- Depending on the type of error this probability can be anything, but it will in many cases depend on the probability of failure when no error has occurred
- A robust pipeline is more likely to survive unforeseen loads

$P(Failure|\overline{E})$ is the ***nominal failure probability***

- Depends on all uncertainties that are known and accounted for in design through structural reliability analysis

P(E) is the probability of the error occurring, leading to failure or not. It is controlled through QA/QC

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Nominal failure probability is the probability of failure if everything is done correctly

It ensures a consistent robustness

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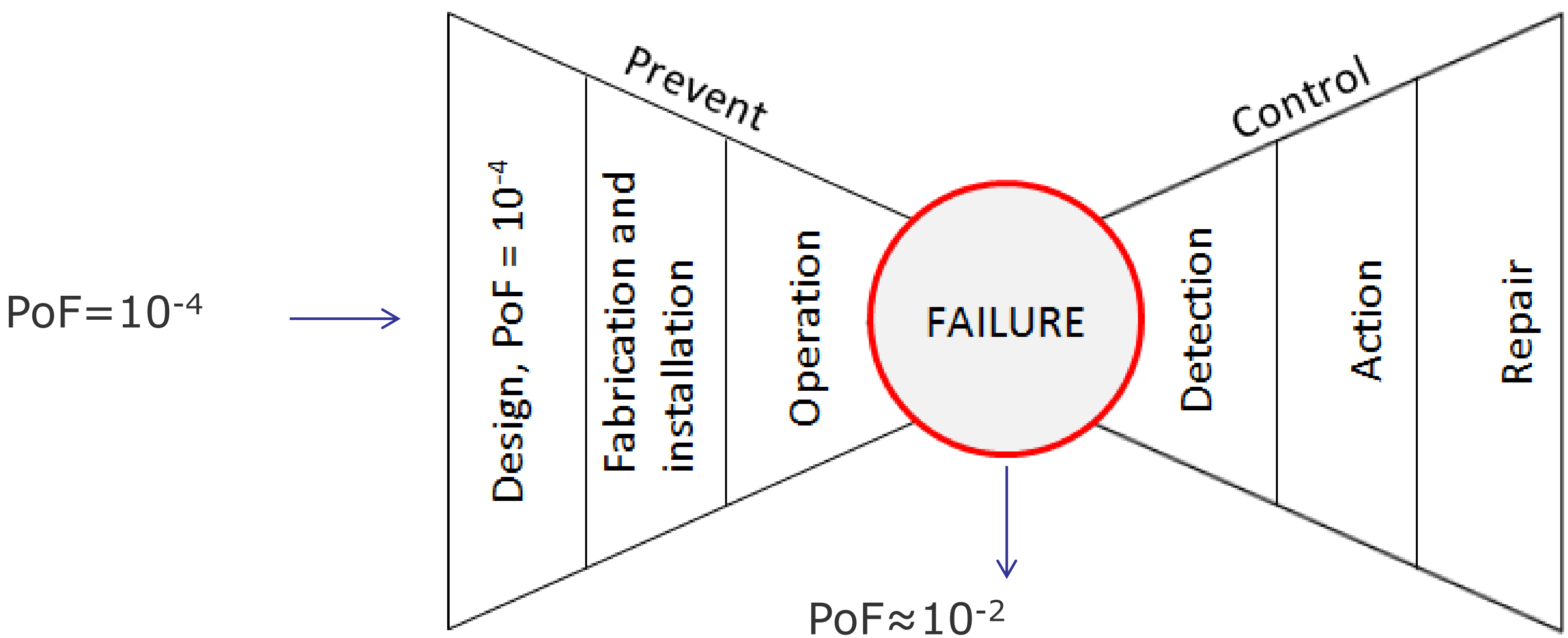
The Nominal Probability of Failure
What does it mean?

- The NOMINAL and EXPECTED probability of failure



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What now?

- Should we change how we deal with risk in design?
- Misconceptions of failure probabilities can be dangerous.
- An industry consensus is needed.

- A study on pipeline risk through a Joint Industry Project could help sort this out.

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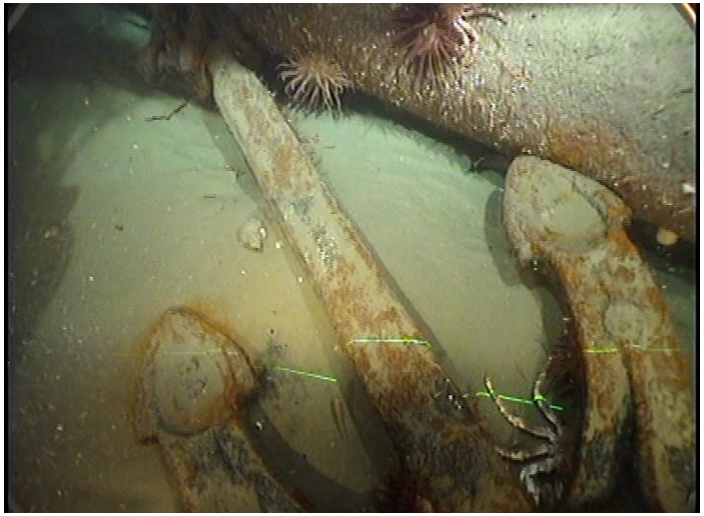
Harmonisation of risk methodologies applied to pipelines

- Failure statistics and nominal failure probability
- Anchor damage and general damage assessment
- Barriers and Bow-Tie
- Third party threats and traffic density close to pipelines
- Pipeline protection



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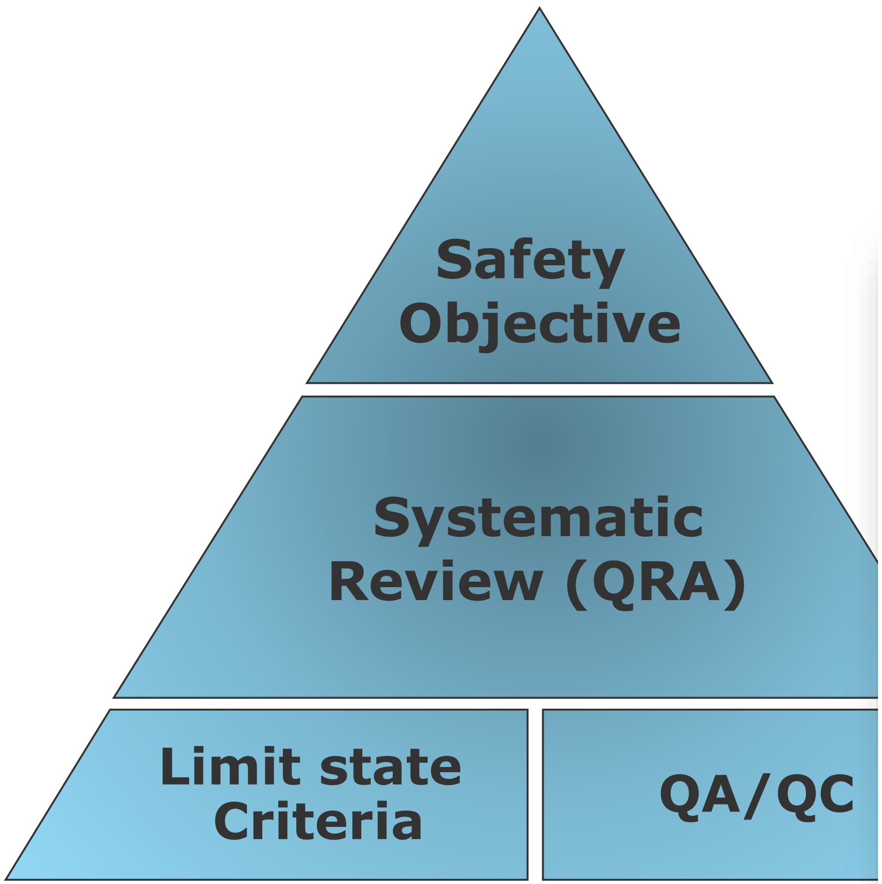
Ultra deep water pipelines –
Safety Philosophy, challenges and risks

Safety Philosophy Structure



- Safety Objective
- Systematic Review
- Limit state criteria

A 300 Systematic review

301 The overall requirement to systematic review in Sec.2 shall be reflected in the offshore construction of the pipeline.

302 Systematic analyses of equipment and offshore construction shall be performed in order to identify possible critical items or activities which could cause or aggravate a hazardous condition, and to ensure that effective remedial measures are taken.

303 The extent of systematic review shall depend on criticality of operations and experience from previous similar operations.

304 The systematic analyses should be carried out as a failure mode effect analysis (FMEA) for equipment and hazard and operability studies (HAZOP) for critical operations. Recommended practice for FMEA and HAZOP is given in DNV-RP-H101. For HAZOP, reference is also made to API RP 17N.

Guidance note:

Typical items to be covered for HAZOP include:

- simultaneous operations
- lifting operations including pipe joints transportation and storage
- dry and wet buckles including flooding of pipe
- initiation and lay down including shore pull
- operations inside safety zones
- critical operations (laying in short radii curves, areas with steep slopes etc.)
- failure of equipment and measuring and monitoring devices
- tie-in operation
- pre-commissioning activities
- environmental conditions and weather criteria
- emergency abandonment
- loss of station keeping capabilities
- survey.

It is desired to mitigate potential hazards by engineering measures.

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305 The results of the FMEA analysis or HAZOP studies shall also be used in determining the extent and depth of verification of equipment and procedures.

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Thanks

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