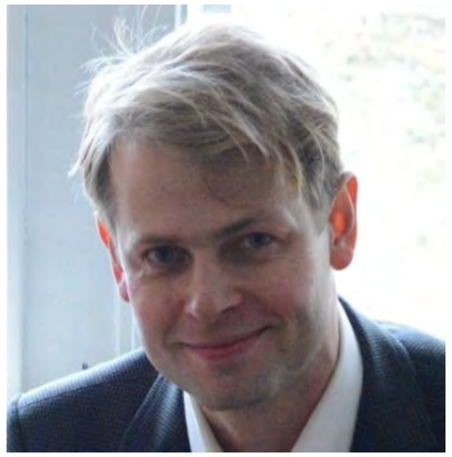
Back to Basics—the Use of Structural Reliability Analysis in Pipeline Design to Cut Costs in the Maria Development

by Reinert Hansson, Wintershall



Reinert Hansson
Senior Pipeline Engineer
Wintershall

Change of the tides

The oil and gas industry has seen a dramatic reduction in the selling price of its main product, forcing the industry to significantly reduce its cost base. Industry costs rose significantly in previous years, due to several factors including overdesign of facilities. However, cost reduction cannot be allowed to happen nor at the expense of the safety of oil workers nor the environment. In this context, the use of advanced statistics and reliability analyses could offer some solutions, as shown on the Wintershall-operated Maria project.

Reliability Based Design

The oil and gas industry typically requires that the critical components used in facilities have a certain reliability. That means that the probability of failure of the component is below a certain limit in order to ensure safe operation.

The reliability of a structure can be assessed directly by performing a so-called structural reliability analysis (SRA). This involves assessing all the variability and uncertainty governing the loading of a structure and the capacity of the structure to withstand loading. For subsea pipeline design, this includes variability in the environmental conditions, currents and waves, seabed conditions, materials, geometrical properties of the pipe and also uncertainty with respect to correct modelling of a given problem. If the designer can understand and map all this variability and uncertainty, he or she can calculate the probability that a structure will fail. However, in most cases the complexity of the structural reliability analysis method prevents this from being used as a general design tool.

Limit State Design

The majority of subsea pipeline projects globally are designed in accordance with the DNV-OS-F101 design code for Subsea Pipeline Systems. This code instead prescribes a limit state design method. Most engineers will be familiar with limit state methods as they are widely used across the industry. A typical (simplified) formulation will be as follows:

$$\frac{L_{Ch} \times \gamma_L}{R_{Ch} \times \gamma_R} \leq 1$$

On the top of the fraction a characteristic conservative) estimate of the load is multiplied with a given safety factor. On the bottom of the fraction a characteristic (conservative) resistance is multiplied with a given safety factor. The criterion then stipulates that the result of this fraction (typically called the utilisation) shall be below unity. The design code describes how to calculate each of the variables in the formula and thereby removes the majority of the complexity from the design challenge. The beauty of this is that the formula given in the code is calibrated to ensure that the desired reliability of the structure is achieved. Limit state design therefore represents a very efficient although conservative method to ensure the reliability of a system.

Limit state design formulas are typically very general and designed to be applicable for a large variety of cases. In order to ensure that they always offer a conservative result, in most cases they will be very conservative leading to a risk of overdesign. However, the results of limit state design methods are not challenged often enough even when it is clear to engineers that resulting designs are based on very conservative assumptions and the potential cost related to overdesign is significant.

There are many reasons for this. We are a very conservative industry and traditionally not quick to change out methods which are proven to be robust and safe. Moreover, the knowledge among engineers about the background for the formulas used on a daily basis may be lacking, and also not typically described in the design code documents.

Trawl pull-over

The Maria field is served by two subsea templates tied back to three host facilities in the Haltenbanken area of the Norwegian Sea. In an area with some fishing activity, the 100 km of pipelines could come into contact with the heavy equipment the fishermen use to trawl the ocean floor, representing a major risk for any infrastructure on seabed.

In the case of the Maria project an additional challenge is caused by the fact that the pipelines are laid across very uneven seabed created by icebergs which scarred the seafloor at the end of the last ice age. This has created free-spans up to 8m high, leaving up to 60% of the pipeline not in contact with the seabed. Using the standard limit state design method, a design requirement was reached which necessitated that the free-spans under two of Maria's three pipelines were filled. A project of this size requires at least a 3 month campaign with a major rock dumping vessel collecting rock at the shore and shuttling it out to

the Maria field where it would carefully be installed under the lines in order to support them and protect them.

Structural Reliability Analyses

A structural reliability analysis was performed by the project in order to investigate if the high rock volumes needed to fulfill this requirement could be adjusted. First, a sensitivity study was performed to identify the variables which impact the failure probability of the pipe under trawl loading. These included factors such as pipe properties, seabed characteristics, and operating parameters.

The variables which are found to have an impact are included in the reliability analysis as stochastic variables, meaning that their variability is mapped and included in an analysis matrix defining combinations which are analysed in a sophisticated finite element model. A statistical evaluation is performed on the results and finally a Monte Carlo simulation is performed to calculate the failure probability.

The target maximum probability of failure for a subsea pipeline is typically 1/10,000 years. The SRA showed that the reliability of the Maria pipelines designed according to the standard limit state methods were several orders of magnitude better than the target. Even when all the rock previously included to support the pipelines was removed from the initial design, the reliability was still proven to be 1-2 orders of magnitude better than the target, resulting in considerable cost reductions for the project.

Encouraged by the success on the trawl design similar methods have also been employed in other areas of the pipeline design scope including installation design and design of structural bends, with great success.

The way forward

Pipeline design is by and large performed by use of the limit state design methodology. Considering this age of cost management, I think the use of reliability analyses to support the design and maybe challenge certain critical elements could be interesting to many projects.

This is not something the Maria project has invented. In fact, I hear from many other projects and also other disciplines which are reassessing the "standard ways" of doing things and reliability based methods are being utilised more. This is, of course, related to the recent development of the oil price, leading to a shift from schedule driven projects, where the first oil date has typically been the main priority, to a much higher cost focus, even at the expense of technical complexity related to engineering.

The reliability based methods are attractive because they offer a way to document that project optimization, and sometimes significant cost reductions can be performed without corresponding negative impact on HSE or reliability. Compared to the methods traditionally used, the additional engineering can be significant and in certain cases will involve some additional elements of R&D. However, at least for the Maria project, there has been a very healthy return on invested engineering hours whilst still fulfilling the stringent HSE expectations.