BENCH MARK

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Stochastic Challenge Problems

The Stochastics Working Group (SWG) within NAFEMS is focused on extracting significantly more business value from your investment in engineering analysis and simulation through the effective application of stochastic methods to:

- produce repeatable, realistic and rapid results
- reduce design cycle times through faster iterative analysis and simulation
- reduce the number of physical prototypes required for product design validation
- improve accuracy to drive down product, development, manufacturing, and warranty costs

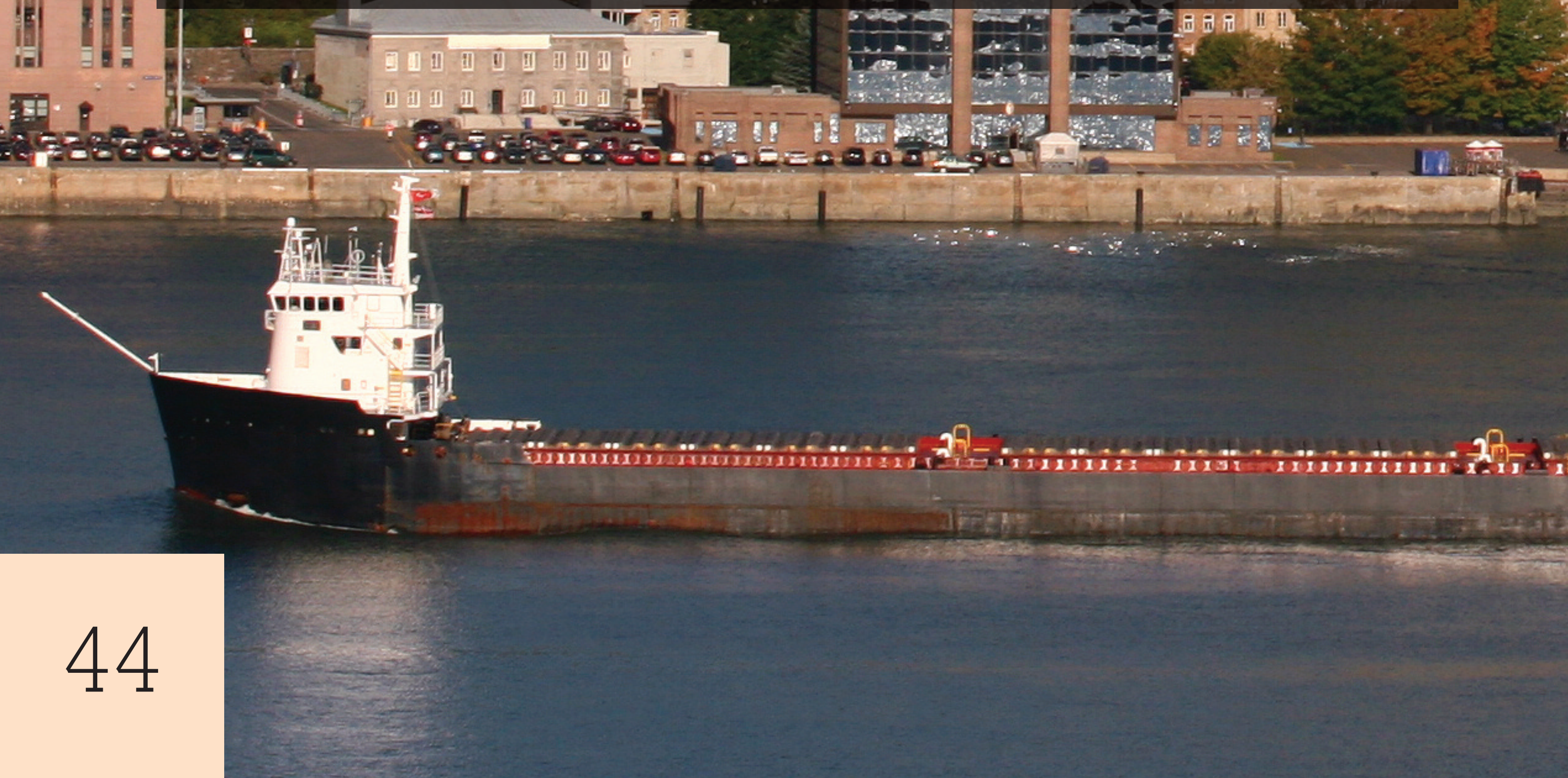
The SWG [1] brings together a rich blend of leading engineering practitioners, software vendors, and academic researchers from around the world. Recently the SWG published a short document titled "What is Uncertainty Quantification (UQ)?" which can be downloaded for free from the NAFEMS website [2].

To promote further the adoption of stochastic methods and tools in the engineering simulation area, the SWG is setting out stochastic challenge problems to solve. The request is going to government, industrial, and educational institutions in the hopes of sharing and showcasing different approaches to uncertainty quantification (UQ) and the conclusions drawn from such analysis tasks.

These benchmark and challenge problems are also linked to Barna Szabo's "FEA Puzzler: How confident are you in your predictions?" [3], as the methods to solve these problems can be applied to quantify the confidence in any of your engineering simulations.

NAFEMS World Congress 2019

During the upcoming NAFEMS World Congress there will be a special session led by the SWG to discuss these benchmark and challenge problems. Potential solutions to these problems will be discussed, along with potential pitfalls and advantages of the analytical methods. This session is open to all congress participants to present their solutions to the benchmark and challenge problems. If you are interested in participating in this session, please contact: swg@nafems.org



Challenge Problem 1

A material test specimen is to be subjected to a tensile load. The specimen has a nominal yield stress of 270 MPa. It must be guaranteed that the material remains in the elastic regime. Therefore a tensile stress of 210 MPa looks permissible for a particular application, since this is only 78% of the yield stress.

With respect to Uncertainty Quantification, the following data is available:

- Yield stress: mean value 270 MPa; standard deviation 13.5 MPa
- Tensile stress: mean value 210 MPa; standard deviation 10.5 MPa

Both stresses are assumed to be normally distributed.

The question is: **"What is the probability that the tensile stress exceeds the yield stress?"**

Although this benchmark problem has a theoretical closed form solution, the challenge is to apply engineering stochastic simulation methods to reproduce this theoretical solution.

Challenge Problem 2

Outline of Problem and Deterministic Solution

The longitudinal strength of a ship can be assessed in a simple way by representing the ship as a beam with a varying cross section, following Archimedes' law. The buoyancy is distributed along the beam, such that it is in balance with the varying weight. As a result, the beam is subjected to a varying Bending Moment, BM, where division by the varying Section Modulus, SM, gives a bending stress of:

$$\sigma_b = \frac{BM}{SM}$$

This challenge problem represents the case of a damaged oil tanker. An explosion has ruptured the deck structure with the consequence that the resulting section modulus at this location is significantly decreased. Of course there is residual strength; however, to keep the bending stress within acceptable limits, the bending moment generated by sea waves must be carefully monitored whilst sailing in open water to reach the repair yard. Is the predicted sea state allowable?

Naval architects can alter the Still Water Bending Moment (SWBM) via changing the tank loading. The SWBM is the static difference between weight and buoyancy. The sea state results in a continuously changing Wave Bending Moment (WBM). The expected sea state results in a maximum wave bending moment of

- WBM = 2.4 GNm with deck in compression
- WBM = 2.1 GNm with deck in tension

Buckling of the damaged deck section must be avoided, and therefore the deck must be kept in tension. This means that the tank loading must result in a SWBM = 2.4 GNm with the deck in tension and prevent buckling during the wave action. This condition results in a maximum tensile stress in the deck being induced by the maximum bending moment: SWBM + WBM.

It is assumed that the ruptured deck has a reduced section modulus, SM = 17.2 m^3, based on visual inspection. This results in a bending stress of:

$$`\sigma_b = \frac{SWBM + WBM}{SM} = \frac{(2.4+2.1)\cdot 10^3}{17.2} = 262 \text{ MPa}$$

Since sailing to the repair yard under careful monitoring may be considered as an exceptional condition, the allowable stress is raised to 90% of the yield stress. The steel has a yield stress of 315 MPa, and this gives an allowable stress of 0.90 × 315 = 284 MPa. Based on a deterministic analysis, the sea state is allowable and hence sailing to the repair yard is acceptable.

Uncertainty Quantification (UQ)

The parameters applied in the deterministic analysis contain uncertainty so each input value can be characterized by a distribution type with a mean value and a standard deviation. The input for UQ is presented in Table 1.

The Challenge

Applying stochastic methods, what is the probability that the imposed bending stress σ_b, exceeds the allowable yield stress σ_{yield}? ■

References

[1] NAFEMS. Stochastics Working Group. nafe.ms/swg (accessed 19 March 2019).

[2] NAFEMS Stochastics Working Group. What is Uncertainty Quantification (UQ)?. : NAFEMS; 2018. nafe.ms/wt08 (accessed 19 March 2019).

[3] Professor Barna Szabó. FEA Puzzler: How Confident Are You?', Benchmark October 2018 - Interactive Simulation. P25. Challenge available from nafe.ms/puzzler

Item	Distribution Type	Mean	Standard Deviation	CoV
Section modulus [m^3]	normal	17.2	1.7	0.10
Still water bending moment [GNm]	normal	2.4	0.12	0.05
Wave bending moment [GNm]	uniform	1.9-2.3	--	--
Yield stress σ_{yield} [MPa]	Lognormal	343	17	0.05

Table 1: Distributions of the input parameters

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