GDAŃSK UNIVERSITY OF TECHNOLOGY

RELIABILITY OF CORRODED STIFFENED PLATE SUBJECTED TO UNIAXIAL COMPRESSIVE LOADING

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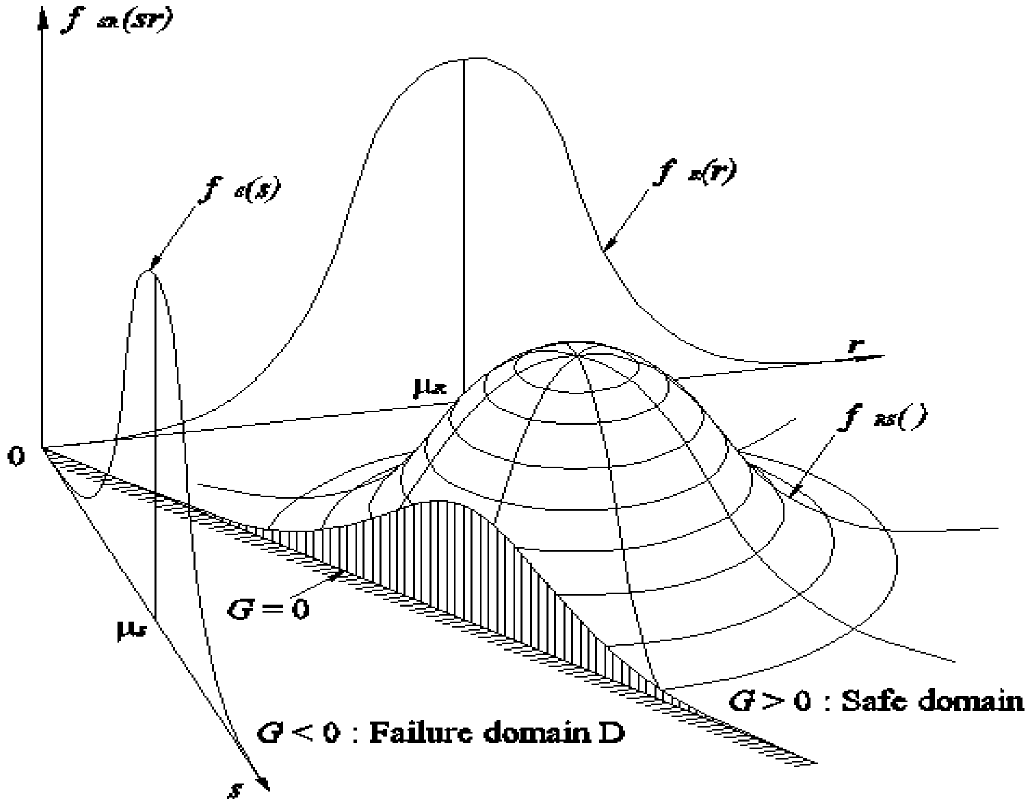
Objectives

- Investigation of the reliability of corroded stiffened plates subjected to compressive uniaxial load
- Comparison between two corrosion models
- Consideration of uncertainties related to mechanical properties, thickness and level of initial imperfections
- Discussion about the origin of the uncertainties and their impact into the reliability

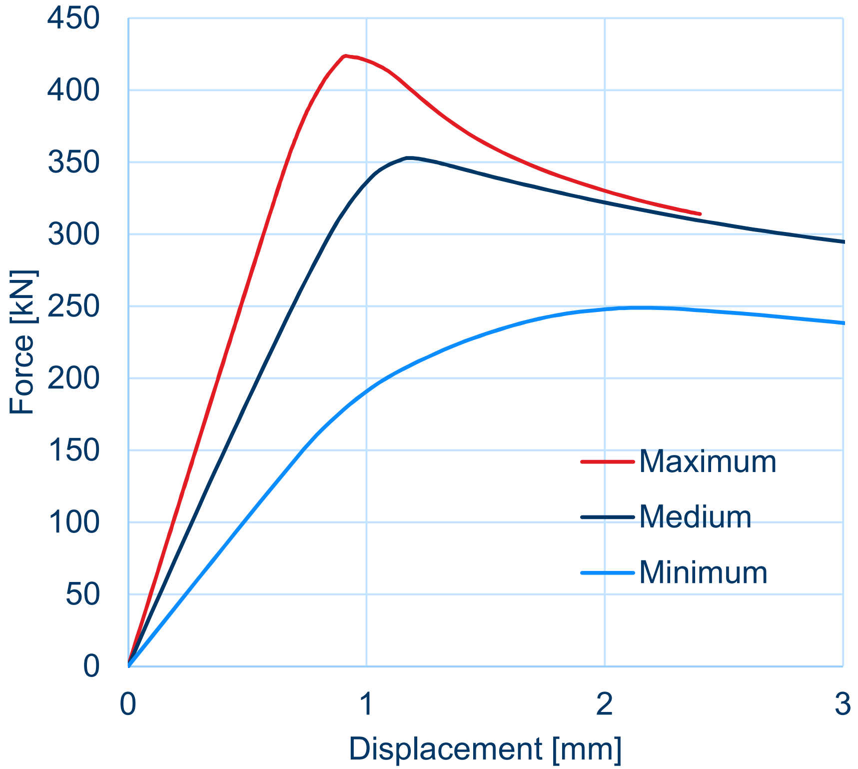
Basic structural reliability definitions



Source: Melchers, R. E. 1999. *Structural reliability: analysis and prediction,* Chichester, John Wiley.

Uitimate strength – basic informations

- **Ultimate strength depends from many factors, including initial distortions, mechanical properties, corrosion degradation and presence cracks.**
- **The ultimate capacity is subjected to high uncertainties with respect to stochastic variations of considered factors**
- **Recent studies revelead that not only thickness is reduced with corrosion development, but mechanical properties too**



Source: Woloszyk, K., & Garbatov, Y. (2019, August). Uncertainty assessment of ultimate strength of corroded stiffened plates subjected to maintenance. In *Sustainable Development and Innovations in Marine Technologies: Proceedings of the 18th International Congress of the Maritime Association of the Mediterranean (IMAM 2019), September 9-11, 2019, Varna, Bulgaria* (p. 429). CRC Press.

Stiffened plate failure modes – according to Common Structural Rules

- **Beam column buckling**

$$\sigma_{CR1} = \begin{cases} \sigma_{E1}; & \sigma_{E1} \leq \frac{Re}{2} \\ Re\left(1 - \frac{Re}{4\,\sigma_{E1}}\right); & \sigma_{E1} > \frac{Re}{2} \end{cases}$$

- **Torsional buckling**

$$\sigma_{CR2} = \begin{cases} \sigma_{E2}; & \sigma_{E2} \leq \frac{Re}{2} \\ Re\left(1 - \frac{Re}{4\,\sigma_{E2}}\right); & \sigma_{E2} > \frac{Re}{2} \end{cases}$$

- **Web local buckling**

$$\sigma_{CR3} = \begin{cases} \sigma_{E3}; & \sigma_{E3} \leq \frac{Re}{2} \\ Re\left(1 - \frac{Re}{4\,\sigma_{E3}}\right); & \sigma_{E3} > \frac{Re}{2} \end{cases}$$

Source: IACS 2015. Common structural rules for bulk carriers and oil tankers. London: International Association of Classification Societies..

Limit state function

$$g = \widetilde{X_R}\widetilde{X_I}\widetilde{\sigma_U} - \widetilde{\sigma_L}$$

$\widetilde{X_R}$ - uncertainty parameter related to welding-induced stresses (normal random variable with mean value of 0.95 and strandard deviation of 0.05)

$\widetilde{X_I}$ - uncertainty parameter related to initial imperfections (normal random variable with mean value of 1.00 and standard deviation of 0.05)

$\widetilde{\sigma_U}$ - random variable of ultimate stress, minimum from three failure modes:

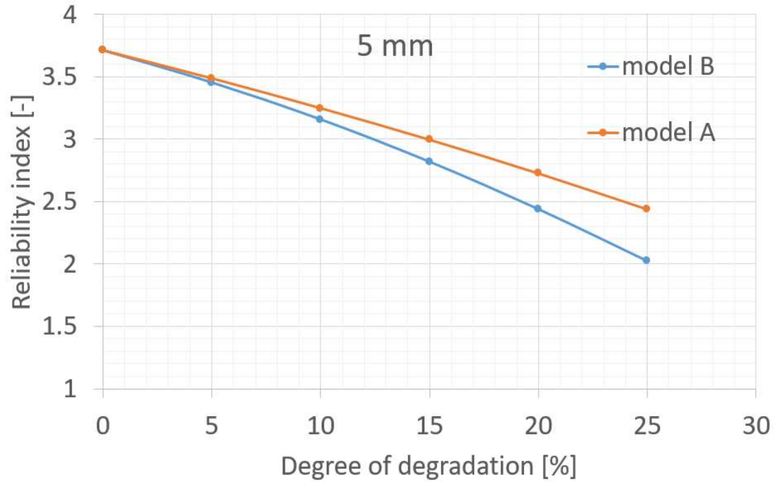
$$\widetilde{\sigma_U} = f\left(\tilde{t}, \widetilde{Re}, \tilde{E}\right)$$

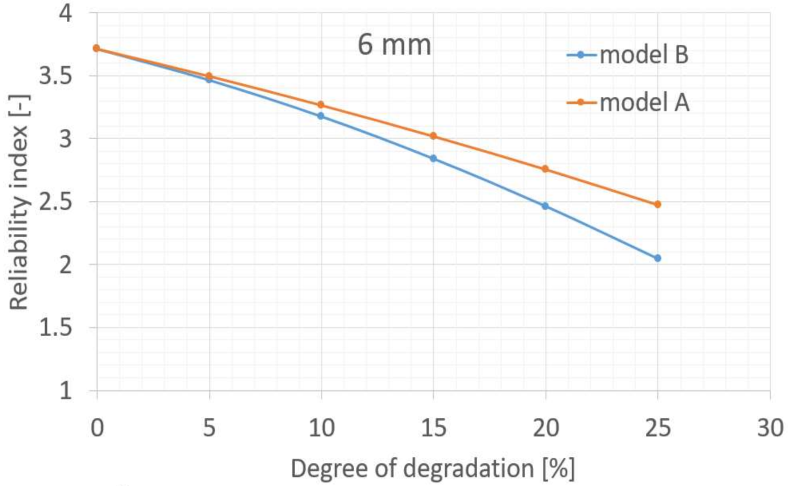
$\widetilde{\sigma_L}$ - loading (normal random variable with CoV=0.1)

Random variables descriptors

DoD [%]	Thickness t [mm]		Yield Stress Re [MPa]		Young modulus E [MPa]	
	Mean value	St. dev.	Mean value	St. dev.	Mean value	St. dev.
5 mm plate						
0	5	0.0685	235.0	7.11	196.0	23.1
10	4.5	0.0771	238.3	7.11	185.7	23.1
25	3.75	0.0897	234.6	7.11	170.1	23.1
6 mm plate						
0	6	0.0822	235.0	7.11	196.0	23.1
10	5.4	0.0925	238.3	7.11	185.7	23.1
25	4.5	0.1077	234.6	7.11	170.1	23.1
8 mm plate						
0	8	0.1096	235.0	7.11	196.0	23.1
10	7.2	0.1233	238.3	7.11	185.7	23.1
25	6	0.1435	234.6	7.11	170.1	23.1

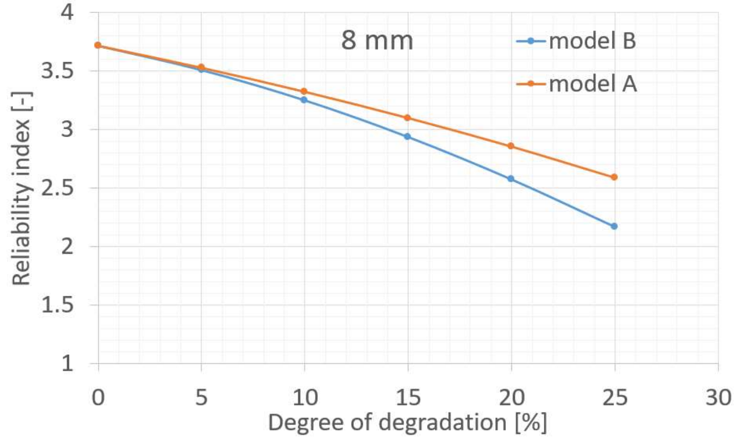
Results





Model A – only thickness reduction is considered

Model B – both thickness, and mechanical properties reduction are considered



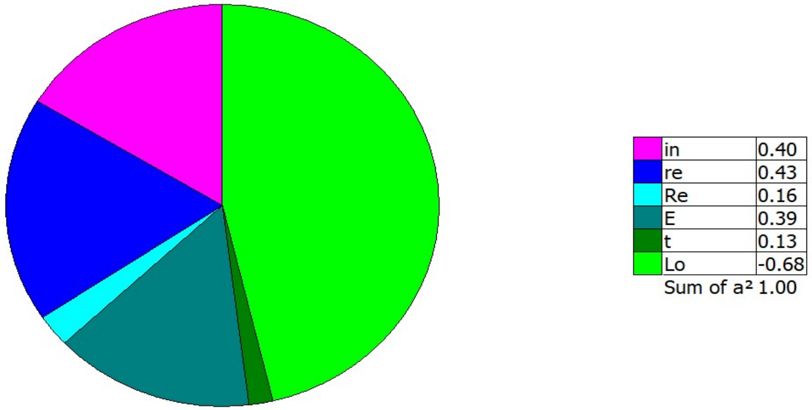
Impact of corrosion measurement data

DoD [%]	Initial thickness [mm]	Corrosion depth [mm]	
		Mean value	Standard deviation
0	5	0	0.19
10	5	0.5	0.28
25	5	1.25	0.40
0	6	0	0.19
10	6	0.6	0.30
25	6	1.5	0.45
0	8	0	0.19
10	8	0.8	0.33
25	8	2.0	0.53

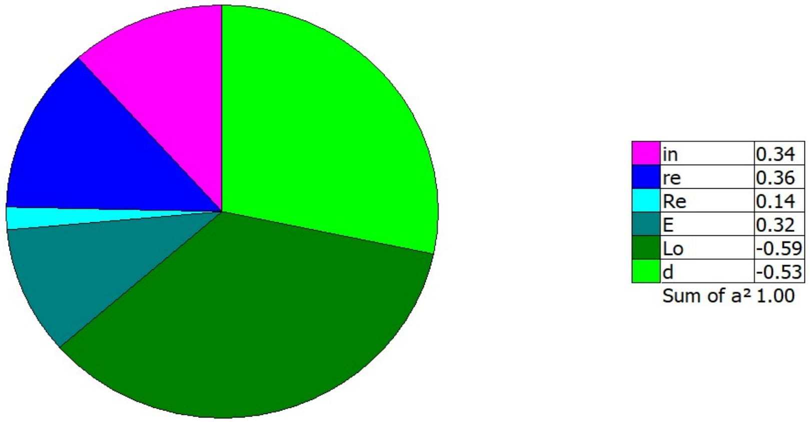
DoD [%]	Initial thickness [mm]	Reliability index [-]		Difference [%]
		Exp.	Real data	
0	5	3.71	3.72	0.2
10	5	3.16	3.09	2.0
25	5	2.02	1.88	6.9
0	6	3.71	3.72	0.2
10	6	3.17	3.14	1.2
25	6	2.04	1.92	6.0
0	8	3.71	3.72	0.2
10	8	3.24	3.23	0.3
25	8	2.16	2.07	4.2

Sensitivity factors of reliability analysis

Uncertainty of thickness based on experiment

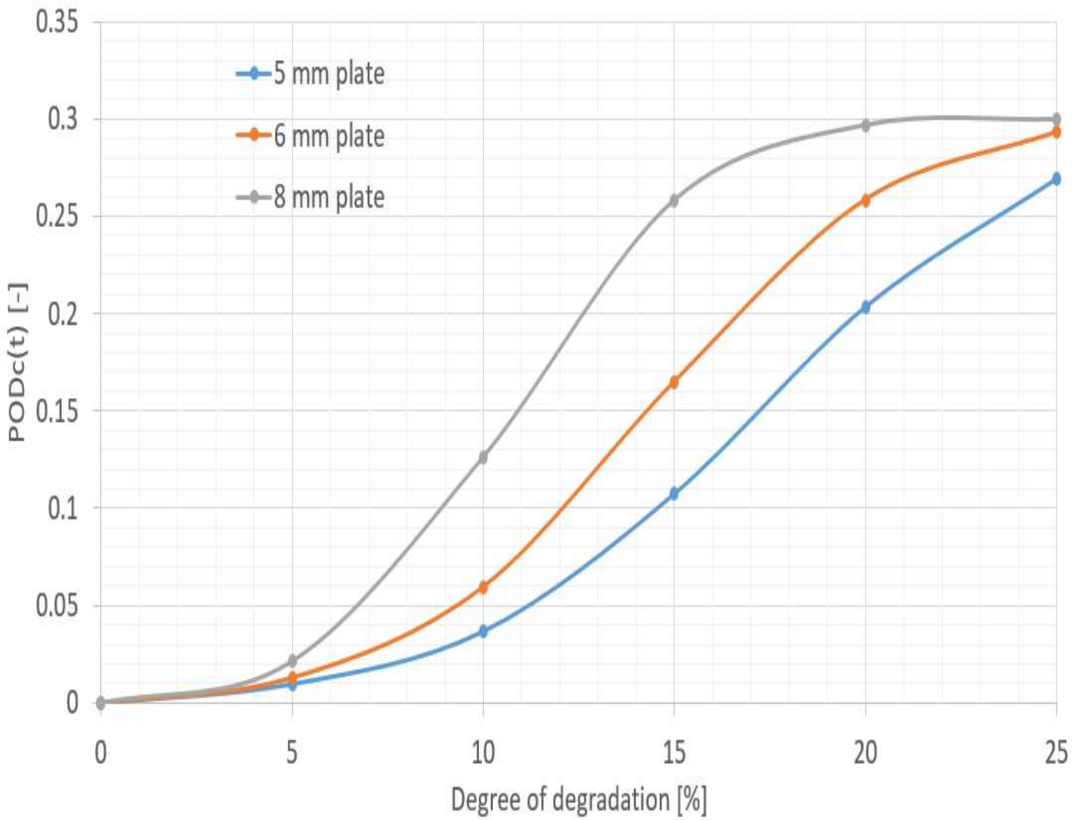


Uncertainty of thickness based on in situ measurements



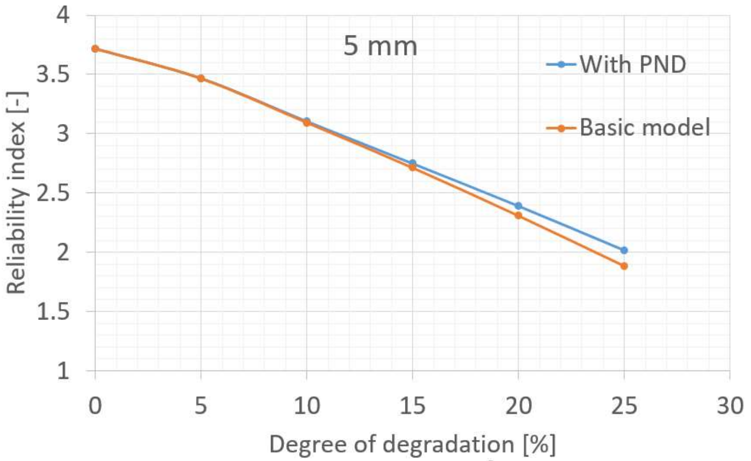
Probability of detection

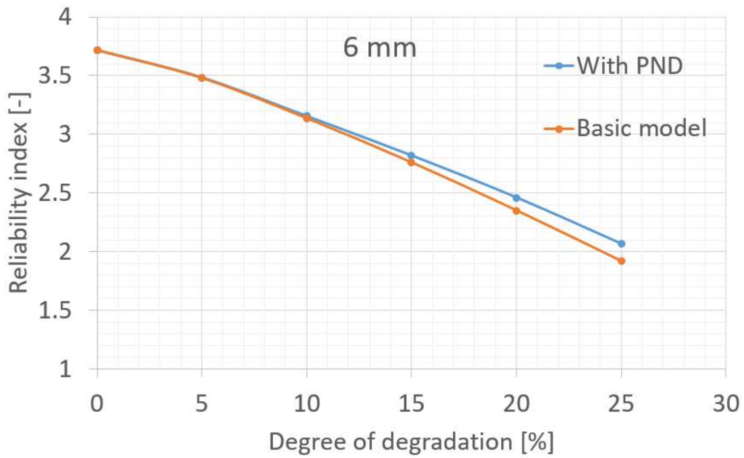
- **Only structural component omitted during inspection may fail**
- **Reliability formulation is extended considering probability of non-detection**
- **More severer corrosion is easier to be captured compared to moderate one**

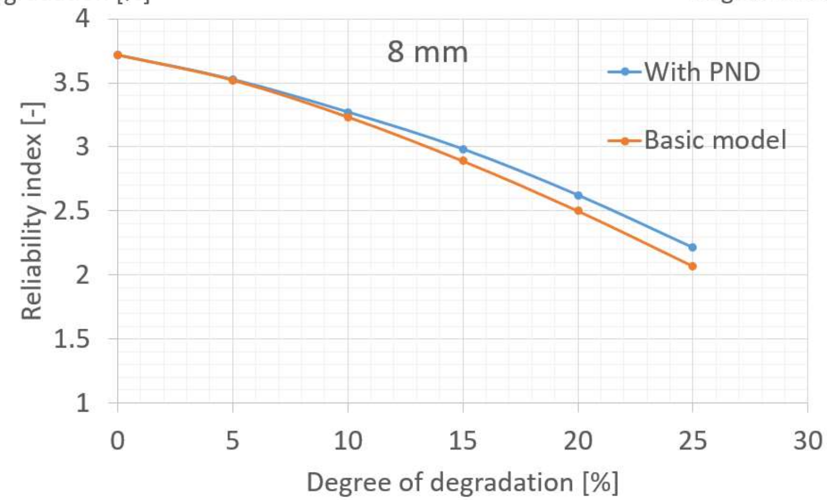


Probability of detection for considered plates

Impact of detection probability







Conclusions

- A simplified approach to assess the reliability of corroded stiffened plates was presented
- The presetend approach is fast and practical, with comparison to e.g. advanced nonlinear FE analysis with multiple random runs
- The reliability index is significantly lower, when both thickness and mechanical properties reduction are taken into account
- The reliability formulation is very sensitive with respect to origin of uncertainty formulations
- Further studies related to uncertainty quantification are essential
- The reliability index is slightly higher, when only structural members with nondetected severe corrosion degradation are considered

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