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REVIEW

Of Doctoral Dissertation of mgr. inż. Krzysztof Wołoszyk

Experimental and numerical investigations of ultimate strength of degradated structures
(Doświadczalne i numeryczne badanie nośności granicznej zdegradowanych konstrukcji)

Supervisor: dr hab. inż. Tomasz Mikulski, prof. PG
Second supervisor: Prof. Yordan Garbatov

1. Basis for reviewing the Dissertation

The review was written following the letter from prof. dr. hab. inż. Michał Wasilczuk, Chairman of the Council of Scientific Discipline Mechanical Engineering at the Gdansk University of Technology of 2 June 2021 (Przewodniczącego Rady Dyscypliny Naukowej Inżynieria Mechaniczna Politechniki Gdańskiej z dnia 2.06.2021 r.)

2. Contents of the Dissertation

The Dissertation is composed of 273 pages. It contains eleven proper chapters, Conclusions, list of author's papers, list of references, lists of figures and tables as well as two appendices.
In Chapter 1 brief information about the ship structures including also types of loading and response is given, with the focus on buckling and ultimate capacity. The scope of the Dissertation is defined as the investigation of the ultimate strength of corroded structural elements.
In Chapter 2 methods of analysis of typical ship hull members and ship hulls are described, divided into (i) numerical methods such as the Caldwell method, Smith method, nonlinear finite

element analysis as well as The Idealised Structural Unit Method and (ii) experimental approach: the full-size experiments, unstiffened plates, stiffened plates and panels and box girders modelling ship hull girder in a simplified manner. The influence of various factors on the ultimate strength of welded structures such as welding-induced residual stresses, welding-induced distortions, local denting, locked cracks, corrosion is also discussed.

In Chapter 3 the motivation, objectives and the research hypothesis including a brief description of the chapters of the thesis are given.

In Chapter 4 the marine corrosion is described in brief, governing factors are listed presenting also models accounting for them, dividing into time-independent and dependant. Experimental set-up of corrosion degradation is then presented including specimens, controlling parameters influencing corrosion and measuring techniques. The results of the investigation is presented, separately for small and large-scale specimens.

Factors with the significant influence on the ultimate capacity of corroded stiffened plates are identified in Chapter 5.

Experimental set-up for mechanical analysis is presented in Chapter 6 together with the results of tests for intact and corroded stiffened plates.

Modelling of uniform and non-uniform degradation of plate surfaces is presented in Chapter 7 with corrosion modelling using random fields.

Numerical investigations of corroded specimens subjected to tensile loading are presented in Chapter 8 and verified against experimental results to evaluate the mechanical properties.

Numerical analysis of intact and corroded stiffened plates are presented in Chapter 9.

The simplified formulation for estimation of the ultimate strength of corroded stiffened plates is derived in Chapter 10.

Chapter 11 is devoted to the reliability analysis of stiffened plates and ship hull girder including the corrosion effect.

The Dissertation is summarized in Chapter 12, where final conclusions and recommandations continuation of investigation is also given.

3. Evaluation of Dissertation

The ultimate capacity of compressed plates and stiffened plates and, actually, the structural response of these members is a key factor for evaluation of the ultimate strength of the ship hull referred to as an ultimate limit state in the design process. Despite a lot of research, papers and reports concerning the subject there is still a significant amount of aspects which call for investigation. One of them is the influence of corrosion degradation on the structural response

of compressed ship panels. The Dissertation covers various aspects of analysis of such structures including intact and corroded panels using experimental and numerical approach. It can be found that the main objective of the Dissertation which should be understood as a thorough investigation of the corrosion degradation on the structural response, ultimate strength and reliability of stiffened panels has been achieved and the hypothesis formulated in Chapter 3 – "the central research hypothesis" – has been positively verified.

The most significant research achievements presented in the Dissertation can be summarized as follows:

- Development of the experimental models, carrying out corrosion degradation tests and analysing the results to be used in the numerical analysis including uncertainty analysis.
- Development of the experimental and numerical models for the mechanical analysis and comparing the results.
- Modelling corrosion degradation using random field theory.
- Conclusion regarding importance of simultaneous accounting for non-uniform corrosion distribution and changes in mechanical properties.

4. Remarks and observations

- Page 14: Caption of Fig. 1.1. Nonlinear response of the buckled plate – it should rather be "Nonlinear response of the compressed plate".
- Page 21: "The ultimate strength of the ship hull is affected mostly by:" if "material properties" are listed why not begin with dimensions and scantling?
- The same part: "(…) Initial distortions and residual stresses due to low-quality welding" – only low-quality? Are they generated or are they greater in this case?
- Page 35: "The relationship between the flow velocity (v) may be modelled with the use of an exponential function [219]" – it is guessed that it should be "The relationship between the flow velocity and corrosion rate".
- Page 68: Type of geometrical nonlinearity is defined as "large deformations". Does it mean large displacements or large strains? What about the analysis presented in Chapter 8 – at the level of strain 40% it should be the analysis assuming large strains.
- Page 82: "In the first phase of the loading, all specimens behave similarly, and the curve inclination is equal to the Young modulus of the material." In Fig. 6.6 axes units are kN and mm, therefore it would be better to write "the curve inclination corresponds to the Young modulus".

- The same part: "After reaching the bifurcation point (around 0.5 mm of displacement), the plates start to buckle, and the inclination of the curves is changing.". From description of the model we know that the initial imperfections (deflections) are imposed therefore we should expect (and we see) a smooth solution with the bifurcation point, referred to as imperfect path (note that the concept of bifurcation buckling is presented by the Author at page 14, Fig.1.1). The similar situation appears in other parts of the Dissertation – see for example page 104, Fig. 6.37.
- Page 151: The Author declares "Concerning the material model, a bilinear stress-strain material relationship with hardening is employed. The material properties are considered as presented in Section 6.5 for both intact and corroded cases." If this is the case, what purpose of the methodology presented in Chapter 8 is as we read in the Conclusions of Chapter 8 (page 149, Subchapter 8.7): "The methodology presented in this chapter is revealed to be practical for evaluating the mechanical properties of corroded steel specimens.".
- Page 157: Caption of Figure 9.8. "Comparison between stress-strain curves for specimens with real initial imperfections and generated using Smith approach." – the Smith approach concerns the structural response of the ship hull girder, here the Author probably means approximate formulations – if this is the case it would be good to know what formulations; those as in 11.5.1 (CSR)?
- Page 158: Table 9.2. Applied boundary conditions. – direct application of the boundary conditions as specified would result in the singular stiffness matrix as none of the edges (nodes) is blocked in the direction of z-axis.
- In several places the Author describes the results without explaining the reason of difference between experimental and numerical results, examples: page 187, Fig. 9.37 – "The major differences after the collapse are observed only for the specimen with a medium level of corrosion severity.", page 190, description of the results presented in Fig. 9.41 – "However, the numerical model predicted another failure mode, similarly to previous specimens." In fact, there is a remark earlier that it may be due to uncertainty of material properties.
- Page 225: The Author finds: "As it can be noticed, after four years of exploitation, without accounting for the coating life, the required reliability index is not satisfied. After this time, some maintenance action needs to be done." It seems that the Author

aspires to formulate practical recommendation, however, disregarding coating makes the analysis incredible, four years is really short time and recommending "some maintenance action" worthless. Maybe more general remark at this point: it is due to the Author to compose the Dissertation, however, Chapters 1 – 9 (10) prove the Author's knowledge and capability of performing experimental and numerical analyses, developing and applying mathematical models of various phenomena. The Chapter on reliability does not significantly improve the contents of the Dissertation.

- Page 228: The Author claims "The constitutive laws for changes in mechanical properties were developed, in terms of marine immersed corrosion degradation" – the term "constitutive law" refers to stress-strain relationship, what is derived in the Dissertation is the yield stress and ultimate tensile stress for corroded specimens with respect to their nominal values.

The remarks are, of course, subject to discussion and the minor shortcomings do not decrease an overall very good evaluation of the Dissertation.

5. Sumary

The Dissertation presented for reviewing concerns both experimental – in two aspects – and numerical analysis therefore it covers a vast research area. In both types of analysis the Author proved a profound knowledge and capability to perform experiments and numerical computations. The Dissertation provides very good and interesting insight into the structural response of intact and corroded stiffened plates, presenting interesting and generally well-commented results and valuable conclusions.

I find the Dissertation Experimental and numerical investigations of ultimate strength of degradated structures presented by mgr. inż. Krzysztof Wołoszyk to meet the requirements imposed by the Act on Scientific Degrees (Journal of Laws 2003 No 65, item 595 with amendments) and can be the basis for his application for a doctoral degree in the discipline Mechanical Engineering, therefore I am applying for admission of the Dissertation to public defence.

Moreover, in the case of positive outcome of the defence, I am presenting an application to grant Mr. Wołoszyk "Dissertation with Distinction".

Uważam, że rozprawa doktorska pt. „Doświadczalne i numeryczne badanie nośności granicznej zdegradowanych konstrukcji" autorstwa mgr. inż. Krzysztofa Wołoszyka spełnia wymagania stawiane w ustawie z dnia 14 marca 2003 r. o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki (Dz.U. 2003 nr 65 poz. 595 ze zmianami) i może stanowić podstawę o ubieganie się przez niego o stopień naukowy doktora w dyscyplinie *inżynieria mechaniczna*, wnoszę zatem o dopuszczenie rozprawy do publicznej obrony.

W przypadku pozytywnego wyniku obrony stawiam wniosek o wyróżnienie rozprawy doktorskiej mgr. inż. Krzysztofa Wołoszyka.