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Numerical assessment of ultimate strength of severe corroded stiffened plates

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ABSTRACT

The objective of this work is to investigate numerically (using the non-linear FEM and the approach stipulated by the Common Structural Rules) the severe nonuniform corrosion degradation effect on the ultimate strength of stiffened plates and compare the results to the already published experimental works. Different factors governing structural behavior of corroded stiffened plates are investigated, such as corrosion degradation level, material properties, initial imperfections and boundary conditions. The numerically estimated ultimate strength demonstrated to be very close to those observed during the experimental test. A sensitivity analysis with respect to the most important governing parameters of the numerical estimation of the ultimate strength is also performed and several conclusions are derived. The applied calculation procedure avoids using of a pitted surface of the corroded plates and instead of that an equivalent thickness is applying leading to a relatively fast and practical approach for ultimate strength assessment of corroded stiffened plates.

1. Introduction

Ultimate strength is one of the fundamental assessment criteria during the ship structural design and it is commonly used in the design of different metal structures. One of the first attempts to analyze the ship hull ultimate strength was performed by Caldwell [1] by applying the rigid plastic mechanism approach, where the yield stress of the buckled part of the material was reduced. Turner [2] introduced the Finite Element Method (FEM) and at first it was used only for an elastic behavior analysis of structures and later to evaluate the ultimate strength, where the elasto–plastic large deflection become possible to be accounted only since the early 1970s.

The ultimate strength assessment of the ship hull structures (multi-step procedure) was also introduced into the Common Structural Rules [3,4].

With the progress of the development of the numerical methods, the ultimate strength analysis become to be a common tool in the design accounting for different governing factors that initially were difficult to be included into the analytical approaches. Some examples are the initial imperfections [5] welding induced stresses [6] nonuniform corrosion degradation [7].

One of the most important degradation mechanism in the aging metal structures is non-uniform corrosion degradation, which can create a local failure mechanism, affecting the load carrying capacity [8–10].

Paik et al. [11] investigated how pitting corrosion influences the plate strength and concluded that the decrease of plate ultimate strength is very significant and the smaller cross-sectional area of the plate governs the ultimate strength when the plate is subjected to an axial compressive load. Paik et al. [11] also investigated the ultimate strength behavior of welded steel plates subjected to biaxial loading with various initial imperfection shapes. Beside the initial imperfection amplitude, the shape of the initial imperfection has a significant effect on the ultimate strength and it is effecting the in-plane stiffness.

Saad-Eldeen et al. [12] experimentally tested three corroded box girders subjected to pure vertical bending loads and analyzed the initial and post–collapse plate deflections concluding that, for a certain slenderness ratio, the initial imperfection shape governs the post–collapse.

The influence of a randomly distributed corrosion thickness on the ultimate strength of rectangular steel plates was investigated in [13], using the Monte Carlo [14] simulations for generating the plate thickness distribution considering different degree of degradation and it was concluded that the shape of the corrosion pits and thickness distributions have a significant effect on the ultimate strength of corroded plates.

Garbatov et al. [15], [16] performed tensile strength tests of small-scale severely corroded specimens identifying the mechanical properties change with a function of the degree of degradation.

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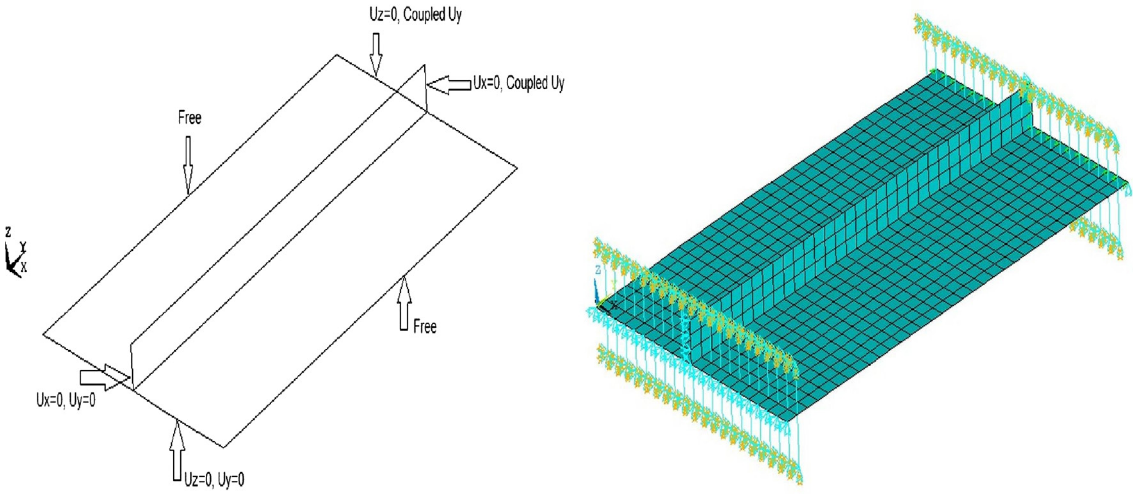

Fig. 1. Geometrical FE model of stiffened plate.

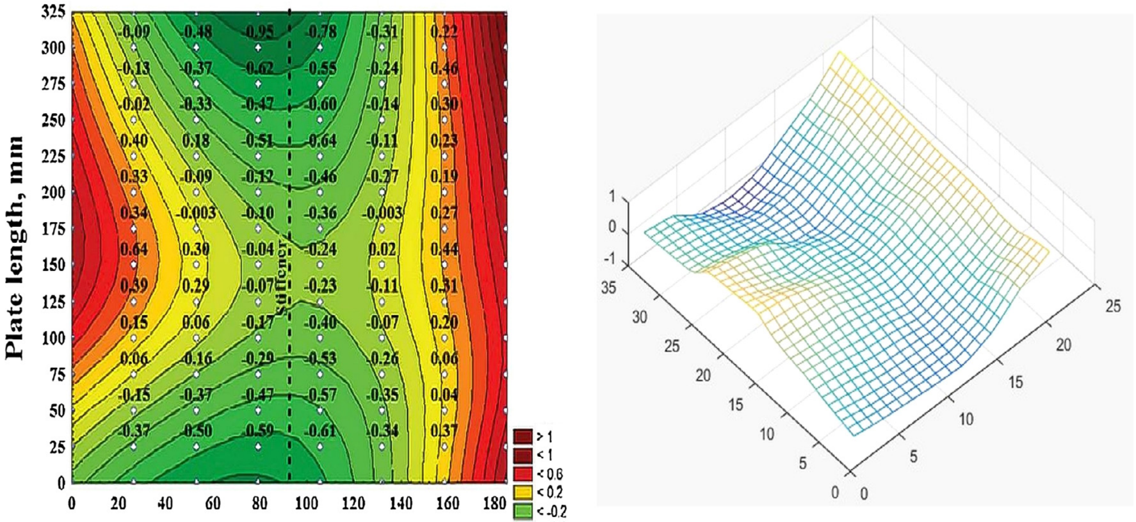

Fig. 2. Measured [7] (left) and modeled (right) initial imperfection, mm.

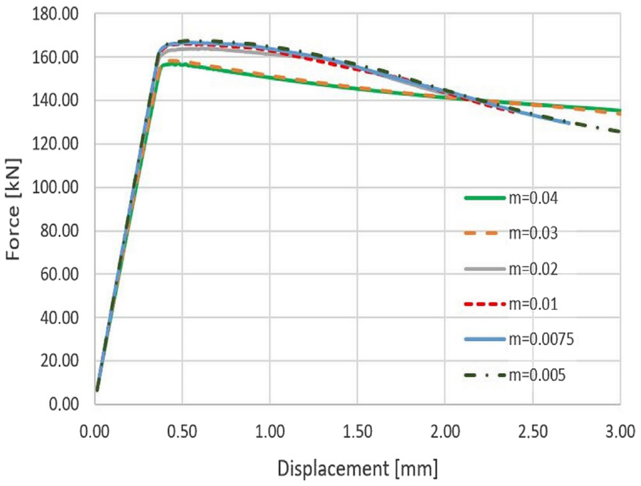

Fig. 3. Mesh refinement study.

Table 1
Specimens properties.

	DoD [%]	t_{eqv} [mm]	E [GPa]	σ_y [MPa]
Specimen 8	11	4.005	185	238.3
Specimen 7	33	3.015	162	228.4
Specimen 6	43	2.565	151	216.5
Specimen 5	45	2.475	149	213.6
Specimen 4	46	2.43	148	212.1
Specimen 3	46	2.43	148	212.1
Specimen 2	58	1.89	136	190.2
Specimen 1	70	1.35	124	161.6

The results of the experimental and numerical strength assessment of the stiffened plates subjected to severe non-uniform corrosion degradation and compressive load studied in [7] will be numerically analyzed in the present work, exploring the nonlinear FE method. Stiffened plate specimens tested in this experiment are with the different non-uniform corrosion degradation levels and initial imperfection shapes and amplitudes and are of a 325-mm length and 185 mm wide.

2. Finite element model

The finite element model is generated employing the commercial