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Experimental and numerical analysis of small-scale panels with indented stiffeners

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ABSTRACT

During the construction process of the ship's hull, the ultimate strength of the stiffened panels is reduced due to both initial imperfections and residual stresses. In service, these stiffened panels are exposed to damage that causes permanent deformations and localized residual strength, reducing additionally the ultimate strength of damaged panels, which must be considered in the design process to preserve the structural integrity. The paper provides analyses of the effect of damaged stiffened panels on the ultimate strength considering the residual stresses caused by indenting depth and different locations. Experiments were performed using small-scale models representative of a full-scale bottom panels from a cargo compartment at the midship of a typical Suezmax tanker. Experimental tests of the indentation were conducted on the intersection plate-stiffeners, where the force-displacement responses were analyzed. After the indentations, the panels were submitted to uniaxial compression experimental tests, in order to evaluate the loss of ultimate strength compared with the equivalent intact panel. Finite element models were developed by ABAQUS software in three steps sequentially: panel indentation, indenter taking off, and uniaxial compressive loading. Plastic strains and residual stresses caused by the indentation are incorporated in the ultimate strength analysis of the panels. Initial imperfections and maximum denting depth of the panels were measured in the small-scale models for the numerical-experimental correlation. Both indentations and ultimate strength presented a good agreement. A parametric study was performed using the numerical model to determine the residual strength due to the damage and its relationship with both dent depth and location.

1. Introduction

Longitudinal stiffened panels are the main components of the ship's hull structure, which is designed to withstand large compressive loads due the global bending moment. Several studies were carried out about the ultimate strength of the intact stiffened panels in uniaxial compression, for example, as those performed by Guedes Soares and Gordo [1], Grondin et al. [2], Sheikh et al. [3], Paik et al. [4], and Zhang and Khan [5]. It was determined that the ultimate strength is governed by the plate slenderness and stiffeners column slenderness of the panel [6], and influenced by factors such as imperfections [7], residual stresses [8], and boundary conditions [9], among others.

During the construction of the panels, the ultimate strength is reduced by the initial geometric imperfections and residual stresses due to the welding process. During service, these panels are exposed to damage caused by accidents, such as collision, grounding, dropped objects and explosion, causing local permanent deformations and residual stresses, which reduces ultimate strength of the stiffened panel, and, under extreme conditions, can lead to the global collapse of the hull girder.

These damages can be represented by a dent in the structural element. Paik et al. [10] investigated the effects of dent parameters on the collapse of plates using finite element analysis and introduced a reduction factor to predict the strength of indented plates in relation to the intact plates. A better understanding about the residual ultimate strength due to indented stiffened panels is important for the definition of the design tolerances to; improve the structural reliability of the ships and support the decision making related to the necessity of panel repairing.

Experiments using full-scale prototypes are very expensive and thus rarely performed [11]. Recorded data are quite limited, as the tests performed by Hu et al. [12] and Hu and Jiang [13]. As an alternative, small-scale models have been used. Estefen and Estefen [14] worked in a technique for small-scale panel fabrication able to provide very low levels of geometric imperfection magnitude which could attend in scale the code's recommendations. Estefen et al. [15] studied the influence of the initial imperfections on small-scale panels caused by the fabrication process.

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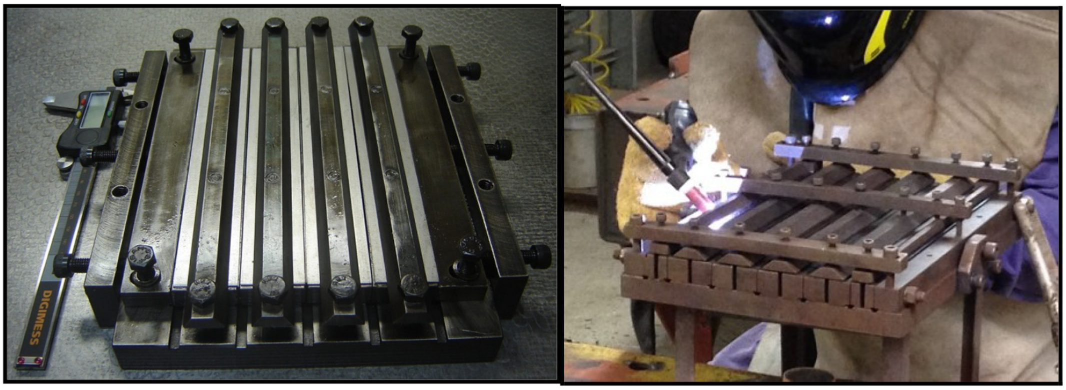

(a) Panel mold

(b) Welding of the small-scale panel

Fig. 1. Mold for the panel welding during the fabrication.

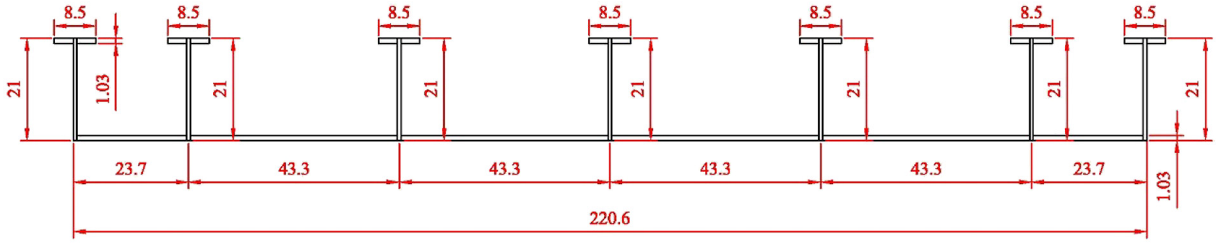

Fig. 2. Transversal view of the small-scale model (dimensions in mm).

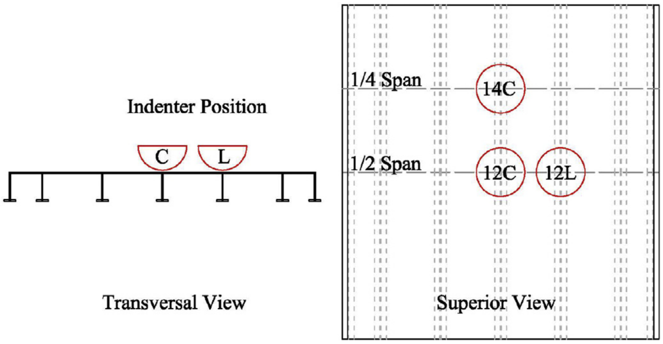

Fig. 3. Transversal and superior views of the small-scale panel with the indenter position used for the nomenclature of the test specimens.

However, experimental studies to investigate the behavior of stiffened plates under quasi-static lateral loads have been performed, as for example by Alsos and Amdahl [16, 17]. In the quasi-static analysis, there is a disadvantage of neglecting dynamic effects, such as the strain rate effect. On the other hand, the main advantage is the possibility of continuous recording of the damage process [18]. Gruben et al. [19] investigated the structural response of stiffened panels under low-velocity impact loading and compared it with similar quasi-static tests, where both behaviors were similar in terms of force-displacement response, concluding that the quasi-static test was considered to provide a good reference for low-velocity loading situations. Furthermore, the use of the method of energy in small-scale models; requires very small indenters and high impact velocities, resulting in scenarios that are not applicable in ship structures [20]. Amante et al. [21] working with damaged small-scale panels concluded that for the same impact

Table 1
Characteristics of indentations of the tested specimens.

Specimen	Depth (mm)	Location	Stiffener
SP1-D0	–	–	–
SP2-D0	–	–	–
SP3-D5-12C	5	1/2	C
SP4-D5-14C	5	1/4	C
SP5-D5-12 L	5	1/2	L
SP6-D12-12C	12	1/2	C
SP7-D12-12 L	12	1/2	L

Fig. 4. Imperfection measurements using the laser scanner.