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Influence of initial distortion of 3 mm thin superstructure decks on hull girder response for fatigue assessment

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This paper investigates the influence of initial distortion of 3 mm thin superstructure decks on hull girder response and fatigue assessment. Part of the traditional superstructure of a prismatic passenger ship is replaced by thin decks with initial distortion amplitude of 0, 1 and 2 times the IACS limit value for thicker plates, i.e. 0, 6 and 12 mm. Both geometrically linear and nonlinear finite element (FE) analysis is used. For reference also traditional superstructure with 5 mm plate thickness is analyzed. Thin straight superstructure decks give 43% of weight reduction and carry approximately 30% less load than corresponding thick straight decks in traditional model. The load that is not carried by thin decks is divided between other traditional decks. The redistribution of forces also happens at the deck level between plates, stiffeners, girders and longitudinal bulkheads. The presence of initial distortion with the shape of one half wave between web frames and stiffeners causes an additional few percent-decrease in forces carried. The results and conclusions are similar for hogging and sagging loading conditions and differences between geometrically linear and nonlinear FE analysis are very small. This means time saving since the panel loading for fatigue assessment can be defined from geometrically linear hull girder response analysis without considering the initial distortions.

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1. Introduction

Economic reasons have motivated the metal industry to search for the new lightweight solutions. For instance, the size of the modern passenger ships has been increasing in order to accommodate more cabins with windows and balconies. Using thin, i.e. less than 5 mm thick steel plates and smaller stiffeners and stiffener spacing in the superstructure helps to reduce the weight and lower the vertical center of gravity, potentially resulting in one additional deck. However, the structural analysis and fatigue design of such thin structures is challenging due to larger initial distortions [1]. For instance, the methods for fatigue assessment are not fully validated for plate thicknesses less than 5 mm, see e.g. Refs. [2–4].

With respect to fatigue strength assessment, it was shown in Ref. [1] that 3 mm thin welded dog bone specimens have in addition to larger angular misalignment also different shape compared to thicker plates. The curved shape and the slenderness L/t of the specimen influence the structural stresses near the weld significantly. To capture this straightening effect, i.e. the decreasing of the structural to nominal stress ratio under tension loading, the geometrically nonlinear finite element (FE) analysis with the actual specimen shape is necessary. When the influence of the surrounding structure is added, it turns out that the structural stresses near the weld are mostly influenced by the initial distortion shape, secondly by its magnitude and unlike for dog-bone specimens the straightening effect under loading is significantly less important [5]. This means that using geometrically nonlinear FE analysis for panels is not as important as for small-scale specimens.

However, the analysis with thin initially distorted panels in Ref. [5] was done using theoretical boundary conditions, i.e. three edges fixed and one edge transverse to stiffeners loaded with constant displacement. The validity of these assumptions should be further studied, since the initial distortion can influence the axial and bending stiffness of the panel. This may change the load carrying mechanism of the hull girder similarly as in Ref. [6] when part of the decks were replaced by web-core sandwich structures with non-symmetric joints causing local bending. Also bulkheads, girders and web frames can influence the load distribution in the panel.

To understand the panel loading, the physical behavior of the hull girder in bending needs to be considered. This is challenging because the modern passenger ship does not follow the simple beam theory [7–14]. The vertical bending stress/strain distribution in the cross section is nonlinear mainly due to shear effects caused by discontinuities between hull and superstructure and large openings in side shell and longitudinal bulkheads [8,10–12]. Also vertical flexibility at the connection between hull and superstructure changes the load carrying mechanism [7,9]. The complicated interaction of hull and superstructure is investigated e.g. in Refs. [7–14]. The influence of initial distortion shape and magnitude on the buckling and ultimate strength of plates and stiffened panels has been studied e.g. in Refs. [15–18]. In ultimate strength analysis of box girders or simple cross-sections, see e.g. Refs. [19–21], the initial distortion has been accounted for by typical values for slight, average or severe initial welding induced distortions with simplified shapes as suggested e.g. in Ref. [22] or quality standards like IACS [23]. However, the global behavior with thin initially distorted superstructure decks as part of the modern passenger ship is not studied. Also very little attention has been paid on the influence of initial distortion for the fatigue assessment. In order to understand the complicated interaction between thin initially distorted superstructure decks and other traditional structures and its influence on the panel loading for fatigue assessment, further analysis is needed.

This paper investigates the influence of initial distortion of 3 mm thin superstructure decks on hull girder response and panel loading for fatigue assessment. Geometrically nonlinear FE analysis is carried out for the prismatic passenger ship with thin initially distorted superstructure decks. Comparison is made between geometrically linear and nonlinear analysis as well as between initially distorted and ideally straight thin decks. For reference also traditional 5 mm thick ideally straight decks are analyzed. This way the effects of thickness reduction, initial distortion and geometrical nonlinearity are separately revealed.