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Structural behaviour of a high tensile steel deck using trapezoidal stiffeners and dynamics of vehicle–deck interactions

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Abstract

As an early part of a large design and fabrication-oriented project FasdHTS funded by the GROWTH programme of the European Commission, an exotic concept ship was designed in very high tensile steel (EHS690) with the purpose of finding out consequences for design and production. The project has already produced a considerable bank of knowledge for design and shipyard production in this material.

This paper presents analysis and discussions on static and dynamic behaviour of a high tensile steel deck designed with trapezoidal stiffeners. First, a finite element model of the deck structure is created. The influence of support condition for the longitudinal girders, and the contact area between the vehicle tyre and panel were analysed. The results from modal analysis of the structure under different load conditions are presented. The different load conditions comprise the unloaded and loaded deck, and the load type, i.e. cargo loads or vehicle loads (car loads or truck loads). From the frequency response analysis under harmonic excitation, it shows how the locations and numbers of cars parked on the deck influence the dynamic response of the structure. Furthermore, by studying the car–deck interaction, it is found that the effects of normal cargo loads are quite different from the vehicle loads due to the spring/damping effects of the vehicles. It is suggested that the carloads have a similar mechanism to that of tuned mass dampers. Finally, two transient analyses of the structure due to excitations transferred from deck supports and lorry braking-induced loading are performed.

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It is suggested that the deck structure and vehicle design could have more interactions with each other.

Keywords: Lightweight deck; Trapezoidal stiffeners; Structure response; Static; Structural dynamics; Vehicle dynamics; Tyre pressure; Transient analysis

1. Introduction

With the growing demands for fast ships, weight is a key factor in the structural design. Thus, the lightweight ship's deck structure is widely used in high-speed ships and the research concerning this type of structure has recently attracted a lot of effort.

The classification societies do not normally require a dynamic analysis of a deck structure in ships. The design is based on a quasi-static model of analysis. It is expected that a very lightweight deck structure has a somewhat higher natural frequency in the non-loaded condition and a relatively lower frequency in the as-loaded condition compared to a conventional deck structure. The reason is of course that the designer makes an effort to reduce the mass of the structure, while limiting the deformation. It is inevitable that stress levels increase and that the deformations for the as-loaded condition increase.

The consequences of working with different stiffness and thus frequencies are not known from experience and need to be better researched before entering production. Complex structures and the use of non-conventional materials are factors that make the analysis of these types of ships more challenging. It is expected that the natural frequencies of the ship deck may decrease and new problems of vibration and damping can be expected. With the increase of the design speed of the ship, the speed of cargo loading and discharge will also increase. When combined with lightweight design, the dynamics of the cargo loading may be more important to study. It is known that the behaviour and the strength considerations of the structural elements under dynamic loading are quite different from those under static or quasi-static loading conditions [1].

There are mainly three types of lightweight deck structures, the first type is to use aluminium for the panel, which can significantly reduce the weight, but the cost of construction and material will be higher than the conventional deck. The second type of deck structure is characterised by employing composite material (such as FRP) to fabricate the structural members. The third type is to employ very high tensile steel to form ship plating. In the FasdHTS-project, the target ship is designed with EHS690 steel. The Poisson's ratio for that is 0.3, the modulus of elasticity is 210 GPa, the density is 7800 kg/m^3, and the yield stress is 690 MPa.

Although lightweight deck structures are widely used, the information available in respect of the design recommendations is still under development.

Based on FE analyses of a deck structure using box shape aluminium panels, Jia and Ulfvarson presented the static and dynamic behaviour of a lightweight ship deck on a pure car truck carrier (PCTC) vessel [2,3]. By varying special parameters, such as material in the panel, numbers and locations of loaded cars, the speed of running cars on the deck during loading and the frequencies of the propeller excitation, they contributed to the understanding of how a conventional steel structure is improved by introducing