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A parametric study for the structural behaviour of a lightweight deck

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Abstract

Lightweight structures are increasingly used for high-speed ships. Research of fatigue and stability of the highly stressed thin plate structures is an ongoing activity, which produces valuable information for the structural engineers. One topic that should be an integrated part of these studies is the dynamic behaviour of lightweight deck structures. When the deck structures are made extremely lightweight, the natural frequencies of the structures as such may increase while the loaded decks will most likely deflect more than conventional decks do. It is then expected that the natural frequencies of the decks will decrease and new problems of vibration and damping will appear. There is concern for resonance with propeller blade frequencies but also with the wave responses of these high-speed ships.

The subject of this paper is to study the static and dynamic behaviour of a lightweight ship deck. A theoretical model was made in order to study the interaction between the car and the deck. The model indicates that the car chassis is a significant part of the problem and influences the solution. A finite element model of the ship deck was generated and special parameters, such as material of the panels, numbers and locations of loaded cars were studied. The speed of running cars on the deck during loading and the frequencies of the propeller excitation were varied in order to understand their influences on the structural response. Based on the results from finite element analysis obtained, it is shown how a conventional steel structure is improved by introducing lightweight material. The structural behaviour is significantly influenced from both a static and dynamic point of view.

Keywords: Lightweight ship's structure; Ship's car deck; Vibration analysis; Parametric study

1. Introduction

The lightweight ship's deck structure is widely used in high-speed ships and the research concerning this type of structures has recently attracted a great deal of research of effort. When lightweight ships are developed, different kinds of questions and problems have appeared. 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 loaded ship deck will decrease and new problems of vibration and damping can be expected. The question still remains: Do these lightweight ship decks have a similar performance as the traditional ship decks? Can such decks be safely designed with simplistic criteria, i.e. with quasi static load cases?

There are mainly three types of lightweight deck structure, the first type is to use the aluminium for the material of panel, which can significantly reduce the weight, but the cost for construction and material will be higher than the conventional steel deck. The second type is characterized by employing composite material (such as FRP) to fabricate the structural members and the panels for the deck. The third type belongs to those that the high tensile steel is employed to form T shape stiffened plates.

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

Smith has carried out considerable research on the deck and hull structure using composite material such

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as FRP [1], and gave some guidelines on the design and fabrication of composite deck and hull structure. Because of the cost he concluded that structure using FRP seems unlikely to become competitive with steel for construction of ships over about 40 m in length. However, the production of sandwich structure may change this situation in particular if problems concerning fire and smoke are solved.

With the recent trend to widely use high tensile strength steel in the structure, much effort has been given to study the buckling behaviour of the structure. By conducting parametric analysis for stiffened plate, Sheikh et al. concluded that the plate transverse flexural slenderness is the most influential parameter affecting both the strength and behaviour of stiffened steel plate for all the buckling failure modes under combined compression and bending [2]. It was found by Grondin that both the magnitude and the shape of the initial imperfection have significant influence on the stiffened plates failing by plate buckling [3]. By performing a parametric study of the post-buckling behaviour of a stiffened plate, Mateus present that the slender plates have their collapse mechanism dominated by elastic effects [4].

While very little research has been carried out concerning the structural behaviour of the deck using aluminium panels.

To study the main behaviour of the mechanical system, i.e. the ship deck together with loaded cars, a theoretical model was made in this paper. This model shows that the car chassis constitutes a significant part of the problem and influences the solution. To make a more accurate study of the behaviour, detailed finite element models of loaded and unloaded ship decks were modelled. Parameters such as the material type of the panels, numbers and locations of the loaded cars on the ship deck, the speed of the car running over the deck, and the frequencies of the propeller excitation were varied in order to understand their influence on the structural response. Based on the results obtained from the finite element simulations, we saw that the aluminum panels have a significant effect on the structure behaviour from both a static and dynamic point of view. By studying the dynamic modes, the stress distribution as well as the deformation for the lightweight ship's deck structures, the understanding increased and some suggestions for future study are also given.

2. The influence of spring and damping of the car

2.1. Simplified model of a car chassis-beam system

In order to describe the vertical dynamics of the system of a car-ship's deck, a mathematical model was employed by reducing the car body and car chassis to a discrete system. This was here realized as a model of a quarter car attached to a beam at an arbitrary point as shown in Fig. 1. Here we assume that the structural behaviour of one strip of the deck can represent the behaviour of a typical deck, thus a beam is employed to represent a strip of deck. By simplifying the beam model as a mass attached with a spring, we finally arrived at the model shown in Fig. 2.

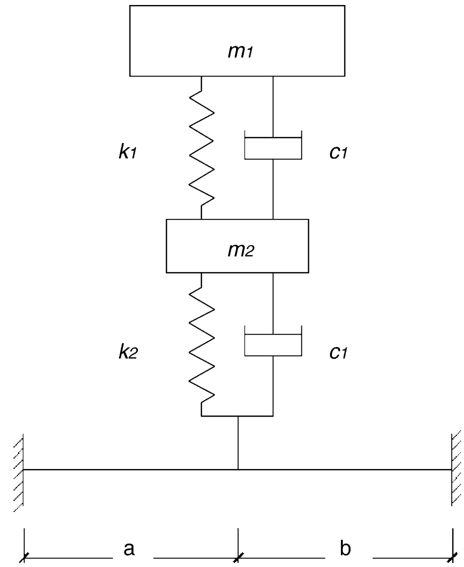

Fig. 1. A quarter car model attached to a beam at an arbitrary point.

In Fig. 2, m_1, represents the mass of the car body and k_1 and c_1 represent the stiffness and the damping between the car body and the wheel hub. m_2 is the weight of the chassis. k_2 and c_2 represent the tyre stiff-

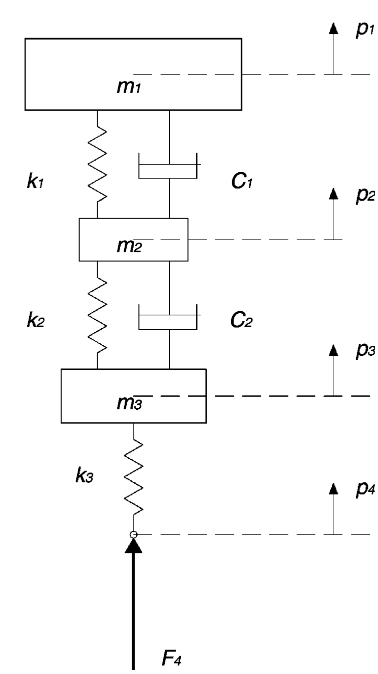

Fig. 2. Mathematical model of car-beam system.