Journal of Fluids and Structures 81 (2018) 201–229

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Full-scale measurements of slamming loads and responses on high-speed planing craft in waves

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ARTICLE INFO

Article history:
Received 1 November 2017
Received in revised form 27 February 2018
Accepted 4 May 2018

Keywords:
Slamming
Planing craft
Experiments
Data processing
Statistical analysis

ABSTRACT

Full-scale trials on a high-speed planing craft in waves were conducted to investigate the characteristics of slamming impacts and related rigid body and structural response. Measurements of acceleration, pressure, strain and global hull deflection were made in different sea conditions and at different speeds and headings. Low pass filtering is used to remove unwanted noise from the acceleration signals and extract the rigid body response. Methods for removing trends from the strain signals and identifying the peaks in the pressure and strain signals are established. Characteristic results including time series, distributions of peak values, averages of the largest 1/3rd and 1/10th peak values and individual impact events, are presented and discussed. The Weibull and Generalized Pareto models are used to describe the pressure and strain peak values and for estimating extreme loads and responses. Automated algorithms for fitting the statistical models to the peak value distributions are developed and the goodness-of-fit of the models to the data is examined.

1. Introduction

Planing craft travelling at high-speed in waves frequently experience severe slamming impacts. The nonlinear nature of high-speed craft motions and randomness of the wave environment implies that each hull–water impact is unique. The characteristics of the resulting impact loads, which act on the hull bottom, depend on a number of parameters. The most important in terms of severity of impact are the trim angle, hull deadrise angle and impact velocity at the instant of impact with water (Allen and Jones, 1978). The response of high-speed planing craft to slamming impacts is mainly characterized by transient and dynamic accelerations and local structural deformations. Slamming impacts can thus have an adverse effect on the hull structure, human comfort and performance, and equipment.

The importance of slamming impact loads for high-speed planing craft has led to a significant body of work trying to understand the complex physics involved and model the impacts using a wide range of methods, see for example Temarel et al. (2016). The interest in the present work lies in experimental studies, both full-scale and model-scale investigations, and the methods used to analyse the data. Full-scale trials are expensive to conduct and usually confidential to the ship builder or owner. Full-scale data for loads and responses on high-speed planing craft in waves is therefore not widely available.

One of the early and most significant works is that of Allen and Jones (1978) who measured pressure, acceleration and strain on two planing hulls in waves. The measured data together with the results from a semi-empirical method were used to develop a simplified method for predicting the hull bottom impact pressure loads for structural design purposes that is still widely used today. Garme and Rosén (2003) conducted full-scale trials on a high-speed planing craft in waves to study

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https://doi.org/10.1016/j.jfluidstructs.2018.05.006

the characteristics of slamming impacts and gather data for validating their numerical model. The craft was a Storebro 90E and has an overall length of 9.5 m, displacement of 6.5 tonnes, deadrise angle at amidships of 22° and a maximum speed of +40 knots. Measurements of rigid body motions and accelerations, pressures and laminate and shear strain were made in different sea conditions (significant wave heights ranging from 0.4 m to 1.5 m and mean periods from 2.5 s to 4 s), and at different speeds (ranging from 10 to 40 knots) and headings (head and bow seas). The impact pressures recorded in bow seas (the angle between boat and wave direction $\mu = 150^\circ$) were found to be significantly higher than in head seas ($\mu = 180^\circ$), which are generally considered as the most severe condition regarding impact loads because here the largest relative motions and velocities are experienced. This was concluded to be due to smaller effective deadrise angle, i.e. the relative angle between the hull and water surface at the moment of impact, in bow seas. The vertical accelerations recorded in bow seas were, however, lower than head seas, which is attributed to the fact that in bow seas the high pressure loading acts on a smaller area of the hull, thus resulting in lower forces and accelerations. The semi-empirical methods used in the design of high-speed craft assume direct relationship between rigid body accelerations and pressure and, thus, may underestimate the loading in such conditions. The statistical averages of the peak pressures and structural responses were also found to correlate well. Mørch and Hermundstad (2005) measured accelerations, pressures, strains, and local panel deflections on a high-speed recreational craft to understand better the impact loads experienced in waves for design purposes. The craft (Nidelv 610) has an overall length of 6.1 m, fully loaded displacement of 1870 kg, deadrise angle of 19.5° and a top speed of 40 knots. Tests were performed in different sea states (significant wave heights ranging from 0.32 m to 0.55 m) at various speeds (ranging from 30 to 40 knots) and headings in both fully and partially loaded conditions. The loads and responses measured in the fully loaded condition were found to be lower than those measured in the partially loaded condition (displacement of 1550 kg). From comparisons of the pressure and strain measurements with the DNV (1997) rules it is found that design pressures are too low and that there is a large safety margin for the required laminate thickness based on design pressures. Riley et al. (2014) performed a detailed investigation into the characteristics of accelerations measured on high-speed craft in waves and presented a method quantifying wave impacts loads using full-scale acceleration data, in particular the amplitude and duration of rigid body heave acceleration. The acceleration data recorded during the seakeeping trials of a large number of manned and unmanned high-speed planing craft in moderate and rough seas was used. The crafts tested have lengths ranging from 10 to 25 m and displacements ranging from approximately 6.35 to 52.6 tonnes. Significant wave heights varied from approximately 0.6 to 2 m and forward speeds varied from 8 to 45 knots.

Model scale investigations of loads and responses on high-speed planing craft include both free-fall or constant velocity water impact tests, e.g. Tveitnes et al. (2008), Lewis et al. (2010) and Allen and Battley (2015), and towing tank tests in waves, e.g. Fridsma (1971), Rosén and Garme (2004), Taunton et al. (2011), Begovic et al. (2014) and Judge et al. (2015). In water impact tests a common approach is to simplify the complex three-dimensional hull–water impact problem to a transverse section, e.g. a wedge or even a hull panel, vertically impacting the calm water surface. Impact tests provide useful insight into the physics of slamming and the effect of several parameters on the loads and responses; however, there is no consensus as to whether the loads and responses measured on a wedge accurately reflect those measured on a full-scale craft. Towing tank tests are a better representation of the full-scale problem. Rosén and Garme (2004) performed a detailed investigation into the pressure distribution on planing craft in waves. The model hull is a simplified version of the full-scale craft tested by Garme and Rosén (2003) with a scale of 1:10. The model was tested in calm water, and regular and irregular head and oblique waves at three speeds. The measurements made include rigid body motions and acceleration and pressures. A dense matrix of pressure sensors and high sampling frequency (2.5 kHz) was used to accurately capture the transient and highly localized pressure distribution. The sampling frequency was found to be sufficient in most cases except for extreme impacts where the rise times are of the order of 1 ms. A method for reconstructing the complete pressure distribution on the hull surface from the discrete point measurements is presented. The impact loads obtained from integrating the reconstructed pressure distribution are found to correlate relatively well with the inertia force derived from the acceleration signal. It is concluded that observed differences are due to the fact that the derived pressure force only considers the load acting on the forward part of the hull (the instrumented area), whereas the acceleration-derived force is related to the total load on the hull. Begovic et al. (2014) investigated the influence of bottom warping, i.e. deadrise angle variation along the hull length, on the seakeeping performance of planing hulls using model tests. One monohedral ($\beta = 16.7^\circ$) and three warped (deadrise angle varies linearly from transom to 0.8L) hard chine planing hull forms were tested in regular waves at three speeds ($C_V = 0.942$, 1.275 and 1.594). The choice of regular waves was to provide a database for numerical model validation and obtain better insight into the physics of the responses. Model speed, heave, pitch, added resistance and accelerations at the bow and close to midship were measured during the tests. Bottom warping is found to have limited effect on the motions but significant effect on the bow accelerations, particularly at high speed where lower accelerations were measured on more warped hulls. Spectral analysis of the data further revealed that bottom warping has a larger influence on higher order acceleration harmonics than the first harmonic. Taunton et al. (2011) developed a new series of high-speed hard chine planing hulls and performed an extensive investigation into their motions and accelerations in waves. The series has L/B ratios typical of modern high-speed interceptor craft and race boats and a deadrise angle of 22.5°. The models were tested in irregular head waves at three speeds. The Cartwright & Longuet-Higgins and Gamma distributions were fitted to heave and pitch motions and accelerations respectively. A method for predicting human performance on-board full-scale craft using the statistical data is presented.

The lack of full-scale experimental studies in the literature is also partly due to the complexities involved in making full-scale measurements and processing the data. Two common issues related to making measurements on high-speed