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Wave slam on wave piercing catamarans in random head seas

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ABSTRACT

A hydro-elastic 2.5 m wave piercing catamaran model with a short centre bow has been tested in random head seas. Slamming wave impacts were found to be close to the aft end of the short centre bow. These occurred at time intervals of over 3 encountered modal wave periods, with longer intervals in smaller seas and for shorter modal periods. Slams were only detected in wave heights exceeding 1.5 m at full scale. Slam loads in 4 m seas were mostly about 25% of the hull weight but some reached 132% of the hull weight. Slam durations were generally about 0.35 s at full scale. Slam induced bending was found to reach 11% of the product of hull weight and length. Simulation of slamming within a time domain seakeeping computation showed slightly higher median relative velocities at the slam instant than was observed in the model tests.

1. Introduction

This investigation aims to identify the random sea slamming behaviour of the INCAT Tasmania Wave Piercing Catamaran (WPC) design. This incorporates a short central bow with substantial reserve buoyancy above the waterline in the bow area (INCAT Tasmania, 2016). The approach here is to investigate the slamming by towing tank tests in random waves and thus to establish a data base representing the observed slam events. Slam occurrence and loadings are then related to the kinematics of the ship motion and an empirical algorithm is developed for slam occurrence and severity for incorporation in a time domain sea keeping program (Holloway and Davis, 2006).

High speed catamaran ferries operate at length Froude numbers in excess of 0.5 and so experience heave and pitch motions in excess of the wave height and wave slope (Davis et al., 2005). These large motions expose vessels to wave impact in the bow region. Deck diving in following seas can be hazardous (Lavroff et al., 2010) and the WPC design virtually eliminates deck diving and green water over the bow by virtue of the short centre bow. The configuration is inherently non-linear since the keel of the central bow is close to the water line and thus has little effect on the motion in small or moderate seas but in large seas can generate large upward forces when immersed in large waves. When the arched cross section between main hulls and the central bow fills with water, large slam forces can arise due to the confluence of displaced water at the top of the arches. Slam induced bending loads thus become critical design loads (Lavroff et al., 2011).

Whilst it is possible to simultaneously compute the transient hydrodynamic and structural response problems (McVicar et al., 2014) this involves computing times for random seas which can be as much as 10^5 times real time per CPU (McVicar et al., 2014) owing to the long period of wave encounter relative to short duration slams (McVicar et al., 2015). Using the two dimensional Green function, time domain method (Holloway and Davis, 2002) this is reduced to approximately 10 min of CPU time per minute of real time. Therefore we aim here to develop empirical relations for slamming to be applied in time domain high speed strip theory (Davis and Holloway, 2003) to investigate the statistics of slamming in random seas within a practicable overall time frame of computation (French et al., 2010, 2012). Since slam events do not have a dominant effect on hull motions, any one slam event has little effect on the prediction of subsequent slam events after a number of subsequent wave encounters. Hydro-elastic effects, which are important owing to the similar time scales of slam duration and hull whipping period (Lavroff et al., 2007, 2009), are incorporated by the use of the empirical algorithm emanating from the hydro-elastic tank test data.

In the random sea tests to be reported here a segmented model originally tested in regular waves (Lavroff et al., 2007) has been used. The model design follows broadly similar techniques to those of McTaggart et al. (1997), Hermundstad et al. (2007), Dessi et al., (2003, 2007) and Okland et al. (2003). The hull segments are attached to backbone beams which incorporate flexible links at the segment joints. A model with three segments is considered sufficient in the present testing as higher order modes than the two node mode are not expected to be significant (McVicar et al., 2015).

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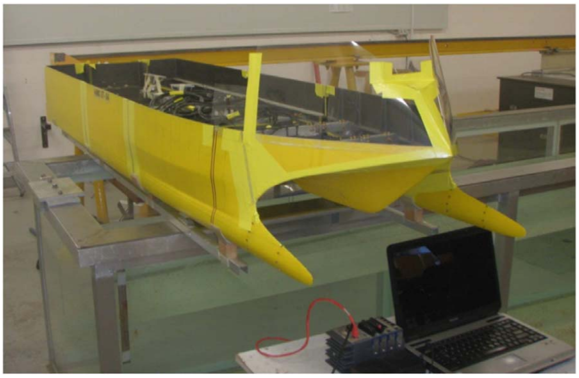

Fig. 1. The 2.5 m hydro-elastic segmented model of the 112 m INCAT Tasmania WPC. The cRIO DAQ system can be seen at the bottom of the photo next to the personal computer.

Computation of the unsteady hydrodynamic response here uses the time domain, high speed strip (or 2.5D) theory (Holloway and Davis, 2002) based on the two dimensional transient Green function (Davis and Holloway, 2003) formulated in a spatially fixed reference frame. This method has been developed for random seas (French et al., 2010, 2012) and gives good motion predictions for length based Froude numbers above 0.3. This method predicts the long term motion response in a random seaway and thus predicts when slams occur and the slam severity. The developed code is applied here to the prediction of slamming for a 112 m INCAT Tasmania built WPC operating under representative head sea conditions.

2. Towing tanks tests of the hydro-elastic model in random head seas

2.1. Design of the hydro-elastic model

Fig. 1 shows the 2.5 m, 27 kg model used in the tank testing and Fig. 2 shows a schematic layout of the model. Note that in this section we are reporting the results of model scale tests using model scale parameters as directly measured. The model has segments connected by flexible links (Lavroff et al., 2009): a rigid central section with aft wet deck attached and port and starboard forward and aft demi-hull sections. The bow is mounted on transverse beams, pin jointed at the demi-hull connections and each with flexible links approximately mid-way between the overall centre line and the demi-hulls. All eight flexible links are short rectangular aluminium sections machined with larger plugs which bolt rigidly into the hollow beams forming the backbones of the demi-hulls and the transverse bow mounting beams. The flexible links tune the main model vibratory modes to appropriate frequency and facilitate measurement of dynamic bending loads by strain gauges mounted on the upper and lower surfaces of each link. Thus dynamic vertical bending moments (VBMs) in the main demi-hulls can be recorded and the vertical load on the bow and its location determined. The main longitudinal whipping mode of the model is tuned to a frequency of 13.8 Hz to simulate full scale whipping at approximately 2.4 Hz and was found to have damping similar to that observed at full scale (Lavroff et al., 2009). The bow of the model was fitted with an array of pressure tappings for Endevco fast response strain gauge pressure transducers. Fig. 2 shows the location of these pressure tappings along the top of the starboard arched cross sections.

2.2. Towing tank random wave test conditions

The model was tested in random waves in the 100 m towing tank at the Australian Maritime College of the University of Tasmania. A paddle wave maker generated a JONSWAP wave spectrum of the required significant wave height and wave period in 500 component bands (French et al., 2015). Fig. 3 compares the spectrum achieved by the wavemaker with the ideal JONSWAP spectrum. It is noted that the spectra are of relatively narrow bandwidth.

The testing time recommended by Lloyd (1989) was found to require approximately eight runs along the tank at each condition. Table 1 lists the test conditions used for the model tests and the number of slams observed at each condition: there were between 66 and 171 slams at each condition and a total of 1812 slams observed over 18 test conditions.

2.3. Observations of wave slams in random head seas

Slams were identified using the pressure transducers located at the top of the arch between the demi-hulls and centre bow (Fig. 2). These transducers only recorded pressure transients when the water surface impacted at the arch top. Fig. 4 shows a typical transient pressure record sampled at 5 kHz to resolve the pressure transients clearly. The pressure transducer located close to the aft end of the centre bow was used as the reference for the purpose of slam identification. Signal records were inspected manually to eliminate spurious small noise components being identified as slams. As can be seen in Fig. 4 the pressure peak generated by a typical slam was of approximate duration 0.01 s. The peak shown in Fig. 4 would correspond to a panel pressure of approximately 380 kPa at full scale.

Fig. 5 shows the median peak slam pressure distribution along the length of the hull as a function of normalized encounter angular frequency. Ship frames are spaced at 1.2 m at full scale or 2.68 cm at model scale, the centre bow truncation being at frame 71 from the demi-hull aft transoms of the vessel. The dimensionless angular wave encounter angular frequency ($\omega_{0e}^{*}=2\pi f_{0e}\sqrt{L/g}$) is normalized by the hull

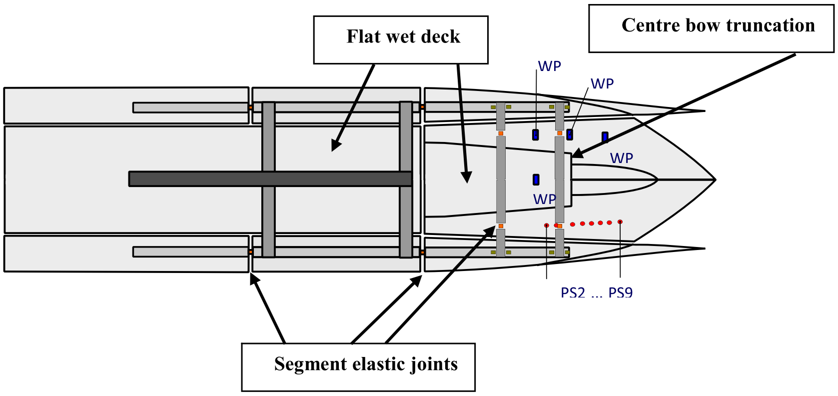

Fig. 2. Structural arrangement of the 2.5 m segmented catamaran model showing discrete model segments, elastic connecting links or joints between segments, wave probe (WP) and pressure transducer (PS) locations (only the arch top locations are shown here).