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Wave slamming loads on wave-piercer catamarans operating at high-speed determined by hydro-elastic segmented model experiments

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ABSTRACT

Catamaran vessels operating at high-speed can be exposed to deck diving and bow damage and one resolution of this problem is the wave-piercer design of INCAT Tasmania. Owing to the complexity of the unsteady non-linear flow in the bow area during large wave encounter model testing has been undertaken to identify the peak dynamic slam loads on the ship structure. This paper provides experimental benchmark information relating to the wave slam loads on wave-piercing catamaran ferries. Since the time frames of transient slam loadings and whipping vibration of the entire hull in its first bending mode are similar it is important that the test model replicates the whipping response and therefore needs to be a hydro-elastic model. A 2.5 m hydro-elastic segmented catamaran model has been developed based on the 112 m INCAT Tasmania wave-piercer catamaran to establish the peak wave slamming loads acting on the full-scale vessel. Towing tank tests were performed in regular seas at a maximum full-scale operating speed of 38 knots. The model was instrumented to measure the dynamic slam loads acting on the centre bow and vertical bending moments acting in the demihulls of the catamaran model as a function of wave frequency and wave height. Peak slam loads measured on the centre bow were found to approach the total weight of the model, this being a broadly similar result to the peak loads measured at full-scale. It was found that global dimensionless heave and pitch accelerations peaked in the same range of encounter frequency as did the peak slam load.

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Nomenclature

c	Distance of slam force on transverse beam from centreline of port demihull pin joint mount (m)
F	Peak sagging slam force (N)
F'_i	Slam force acting on centre bow transverse beam (N)
F'_1	Slam force acting on centre bow forward transverse beam (N)
F'_2	Slam force acting on centre bow aft transverse beam (N)
F'_T	Total slam force acting on centre bow mounted on transverse beams (N)
g	Acceleration due to gravity (m s^{-2})
$H*$	Non-dimensional heave motion = heave amplitude/wave amplitude
l_1	Distance between centreline of demihull pin joint mount and centre of elastic hinge (m)
l_2	Distance between strain gauges mounted on port elastic hinge and starboard elastic hinge of centre bow transverse beam (m)
L	Overall length of model (m)
m	Model mass (kg)
M	Bending moment (Nm)
M'_1	Moment acting on port elastic hinge of centre bow transverse beam (Nm)
M'_2	Moment acting on starboard elastic hinge of centre bow transverse beam (Nm)
$P*$	Non-dimensional pitch motion = pitch amplitude/maximum wave slope
t_i	Time reference points (s)
w_2	Distance between centrelines of centre bow forward and aft transverse beams (m)
x_1	Position of total slam force acting on centre bow in transverse beam configuration measured from the centreline of the aft transverse beam (m)
ς	Wave amplitude (m)
ρ	Density of water (kg m^{-3})
ω_e	Wave encounter frequency (rad s^{-1})
ω_e^*	Dimensionless wave encounter frequency $\omega e\sqrt{l/g}$, where l = vessel waterline length

1. Introduction

The most common design of high-speed multi-hull vessel used by ship builders is the catamaran with a flat wet-deck section joining the two demihulls. Generally the flat wet deck extends right to the bow with a straight or only slightly curved front edge connecting the bows of the two main demihulls. This type of design is effective during operation in smaller waves but it is prone to deck diving when operating in following seas. This can cause the wet-deck leading edge to interact with the encountered wave surface and become submerged imparting a large impulsive slam load on the bow structure. This has been known to cause significant structural damage to the bows and hulls of high-speed vessels (http://taiwantoday.tw/ct.asp?xItem=113812&ctNode=435). Such deep water entry is possible with such conventional catamaran designs since in the absences of strong bow flare above the waterline there is insufficient reserve buoyancy above the waterline in the bow area. Further, some hull designs of the semi-SWATH type seek to reduce large vertical motions in the bow area by incorporating submerged bow sections. As a result such designs are relatively soft with regard to vertical displacement at the bow and are thus more vulnerable to deck diving when operating in large seas.

The occurrence of deck diving and damaging bow immersion at high-speed can be significantly reduced with the introduction of a centre bow with substantial reserve buoyancy above the waterline, as in the design of INCAT Tasmania wave-piercer catamaran vessels (Fig. 1). The wave-piercing design adopted by INCAT (http://www.incat.com.au/) is configured to reduce wave response in moderate head-seas whilst providing inherent protection with forward buoyancy against bow entry into large

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