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On the torsional vibratory response of 13000 TEU container carrier – full scale measurement data analysis

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ABSTRACT

The torsional vibratory response of large container carriers has been suspected to be the main source of fatigue damage to the hatch corner structure, and has attracted considerable attention from ship designers. In line with this, this paper presents the results of the full scale measurement data analysis of a 13000TEU container carrier voyaged between Europe and China, with particular focus on its torsional vibratory response. First, the torsional mode shapes were extracted using the acceleration data measured at five different locations along the ship length and the natural frequencies were estimated by taking a Fourier transform of the modal magnitude time histories., The modal damping ratios were estimated based on the extracted time histories of the torsional modal magnitude and the correlation between the natural frequencies and damping ratios was examined. Modern signal processing techniques, such as the proper orthogonal decomposition and random decrement technique, were used for data analysis. Finally, a different level of contribution of the mode shapes to the total fatigue damage was investigated after decomposing the strain signal into different modal components. The torsional response of the vessel was not significant during its measurement campaign period.

1. Introduction

Hydroelasticity, such as springing and whipping, is considered the main cause of fatigue damage to large container carriers. The relative high forward speed of a container carrier along with its low stiffness due to the large deck opening increases the likelihood of resonance between the hull girder vibration and the excitation from incoming waves. Moreover, the large flare angles and flat stern of a container carrier also plays an important role in exciting the whipping vibration induced by the slamming impact load, either on the flare or stern. Container carriers distinguish themselves from other type of ships in that it has large deck openings leading to a very low natural frequency of the torsional vibration modes. The hatch corners of container carriers are typically prone to fatigue damage because of their structural characteristics, particularly under a torsional load; hence, they should be designed carefully to avoid premature fatigue cracking due to the torsional vibration induced by springing and whipping.

From a numerical analysis point of view, the hydroelastic response of container carriers has attracted more attention than other types of vessel because of its complicated structural behavior. Large deck openings makes the shear center of the cross section to stay far below the keel line, hence horizontal bending always takes place together with torsion in a coupled way. In addition, the openings on deck allow the cross section to behave as a thin-walled beam, so that torsional distortion always entails warping deformation, leading to warping-induced axial stresses. These have been handled successfully by numerical tools relying on some sophisticated beam theories, or a 3D whole ship model (Senjanovic et al., 2008; Kim, 2009; Malenica and Derbanne, 2014; Kim and Kim, 2014).

A full scale measurement campaign has also been attempted to achieve a better understanding of the hydroelastic response of modern merchant ships. Low speed blunt ships, such as bulk and ore carriers, were studied and the influence of the springing effect on the fatigue damages were investigated (Storhaug et al., 2003, 2007). The majority of full scale measurement campaigns focused on the hydroelastic responses of container carriers (Storhaug and Moe, 2007; Heggelund et al., 2011; Drummen et al., 2006). Andersen and Jensen (2014) analyzed the full

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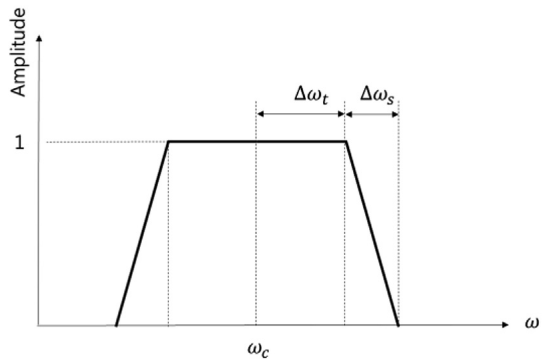

Fig. 1. Band-pass filter and its parameters.

Table 1
Main specifications of CMA-CGM Magellan.

Vessel name	CMA CGM Magellan	
Operator	CMA-CGM	
Owner	CMA-CGM	
Flag/Nationality	France	
Completion year	2010/06	
Shipyard	Daewoo Shipbuilding & Marine Engineering Ltd, South Korea	
Engine design	14RT96flex-C	
Power output	80,080	kW
Maximum speed	24.1	kts
Overall length	365.50	m
Overall beam	51.20	m
Maximum draft	15.50	m
Maximum TEU capacity	13344	TEU
Reefer container	800	TEU
Dead weight	157,092	ton
Gross tonnage	153,022	ton

scale measurement data of a 9400TEU container carrier, and found that the wave-induced vertical hogging bending moment exceeded the design value, and the whipping-induced response was almost comparable to that of the wave-induced one in terms of its magnitude. Storhaug and Moe (2007) analyzed a 294 m long container carrier during its operation in the North Atlantic seaways and found that the global hull girder vibration induced by springing/whipping was significant and should be taken into consideration in the design stage. Okada et al. (2006) analyzed the full scale measurement data of a post-panamax-sized container carrier, particularly focused on the deflection of cross decks. They found that the fore-aft deflection of a cross deck strip was generally much smaller than the design assumptions due to less severe actual stack load.

On the other hand, modern signal processing technologies have evolved significantly over the past few decades, and the combination of these techniques with full scale measurement data enables researchers to derive some important information from the measurement data. So called, operational modal analysis, through which the unknown modal parameters can be estimated using the output data only, has proven its versatility and is used popularly in many engineering fields. Among others, proper orthogonal decomposition (POD) and random decrement technique (RDT) are popularly used signal processing techniques for the identification of modal parameters. Lumley (1970) first applied the method to analyze the spatial distribution characteristics of turbulence in a fluid field, and later extended it to extracting the mode shapes of a vibrating structure (Feeny and Kappagantu, 1998; Feeny, 2002). RDT is another interesting technique that can be used to extract some modal parameters. Cole (1968, 1971) originally developed the technique in the form of an ‘auto’ random decrement to identify the dynamic characteristics and in-service damage detection of the space structure from the measured response only. Later, Ibrahim and Mikulcik (1977) introduced the concept of a cross random decrement that enabled the identification of the mode shapes of a multi-DOF system.

Kim and Park (2013) applied a RDT together with the wavelet transform to identify the modal parameters of a hydroelastically responding ship structure. They reported that the derived natural frequencies did not show any significant discrepancy compared to those obtained by the still water wet hammering test results, but the damping ratios under wet towing conditions were up to 20% higher than those obtained by the wet hammering test. Mariani and Dessi (2012) estimated the mode shapes of a vibrating hull structure on a small scale model. They applied the POD method to extract the mode shapes of a segmented hull model connected to a backbone structure running from bow to stern. The

Table 2
Accelerometer positions.

Sensor	Location	X (m)	Y (from CL, m)	Z (m)
A1	PS frame 11	8.80	22.945	28.12
A2	SB frame 11	8.80	−22.945	28.12
A3	Funnel	60.70	0	57.25
A4	PS frame 56	76.15	22.945	28.12
A5	SB frame 56	76.15	−22.945	28.12
A6	PS frame 91	177.30	22.945	28.12
A7	SB frame 91	177.30	−22.945	28.12
A8	Wheelhouse	217.15	0	55.65
A9	PS frame 132	262.35	22.945	28.12
A10	SB frame 132	262.35	−22.945	28.12
A11	PS frame 150	318.30	12.805	30.266
A12	SB frame 150	318.30	−12.805	30.266

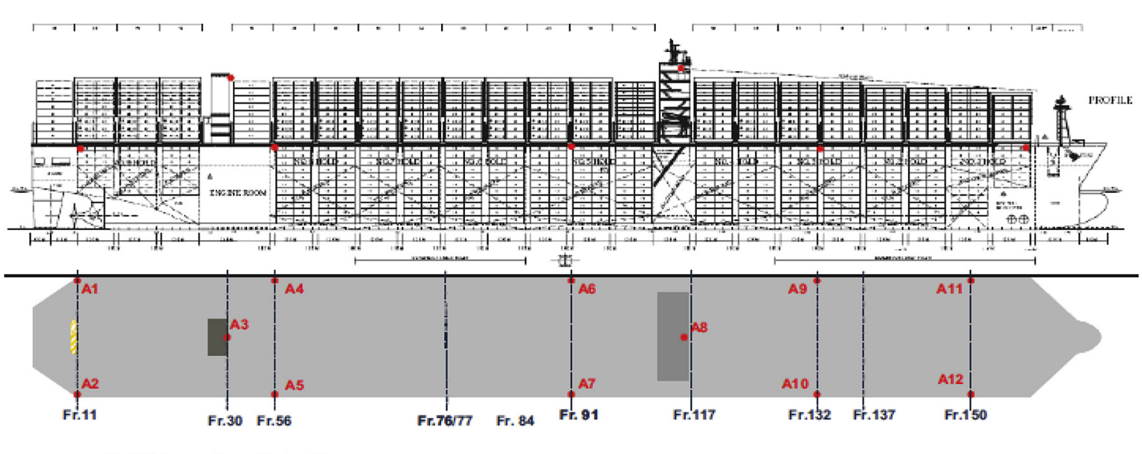

Fig. 2. Accelerometer arrangement on the ship.