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Analysis of wave slam induced hull vibrations using continuous wavelet transforms

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ABSTRACT

Large high-speed wave-piercing catamarans are subject to continuous wave induced hull vibrations during their lifetime of operation. In severe sea conditions, the vessel experiences high load impacts, known as slamming, accompanied by high frequency structural response giving rise to fatigue effects. Classical vibration analysis techniques such as the Fourier Transform fail to identify the exact response frequencies of slamming events due to the transformation to the frequency domain and the loss of temporal information about these transient events which is of great importance to fatigue analysis. The work presented in this paper introduces, describes, applies and recommends the continuous wavelet transform as an effective means to investigate the wave induced hull vibrations in both the time and frequency domains simultaneously.

1. Introduction

When operating in rough seas ships may experience water impact loads (known as slamming) due to excessive relative motion between the vessel and the waves. A shudder or vibration occurs following such impacts known as whipping. Severe slamming loads might result in abrupt changes in vessel motions and high stress levels which may in turn cause structural damage. Such damage has a direct influence on short term cost due to the repairs and loss of service time; in addition, long term financial losses might occur due to bad publicity.

Slamming on multihull ships is different from slamming on monohulls in terms of slam location and severity. Twin hull ships experience a unique type of slamming called wet-deck slamming, when the underside of the cross deck structure comes in contact with the wave surface in the presence of sufficient relative motion between the vessel and the water surface. Serious damage occurred on the HSS 1500 Stena bow structure due to a severe slamming event in rough seas Fig. 1

Deformation of longitudinal stiffeners has also been reported on an 86 m Austal vessel due to severe slamming loads (Rothe et al., 2001). On wave piercing catamarans, Incat Hull 050 suffered side shell buckling Fig. 2, and tripping of brackets in the centre bow area following a severe asymmetric slam event in the starboard archway between the centre bow and the demi-hull (Thomas et al., 2002, 2003a).

The calculation of slam loads on large catamarans fitted with a centre bow is a complex task and extreme loads to date have not been established through a proven theoretical approach. Unfortunately the kinematics of slamming events is also not well understood on large high-speed catamarans. Classification of slamming events and the factors affecting the slamming occurrences can only be reliably evaluated by full scale measurement and/or model testing. By comparison with the extensive work that has been carried out for slamming on monohulls, for example (Aertssen, 1979 and Iaccarino et al., 2000), little work has been published on full scale measurement of loads and motions of large high speed catamarans. Roberts et al. (1997) extrapolated sea trials stresses of two 81 and 86 m Incat catamarans at a probability of 10^{-8} using Weibull and Gumbel extreme value plots. The analysis assumes that extrapolated full scale stresses can be directly compared with the FE model stresses at the same locations in a quasi-static analysis. Sea trials extreme value stresses at a probability of 10^{-8} were extrapolated by Steinmann et al. (1999) using the Ochi extrapolation procedure (Ochi, 1964), which assumes a linear relationship between stresses and wave height. This assumption does not hold for large high speed catamarans in moderate to heavy seas when highly non-linear slamming loads occur as well as regular wave loads. Individual slamming events were identified during data post processing and the peak slam responses were compared to the quasi-static global response levels as defined by classification societies. Extreme value analysis was implemented in both cases

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to compensate for the dynamics of slamming. Slam dynamics were also explored extensively without extrapolation techniques by Thomas et al. (2002), (2003a) to investigate the peak load values during an extreme slamming event that caused buckling of the superstructure shell plates on an 96 m Incat catamaran during her regular service across Cook Strait in New Zealand. The investigation resulted in improved understanding of slamming dynamics showing that the slamming load during this particular asymmetric event was in excess of 1000 t.

Slamming data are usually collected using either sea trials data or model tank testing. Slamming data is non-stationary and random in nature. Fig. 3(a) shows the vessel under investigation while Fig. 3(b) shows an example of the ship hull structural response to slamming as seen on a strain gauge fitted on the bottom centre girder web, T1–5, Fig. 4, on INCAT Hull 060 during an extensive sea trials program to determine the vessel's operational envelope. Hull 060 was originally a high-speed passenger ferry but subsequently configured to US Navy specification for military purposes and is known as HSV-2 SWIFT. Vessel specifications are given in Table 1.

Fig. 1. Damage of bow structure on HSS 1500 Stena due to severe slamming loads.

Fig. 2. Side shell buckling as a consequence of severe slamming loads, Hull 50 of Incat Tasmania.

Spectral analysis by fast Fourier transform, FFT, represents an appropriate tool for exploring the energy content of a stationary signal in the frequency domain. However, non-stationary signals such as slamming lose all time information in such an analysis which is of extreme importance in identification of slamming occurrence. Although the frequency domain provides valuable outcomes, it is of little value in respect of slamming without information about the time for a particular response frequency to occur. In other words, it is desirable to define a frequency component and its corresponding time of occurrence. Unfortunately, this cannot be determined accurately according to the Heisenberg uncertainty theorem as applied to signal analysis. The theorem was first defined in the field of quantum mechanics by Heisenberg (1927) stating "the simultaneous determination of two related quantities, for example the position and momentum of a particle, has an unavoidable uncertainty". This uncertainty is not related to the measuring means or devices but the physical nature of the measured quantities. For any signal represented in the time domain, the frequency and time characteristics follow this same principle. In other words, it is impossible to define a frequency and its corresponding time of occurrence simultaneously (Polikar, 2001), simply because a time interval is needed to define a frequency. Instead, a band of frequencies can be identified only during a finite time interval. The FFT describes explicitly the frequency components of a signal on the basis of time information which means that an FFT cannot be used to analyse non-stationary signals in which the localisation of transients is of extreme importance.

To overcome this problem, the Short Time Fourier transform (STFT) was introduced by Gabor (1946), in which the time record is divided into equal size windows. For each of these windows, an FFT is applied to extract the frequency components within the predefined window. However, lower frequency signal components, which correspond to a wider time frame, cannot be identified within the specified window borders. Window size optimisation is therefore necessary to obtain the best representation of the frequency content in the signal. Narrow windows give more precision about time information but less about frequency and vice versa. Wavelet transforms solve this dilemma by presenting the signal frequency content in frequency bands over specific time durations. Simultaneously, narrow time windows are used to resolve high frequency components while wider

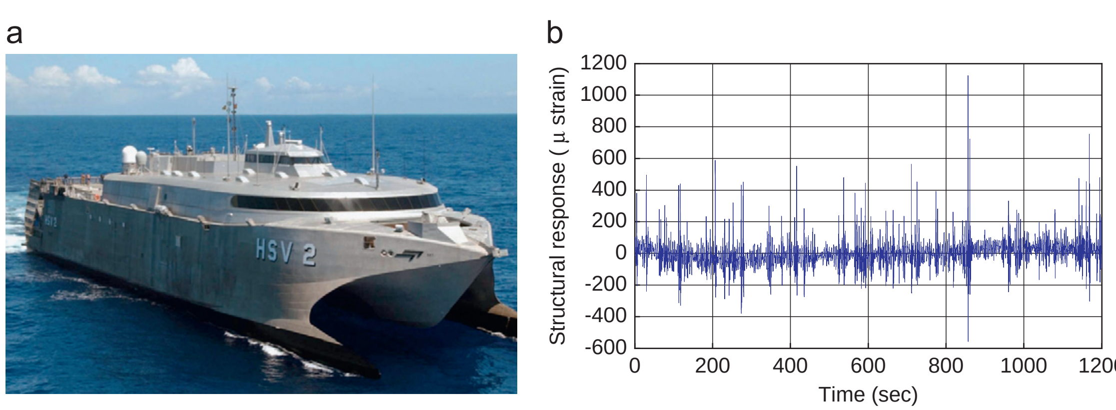

Fig. 3. (a) INCAT Hull 061, (b) random structural response signal during sea trials for a strain gauge fitted approximately amidships on the demi-hull keel at 20 knot.