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Towards realistic estimation of ship excessive motions in heavy weather. A case study of a containership in the Pacific Ocean

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A B S T R A C T

Synchronous roll and parametric roll resonance are critical phenomena that lead a ship, under certain conditions, to quickly develop large roll amplitudes. This will result in excessive accelerations that can be dangerous for a ship and her cargo. Ships with large bow and stern flare (i.e. container carriers and RoPax) are especially prone to this type of hazards. Therefore, it is of utmost importance for ship operators to be aware of a set of conditions under which these two unwanted phenomena happen. This will help implementing necessary counter measures, either operational (speed or course alterations) or tactical (route finding).

In this context, the development of a fast and reliable method for screening the conditions leading to excessive accelerations would improve ship safety. Therefore, in this study, we propose a method detecting critical scenarios for a container ship in heavy weather conditions. The method utilizes an original, six-degree numerical model of ship motions, called LaiDyn, to investigate large amplitude motions and the associated longitudinal and transverse accelerations that a ship is experiencing.

Finally, the accelerations that are calculated for a set of operational conditions are checked against their predefined threshold values associated with the cargo lashing system.

The proposed method can be used for operational purposes, at the stage of route planning, where the expected accelerations could be considered as another objective function in the route-finding algorithm.

1. Introduction

With the continuous increase in ship size, thus their payload capacity, the prediction of ship motions and high accelerations, is an important safety issue. Excessive accelerations that can arise by synchronous roll and parametric roll resonance can lead to unwanted consequences to people on board a ship (injuries due to the sudden, unexpected and violent motion of a ship) or ship cargo. The latter is due to the accelerations, which are higher that the design values for a given lashing system, causing cargo shifting. The latter, depending on a ship type, may trigger further consequences, compromising the safety of ship, cargo and the environment.

To prevent such situations, the awareness of the critical scenarios leading to large motions and high accelerations is required by ship operators. In order to arise such awareness, a proper method detecting the critical parameters of a ship given a wave pattern is needed. Such a method could help at the stage of route planning, where the expected accelerations, for anticipated operational conditions, could be considered as another objective function in a route-finding algorithm (Zhang et al., 2015; Decó and Frangopol, 2013; Dong et al., 2016).

One of the phenomenon leading to sudden heavy roll, in apparently calm and controllable conditions is parametric rolling. Especially, it is important for ships which hulls feature large bow and stern flare, such as container and Ro-Ro vessels. Perhaps it is the most complicated phenomena to understand and manage by officers onboard (Prpic Oršic et al., 2014; Krueger, 2006). Parametric roll is a resonance phenomenon but it is distinct from synchronous resonance between external periodical forces (T_e) and natural period of the system (T_n). A ship can experience parametric resonance if the wave encounter period is half the roll period (Belenky et al., 2006) T_e=0.5T_n.

There are a few proposals regarding numerical tools simulating parametric rolling, which can be applied for a detailed analysis of ship behaviour in the sea, for example (Ribeiro et al., 2013; Chang, 2008; Belenky et al., 2006). For operational guidance, a simplified solution is

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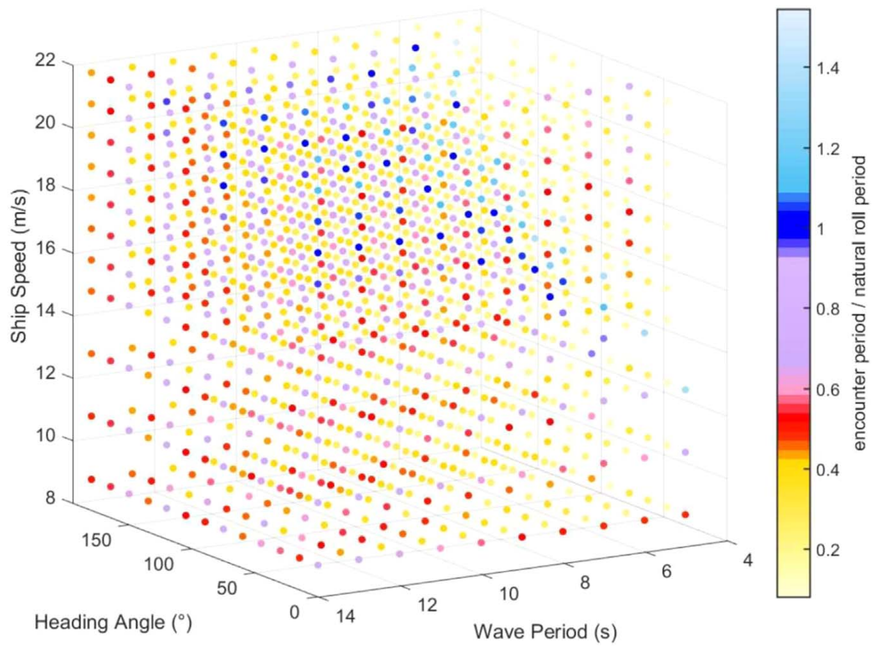

Fig. 1. Example of encounter periods associated to a population of operative conditions (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.).

usually preferred, where all the relevant information is depicted in a polar plot, as a function of ship heading and speed, for a defined sea state; see for example (Krueger, 2006; Levadou and Gaillarde, 2003; Hashimoto et al., 2008; Shigunov et al., 2010). Such methods provide a good general overview of situations that may lead to excessive rolling that shall be avoided. Therefore, they are good for screening the conditions to select the critical ones. However due to the static nature of the methods, the evaluation of accelerations that a ship may suffer under certain conditions, is not possible.

In this paper, we present a fast and reliable method determining the critical operational conditions of a container ship, leading to large amplitude motions resulting in excessive accelerations. The method is two-fold. First, the operational and environmental conditions close to resonance are defined for a given ship. This part recalls what is already proposed by IMO (2007). Second, these conditions are inputted to the numerical model of ship motions in irregular seas simulated in time domain, to evaluate the response of the ship in terms of motions and accelerations.

The numerical model of ship motions adopted here is based on a six-degree of freedom dynamic model, solved in time domain that works on a discrete representation of the hull, taking into account non-linearities (Matusiak, 2013). Ship speed is obtained by taking into account the ship resistance and the propeller behaviour in waves: this allows performing a more realistic simulation of ship operational conditions.

The time histories of all the simulated cases are collected and further analysed. Particular attention is given to the lateral accelerations, since a realistic estimation of accelerations is useful for cargo shifting assessment for any container ship (Shigunov et al., 2013).

Finally, the accelerations for all the studied operational conditions are checked against their thresholds, provided for a lashing system design.

Recently standards for dimensioning the container securing system has been introduced by Germanischer Lloyd- GL (2013), however, there are still container ships operating according to the previous design standards, which are less strict than the contemporary GL's rules.

To account for that, the exceedance of the maximum lateral acceleration of 0.5g is used for the identification of cargo loss events (Shigunov et al., 2010). In setting the critical scenarios, in terms of environmental and ship operational conditions, a route across the Pacific Ocean is assumed. Although this ocean area is characterized by less severe sea states than North Atlantic Ocean, it takes longer for a ship to cross it, thus the exposition to heavy sea states is prolonged.

The analysis is carried out for a ship hull that is well studied and known for its vulnerability to parametric roll (Reed, 2011; Garbatov and Soares, 2011). This kind of container ship can carry about 4800 TEU and it can be representative of the 16% of the actual ocean going container ship fleet. The remainder of this paper is structured as follows: Section 1 introduces a two-fold method that is used to evaluate the accelerations during ship operation, in Section 2 the method is applied to a ship traversing the Pacific Ocean, and the obtained results are shown and discussed in Section 3. Section 4 concludes.

2. A method detecting excessive accelerations for a ship in operation

It is known that the synchronous and parametric roll occur for a specific range of wave encounter frequency. This frequency can be adjusted by ship speed and/or course alteration, (Umeda, 2013). By doing that one can obtain the set of ship speed and headings (knowing the wave characteristics) that would lead to resonant critical scenarios. This is done as follows. First, the severe weather scenarios, in terms of wave mean period and significant wave heights, are set. From this population of wave conditions the ones having the encounter period equal to the natural roll period or equal to half natural roll period are chosen; then they are further simulated in the numerical ship motion model LaiDyn to evaluate the accelerations.

In Fig. 1 an example of a population of operative conditions is provided, defined by ship headings, speeds and wave periods. The encounter period associated to these operative points is given by the colour. Blue points represent operative conditions having the encounter period close to the natural roll period. Red points represent the operative conditions having the encounter period close to half natural roll period; the majority of these points is characterized by low speeds and high wave periods. For the detailed list of operational conditions found in the synchronous and parametric roll resonance range (i.e. blue and red points of Fig. 1), please refer to Table 3 and Table 4 in Section 3.