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# Analysis of dynamic response of a restraining system for a powerless advancing ship based on the Kane method

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## ABSTRACT

Following general explanations of the working principles of different existing retardation systems to restrain an advancing powerless ship the principles of a new overhead retardation system are presented. A two dimensional simplified model of the activated overhead system is formulated based on Huston's interpretation of the Kane methodology. Reduced Kane equations are used in the actual simulation, once initial conditions and mechanical analysis of constituent elements have been formulated. Having presented the computational process the various velocity, motion and joint constraint force characteristics of the anchor, the ship and the other elements are monitored in the time domain for the duration of the retardation process. Validation of the Kane based method is established utilising the conservation law and the Lagrangian based formulation of the retardation system within the ADAMS software. The results indicate that a peak value of constraint will occur because of the sudden movement of anchor and this peak is affected significantly by initial ship speed. Variation in anchor chain, overall cable length and its horizontal projected length has little influence upon retardation system performance, whilst the changes of sea bed friction, anchor mass, water depth, initial ship velocity and ship mass will make retardation behaviour different.

## 1. Introduction

As a consequence of increased cargo transportation with larger ships travelling at greater speeds collision risks have been raised between ships and above waterway transportation bridges. This has also led to more fatal collisions between ships and bridges (Mou et al., 2010; Yan and Dai, 2011), which not only adversely affect traffic safety but also cause considerable losses. Therefore, research on ship collision with bridges has become an important international topic. The flexible collision-prevention devices have been focused on by an increasing number of researchers (Fan and Yuan, 2014; Qiu et al., 2015) as rigid anti-collision devices can damage both the prevention devices and the colliding ship.

Wang et al. (2008) developed a flexible, energy-dissipating ship retardation device consisting of hundreds of steel-wire-rope coil (SWRC) connected in parallel and series. Zhou et al. (2012) analysed the elastic behaviour of the retardation device by treating it as a circular elastic ring attached to a pile through elastic foundations. A non-dimensional parameter, corresponding to the ratio of the elastic foundation stiffness to the bending stiffness of the circular ring, was identified as important and a ratio was found to optimize the crashworthiness of the retreating structure. Wang et al. (2012) applied impact dynamics theory to illustrate how wave propagation and the dynamic behaviour of materials influence the impact force and energy transformation. The results generated illustrated that it was the material-dependent wave impedance that played a dominant role, rather than ship total mass and rigidity in determining the resulting impact force of ship and bridge pier.

Zhu et al. (2012) made several large-scale impact tests involving flexible pile-supported protective structures that absorbed impact energy through large deflections and yielding. The complexity of a three-dimensional analysis necessitated a simplified energy-based analysis method to estimate the lateral deflections. Comparison between calculations and test measurements demonstrated that the simplified analysis method gave conservative results concerning the energy-absorbing capability.

A floating fender system can automatically adjust its elevation with the changes in water level.

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Jiang and Chorzepa (2015) used an explicit nonlinear dynamic finite-element analysis program to evaluate the performance of a new floating fender system composed of fiber-reinforced plastic (FRP) box modules filled with rows of FRP tubes. The analysis indicated that the new fender system had excellent energy-absorbing capabilities, facilitated significantly smaller collision forces and increased collision duration imposed on the bridge pier and colliding ship. Jiang and Chorzepa (2016) applied the same analysis method to a floating fender based on different materials. In this case the floating steel fender system was primarily composed of readily available steel plate structures and rubber components. Because the proposed fender system extended the impact duration, the peak impact force between the bridge pier and the colliding vessel was notably reduced.

Wu et al. (2009) and Chen et al. (2009) researched a flexible floating collision-prevention system consisting of a string of surface buoys connected by cables. Each buoy is connected with a bottom slidable anchor. When the buoy arrangement is struck by a disabled ship, its kinetic energy is dissipated through the movement of the anchors. Chen et al. (2013) proposed the small balance method to determine the buoy position, anchor movement and the history of anchor chain forces due to ship collision with the flexible floating buoy blocking system. The predictions showed good agreements with model test measurements.

An overhead retardation system, mainly made up of gravity anchors and associated anchor chains connected at one end to a restraining net with supporting frames represents a new type of flexible ship collision prevention device. Its working principle is similar to an earlier floating buoy system investigated by Wu et al. (2009), Chen et al. (2009) and Chen et al. (2013). Such systems require precise determination of the dynamic characteristic of the anchor chains and restraining cables. This means that it is necessary to apply a multibody dynamic method to address such systems.

Recently Ku and Ha (2014), Xu et al. (2015), Tran and Kim (2015) and McNatt et al. (2015) have carried out multibody dynamic analysis within the context of offshore engineering applications. Similarly Chang et al. (2012) applied the multi-body dynamics approach to a single-point mooring buoy system consisting of a surface buoy, cable segments modelled as individual components and an anchor. Jiang et al. (2015) employed the homogeneous matrix method to model and simulate a four-body system with a floating base. The motions were analysed subject to wave and wind loads when the upper parts were spread sequentially or synchronously.

Based on the Kane method Shen et al. (2003) studied the rolling response of the ship in waves and the motion of a heavy load "synchro-slipping". This approach was also adopted by Yang et al. (2014) to analyse the dynamic response of an underwater snake-like robot.

He et al. (2014) undertook the dynamic analysis of an offshore crane based on rigid-flexible coupling and the application of virtual prototyping-based multibody dynamics. After combining the computer software suites of ADAMS and ANSYS numerical calculations were carried out and model validity verified through comparison with experimental measurements.

However, the investigation of the dynamic response of anchor chain and restraining cable using multibody dynamic methods are rather scarce. This is particularly the case when addressing the condition of gravity anchor movements. Since the Kane method has the advantages of both vector and scalar based mechanics, it is applied in this paper to provide a preliminary analysis of the influence factors and system parameters on the responses of a powerless ship restraining system.

Section 2 presents the working principle of a proposed ship restraining system together with its mathematical model. Then, mechanical analysis of the system and related solution methods are formulated in Section 3. Comparative studies of theoretical predictions and simulations are given in Section 4. Section 5 provides conclusions and paper closure.

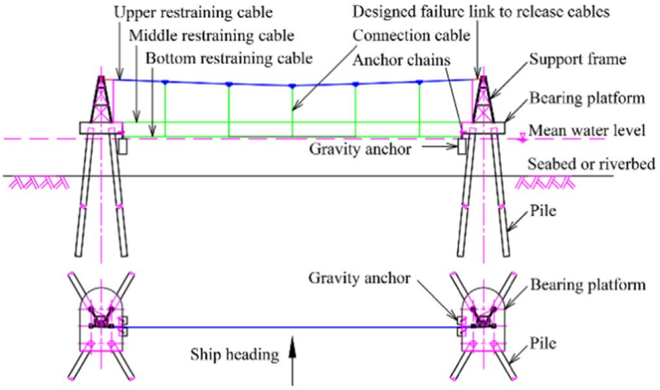

**Fig. 1.** Front elevation and plan of a single unit of overhead retardation system.

## 2. Working principle of retardation system and its mathematical model

The proposed retardation system is concerned with stopping a powerless ship advancing into restricted water beyond a generally non-navigational bridge. The retardation system needs to be located upstream of the bridge at a distance commensurate with maximum stopping distance of ships using the waterway under consideration. The proposed overhead retardation system is introduced in Section 2.1 together with an explanation of the underlying principles necessary to formulate the mathematical model addressed in other sub-sections.

### 2.1. Working principle of the overhead retardation system

The proposed retardation system is composed of an upper, middle and bottom restraining cable strung between two support frames and linked by vertical connection cables as illustrated in Fig. 1. Depending upon the particular waterway to be investigated the total span of the bridge to be protected by the retardation system may need one or more of the described units.

The middle and bottom cables exist so that smaller ships can trigger the retardation system. The arrangement of horizontal and vertical cables are collectively referred to as the "retardation net". The upper restraining cable is kept in place by a secondary weak link connection at the top of each support frame. The continuation of the upper retraining cable beyond the weak link is connected to the end of the anchor chain. The chain is ultimately connected to the anchor. The middle and bottom cables have a weak link to the anchor chains. These links cannot sustain the anchor chain tension once the anchor has been released from the bearing platform. Therefore, if the ship makes contact with the middle or bottom cable, the weak connections with the anchor chains will fail. Hence the upper cable will be pulled downwards and break its associated weak links. Ship contact with the upper restraining cable also leads to the failure of the identified weak links. Hence the overhead net falling on to the deck of the ship is triggered by a ship making contact with upper, middle or bottom restraining cables. This paper does not address safety issues related to this reaction or subsequent operation of the retardation system.

A releasable concrete anchor and the associated studless anchor chain are stored on a 'bearing' platform identified in Fig. 1. The support frame is fixed to the sea-bed or riveted by penetrating piles through the seabed. The restraining cable will begin to pull at the anchor chain once the ship has advanced sufficiently to allow the metal pin supporting the anchor to be dislodged from the bearing platform. The anchor will drop to the seabed or riverbed.

When the restraining cables and anchor chains have become taught anchor dragging will commence and start to reduce the speed of advance of the ship. Ultimately the ship will be stopped as a consequence of the influence of the drag forces induced by the friction