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Experimental evaluation of the tension mooring effect on the response of moored ships

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A B S T R A C T

Tension mooring may be applied to improve operational and security conditions of exposed port terminals. This paper analyses the influence of the type of fender facing on the efficacy of tension mooring in terms of reduction of the moored ship motions and improvement of the operational and security conditions at berth. Two mooring line pretension conditions and two types of interfaces between the ship and the fenders were experimentally investigated. The physical model was designed based on the characteristics of a real port terminal with operational problems—the Leixões oil terminal, Portugal. The analysis of the moored ship response shows that high friction fender facings reduce moored ship motions and significantly increase the tension mooring efficiency. The magnitude of pretension forces and the type of ship–fenders interface are important aspects when looking at common environmental conditions, but their contribution to reduce moored ship motions during rough (extreme) conditions is limited. It was also concluded that friction forces developed at that interface provide additional damping to the dynamic system composed of the moored ship and help preventing resonance, in particular when contributions from other sources of damping are minimal, as it is shown for roll.

1. Introduction

Downtime and mooring problems at ocean facing ports are often related with excessive motions of the moored ships caused directly by wave action or indirectly by wave related phenomena, such as long waves or harbour resonance (*e.g.* González-Marco et al., 2008; Kwak et al., 2012; Morais and Abecasis, 1978; Neves, 1997; Sakakibara et al., 2001; Shiraishi et al., 1999, 2006; Van der Molen and Moes, 2009; Yoneyama et al., 2004). Therefore, the reduction of those motions is important to increase the on and off-loading operations efficiency, to minimize port operational costs as well as to reduce security and environmental risks, especially when dealing with dangerous cargoes (such as oil or gas). Soft countermeasures, often related to the ship mooring system, may be applied to that purpose as an alternative (or complement) to the construction of new sheltering structures or the adaptation of existing ones, the modification of the port layout (*e.g.* Nakamura and Morita, 1998) or the reduction of reflection coefficients of the harbour inner boundaries (*e.g.* Taveira-Pinto et al., 2011; Uzaki et al., 2010).

Those countermeasures need to be taken into account as they may be less expensive, quicker to apply and effective as well. Sakakibara and Kubo (2008) confirmed by field observation and numerical simulations that modification of the mooring system was an effective countermeasure for restraining the large and low-frequency motions of a ship and improving the security of the system itself. The modifications included the change of the stiffness of mooring lines and fenders (load-elongation characteristics) and the use of additional mooring dolphins. In recent years non-conventional and automatic mooring systems have been developed that present high potential to be efficient in reducing low-frequency ship motions, but each one with its own advantages and limitations. Yoneyama et al. (2006) studied experimentally a system able to shift automatically the natural periods of the mooring system from the predominant period of long-period waves, by changing the stiffness and tension of the mooring lines, to prevent resonance. De Bont et al. (2010) evaluated the performance of a system composed of vacuum pads and hydraulics systems to secure and control the response of moored ships at berth. Van der Burg (2011) presents cylindrical mooring units designed to maintain adequate tensions on the mooring lines and to minimize ship motions whose principle of operation is based on hydraulic systems. Trial units of the last two systems were already applied in real port terminals.

Some of the principles behind the systems referred are not completely new. The tension mooring concept has long since been advocated (*e.g.* Bruun, 1988, 1989) as an effective technique to reduce the motions of ships at berth and it is common practice in several ports when adverse conditions are expected. It consists basically in pressing the ship against the fenders by applying pretension

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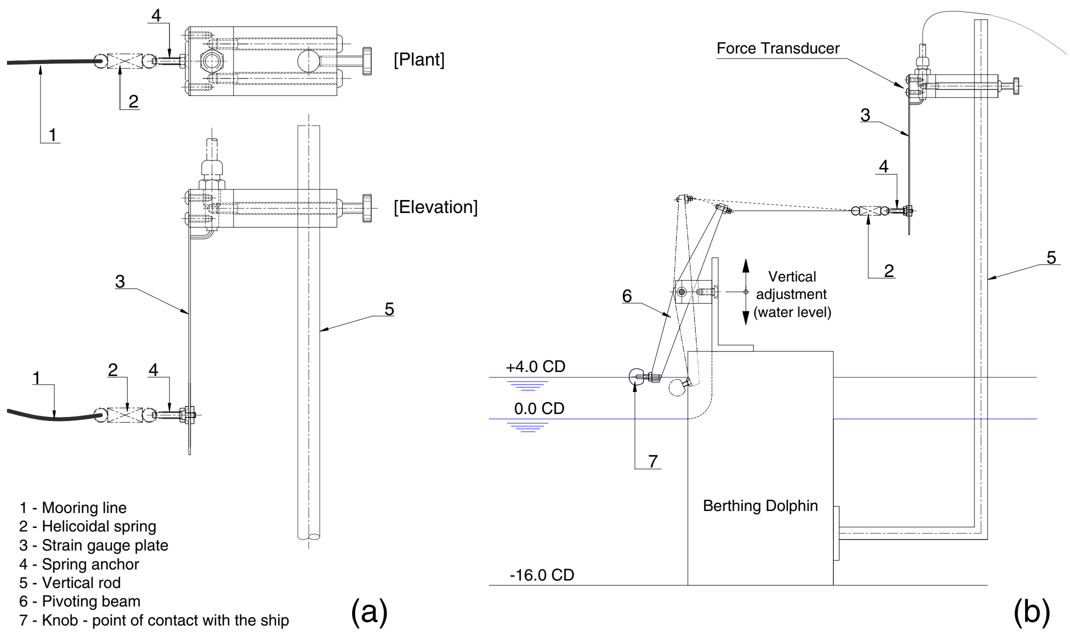

Fig. 1. Force transducers setups: (a) mooring line configuration, (b) fender configuration.

loads in the mooring lines (higher than usually), in order to use the fender friction and the fender and mooring line energy absorption capacity, to reduce ship motions and mooring loads. However, the magnitude of such pretension loads is not precisely fixed (Bruun, 1988), depending on the type of ship and site conditions, among others. Numerical and physical modelling studies as well as practical experience suggests than pretension loads higher than 100 kN may be required in the mooring of large ships to reduce motion amplitudes to acceptable values.

An usual rule of thumb is that ship motions can be more effectively reduced by pretensioning the breast lines (Bruun, 1988; OCIMF, 2008; PIANC, 1995) as they press almost directly the ship against the fenders. However, local conditions may require that other mooring lines are pretensioned as well. OCIMF (2008) provides some practical guidance on the application of pretension to the different ship mooring lines. The effects of pretension on the response of moored ships have been discussed in a number of cases. Kubo et al. (2000) shows the importance of preventing mooring lines of being slack and applying high pretension loads when mooring large ships. Van der Molen et al. (2006) demonstrated that the modification of pretension forces may reduce ship motions and mooring forces if the natural periods of the system are changed, due to the change of stiffness, and shifted away from the resonant periods of the harbour or the incoming infra-gravity waves. Other authors analysed, either numerically or experimentally, and discussed the advantages that may result from the use of mooring line pretension on the response of ships or on the operational conditions of port terminals (Cornett et al., 1999; Gravesen, 2005; Rosa-Santos et al., 2009; Weiler and Dekker, 2003). It is however important to discuss the influence on the efficacy of the tension mooring concept of the type of interface between the ship and the berth, taking into account the response of the moored ship in its six degrees of freedom.

Small-scale physical models of port and offshore terminals are a valuable tool to study the response of moored ships to different environmental conditions (waves, currents, wind) and design parameters (type of ship, load condition, mooring arrangement, water depth). Despite being a simplified reproduction of reality (prototype), physical

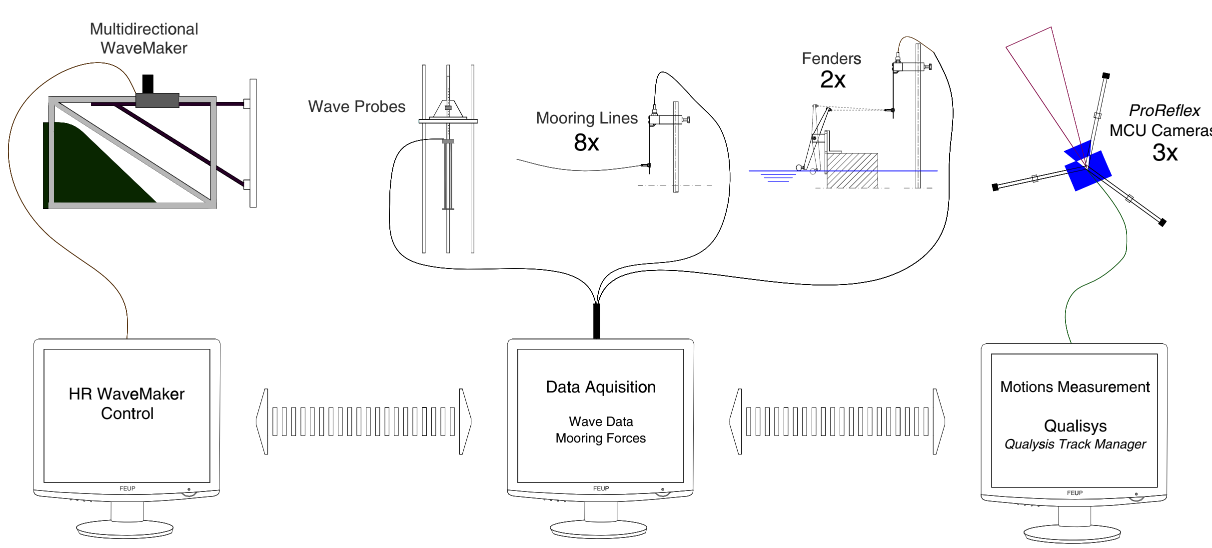

Fig. 2. Operation of the systems used in the study.