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Human responses to wave slamming vibration on a polar supply and research vessel

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A R T I C L E I N F O

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A B S T R A C T

A polar supply and research vessel is pre-disposed to wave slamming which has caused complaints among crew and researchers regarding interference with sleep, equipment use and research activities. The present work undertook to survey passenger claims of sleep interference, disturbed motor tasks and equipment damage as a result of wave slamming during normal operations of this vessel. The hypothesis was investigated that whole-body vibration metrics from ISO 2631-1 are potentially suitable for the prediction of human slamming complaints. Full-scale acceleration measurements were performed and wave slamming events were subsequently identified from the human weighted acceleration time histories. A daily diary survey was also conducted to gather the human response. The vibration caused by wave slamming was found to be strongly correlated with sleep disturbances and activity interference. Sleep and equipment use were found to be the most affected parameters by slamming. Daily vibration dose values were determined by accumulating the vibration as a result of slamming over 24 h periods. This metric accounted for increased magnitudes and frequency of slamming incidents and proved to be the best metric to represent human responses to slamming vibration. The greatest percentage of activities affected by slamming related to sleep regardless of daily cumulative VDV magnitude. More than 50% of the recorded responses related to sleep when the daily cumulative VDV ranged between 8.0 $m/s^{1.75}$–10.0 $m/s^{1.75}$. The peak vertical vibration levels recorded on the vessel reach magnitudes which are associated with sleep disturbance in environments where acoustic noise is present.

1. Introduction

Ship environments expose the crew and passengers to noise and vibration even during the hours of relaxation and sleep which could persist for weeks on end (Gibbons et al., 1975). Sillitoe et al (Sillitoe et al., 2010). relate mechanical noise and vibration in accommodation areas to the potential degradation of rest and sleep quality of vessel occupants, thereby increasing the likelihood and severity of fatigue symptoms. Scott (2006) states that although vibration levels on ships are regulated, guidelines specify vibration levels that are linked to the manifestation of physical symptoms such as headaches and nausea.

Currently no consideration is afforded to long-term low intensity vibration exposure, which affects human sleep patterns and places the human body in a constant state of aggravation (Scott, 2006). Several studies have identified a positive association between whole-body vibration exposure and increased subjective perceptions of fatigue (Abbate et al., 2004; Newell and Mansfield, 2008). Importantly, fatigue from tiredness and sleeplessness is the largest identifiable and preventable cause of accidents in all modes of transportation (Akerstedt, 2000).

Slamming is defined as the exposure of a vessel structure to large forces from wave impacts for a short duration of time (Kapsenberg, 2011), typically when the vessel bow or stern emerges from a wave and re-enters the water with an impact (American Bureau of Shipping, 2013). Slamming specifically relates to the impulsive pressure caused by water entry, whereas whipping or springing refers to the global vibratory response that follows a slamming event (Dessi, 2014).

Human responses to wave slamming were investigated on a polar supply and research vessel (PSRV) which is prone to stern slamming. Slamming is problematic due to claims that slamming inhibits oceanographic research operations and causes violent and dangerous wave activity on the aft-deck where container

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laboratories are mounted (Omer and Bekker, 2016). Passengers further claimed that slamming disturbs their sleep, inhibits equipment use and interferes with motor tasks such as typing and writing (Bekker, 2013). An earlier pilot study on the PSRV surveyed human responses to slamming vibration during a research voyage to Marion Island (Omer, 2016). The survey conducted through the questionnaire did not receive the expected participation. This factor limited the planned use of the survey for quantitative analysis and comparison with the measured data. Feedback from the respondents recommended that the survey should be shortened and some instructions clarified. However some mentioned comments and reported incidents did provide useful insight as to the discomfort and possible equipment damage caused by slamming. The survey provided for daily comments by the participants, two of which are quoted here:

Subject M49: "*Firstly, the semi-predictable slamming of the ship has the potential to damage the deployment of expensive scientific equipment/instruments … Secondly, the slamming of the ship also prevents some oceanography from being done since aft deck activities become extremely dangerous/impossible during serious sessions of slamming …,… and thirdly, slamming does not specifically prevent me from sleeping, but severe slamming more often than not wakes me up.*"

Subject M59: "*I have spent 35 days on-board this vessel and not one day went by where the ship did not slam or shudder! The slamming not only affects our instrumentation but sleep + mood patterns.*"

To date neither the effect of wave slamming on human response, nor its potential interference with activities, has been explicitly studied. As such it remains to determine how slamming correlates to human factors. Furthermore, the need is identified to develop methods to evaluate and predict human responses to slamming vibration which is impulsive and transient in nature. Current whole-body vibration standards (BS 6841, 1897; ISO 2631-1, 1997) provide guidelines for the evaluation of vibration in relation to human response but do not specify metrics through which discomfort can be predicted as a result of high crest factor waveforms (Patelli et al., 2013).

In light of this background the current study undertook to survey passenger claims of sleep interference, disturbed motor tasks and equipment damage as a result of wave slamming during normal operations of the PSRV. The correlation between human responses and whole-body vibration metrics from ISO 2631-1 (ISO 2631-1, 1997) are investigated to determine if such metrics could be used to predict likely responses of passengers to slamming vibration on ships.

2. Methodology

Fig. 1 provides a diagram of the methodology used to determine if whole-body vibration metrics from ISO 2631-1 are potentially suitable for the prediction of human responses to wave slamming. As per the methodology of ISO 2631-1 full-scale acceleration measurements were performed on the slamming-prone PSRV during normal operation. As current complaints of wave slamming include claims of a highly impulsive vibration experiences (Bekker, 2013), human weighting filters were applied to vibration measurements to account for perceived vibration sensitivity. Wave slamming incidents were subsequently identified from the acceleration time histories. Whole-body vibration metrics were calculated for slamming events as per the methodology specified in ISO 2631-1 (ISO 2631-1, 1997). Concurrent to the engineering measurements, passengers were requested to complete a daily diary survey during a voyage in which they document sleep interference, disruption of motor activities, equipment damage and rate the worst slamming incident for that day if slamming occurred. Correlations between vibration metrics and survey responses of slamming severity were investigated and benchmarked to determine the best correlated metrics to human responses and how complaints corresponded to vibration magnitude.

2.1. Full scale measurements and voyage description

Fifteen accelerometers were mounted to structural girders of the investigated PSRV. Vertical acceleration was recorded as available space in the cable trays through water-tight ship sections limited the possible number of measurement channels. Earlier measurements by Bekker (2013) showed that wave slamming on the investigated vessel causes vertical, fore-aft and lateral excitation of the vessel structure, with the latter directions being about a third of the magnitude compared to vertical acceleration.

Three LMS SCADAS mobile data acquisition units were connected using fibre-optic cables and used in a master-slave configuration. Data was continuously acquired using LMS Test. Lab Turbine Testing software at a sample rate of 2048 Hz. The accelerometers included ICP (100 mV/g, Model: PCB333B32), DC (200 mV/g, Model: PCB3711B111OG) and seismic accelerometers (1000 mV/g, PCB393B12) as shown in Fig. 2 and Fig. 3. Data was continuously recorded and stored in 5 min data records.

Fig. 3 shows the placement of two sensors on structural girders on the port- and starboard side of the Bridge on Deck 9. An accelerometer was mounted towards the aft of the super-structure in the stairwell of Deck 8, which is the accommodation deck for the Captain and high-ranking ship officers. A further measurement was performed on accommodation Deck 5. Two sensors were placed on structural girders in the floor of the flat transom in the steering gear room on Deck 2 (Fig. 3). Towards the bow, two sensors each were placed at the stern thrusters and to the port-and starboard sides of the Central Measurement Unit (CMU) on Deck 3. A further four sensors measured acceleration in the corners of the Cargo hold towards the front of the super-structure on Deck 4. Finally, two sensors were placed in the Bow cargo space.

As the accommodation spaces on the vessel comprise Deck 4 to Deck 8, the accelerometers on Deck 5 and Deck 8 are likely to be the

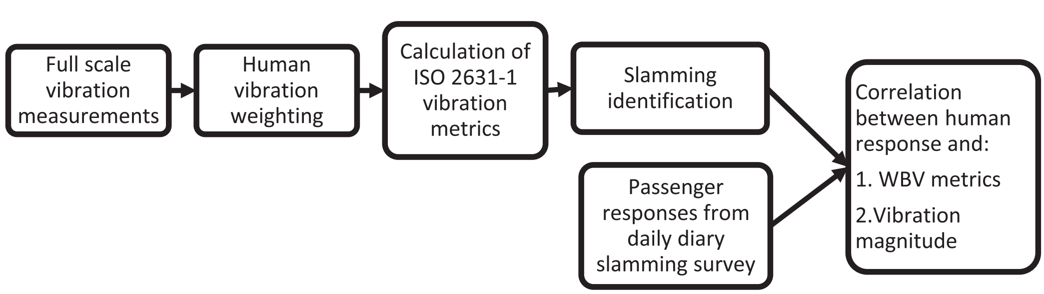

Fig. 1. Methodology for the assessment of human response to slamming vibration.