Review of the seakeeping criteria for the study of a passenger ship criteria in Indonesian water

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Abstract. The human sickness of the ship’s crews and passengers is considered as main requirements to be fulfilled in ship design stages which is related to the performance of ship motion when operating in seaway. This paper describe review some seakeeping criteria which are published by several institutions for the purpose of ship safety and comfort. Since these criteria were initially issued based on extreme sea conditions, it is necessary to study if they are applied to relatively moderate sea conditions in Indonesian. For this reason, a new approach is proposed to deal with a new criteria by measuring motions directly on the ship in operation. Briefly method is described as first, the ship motion in 6 degrees of freedom is measured by sensors which is installed in a particular place on the ship’s board, for which the data generated include an angular velocity, a vertical and a tranversal acceleration of motions. Second, Fast Fourier Transform (FFT) algorithm is adopted to process the measured data which are presented in the form of time series and spectrum diagrams, and the Power Spectral Density (PSD) method is also used to eliminate nois data. Third, the ship motion criteria for the case of the passenger ship is determined and it compare to the existing criteria.

1. Introduction
Ship motion at sea can disturb the balance of crew members and passengers making Motion Induced Interruptions (MII). MII can cause decreased energy and increase fatigue, increase drowsiness, dizziness and can even interfere with gastric awareness which results in motion sickness incidences (MSI) and more seriously causes vomiting incidents. Sickness conditions that occur on the crew of the ship are things that must be considered because it involves the safety of the ship during voyage. Antaço and Soares [3] explained that 60% of ship accidents occur in conventional ocean going ships and high speed craft were caused by human factors and were followed by equipment failure and environmental factors. According to Alert! [4], based on ship accident investigation reports, almost all ship accidents were caused by crew fatigue. Baker and Mc Cafferty’s opinion [5] that fatigue must be closely related to the decrease in awareness of the situation and also the human error that caused the accident. According to Allen et. al. [6], crews ship fatigue has been investigated in the maritime domain, where the factors that cause fatigue are as follows: lack of sleep, lack of rest due to limited time, poor sleep quality, vibration, room noise, ship motion, and high workload [4][7]. Haward [8] explained the main causes of sleep disorders were motion and noise. And motion can affect to decrease an operator performance and also safety [9].
Some suggestions have been given by related organizations for how to manage and reduce fatigue at sea during the ship's operation [4][7][10]. Proposed steps to be taken by passengers or crew include sleeping patterns, watching schedules, environmental manipulation, workload management, and food management. The ship design must consider to providing comfortable accommodation, minimizing vibration and noise, increase comfort in the room, and providing good work facilities to reduce workload.

Actually several regulations that support the human factor in ship design have been issued by the Classification Bureau. At least 93 documents have been identified as having relevance in dealing with human factors in relation to ship design [11][12] (see Table 1). And 30 documents have briefly explored the design requirements of a ship which are intended include Habitability, Ergonomics, Maintainability, Controllability, Workability, Survivability, Maneuverability, System Safety, and Occupational Health and Safety [11].

| Classification Institutions | Habitability | Ergonomics | Maintainability | Controllability | Workability | Survivability | Maneuverability | System Safety | Occupational Health and Safety |
|----------------------------|--------------|------------|----------------|----------------|-------------|--------------|----------------|---------------|-----------------------------|
| DNV                       | 18           | 1          | 0              | 1              | 7           | 6            | 3              | 3             | 11                          | 0             |
| ABS                       | 17           | 6          | 2              | 1              | 4           | 7            | 3              | 1             | 9                           | 3             |
| LR                        | 16           | 2          | 0              | 1              | 6           | 2            | 6              | 3             | 7                           | 1             |
| IMO                       | 27           | 2          | 2              | 1              | 8           | 6            | 11             | 3             | 14                          | 4             |
| ISO (CT8)                 | 13           | 7          | 0              | 0              | 2           | 3            | 4              | 0             | 2                           | 0             |
| ASTM                      | 2            | 1          | 2              | 1              | 1           | 2            | 1              | 0             | 2                           | 1             |

Total 93 17 6 5 28 25 29 10 45 9

Lloyd's Register (LR) [13] in 2008 had systematically issued references to human factors in ship design, such as: (i) Habitability, related to accommodation facilities that were of a standard and comfortable standard, including furniture and washing equipment, for example. Galley, Provisions under consideration regarding variations in room size, room shape, gender of seamen, and various causes of stress from the environment: heat, vibration and noise. (ii) Maintainability is a system for designing operational maintenance tasks to be safer, faster, and more effective, the goal being to improve the performance of equipment and systems. This system includes tool considerations, tool removal, access, operator expertise, and lifetime guarantee. (iii) Workability is a consideration that must be given to the operator, materials, usage procedures, tasks, equipment and including the software, and the environment in which the system is used. (iv) Controllability is designing a ship control center system which includes the design of an engine control room, design for a cargo control room, etc., a design can be in the form of integration between people or operators with equipment and systems such as communication equipment, control facilities, color or display in the form of text display, image or video. (v) Maneuverability is a form of ship maneuver system design that has the most precise and consistent maneuverability, the design of the system includes the ship's manning and operational patterns, the main driving machine, the steering system, and also its propulsion system. And (vi) Survivability is the provision of safety equipment in the form of adequate fire fighting facilities, rescue systems, damage control, and safety arrangements on board. In 2009 Lloyd's Register (LR) re-issued two additional factors related to human factors [14], such as: (i) occupational health and safety (OHS) is the protection of safety and welfare for workers, protection of work impacts, maintaining the work environment and protecting living conditions for health, (ii) Safety of the system is a risk consideration for people using the ship's system.
Guidelines and standards to improve the crew's habitability and comfort are ready applied on the ship by controlling environmental design and increasing the comfort rating of personnel, giving them time to sleep and rest better in order to improve the performance of these personnel. For crew comfort rating on board, the Det Norske Veritas (DNV) classification publishes additional comfort ratings divided into two groups: (i) noise rating and (ii) vibration rating with COMFV notation or COMF-C notation for room state notification [15]. For example DNV has divided into three comfort ratings: 1 (highest or very comfortable), 2 (moderate) and 3 (acceptable). For the measurement of noise rating regulated in the DNV classification must follow the ISO 2923 standard. The noise rating standards in DNV can be seen in table 2.

### Table 2: Noise level on accommodation in dB, referring to DNV 2009 [15]

| Location                  | Comfort Rating nr (crn) |
|---------------------------|-------------------------|
|                           | 1 | 2   | 3   |
| Wheel house               | 60| 60  | 65  |
| Crew cabins               | 50| 55  | 60  |
| Crew public spaces        | 55| 60  | 65  |
| Engine control room       | 70| 70  | 75  |
| Open deck recreation      | 70| 70  | 75  |

In addition, the classification of the American Bureau of Shipping (ABS) has also provided several standard guidelines covering comfort and habitability [16] [17]. This guide has five aspects of ship criteria and layout namely noise, lighting, vibration throughout the body, accommodation, and climate in the room. For ships that have met the minimum threshold guidelines for the five aspects will be given the HAB notation by the ABS classification while the HAB + notation for stricter livability eligibility criteria. To measure comfort levels ABS recommends noise level standards provided by the International Maritime Organization (IMO). ABS and IMO have published a framework for considering ergonomics and work environments on ships in order to reduce accidents or workplace abuses [18]. IMO has also issued guidelines on noise level limits on ships [19] which can be seen in table 3.

### Table 3: Noise level on board according to IMO 1981 [19]

| Noise Level Limits                        | dB(A) |
|-------------------------------------------|-------|
| Machinery space (continuously manned)     | 90    |
| Machinery space (note continuously manned)| 110   |
| Machinery control rooms                   | 75    |
| Workshops                                 | 85    |
| Non-specified work space                  | 90    |
| Normally unoccupied space                 | 90    |

2. Criteria of Ship motion performance

Research on the factors causing human sickness has been carried out by several researchers and institutions which then propose several criteria. The proposed criteria generally relate to restrictions on the behavior of ships when operating at sea in order to avoid the occurrence of human sickness on crew or passengers. A ship float in the high seas with 6 degrees of freedom [20] which are surge, sway, heave, roll, pitch, and yaw as shown in Figure 1. These motions can be grouped in rotational movements, i.e. the ship rotates with respect to the x, y and z axis (pitch, roll, yaw), and translational motion shifts on the ordinate axis.

Previous researches have discussion about a seakeeping or motions criteria of ship that is include Rumawas [21], Pattison and Sheridan [22], Ghaemi and Olszewski [23], Stevens and Parsons [24]. All their papers refer to the criteria of ship motion issued by the North Atlantic Treaty Organization.
(NATO) STANAG 4154, the Nordic Co-operative Organization for Applied Research (NORDFORSK), the US Coast Guard Cutter Certification Plan, and Tasaki. The seakeeping criteria include a maximum roll amplitude, a pitch amplitude, a vertical and a lateral acceleration of motions.

![Figure 1 Ship motion with 6 degree of freedom](image)

Table 4 show the operability criteria set by NATO STANAG [25]. Ship design must refer to the seakeeping criteria outlined in the table adjusting the area of operation of the ship and the type of ship.

| Personnel criteria limits (NATO STANAG 4154) [25] |
|-----------------------------------------------|
| **Rekommended Criteria** | **Limit** | **Location** |
| Motion sickness incidence (MSI) | 20% of crew @ 4 hrs | Task location |
| Motion induced Interruption (MII) | 1/m | Task location |
| **Default Criteria** | **Root mean square (RMS)** |
| Roll | 4° |
| Pitch | 1.5° |
| Vertical acceleration | 0.2 g | Bridge |
| Lateral acceleration | 0.1 g | Bridge |

The history related of NATO STANAG 4153 is written by Pattison and Sheridan [21]. Starting from the meeting of NATO subgroup 5 NG/6 in 1986, it was revealed that the navy found difficulties in the performance behavior of the crew during the study design. the next meeting made aware that some naval engineers were unable to effectively pursue the effects of the ship's movement on the crew. This organization understands the acceleration mechanism that causes a person to stumble incident, but cannot yet understand the implications of mental effects and physiological effects. To remedy this situation, protection experts who are now National Biotechnology Laboratories from the University of New Orleans, The New Orleans Bio Dynamics Laboratory (NBDL) at the American, British and Canadian Warship Operations Workshop (ABC-17) was invited to Halifax in late 1989. Fractional group in 1990, NATO made an experimental program planning on a ship motion simulator at NBDL. at the meeting the Dutch then joined the United States, Britain and Canada to form a naval group consisting of four countries, doctors, and behavioral scientists [21].

The results of the NATO meeting finally got an agreement on the criteria of the effect of ship motion on human performance. The criteria are defined into five factors as follows [21] such as (i) Motion induced interruptions (MII), (ii) Motion induced fatigue (MIF), (iii) Cognitive performance, (iv) Motion sickness incidence (MSI), and (v) Habituation.

In Table 5, the seakeeping criteria of NORDFORSK have been set for general operational restrictions on various types of vessels. Cretrian boundaries include the roll limit and the acceleration motion. For example in this criterion, the limitation of motion for fast small craft is to protect various types of personnel work for the movement of the roll limit of these criteria, such as Light manual
work, heavy manual work, intellectual work, transit passengers, and Cruise liners. The purpose of this criteria is to expect the effectiveness of human comfort.

Table 5 Seakeeping criteria according to NORDFORSK 1987 [26]

| General Operability Limiting Criteria for Ships | Marchant Ship | Navy Vessels | Fast Small Craft |
|------------------------------------------------|--------------|-------------|-----------------|
| RMS of vertical acceleration at FP             | 0.275 g (L ≤ 100 m) | 0.275 g | 0.65 g |
|                                                  | 0.050 g (L ≥ 330 m) |            |            |
| RMS of vertical acceleration at Bridge          | 0.15 g         | 0.20 g     | 0.275 g |
| RMS of lateral acceleration at Bridge           | 0.12 g         | 0.10 g     | 0.10 g |
| RMS of Roll                                    | 6.0 deg        | 4.0 deg    | 4.0 deg |
| Probability of slamming                         | 0.03 (L ≤ 100 m) | 0.03       | 0.03 |
|                                                  | 0.01 (L ≥ 330 m) |            |            |
| Probability of deck wetness                     | 0.05           | 0.05       | 0.05 |

Likewise for seakeeping criteria issued by the U.S. Coast guard cutter certification which contains roll / pitch movement criteria, at this time the seakeeping boundary is used by the US Navy and U.S. Coast Guard (USCG). Table 6 explains the criteria of MSI and MII with USN and USCG limits are equivalent, but in the table stated in different units, the NATO STANAG 4153 and NORDFORSK criteria use the root mean square (RMS) unit, while the US Coast Guart criteria uses the unit of amplitude single significant (SSA). Table 7 show the criteria of operability limitation for a ships introduced by Tasaki [23] that involve the probability occurrence of slamming, deck wetness and propeller emergence.

Table 6 Operability limiting criteria for ships according to USCG [23]

| Criterion                                      | Limit       | Location                      |
|------------------------------------------------|-------------|-------------------------------|
| Vertical acceleration                           | 0.4g SSA    | forward perpendicular         |
| Vertical acceleration                           | 0.2g SSA    | bridge                        |
| Lateral acceleration                            | 0.2g SSA    | bridge                        |
| Motion Sickness Incidence (MSI)                 | 5% in a 30 minute exposure | task location               |
| Motion Induced Interruption (MII)               | 2.1 tip per minute | task location               |
| Roll                                            | 8.0° SSA    |                               |
| Pitch                                           | 3.0° SSA    |                               |

Table 7 Operability limiting criteria for ships according to Tasaki [23]

| Criterion                                      | Limit       | Location                      |
|------------------------------------------------|-------------|-------------------------------|
| Vertical acceleration                           | 0.80g @ P=0.001 | forward perpendicular       |
| Lateral acceleration                            | 0.60g @ P=0.001 | bridge                        |
| Roll                                            | 25.0° @ P=0.001 |                               |
| Slamming (probability)                          | 0.01        |                               |
| Deck wetness (probability)                      | 0.01        |                               |
| Propeller Emergence (probability)               | 0.1         |                               |
3. Ship motion measurement

The methodology used in evaluating ship motion is by direct measurement on the deck of the ship by using the ADIS16364 sensor with 6 axis motion. This sensor is equipped with an accelerometer sensor (3 axis) and gyroscope sensor (3 axis) (sensor specifications: see table 5 and figure 2). To measure the roll and pitch motion used gyroscope while the vertical movement and lateral acceleration use the accelerometer sensor.

Placement of sensor measurement points according to NATO STANAG 4154 recommendations [25] Motion Sickness Incidence (MSI) and Motion Induced Interruption (MII) measurements are at the crew assignment location, vertical acceleration and lateral acceleration measurements in the bridge space while roll and pitch measurements are not determined but at this research was carried out measurements in the bridge room.

![ADIS16364 sensor](image)

**Figure 2 ADIS16364 sensor [27]**

| ADIS16364 specification |
|-------------------------|
| Triaxis digital gyroscope with | : +750/sec, +1500/sec, +3000/sec |
| Digital range scaling | |
| Tight orthogonal alignment | : <0.050 |
| Triaxis digital accelerometer | : +5.0g |
| Calibration temperature range | : -20°C to +70°C |
| Application | - Medical Instrumentation, |
| | - Robotics, |
| | - Platform controls, |
| | - Navigation. |

The data generated by ADIS16364 is in the form of angular velocity data generated by the gyroscope sensor to measure roll and pitch motion, in addition the data measured by the accelerometer sensor in the form of velocity to gravity is to measure vertical acceleration and tranversal acceleration movements. The results of field tests conducted by Rumawas [28] namely by direct testing above Offshore Supply Vessels (OSV), rotational speed is measured and recorded using the ADIS16364 sensor in degrees per second (deg / s), while vertical and lateral movements are accelerated in g-force (g). In his research the rotational speed is integrated into motion and presented in degrees (deg) which are recorded per 15 minutes and presented in the form of time series and spectrum diagrams, he uses the Fast Fourier Transform (FFT) algorithm and the result data is processed to eliminate irregular motion noise using Power Spectral Density (PSD) method with Matlab v 2012 [28] (see figure 3).
Furthermore, the statistical values for lateral and vertical acceleration are sought to obtain the RMS values according to table 6

![Figure 3 Lateral and vertical acceleration on OSV [28]](image)

**Table 6** Summary of lateral and vertical acceleration values using statistical analysis [28]

| Ship | Season | Lateral acc. | Vertical acc. [g] |
|------|--------|--------------|------------------|
|      |        | Lateral acc. | Vertical acc. [g] |
|      |        | Min         | Mean     | Max         | Min | Mean | Max | RMS |
| A    | summer | -0.076      | 0.010    | 0.098       | -0.149| -0.011| 0.153| 0.026|
| A    | winter | -0.269      | 0.002    | 0.263       | -0.720| -0.012| 0.562| 0.097|

![Figure 4 Lateral Acceleration During Survey](image)

McCauley and O’Hanlon have developed a formula to determine the value of motion sickness incidence (MSI), this formula is used to calculate the impact of ship movements on the percentage of personnel suffering from seasickness [14], the following is the formula:

\[
MSI = 100 \left[ 0.5 + \text{erf} \left( 2.5 \log_{10} \left( \frac{a}{g} \right) - \mu_{MSI} \right) \right]
\]  (1)
where, erf is an error function, to get erf according to the following formula:

$$\text{erf}(x) = \frac{1}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

(2)

**Figure 5** Survey results on OSVs in measuring MII and MSI values [28]

To achieve the representative criteria of ship motion for the Indonesia water, it is necessary to evaluate the motion of ships across three waters locations in Indonesia which have the characteristics of different waves, namely the Malacca Strait (the Indonesian sea at western), the Java sea (the central Indonesian sea), and the Banda sea (the Indonesian sea at eastern) (see figure 6).

**Notes:**
1. ★ : Indonesia’s sea area surveyed
2. ~ : surveyed route

**Figure 6** Survey area of the study
4. Conclusions

Seakeeping criteria which are widely used to evaluate a ship design performance in seaway is reviewed. Since the study limited on the passenger ship, the NORDFORSK 1978 criteria is suitable used in future study for cruise liner. The criteria was initially published based on North Sea conditions, so that necessary to study seakeeping criteria consider to the sea conditions in Indonesian. The direct measurement method is proposed to measure ship motion response in seaway. Fast Fourier Transform (FFT) algorithm is developed to identify the measured data, and the Power Spectral Density (PSD) method is adopted to eliminate noise data. This developed approach is expected to be suitable method in developing the seakeeping criteria of passenger ship in Indonesian water.

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