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Excessive Acceleration Criterion Applied to an Indonesia Ro-Ro Ferry

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ABSTRACT

Most Indonesian ro-ro ferries may vulnerable to excessive acceleration because the metacentric height generally more significant than 8% of ship breadth, and the passenger accommodation is located in a high position on superstructure above the vehicle deck. This paper discusses applying the Second Generation Intact Stability Criteria (SGISC) excessive acceleration criterion to an Indonesian ro-ro ferry. The results show that the ship complied with vulnerable to level 1 of excessive acceleration criteria. The ship was vulnerable to criteria level 1. The metacentric height for the ship passes level 1 was 1.60 meters for the crew accommodation and 1.70 meters for the executive passenger accommodation. The ship passes level 2 of excessive acceleration for all passengers and crew accommodations even using the wave scatter recommended by IMO if the metacentric height smaller than 5.89 meters.

Keywords: *excessive acceleration, ro-ro ferry, stability criteria, metacentric height*

1. INTRODUCTION

The new generation intact stability criteria address five stability failures in waves: dead ship condition, parametric rolling, pure loss of stability, surf riding/broaching-to, and excessive acceleration. A physical model was developed for each phenomenon, and a multi-layer approach was used to assess the vulnerability of a ship in three levels. A ship should not fail at least one of the three levels assessments for each loading condition. If the ship fails in level 1, the ship should be tested for the vulnerability criteria level 2. If the ship does not pass level 2 of vulnerability, then a direct stability assessment must be performed with a six-degree freedom simulation of ship behaviour in a seaway. The next step of the Second Generation Intact Stability Criteria is to provide operational guidance or operational limitation (Baccadamo and Rosano, 2019).

The investigation result of the accident triggered the excessive acceleration criterion onboard container ship CHICAGO EXPRESS in 2008 and CCNI Guayas in 2009 (Federal Bureau of Marine Casualty Investigation of Germany, 2008; 2011). The investigation of the accidents showed that a small roll period due to large metacentric height and low roll damping due to speed loss in waves lead to a large lateral acceleration of more than 1.0 of gravity acceleration, causing injuries and fatality. After the accidents, Germany submitted a document to IMO to include the excessive acceleration as a part of the SGISC (IMO, 2009). Sample calculations based on the draft criterion of excessive acceleration have been conducted for different ship type and dimension with different standard values for level 1 and level 2 criteria (IMO, 2015a; IMO, 2016). Some inconsistencies between level 1 and level 2 were found. Therefore, IMO determined the standard values for level 1 and level 2 to be adopted in the excessive acceleration criterion (IMO, 2018). The criterion was also determined the ship characteristics should be tested, namely a ship with passengers and crew accommodations located more than 70% of ship breadth above the waterline or to a ship with metacentric height larger than 8% of ship breadth (IMO, 2015b) for each loading condition. This requirement means that a ship with a high location of passengers and crew accommodations and a large metacentric height should be tested against the excessive acceleration criterion.

The Indonesian ro-ro ferries were characterized by breadth-to-draught ratio ranges between 3.0 to 8.0 (Paroka et al., 2020a). Most of the ships have a breadth-to-draught ratio larger than 3.50 that used a maximum ratio to develop the weather criterion. The ships were designed with a large breadth to fulfil the required deck area for vehicles. The ship's draught was smaller than the other ship type because most ferry ports in Indonesia with shallow water. As a result, the metacentric radius of the ships becomes larger. However, the vertical centre of gravity was large because all payload located above the main deck (the main deck is used as vehicle deck, and the passenger accommodation is located on the superstructure above the vehicle deck), the metacentric height of Indonesian ro-ro ferries mostly larger than the other ships types with similar dimension. Most Indonesia ro-ro ferries have a metacentric height larger than 8% of ship breadth. Some ships have a metacentric height larger than 30% of ship breadth. As a result, the natural roll period could be smaller than the minimum natural roll period given in the weather criterion of the International Maritime Organization (IMO), mainly for small ro-ro ferries (Paroka et al., 2021).

The Indonesian ro-ro ferries may vulnerable to excessive acceleration, mainly in the resonance frequency of roll motion. With a large metacentric height, the natural roll period becomes smaller. When the ship experiences a large roll angle, the angular velocity of roll motion could be largely due to the small roll period. The ship may lead to a large lateral acceleration lead to excessive acceleration. Cargo damage such as a car shift in the vehicle deck, which could lead to a significant static heeling angle, could occur due to the lateral acceleration. Excessive acceleration could also affect passenger comfort, mainly if the passenger accommodation is located in a higher position on the ship. Some cases of furniture damage on the passenger accommodation deck and a truck at the vehicle deck overthrown have been found in some accidents. Therefore, excessive acceleration becomes essential to evaluate to avoid cargo damage, a static heeling angle that can induce unstable condition to lead to capsizing and passenger comfort.

This paper discusses the measurement of the excessive acceleration of an Indonesian ro-ro ferry based on the Second Generation Intact Stability Criteria of IMO. The purpose is to identify whether the Indonesian ro-ro ferries vulnerable to excessive acceleration. This identification is important because mostly the Indonesian ro-ro ferries have large metacentric height. The height of passenger accommodation from the waterline may be larger than 70% of the ship breadth because passenger and crew accommodations of Indonesian ro-ro ferries are mostly located above the main deck (used as vehicle deck). The obtained results could be used to develop operational guidance, including a fastening method to avoid car movement at vehicle deck and designing the ships in the future, mainly to determine passenger and crew accommodation.

2. METHODOLOGY

2.1 Ship Data

An Indonesian ro-ro ferry built in an Indonesian shipyard was used as a sample ship in this paper. The principle dimension and the ship's general arrangement are shown in Table 1 and Figure 1, respectively. The ship was designed to load 15 trucks and six small cars on the vehicle deck with distribution, as shown in Figure 1. The passenger accommodation for 212 passengers was divided into three different locations of accommodations. An economic class with a sleeping bed facility for 96 passengers is located at a distance from the after perpendicular of 6.65 meters to 19.35 meters. An economic class with chairs for 84 passengers is located with distance from the after perpendicular between 21.41 meters and 30.05 meters. There is also an executive class with a sleeping bed for 32 passengers located between 35.18 meters and 39.65 meters from the after perpendicular. The superstructure for passenger accommodation is located above the vehicle deck with a height of 5.96 meters from the waterline. This distance is smaller than 70% of ship breadth. Detail about the location of passenger accommodation was shown in Figure 1.

Table 1. Ship principle dimension

Item	Dimension
Length (L_{pp})	47.25 m
Breadth (B)	13.00 m
Depth (D)	3.40 m
Draught (d)	2.40 m
Metacentric height (GM)	4.72 m
Service speed	12 knot

The crew accommodation was located in the superstructure above the passenger's accommodations with a height of 8.34 meters. This distance is also smaller than 70% of ship breadth. The distance from the after perpendicular ranges between 27.26 meters to 41.49 meters. Twenty-four persons of ship crew occupy this space.

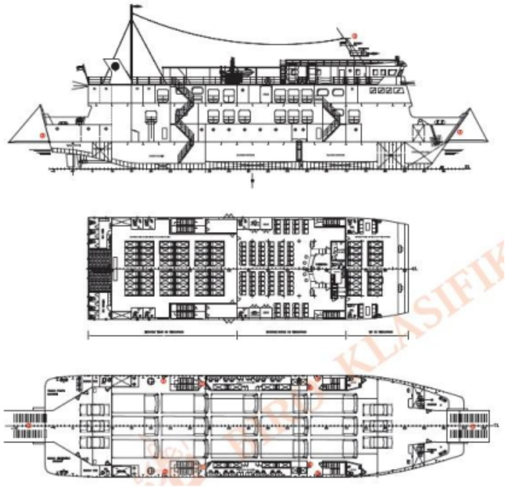

Figure 1. General arrangement

The natural roll period and the damping coefficients consist of linear and quadratic damping coefficients were determined by model experiment (Paroka et al., 2021). The non-dimensional logarithmic decrement of roll decay could be determined with two approaches. Here, the formulae proposed in the SDC 3/INF.11 (IMO, 2015b) was used even the result of roll decay test for the subject ship available. The effective wave slope coefficient for variation of wave frequency is calculated using the simplified Froude-Krylov moment with the assumption of a rectangular section of the ship hull. The cosine and sine parts of the Froude-Krylov wave exciting moment are determined under the assumption that the ship hull form is laterally symmetric (IMO, 2015b). The wet moment of inertia of roll was determined based on the radius gyration coefficient obtained by using the formula in the weather criterion (IMO, 2008). The equivalent linear damping coefficient was stochastically determined based on the linear and quadratic damping coefficients.

The vulnerability criteria level 1 and level 2 for excessive acceleration were calculated for several vertical centres of gravity. The wet roll moment of inertia, the linear and quadratic damping coefficients, was assumed to be independent of the vertical centre of gravity. However, the equivalent linear damping coefficient changes depending on the alteration of the natural roll period and the sea state. The calculations were conducted for different locations of passenger accommodation as well as the location of crew accommodation.

2.2 Wave data

The ship operates in one route of inter-island transportation in the eastern part of Indonesia. The route can be changed depending on the Ministry of Transportation of Indonesia policy. The stability condition, including the excessive acceleration of the ship, may vary due to different environmental conditions of the operation route. The wave condition of Indonesian seas could be lower than the wave scatter recommended by IMO to evaluate excessive acceleration. The wave steepness is also smaller than the wave steepness in the weather criterion of IMO (Paroka, 2014). However, general scatter wave data for the Indonesian sea has yet not been available recently. One of the most extreme sea states in the Indonesian seas is in the South China Sea, with scatter wave data has been published by Ogawa (2015). The other alternative scatters wave data that can be used for stability analysis is local scatter wave data for each ferry route. Data can be developed based on wave data recorded provided by Berrisford et al. (2019). In this paper, the vulnerability level 2 for excessive acceleration criteria was calculated based on the scatter wave data of IMO, and the wave data provided by Borrisford et al. correspond to the operation route of the subject ship. Table 2 showed the scatter wave data of a ferry route connecting Lombok Island and Flores Island.

Table 2. Scatter wave data of Lombok Street

H_s (m)	**T_z (second)**												
	6.64	**7.58**	**8.43**	**9.27**	**10.11**	**10.95**	**11.80**	**12.64**	**13.48**	**14.32**	**15.17**	**16.01**	**16.85**
0.57	0	17	13	6	6	5	0	0	0	0	0	0	0
0.72	1	25	114	146	193	73	23	2	0	0	0	0	0
0.86	12	112	288	452	575	382	191	60	9	1	0	0	0
1.00	15	211	459	753	789	627	435	182	32	6	3	0	0
1.14	18	235	541	798	814	674	487	263	78	25	3	0	0
1.29	16	137	490	684	737	561	363	249	129	36	12	3	0
1.43	8	68	267	510	536	413	306	157	80	35	33	4	0
1.57	10	32	121	249	320	306	244	134	43	26	8	8	0
1.72	2	15	58	104	124	157	138	109	52	20	11	7	1
1.86	1	13	34	50	30	68	73	62	34	12	8	5	1
2.00	0	11	14	20	13	28	32	33	24	13	1	1	0
2.15	0	6	12	13	6	3	5	11	15	11	3	1	0
2.29	0	0	10	5	1	0	1	0	6	4	4	1	0
2.43	0	0	4	4	0	1	0	1	0	1	1	0	0
2.57	0	1	1	2	0	0	0	0	0	0	3	0	0
2.72	0	0	0	2	1	0	0	0	0	0	0	0	0
2.86	0	0	0	0	0	0	0	0	0	0	0	0	0
3.00	0	0	0	1	0	0	0	0	0	0	0	0	0

3. RESULTS DISCUSSION

The vulnerability level 1 of excessive acceleration criteria for each passenger accommodation and crew accommodation is shown in Figure 2. The legend indicated by Pass_1 corresponds to the economic class of passenger accommodation with sleeping bed, Pass_2 designate the economic class of passenger accommodation with chairs, and Pass_3 corresponds to the executive class of passenger accommodation. The legend indicated by Crew is location crew accommodation. Here, the non-dimensional logarithmic decrement of roll decay was determined based on the formulae recommended by IMO (IMO, 2015b). The subject ship was vulnerable against level 1 criteria for all passenger accommodations and the location of crew accommodation. The ship would comply with the criteria if the metacentric height for full loading condition were 1.60 meters or 12.3% of ship breadth for the crew accommodation and 1.70 meters or 13.1% of ship breadth for VIP passenger accommodation with a sleeping bed. For the others passenger accommodations, the metacentric height corresponds to vulnerability criteria level 1 was larger than 1.70 meters. These metacentric heights were larger than the minimum metacentric height of ships recommended by IMO (IMO, 2015b) to test against excessive acceleration. This metacentric height is larger than that obtained by the vulnerability criteria level 1 for dead ship condition (Paroka et al., 2020b).

For the metacentric height of the subject ship in full loading condition, the lateral acceleration corresponds to the level 1 criteria was 7.92 for the crew accommodation and 7.33 for VIP passenger accommodation with a sleeping bed. These results show that the ship could vulnerable to excessive acceleration level 1 even the height of crew or passenger accommodations from the waterline is smaller than 70% of ship breadth, but the metacentric height of the ship is larger than 8% of ship breadth, mainly if the accommodation rooms are located in the forepart of the ship. The metacentric height of the subject ship was 36% of ship breadth.

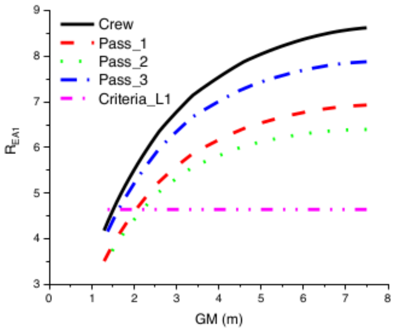

Figure 2. Vulnerability level 1 for passenger and crew accommodations

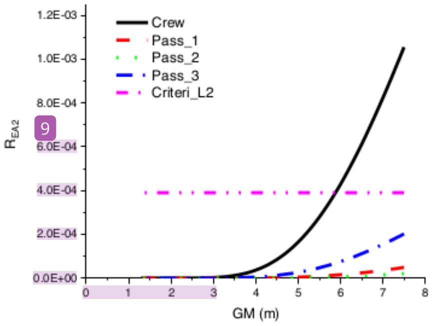

Figure 3. Vulnerability criteria level 2 for passenger and crew accommodations with wave data of IMO

Based on these results, the ship should be tested for the vulnerability criteria level 2 with results shown in Figure 3 for each crew and passengers accommodations, respectively. The ship complies with the criteria in full loading condition with a metacentric height of 4.72 meters. The minimum metacentric height for the crew accommodation vulnerable to level 2 is 5.89 meters. The long-term probability index for the passenger's accommodations is smaller than the minimum value of the long-term probability index for which the ship vulnerable to excessive acceleration for all tested metacentric height. These results showed consistency of level 1 and level 2 criteria.

A smaller value of the long-term probability index for excessive acceleration was obtained if the scatter wave data of the operational area of the ship shown in Table 2 is used. The long-term probability index with this wave data was shown in Figure 4. The ship was not vulnerable to excessive acceleration, even for the crew accommodation. The long-term probability indexes are very small compared to the minimum requirement values correspond to vulnerability due to excessive acceleration. A significant difference of long-term probability index due to wave data between the IMO recommended wave data, and the wave data of the ferry route was obtained. These results mean that the wave data play an essential role regarding the excessive acceleration criteria.

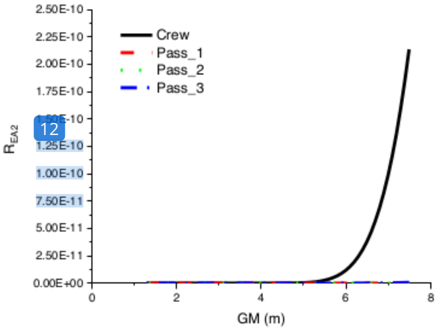

Figure 4. Vulnerability criteria level 2 for passenger and crew accommodations with wave data of Lombok Strait

Even the long-term probability index of excessive acceleration is smaller than the value determined in SGISC, excessive acceleration could occur in a particular wave characteristic, but the occurrence probability of such wave is very small. Therefore the long-term probability becomes small. Even the obtained probability is small, a short-term probability analysis for each combination of wave height and wave period seems to be essential to obtain the operational limits of the ship.

Figure 5 shows that the maximum wave height for each metacentric height with short-term probability is the same as the standard value of the long-term probability index for ship vulnerable to the excessive acceleration criteria level 2. Here, the mean wave period was calculated using Pierson-Moskowitz's formulae (Umeda and Yamakoshi, 1994).

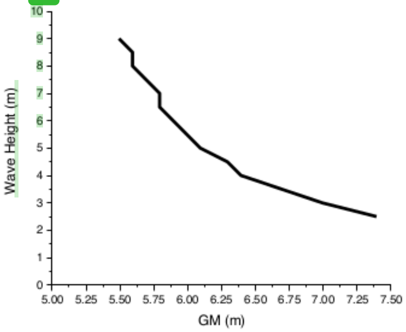

Figure 5. The limit of significant wave height corresponds to metacentric height.

The ship could be vulnerable to excessive acceleration when the significant wave height is larger than 2.0 meters if the ship's metacentric height becomes 7.39 meters. The wave height for the ship vulnerable due to excessive acceleration increases when the metacentric height decreases. The ship's metacentric height with a short-term probability of excessive acceleration larger than the standard value of long-term probability index given in SGISC is smaller than the metacentric height for full loading condition even for a significant wave height of 9.0 meters. Nevertheless, the ship may not be operated in such wave condition because the ship does not comply with other criteria, namely dead ship condition.

The non-dimensional logarithmic decrement of roll decay in criterion level 1 could be smaller than that obtained by a model experiment. Therefore, the metacentric height for the ship that complies with the level 1 criterion seems to overestimate compared to the metacentric height corresponds to the level 2 criterion. Therefore, the level 1 criterion should be tested using the non-dimensional logarithmic decrement of roll decay obtained by a model experiment. The other factor that should be considered regarding stability evaluation that corresponds to excessive acceleration is the effective wave slope coefficient and the damping coefficient, mainly for a ship with a small draught and large metacentric height. Figure 6 showed the effective wave slope coefficient for the level 1 and level 2 criteria obtained by the model experiment for resonance frequency.

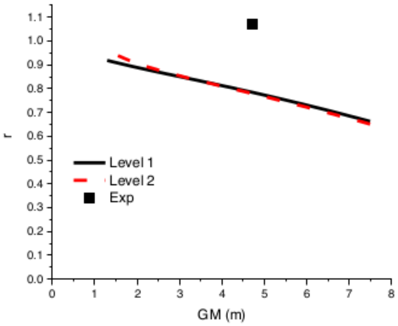

Figure 6. The effective wave slope coefficient

The effective wave slope coefficient for the level 1 and the level 2 criteria was smaller than that obtained by a model experiment. The minimum metacentric height for ship comply with the excessive acceleration criteria becomes smaller when the effective wave slope coefficient obtained by the model experiment is used (Paroka et al., 2021). However, the model experiment is impossible to conduct for all wave frequencies as required to calculate the long-term probability index of excessive acceleration in level 2 of the vulnerability criterion.

4. CONCLUSIONS

The excessive acceleration criteria of Second Generation Intact Stability Criteria has been applied to an Indonesian ro-ro ferry. Level 1 and level 2 of vulnerability to excessive acceleration have been calculated for three passenger accommodation and crew accommodation locations. The ship was vulnerable against the level 1 criterion, but the ship complies with the level 2 criterion. The minimum metacentric height for the ship complies with the level 1 criterion was 1.60 meters. This metacentric height is larger than 8% of ship breadth. The location of passengers and crew accommodation plays an essential role in the excessive acceleration criteria. Therefore, the placement of passengers and crew accommodation in the design of the Indonesian ro-ro ferry should consider the excessive acceleration criterion.

The ship could be vulnerable to excessive acceleration in a particular wave characteristic. Maximum wave height for the ship complies with the excessive acceleration criteria increases when the metacentric height decreases. The ship in full loading condition will vulnerable due to excessive acceleration if the ship operates in a significant wave height of 9.0 meters or larger, but it is impossible for the subject ship because the ship could fail in the other criteria.

The scatter wave data has a significant effect on the long-term probability of excessive acceleration. Therefore, scatter wave data correspond to Indonesian seas should be developed in the future considering the application of Second Generation Intact Stability Criteria to Indonesian ro-ro ferry. The present used scatter wave data ware provided only for one route of the ro-ro ferry.

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