The Effects of Side-Casings Balance on Open-Deck-Ro-Ro Vessels in Term of Intact Stability

Hasanudin ¹, A Zubaydi¹, W D Aryawan¹, I K A P Utama¹

¹Department of Naval Architecture, ITS, Surabaya, Indonesia

Abstract. Roll-on Roll-of (Ro-Ro) is one of the most favourite types of ship, which can carry passengers, cars, and cargoes at the same time. Reports from National Committee for Safety Transportation (KNKT) indicated that there is tendency of increase of Ro-Ro vessels accidents due to stability problems. The current paper discusses an Open-Car-Deck-Ro-Ro 40 m length without side-casings which capsized on Halmahera sea. The Ro-Ro was originally designed with side-casings on the right and left sides of car deck but removed to improve car deck capacity. The side-casings reduce one truck capacity, improve 72.539 GT, and improve survival stability. The Ro-Ro stability was calculated with four loading conditions with assumption weight and center gravity (KG) of the ship with and without side-casings the same. It shows all condition with added side-casings will increase righting lever GZ at angle ≥ 10°. Also, range righting lever curve GZ positive increase, at full load arrival 0°-29° become 0°-53°, at full load departure 0°-25° become 0°-42°, at ballast load arrival 0°-44° become 0°-66°, and at ballast load departure 0°-36° become 0°-52°. Then stability curves were assessed by Intact Stability Code 2008 (ISC 2008) obtained all load case ship with side-casings pass all criteria otherwise ship without side-casings fail especially area 30°-40° ≥ 0.03 m.rad and maximum GZ ≥ 25°. The case study indicates installed side-casings reduce cargo capacity but improve survival stability.

1. Introduction

The increase of world business system and the wide of sea exploration in the varying sea state need a lot of ships with varying type and size, thus increased ship accidents [1]. Significant ship accident occurred between 2011 and 2015, showed the accident increase from 1,750 cases into 3,300 cases and the trend decreased into 2,200 cases in 2018 [2]. Among others, cargo ships were in the top rank in the case of a ship accident, but most victims experienced by Ro-Ro vessels [3]. The International Maritime Organization (IMO) recorded the cause of ship accident: 40.3% grounding, 25.4% hull damage, 14.3% capsizing, 5% sinking, and 15% others. Causes of ship accident are generally attributed to technical failure, human error, poor management, and bad weather, and caused by combination sources in the same time [4] [5]. These conditions constitute challenges for naval architect engineers to improve ship design technology to reduce risk of ship accident.

Ro-Ro is the most favourite vessel, which can carry passengers, cars, and cargos in the same time. Ro-Ro are usually operated in rivers, straits, and between islands with small and medium distances mostly in developed countries [6]. There are two types of Ro-Ro ships, namely Close-Car-Deck-Ro-Ro (CCDR) for medium operation and Open-Car-Deck-Ro-Ro (OCNR) for medium-long operation. OCDR has lower Gross Tonnage (GT) than CCDR and conversely, CCDR has smaller survival ship stability than CODR because it has open car deck on the right and left sides of the hull, thus it has less the righting
lever curve GZ stability [7] [8]. To anticipate this handicap, OCDR is generally equipped with side-casings on the right and left sides of the hull [9].

The present paper discusses the use of side-casings to avoid ship accident such as OCDR without side-casings which capsize in Halmahera sea. The analysis included the increasing of GT, reduction of car capacity, and assessment of ship survival stability both without and with side-casings. The purpose of this study is to determine the effect of side casings on economic and technical aspects thus agreement between the two is achieved. A popular commercial software (MAXSURF) was used to model, calculate, and assess the survival intact stability.

2. Literature Studies

2.1. Buoyancy Principles
Ship as buoyancy body follows balance forces and moments law. The balance force is known as Archimedes’ law as balance with gravity force direction center of earth and buoyancy force direction opposite it. Displacement of ship consists of Light Weight Tonnes (LWT) and Dead Weight Tonnes (DWT). LWT components consists of the weight of steel, machinery, equipment, and outfitting, meanwhile DWT components consist of the weight of payload, fuel oil, lubrication oil, fresh water, consumable and crews. Balance force can be written Equation 1 as follows:

$$\Delta = \text{LWT} + \text{DWT}$$  \hspace{1cm} (1)

Displacement forces depend on ship hull under water line from base line until draught water line, from stem to stern. Displacements force can be written with Equation 2:

$$\Delta = \rho \cdot g \int_{0}^{L_{w}} B_M dT dL$$  \hspace{1cm} (2)

When centre of gravity and centre of buoyancy are not aligned, ship will rotate transversely called roll or rotate longitudinally called trim. At the time when centre of gravity is in front of centre of buoyancy, ship will be trimmed by stern, otherwise when centre of buoyancy is in front of centre of gravity, ship will be trimmed by stem. Nonetheless, propeller must always be under water during the ship operation.

2.2. Stability Principles
Even keel occurs when centre of gravity (G) and centre of buoyancy (B) are aligned. When ship gets excitation force / moment from side hull, the ship heel and B will move dependent on hull form under waterline. Vertical projection between G and B make distance known as the righting lever GZ line (Figure 1, left). After force / moment disappear, the ship will oscillate back to the start (ship stable). But if after force / moment disappear, the ship does not oscillate back to the start (ship unstable / will capsize). The righting lever curve GZ ship stability is calculated at every heel angle as shown in (Figure 1, right). Ship unstable is not permitted because will endanger cargoes, crews, and passengers [11].

![Figure 1. Ship stability principles](image)

GZ positive does not guaranty the ship safe from capsize risk. Rahola is the founding father trigger ship stability criteria make it with collected many data ship survival and ship capsizing. The criteria were
adopted by IMO and become intact stability standard applied in the world. Hereafter, Japan delegation added with weather criteria in the intact stability [12]. The criteria are known as ISC 2008 and applies to many types of ship. For passenger ship, the criteria is given in [13]:

- The area under the righting lever curve GZ shall not be less than 0.055 meter-radians up to \( \theta \geq 30^\circ \) angle of heel and not less than 0.09 meter-radians up to \( \theta \geq 40^\circ \) or the angle of down-flooding \( \leq \theta_0 \) if this angle is less than 40°. Additionally, the area under the righting lever curve GZ between the angles of heel of 30° and 40° or between 30° and \( \theta_0 \), if this angle is less than 40°, shall not be less than 0.03 meter-radians.
- The righting lever GZ shall be at least 0.2 m at an angle of heel equal to or greater than 30°.
- The initial metacentric height GM shall not be less than 0.15 m.
- The ability of a ship to withstand the combined effects of beam wind and rolling
- The angle of heel on account of crowding of passengers to one side as defined below shall not exceed 10°.
- The angle of heel on account of turning shall not exceed 10°.

2.3. Ship Tonnage Measurement

The first tonnage was introduced in 13th century to measure a country military strength indicator. Next tonnage function as foundation to collect tax base on cargo capacity. Moorsom introduced new system to calculate tonnage in the 19th century and his calculation system has spread to some country until 20th century. IMCO (at the time IMO) felt necessary to introduce single system to calculate tonnage which was applied in 1959. IMO held an international conference about this calculation system called International Convention on Tonnage Measurement of Ships 1969 (ICTMS 1966) which in force 18 July 1982. Over time tonnage use to select ship type, safety appliance requirements, crewing, and basic calculation ship insurance. There are two types of ship tonnage, namely Gross Tonnage function all included space volume and Net Tonnage function cargo volume and passengers in the ship. Gross Tonnage can be calculated as Equation 3 [14][15]

\[
GT = K_1 \cdot V
\]  

Where: V is included space volume in the ship. \( K_1 \) is coefficient which computed with logarithmic function include space in the ship. The coefficient can be calculated with Equation 4 [15].

\[
K_1 = 0.2 + 0.02 \log_{10} V
\]

Included space with opening for example Ro-Ro is calculated with special method. Car space with opening in front for opening in front and end so included space reduced with \( \frac{1}{2} \) ship breadth. Not fully opening in the side of hull with 1/3 height of space be included space reduced with \( \frac{1}{2} \) ship breadth too.

3. Case Study Data and Method

A case study of OCDR which capsize in Halmahera Indonesia water on the 16 August 2018 was used. Main dimension of the OCDR can be seen in Table 1:

| Item                      | Symbol | Unit     | Ship Dimensions |
|---------------------------|--------|----------|-----------------|
| Length Overall            | Loa    | meter    | 45.00           |
| Length Between Perpendicular | LBP   | meter    | 40.00           |
| Breadth Moulded           | B      | meter    | 11.0            |
| Depth Moulded             | H      | meter    | 3.20            |
| Summer Draught            | T      | meter    | 2.2             |
| Freeboard                 | Fb     | millimeter | 1000           |
| Gross Tonnage             | GT     | tonnage  | 401             |
| Net Tonnage               | NT     | tonnage  | 120             |
| Machinery Capacity        | HP     |          | 2 x 650         |

Table 1. Main dimensions of case study OCDR
In term of ship length this data include medium, B/T ratio height to carry car more in the deck, low draft to operate shallow water, freeboard has fulfilled calculation of International Load Line Convention 1966, GT calculation 401 and NT 120 base on ICTM calculation. The ship used two propellers with 2 x 650 HP. Because its length ≥ 20 m, GT ≥ 150 and Power ≥ 250 HP, the ship must be registered in domestic class. Hull form of the ship with side-casings and existing without side-casings are shown Figure 2. Under deck hull, both ships are the same, but different installation side-casings in the car deck: Figure 2 (left) is ship without side-casings and Figure 2 (right) is with side-casings. Height of side-casings is 2/3 of car deck to improve stability and minimize GT. Furthermore, stability analysis was carried out using ISC 2008 and GT analysis.

![Body plan without side-casings](image1)

![Body plan with side-casings](image2)

**Figure 2. Hull form of case study OCDR**

Stability calculation used four load cases: departure full load, arrival full load, departure ballast load and arrival ballast load, and shown in Table 2. The biggest displacement occurs in departure full load and smallest displacement in the arrival ballast load. When the ship departure, all tanks are full load 100% and when arrival the remaining tanks are 10%. It influences the free surface moment and increases KG. Free surface calculation has been stated in ISC 2008 [13]. Centre of passengers crowded is calculated at 3.5 meter of centre line and exactly in master point. The paper assumes weight (W) and center of gravity (KG) of OCDR with and without side-casings are the same, because side-casings are constructed by light material such as the polyurethane foam covered by HPE.

**Table 2. Load-case conditions of case study OCDR**

| Item        | Load-case 1: Full load Departure Mass (Ton) | Load-case 2: Full load Arrival Mass (Ton) | Load-case 3: Ballast Departure Mass (Ton) | Load-case 4: Ballast Arrival Mass (Ton) |
|-------------|---------------------------------------------|------------------------------------------|------------------------------------------|-----------------------------------------|
| LWT         | 474.100 KG (m)                              | 474.100 KG (m)                           | 474.100 KG (m)                           | 474.100 KG (m)                          |
| Consumable  | 2.700 KG (m)                                | 2.700 KG (m)                             | 2.700 KG (m)                             | 2.700 KG (m)                            |
| Passengers  | 23.550 KG (m)                               | 23.550 KG (m)                            | 0.000 KG (m)                             | 0.000 KG (m)                            |
| Trucks      | 140.000 KG (m)                              | 140.000 KG (m)                           | 0.000 KG (m)                             | 0.000 KG (m)                            |
| W.B.T 1 (P) | 0.000 KG (m)                                | 0.000 KG (m)                             | 20.689 KG (m)                            | 20.689 KG (m)                           |
| W.B.T 1 (S) | 0.000 KG (m)                                | 0.000 KG (m)                             | 20.689 KG (m)                            | 20.689 KG (m)                           |
| F.O.T (P)   | 23.642 KG (m)                               | 23.642 KG (m)                            | 23.642 KG (m)                            | 23.642 KG (m)                           |
| F.O.T (S)   | 23.642 KG (m)                               | 23.642 KG (m)                            | 23.642 KG (m)                            | 23.642 KG (m)                           |
| F.W.T (P)   | 29.723 KG (m)                               | 29.723 KG (m)                            | 29.723 KG (m)                            | 29.723 KG (m)                           |
| F.W.T (S)   | 29.723 KG (m)                               | 29.723 KG (m)                            | 29.723 KG (m)                            | 29.723 KG (m)                           |
| W.B.T 2 (P) | 0.000 KG (m)                                | 0.000 KG (m)                             | 23.184 KG (m)                            | 23.184 KG (m)                           |
| W.B.T 2 (S) | 0.000 KG (m)                                | 0.000 KG (m)                             | 23.184 KG (m)                            | 23.184 KG (m)                           |

Displacement:

| Item | Load-case 1: Full load Departure Mass (Ton) | Load-case 2: Full load Arrival Mass (Ton) | Load-case 3: Ballast Departure Mass (Ton) | Load-case 4: Ballast Arrival Mass (Ton) |
|------|---------------------------------------------|------------------------------------------|------------------------------------------|-----------------------------------------|
| LWT  | 747.080 KG (m)                              | 651.023 KG (m)                           | 671.275 KG (m)                           | 575.218 KG (m)                          |
| KG   | 4.338 KG (m)                                | 4.338 KG (m)                             | 4.338 KG (m)                             | 4.338 KG (m)                            |
| KG + KG_{fs} | 5.277 KG (m)                              | 5.277 KG (m)                             | 4.749 KG (m)                             | 4.749 KG (m)                            |
| LCG  | 19.207 KG (m)                               | 19.142 KG (m)                            | 19.610 KG (m)                            | 19.603 KG (m)                           |

In this work, a novel way to compare the problem car deck capacity and ship stability of OCDR with and without side-casings are presented. The methodology to solve the problem is shown in Figure 3.
Figure 3 describes the stages of methodology: First, collecting data of principal dimensions and general arrangement, lines plan and stability booklet, which were obtained from KNKT. Second, analysing car deck capacity by re-arrangement truck on OCDR with and without side casings. Third, calculating and analysing the righting lever curve (GZ) stability of OCDR with and without side casings. Fourth, assessing the criteria using ISC 2008 from IMO. Fifth, comparing both economic and technical aspects. Finally, conclusions can be drawn together with suggestions on the use of side casings both in the contexts of techno-economy.

4. Discussion

4.1. Analysis of Car Deck Capacity
Cars capacity is the biggest income compared to passenger and cargoes of OCDR, especially in the developing countries. OCDR without side-casing has wider car deck area so that can improve the cars capacity and income. Original general arrangement of ship without side-casings can be seen in Figures 4 and 5.
To improve safety side-casings are added on original ship with 1.25 m breadth, 1.6 m height and alongside of car deck as shown in Figure 6 (red hatch line car deck side view). When shown from top view side-casings drawn inside of left and right on the car deck, it can be seen in Figure 7.

Figure 5. Top view of OCDR without side-casings with full cars capacity

Figure 6. Side view of OCDR with side-casings with full cars capacity

Figure 7. Top view of OCDR with side-casings with full cars capacity

Compare Figure 5 and 7 above, the ship with side-casings only carry six medium truck less one truck than without side-casings. Decrement one truck situates on row number three on centre car deck. Decrement one truck will reduce 16.6 % income of the Ro-Ro. OCDR without side-casings more profitable than with side-casings.

4.2. Analysis of Tonnage Measurement

Enclosed space addition only extra side-casings on left and right-side car deck. GT is calculated by ICTMS 1966 (Equations 3 and 4) volume of side-casings were calculated based on Figures 6 and 7 (red hatch line) that is 291 m$^3$. First, its volume will be used to calculate a coefficient as following:

$$K_1 = 0.2 + 0.02 \log_{10} 291 = 0.249 \quad (5)$$

using Equation (6):

$$GT = 0.249 \cdot 291 = 72.54 \quad (6)$$

Result calculation shown Equation 6 with added side-casings can improve 72.54 GT so that become 473.54 GT, if the value GT is changed to percentage become 14.5% compared with side-casings. It will influence additional to tax to be paid in the port. OCDR without side-casings are more profitable than that with side-casings.
4.3. Ship Stability Analysis

This section discussed analysis of ship stability with and without side-casings with four conditions: departure full load, arrival full load, departure ballast load and arrival ballast load. Furthermore, each side-casings and condition will assess survival intact stability with ISC 2008. One criterion fails to satisfy ISC 2008 meaning that the ship has high risk to capsize, and if more than one criterion fails, the condition become worse. Each stability calculation with loading condition was described as follows:

4.3.1. Ship Stability Analysis with Departure Full Load

The fist OCDR was analysed on load case 1 full load departure, the load case can be obtained in Table 2 columns 2-3 for the ship without and with side-casings. It was assumed that weight of both ships is the same. Results of stability calculation can be seen in Figure 8 (left is the righting lever curve GZ and right is value calculation).

![Figure 8. The righting lever curve GZ of OCDR stability at full load departure condition](image)

| Angle (deg.) | GZ (m) |
|--------------|--------|
| A            | B      |
| 0            | 0      |
| 5            | 0.12   |
| 10           | 0.243  |
| 15           | 0.299  |
| 20           | 0.252  |
| 25           | 0.132  |
| 30           | -0.039 |
| 35           | -0.245 |
| 40           | -0.471 |
| 45           | -0.707 |
| 50           | -0.946 |
| 55           | -1.184 |
| 60           | -1.416 |
| 65           | -1.641 |
| 70           | -1.856 |
| 75           | -0.874 |

Table 3. Survival assessment of OCDR stability at full load departure condition

| Criteria | Unit | IMO’s Criteria | Without Side-casings (A) | With Side-casings (B) | (A) and (B) Comparison |
|----------|------|----------------|--------------------------|-----------------------|------------------------|
| Area 0° to 30° | m.rad | 0.055 ≤ | 0.0921 Pass | 0.2045 Pass | 54.96% |
| Area 0° to 40° | m.rad | 0.090 ≤ | 0.0921 Pass | 0.3165 Pass | 70.90% |
| Area 30° to 40° | m.rad | 0.030 ≤ | 0.0003 Fail | 0.112 Pass | 99.73% |
| Angle of max GZ | deg | 25.00 ≤ | 15 Fail | 30.5 Pass | 50.82% |
| Initial GMo | meter | 0.150 ≤ | 1.358 Pass | 1.429 Pass | 4.97% |
| Passenger crowding | deg | 10 ≥ | 5.4 Pass | 5.2 Pass | 3.70% |
| Turning angle | deg | 10 ≥ | 1.8 Pass | 1.7 Pass | 5.56% |

Table 3 above the first column is number assessment, the second column is unit, the fourth column is actual ship stability with side-casings, the sixth column is actual ship stability with side-casings and the end is comparison stability between ship with and without
side-casings. In the assessment if ship stability values satisfy ISC 2008 IMO written “pass” and opposite written “fail”. Value A and B can be compared as follows:

\[
Comparison = \frac{Value\ B - Value\ A}{Value\ A} \times 100\%
\]  

(7)

Result calculation, OCDR with side-casings satisfy all ISC 2008 criteria, but OCDR without side-casings two criterial fail satisfy that is: area criteria (3) with value 0.0003 m.rad < 0.030 m.rad and maximum heel angle GZ (2) 15° < 25°. From stability value comparison, installed side-casings will increase 99.73% area 30°–40°, 70.9%, area 0°–40°, 54.96% area 0°–30°, 50.82% angle of maximum GZ, 3.70% GMo, reduce 3.7% moment passenger crowding and reduce 5.56% turning angle.

4.3.2. Ship Stability Analysis with Arrival Full Load

The second OCDR was analysed on load case 2 full load arrival can be got on Table 2 column 4-5 for the ship with and without side-casings. Results of stability calculation can be showed in the Figure 9 left is the righting lever curve GZ curves and right is value calculation.

Figure 9. The righting lever curve GZ of OCDR stability at full load arrival condition

Figure 9 has lower curves than Figure 8 at the same scale, because centre of gravity increases with reduce fuel oil, fresh water, consumable for operation and the tank location in the bottom. The tank capacity assumption 10% left at this condition, this is will generate free surface moment thus increase KG. Comparison curve B ship with side-casings higher than curve A without side-casings, both the curves have the same heel angle <10° but upper the angle a curve A drastically up than curve B. Range of heel angle B 0°–42° almost one half time than curve A 0°–25°, both A and B curves have positive value but need assessing survival intact stability level ISC 2008 as following:

Table 4. Survival assessment of OCDR stability at full load arrival condition

| Criteria                          | Unit   | IMO’s Criteria | Without Side-Casings (A) | With Side-Casings (B) | (A) and (B) Comparison |
|-----------------------------------|--------|----------------|--------------------------|-----------------------|------------------------|
| Area 0° to 30°                    | m.rad  | 0.055 ≤        | 0.0544 Fail              | 0.1218 Pass           | Pass                   |
| Area 0° to 40°                    | m.rad  | 0.090 ≤        | 0.0544 Fail              | 0.1632 Pass           | Pass                   |
| Area 30° to 40°                   | m.rad  | 0.030 ≤        | 0.0009 Fail              | 0.0415 Pass           | Pass                   |
| Angle of max GZ                   | deg    | 25.00 ≤        | 15.5 Fail                | 25 Pass               | Pass                   |
| Initial GMo                       | meter  | 0.150 ≤        | 0.809 Pass               | 0.881 Pass            | Pass                   |
| Passenger crowding                | deg    | 10 ≥           | 9.8 Pass                 | 9.4 Pass              | Pass                   |
| Turning angle                     | deg    | 10 ≥           | 3.5 Pass                 | 3.2 Pass              | Pass                   |
Table 4 above OCDR with side-casings satisfy all ISC 2008 criteria but OCDR without side-casings four criteria fail that is: criteria (1) value 0.0544 m.rad, criteria (2) value 0.0544 m.rad, criteria (3) value 0.0009 m.rad, and maximum GZ (4) value 15.5° lower than criteria of ISC 2008 IMO. From stability value comparison, installed side-casings will increase 78.31% area criteria (3), 66.67% area criteria (2), 55.34% area criteria (1), 38.00% angle criteria (4), 8.17% GMo criteria (5), reduce 8.57% angle criteria (7) and reduce 4.08% angle criteria (6).

4.3.3. Ship Stability Analysis with Departure Ballast Load

The third OCDR was analysed on load case 3 full load departure can be got on table 2 column 6-7 for the ship with and without side-casings. Results of stability calculation can be showed in the Figure 10 left is the righting lever curve GZ curves and right is value calculation.

![Figure 10. The righting lever curve GZ of OCDR stability at full load ballast condition](image)

Figure 10 has higher curves than Figure 8 at the same scale, because OCDR ballast load departure without cars and passengers so that displacement is small, and KG is small too. Comparison curve A ship without side-casings higher than curve B with side-casings, both the curves have the same heel angle <10° but upper the angle a curve A drastically up than curve B. Range of heel angle A 0°~44° almost one half times than curve B 0°~66°, both A and B curves have positive value but need assessing survival intact stability level ISC 2008 as following:

| Angle (deg.) | GZ (m)   |
|--------------|----------|
|              | Without Side Casings (A) | With Side Casings (B) |
| 0            | 0         | 0                  |
| 5            | 0.198     | 0.198              |
| 10           | 0.403     | 0.402              |
| 15           | 0.595     | 0.614              |
| 20           | 0.673     | 0.82               |
| 25           | 0.64      | 0.984              |
| 30           | 0.522     | 1.067              |
| 35           | 0.355     | 1.087              |
| 40           | 0.159     | 1.019              |
| 45           | -0.055    | 0.864              |
| 50           | -0.28     | 0.668              |
| 55           | -0.509    | 0.465              |
| 60           | -0.74     | 0.251              |
| 65           | -0.968    | 0.022              |
| 70           | -1.192    | -0.223             |

Table 5 above OCDR with side-casings satisfy all ISC 2008 criteria but OCDR without side-casings one criteria fail that is: maximum GZ (4) value 15.5° lower than criteria of ISC 2008 IMO. From stability
value comparison, installed side-casings will increase 67.29% area criteria (3), 38.71% angle maximum GZ criteria (4), and 21.45% area criteria (1).

4.3.4. Ship Stability Analysis with Arrival Ballast Load
The fourth OCDR was analysed on load case 4 full load departure can be obtained in Table 2 columns 8-9 for the ship with and without side-casings. Results of stability calculation can be seen in Figure 11 left is the righting lever curve GZ curves and right is value calculation.

Figure 11. The righting lever curve GZ of OCDR stability at ballast arrival condition

Figure 11 has lower curves than figure 8 at the same scale, because centre of gravity increases with reduce fuel oil, fresh water, consumable for operation and the tank location in the bottom. The tank capacity assumption 10% left at this condition, this will generate free surface moment so increase KG. Comparison curve A ship without side-casings higher than curve B with side-casings, both the curves have the same heel angle <15° but upper the angle a curve A drastically up than curve B. Range of heel angle A 0°~36° almost one half time than curve B 0°~52°, both A and B curves have positive value but need assessing survival intact stability level ISC 2008 as following:

| Criteria | Unit | IMO’s Criteria | Without Side-casings (A) | With Side-casings (B) | (A) and (B) |
|----------|------|----------------|--------------------------|-----------------------|-------------|
| Area 0° to 30° | m.rad | 0.055 ≤ 0.192 | Pass 0.2308 Pass | 16.81% |
| Area 0° to 40° | m.rad | 0.090 ≤ 0.2089 | Pass 0.339 Pass | 38.38% |
| Area 30° to 40° | m.rad | 0.030 ≤ 0.0169 | Fail 0.1082 Pass | 84.38% |
| Angle of max GZ | deg | 25.00 ≤ 20 | Fail 27.3 Pass | 26.74% |
| Initial GMo | meter | 0.150 ≤ 1.808 | Pass 1.808 Pass | 0.00% |
| Passenger crowding | deg | 10 ≥ 0 | Pass 0 Pass | 0.00% |
| Turning angle | deg | 10 ≥ 1.4 | Pass 1.4 Pass | 0.00% |

Table 6. Survival assessment of OCDR stability at ballast arrival condition

Table 6. above OCDR with side-casings satisfy all ISC 2008 criteria but OCDR without side-casings two criteria fail that is: criteria (2) value 0.0169 m.rad, and angle of maximum GZ criteria (4) 20° lower than criteria of ISC 2008 IMO. From stability value comparison, installed side-casings will increase 84.38% area criteria (3), 38.38% area criteria (2), 26.74% area criteria (4), and 16.81% area criteria (1).
Conclusions
Tonnage analysis was carried out using ICTM-1966 and stability was assessed using ISC 2008. Furthermore, many comparisons were made out for OCDR without and with side casing. The conclusions were drawn as:

- Added side-casings on OCDR will decree one truck so that will reduce 16.6% income of the OCDR. Also, will improve 72.54 GT so become 473.54 GT, if the value GT is changed to percentage become 14.5% capered with side-casings. It will influence additional tax to be paid in the port.
- Opposite with economical loss, added side-casings improve the righting lever curve GZ. Ship with side-casings has the righting lever curve GZ higher and wider than without side-casings, both the curves have the same heel angle <10° but upper the angle a curve with side-casings drastically up than curve without casings. Largest GZ curve at ballast load departure with side-casings and smallest GZ curve at full load arrival. Beside side-casings the other components which influence GZ curve that is: cars, passengers, and tanks.
- From assessment OCDR with side-casings all condition load case conditions satisfy IS 2008. The opposite result shows OCDR without side-casings none loading condition satisfy IS 2008. One criterion fails mean the ship has high risk to capsize moreover more than one criterion, proven the OCDR without side-casings capsize in Halmahera Sea at Indonesia 16th august 2018.
- Based on the result of study, the reseacher puts some suggestions to the following: Side-casings must be installed ODCR ship on left and right on the car deck to increase stability. ODCR without side casings is dangerous if any must prove to meet the 2008 ISC criteria.

Acknowledgements
The authors would like to express their sincere gratitude to Mr Aleik Nurwahyudi from the National Committee for Safety Transportation (KNKT) for providing valuable data and constructive discussion during the preparation of the paper.

References
[1] Z. Zhang and X.-M. Li, “Global ship accidents and ocean swell-related sea states,” Nat. Hazards Earth Syst. Sci., vol. 17, no. 11, pp. 2041–2051, Nov. 2017.
[2] EMSA, “Annual Overview Of Marine Casualties And Incidents 2019.” European Maritime Safety Agency, 2019.
[3] IMO, “IMO and Ro-Ro Safety,” 1997.
[4] O. Ugurlu, U. Yildirim, and E. Yuksekyildiz, “Marine accident analysis with GIS,” J. Shipp. Ocean Eng., vol. 3, no. 1–2, p. 21, 2013.
[5] H. Kim, S. Haugen, and I. B. Utne, “Assessment of accident theories for major accidents focusing on the MV SEWOL disaster: Similarities, differences, and discussion for a combined approach,” Saf. Sci., vol. 82, pp. 410–420, 2016.
[6] A. Nurwahyudy, “Contemporary issues in domestic RO-RO passenger ferry operation in developing countries,” World Marit. Univ., 2014.
[7] B. H. Iskandar, N. Umeda, and M. Hamamoto, “Capsizing probability of an Indonesian Ro-Ro passenger ship in irregular beam seas (second report),” J. Soc. Nav. Archit. Jpn., vol. 2001, no. 189, pp. 31–37, 2001.
[8] Hasanudin, I. K. Utama and J.-H. Chen, “Application Side-casings on Open Deck Ro-Ro to Improve Ship Stability,” in IOP Conference Series: Earth and Environmental Science, 2018, vol. 135, p. 012017.
[9] S. Anggoro, *Analysis of the Intact Stability of Indonesian Small Open-deck Roll-on/Roll-off Passenger Ferries*. University of New South Wales master’s thesis, 2008.

[10] A. Francescutto and A. D. Papanikolaou, “Floatability and Stability of Ships: 23 Centuries after Archimedes,” in *The Genius of Archimedes -- 23 Centuries of Influence on Mathematics, Science and Engineering*, vol. 11, S. A. Paipetis and M. Ceccarelli, Eds. Dordrecht: Springer Netherlands, 2010, pp. 277–288.

[11] Hasanudin and J.-H. Chen, “Modification of the Intact Stability Criteria to Assess the Ship Survivability from Capsizing,” *Procedia Earth Planet. Sci.*, vol. 14, pp. 64–75, 2015.

[12] P. Ruponen, “Rahola criterion revisited: an overview of Jaakko Rahola’s research and career,” in *Proceedings of the 17th International Ship Stability Workshop ISSW2019, Helsinki, Finland*, 2019, pp. 15–20.

[13] IMO, *International Code on Intact Stability 2008*. London.

[14] A. Vasudevan, “Tonnage measurement of ships: Historical evolution, current issues and proposals for the way forward,” 2010.

[15] IMO, *International Convention on Tonnage Measurement of Ships, 1969*. London, 1966.