

Application Side Casing on Open Deck RoRo to Improve Ship Stability

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Abstract. RoRo is a vessel that can transport passengers, cargo, container and cars. Open Car Deck is favourite RoRo Vessel in developing countries due to its small GT, small tax and spacious car deck, but it has poor survival of stability. Many accident involve Open Car Deck RoRo which cause fatalities and victim. In order to ensure the safety of the ship, IMO had applied intact stability criteria IS Code 2008 which adapted from Rahola's Research, but since 2008 IMO improved criteria become probabilistic damage stability SOLAS 2009. The RoRo type Open Car Deck has wide Breadth (B), small Draft (D) and small freeboard. It has difficulties to satisfy the ship's stability criteria. Side Casings which has been applied in some RoRo have be known reduce freeboard or improve ship's safety. In this paper investigated the effect side casings to survival of intact dan damage ship's stability. Calculation has been conducted for four ships without, existing and full side casings. The investigation results shows that defect stability of Open Deck RoRo can be reduce with fitting side casing.

1. Introduction

RoRo vessel is the most successful ship which able to carry passenger, goods and vehicles at same time. Besides the flexibility of the cargo, this type of vessel also able to operate in river, strait and even sea. This type of vessel also equipped with ramp door installed in after, side or forward of the hull as the entrance of the payload. The first RoRo was used in 1891 to carry train crossing strait which not connected with bridge. The first RoRo was equipped with rail which connected to a pier [1]. In Second World War, the principal of RoRo vessel was used to carry tank and other fighting vehicles as landing craft. The extreme popularity of RoRo was occurred during 1940 to early 1950s, RoRo used as short route ferry which pushes the development of land and sea transportation. Until 1994, there are 4,600 RoRo vessel to serve vehicles, mix of container and vehicles [2].

There are several problems of RoRo vessel, those are: lack of watertight, stability, low freeboard, safety of cargo, safety equipment and crew safety [2]. IMO has applied detail many rules such as SOLAS, MARPOL, MEPC, ILLC etc [3]. Nevertheless, there are still numerous accident occurred. Based on the accident data of ship with size >150GT from 1993-2013. The data shows averagely 150 ship lost each year. General cargo provides the highest contribution, it contributes 42% and RoRo vessel contributes 6% from total accident [4] [5]. however based on casualties data, the RoRo vessel accidents demand 1/3 of total loss of lives due to ship accidents [2]. The accident data also stated that more than 70% of RoRo accidents is collision case which followed by the capsized of the vessel less than 10 minutes [2].

Small size RoRo are mostly operated in archipelagic country to connect its spread islands [6]. Open deck RoRo vessel is the highest number of RoRo type which used by archipelagic country. The car deck in RoRo is designed open to reduce GT in order to decrease tax, also decrease usage of ventilation. There are numerous bad records of this vessel which taken loss of lives and goods due to lack proper application of safety standard [7]. Defect stability and damage compartments are the main factors of the sink of RoRo vessel. Also, the economical perspective of small GT become the contributor also. IMO has issued IS Code 2008 for intact stability and SOLAS 2009 which affect for cargo and passenger including RoRo vessel. If this regulation must be applied for developing country, there will be a lot of existing vessel must be



grounded which may lead to huge economical loss[8]. This paper studies the solution for the existing vessel by modification of side casing by the point of view of ship stability.

2. Literature Review

The theory of buoyancy is believed introduced by Archimedes in 300 BC. The principle of floating object in water is developed as ship stability [9]. The research of stability criteria was introduced by Rahola in 1939 which studies asses' ship accident due to of flaw of stability. Based on the statistical data of capsized survived ship, an analysis are made and resulting criteria of safe stability. The basic of determination of dynamic stability is 40° roll. This Rahola criteria still not accounted the importance of hydrodynamic characteristic of vessel such as seakeeping. This criteria are based on coaster ship which sails in Baltic Sea. However, it is very popular among regulators. GL has adopted this Rahola criteria for its battle ship after World War 2. Even though this Rahola criteria was developed for special ship, but this criteria affects stability criteria widely [10] [11].

2.1. Intact Stability

The next step, IMO adopted the principal of Rahola criteria to measure the survival of intact stability [10] [12]. In 1948 IMO introduced regulation of intact stability which compiled in SOLAS'48 recommendation annex D, in 1960, SOLAS applied the first regulation of intact stability. In 1968 a regulation of stability are made based on righting arm and in 1985 the weather factors are adopted in intact stability criteria [13] [14]. The purpose of IS Code is to prevent ship capsized (from point of view MG and GZ area), the survivability of ship in bad weather, avoiding excessive free surface effect and guarantee the integrity of compartment watertight [15].

IS Code 2009 is applied for passenger ships, oil tanker of 5000 dwt and above, cargo ships carrying timber on its deck, cargo ships carrying grain in bulk and high speed craft. Special IS code 2009 criteria can be applied to Passenger ships, Oil tankers of 5,000 dwt and above, Cargo ships carrying timber deck cargoes, Cargo ships carrying grain in bulk and High-speed craft. There are specific criteria recommended for Fishing vessels, Pontoons, Containerships greater than 100 m, Offshore supply vessels, Special purpose ships, and Mobile offshore drilling units (MODUs) [16].

For passenger ships/ RoRo must comply these criteria:

- Area under GZ curve for $0^\circ - 30^\circ \geq 3.1513$ meter.degree
- Area under GZ curve for $0^\circ - 40^\circ \geq 5.1566$ meter.degree
- Area under GZ curve for $30^\circ - 40^\circ \geq 1.7189$ meter.degree
- Maximum righting arm GZ at 30° or greater ≥ 0.20 meter
- Angle of maximum GZ righting arm $\geq 25^\circ$
- Initial GM_i at 0° measured at 1 radian ≥ 0.150 meter

RoRo vessel also must satisfies several special intact stability criteria:

- All crowding passenger at one side of the ship $\geq 10^\circ$
- Turn angle during maneuvering $\geq 10^\circ$
- Severe wind and rolling from side of the vessel, area a \geq area b

2.2. Damage Stability

The regulation of damage stability generally using deterministic damage stability and recently has developed to probabilistic stability [17]. Deterministic damage stability is a survival criteria when one or more compartment is damage or flooded, where the damage determined during design stage. While probabilistic damage stability is a survival criteria when one or combination of group compartment experiences damage or flooded which calculated with probabilistic statistic. Subdivision of transverse bulkhead, longitudinal bulkhead and deck has significant influences to reduce probability of damage compartment. Less damaged compartment higher the chance of survivability. The sum of one and compartment combination or attained must be greater than required. The approach of probabilistic damage stability refers to the factual approach that one or group of compartment which causes ship capsize are occurred random. SOLAS 2009 part B-1 or SOLAS 1974 Revision 2009 has applied cargo and passenger ship to fulfil these criteria [18]. The calculation of probabilistic damage stability is complicated which requires software and high specification computer [19].

2.3. Side casing

Side casing first introduced as Glasgow Concept which adding the tanks at side of the hull ship. Low side

casing positioned under the vehicle deck, the purpose is to reduce the speed of penetration during damage. Up side casing positioned left and right side of the main car deck, the purpose is adding freeboard and adding survival stability. Principle of up side casing the same with sponson that applied to improve ship stability. There are two type up side casing such as: inboard side casing which follow ship deck and outboard side casing which appendage out from hull. The study of correlation about side casing and intact stability showed up side casing can improve righting arm lever and peak of GZ curve more than 25°. it is difficult to satisfy because RoRo has wide deck [7]. Adding side casing on large RoRo also can improve survival of probabilistic damage stability, up side casing better than low side casing [18].

3. Method

Indonesia is developing country which have thousands island is representation of Open Deck Small RoRo operation in the world. RoRo is favorite ship because can carry passenger, cargos and cars. In this paper the RoRo operation area is choice in the Bone Gulf, Celebes, Indonesia. The area has medium liner, worse weather at special months, crowded passengers, sea state 5 and many ships accident caused loss of lives, cargos and cars. This paper analyses four ship from the survey its area. Three ship is exist and one ship is capsized cause damage stability. The survey got some drawings and documents such as: stability booklet, lines plan, and general arrangement.

SOLAS 2009 Part B-1 give three loading conditions to calculate Probabilistic Damage Stability such as: Deepest Subdivision Draught (d_s), Light Service Draught (d_l), and Partial Subdivision Draught (d_p). Then combination one and group compartments can be made with triangle as shown in Figure 1. The combination depend on transverse bulkhead. Peak triangle show combination of group compartments. Tier one show single damage compartments, tier two show two compartments damage, tier three show third compartments damage etc.

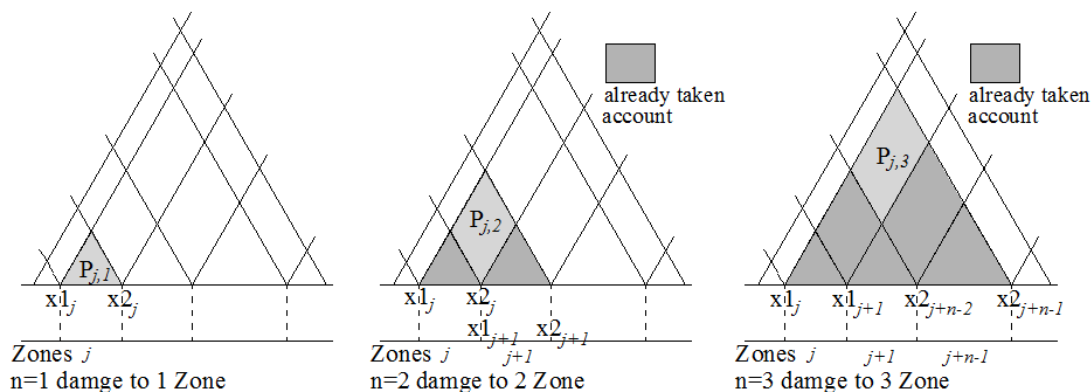


Figure 1. Single and combination damage group compartments

The calculation of probability flooded compartment (p_j) using distance function of after transverse bulkhead ($x1$) and the distance of the forward transverse bulkhead ($x2$) from AP. j in the floodable triangle is the number of transverse bulkhead in ship. The probability of damage compartment is based on Equation (1), for two flooded compartment uses equation (2), for three or more uses equation (3)

$$p_{j,1} = p(x1_j, x2_j) \quad (1)$$

$$p_{j,2} = p(x1_j, x2_{j+1}) - p(x1_j, x2_j) - p(x1_j, x1_{j+1}) \quad (2)$$

$$p_{j,n} = p(x1_j, x2_{j+n-1}) - p(x1_j, x2_{j+n-2}) - p(x1_{j+1}, x2_{j+n-1}) - p(x1_{j+1}, x2_{j+n-2}) \quad (3)$$

The calculation of survivability (s_i) from flooded compartment and group of compartment uses the function of GZ arm stability which experiences damage. For passenger ship, the GZ stability arm uses the minimum of intermediate survivability or the final survivability times moment as shown in equation (4).

$$s_i = \text{minimum}(s_{\text{intermediate},i} \text{ or } s_{\text{final},i} \cdot s_{\text{moment},i}) \quad (4)$$

The calculation of Attained Index (A) is the indicator of ship survivability based on probabilistic damage stability. It calculated by summary of index probability of damage times survivability as shown in equation (5), due to the existing of transverse bulkhead and deck, index A is increased as stated in equation (6). The calculation of index A is must accounted three conditions Deepest Subdivision Draught (A_s), Light Service

Draught (A_i) and Partial Subdivision Draught (A_p). Where it will be times the constant value as written in equation (7).

$$A = \sum p_i \cdot s_i \quad (5)$$

$$A = \sum p_i \cdot (v_i \cdot r_i \cdot s_i) \quad (6)$$

$$A = 0.4 \cdot A_s + 0.4 \cdot A_p + 0.4 \cdot A_l \quad (7)$$

The calculation of Required Index (R) is the measurement of minimum index which required by SOLAS 2009. Part B-1. For cargo ships the R Index is the function of ship's length, while the passenger ships is the function of number of passenger carried by the ship. More passenger onboard the ship the R index is higher. Ship comply the probabilistic damage stability criteria when attained index is higher than required as written in equation (8).

$$A \geq R \quad (8)$$

4. Discussions

There are four RoRo open car deck which got from survey, the main dimension as shown in Table 1:

Table 1. Main Dimensions

Dimension	Unit	Ship A	Ship B	Ship C	Ship D
Loa	m	44.5	55.51	56.26	55.72
Lpp	m	41.83	51.07	52.50	49.66
B	m	11.30	14.00	13.10	16.2
H	m	3.70	3.70	2.70	3.80
Fb	mm	909	2.75	564	760
Gt		862	1112	1172	1376
Nt		259	1305	352	413
Passengers	persons	288	360	282	
Cars		17	25	30	
Crews	unit	18	19	22	

the lines plan are built in computer model using Maxsurf Modeler as shown in Figure 2. Ship A is inboard side casing and ship B, C, D are outboard side casing

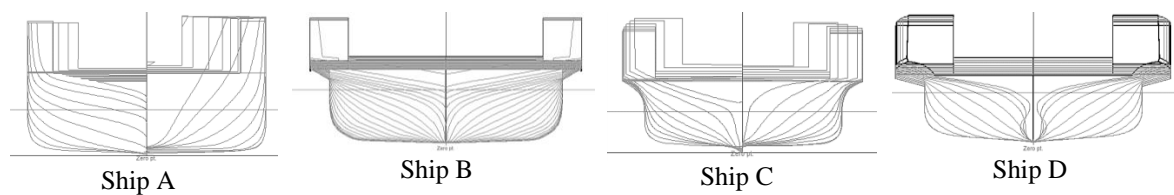


Figure 2. Lines plan

Based on lines plan, the 3D hull model are built with the existing side casing as shown in Figure 2. Ship A has the longest side casing, followed by Ship C, D and ship B. The next modeling is to build three variation model of side casing. Without side casing, existing side casing and full side casing. For model without side casing, the model are built only until deck and for the full side casing are built continuous along the side of the ship.

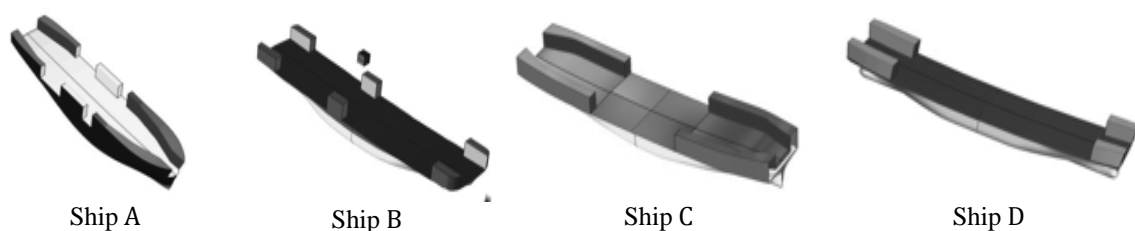


Figure 3. 3D hull form of existing ships (existing side casing)

The next step is to design the compartment and tanks based on the general arrangement. The permeability of the tank and compartment are determined by the fluid types inside the tank.

4.1. Intact Stability Analysis

This 4 ships are calculated with 3 variation of side casing: without side casing, existing side casing and full side casing. Each variation of side casing uses 3 load-cases: load-case deepest subdivision draught, light service draught, and partial subdivision draught. The result calculation can be showed at table 2-5

Table 2. Intact stability of ship without side casing

Ship	Intact Stability		
	d_s	d_p	d_l
A	Pass	Pass	Pass
B	Fail	Fail	Fail
C	Fail	Fail	Fail
D	Fail	Fail	Fail

Table 3. Intact stability of ship with existing side casing

Ship	Intact Stability		
	d_s	d_p	d_l
A	Pass	Pass	Pass
B	Fail	Pass	Pass
C	Pass	Pass	Pass
D	Pass	Pass	Pass

Table 2 Ship A without side casing satisfies all IS Code 2008 Criteria for all load cases. Ship B at deepest load case is not comply with IS Code 2008 due to the area under curve GZ 30°-40°, maximum GZ at 30° or greater and maximum angle GZ. Ship B at partial and light loading condition doesn't comply IS Code 2008 at maximum angle GZ. Ship C fails only for all loading conditions loading deepest, partial and light doesn't fulfil IS Code 2008 criteria maximum GZ. Ship D fails only for all loading conditions loading deepest, partial and light doesn't fulfil IS Code 2008 criteria maximum GZ. The area under curve GZ 30°-40° doesn't fulfil criteria at deepest and partial loadcase deepest and partial.

Table 3. Show ship A, C and D with existing side casing satisfies all IS Code 2008 Criteria for all load cases. Ship B at deepest load case is not comply with IS Code 2008 due to the area under curve GZ 30°-40° \geq 1.7189 meter degree, maximum GZ at 30° or greater and maximum angle GZ \geq 25.0 degree. It is caused L/B of ship B too large.

Table 4. Intact stability of ship with full side casing

Ship	Intact Stability		
	d_s	d_p	d_l
A	Pass	Pass	Pass
B	Pass	Pass	Pass
C	Pass	Pass	Pass
D	Pass	Pass	Pass

Table 5. Intact stability of all ship

Ship	Intact Stability		
	Without Side Casing	Existing	Full Side Casing
A	Pass	Pass	Pass
B	Fail	Fail	Pass
C	Fail	Pass	Pass
D	Fail	Pass	Pass

Table 4 show ship A, B, C and D with full side casing satisfies all IS Code 2008 Criteria for all load cases deepest subdivision draught, light service draught, and partial subdivision draught. Full side casing has positive effect to improve survival of intact stability.

Table 5 is summary from table 1 until table 3. Generally adding side casing can improve survival of intact stability. Ship A is the best ship which can satisfied IS Code 2008 Criteria From without side casing until side casing. For ship existing only ship B which not fulfil IS Code 2008 criteria. When all ships used full side casing all IS Code 2008 satisfied.

4.2. Probabilistic Damage Stability Analysis

Calculation of probabilistic damage stability was used Maxsurf Stability. Important thing before calculation arrange bulkhead position base on subdivision in general arrangement. Amount and position of bulkhead effect p_i value (probability damage compartments). Bulkhead after and foreword position are measured from AP. Combination of one compartment and group compartments four ships are showed by picture 8 as following:

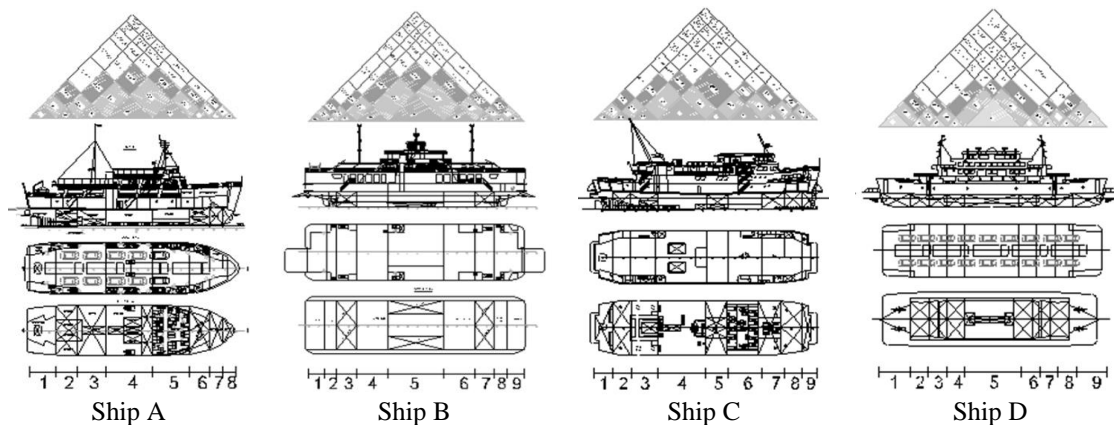


Figure 4. Combination damage of group compartments and general arrangement

There are 8 compartments in Ship A, so the combination of the damage stability is 8 single damage compartment, 7 double group of damage compartment, 6 triple group compartment and so on. There are 9 compartment in Ship B, the combination of the damage stability are 9 single damage compartment, 8 double group damage compartments, 7 triple group compartments and so on. Ship C and D have the same damage compartments combination with ship B. The next step the probabilistic damage stability conducted where the results are shown in Table 6 to Table 9.

Table 6. Value A and R of ship without side casing

Ship	Probabilistic Damage Stability				
	A_s	A_p	A_l	A	R
A	0.588	0.892	0.854	0.763	0.706
B	0.424	0.538	0.571	0.499	0.714
C	0.636	0.819	0.555	0.693	0.706
D	0.510	0.502	0.502	0.505	0.688

Table 7. Value A and R of ship with existing side casing

Ship	Probabilistic Damage Stability				
	A_s	A_p	A_l	A	R
A	0.590	0.988	0.988	0.829	0.706
B	0.534	0.805	0.708	0.677	0.714
C	0.815	0.911	0.787	0.848	0.706
D	0.510	0.502	0.502	0.505	0.688

Table 6 shows the results of attained and required probabilistic damage stability for ship without casing. The results A compared to R value. It shows that ship A only A_s value which less than R, condition $A_p > R$, $A_l > R$, and $A > R$ so this ship comply damage stability SOLAS 2009. All values of ship B (A_s , A_p , A_l and A) less than required, so this ship does not complies damage stability SOLAS 2009. Ship C only has A_p value which greater than R ($A_p > R$) and the other values are less than required. So it can be concluded that this ship does not complies damage stability SOLAS 2009. Ship D all the values (A_s , A_p , A_l and A) are less than R so it can be concluded than ship D does not complies damage stability SOLAS 2009. Generally for ship without side casing, only ship A which complies damage stability SOLAS 2009.

Table 7 shows the results of attained and required probabilistic damage stability for ship existing casing. The results A compared to R value. It shows that ship A only A_s value which less than R, condition $A_p > R$, $A_l > R$, and $A > R$ so this ship complies damage stability SOLAS. Only values A_p of ship B more than required, so this ship does not complies damage stability SOLAS. All values of ship C (A_s , A_p , A_l and A) more than required, so this ship can be concluded complies damage stability SOLAS 2009. Ship D, all the values (A_s , A_p , A_l and A) are less than R so it can be concluded than ship D does not complies damage stability SOLAS 2009. Generally for ship with existing side casing, half of them complies damage stability SOLAS 2009.

Table 8. Value A and R of ship with full side casing

Ship	Probabilistic Damage Stability				
	A_s	A_p	A_l	A	R
A	0.656	0.934	0.930	0.822	0.706
B	0.677	0.986	0.910	0.847	0.714
C	0.829	0.937	0.982	0.903	0.706
D	0.975	0.940	0.938	0.953	0.688

Table 9. Summary of probabilistic damage stability calculation

Ship	Probabilistic Damage Stability		
	Without side casing	Existing	Full Side Casing
A	Pass	Pass	Pass
B	Fail	Fail	Pass
C	Fail	Pass	Pass
D	Fail	Fail	Pass

Table 8 indicates that all A values are greater than R so it is concluded that all ships with full side casing satisfy probabilistic damage stability. Ship A has As value less than R, however the A value is greater than R so the ship passes criteria of damage stability SOLAS 2009 so as the ship B.

Table 9 summaries the results of probabilistic damage stability from table 2 until table 4 for comparison A and R. If the value of A is greater than R it passes, contrary if A less than R it is fail. From Table 9, all variation of ship A passes criteria of the probabilistic damage stability SOLAS 2009. From several existing ships only two ship that satisfy the probabilistic damage stability SOLAS 2009, those are ship A and ship C. When existing side casing of ship is extend become full side casing, all ships satisfy the probabilistic damage stability SOLAS 2009.

5. Summary

Based on the analyses and discussion previously, it can be concluded that the installation of side casing in open car deck RoRo vessel able to increase survivability of the intact stability and damage probabilistic stability, it can to be solution for the ship which have defect stability. There are several detail conclusions which can be drawn, those are:

1. One of four the ships existing which operation in Bone Gulf, Celebes, Indonesia does not comply the IS Code 2008 criteria. The ship fails in maximum GZ angle $> 25^\circ$.
2. Based on the intact stability, almost all ship without side casing do not comply IS Code 2008, when added existing casing, three of fourth of them are comply the criteria and it comply all criteria when full side casing are added. The full side casing installation has significant influence in increasing survival of intact stability.
3. Ship which satisfies IS Code 2008 not always fulfil damage stability criteria. There is only two ship with existing side casing which fulfil the damage stability criteria.
4. The probabilistic Damage Stability analysis stated that all ship without side casing not comply SOLAS 2009, however when it added side casing, only one ship comply IS Code 2008. All ships comply SOLAS 2009 when they added full side casing. It can be concluded that additional side casing increases survivability and Probabilistic Damage Stability.
5. Ship A with all variation side casing and load cases satisfy IS Code 2008 Criteria and Damage Stability SOLAS 2009 Criteria. The best ship to fulfil stability is ship A followed by ship C, ship D and ship B.

Based on the conclusions, there are several recommendations in order to increase survivability of ship, those are:

1. For existing open deck RoRo vessel which doesn't comply intact stability and damage stability can be modified with the installation of side casing in order to comply the criteria of stability. The new designed open car deck RoRo is recommended use side casing.
2. The analysis conducted in this paper neglected the water trap on car deck. It assumes that the ingresses water in car deck directly wiped to freeing port or by scupper which equipped with pumps so the water dumped to sea.

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