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Effect of Watertight Subdivision on Subdivision Index for Medium Size Ro–Ro Passenger Ferries

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ABSTRACT: Ro-pax vessels should fulfil the requirements of the current harmonised SOLAS Convention. The study analyses the effect of various ro-pax vessel subdivision arrangements on the subdivision index. A Polish ferry was chosen as a generic ship to perform the study. For illustration of damage survivability, the attained subdivision index A was calculated for a number of modified configurations. The arrangements included single and double sides above and below the car deck, with and without a double buoyant car deck. The conclusions of the study can be used in the design of new ro-pax vessels.

NOMENCLATURE

BP = base plane
b = breadth of double sides
GM = metacentric height
GZ = righting lever
h_0 = GM_0 – initial metacentric height of the intact ship
i_x = transverse moment of inertia of the free surface of floodwater
K = volumetric stiffness of the ship
l = length of compartment
r_C = differential metacentric radius
r_w = metacentric radius of floodwater
T = draught of the intact ship
V = volume displacement
v = volume of floodwater
z_w = height of centre of gravity of floodwater above BP
ΔJ = increment of transverse moment of inertia of the undamaged waterplane due to sinkage

1 INTRODUCTION

Pawłowski & Laskowski (2014) discuss the effect of various subdivision arrangements of ro-pax vessels on damage stability. The ship investigated had the old type of subdivision, as in Figure 1, confined to space below the bulkhead deck (car deck), densely subdivided by transverse bulkheads.

Most of these compartments were void, not used for the carriage of any cargo or supplies. Above the car deck, there was no reserved buoyancy. This type of subdivision was common until end of the 1990s.

Nowadays, space below the car deck is frequently utilised for ro-ro cargo in the form of a long lower hold (LLH), stretching for about half of the ship length (see Figure 2). It has double sides, subdivided by transverse bulkheads, usually terminated at the car deck, and no transverse bulkheads in cargo space. For better safety, the double sides should extend above the car deck; see examples discussed by Pawłowski (1999), and shown in RINA (2001).

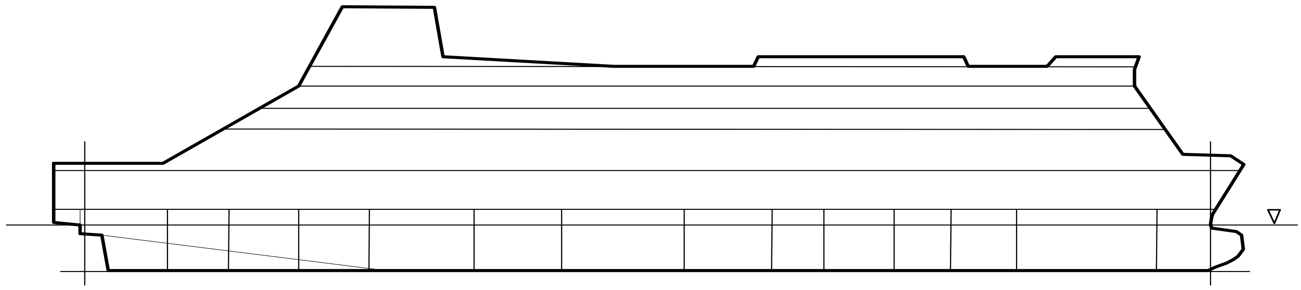

Figure 1. Watertight subdivision of old ro-ro ferries

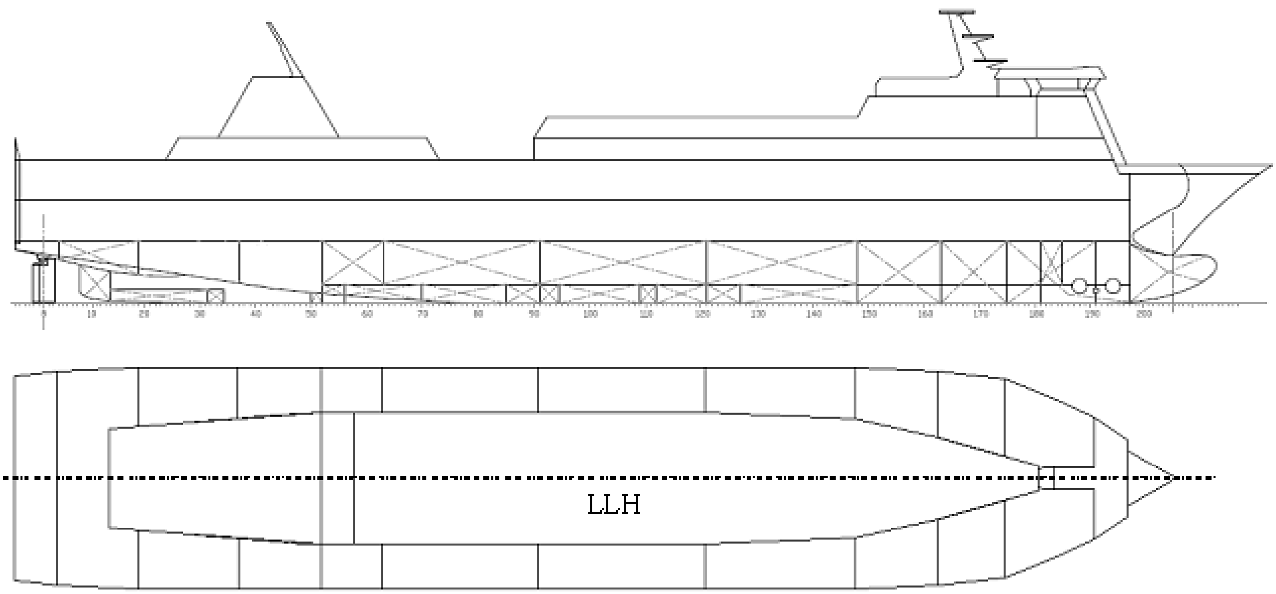

Figure 2. Watertight subdivision of the investigated ro-pax

The current study is performed using a Polish ferry as generic ship, shown in Figure 2, built in 1990, still in operation, whose main particulars are as follows:

- overall length LOA ◎ ◎◎◎ m,
- subdivision length Ls ◎ ◎◎◎◎◎◎ m,
- length between perpendiculars Lpp ◎ ◎◎◎ m,
- breath B ◎ ◎◎ m,
- depth H ◎ ◎◎◎ m,
- design draught T ◎ ◎◎◎ m,
- width of double sides b◎B/◎◎◎◎◎◎ m,
- height of double bottom hb ◎B/◎◎◎◎◎◎◎◎m,
- height of CG above BP KG ◎ ◎◎◎◎◎ m,
- metacentric height GM ◎ ◎◎◎◎ m,
- block coefficient cB ◎ ◎◎◎◎◎◎,
- number of persons on board N = 314,
- required index of subdivision R = 0.69058.

The ship fulfils the requirements of the IMO resolution A.265 (1974), the predecessor of the current harmonised SOLAS Convention (2009). The said resolution does not require reserved buoyancy above the car deck. In the case of a LLH below the car deck, the width of the double sides should be equal to b = 0.2B, while the height of the double bottom should be at least hb = 0.1B. In view of damage safety, the height of the double bottom should be as low as possible. A minimum height of the bottom for the ship investigated according to PRS equals hb = 1.025 m.

2 NUMERICAL EXAMPLES

2.1 *Example 1*

For illustration of damage survivability, the attained subdivision index A will be calculated for a number of modified configurations. The generic one, treated as Example 1, is shown in Figure 2 and Figure 3. The ship has four decks. Deck 1 is the inner bottom and Deck 2 is the car deck at a height 7.9 m, Deck 3 at a height 13.2 m, and Deck 4 at a height 18,2 m. Ballast tanks in the double sides and double bottom are connected to each other, creating thus a symmetric space (Figure 3), beneficial in the case of flooding. It allows for a rapid cross-flooding if the tanks in the double sides are provided with efficient air-escapes (vents) placed at the sides, close to the top of tanks, to eliminate detrimental air cushions that may occur during flooding. The same should apply to cargo space on Deck 1. To increase further real safety in damage condition, the car deck should be equipped with down-flooding arrangements, thus making the car deck transparent for floodwater and air. The down-flooding arrangements prevent the accumulation of water on car deck, which is the main reason for the capsizing of damaged ro-ro ships. For the generic ship, according to the original design, the index of subdivision A = 0.73015, which is more than the required value R = 0.69058.

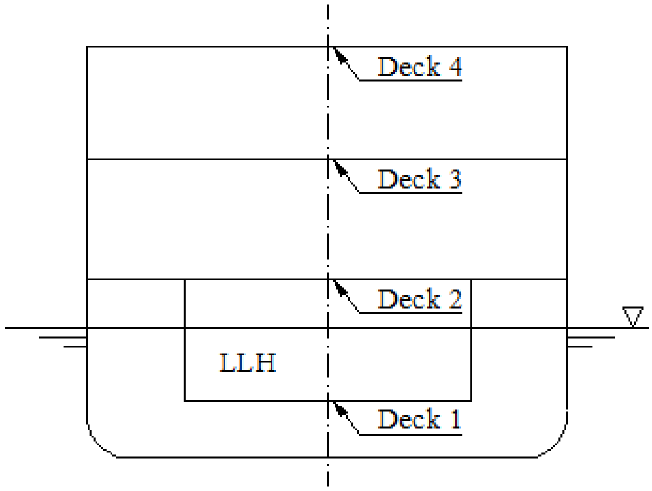

Figure 3. Cross-section of the original design

2.2 *Example 2*

The ship as above, but with Deck 2 as a pontoon creating a buoyant 1600 mm double deck of the same as the height of deck girders, is shown in Figure 4, divided longitudinally at the PS. Spaces above Deck 3 are not included in stability calculations, therefore they will not be shown further down. At the design draught, the underside of the buoyant deck is merely 0,4 m above the waterline. The attained index value is now A = 0.74574, which is only marginally higher than in the previous case. This is because the buoyant deck in this case remains under water over most of its length in the majority of damage scenarios, due to the bow trim, thus insignificantly contributing to the reduction of the free surface effect.

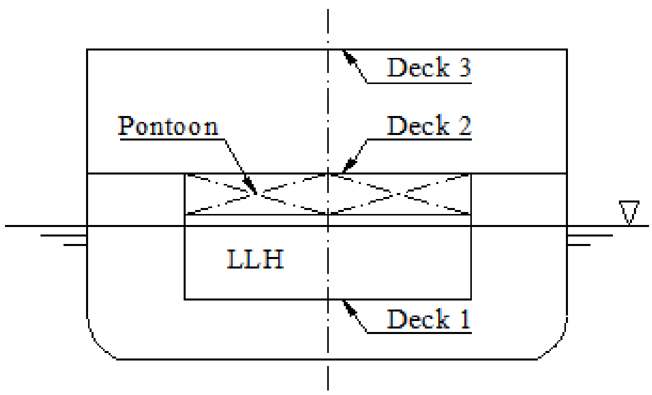

Figure 4. Cross-section of the ship in Example 2

The other reason is a small residual freeboard and the lack of reserve buoyancy above the car deck.

Ro-ro ships, in general, have high deck girders because of the large unsupported deck spans. In view of the problem of cargo handling, stowage is usually restricted to spaces below the flanges of these girders. There is an opportunity, therefore, to seal off the space upwards from the flanges of the deck girders to the deck plating to form a chamber (pontoon) that can provide additional buoyancy, and depending on its location, height and extent, that is of some advantage in terms of damage survivability. The problem of locating the buoyant deck is a fairly involved exercise, discussed by Pawłowski (1999). Adding a pontoon hardly changes the weight of the ship.

The Roroprob EU research project (2000–2003) did not account for the option of a buoyant car deck. Two first ro-pax vessels ever built in the world with a double car deck were built at the Shipyard Nova in Szczecin in 2001, described in Best Ships (2001). They incorporated the features discussed above. The double deck appeared to be very effective on these ships.

2.3 *Example 3*

A ship as in Example 2, but with added wing tanks on Deck 2 of breadth b = 0.1B, extending to Deck 3 (Figure 5). In this case there is a substantial increase of the index to the value A = 0.83255. As can be seen, adding reserved buoyancy above the car deck significantly increases the index. And this observation can be taken as a rule.

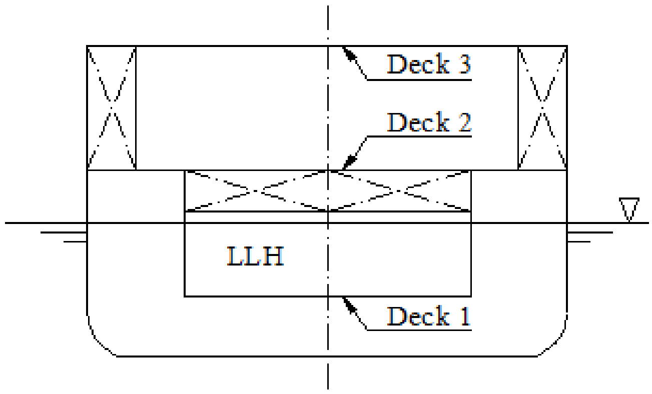

Figure 5. Cross-section of the ship in Example 3

2.4 *Example 4*

A ship as in Example 3, but with car deck raised to 8.1 m, resulting in change of deck height by 0,2 m. Positioning of all tanks adjacent to deck 2 is altered. The height of the buoyancy pontoon changed from 1.60 m to 1.80 m. The subdivision index obviously increased to A = 0.86729.

2.5 *Example 5*

Changes were introduced similar to those described in the previous examples, but with no change to the height of the car deck. They involved introducing a sheer of the car deck in the form of a segmented line, with knuckles some ⅓ of deck length from the ends, with a rise of the deck at the ends by 1.00 m. All tanks adjacent to Deck 2 changed their position accordingly. The subdivision index increased to A = 0.87804.

3 FURTHER NUMERICAL EXAMPLES

The study analysed in addition the impact of the length of the long lower hold LLH on the subdivision index and decreased height of the double bottom. In examples 1a) to 5a) computations were performed for a long lower hold LLH lengthened by 4.2 m towards the stern of the generic ship with the closing stern frame moved from 39.2 m to 35.0 m.

In examples 1b) to 5b) the double bottom was lowered from 2.40 m to 1.40 m, and the buoyancy pontoon height raised from 1.60 m to 2.00.

The relations between parameters in examples 1-5 were maintained. However, the subdivision index for the expanded long lower hold LLH was significantly lower compared to the generic ship. Lowering of the double bottom, in practice, had no significant impact.

The tables below present the indices of subdivision for particular design cases.

Table 1. Subdivision index for generic ship parameters.

Nr	Parameter	A
1	Generic	0.73015
2	Example 1, plus pontoon 1.6 m	0.74574
3	As in 2, plus wing tanks on car deck 0.1B	0.83356
4	As in 3, plus deck raised by 0.2 m to 8.1m, pontoon height 1.8 m	0.86729
5	As in 3, plus 1 m sheer of car deck	0.87804

Table 2. Subdivision index for original ship parameters with lengthened LLH.

Nr	Parameter	A
1a	Generic ship	0.68307
2a	As in 1a, plus pontoon 1.6 m	0.69210
3a	As in 2a, plus wing tanks on car deck 0.1B	0.79705
4a	As in 3a., plus deck raised by 0.2 m to 8.1m, pontoon height 1.8 m,	0.81254
5a	As in 3a, sheer of car deck 1 m	0.80055

Table 3. Subdivision index for original ship parameters with lowered double bottom.

Nr	Parameter	A
1b	Generic ship	0.72476
2b	As in 1b, plus pontoon 2.0 m	0.73277
3b	As in 2b, plus wing tanks on car deck 0.1B,	0.83243
4b	As in 3b, plus deck raised by 0.2 m to 8.1m, pontoon height 2.0 m	0.86086
5b	As in 3b, sheer of car deck 1 m	0.87620

4 CONCLUSIONS

The analysis of the indices of subdivision for various configurations of the general arrangement shows the following conclusions:

1 The long lower hold LLH under the car deck contributes positively to the attained subdivision index A. Nevertheless, in the case of hull damage, symmetrical flooding achieved by cross-flooding of the opposite side tanks is recommended along with an effective air venting system to eliminate potential air cushions;
2 An additional buoyancy pontoon under the car deck slightly increases survivability measured by the subdivision index;
3 Side tanks of the width b = 0.1B significantly increase the subdivision index and does not limit operational capacity of the ferry – space between deck girders and side frames is anyway useless for the carriage of ro-ro cargo;
4 Another option for increasing the subdivision index is to raise the height the car deck. However such a solution is not always feasible;
5 Sheer of aft and fore car deck enhances safety, but not as much as expected;
6 The length of the long lower hold LLH should be carefully set as excessive extension could lead to a considerable drop of the subdivision index;
7 The impact of double bottom on subdivision index is negligible, supported also by work of Sonne Ravn (2003).

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