The effect of L/B and B/T variation on subdivision indexes

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ABSTRACT: This paper examines the addresses the Ro-Ro ship regarding the effect of variation of bulkheads' positions on the attained subdivision index. In addition L/B and B/T ratios were also varied to obtain the relation between the subdivision index and the varied ratios. The initial ship (car-truck carrier) was analysed first and the subdivision zones were established first along with the calculation of the attained and required subdivision indexes using the probabilistic method through GHS application. In order to improve the attained index and get a safer ship variations of positions of transverse bulkheads were investigated to get better indexes of the adjacent subdivision zones. Diagrams that show potential solutions for making the initial ship safer were presented.

1 INTRODUCTION

The attained subdivision index depends on number of parameters with many of them restricting each other. To improve the design tools, understanding the correlation between those parameters is crucial.

For the attained subdivision index calculation the method described in the IMO Resolution MSC 19(58) was used. Various configurations of Ro-Ro ships were examined and an extensive database (Slapničar 1998) was prepared by thorough literature survey. The database contains principal data for 200 ships. Total number of ships for which it was able to identify type of midship section, from clear and available general plans, is about 100 and a typical car-truck carrier was chosen for the analysis.

To check standard of subdivision the attained subdivision index, A, is calculated in accordance with the IMO rules. It should not be lower than required subdivision index, R.

According to IMO the required subdivision index solely depends on the subdivision length of a ship.

$$R = \left(0.002 + 0.0009 \cdot L_s\right)^{\frac{1}{3}} \tag{1}$$

The attained subdivision index, A, is calculated for two subdivision load lines. The first one is the deepest subdivision load line that corresponds to the summer draught assigned to the ship. The second one is partial load line that corresponds to light ship draught plus 60% of the difference between the light ship draught and deepest subdivision load line.

For the economical reasons ship should be operating on draughts close to summer draught and that is why the rules use only two draughts. The attained subdivision index, A, is calculated as the mean value for two mentioned draughts.

$$A = \frac{1}{2}\left(A_f + A_p\right) \tag{2}$$

$$A_f = \sum_i p_i s_f \tag{3}$$

$$A_p = \sum_i p_i s_p \tag{4}$$

where A_f = index for the deepest subdivision load line; A_p = index for the partial load line; p_i = probability of flooding; s_f, s_p = probability of survival.

For the damage stability calculation software application GeneralHydroStatics (GHS) was used.

The rules concerning intact and damaged stability are inconsistent in this case. While all classification societies require intact stability to be calculated for various realistic loading conditions and real (trimmed and heeled) waterlines the IMO rules require calculation at one realistic waterline (summer draught) and the partial waterline at the draught previously described which is not directly related to any loading condition of the ship. Using real loading conditions would lead to more complex damaged stability calculation but it would also give the ships crew better data of the damaged ship behaviour in situations they might find themselves in.

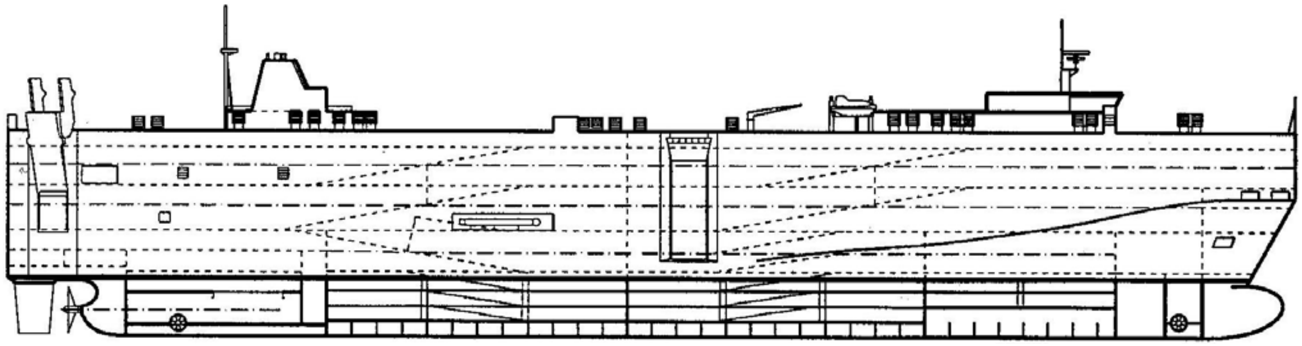

Figure 1. Initial design – side view

2 INITIAL DESIGN ANALYSIS

Initial design for the analysis is a typical car-truck carrier (Fig. 1) built for long intercontinental routes. Main particulars are presented in Table 1.

Table 1. Main particulars of initial ship

Subdivision length, L_S	171.43 m
Length over all, L_{OA}	176.00 m
Length, L_{PP}	165.00 m
Breadth moulded, B	31.10 m
Main deck height, H	14.46 m
Upper deck height, H_1	28.00 m
Design draught, T	8.77 m
Displacement on T	24,825 t
Deadweight on T	12,594 t
Maximal car capacity	4632 m

Vehicles are transported on eleven decks as follows (Fig. 2):

- Decks 1 (double bottom top), 2, 3, and 10 – cars only.
- Decks 4, 6 and 8 – truck decks (where deck 6 is main and subdivision deck).
- Decks 5, 7, and 9 – hoistable decks (cars only).
- Deck 11 – the upper (weather) deck (cars only).

Six transverse watertight bulkheads extend from the bottom to the main deck. These bulkheads are equipped with hydraulic operated watertight doors which enable vehicle manipulation while ship is in harbour. Double-bottom top and the main deck are the only watertight vehicle decks while the others are treated as non-watertight.

Onboard accommodation for 25 crew members and 12 passengers is provided. The ship is propelled by one reversible low speed diesel directly connected to the propeller over the shaft. One bow thruster is driven by an electrical motor. There are also three auxiliary engines connected to the generators. Ballast system consists of three pairs of ballast tanks spreading through the whole double bottom, one fore ballast tank and three aft ballast tanks.

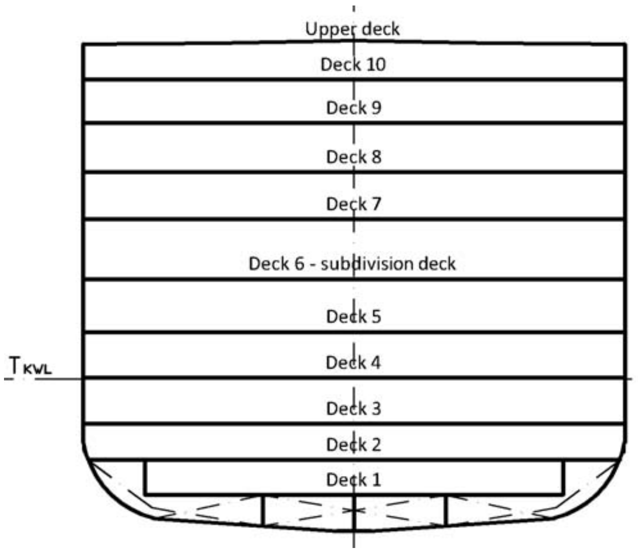

Figure 2. Initial design – cross section

3 CASE STUDY

Bulkheads divide the ship in six floodable zones (Fig. 3). No zone is homogenous and they consist of various sub-zones with different permeability.

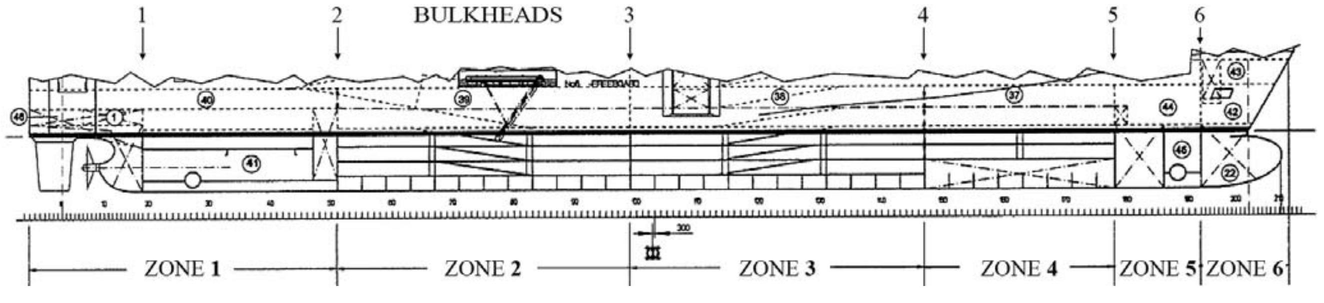

Figure 3. Tank and compartment subdivision in floodable zones

Critical points are the points of progressive flooding i.e. flooding of these points would probably cause the loss of the ship. Every weathertight closing is considered to be a critical point while all of thewatertight closings are discarded as such. They are closely related to the accounts for probability of survival, *s*, which equals zero if the lowest edge of the opening goes underwater in the final phase of the flooding.

Critical points (Table 2) were defined as follows:

Table 2. Critical points

	Distance from AP m	Distance from CL m	Distance from BL m
CP 1	–4.635	15.550	14.460
CP 2	134.650	15.550	14.460
CP 3	139.750	14.300	14.460
CP 4	148.250	11.650	14.460
CP 5	158.450	7.900	14.460
CP 6	9.900	15.100 s	15.260
CP 7	11.100	15.100 s	15.260
CP 8	39.250	15.130 s	15.260
CP 9	114.680	14.950	15.260
CP 10	118.920	14.950	15.260
CP 11	144.400	12.060 s	15.260
CP 12	157.650	0.600	14.910
CP 13	157.650	1.400	14.910
CP 14	158.750	10.150 s	18.710
CP 15	18.200	15.550 s	21.910
CP 16	25.000	15.550 s	21.910
CP 17	33.500	15.550 s	21.910

Coordinate system origin is at the AP and the BL;
CP = critical point; s = symmetrical pair of critical points

First we calculate the attained index for the case of damage of each zone exclusively and then for the combination of two or more consecutively damaged zones (Table 3).

Table 3. Initial design - attained subdivision indexes

No. of zones damaged	100% draught	60% draught
1	0.417	0.508
2	0.067	0.089
3	0.003	0.027
4	0.000	0.000
	$A_f =$ 0.486	$A_p =$ 0.624

This averages:

$$A = \frac{1}{2}\left(A_f + A_p\right) = 0.555 \qquad (5)$$

The attained subdivision index is greater at 60% draught than at full draught which is understandable since the freeboard and the positions of the critical points are higher above the waterline at lower draughts. From the contribution to the overall subdivision indexes it is clear that the probability of ship's survival is very low when more than one zone is flooded. The attained subdivision index for the full load line, A_f, is lower than required index, *R*. The distribution of contribution to the overall index by zones (Table 4) shows us that the zones 3, 5 and 6 contribute the least.

Table 4. Initial design - attained indexes by zones

Zones	p_i	s_i	$p_i \times s_i$	*A*
6	0.021	1.000	0.021	0.021
5	0.021	1.000	0.021	0.042
4	0.090	0.886	0.080	0.122
3	0.185	0.762	0.039	0.263
2	0.151	0.259	0.141	0.302
1	0.115	1.000	0.115	0.417
			1-zone damage:	0.417
6+5	0.033	1.000	0.033	0.450
5+4	0.056	0.598	0.034	0.484
4+3	0.091	0.000	0.000	0.484
3+2	0.092	0.000	0.000	0.484
2+1	0.063	0.000	0.000	0.484
			2-zone damage:	0.067
6+5+4	0.027	0.094	0.003	0.486
5+4+3	0.005	0.000	0.000	0.486
4+3+2	0.000	0.000	0.000	0.486
3+2+1	0.000	0.000	0.000	0.486
			3-zone damage:	0.003
6+5+4+3	0.000	0.000	0.000	0.486
			4-zone damage:	0.000
	Attained index in this condition:			0.486
			Required index:	0.542

4 VARIATION OF THE BULKHEADS' LONGITUDINAL POSITIONS

Small values of the attained indexes for zones 5 and 6 is hardly improvable since it is caused by their position (fore peak). Position of the collision bulkhead (bulkhead 6) is very strictly defined by the rules of classification societies. Bulkheads 4 and 5 are tank bulkheads and variation of their longitudinal position would change the volume of the tank. Thus, zone 3 should be varied to attain higher contribution to the subdivision index.

Moving the bulkhead 3 forward was performed to make the zone smaller. Total capacity and complexity of the loading/unloading should have remained the same as on initial design. Since the ships' car carrying capacity was of the primary interest the only logical solution was to move the bulkhead one average car lengths forward i.e. 4 metres.

The modification was conducted in GHS and the results are presented in Table 5 and Table 6.

Table 5. Attained indexes after longitudinal position variation

No. of zones damaged	100% draught	60% draught
1	0.392	0.478
2	0.073	0.085
3	0.018	0.027
4	0.000	0.000
	$A_f =$ 0.483	$A_p =$ 0.590

This averages:

$$A = \frac{1}{2}\left(A_f + A_p\right) = 0.537 \tag{6}$$

Table 6. Attained indexes by zones after longitudinal position variation

Zones	p_i	s_i	$p_i \times s_i$	A
6	0.021	1.000	0.021	0.021
5	0.021	1.000	0.021	0.042
4	0.068	0.998	0.067	0.109
3	0.212	0.606	0.129	0.238
2	0.151	0.259	0.039	0.277
1	0.115	1.000	0.115	0.392
			1-zone damage:	0.392
6+5	0.033	1.000	0.033	0.426
5+4	0.052	0.778	0.040	0.466
4+3	0.086	0.000	0.000	0.466
3+2	0.092	0.000	0.000	0.466
2+1	0.063	0.000	0.000	0.466
			2-zone damage:	0.073
6+5+4	0.027	0.652	0.018	0.483
5+4+3	0.009	0.000	0.000	0.483
3+2+1	0.000	0.000	0.000	0.483
			3-zone damage:	0.018
6+5+4+3	0.001	0.000	0.000	0.483
			4-zone damage:	0.000
	Attained index in this condition:			0.483
			Required index:	0.542

The final attained index is lower than required which is mainly due to the zone 2 getting larger and participating significantly less to the overall attained index (larger amount of flooding water means greater loss of stability). Contribution of the new reduced zone 3 to the overall attained index, *A*, was larger than in initial design, as expected.

5 VARIATION OF PRINCIPAL DIMENSIONS

Variation of the *L*/*B*, *B*/*T* ratios was performed with the constant values of displacement and block coefficient. Chosen ratios were varied from –8% to +8% in steps of 2%. This variation span gives us a clear information of the trends on required and attained indexes with a relatively small change of the initial design principal dimensions.

New values of *L*, *B* and *T* were calculated:

$$L = \sqrt[3]{\frac{V(L/B)^2(B/T)}{C_B}} \tag{7}$$

$$B = \frac{L}{L/B} \tag{8}$$

$$T = \frac{B}{B/T} \tag{9}$$

where V = initial design's displacement (23,120 m^3); C_B = initial design's block coefficient (0.514).

Scaling of the initial design (Table 7) was performed in GHS with decks remaining at their initial positions.

Table 7. Variation of principal dimensions

Design	Ratio	L m	B m	T m
Initial	L/B=5.305 B/T=3.548	165.00	31.10	8.766
I_1	L/B+2% = 5.411	167.20	30.89	8.708
I_2	L/B+4% = 5.517	169.37	30.70	8.650
I_3	L/B+6% = 5.624	171.54	30.50	8.596
I_4	L/B+8% = 5.730	173.70	30.31	8.544
J_1	L/B–2% = 5.199	162.80	31.31	8.825
J_2	L/B–4% = 5.093	160.57	31.53	8.885
J_3	L/B–6% = 4.987	158.33	31.75	8.948
J_4	L/B–8% = 4.881	156.08	31.98	9.013
K_1	B/T+2% = 3.619	166.10	31.31	8.651
K_2	B/T+4% = 3.690	167.18	31.50	8.539
K_3	B/T+6% = 3.761	168.24	31.71	8.431
K_4	B/T+8% = 3.832	169.29	31.91	8.329
L_1	B/T–2% = 3.477	163.90	30.89	8.885
L_2	B/T–4% = 3.406	162.77	30.70	9.007
L_3	B/T–6% = 3.335	161.63	30.46	9.135
L_4	B/T–8% = 3.264	160.48	30.25	9.267

With the variation of the *L*/*B* ratio the required subdivision index changes accordingly due to the changes of subdivision length (L_S). The attained subdivision index changes mainly due to the changes of draught and breadth of the ship. Designs I_1 to I_4 are narrower, thus lesser stability and designs J_1 to J_4 have larger draught which leads to lesser freeboard.

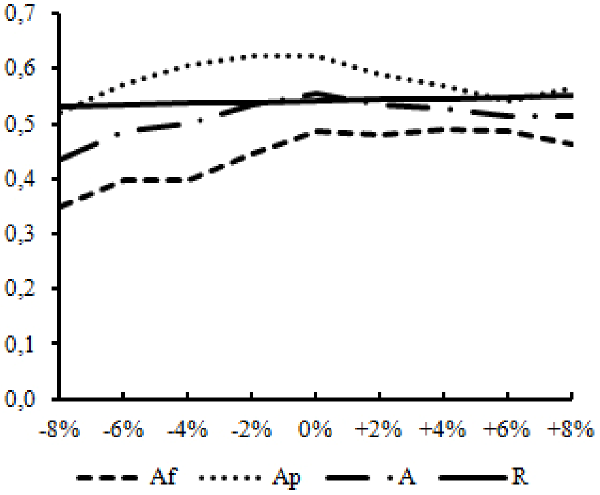

Figure 4. Effect of *L*/*B* variation on subdivision indexes

The calculation shows that the only ratio that satisfies the requirements is the one of the initial design (Fig. 4). Value of the attained subdivision index of the design J_1 (–2% variation of *L*/*B*) is close to the required value and with some small corrections of that design (e.g. critical points minor repositioning) it might also pass the requirement. But still the initial design has a larger margin between the attained and the required value.

Variation of the *B*/*T* ratio has a similar trend on required subdivision index i.e. the index increases with the increase of the ratio (L_S as well). As it can be seen on Figure 5, small changes in *B*/*T* significantly change the attained index so the only favourable designs are the ones with the increased *B*/*T*. It is due to the increase of breadth which leads to better stability (metacentric heights) and decrease of draught which leads to larger freeboard, i.e. larger margin for flooding.

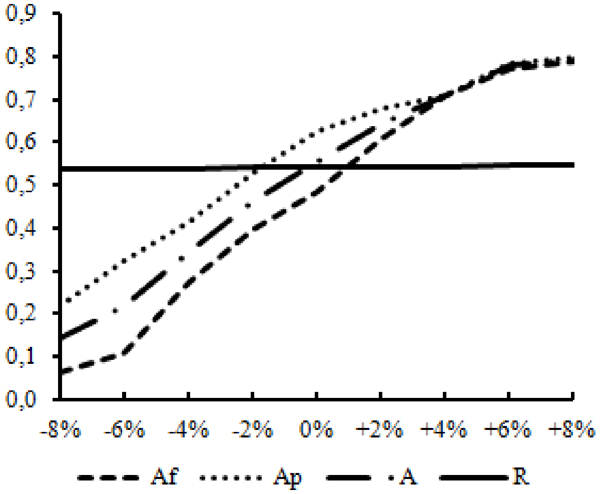

Figure 5. Effect of *B*/*T* variation on subdivision indexes

6 CONCLUSIONS

This paper along is continuation of the previous work on subdivision and safety (Slapničar 1998, Stupalo 2005).

Longitudinal repositioning of the bulkheads is almost insignificant in this investigation since it was restrained only to moving bulkhead 3. It caused a decrease of the attained subdivision index and implied that better values of the index should be achieved through adequate positioning of the critical points and not through moving the bulkhead. The best longitudinal subdivision of the ships mid part is with equal zones. At the fore part floodable zones should be smaller.

Varying of the *L*/*B* ratio gives us a slightly convex curve of attained subdivision index which, at its maximum, could give a value that fulfils the requirement.

Curve of the attained index increases with an increase of a *B*/*T* ratio so when in need for a larger values of attained indexes this might be the way to obtain them.

While the ships design goes in the direction of fulfilment of the requirements the optimum design is the initial design as a well designed ship since she doesn't have large margins between *A* and *R* but still satisfies the requirement.

Larger margins between indexes would mean that the other aspects of a design (besides the damaged stability) could probably be improved while the value of the attained index would still stay above the required. On the other hand, in the situation where every improvement or redefinition of damaged stability rules also applies to the existing ships, too small margin between those indexes might lead to the costly modification of the ship.

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