ON THE PROBABILISTIC SUBDIVISION OF THE SHIPS

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Abstract

The SOLAS Regulations of the Chapter II-1, Part B-1 are based on the probabilistic criterion for ship damages suggested by Wendel. At present these Regulations must be applied for cargo ships of 100 meters and over in length.

The method consists in the assessment of the Attained Index of Subdivision "A" which is compared with the Required Subdivision Index "R".

In this probabilistic concept a ship needs not necessarily to survive in any possible case of damage; the existing rules consider only the global value of the index "A", whichever the contribution of the considered damaged zone would be.

In this paper numerical examples highlight that the application of such regulation could determine on the ships the occurrence of vulnerable zones of high flooding probability and low or no ship survival probability, with possible catastrophic consequences for the human life and/or for environmental damages. Therefore, there is the need to improve the mode of the "A" calculation by assuring a uniform distribution of survival probability over the length of the ship.

We have also highlighted that the SOLAS expression of the existing survivability factor "s "could give in some damaged conditions wrong information on the effective ship survivability and for this reason a new method, based on $GZ_{(Area)}$, it is necessary for the survival factor of damaged ships.

1. INTRODUCTION

Safety is a relative concept, both culturally and economically, and it is more important for the advanced societies than for those where life expectancy is marginal.

The safety of human life has become a topic of great interest for all the ship operators, after catastrophic accident at sea .

Evacuation of passengers and crew into lifeboats is an action of great hazard, and could be impractical in rough sea, with disastrous consequences. Therefore, the safety effort must be focused upon the ship itself to assure that abandonment at sea is indeed the last resort.

The ship which can not sink is not yet built and it is not possible to build it in the future.

The ship's probability to survive after damage is dependent on the residual buoyancy and stability and on the environmental conditions (wind, waves).

The purpose of international safety regulations is to assure an adequate safety standard concerning the ability of a vessel to survive damaged in a given sea state.

The required damage stability can not in all cases guarantee the survival of the ship over long time, specially if the accident takes place at unfavourable weather conditions. In any case the safety of human life depends on the survival time of the ship. Therefore, in the safety regulations this time should be compared with the probable evacuation time of the people.

However, the relation between regulations and casualty is generally a compromise among different requirements: economics, engineering, politics all have a strong influence.

The existing SOLAS subdivision regulations for cargo ships over 100 m. in length are based on probabilistic concepts. The IMO SLF Sub-Committee in the 42nd Session of 1999 established to revise these rules in order to introduce new probabilistic regulations applicable to all types of merchant ships.

On this topic a research project (HARDER) has been also financed by Europe Community and the IMO SLF Sub-Committee decided to deal with the revised regulations when relevant results from HARDER project will be available

2. SURVIVAL PROBABILISTIC CONCEPT

The survival of a damaged ship includes the following probabilities:

-the probability of flooding "p" relating to each single compartment and each possible group of two or more adjacent compartments;
-the probability "s" that the residual buoyancy and stability after damage will be sufficient for ship survival.

The global survival probability of the ship is given by the "Attained Subdivision Index

$$\text{"A"} = \sum p\, s \qquad (1)$$

determined as a sum of the products of these two probabilities, taking the summation over each single compartment and each group of two or more adjacent compartments.

The existing rules establish for the considered ship the necessity to have sufficient survival cases in aggregate which contribute to a ship's Attained Index equal or greater than the Required Subdivision Index R. This is obtained by a statistical sample of previous existing ships in order to ensure the average level of safety attained under the new probabilistic regulations equal to that attained under the previous deterministic regulations.

In any case, the existing probabilistic rules for cargo ships and those recently proposed for all types of ships consider only one global value of the Index "A", whichever contribution of the considered damaged zones

Such regulation could neglect the presence of vulnerable zones

The SOLAS future regulations should lead to an uniform distribution of the survival probability over the ship length by assuming an adequate, as far as possible, equal value of this probability in the final flooded condition for the single compartment and/or group of compartments under consideration.

3. SURVIVAL CRITERION

Whichever zone of the ship under consideration has been flooded, the ship survival probability “s” is given by the probability of not capsizing or sinking after such flooding. This factor is strongly dependent on the residual stability characteristics after damage.

In the SOLAS rules the factor "s" has been set to unity if the following conditions are verified:

- the final waterline and any waterline during the period of flooding is below the lower edge of any opening through which progressive flooding may take place;
- the angle of heel in final stage of flooding ϑ_c is not to exceed 25 degrees;
- in final stage of flooding there is a range of the righting lever curve of at least 20 degrees beyond the angle of equilibrium in association with a maximum righting arm of 0,1 m within the same range; for larger values always 0.1 m. will be considered; the factor "s" is set to zero value for ϑ_c equal or more than 30^0.

However the existing formula for “s”factor can be in some damage cases a wrong evaluation of the ship survival.

Several different proposals for the determination of this factor have been also suggested;damaged GM and damaged Freeboard were used in IMO resolution A.265; other damage stability criteria employ the use of properties of GZ lever curves, such as GZ_{Max}, $GZ(_{Range})$ or $GZ_{(Area)}$.

We think that an effective rational value of the survival factor "s_i^*" can be given by the lever righting area $GZ_{(Area)}$ which is a very meaningful parameter of the damaged ship resistance to heeling moments due to environmental conditions of the sea.

For this purpose the survival factor should be determined for each compartment or group of compartments by the algebraic “a”= $GZ_{(Area)}$ up to 40 degrees or the angle of downflooding, whichever is less being "a" the difference between the positive lever righting area "b"=$GZ_{(Positive\ Area)}$ and the eventual negative lever righting area "c"=$GZ_{(Negative\ Area)}$.

Only for example, relating to a numerical determination of the attained subdivision index, we have considered the following ratio:

$$"s^*"= "a"/0.030 \text{ m rad} \qquad (2)$$

if this ratio is equal or lower than one; the ratio greater than one could be considered a safety coefficient "k" for the ship in damaged conditions.

Consequently the Attained Subdivision Index shall calculated for the ship by the following proposed formula:

$$A^*= \sum p.s_i^* \qquad (3)$$

Where the factor "s_i" given by the text of the SOLAS chapter II-1,part B-1 should be replaced by the new expression of the survivability factor

$$s_i^*= 0.5\ s_l^*+ 0.5\ s_p^* \qquad (4)$$

being:

$$s_l^* = "a_l"/0.030 \text{ m rad} \qquad (5)$$

the factor at the deepest subdivision load line

$$s_p^* = "a_p"/0.030 \text{ m rad} \qquad (6)$$

the factor at the partial load line

In particular, in order to obtain uniform safety over the length of the ship should be taken , as far as possible, a constant values of survival factor "s^*_i" and eventual constant safety coefficient “k” for each single compartments or for two or more adjacent compartments according to considered type of ship.

4. PRACTICAL APPLICATION

In order to verify the possibility of vulnerable zones and the influence of the suggested formulation for the factor "s^*_i" on the calculated Attained Index "A^*", and consequently the effect of the transverse bulkhead positions on the global survival probability of a damaged ship, six standard box form ships 200 metres in length and with the same principal dimensions (Table 1) were considered.

All the six box forms are divided only into longitudinal compartments. By different position of transverse bulkheads four of these are divided into 11 zones, numbered from aft, and two in 12 zones by an additional bulkhead.

According to the SOLAS existing rules the following parameters were determined:

- the factor "p" relating to the flooding probability of single compartment or group of two adjacent compartments under consideration;
- the Required Subdivision Index

$$R = (0.002 + 0.0009\,L_S)^{1/3} = 0.566705 \qquad (7)$$

Table 1 Particulars of the investigated box-forms.

Length L_S	200 m
Breadth B	40 m
Depth D	24 m
Draught (deepest) d_S	12 m
Draught (partial) d_P	9.60 m
BM (deepest)	11.11 m
GM (deepest)	0.161.m
BM (partial)	13.89 m
GM (partial)	0.162 m

In tables 2a (box forms 1, 2, 3 and 4) with 11 zones; and 2b (box forms 5 and 6) with 12 zones the results of the calculation relating to the existing survivability factors “s” and to the proposed "s^*" are summarized.

The following considerations can be derived from the analysis of these results:

-The SOLAS rules give in any case "A"> "R" (Tab.3).

Table 3 Existing “A” and proposed “A*” Attained Subdivision Index

Box Form	"A"= $\sum p.s_i$	"A^*" = $\sum p.s_i^*$
1	0.72614	0.54933
2	0.704148	0.474080
3	0.654902	0.632921
4	0.650686	0.650686
5	0.77907	0.718671
6	0.760966	0.635868

However, these rules take not in account groups of compartments having high flooding probability and no or low survival probability, as shown by the results relating to some adjacent compartments of the considered box forms (Tab.4)

Table 4 Adjacent compartments with no or low "s"

Box Form	1	2	3	4
Compartments	2-3	3-4	5-6	4-5
Compartments	9-10	8-9	6-7	5-6
Compartments				6-7

With an additional bulkhead the existing rules applied to the box forms 5 and 6 seem give satisfactory results for nearly constant factor of survivability relating to all the compartments or all group of two adjacent compartments.

The proposed rules, based on $GZ_{(Area)}$,give an attained subdivision "A^* "≤ "A" and for the box forms 1 and 2 the value of "A^*" is lower than the required index R.

These new rules should give for the ship in damaged condition both an effective index of survivability by the factor "s* " and an important parameter of the ship safety by the index "k".

In particular the result "A *" <"A" mostly for the box forms 1, 2 and 6 is due to compartments having positive value of the survivability factor according SOLAS rules, but negative or very low $GZ_{(Area)}$ up to 40 degrees with negative GM in upright flooding condition, as shown by the GZ curves of the following groups of adjacent compartments:

Box n.1
-negative area at each load condition: group compartments 3-4 and 8-9 (Fig.2)
-negative area at partial PLL and very low positive area at deepest DLL load conditions: group compartments 4-5 and 7-8 (Fig. 3).

Box n.2
-negative area at each load condition: group compartments 2-3 and 9-10 (Fig.4) or 5-6 and 6-7 (Fig. 5);
-negative area at partial PLL and very low positive area at deepest DLL condition: group compartments 4-5 and 7-8 (Fig.6).

Box n.6
-negative area at each load condition: group compartments 5-6 and 6-7 (Fig.7)
low positive area at each load condition: group compartments 3-4 and 9-10 (Fig.8).

Tab. 2a - Comparison among existing and proposed subdivision indices

	Box Form 1						**Box Form 2**					
Comp.	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**
1	.012698	1	.284	.265	1	9.16	.012698	1	.284	.266	1	9.16
2	.020093	1	.194	.168	1	6.00	.011338	1	.242	.219	1	7.69
3	.025833	1	.202	.175	1	6.28	.024398	1	.200	.174	1	6.23
4	.031574	1	.196	.177	1	6.21	.046269	1	.162	.131	1	4.95
5	.037315	1	.201	.180	1	6.36	.021416	1	.248	.224	1	7.86
6	.043056	1	.201	.180	1	6.36	.089063	1	.130	.091	1	3.67
7	.043056	1	.201	.180	1	6.36	.025195	1	.248	.224	1	7.86
8	.043056	1	.196	.177	1	6.21	.064562	1	.162	.131	1	4.95
9	.043056	1	.202	.175	1	6.28	.043056	1	.200	.174	1	6.23
10	.043056	1	.194	.168	1	6.00	.025195	1	.242	.219	1	7.69
11	.035816	1	.284	.265	1	9.16	.035816	1	.284	.266	1	9.16
1 - 2	.022588	1	.046	.043	1	1.47	.018483	.933	.127	.108	1	3.90
2 - 3	.031111	0	-.137	-.080	0	-3.62	.024149	.760	-.021	-.003	0	-0.39
3 - 4	.038889	.587	-.011	-.026	0	-0.62	.042448	0	-.133	-.093	0	-3.75
4 - 5	.046667	.974	.029	-.011	.29	0.29	.043056	1	.022	-.013	.15	0.15
5 - 6	.054444	.974	.038	-.005	.55	0.55	.054844	.806	-.004	-.052	0	-0.92
6 - 7	.058333	.974	.038	-.005	.55	0.55	.059766	.806	-.004	-.052	0	-0.92
7 - 8	.058333	.974	.029	-.011	.29	0.29	.054688	1	.022	-.013	.15	0.15
8 - 9	.058333	.587	-.011	-.026	0	-0.62	.066406	0	-.133	-.093	0	-3.75
9 - 10	.058333	0	-.137	-.080	0	-3.62	.047656	.760	-.021	-.003	0	-0.39
10 - 11	.055660	1	.046	.043	1	1.47	.046270	.933	.127	.108	1	3.90

	Box Form 3						Box Form 4					
Comp.	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**
1	.021170	1	.145	.217	1	6.04	.012698	1	.284	.266	1	9.16
2	.012178	1	.243	.220	1	7.72	.011338	1	.242	.219	1	7.68
3	.025833	1	.207	.175	1	6.37	.013857	1	.248	.221	1	7.95
4	.018057	1	.247	.224	1	7.84	.016377	1	.250	.223	1	7.88
5	.020576	1	.247	.224	1	7.84	.094657	1	.086	.040	1	2.09
6	.144444	1	.418	-.003	1	0.64	.144444	1	.037	.057	1	1.56
7	.025195	1	.247	.224	1	7.84	.025195	1	.252	.223	1	7.88
8	.025195	1	.247	.224	1	7.84	.025195	1	.250	.223	1	7.88
9	.043056	1	.207	.175	1	6.37	.025195	1	.248	.221	1	7.98
10	.025195	1	.243	.220	1	7.72	.025195	1	.242	.219	1	7.68
11	.057598	1	.145	.217	1	6.04	.035816	1	.284	.260	1	9.16
1 - 2	.022031	1	.052	.043	1	1.59	.018483	1	.127	.107	1	3.79
2 - 3	.025738	.89	.028	.008	.59	0.59	.019336	1	.086	.060	1	2.43
3 - 4	.031450	.85	.051	.027	1	1.31	.023203	1	.105	.075	1	4.15
4 - 5	.029648	1	.121	.085	1	3.44	.045366	0	-.121	-.119	0	-3.99
5 - 6	.057279	0	-.022	-.152	0	-2.89	.097198	0	-.329	-.366	0	-6.09
6 - 7	.064360	0	-.022	-.152	0	-2.89	.064360	0	-.079	-.155	0	-3.9
7 - 8	.038672	1	.121	.085	1	3.44	.038672	1	.079	.082	1	5.36
8 - 9	.047656	1	.051	.027	1	1.31	.038672	1	.105	.075	1	4.15
9 - 10	.047656	.89	.028	.008	.59	0.59	.038672	.93	.086	.060	1	2.43
10 - 11	.006270	1	.052	.043	1	1.59	.046270	1	.127	.107	1	3.79

Tab. 2b - Comparison among existing and proposed subdivision indices

	Box Form 5						Box Form 6					
Comp.	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**	**"p"**	**"s"**	**"a_l"**	**"a_p"**	**"s*"**	**"k"**
1	.012698	1	.284	.266	1	9.16	.012698	1	.284	.266	1	9.16
2	.011338	1	.242	.219	1	7.68	.011338	1	.242	.219	1	7.68
3	.019845	1	.224	.193	1	6.95	.019845	1	.224	.193	1	6.95
4	.024098	1	.227	.195	1	7.03	.024098	1	.227	.195	1	7.03
5	.031467	1	.222	.188	1	6.83	.019904	1	.253	.223	1	7.93
6	.040185	1	.217	.181	1	6.62	.083719	1	.145	.090	1	3.90
7	.043056	1	.217	.807	1	6.62	.025195	1	.254	.223	1	7.93
8	.039171	1	.222	.188	1	6.83	.035438	1	.224	.197	1	6.95
9	.035438	1	.227	.196	1	7.03	.035438	1	.227	.195	1	7.03
10	.035438	1	.224	.196	1	6.95	.035438	1	.224	.193	1	6.95
11	.025195	1	.242	.219	1	7.68	.025195	1	.242	.219	1	7.68
12	.035816	1	.284	.266	1	9.16	.035816	1	.284	.266	1	9.16
1 - 2	.018483	1	.127	.108	1	3.90	.018483	1	.127	.108	1	3.90
2 - 3	.022331	.970	.030	.023	.89	0.89	.022331	.970	.030	.023	.89	0.89
3 - 4	.031388	.940	.030	.023	.69	0.89	.031388	.970	.026	.011	.69	0.69
4 - 5	.038954	1	.050	.015	1	1.08	.032597	1	.089	.053	1	2.37
5 - 6	.048958	.970	.040	.004	.73	7.29	.051258	.810	-.001	-.055	0	-2.44
6 - 7	.061204	.970	.039	-.004	.59	0.59	.063369	.850	.004	-.052	0	-0.96
7 - 8	.056406	.970	.040	.004	.59	0.73	.044297	1	.093	.060	1	2.47
8 - 9	.052547	1	.050	.015	1	1.08	.050625	1	.089	.011	1	2.37
9 - 10	.050625	.940	.030	.023	.69	0.89	.050625	.970	.030	.011	.69	0.69
10 - 11	.044297	.970	.030	.023	.89	0.89	.044297	.970	.030	.023	.89	0.89
11 - 12	.046270	1	.127	.108	1	3.90	.046270	1	.127	.107	1	3.90

5. CONCLUDING REMARKS

The probabilistic method of assessment of damaged stability, based on statistical damage information, gives us a means whereby the safety standard of a ship should be assessed.

There are proposal by IMO to accept in the next years only probabilistic rules both for passenger and cargo ships

The SOLAS existing subdivision rules chapter II-1, part B-1 relating to cargo ships do not seem to offer a correct comparative safety evaluation of the ships against any possible damage.

The calculated attained index "A" may be considered as conventional measure of the ship safety in damaged condition and it should be considered as the global probability of ship survival in the case of hypothetical damage flooding. This index "A"= $\sum p.s$ = $\sum dA$ is a summation of the contribution dA given by each possible damage flooding of the ship. In the existing subdivision rules for cargo ships "A" must be higher than the required index R, whichever the contribution of the considered flooding may be. The application of such regulation can determine on the ship the probability of the occurrence of vulnerable zones having high value of flooding probability and low or no value of the ship survival probability, and consequently with high probability relating to the loss of human life. A box-shaped barge with transversal subdivision only is not appropriate to conclude upon a survival criterion , however, we think that in the paper has been also highlighted that the SOLAS "s" factor could give in some damaged conditions wrong information on the ship survivability.

Therefore, there is the need to improve the calculation of the attained index "A". In particular, it is evident that this calculation must be carried out by taking in account the following considerations:

- To assume a different clearly meaningful survival factor, which could be, for each damaged zone, the algebraic total $GZ_{(Area)}$ up to 40 degrees, or up to the flooding angle, if this is less than 40^{o}, as this factor gives a good indication on the safety level of damaged ship.
- To have a constant value, as far as possible, for the survival factor on each damaged zone over the ship length and to accept a minimum value for this factor on the considered zone.

This condition should be obtained before the ship construction, by careful consideration of, the bulkheads position.

Some other considerations can be done on the subdivision rules, such as:

-the light service draught, due to its significant influence on the index "A", should be clearly defined so that to avoid possible different interpretations;
-a suitable and clearly defined maximum value of KG should be selected for all the load conditions of the ship.

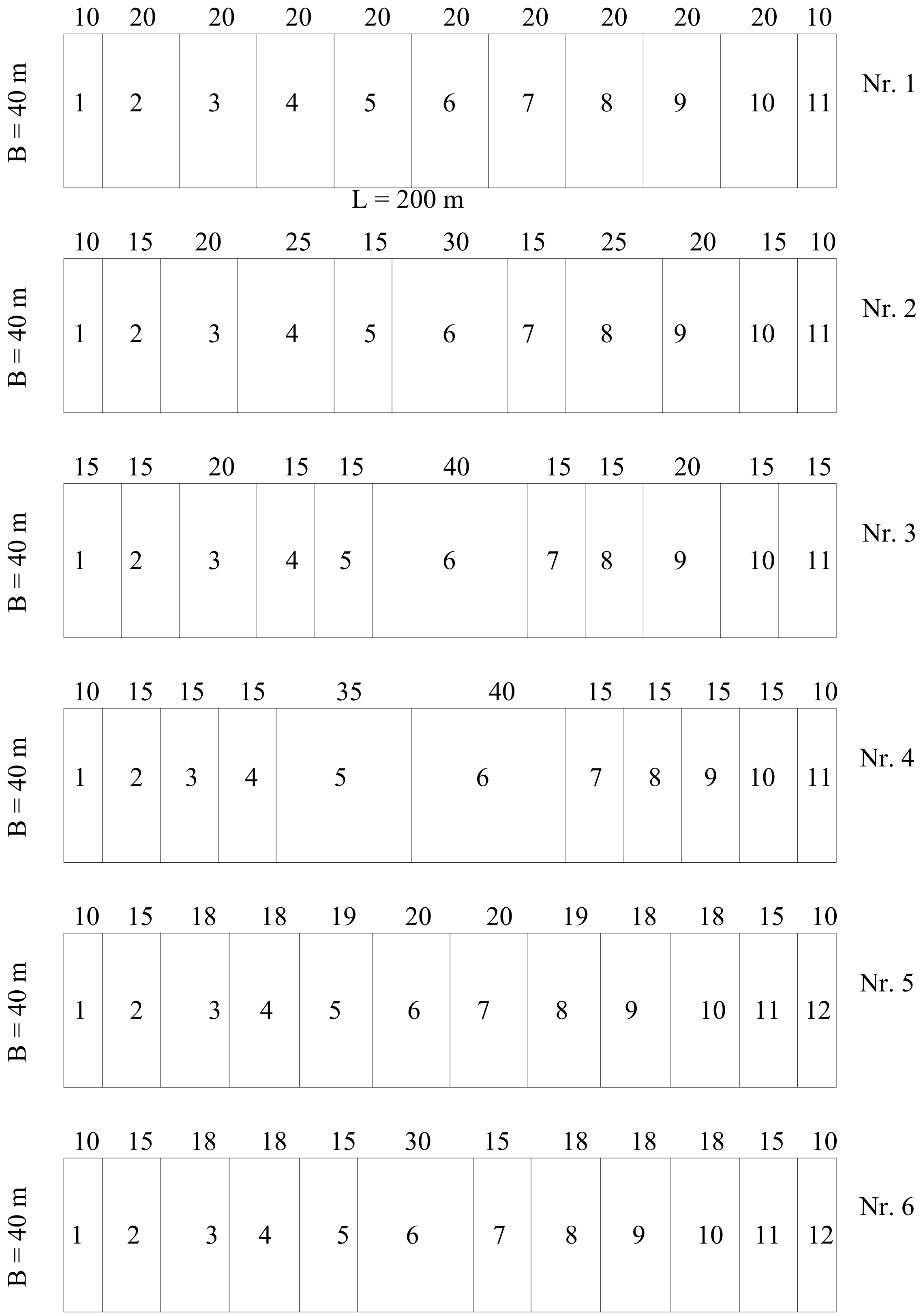

Fig. 1 – Box Form Ships

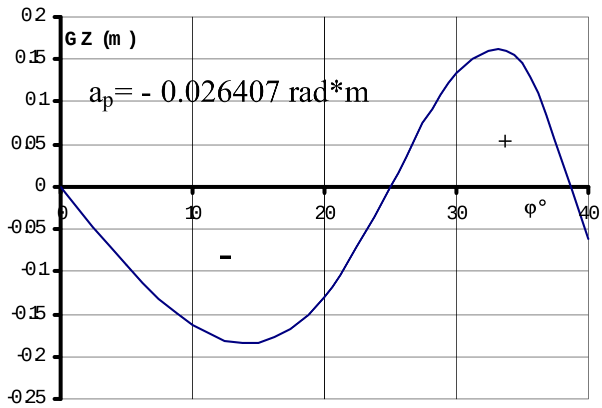

Fig. 2a – PLL Nr.1 Damaged Comp. 3-4

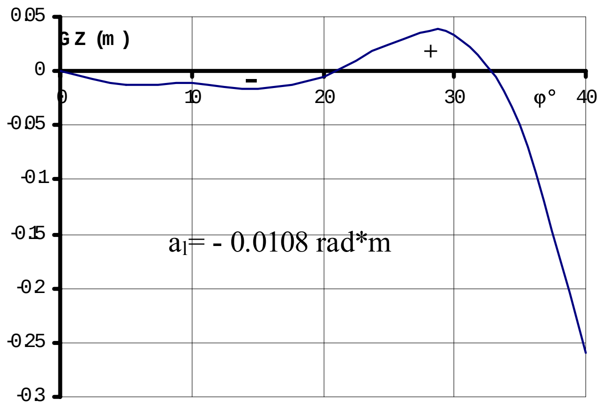

Fig. 2b – DLL Nr.1 Damaged Comp. 3-4

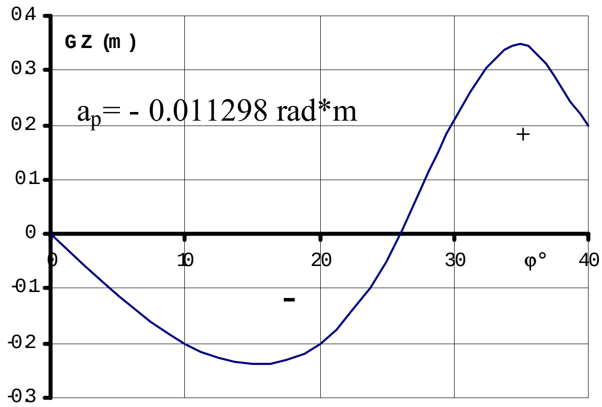

Fig. 3a – PLL Nr.1 Damaged Comp. 4-5

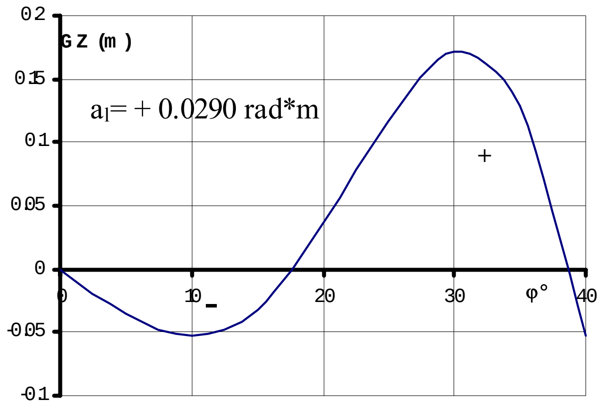

Fig. 3b – DLL Nr.1 Damaged Comp. 4-5

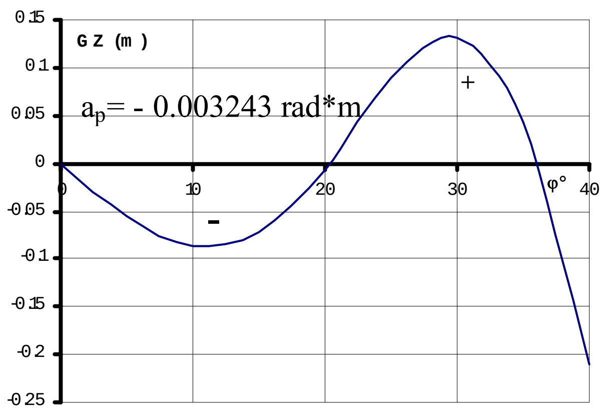

Fig. 4a – PLL Nr.2 Damaged Comp. 2-3

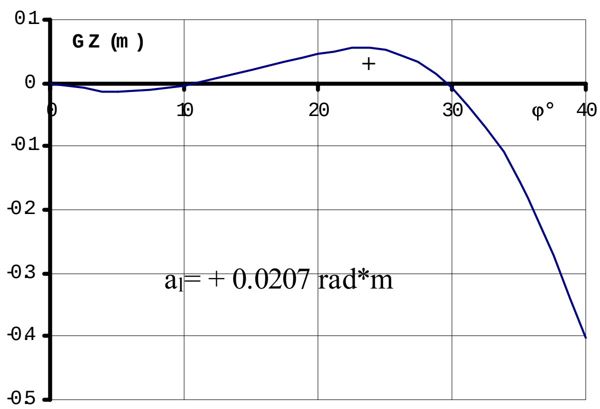

Fig. 4b – DLL Nr.2 Damaged Comp. 2-3

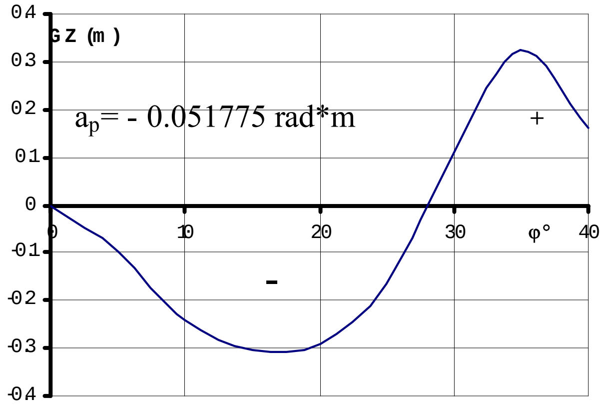

Fig. 5a – PLL Nr.2 Damaged Comp. 5-6

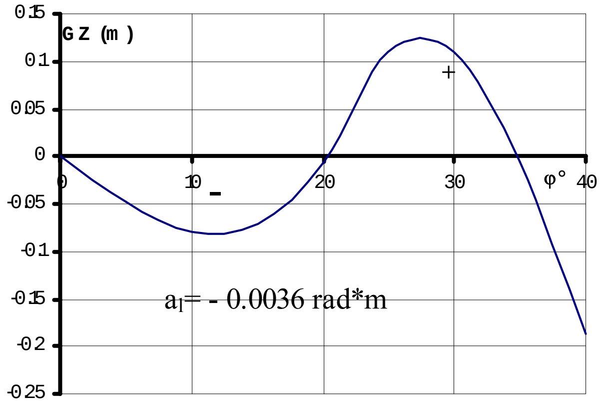

Fig. 5b – DLL Nr.2 Damaged Comp. 5-6

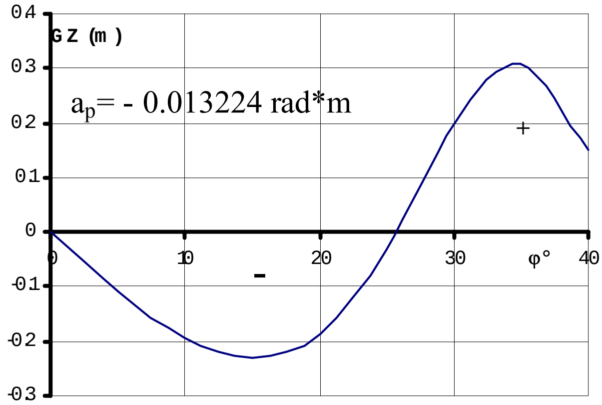

Fig. 6a – PLL Nr.2 Damaged Comp. 4-5

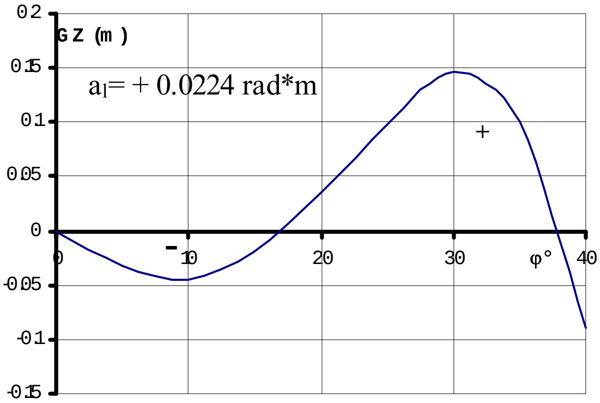

Fig. 6b – DLL Nr.2 Damaged Comp. 4-5

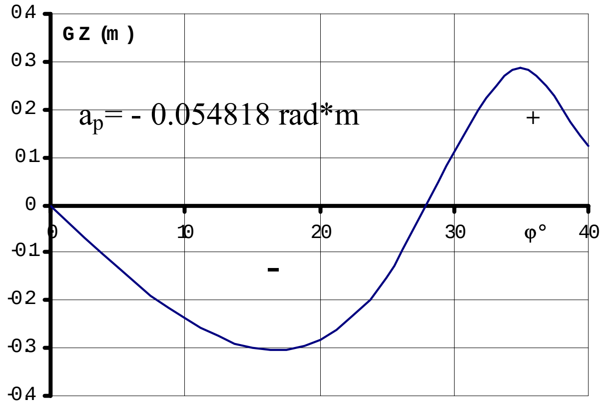

Fig. 7a – PLL Nr.6 Damaged Comp. 5-6

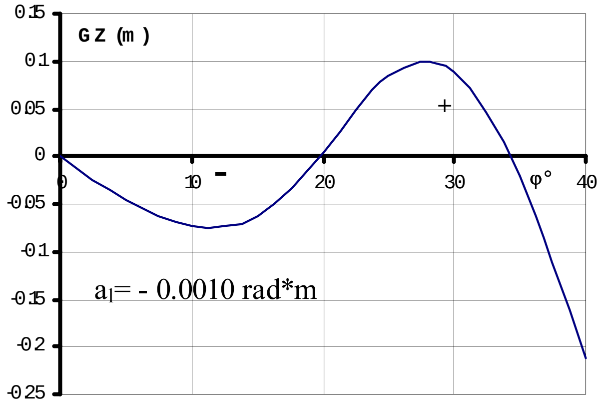

Fig. 7b – DLL Nr.6 Damaged Comp. 5-6

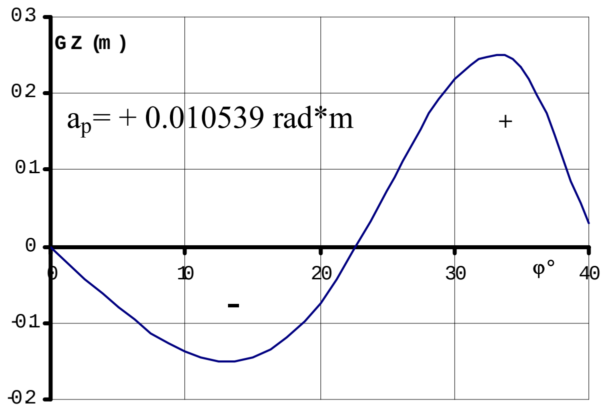

Fig. 8a – PLL Nr.6 Damaged Comp. 3-4

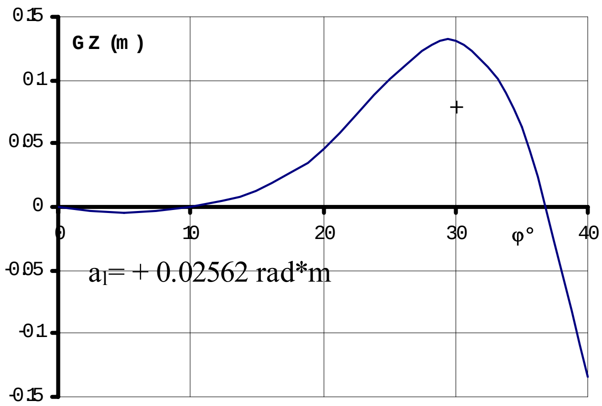

Fig. 8b – DLL Nr.6 Damaged Comp. 3-4

6. ACKNOWLEDGEMENTS

This work has been financially supported by University of Naples "Federico II" within the frame of 2002-2003 research program.

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