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Comparison of bulk carriers safety at alternate and homogeneous loading

SUMMARY

Bulk carriers have been designed with a small margin of safety. The extensive corrosion and very difficult operation conditions caused that some of old bulk carriers have insufficient strength to withstand the heaviest storms.

The paper presents the influence of changing the loading condition from alternate loading (cargo in every second hold) into uniform (cargo in each hold) distribution of heavy cargo on the improvement of safety of old bulk carriers. The strength of the structures, ship stability and transverse accelerations are analysed depending on the loading conditions. The flooding of one hold is also taken into account in the analyses.

INTRODUCTION

Heavy losses of bulk carriers during the last five years [1] (over 100 ships and over 600 lives lost) caused that international organizations have started to explain the reasons of these catastrophes. The majority of them are damages of structure in heavy weather conditions [1]. The analyses of bulk carriers losses enabled to determine typical scenarios of their sinkage (for example [2]):

- appearance of cracks of side plating or even break in the side due to excessive corrosion of the end connections of side frames
- flooding of the hold with sea water
- collapse of the corrugated bulkhead loaded at one side (alternate loading condition) by heavy cargo and water, or/and significant change of the ship's trim causing the deck submergence
- wave attack on hatch covers of undamaged holds in extremely heavy weather conditions and damage of hatch covers (the hatch covers are designed to withstand the load of 1.7 m height of water)
- flooding of the next holds and sinkage of the ship due to lack of buoyancy.

The bulk carriers have been designed with a small margin of safety. Higher tensile steels were used widely. Accelerations acting on the large density cargo overload the corroded structure. This causes damage to the structure members – most frequently the frames side brackets and, as a result, the cracks of side plating or even collapse of the side. After flooding the hold, the corroded corrugated bulkheads are normally not able to sustain the load caused by heavy cargo and water acting at one side as it happens in alternate loading conditions. The collapse of a bulkhead creates a very dangerous situation for the ship, leading usually to its sinking as it has been above described.

The corrosion of high strength steel normally used for bulk carrier's construction causes more intensive decrease of structure strength than it is in the case of ships built of normal steel.

WAYS OF IMPROVING THE STRENGTH OF OLD BULK CARRIERS

Within the scope of the general strength of bulk carriers, stresses resulting from bending and shearing of the hull girder are analyzed. Additionally, the possibility of buckling of the compressed deck or bottom structure, resulting from the general bending, is checked. The corrosion reduces the thickness of the structure members during operation of the ship which results in the decreased section modulus. It has been agreed within IACS (International Association of Classification Societies) that the section modulus of the corroded cross section of the hull is not to increase the maximum stresses in hull girder to a level greater than 10% of the permissible stresses. If the maximum stresses are greater, there are two ways of solving the problem:

- strengthening the hull in order to increase the section modulus, (replacement of the corroded members, installing additional longitudinals or doublers)
- decreasing the design value of the maximum bending moment in still water.

Usually, ship owners choose the second solution, as repairs, to improve the strength of the ship, are expensive. Decreasing of the design bending moments can be reached by resigning of the loading conditions which generate the greatest bending moments. The change of alternate loading into homogeneous one also decreases the bending moments.

The zone strength analysis enables to determine the stresses and identify the most loaded principal members. The results of zone strength calculations for different loading condition of a bulk carrier (L=280 m) are shown in Fig.5.

If the zone strength of the ship structure is not sufficient (for example, due to corrosion wastage) there are two ways of improving that situation:

- changing the alternate loading (heavy cargo in every second hold) of the ship into the homogeneous loading as the uniformly distributed cargo significantly reduces the loads acting on the bottom and bulkhead structure
- replacement of the corroded members in which the stresses exceed the permissible stresses.

The reduction of the local strength is a result of corrosion wastage or damage of the structure during unloading of ship (indents, deformations, cracks, etc.). The direct reason of losing the strength of the structure members is due to their bad maintenance. The local strength is estimated during the periodical surveys made by surveyors of the classification societies. Surveyors have to verify the thickness measurements which are the basis for the general and zone strength calculations and give, after inspection of hull structure, recommendation for replacing the corroded or damaged members. To improve the periodical surveys of bulk carriers IACS has introduced the Enhanced Survey Programme, based on special unified requirements and guidelines (for exemple [3]).

STRENGTH OF BULKHEADS IN SHIP DAMAGE CONDITIONS

The losses of bulk carriers have caused that IACS is now considering the possibility of introducing additional requirements, where the individual flooding of each hold is the additional loading condition which should be taken into account in evaluating the structure.

This requirement will have great influence on the scantlings of bulk carriers in the future. The flooding of one hold is very dangerous for existing bulk carriers, as it can lead, according to the scenario, to progressive flooding. To stop such flooding, relevant strength of corrugated bulkheads, as a second line of defence, is required. However the corrugated bulkheads of existing bulk carriers are not able to withstand loads resulting from the simultaneous loading of the bulkhead by heavy cargo and water from flooded hold, in alternate loading condition (Fig.1).

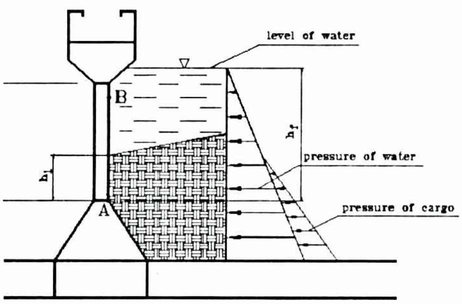

Fig.1. Load of the bulkhead in flooding condition

The results of calculations of the corrugated bulkheads strength, performed for four ships according to the proposed requirements, show that only one bulkhead, which is the deep tank standard bulkhead, almost satisfies these requirements (Table 1).

Table 1. Bending stresses in the bulkhead corrugations, in the alternate loading and flooding conditions

Ship	Lpp [m]	No of holds	Bulkhead location between holds	R_e [MPa]	σ [MPa]	σ / R_e
1	215,0	7	1-2	235	313	1,33
2	136,0	5	2-3	235	273	1,16
3	185,0	7	1-2	235	258	1,09
4	163,0	5	1-2	235	331	1,4

σ - *the normal stress resulting from bending the bulkhead corrugations, at the point A (Fig.1)*
R_e - *material yield point*

The double bottom structures of existing bulk carriers are also not able to carry the load caused by the cargo and water in the flooded holds. This is illustrated by the results of calculations presented in Fig.5. The calculations have been performed by using the MAESTRO program.

STABILITY OF BULK CARRIERS IN DAMAGE CONDITIONS

The damage stability of bulk carriers was analyzed in [4] and the analysis showed that:

- The loss of buoyancy due to damage can occur in the following cases (see Tab.2):
  - on small bulk carriers with two cargo holds, at any loading condition and after flooding at least one hold or engine room
  - on bulk carriers with five cargo holds, after flooding two first holds or the aft hold and engine room, especially at heavy cargo condition
  - on bulk carriers with seven cargo holds, only at heavy cargo condition and with the engine room and aft hold flooded simultaneously
- When the first holds (or the aft hold and the engine room) are flooded, the forward part of the ship (the aft part of the ship) submerges and water can get through hatch covers and ventilation heads to the undamaged holds. This normally results in the loss of the ship
- The flooding of a single compartment (a hold or the engine room) of a bulk carrier with more than four holds does not cause losing its buoyancy

Table 2. The compartments after flooding of which the ship loses positive buoyancy (see Fig.2)

Loading condition	2 holds	5 holds						7 holds		
	Ship's length [m]	Ship's length [m]						Ship's length [m]		
	88	185	137	172	133	150	134	186	215	185
Ballast	2 & 3 3 & 4	—	—	—	—	—	—	—	—	—
Heavy cargo	4 2 & 3 3 & 4 4 & 5	5 & 6 6 & 7	5 & 6 6 & 7	2 & 3 6 & 7	2 & 3	2 & 3 6 & 7	2 & 3	—	—	2 & 3
Homogeneous cargo	2 3 4 1 & 2 2 & 3 3 & 4 4 & 5	2 & 3 6 & 7	2 & 3 5 & 6 6 & 7	2 & 3 6 & 7	2 & 3	2 & 3	2 & 3	—	—	—

It should be read as follows: e.g.: „2 & 3" - the engine room and aft hold flooded, „6 & 7" - the fore holds „1 & 2" - flooded on a ship with five holds, „4 & 5" - the fore hold No 1 and forepeak flooded on a ship with two holds.

- The damaged and having positive buoyancy bulk carriers are stable
- The trim and heeling angles of damaged bulk carriers in an equilibrium position are rather small and the cargo cannot shift at these angles.

flooding causes the submergence of the deck (Fig.3) and the hatch covers of existing bulk carriers are not able to withstand the wave loads.

The increase of the trim is smaller in the case of the homogeneous loading than in that of alternate loading (Fig.3) and the first case is more safe from the point of view of hatch cover strength.

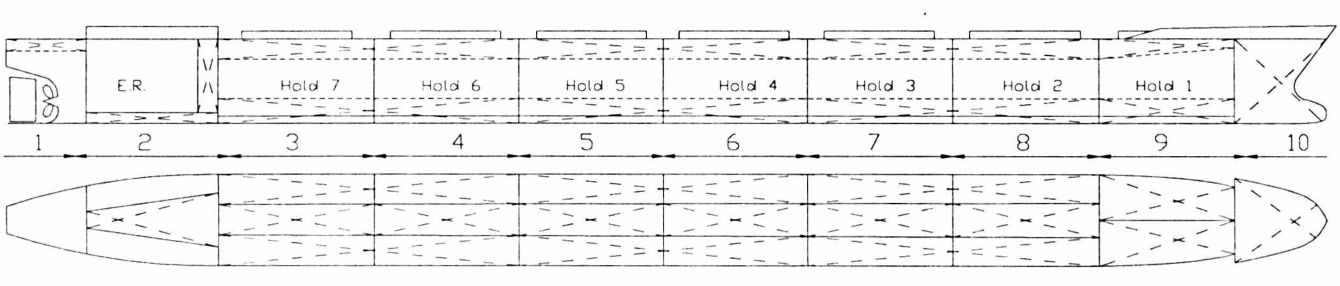

Fig.2. Subdivision of the bulk carrier into watertight compartments (1÷10 - compartments considered as flooded)

THE INFLUENCE OF LOADING CONDITION ON THE BEHAVIOUR OF BULK CARRIERS AND LOADING OF THEIR STRUCTURES IN WAVES

Transverse accelerations as a dynamic response of the ship in waves

Heavy cargo is usually loaded in every second hold of bulk carrier to raise the centre of mass of the ship because uniformly distributed cargo in all holds makes the ship too "stiff " and high transverse accelerations can occur, which makes the ship inconvenient for the crew. To investigate the influence of the change of the loading condition on the transverse accelerations (a_T), the accelerations at the bridge of a bulk carrier of L=215 m (with seven holds) were calculated in different sea states and different heading angles of the ship against waves. The sea state is determined by the significant wave height H_s, characteristic period T and relative angle β (β=180° determines the head waves).The results of the calculations are presented in Tab.3. The numbers in it determine the average from 1/10 of the highest transverse accelerations in given sea states. It can be observed from the table that:

- the change of loading condition from alternate to homogeneous increases the transverse accelerations at bridge in average by about 25%
- the change of heading angle for example from β=120 to 150° reduces a_T by about 60%.

The calculations show that the transverse accelerations can be controlled (reduced) by changing the course of the ship in relation to waves.

Table 3. Acceleration (a_T) at the bridge at different loading conditions [m/s^2]

(H_s,T)	Alternate for β=			homogeneous for β=		
	120°	150°	180°	120°	150°	180°
(2.5, 4.4)	0.15	0.07	0.0	0.16	0.07	0.0
(3.5, 5.3)	0.47	0.16	0.0	0.5	0.17	0.0
(4.5, 6.1)	0.94	0.29	0.0	1.1	0.32	0.0
(5.5, 6.9)	1.67	0.49	0.0	2.2	0.59	0.0
(6.5, 7.8)	2.90	0.87	0.0	3.8	1.1	0.0
(7.5, 8.8)	4.5	1.58	0.0	5.6	1.86	0.0
(8.5, 9.8)	5.9	2.43	0.0	6.8	2.5	0.0
(9.5, 10.7)	6.9	3.16	0.0	7.7	3.0	0.0
(11, 11.7)	7.9	3.9	0.0	8.4	3.54	0.0
(13, 12.8)	8.7	4.6	0.0	9.1	3.13	0.0
(15, 14.3)	9.0	4.98	0.0	9.1	3.99	0.0
(17, 16.1)	8.66	4.88	0.0	8.6	3.67	0.0

Trim after flooding

The increase of the trim after flooding the first or the last holds is dangerous in the case of alternate loading for hatch covers as normally the

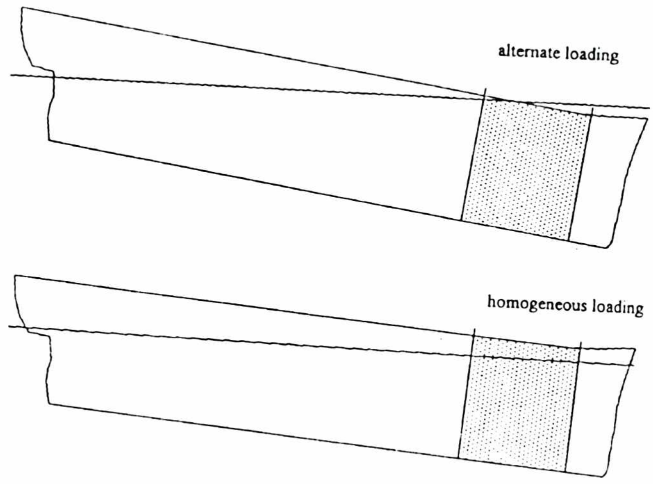

Fig.3. The trim of a bulk carrier with seven holds, loaded alternately and homogeneously, after flooding the first two holds

Ship structure strength

The influence of the loading condition on the ship strength is significant. The homogeneous loading of bulk carriers by heavy cargo causes much smaller bending moments than the distribution of the cargo in every second hold (see Fig.4). The change of the ship loading from alternate into homogeneous causes also the change of the hull deflection from hogging to sagging. In the sagging condition, the deck is compressed and this can become dangerous for large bulk carriers since, after flooding the midship hold of such ships, the increase of the deck compression is so great that the deck structure can buckle and this can lead to the collapse of the ship's hull. Resignation of the alternate loading condition significantly decreases the loads of bulkheads which results in smaller stresses, even in the flooding conditions. This can be observed when comparing the results of the calculations, presented in Tab.1 and 4.

Table 4. Maximum values of bending stresses in the bulkhead corrugations in the homogeneous loading and flooding conditions

Ship	σ [MPa]	R_e [MPa]	σ / R_e
1	204	235	0,87
2	184	235	0,78
3	207	235	0,88
4	265	235	1,13

However, the change of the loading condition most significantly influences the loading of the bottom structure. The stresses in the principal members of the bottom structure are much smaller (even in the flooding condition) in the homogeneous loading than in the alternate loading. This can be observed when comparing the results of calculations, presented in Fig.5.

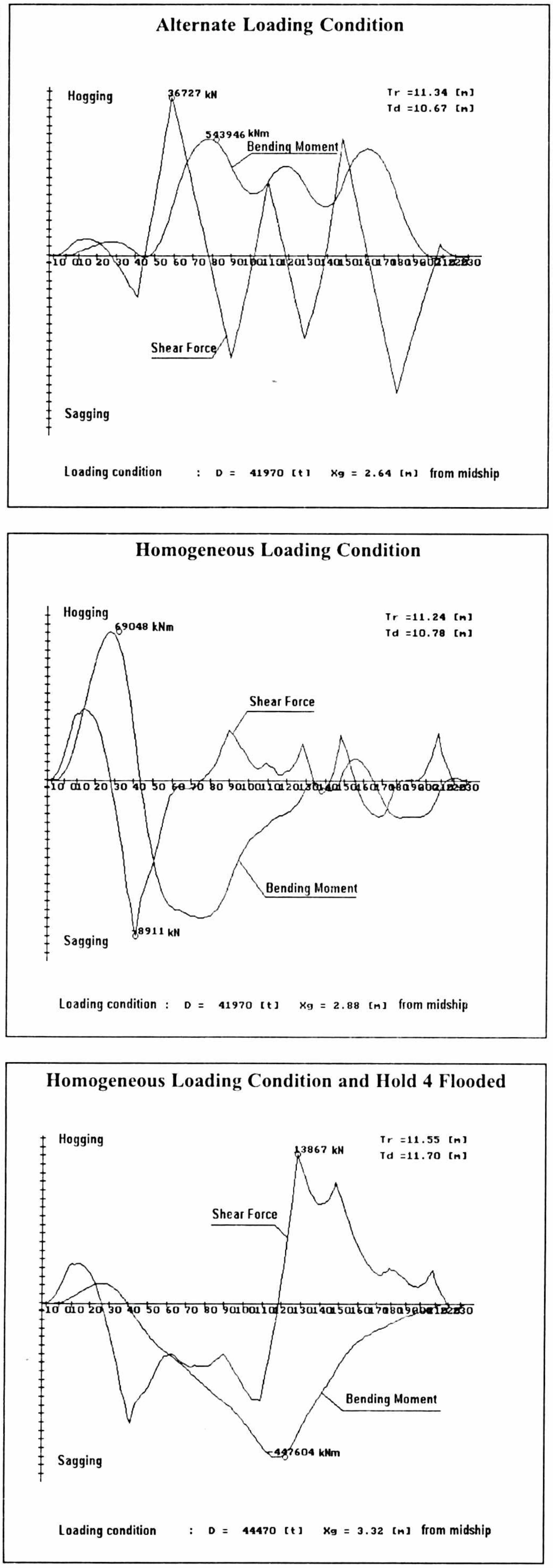

Fig.4. Still water bending moments and shear forces in a bulk carrier of L=185 m

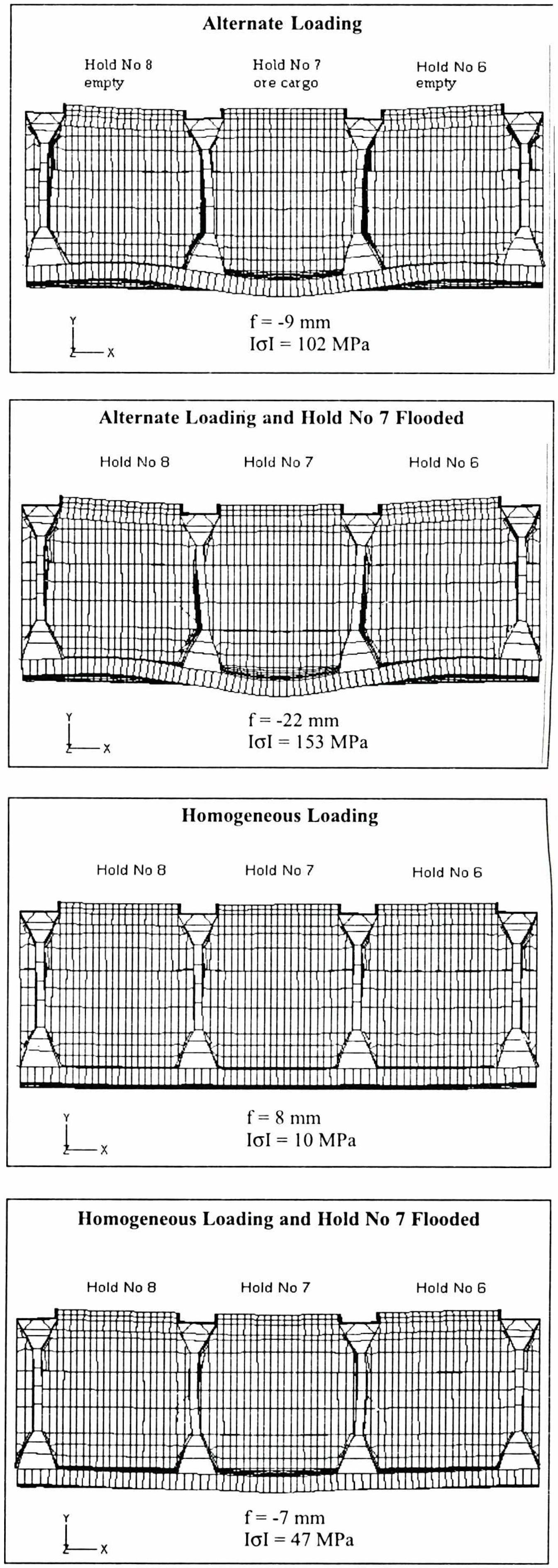

Fig.5. Results of the zone strength analysis of a bulk carrier (L=280 m)

CONCLUSIONS

- Heavy losses of bulk carriers during the last five years resulted in the discussion on introducting of new minimum safety standards which take into account the damage conditions (with one flooded hold). The existing bulk carriers are not able to satisfy these requirements; therefore it is necessary:
  - to strengthen their structure or
  - to decrease their loading.
- Ship owners usually choose the second solution as the strengthening of the ship is expensive. The decrease of bulk carrier loading can be obtained by:
  - resigning from the loading conditions which generate the greatest bending moments or shear forces
  - changing the alternate loading of the ship with heavy cargo in every second hold into the uniform distribution of the cargo in all holds.
- Uniformly distributed cargo in all holds decreases the loads acting on the bottom and bulkheads. However, such loading causes:
  - the increase of transverse accelerations which can be decreased at sea by changing the relative angle between the ship's course and the wave direction
  - the sagging deflection of the ship which can lead to buckling of the deck and collapse of the ship hull after flooding the midship hold on large bulk carriers.
- The damaged bulk carriers in heavy weather increase the trim which normally results in deck submergence. Subsequently the waves attack and damage the hatch covers of unflooded holds. The increase of trim after flooding the first holds of the ship loaded homogeneously is smaller than in the case of alternate loading.
- The flooding of one compartment (hold) of a bulk carrier with more than four holds does not cause the loss of its buoyancy.
- The damaged and having positive buoyancy bulk carriers will not capsize.

NOMENCLATURE

a_T	- ship transverse acceleration
D	- ship displacement
f	- maximum deflection of bottom primary members
H_s	- significant wave height
L	- ship length
L_{pp}	- ship length between perpendiculars
R_e	- yield strength
T	- characteristic wave period
T_d	- forward draught
T_r	- after draught
x_g	- longitudinal coordinate of ship's centre of gravity
β	- ship heading angle against wave
σ	- in Fig.5: stress resulting from bending of bottom primary members
	- in Tab. 4: maximum bending stress in bulkhead corrugations

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Conferences

INLAND AND MARITIME NAVIGATION AND COASTAL PROBLEMS OF EAST EUROPEAN COUNTRIES

Under this slogan a conference was held from 1 to 5 September 1996 in Gdańsk. It was organized by Technical University of Gdańsk, Marine Civil Engineering Department, under auspices of Permanent International Association of Navigation Congresses (PIANC), Permanent Committee for Development and Cooperation (PCDC) and Central Dredging Association (CEDA). The conference, held in the main building of the University, had a worldwide range gathering 79 persons from 22 European countries, Japan and USA, , apart from 57 Polish participants who were the largest group. The numerous groups were also of Belgium (18 persons) Germany (11 persons) and Netherlands (9 persons).

61 papers were prepared for the conference, 42 of which were presented and discussed during four working sessions:

I Inland and maritime navigation and coastal problems particularly in the Baltic Sea Countries (10 papers)

II Inland and maritime navigation and coastal problems particularly in the Black Sea and Adriatic Sea countries (9 papers)

III Inland navigation particularly in East European countries without direct access to sea (11 papers)

IV Environmental aspects of dredging (12 papers)

Moreover, a panel session with 19 papers took place.

37 papers were prepared by experts from abroad, and the remaining 24 - by representatives of Polish institutions.

The following topics were within the scope of the conference:

- Inland navigation in East European countries and its link to other countries (existing state and future development)
- Maritime navigation in East European countries with particular consideration of shipping in different seas (Baltic, Black Sea, Adriatic) and along coasts of these seas (existing state and future development)
- Competitiveness of navigable waterways
- Pollution of different seas due to contaminated water of rivers having their mouths in the considered seas. Contaminated dredging material dealing with contaminated sediments
- Coastal problems in East European countries with particular consideration of sediment, beach and harbour pollution. Management of coastal zone
- Rehabilitation and modernization of existing structures connected with inland and maritime navigation and beach protection
- Particular areas of shipping (e.g. short sea shipping from Scandinavian ports up to rivers in North-East Europe)
- Dredging operation and dredged material disposal in the sea
- Beneficial uses of dredged material.

It should be acknowledged that the conference was very well organized and efforts were made to take care of participants' convenience and needs. The conference was accompanied by many additional events which made the mutual acquaintance of the participants possible, as well as it gave an opportunity of sightseeing the most important ancient monuments of Gdańsk, visiting the Baltexpo '96 International Exhibition and hearing an organ concert in the old cathedral church in Oliva.

The conference proceedings were issued in three neatly edited volumes, which contained also the list of names and addresses of all participants to make further mutual contacts of them easier.

The organizers did not forget to attach a booklet to the conference materials, in which information about Polish maritime economy was presented.