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SPECIAL PROBLEMS ON THE HYDRODYNAMICS OF THE HIGH SPEED PLANING CRAFT

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Abstract: *In the first part of this paper there are presented the stages achieved at the design of the craft and the necessity of replacement the traditional building materials by others with high performance. The influence of the waves on the hull plates of the craft is analysed, performing a calculation program for the study of the wave elements as a function of the wind speed. In the second part, there are analysed the wave effects on the craft's hull plates, both statically and dynamically, determining the dynamical bottoming factor of the wave. Finally, it is calculated the number of cycles in a navigation season, acting on the hull plates on the wave steps.*
Keywords: *waves, the wave characteristics in the Black Sea, loads, number of cycles from the wave, material fatigue.*

1. INTRODUCTION

After the craft building analysis – pleasure, fishing and sport crafts on the market of Europe and America (1099 models performed in 1997) it results that 85% were made of composite materials, 12.4% of rolled steel and 2.1% of aluminium.

The idea of composite material design with high mechanical performance is based on the use of some high strength materials and on the observation that when the diameter of the reinforcing filament decreases, the strength increases.

The designing process of the craft includes the flow in which the designer analyses the following:

- the environmental conditions for the operating area of the craft (establishing the operation restraints, if any);
- the loads in the different navigation conditions from which the dimensions of the hull plates and the strength structure result ;
- the craft's reactions (motions and accelerations);
- stresses and strains of the craft's hull plates and strength structure;
- the safety of the craft based on the risk criteria.

The details of the craft designing process are shown in Figure 1 from [7] and [8] resulting that the fatigue, impact and vibrations are important stresses both for the hull plates and for the strength structure. One of the important problem in judicious sizing of a planning craft is the determination of the fatigue loads resulted from the slamming and shock in general, which stress the bottom plates and implicitly the craft's structure.

2. THE FATIGUE LOADS RESULTED FROM THE PLANNING OF THE CRAFT OVER THE BLACK SEA WAVES

The classification registers (LR, DNV, ABS) included in their rules some calculation details of the pressure on the bottom of the high speed craft.

At choosing the designed pressure for a planning craft, the following calculation methods are outlined:

a. the method based on the calculation of the statically pressure on the hull adding an equivalent statically pressure (considered as an impact pressure)
b. the method based on the calculation of the statically pressure adding a multiplication factor resulted from the acceleration of the hull's free falling, specifically the acceleration of the craft's gravity centre [1] pag 89.

The analysis of the actual navigation conditions in the Balck Sea and of the real time how long the craft is constrained to the wave action bringing about variable stresses of alternating unsymmetrical type, leads to the conclusion that the duration of a navigation year is seven months (from April to October). During the other five months, the wind conditions, the sea state and the air temperature don't allow to a craft of L $\approx$ 20m to operate according to her destination.

The design assumption for the fatigue of the craft's hull plates and strength structure is that the craft interacts with all the quasi-armonic waves forming the Black Sea spectrum between 0.15…1.5 m and the loading level of the bottom depends on each wave height. The local stresses of the bottom are given by slamming causing maximum pressures in the planing area due to the dynamical shock factor, k_d, that increase the dynamical planing pressure in smooth sea proportional to the incident wave height.

The data from the speciality literature [2], [3], [4], [5] refer to the high and long waves used to the design of the cargo ships and big sized marine structures, while in the interest area the information is poor and rather contradictory.

The measurements performed at the hydrometeo station “GLORIA” were used, the measurements being materialized in two categories of correlations, as follows:

- tabular correlation between the wind speed and the appearance rate (the effective/real time of action) for each direction considered and each month from April to October.
- graphical correlation between the wind speed and the wave height respectively the wave period for each cardinal and intercardinal direction

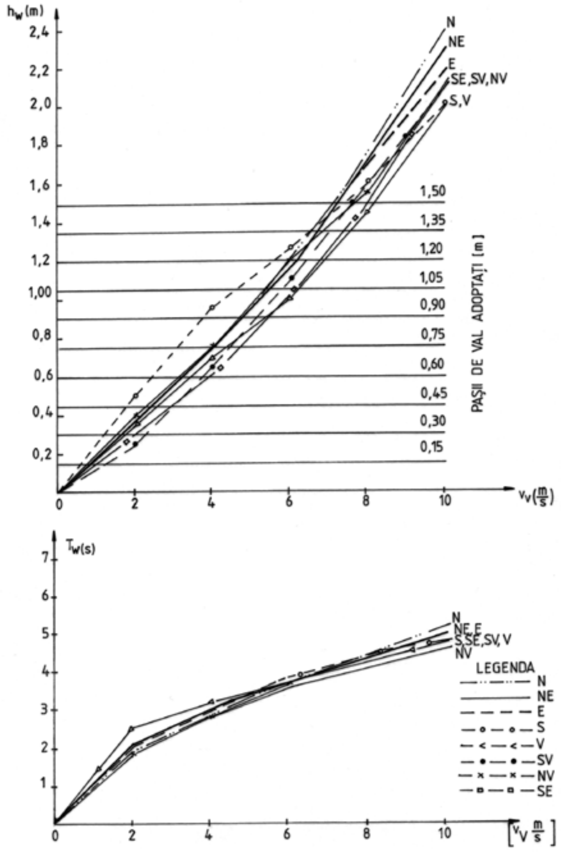

Figure 1. Significant dependences, h_w=f(v_v) and T_w=f(v_v) at the measuring “GLORIA” station 1997

3. COMPUTER –AIDED ANALYSIS

The study on the Black Sea waves included two main stages:

a. Determination of the multiple characteristics of wind and waves for the wave height steps of 0.15 m (correlation $h_w = f(v_v)$ and $T_w = f(v_v)$ between the limits hw=0.15…2.4m) Fig 1.

b. Determination of effective time of action of wind and implicitly of waves on the 8 directions (cardinal, intercardinal) followed by the calculation of the encounter periods wave-ship for the most unfavourable running directions and by the evaluation of the number of cycles that stress the craft from the view point of fatigue for each wave height step.

The first stage was based on the following measured physical data:

- the wind speed: 2,4,6,8 and 10m/s;
- the maximum wave height: between 0.30 and 2.5m;
- the maximum wave period: between 2 and 5 seconds.

The measurements were performed on the 8 directions (cardinal/intercardinal) and had as a starting point the smooth sea (the waveless sea).

For processing the measured data on the established steps a multiple inverse interpolation algorithm was used allowing to express the function h_w=f(v_v) and the inverse function v_v=f^{-1}(h_w) for each direction.

The interpolation method and the block diagram of the program “VALMANE” are shown in Figure 2 and the subprograms “INVAL” and “PERVAL” are presented in the APPENDIX 4.11 from [7], [8]. The results obtained by “VALMANE” program are synthetized in Figure 1 by the correlation h_w=f(v_v).

To be a true interpolation method, the wind speed of 10 m/s was used, corresponding to the wave height of over 2m, although the limit of the study has the maximum height of 1.5m

Based on the same measurement source (GLORIA), the distribution of winds and waves was processed on the eight directions reaching a reference time of 186 hours as a total monthly time of effective navigation (100%).

For subsequent developments, the tabular data were restructured on months, the effective times of wind action being expressed for each wave height step in each action direction (Tables 4.8 and 4.9 from [8].)

The prevalent phenomenon of the wave on the craft is the slamming resulting maximum dynamical pressures on the planing area.It is considered with complete physical and energetical cover that the dynamical shock factor, k_d, increases the dynamical planing pressure in waveless sea proportional to the incident wave height.

The variation law of the dynamical factor (k_d) is still under discussion. Beukelman and Radev [6] achieved a digital model that leads to a linear function of pressure and the suitable tests of impact by falling from different wave heights and different flaring angles showed a dependence of impact pressures and accelerations on the wave height very close to a straight-line, Figure 3 (just slightly parabolic to small values under the reference line and to great values over it).

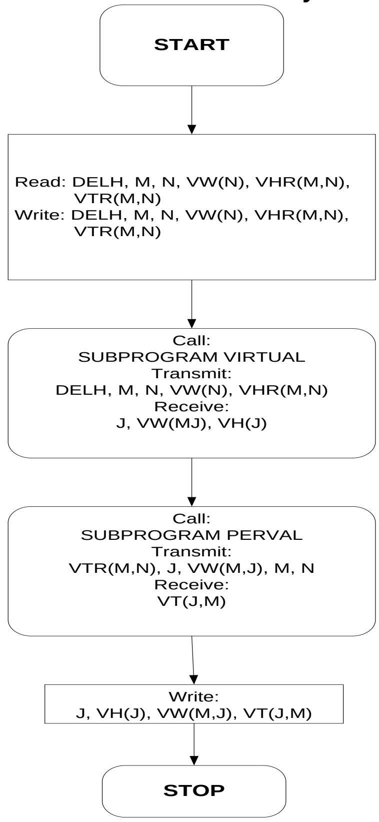

Figure 2 – Block chart of "VALMANE" programmer

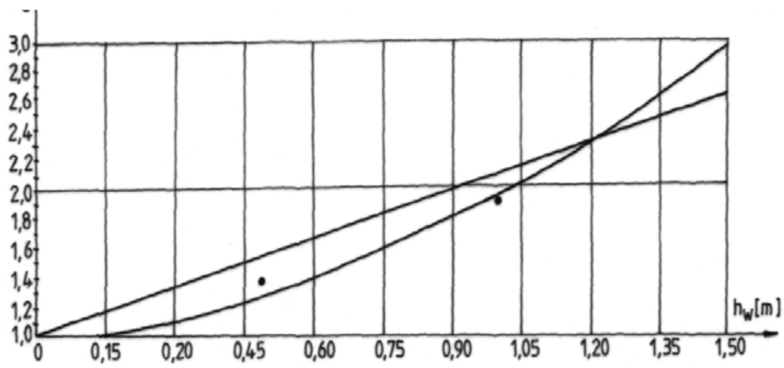

Figure 3 The variation of the dynamical factor with the wave weight

The linear dependence will be of the type $k_d = h_w tg\gamma'$ ($tg\gamma' = 1{,}111$, $\gamma' = 16{,}9^\circ$) and the parabolic dependence will be in the form of $k_d = 1 + ah_w^2$. The determination of "a" was achieved with a control point on the intersection ($h_w = 1{,}2m$, $k_d = 2{,}333$). By using the experimental points from Figure 16 [6] and the graphical parabola with coordinates given in Table 4.10 [8], the optimum value of parameter a=0,926 was determined and the analytical expression of the impact parabola is:

$$k_d = 1 + 0{,}926 h_w^2 \quad (1)$$

(1) so, the corrected equation is accurate and can be applied for the steps of stress σ ($\sigma_w = \sigma_{ac} k_d$)and pressure p ($p_w^g = p_{ac}^g k_d$).

Naturally, the steps of dynamical pressure will follow the wave height steps and the steps of loading the panel for the calculation of fatique will follow the dynamical pressure steps of slamming.

In the present work the evaluation matter of the response vibrations of whipping type isn't analysed, the number of the fatique cycles limiting to the effective number of slamming at a given wave height.

A strong argument in the support of these assumptions is the results obtained by Marchant and Stevens in [1] by large-scale tests with a ship of 11,6 m long and 56 kn speed. The impact acceleration physically measured in various cruise configurations reaches the value of 7.2 g in the gravity center and taking into account the craft's speed under study (20 kn and 28 kn) a maximum value of the dynamical factor $k_{d_{mac}}$ =3,0 is fully justified according to the recommendations of Allen and Jones [1] for the fatigue calculation.

Consequently , both for the dynamical impact pressure and for the loading level of the fatigue stress, the reference values are those corresponding to the planning on the smooth sea and the maximum values are those multiplied by 3 corresponding to the planing on the waves of 1.5m height. Between these extreme values, in the first approximation it is accepted a linear dependence and in the accurate calculation, a parabolic dependence, see Figure 3.

4. NUMBER OF CYCLES ON THE NAVIGATION SEASON ACTING ON THE CRAFT

Once the problem of loading stages was cleared up, it appeared the difficult matter of determining the number of cycles for each wave height which cumulated for the seven months of operation, leads to the total number of cycles during a year, therefore, to a zone from the comparative diagram of Wohler. This is a typical navigation problem that presumes two calculation assumptions as follows:

a. there is a good agreement between the effective action time of wind and the appearance rate of waves, on each direction;

b. for each month, the craft runs on the most unfavourable direction (where the wind blows hard and there is the most frequent wave)

In these assumptions, knowing the effective action time and each wind direction, it is necessary to calculate the effective encounter period wave-craft, supposing that the craft runs head sea, half a time and half a time it runs infollowing sea.Considering the real wave period according to the values from [8] Table 4.9 – “T_w^i” for a wave height step and each cardinal direction – the encounter periods will be calculated with the relation:

$$T_e^i = \frac{2\pi}{\frac{2\pi}{T_w^i} - \frac{U\cos\tau_i}{g}\cdot\frac{4\pi}{{T_w^i}^2}} \qquad (2)$$

Where: U [$\frac{m}{s}$] – the craft’s speed

δ_i [degrees] – the relative direction craft-wave (180 ^{O} - head wave; 0 ^{0} - following wave)

Consequently, under ahead running, the craft under study will be stressed by a number of cycles:

$$n_j^d = \frac{1}{2}\left[\sum_{i=1}^{8}\frac{t_i}{T_e^i}\right]_d \qquad (3)$$

Where: t – the effective times in which the wind and the waves act on each direction;

T – 186 hours – the navigation period/time in a month;

i = 1…8 = number of directions considered.

Accordingly, under astern running, the number of cycles will be:

$$n_j^i = \frac{1}{2}\left[\sum_{i=1}^{8}\frac{t_i}{T'_e}\right]_i \qquad (4)$$

Where : $(T_e^i)_d, (T_e^i)_i$ - are the effective encounter periods craft-wave, under ahead and astern running;

The total yearly number of cycles at the same wave step will be:

$$n = \sum_{i=1}^{7} n_j \qquad (5)$$

The more complex computing program “DUVALDIR”, is organized according to the block diagram shown in the Appendix 4.12-1 and 4.12.2 from [7], [8] and a part of the intermediary and final results are presented in Table 1 and in Figure 4.

Calculate number of fatigue cycles on wave height stages during a year of operation

Table 1

$\frac{h_w[m]}{T_w med[s]}$ Month		0,15/0,88	0,30/1,66	0,45/2,27	0,60/2,68	0,75/2,97	0,50/3,24		1,20/3,78	1,35/3,97	1,50/4,20
	NCD	69604	69392	45067	31872	20275	24133	27708	30360	19849	17117
	NCI	64334	62344	46479	36668	19415	19286	18308	21035	16130	13294
	NCD	41773	19405	30609	26024	32992	22007	42977	32000	23408	25996
	NCI	34498	20166	23926	25785	32786	19629	24430	24228	11647	27539
	NCD	49972-	39037	24025	33942	28800	26387	34771	25247	23589	25406
	NCI	41627	34308	19835	20630	21381	19264	34041	22751	22365	28143
	NCD	20655	22498	15819	22636	35235	34244	22989	27972	37853	31649
	NCI	17055	15254	14436	11526	19029	21733	21245	25962	29410	20798
	NCD	0	28255	32097	40118	46095	28553	29839	15856	16094	18143
	NCI	0	22204	25991	30970	36271	23309	21838	15856	19104	19780
	NCD	0	6040	34249	43870	47973	35915	19455	19759	17243	25187
	NCI	0	4197	26478	30410	32235	26382	15331	17360	14187	21527
	NCD	0	4903	23143	48336	30261	30312	43335	27342	26551	18676
	NCI	0	3407	13786	32485	19328	23579	26096	21066	21826	13628
ANUAL		339517	351409	375940	435272	422076	354733	382363	326794	299256	306883

N=3.59 x 10^6 cycles/year

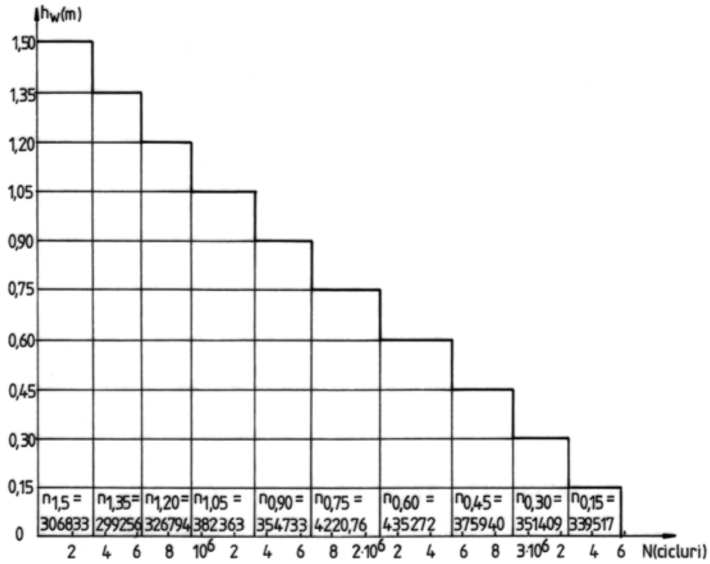

Figure 4 – Graphical diagram of number of fatigue cycles resulted from the variable stresses of waves

REMARKS:

A. As in the following waves there is the possibility that the denominator of the relation (2) to be cancelled resulting an impossibility of the digital computation, an elimination sequence of these cruise versions was provided in the program.

B. In the head waves with low heights, small lenghts and reduced periods, there is the possibility that the encounter frequency to increase very much, the number of cycles to be significant and to result the phenomenon of cablle stoning. As this phenomenon needs a special examination in the program, a higher limit of the encounter frequency was provided, at which the fatigue calculation is stopped.

Finally, knowing the range of stresses, σ'_w, the hydrodynamical pressures, p_w, and the number of cycles that act on the craft in a year, it can pass to a judicious design calculation of fatique.

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