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On Pre-Stressed Hull Structures.

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***Abstract--* "Wave-piercing" super-planing trimaran with air-born unloading, WPT, is developing of "wave-piercing" catamaran, WPC, for twice bigger achievable speeds. As all fast vessels, WPT needs for minimal weight of hull structures. Using of pre-stressed structures is a novel method of hull weight decreasing.**

An example of such structure of WPT begins from external load estimation. And the scheme of pre-stressed structure is selected: two pairs of steel ropes along and across the WPT above-water structure. Than method of pre-strength is selected: constant or varied forces. Varied external loads define the need of varied pre-stress control. Estimation of the corresponded system weight: total structure of above-water platform can be decreased at about 20%.

The method can be applied for airplane wings too.

***Keywords--* super-fast vessel, pre-stressed structure, active control of bending moment, structure weight decreasing.**

I. INTRODUCTION

A new type of a super-fast vessel, a "wave-piercing" trimaran with air-born unloading, WPT, was proposed some years ago, [1]. As all fast vessels, this type is very sensitive to the mass of the hull structure, especially – to the mass of above-water structure.

The examined option of WPT with increased air-born unloading see Figure 1.

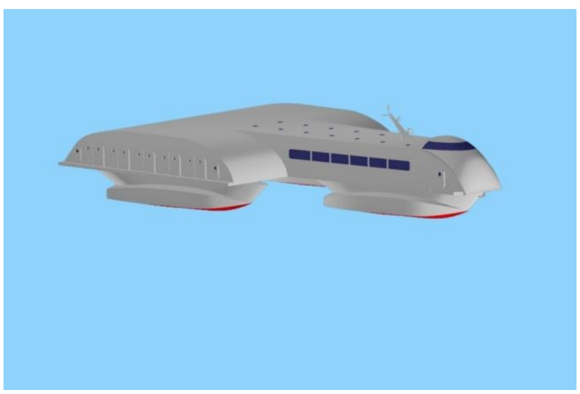

Fig. 1. 100-knots car-passenger WPT.

Besides, this type is not so deeply researched from the external loads point of view. This means that structural designing of the vessel must include some variations in the possible level of the external loads for the estimation of their influence on the structure mass.

Evidently, big enough loads define bigger structural mass, and decreasing mass is very desirable for better economical characteristics of a vessel. And one of the possible method of mass decreasing is a previously strengthening of the structure. Such a method is applied widely enough in civil engineering [2].

II. EXTERNAL LOADS

For most fast vessels, the main external loads are dynamic ones, i.e., the loads are defined by the vertical acceleration in waves. Such loads generate a general longitudinal bending moment and shear force.

In addition, transverse strength is depends from horizontal loads too; see Figure 2.

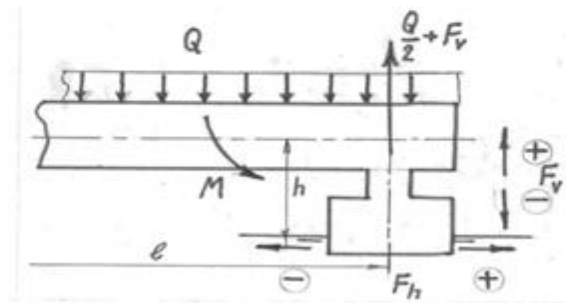

Figure 2. External transverse loads.

The maximal transverse bending moment can be defined as:

$$M_{max}= Q*l/8 + F_V*l/2+ F_h*h \quad (1)$$

Vertical loads are mainly defined by vertical shock accelerations. These accelerations depend on vertical damping forces, includes air-born ones. Today there are not exact data on the shock accelerations of the wing shape as Figure 1, because the previously tested model had the other shape for the above-water wing, Figure 3.

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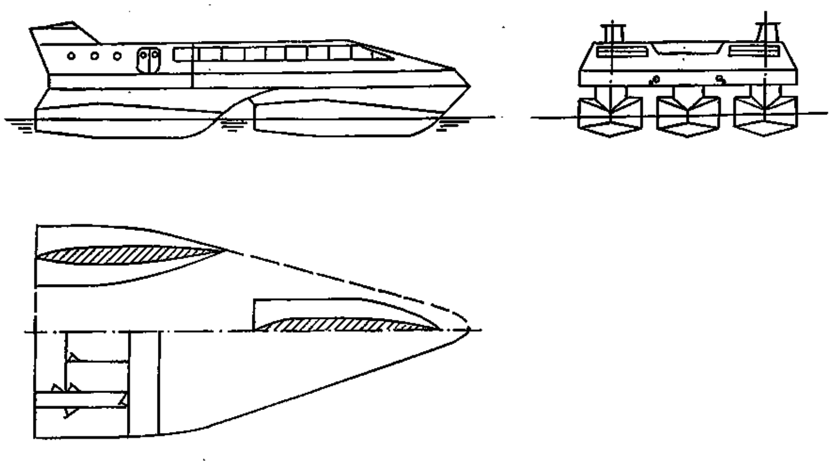

Figure 3. Scheme of tested model.

The results of such tests (vertical accelerations of bow in head regular waves) are shown in Figure 4.

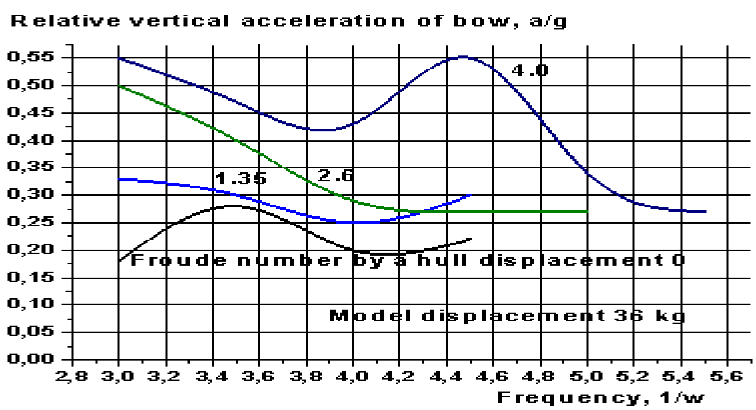

Figure 4. The results of vertical acceleration during seakeeping model tests in head regular waves.

The relative vertical accelerations of full-scale vessels are shown in Figure 5; the design accelerations can be selected for the examined displacement (300 t) and selected sea states. For example, an acceleration of 1.0 g and a speed of about 65 knots will be at Sea State 6.

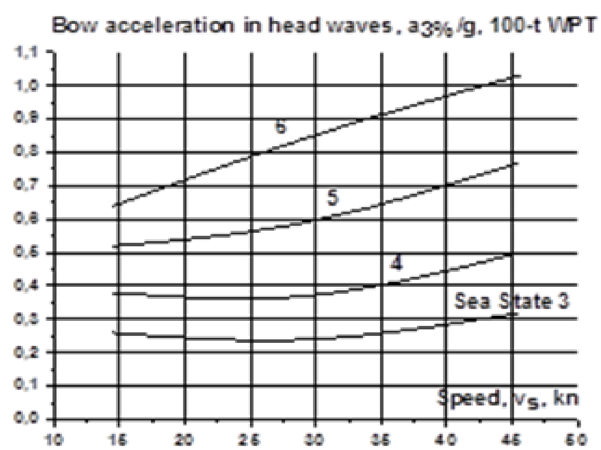

Fig. 5. Full-scale accelerations.

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Let us examine two values of design acceleration as examples of the value influence on the structure mass: 1.0g and 2.0g.

III. Above-Water Structure.

The vessel's purpose defines the need for a big and free enough cargo deck, i.e., the above-water platform, which connects the hulls, is a "flat" enough structure.

This leads to a problem in terms of structural design. The structure plan is shown in Figure 6. The above- water structure (wing + bow part) consists of longitudinal and transverse bulkheads and complex frames (each consists of lower and upper stringers with pillars between them); see below.

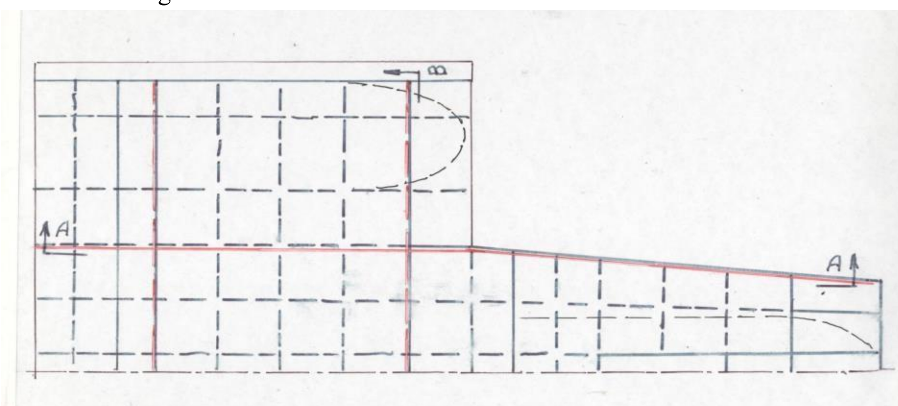

Fig. 6. Structure plan (red lines – steel ropes).

Transverse rows of pillars at the wing form the car hangar. Car doors are at the end of each row (The doors must be air-tight for better flow around the above-water wing).

The external walls of the above-water platform's bow, where the passenger saloon is placed, are connected by complex longitudinal frames in the above-water wing; see Figure 7.

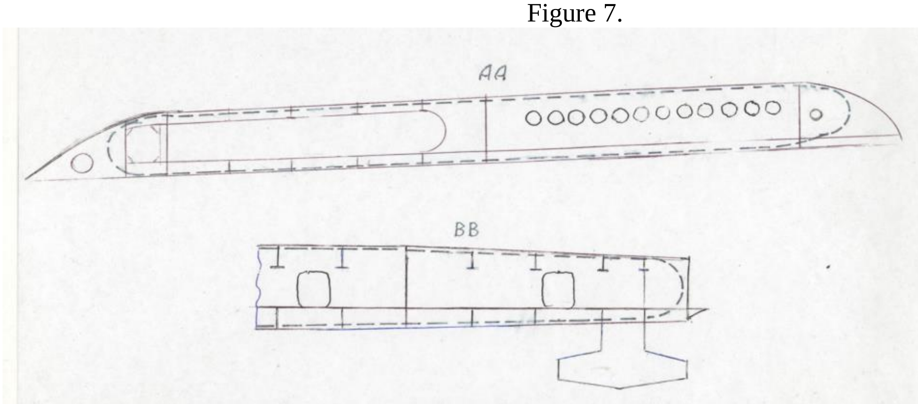

Figure 7. Longitudinal (AA) and transverse (BB) cuts of the wing structure

(dotted lines – added steel ropes).

Usually, some well-known methods of decreasing mass can be applied, such as external load minimization, structural optimization and use of the lightest material. But today there is a lesser-known shipbuilding method, previously strengthened structures. Today, the method is applied for civil engineering (for example, [2]).

The method is a very effective one for light alloy structures and steel ropes as the previously loaders. But there is a specificity of ship structures, their external loads are varied ones. This means that the previously strengthened structure must be applied by a special method. The possible options of previous loads are examined below.

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IV. METHODS OF PREVIOUS STRENGTH

As was noted, the external loads of all ships have changeable signs. This is in contrast to the case in civil engineering structures. Let us examine the various possible methods of the application of previously strengthened structures.

A. Constant uniform pressure: if the external loads are symmetric ones for both signs, Figure 8.

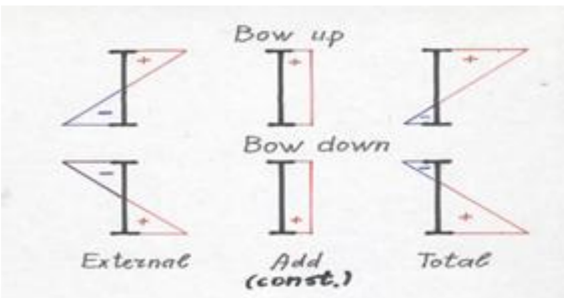

Figure 8. The amplitudes of normal stresses for previous uniform pressure.

If the added stress is about half of the design stress, the resulting pressure stresses will be 1.5 times bigger. This means that such an option does not ensure a decreasing of stresses, i.e., it is not rational method from structure mass point of view.

B. Constant bending moment: if the external loads are not symmetrical for both signs; for example, the "bow up" load is twice as big as the "bow down" load, Figure 9.

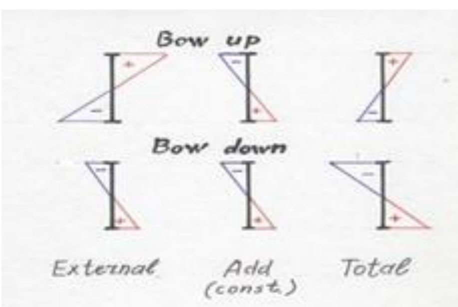

Figure 9. The amplitudes of normal stresses for the previous bending moment.

If the added moment is equal to the difference between the bigger and smaller external moments, the resulting stresses will be the same for the bigger external moment alone. This means that there is no decrease of the resulting moment, i.e., no decrease of the structure mass.

C. Variable (counter-acted) added moment: for any correlations between "bow up" and "bow down" loads, a there is a half of the value compensation, Figure 10.

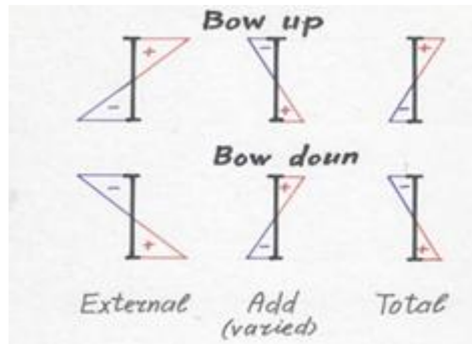

Figure 10. The amplitudes of normal stresses for the counteracted controlled moment.

Evidently, the resulting stresses are equal to half of the initial stresses defined by the design loads.

This means that the structure parts, which are defined by the total moment, can have a smaller mass.

But the need for varied counteraction to the general bending moments means a need for a special system. The system must include some stress sensors, a control block and executing equipment, for example, small-sized winches. The characteristics of the system can be defined after a more exact selection of the needed degree of counteraction to the external bending moments.

A zero approximation of the values of the above-water wing structures is shown below.

V. MASS ESTIMATIONS

The examined options of loads and structure were the following:

- the usual structure and design vertical acceleration 1.0g;
- the same structure and design acceleration 2.0g;
- the structure with an added system of counteracted moments and design acceleration 2.0 g.

Brief results of the mass estimations are shown in the tables 1,2. The first contains the data on the transverse structure mass, the second contains the data on the longitudinal structure the last contains the total data.

It must be noted that the design thickness of the first option was smaller than the permissible minimal thickness. Namely, the last ones were selected for mass estimations of the first value of design acceleration.

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Table 1.
Transverse structures.

Design acceleration, g`s	1.0	2.0
Vertical external force, t	100	200
Force on structure support, t	160	260
Selected thickness of the bulkhead wall, cm	0.4	0.6
Design bending moment, tm	2000	3200
Design thickness of the bulkhead plates, cm	0.6	0.9
1.5*mass of bulkhead walls, t	10	15
1.5*mass of bulkhead plates, t	16	24
Added mass of steel ropes, t	0	8
Total mass w/out ropes, t	58	71
Total mass with ropes, t	58	66

Table 2.
Longitudinal structures

Design acceleration, g	1.0	2.0
Vertical external force, t	100	200
Force on the structure support, t	130	230
Selected thickness of the bulkhead wall, cm	0.5	0.8
Design bending moment, tm	2075	4075
Design thickness of the bulkhead plates, cm	0.6	0.9
1.5*mass of loaded walls, t	Abt. 20	Abt. 32
1.5*mass of loaded plates, t	Abt. 22	Abt. 40
Total mass of the longitudinal structure, t	42	72
Added mass of ropes, t	0	12
Longitudinal structure mass, t	42	54

When the design acceleration is twice as big, the designed thickness is bigger too. But mass growth is proportional to the difference between the minimal permissible thickness selected and the bigger design thickness, not to the difference between the first and second values of design thicknesses.

Therefore, the difference of masses is not straightly proportional to the correlation between the external loads.

The total mass of the above-water wings is shown in Table 3.

Table 3.
Mass of the above-water structure options.

Options	Design acceleration 1.0g, usual structure	Design acceleration 2.0g, usual structure	Design acceleration 2.0g, controlled moments
Transverse structure, t	58	71	66
Longitudinal structure, t	42	72	54
Total mass, t	100	143	120

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Evidently, if the counteracted moments are half of the external ones, the structural mass of the above-water structure is smaller by about 1.2times.

The special system for a permanent monitoring of bending moments and counteraction of them must consist of some sensors for stress monitoring, control block and executive (power) equipment. The equipment can be pairs of small-sized winches for each added steel ropes, the winches will change the strength of the ropes.

VI. Conclusions

1. For the examined vessel and the ranges of the external loads, the twice-bigger design acceleration means an approximately 1.5 times bigger mass of the above-water structure.
2. Only controlled (varied) counteracting moments can decrease the mass of the structure. Any possible constant options for the previous strength are useless.
3. Counteracting bending moment gives up to 20% drop of the above-water structure mass, i.e., about 10% drop of full displacement.
4. The controlled counteraction to the general bending moments can be applied for any heavily loaded structures, for example, for wings of aircraft.

Recommendations.

1. The necessary next step for the super-fast vessel design is some detailed tests with external load measurements in irregular waves.
2. The model must be tested with a motion control system with three flow interceptors on the sterns of the hulls.
3. A special system of controlled counteracted moments must be designed and estimated separately, including their cost and economic effects.

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