"A NEW PROPOSAL FOR A PASSENGERS FAST FERRY OPERATING IN THE ITALIAN ARCHIPELAGO: STRUCTURAL ANALYSIS BY FINITE ELEMENT METHOD"

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SUMMARY

A research program is developing at the University of Naples "Federico II" whose main purpose is to individuate advanced methods for the design of high-speed vessels in aluminum alloy.
The evolution of the structural design in the field of the high-speed transport has led to the application of new technologies of construction. Particularly the use of aluminium seems to be particularly suitable in the realization of fast ferry designed for small and medium coastal shipping.
The structural design process for such ships must satisfy some requirements, which are the strength analysis to the local and global loads and the structural optimisation of weight.
First of all a general layout configuration has been drawn starting from design data and requirements for the connections between Tyrrhenian towns and near islands, of Campania, Pontino, Tuscan and Sicilian archipelagos. The internal subdivision has been obtained basing on the HSC2000 code.
Successively basing on a study that has led to a first step hull form (taking into account hydrostatic and hydrodynamic requirements), the problem of the structural analysis for such ships has been studied. It has been started from the consideration that, for an optimisation of the structural design process, a finite element method in the quasi-static form must be applied to the entire structure, in order to evaluate the "real" stresses and strains all over the hull and to identify the most critical structural elements.
Finally the results obtained have been particularly discussed.

NOMENCLATURE

L_{WL} = Length water line;
L_{OA} = Length over all;
B_{oa} = Breadth over all;
B_{wl} = Breath waterline
∇ = Volume of displacement;
Δ = Displacement;
C_B = Block coefficient;
V = Design velocity
a_{cg} = Vertical baricentric acceleration
α_d = hull deadrise angle (measured where the slamming pressure is evaluated),
α_{ocg} = deadrise angle measured at centre of gravity.
A_P = Total passengers area;
A_V = Vehicles area;
ρ = sea water density;
T = Draught;
D = Depth;
P_E = Effective Power
H = Autonomy (range)
N_{pax} = Number of passenger
Sr is the reference area;
k_1 accounts for the pressure variation along the hull;
k_2 accounts for the equivalent load area, with uniform pressure, supported by the generic elements (plating, stiffener, etc);
k_3 accounts for the hull form
z = the distance of the load point above the baseline;
S =value is obtained in tabular form in the rules.

1. INTRODUCTION

The recent development in the field of the naval cruise and particularly in the fast transportation, has lead the companies to operate great investment on ships that could offer a valid choice on the passengers carriage.
At the present day the most commonly used monohull ships, designed for the coasting trade are built in aluminium and steel. This ships are designed for commercial use passenger and cars liners also use aluminium; large ones may contain as much as 2,000 tonnes of aluminium, allowing for a considerable weight reduction as compared with their steel counterparts.
Fast ferries, with speeds of 25-40 knots, are revolutionising transport over short sea routes. These structures are weight-critical, and aluminium is the preferred material.
In this paper is presented a preliminary structural analysis that lead to the design of a fast ship monohull, about 60metres long. The structural research in progress at the University of Naples "FEDERICO II", regards the structural formulation that can be assigned to a high speed craft starting from the analysis and elaboration of design data used in the towing tank tests; a first step general plan

has been drawn, basing on the HSC2000 rules and a first structural morphology has been proposed.
Then regulation scantling of the longitudinal structures has been carried out basing on the HSC2000 rules and the Marspeed 32 software.
This consideration lead to a first evaluation of the hull weight on the basis of scantling rules that can be utilized for further structural investigation.
Some consideration on the primary structural response to shear actions can be obtained by numerical application of the thin walled beam theory. This theory is based on several assumptions that has been revisited in the paper.
The structural verification to the finite element under the action of wave loads and in still water has been carried out with the utilization of the MSC/PATRAN-NASTRAN software

2. THE NEW PROPOSAL FAST FERRY MONOHULL: DESIGN REQUIREMENT AND GENERAL LAYOUT

The preliminary approach to the general layout for fast mono-hull ships must be based on different factors, that considers the seakeeping ship problems, the maximum availability of space as regards the paying loads, the ship speed, (power to install on board, dimension of the main engines), the restrictions on the useful spaces imposed by the international code of safety for high speed–craft.
It has been considered, the volumes traffic that are possible to involve by the fast transport across the islands. The range and the speed has been chosen on the basis of a connection of the town and the near island in the Campania, Pontine, Tuscan and Sicilian archipelagoes.
The choice of the principal design requirements must be based on the following basic aspects:

- Passengers arrangement.

The passengers are arranged in two superstructure decks, the crew on the upper superstructure deck.

- Ship autonomy

The ship is concerned for navigation in Mediterranean Sea, covering a distance of about 180 miles.

- Ship speed

A maximum velocity of 28 Knots has been assumed; a 26 Kn has been assumed for the operational one.

2.1) CHOICE OF THE MAIN DIMENSIONS

An important factor to the choice of the maximum main hull beam is represented from the transversal and longitudinal tight subdivision. Based on the international code of safety for high – speed – craft, we can consider, beside the two engine room bulkheads and the collision one, a longitudinal tight bulkhead extending from the forward engine room bulkhead to the collision one and vertically extending from the main deck to the bottom. The presence of this longitudinal element represents a great vantage for what concern the answer to the great stability in flooding water.
The preliminary arrangement was developed utilizing HSC (High Speed Craft 2000) code.

In the following are synthesized the main design data and characteristics:

1. Type of vessel: fast ferry only passengers
2. Number of Passengers: 800 passengers
3. Maximum speed: 28 kn
4. Design Speed: 26 kn
5. Autonomy: 180 miles
6. Crew: 20.
7. Hull and superstructure aluminum alloy.

In the table n.1 the principal project dimensions are resumed:

Δ(t)	**L_{oa} (m)**	**B_{oa} (m)**	**L_{wl} (m)**	**D (m)**	**B_{wl} (m)**
375 t	*62.5*	*8.9*	*60.85*	*1.76*	*8.4*
T (m)	**C_b**	**N pax**	**P_D(kw)**	**H (ml)**	**V (kn)**
10.26	*0.406*	*800*	*4 500*	*180*	*26*

Table 1 main data

2.2) HSC 2000 MONOHULL SHIP SUBDIVISION

The recent HSC 2000 code represents an evolution of the precedent HSC 94 code, this one derived from the Dynamically Supported Craft Code of IMO 1977 (DSC Code).
The HSC 2000 recognizes that an adequate level of safety, for high-speed marine vehicles, can be enhanced by the infrastructure associated with regular service on particular routes.
The HSC 2000 code, referring to the existing rules, for increasing the safety standards in regard of the damage risks, subdivides the bottom hull area into two zones. The first one is the raking damage vulnerable one, and the second is the not vulnerable one.
This basic distinction is probably due to ship draft decrease at high cruise speed, caused by hydrodynamic forces. The so-called vulnerable raking zone is an area of the hull that, at the operational speed, certainly lies under water, and is more exposed to the collision risks.
The vulnerable raking damage zone is illustrated in the figure 1.

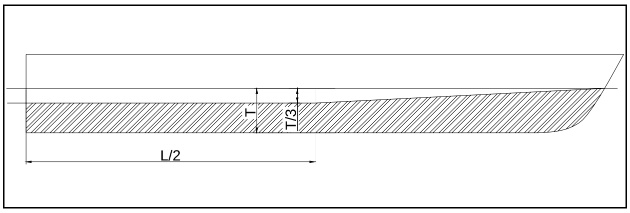

Fig.1 Vulnerable raking zone

The table 2 illustrates the dimensions of the bottom damage, which must be applied to the hull separately:

Table 2 - Dimensions of the bottom damage

Application	Long. ext. (m)	Penetr. (m)	Girth (m)
Vulnerable zone	*55% Lwl afward Pfwd under waterline. 35% Lwl if Lwl ≥ 50m. (L/2 + 10)% if Lwl < 50m*	*0.04 $\nabla^{1/3}$ or 0.5 whichever the least*	*0.1 $\nabla^{1/3}$*
Not Vulnerable zone	*0.75 $\nabla^{1/3}$, (3+ +0.225 $\nabla^{1/3}$) and 11 whichever the least*	*0.02 $\nabla^{1/3}$*	*0.2 $\nabla^{1/3}$*

The bottom damage must not be applied contemporarily on the vulnerable and not vulnerable zone.
The table 3 illustrates the extension of the side damage, that, in case of a multihull, must be applied separately all over each entire hull.

Table 3- Dimensions of the side damage

Application	Long. ext. (m)	Penetr. (m)	Vert. ext. (m)
(Separately to each hull)	*0.75 $\nabla^{1/3}$, (3 + 0.225 $\nabla^{1/3}$) and 11m whichever the least*	*0.2 $\nabla^{1/3}$*	*Full vertical extent of the craft*

In addition to the above mentioned damage, for all the high speed craft, other than air-cushion vehicles, after flooding has ceased and a state of equilibrium has been reached, it must be verified that an increase of the water line equivalent to 50% of the significant wave height, in the worst conditions (the same condition of appliance of the meteorological criterion), does not cause further flooding.
The above-mentioned damage extensions have been applied to obtain general layouts of the fast ferry (see fig. 2).

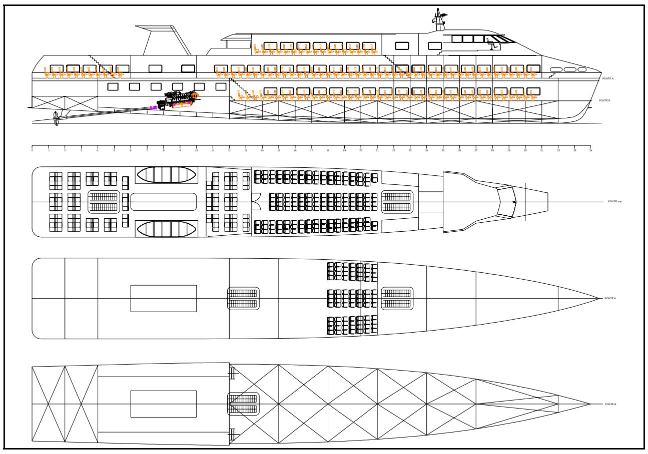

Fig. 2 General layout and arrangement

3. PRELIMINARY AND STRUCTURAL ARRANGEMENT

3.1) LOCAL LOAD ANALYSIS

It is to be point out that in order to define the craft's operating conditions, the centre of gravity acceleration has been considered. This has been taken as severity indicator as for R.I.Na high-speed craft rules.
In particular the philosophy adopted by the R.I.Na HSC rules for scantling of structures assumes that the vertical centre of gravity acceleration is the main parameter accounting for both the sea effect and the ship velocity.
The considered loads are the following ones:

- impact pressure on the bottom hull due to the slamming phenomenon;
- sea pressure on the hull due to hydrostatic and wave loads;
- internal loads generally used to determine scantlings of deck structures.

As far as the impact pressure is concerned, the rules assume it depending from the "area" position and the hull forms. It is given by the following formula (KN/m^2):

$$p_{sl} = 70\frac{\Delta}{S_r}k_1 k_2 k_3 a_{cg} \qquad (1)$$

with:
and is given by the following relation:

$$k_3 = (70-\alpha_d)/(70-\alpha_{ocg}) \qquad (2)$$

a_{cg} is the design value of the vertical centre of gravity acceleration.
The hydrostatic and wave pressure acting on the side structure are given by:

$$p_S = 10\left[T + 0.75S - \left(1 - 0.25\frac{S}{T}\right)z\right] \qquad (3)$$

for load point below the waterline

$$p_S = 10[T + S - z] \qquad (4)$$

for load point above the waterline;

3.2) STRUCTURAL STYLE AND THIN WALLED BEAM THEORY

The main objective is to create a style and overall scantlings according to UNITAS rules and requirements, which can be used "as starting point" for further analysis.
Longitudinally framed structure has been selected (see mid-ship section of fig. (3).
Reinforced frame interval and longitudinal stiffener spacing of 1800mm and 250÷350mm respectively have been adopted.
Based on the UNITAS rules and requirements, eight longitudinal cross sections have been analyzed and a first longitudinal weight distribution and the weight of all the frames and bulkheads has been obtained. Particularly the longitudinal hull weight distribution is shown in fig. (4).
The evaluation of the section modulus can be made in first step by the software Marspeed 32 which is also able to give a distribution of the shear stresses on the transversal section under the action of the regulation longitudinal forces. The software acts basing on the thin walled beam theory, whose main assumptions are:

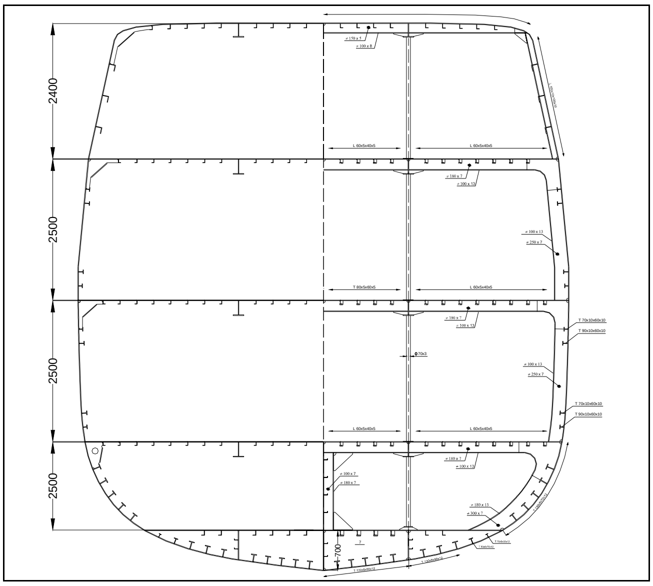

Fig. 3 Midship section

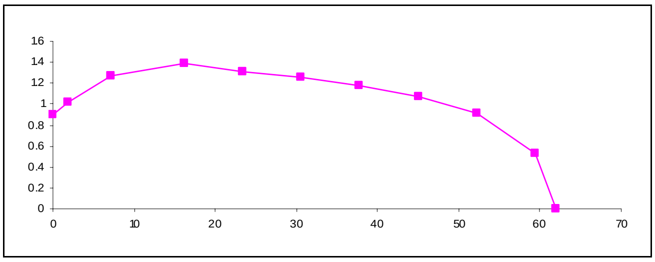

Fig. 4 Longitudinal hull weight distribution (t/m)

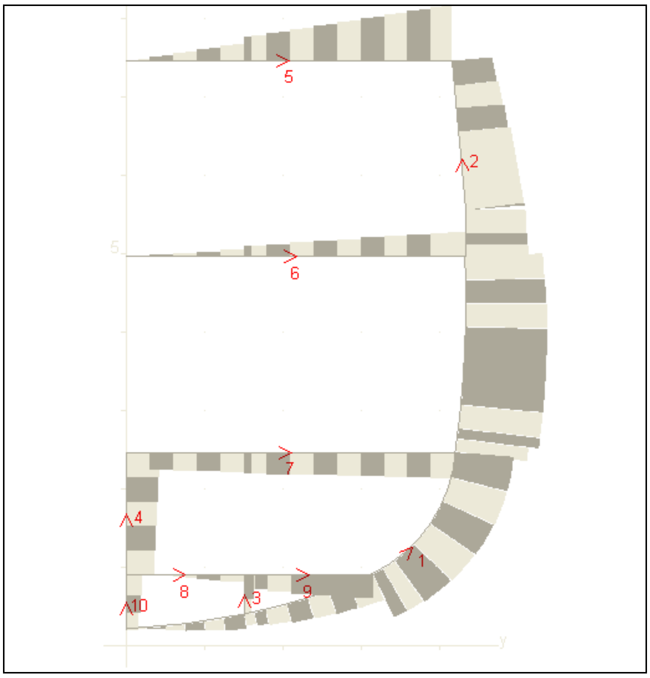

Fig.5 Typical shear stress distribution in a transverse cross section due to vertical shear force

- The hull girder and transversal cross beam are basically prismatic;
- There is no in plane deformation of the longitudinal and transversal cross sections;
- In the case of bending deformations, the plane cross sections remain plane after deformation;
- All the tangential stresses - except those ones due to the uniform twist on an open section- and all the pertaining geometrical quantities are uniformly distributed on the thickness;

The thickness is orthogonal to both boundary lines of the cross section.

Fig. 5 shows the typical shear stress distributions due to a vertical shear force, in a transverse cross section 37.8 from AP.

4. FINITE ELEMENT METHOD ON SHIP STRUCTURE

The necessity of using a direct method for the evaluation of the strains and stresses on a ship starts from the consideration that the hull is a thin walled box girder, in which the longitudinal, transversal and local strength are closely connected.

In fact, for instance, as far as the transversal distribution of the acting loads, a transversal structural schematization is commonly accepted but the deformation of the frames under the transversal loads causes great stresses on the longitudinal girders.

Moreover there is an influence between the deformation of stiffened plates under the local loads and the transversal and longitudinal girders.

This global interaction can be only evaluated using the finite element method and the hull structure morphology constituted of a great number of structural element is a scheme that cannot be neglected when a structural analysis starts to be performed.

4.1) SOME ASPECTS ON THE APPLICATION OF THE FINITE ELEMENT METHOD TO AN ALUMINIUM HIGH SPEED CRAFT

For a traditional aluminium ship above 60 m length, the global loads, start to be of great entity, particularly if evaluated in hogging and sagging condition.

In this case assume a relevant importance:

1. The global longitudinal bending moment and vertical shear forces.
2. The global bending moment and shear forces caused by vibration movements all over the hull, depending on the slamming impact on stern. In this case several problems of fatigue strength and deformation are present, particularly for an aluminium ship, placed in the bottom and the high superstructures zone.
3. The local impact forces in the stern zone, particularly in the sagging condition

As regards fast ships only carring passengers, the inertial loads acting on the decks are not of great relevance, so it is no so important to investigate with care on the relative global deformation, particularly on the intermediate decks.

As far as the case of a ship that brings cars and other heavy vehicles or relevant cargo loads, since the inertial global loads are much more influent, the finite element method can put in evidence how much the strains on the side shell caused by longitudinal loads in sagging and hogging condition, add to the transversal loads caused by the bending of the deck girders. Moreover it is expected to show on the decks local deformation more evident than the global deflection of the hull beam.

4.2) GLOBAL FEM MODELLING OF AN ALUMINIUM NAVAL STRUCTURE

Schematization of the structure.

In a first step structural analysis the global schematization of the and in particular for the side and decks and for the double bottom the structure may be performed in a coarse way, the properties of shell and membrane can be utilized. In this case the mesh size cannot portray stress concentrations.

An aluminium ship present in structural scantling a low width/length ratio for the element of all the reinforced girders. As a consequence for the schematization of the reinforced transversal frames and the beams and longitudinal deck girder, as the width of the utilized elements for the web does not exceed half the length, the properties of shell can be utilized, otherwise the beam for the flanges are utilized.

For the elements representing the longitudinal girders of the superstructures, having a low width since they give a low contribute to the longitudinal strength the properties of beam are utilized, as for the transversal frames.

As far as the stiffened panel of the side shell, particularly in the zone above the waterline, the schematization of the longitudinal stiffeners as beam can be avoided. A sort of spreading on the relative side shell by an increase of thickness be applied. These technique may be allowed since there are no local hydrodynamic and hydrostatic loads and so the for the global longitudinal strength is not necessary the increase the relative inertial moment of the stiffened panel. Generally the increase of thickness is about 40%.

Anyway the stiffened panels of the deck and the double bottom are subjected to great local loads particularly in the case of aluminium fast ferry and in this case they have to be shematizated in the traditional mode (shells and beams).

Application of loads

The application of the global loads must be performed in terms of pressure distribution along the entire hull.:

It is necessary to apply:

1. A gravitational load relative to hull weight and to the no-structural masses.
   In order to reach the target displacement, the last are usually applied creating a set of non structural masses on the entire structure to simulate the distributed loads of the main engines, the cargo on the decks and all the plants also, on the side shells, with a degree of freedom in the vertical direction.
2. Angular accelerations and longitudinal distribution of the vertical acceleration.
   In order to provide information to the utilized FE software, as far as the inertial loads that have a great contribute to the structural response, it is necessary to simulate the heaving movement with a vertical baricentrica acceleration and a pitching one by applying an angular acceleration around the baricentric transversal axe. The software provides to transfer to all the elements of the model the correspondent translational acceleration.
3. A hydrodynamic load.
   This can be applied calculating a simple sinusoidal one, which represents a complex extreme load evaluation. In particular the evaluation of the equivalent wave consists in the determination of heading, wavelength, amplitude and phase. The phase is the position of the wave crest along the ship at the instant in which the reference response is maximum. The other parameters are relative to the geometry of the wave train that the ship encounter.
   The value of the equivalent sinusoidal wave can also be calculated in more simple way as given by the classification rules, in the form of the wave length and amplitude.
4. A hydrodynamic slamming load in the stern zone. This can be made uniformly applying a distributed pressure. Such pressure can be also evaluated taking into account the value of vertical acceleration and its variation along the hull as given by the rules.

Application of boundary conditions

The boundary condition are usually applied taking into account the transversal symmetry of the structure. Since the aim of the calculation is the analysis of the structural response regard the vertical wave bending moment, it is necessary to impose at the ends of the hull the boundary condition of isostatic beam. In correspondence of the diametric plane it is necessary to impose the only degree of freedom along the vertical axe.

Otherwise it is common practice to simulate the action of the fluid on the hull by adding an adequate number of springs elements on the keel, positioned on the stiff location of the hull girder.

5. CASE STUDIES – DIRECT FEM CALCULATIONS FOR AN ALUMINIUM FAST FERRY

A case study of application of the finite element method to an aluminium fast ferry is proposed. The method as been applied to the new ship project at the Naval Department of the University Federico II of Naples. The finite element structural analysis of the aluminium high speed craft as been performed by the special software MSC/Patran for the modelling of the structure and of the loads and for the post processing of the results. The MSC/Nastran was used for the solving of the model.

The aim of the application is to investigate on the global structural response of the ship structure at the answer in terms of equivalent wave having amplitude given by the

Unitas rules, taking into account of the inertial loads, due to the heaving movements, in extreme condition.
After the creation of the geometric model of the ship, the entire structure was modelled (See fig. 6)
The choice of the material has been addressed on a extruded Aluminium of the series 5086 for the plates and bars with a yield stress of 100N/mm^2 in compliance with the numerical registration RRIAD (Registration Record of International Alloy Designation).
As far as the element properties the model consists of predominantly shells for the side, deck and transversal reinforced frames; for the longitudinal stiffeners and girders the beam properties have been used. The model includes the superstructure totally contributing to the longitudinal and transversal strength. The dimensions assigned to the structural elements are derived from the preliminary assessment of the regulation scantling obtained by the Marspeed 32 software (Bureau Veritas).
A system of 0-dimensional elements simulates the weigth of the non-structural masses on the decks and side hull.
In order provide global wave load information for the FE model in a realistic sagging and hogging condition, the hull has been schematized on the Autohydro software. The profile of the obtained sinusoidal equivalent wave has been drawn on the Patran FEM model and a corrispondent pressure distribution has been carried out.
Moreover, an inertial heaving load, that is automatically calculated and applied by the software, is considered calculating the vertical baricentric acceleration, which is given by the rules is:

$$a_{cg} = S\frac{V}{L^{0.5}} = 0.677 \qquad (5)$$

S is tabulated rule value depending from the sea conditions. These are fixed to be of navigation in open-limited sea for which the significative wave amplitude is 2.5÷4m
The boundary conditions have been applied to the model considering the transversal simmetry of the model and of the loads, significantly reducing the mesh size and the computing time, to obtain the following:

- Number of elements: 28251
- Number of nodes: 13869

The pre-processing allows to calculate the total weight of the model. According to the design data and to the first step evaluation of the structural weight as given by the Rules scantlings evaluations the entire ship displacement, the CG position and the weight of the added masses are shown in table 5

Tab. 5 Patran mass properties output

	Mass (t)	LCG (m)	VGG (m)
Hull	*110*	*28.7*	*3.86*
Mass points	*265*	*31.5*	*3.85*
Total	*375*	*30.2*	*3.85*

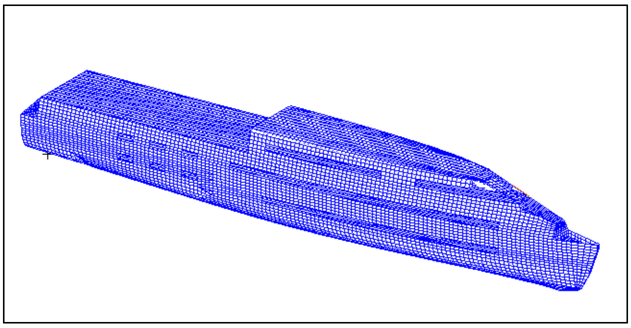

Fig. 6 FEM model of the aluminium high speed craft

5.1 GLOBAL STRUCTURAL RESPONSE

The output from the FEM analysis shows, as we expected to be for a 60m hull, that the vertical deflections and longitudinal global strength of the hull beam under the action of the sinusoidal wave, are relatively of low entity.
In the sagging condition the relative translational displacement in the z-direction in correspondence of the midship section is about 12.7 mm. As a consequence the Von Mises stresses on the bottom and on the upper deck is very low (Fig. 7-8)

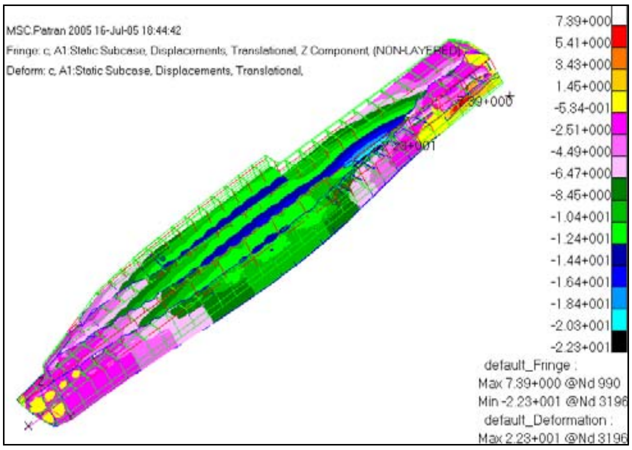

Fig. 7 Amplified vertical deflection in sagging condition

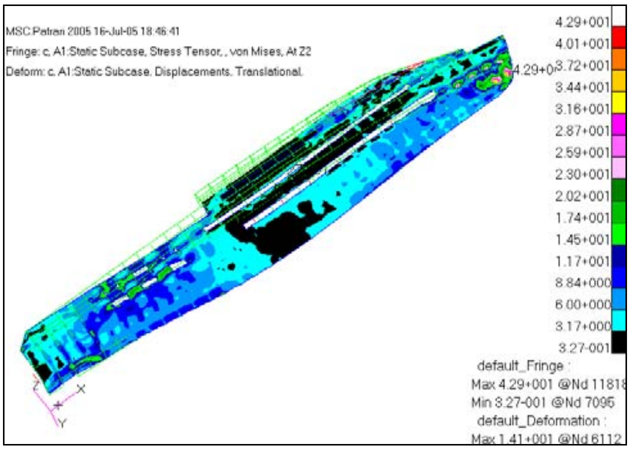

Fig. 8 Von Mises stresses on the side shells in sagging condition

In the hogging condition the relative translational displacement in the midship section is about 11 mm. As it is shown in the fig. 9 the primary stresses and deformation are low. These are more evident as regard the local pressure of the wave on the single panel.

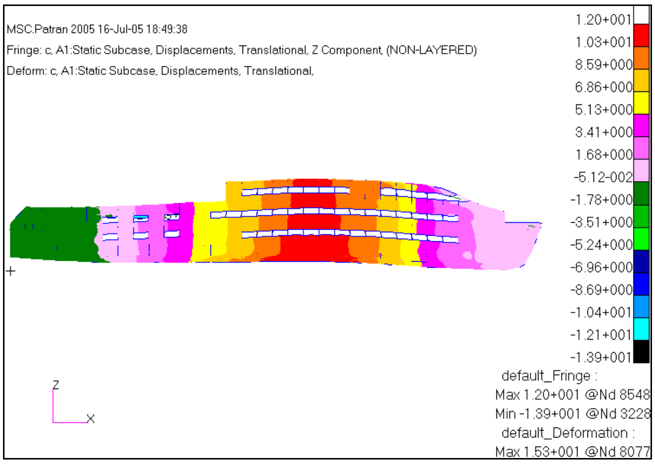

Fig. 9 Vertical deflection in hogging condition

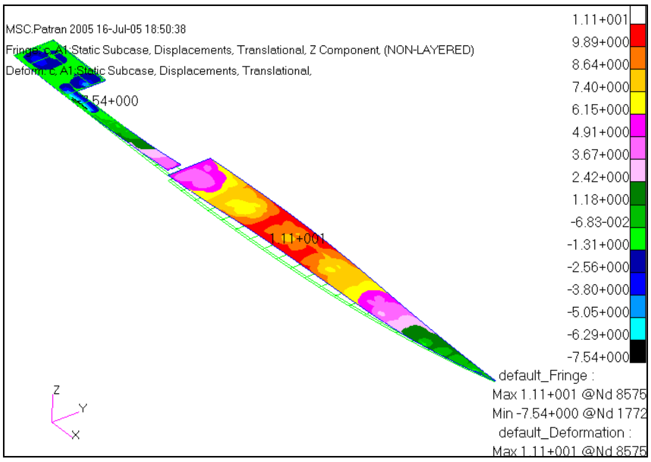

Fig. 10 Vertical displacement of the deck 1

Table 4 Max stresses and strains on the entire structure under the inertial and wave loads

	$\sigma_{V.M.}$(N/mm^2)	Displ (z) mm
Hull bottom plates	*11÷12*	*9.7*
Deck 3 plates	*11÷12*	*14.9*
Deck 2 plates	*2÷8*	*13.5*
Deck 1 plates	*2÷8*	*12.1*
Top-Double bottom plates	*2÷8*	*9.5*
Long. reinf. bottom girders	*4÷15*	*9.2*
Long reinf. deck girders	*7÷18*	*12÷15*

It is to point out that the von mises stresses and strains on the decks may not seem congruent with the total deflection of the hull beam vertical displacement. This is due to the fact that the distributed load of the cargo has a great influence on the structural response of these elements

5.2 ALUMINIUM STIFFENED PANEL STRUCTURAL RESPONSE

In order to locally investigate the strength of the structure to the effect of the slamming loads, in the above-mentioned sagging condition, the geometry of a stiffened aluminium panel has been extracted from the bottom-stern zone and has been remodelled in a more realistic way. The mesh of the panel is a fine one and so, being the shortness of stiffeners elements, these are modelled as shells, as well as the plates. Two loads has been applied, the first relative to the equivalent wave in sagging condition, the second to the Unitas Rules formulation of the slamming impact pressure. Such value is given as a function of the vertical acceleration longitudinally varying along the hull. It is to point out that the panel is also subjecetd to the inertial load due to the heaving movement (fig. 11).
The stiffened panel has no degree of freedom on the border lines to simulate the presence of the reinforced transversal frames and longitudinal girders.

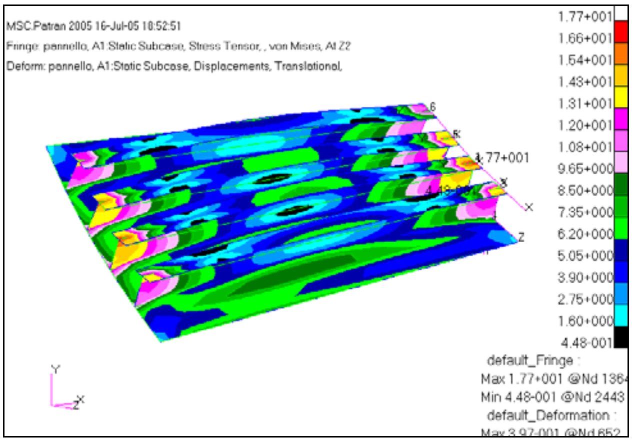

Fig. 11 Von Mises stresses on a bottom-stern stiffened panel under slamming loads

The maximum value of the Von Mises stress on the plate is 13N/mm^2, while on the stiffeners it reaches, in correspondence of the connection with the frames the value of 14.3/mm^2
As regards these results, a comparison can be made between the value in the central zone of the panel with the ones obtained in the global load condition, in which the slamming has not been considered.

Tab. 5 Stresses and strain of the stern stiffened panel

	$\sigma_{V.M.}$(N/mm^2)	Displ (z) mm
Wave	*2.0*	*≈ 0*
Wave+impact	*10.4*	*0.4*

6. CONCLUSIONS

An investigation on the preliminary monohull fast ferry subdivision, compatible with the new IMO H.S.C -High Speed Craft- codes has been developed. A first step general plan has been drawn, basing on the HSC2000 rules and a first structural morphology has been proposed.
A preliminary analysis has been developed for the aluminium monohull structural design.
Thin-walled beam theory, when opportunely applied, can be a valid design tool, for the primary structural response.
The finite element technique has been applied loading the entire hull structure with a rule regulation equivalent wave. An aluminium bottom-stern stiffened panel has been extracted to analyze in a finer way the structural response under a slamming load. The results show that the scantlings deriving from a regulation assessment and finally verified by the direct calculation, are largely sufficient to ensure the structural capability also if an inertial load is applied.

7. ACKNOWLEDGEMENTS

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