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Static and Fatigue Behaviour of the Main Section of a Fast Patrol Boat

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Abstract

This paper analyses the static resistance, as well as the fatigue resistance, of the main section of a fast patrol boat designed and manufactured in Portugal. The ship under study is a high-speed lightweight craft that was mainly fabricated with two types of aluminium series alloys, namely the 5083-H111 and the 6082-T6 alloys, which are commonly used in shipbuilding. The structural response of the critical section of the ship was obtained using the Finite Element Method (FEM), when the structure was submitted to different loading conditions, such as the hydrodynamic and hydrostatic sea loads, the longitudinal sagging or hogging, or the loads on fuel oil tanks. Results obtained for the load cases considered showed that the Von Mises equivalent stresses do not exceed the Yield Strength of the aluminium alloys used in the manufacturing of the ship. In addition, strain gages were placed on the main ship's bulkhead, near a structural detail in its bottom, and real-time acquisition strain data was collected using a computer code routine written in *LabView*. The Rainflow cycle counting method was applied to load spectrum gathered in order to obtain the Rainflow matrix and to predict the fatigue life of the critical main section of the ship.

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Keywords: Naval aluminium alloys; Real-time acquisition strain data; Finite Element Analysis (FEA); Rainflow matrix; Fatigue analysis.

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1. Introduction

The structural integrity of a critical bulkhead of a Portuguese fast patrol boat (Fig. 1a) was assessed during this study [1]. The bulkhead (Fig. 1b) was modelled and numerically analysed through the use of the FEM when submitted to main loadings. The patrol boat usually operates near shore and the propulsion of the craft is obtained using two diesel motors ref. CUMMINS KTA50 M2, capable to reach a maximum speed of 26 knots in a sea state 4 of the *Beauford* wind scale. The patrol boats were built in two aluminium alloys, namely the 5083-H111 and the 6082-T6 alloys, which are commonly used in shipbuilding and each boat is capable to dislocate up to 94 tons. The distance between the perpendiculars of the patrol boat is approximately 26.4 meters.

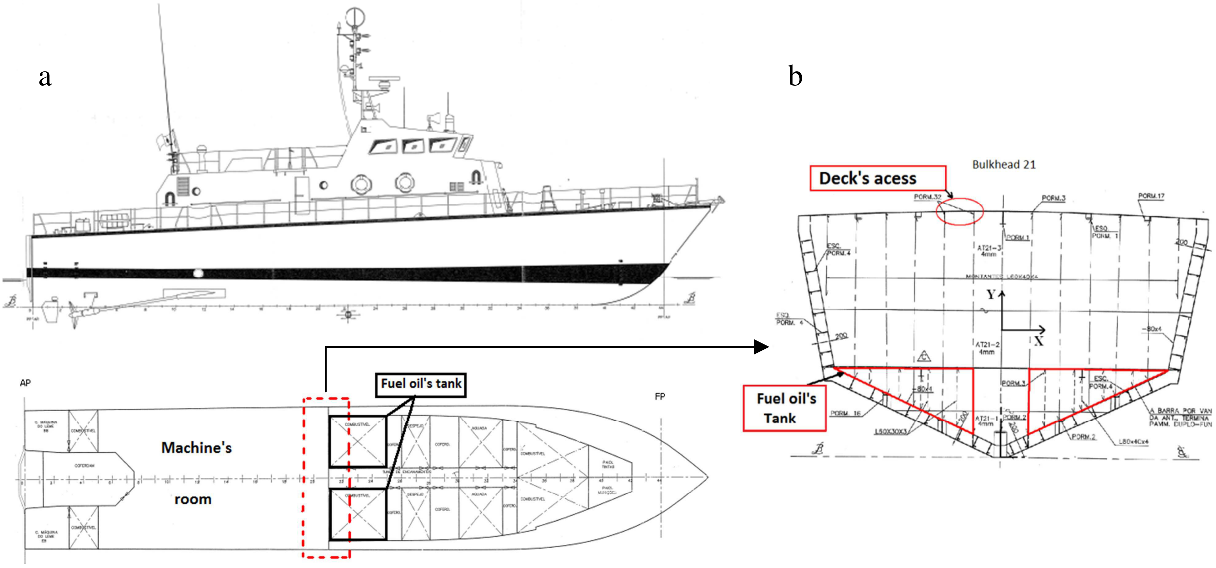

Fig. 1. (a) External overall view of the fast patrol boat; (b) Bulkhead number 21 (amidships).

2. Main loadings

The characterization of the structural response of the ship was carried out by imposing the distribution of service cargos along the length of the ship (Table 1), which was determined by equations given by *The Det Norske Veritas* Classification Society DNV [2], having into account the sea conditions and the vessel's characteristics, among others, that is:

- Length or distance between perpendiculars (L) = 26.4 m;
- Wave coefficient (Cw) = 1.9;
- Fully loaded draught with the craft floating at rest in calm water (T) = 1.5 m;
- Fully loaded displacement (Δ) = 94 tons;
- Greatest moulded breadth of the hull at the fully loaded waterline (BWL) = 5.2 m;
- Greatest moulded breadth (B) = 5.95m;
- Block coefficient (CB) = 0.45;
- Longitudinal distribution factor for acceleration (K_S).

The loads considered include hydrodynamic pressure due to wave pressure, hydrostatic pressure, longitudinal sagging and hogging, but also the liquid's acceleration, such as the existent inside the fuel oil tanks. It was concluded that the critical zone on the ship is amidships, near bulkhead number 21 due to the predominance of sagging.

Table 1. Longitudinal distribution of service cargos along the ship's length.

		Longitudinal position on the ship							
		AP	**0,2L**	**0,4L**	**0,5L**	**0,6L**	**0,8L**	**FP**	**h (m)[1]**
Sagging	Bending Moment (kN.m)	0	710	1858	2053	1858	710	0	------
Sea	K_S	7.5	7.5	7.5	7.5	8.3	9.7	11	-------
	Pressure below waterline (kPa)	4.2	4.2	4.2	4.2	4.6	5.4	6.2	2
		7.5	7.5	7.5	7.5	8.3	9.7	11	1.35
		9.7	9.7	9.7	9.7	10.8	12.6	14.3	0.9
		12.0	12.0	12.0	12.0	13.3	15.5	17.6	0.45
		14.3	14.3	14.3	14.3	15.8	18.4	20.9	0
	Pressure above waterline (kPa)	14.3	14.3	14.3	14.3	15.8	18.4	20.9	0
		16.7	16.7	16.7	16.7	18.2	20.9	23.3	-0.3
		19.1	19.1	19.1	19.1	20.6	23.3	25.8	-0.6
		21.5	21.5	21.5	21.5	23.1	25.7	28.2	-0.9
		24.0	24.0	24.0	24.0	25.5	28.2	30.6	-1.2
Fuel oil tanks	a_v (m/s^2) [2]	34.3	34.3	34.3	34.3	41.1	54.9	68.6	------
	Pressure (kPa)	0	0	0	0	0	0	0	0
		0	8.3	8.3	8.3	9.3	11.5	13.6	-0.3
		0	16.6	16.6	16.6	18.7	22.9	27.1	-0.6
		0	24.9	24.9	24.9	28.0	34.4	40.7	-0.9

[1] The parameter height (h) for the sea's pressure values has its reference (zero) in the waterline or at the top of the fuel oil tanks.

[2] Considering a sea state 9 of the Beaufort wind scale.

3. 3D Modelling and FEA of bulkhead number 21

The bulkhead with several structural reinforcements was modeled (Fig.2a) using *SolidWorks*® software and it was numerically analysed using *ANSYS Workbench*® software (Fig.2b). The finite element mesh was created using shell elements having into account the refinement needed near scantlings, reinforcements or openings, in order to calculate the local stresses near stress concentration regions. As can be seen, the maximum stress induced on the structure under study is approximately 65 MPa (Fig. 2b), applied on a reinforcement located near the opening that allows the access to the upper deck (Fig. 2a, 2b), which represents a static safety factor of approximately 4.6 in relation to the Yield Strength of the reinforcement's material, that is the 6082-T6 aluminium alloy.

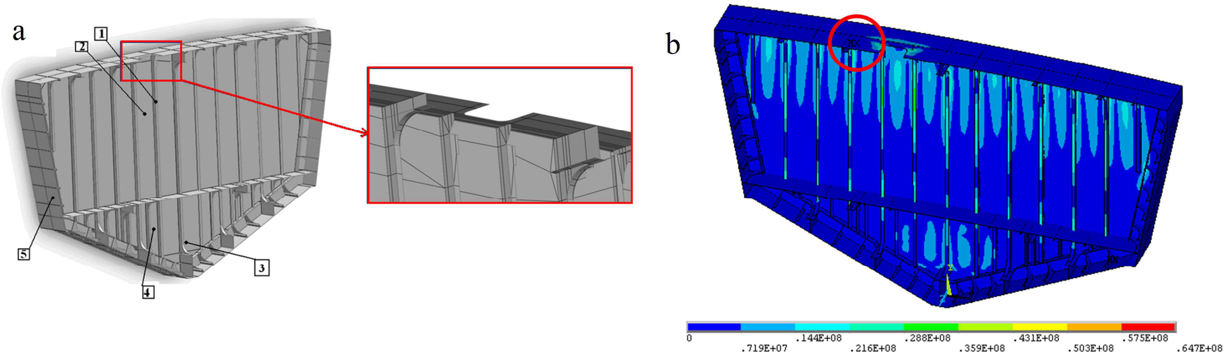

Fig. 2. (a) Overall view of main bulkhead modelled with reinforcements, scantlings and openings; (b) Von Mises equivalent stresses (in Pa) induced in the bulkhead due to the superimposed loadings.

4. Strain-gage data-acquisition and Rainflow matrix

In order to determine the in-service strain values induced amidships, a strain-gage rosette was installed on the main bulkhead of the ship, near a structural detail in its bottom (Fig.2a, position 3), and real-time acquisition strain data was collected using a computer code routine written in *LabView*. Issues, such as sampling frequency (Nyquist theorem), temperature compensation, calibration and signal filtering were considered during the experimental strain-data acquisition task. In addition, signal filtering was achieved using a Butterwoth's low pass filter (LPF), defined in a *MATLAB* routine. The Wheatstone-bridge used was a half-bridge type called *quarter bridge II* in the *Measurement and Automation Explorer* software of *National Intrument* (NI) strain-bridge ref. NI SCXI 1314 (Fig. 3a), with an active gage and a dummy gage, in order to eliminate, in the strain values, the effect of temperature variation. The gages were installed near a T-shape structural reinforcement resistant to sagging and hogging. Strain-data acquisition was carried out during regular in-service patrol conditions. The waves' height and period were 2.5m and 8 seconds, respectively, and the strain values were collected during two hours. The LPF cut-off frequency was defined equal to 35 Hz due to the maximum working frequency of the engines (1800 RPM – 30 Hz). In addition, the definition of the LPF had into account the effect of the electrical noise frequency equal or higher than 50 Hz, which was determined by a FFT analysis. The strain values experimentally obtained are presented in figure 3b. Then, the Rainflow cycle counting method was applied and a Rainflow histogram/matrix generated (Fig.4).

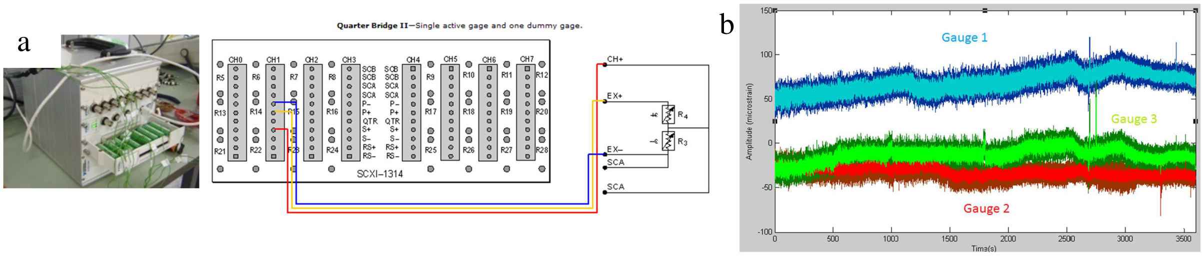

Fig.3. (a) *NI* strain bridge NI SCXI 1314 with a quarter-bridge II defined; (b) Strain-data with (light colors) and without (dark colors) LPF applied.

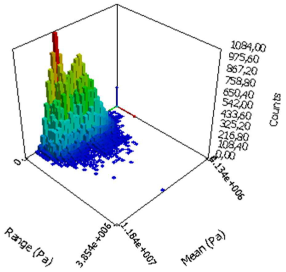

Fig. 4. Rainflow cycle counting applied to the strain-spectrum: stress range, mean stress and number of cycles.

5. Conclusions

When comparing the numerical and the experimental results, it is possible to conclude that the numerical data is in accordance with the experimental data. The stresses induced on the critical bulkhead, at the local where the strain-gage rosette was placed (Fig. 2a, position 3), were comprehended in a range between 5 to 11 MPa (Fig.3b). The equivalent von Mises stress calculated at the same location was equal to 8 MPa. This allows concluding that low stress levels are applied on that region and fatigue failure will not be probable to occur there. However, periodical inspections should be carried out near the more stressed reinforcements.

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