Vertical plane response of a ship on irregular seas

Respuesta en el plano vertical de un buque en mar irregular

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Abstract

This work presents the study of the sea response on the vertical plane for a 40-m length overall coastal patrol vessel (CPV-40) of Colombia's National Navy. The condition studied is at full load and at patrol and maximum speeds. First, we analyzed the response for regular waves with incidence angles of 90º, 120º, 150º, and 180º, obtaining the response for heave and pitch motions through the SCORES program that uses the method called "girdle theory". From the response, it was verifiedthat the amplitudeof the response is proportional to the amplitudeof the incident wave. Thereafter, the calculation of the vertical acceleration was made for four ship positions: bow, stern, cabin, and bridge, with the greatest vertical accelerations on the bow. Finally,the study was conducted for irregular sea considering as measuring parameters the vertical acceleration on the bridge and the pitching angle for the patrol operation, from the NATO document, compliance was verified of the study parameters at RMS level. It was found that for this condition the vessel complies and, hence, the personnel will not be affected in the performance of their functions.

Key words: seakeeping, irregular sea, coastguard patrol, SCORES, RMS

Resumen

En este trabajo se presenta el estudio de la respuesta al mar en el plano vertical para una embarcación de 40 metros de eslora tipo Patrullera de zona de costera, CPV-40 (por sus siglas en ingles Costal Patrol Vessel), de la Armada Nacional de Colombia. La condición estudiada es a plena carga y a velocidades de patrullaje y máxima. Primeramente se analizó la respuesta para olas regulares con ángulos de incidencia de 90º, 120º, 150º y 180º obteniéndose la respuesta para los movimientos de levantamiento y cabeceo mediante el programa SCORES que utiliza el método llamado "teoría de fajas". A partir de la respuesta se verificó que la amplitud de la respuesta es proporcional a la amplitud de la ola incidente. Posteriormente se realizó el cálculo de la aceleración vertical para cuatro posiciones en el buque: proa, popa, camarote y puente de gobierno, presentándose las mayores aceleraciones verticales en la proa. Finalmente se realizó el estudio para mar irregular considerando como parámetros de medición la aceleración vertical en el puente y el ángulo de cabeceo para la operación de patrullaje, a partir del documento de la NATO, se verificó el cumplimiento a nivel de RMS de los parámetros de estudio. Encontrándose que para esta condición la embarcaron cumple y por lo tanto el personal no se verá afectado en el desempeño de sus funciones.

Palabras claves: comportamiento en el mar, mar irregular, patrullero de costa, SCORES, RMS

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Vessel Description

The coastal patrol vessel CPV-40 is a design carried out and constructed by German shipyard, FASSMER, for the Colombian National Navy and it is designed to comply coastguard functions in the Caribbean Sea and the Pacific Ocean of the Republic of Colombia. Mainly border control and marine safety operations are among the functions performed by the vessel; additionally,the ship is in capacity of performing search and rescue operations, environmental control, and humanitarian aid, among others. It has a 15-day autonomy and capacity to transport 24 crew members, along with a 2,000-nautical mile reach at 12 knots under 245-ton displacement conditions and zero seat.

The ship has the following operational profile for 180 days of annualwork:

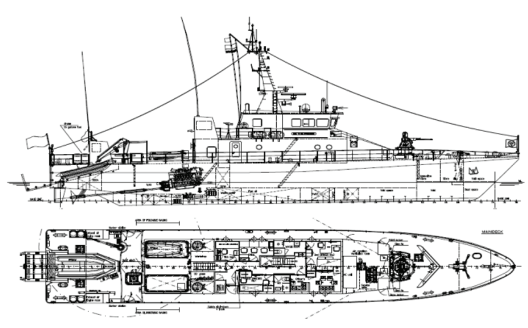
-Patrol speed from 7 to 9 knots: 55%
-Cruising speed from 12 to 15 knots: 35%
-Maximum speed from 19 to 21 knots: 10%

Main Dimensions

Length overall:	40.00 m
Beam:	7.40 m
Forestay:	3.80 m
Draft:	1.86 m
Full-load displacement:	245 Ton

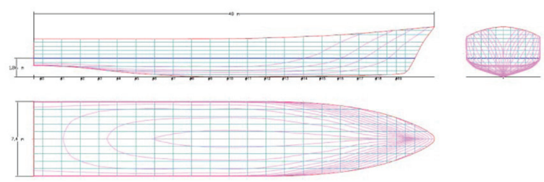
Figs. 1 and 2 show the lateral view of the general disposition, along with the CPV-40 shape lines, respectively.

Fig. 1. General disposition, lateral view



Source: Fassmet (2011)

Fig. 2. CPV-40 shape lines



Source: Fassmet (2011)

Response on regular waves

The following shows the study of the response on regular waves from the implementation of data files of the SCORES program, which permits finding the response to motions generated by irregular seasand regular waves. Values were obtained for frequency of encounter, heave and pitch amplitude, for two speed conditions (12 and 19 knots), and design draft of 1.86 m.

Heave

Figs. 3 and 4 show that the tendency in each of the extremes is: for small ratios of λ/L, the amplitudes tend to be null, except for incident waves at 90º; asthis ratio takes on values toward the far right, the response increases until reaching its maximum value.

The maximum amplitude at a speed of 12 knots is equal to the amplitudeof the incident wave. Upon increasing the speed to 19 knots, amplitudes are produced above the amplitude of the incident wave; this is noted from a wavelength 1.5 times the length overall. If the incidence angle of the wave train is 90°, increased response does not occur with increased speed.

For both speeds, the wave train incidence angle only affects for wavelengths below 1.5 times the length overall; for higher wavelength values, the heave response remains constant in the maximum value.

With higher speed, higher heave amplitude for incidence angles 120º, 150º, and 180º.

Fig. 3. Heave graphic Vs.Wavelength / Length, speed 12 Kn

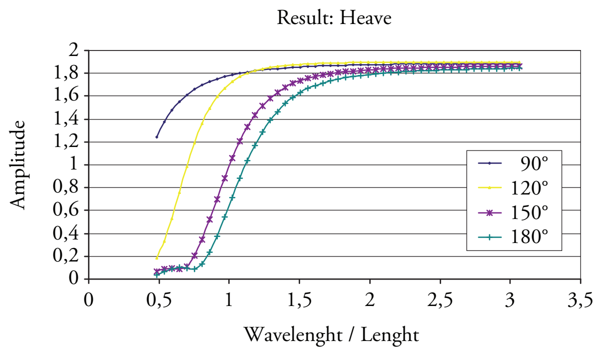


Fig. 5. Pitching graphic Vs.Wavelength / Length,speed 12 Kn

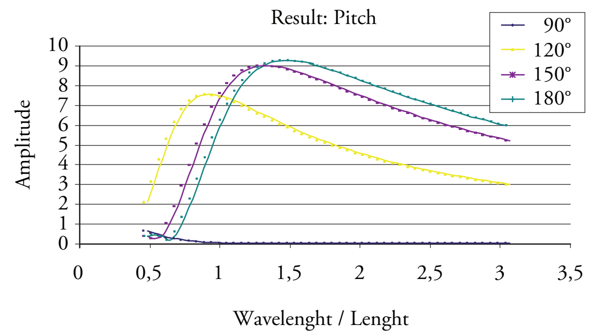


Fig. 4. Heave graphic Vs.Wavelength / Length, speed 19 Kn

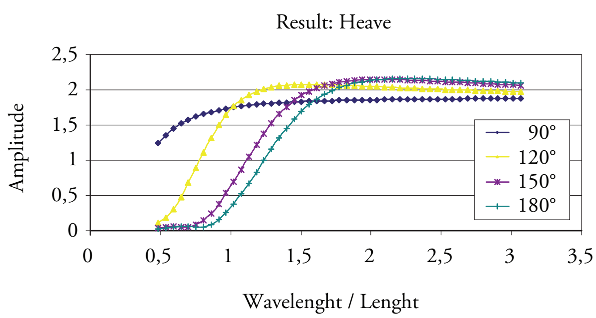
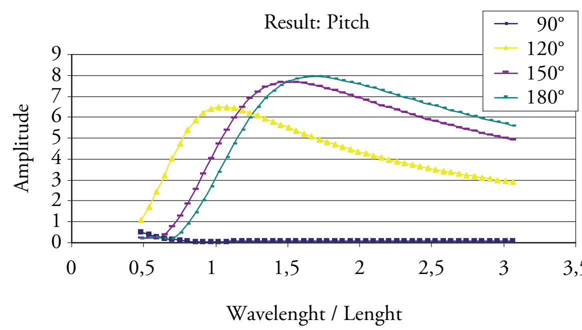


Fig. 5. Pitching graphic Vs.Wavelength / Length,speed 19 Kn



Pitching

Figs. 5 and 6 show that the tendency in each of the extremesis: at small wavelength/ship ratios the amplitude tends to be null; as the ratio takes on values toward the far right, the amplitude shows a negative slope.

When the incidence angle is 90° the amplitude is null, as expected, given that the wave trains on the side do not produce pitching but balance because the ship's length overall is aligned with the wave crest (front of the wave). The amplitude increases as the incidence angle increases. As the vessel's course is changed toward 90º, responses decrease.

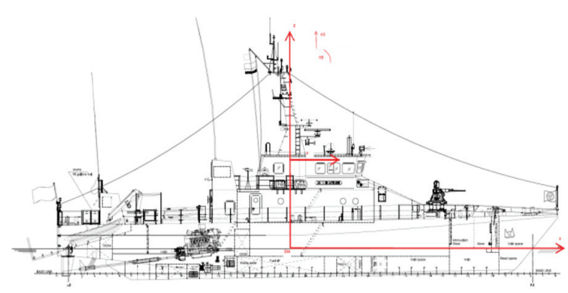
Within an intermediate range of λ/L, the maximum amplitude value occurs, presenting the resonance phenomenon. The highest resonance responses occur when the waves come from the bow, that is, at 180°.

Calculation of vertical acceleration

For vertical acceleration, four points on the ship were analyzed: bow, stern, bridge, and cabin.

$x_1 =$ 3.0 m $\quad$ $x_2 =$ 16.5 m

$x_3 =$ -3.6 m $\quad$ $x_4 =$ -18.0 m



Source: Fassmet (2011)

The motion equationfor the vertical plane is given by:

$$\omega(x,t) = \eta_3 - x \cdot \eta_5$$

$$\omega(x,t) = \zeta_3 e^{i(\omega t + \theta_3)} - x\zeta_5 e^{i(\omega t + \theta_5)}$$

$$\omega(x,t) = (\zeta_3 Cos\,\theta_3 + i\zeta_3 Sen\,\theta_5 - x\zeta_5 Cos\theta_5 - ix\zeta_5 Sen\,\theta_5)e^{i\omega t} \quad (1)$$

$$W = \sqrt{R_{eal}^{\;2} + I_{mg}^{\;2}}$$

$$|\ddot{\omega}|(x,t) = \omega_e^{\;2} W$$

From the data given by the SCORES program, values are takenfor phases and amplitudes in heave and pitch with which calculation is made of accelerations for each point and these are seen in Figs. 10 and 11.

Fig. 10. Graphic of Vertical acceleration Vs. Wavelength/ Length Speeds of 12 Kn

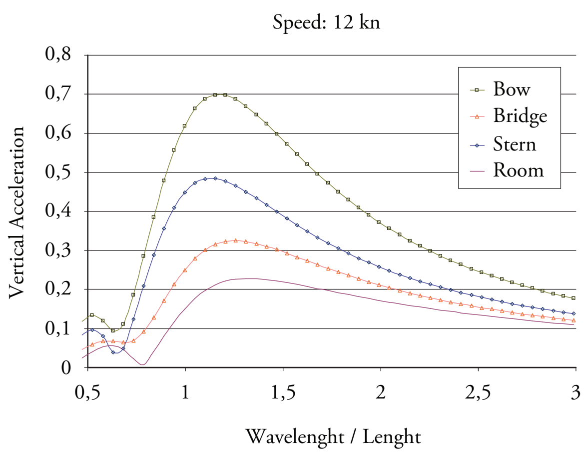
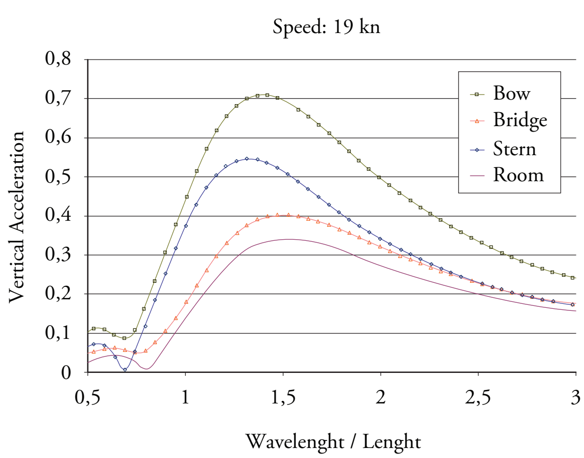


Fig. 11. Graphic of Vertical acceleration Vs. Wavelength/ Length Speeds of 19 Kn



From Figs. 10 and 11, it may be noted that the highest accelerations occur in the bow; these are given for wavelength/ship ratios between 1.2 and 1.5 when speedis 12 knots and between 1.4 and 1.5 for speedof 19 knots. The lowest accelerations occur in the cabin, which is a point to stern closet o the mid section.

Response in irregular sea

Continuing with the study, heave and pitch motions were considered in irregular seas, establishing as measuring parameters acceleration on the bridge and the pitching angle. NATO [1],in its publication *"Common Procedures for seakeeping in the ship design Process"*, established recommendations of parameter acceptance limits according to the mission for military ships. This study took as acceptance limits those recommended in said publication for personnel performance; these are detailed in the following table:

Table 1. Acceptance parameters according to NATO

Motion	Limit	Location
Motion sickness incidence (MSI)	20% of the crew @4h	Work place
Motion-induced interruption (MII)	1/min	Work place
Relative wind	35 knots	Work place if on exposed deck
Roll	4°	
Pitching	1.5°	Bridge
Vertical acceleration	0.2 g	Bridge
Lateral acceleration	0.1 g	Bridge
Relative wind	35 knots	Flight deck

This work was limited to analyzing vertical acceleration on the bridge and pitching angle measured in terms of RMS.

The condition of the ship for the analysis is at full load and at patrol speed of 12 knots, with 180° incident waves with respect to ship motion (sea by bow). Likewise, according to the operation zone, a sea state of 4 is established with the following characteristics:

- Significant wave height (Hs): 1.88 m
- Period (Tp): 7.6 s.
- Wind speedBft: 10 knots

From the results on regular waves, we calculated the spectrum of the parameter response from the following equation:

$$S^{+}_{Re\,sp}(\omega_e) = S^{+}_{Olas}(\omega_e)\, RAO^{2} \qquad (2)$$

RAOS ^{2} of the parameters analyzed are presented in the following figures:

Fig. 12. RAOS² for vertical acceleration

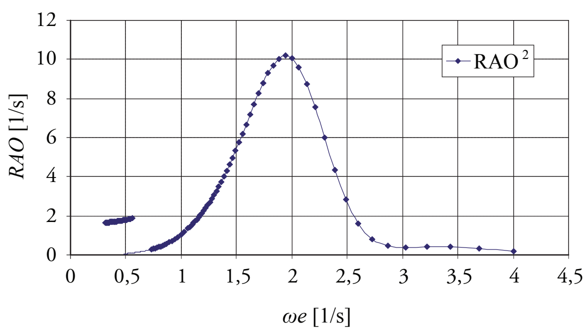
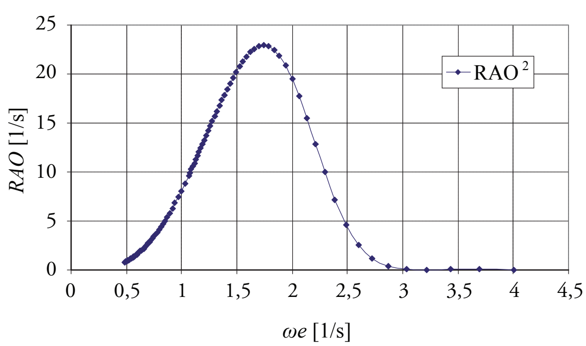


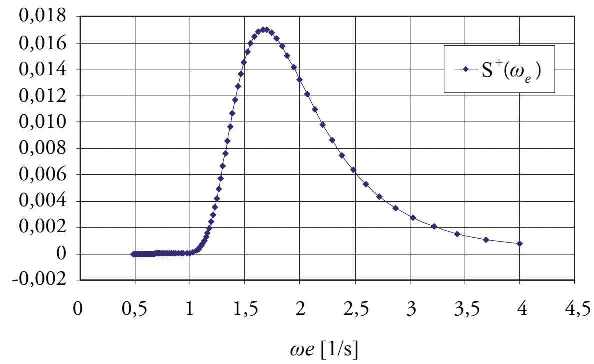
Fig. 13. RAOS² for pitching



The representation of the spectrum of the irregular sea for the state of this study was developed from the Pierson-Moskowitz formula, which is presented in Fig. 14.

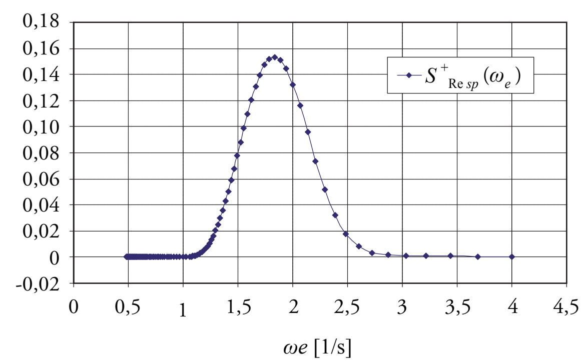
$$S^{+}(\omega) = \frac{8.1x\;10^{-3}}{\omega^{5}} g^{2}\, e^{-0.74\,(g/V\omega)^{4}},\; S.I \qquad (3)$$

Fig. 14. Wave spectrum



The response spectra were obtained from equation (2); these are presented in the following:

Fig. 15. Spectra of the response for vertical acceleration



Variance and RMS of the response are obtained from the following equation:

$$\sigma_{Re\,sp}^{2} = \int_{-\infty}^{\infty} d\omega_e\, S_{Re\,sp}^{+}(\omega_e) = RMS^{2} \qquad (4)$$

The results for the responses and the recommended limit values in terms of RMS are presented by the following table:

Table 2. Recommended limit values in term of

Motion	CPV	Limit	Location
Pitching	0.54°	1.5°	
Vertical acceleration	0.03 g	0.2 g	Bridge

From the previous table, it can be noted that for the condition at full load, navigating at a speed of 12 knots and at sea state of 4, crew performance will not be affected.

Compliance of the recommendations also implies analysis of other events of occurrence, like: immersion of the stern, slamming, and others. These can be obtained from the moments of the response spectrum from the following equation:

$$m_n = \int_0^\infty d\omega\ \omega^n\ S^+(\omega_e) \tag{5}$$

Moments Mo, M2, and M4 were obtained and are represented in the following tables:

Table 3. Moments M_o, M_2, and M_4 for vertical aceleration

Moments	**Units**	**Vertical acceleration bridge**
M_o	[m2/s^4]	0.11
M_2	[m2/s^5]	0.141
M_4	[m2/s^7]	0.184

Table 4. Moments M_o, M_2, and M_4 for pitching

Moments	**Units**	**Pitching**
M_o	[Degrees^2]	0.29
M_2	[Degrees2/s]	0.33
M_4	[m2/s^3]	0.39

Conclusions

From the present study, the following may be concluded:

- The response amplitude is proportional to the amplitude of the incident wave.
- Of the factors studied in this work, ship speed, incidence angle of the wave trains, wavelength and amplitude, the most significant in heave amplitude is wavelength, and for the pitching amplitude it is ship speed.
- The incidence angle of the wave trains is not significant for heave; only its interaction with speed and wavelength.
- The values of maximum acceleration appear in the bow and the minimum values in the cabin, which is the nearest point to the mid section.
- In the condition at full load, navigating at a speed of 12 knots, and sea state of 4 crew performance will not be affected.

References

[1] NATO, North Atlantic Treaty Organization, December, Military agency for standardization 2000.

[2]LEWIS E. Principles of Naval Architecture. Volume III. Motions in waves and Controllability. ISBN 0-939773-02-3. November, 1989.