THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620, e-ISSN 2668-3156
2021

ON SEAKEEPING CAPABILITIES EVALUATION OF A LARGE OFF-SHORE BARGE

Leonard Domnişoru
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture,
Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: leonard.domnisoru@ugal.ro

ABSTRACT

Specially designed barges are involved in the off-shore operations that have to be evaluated by several criteria, including the seakeeping capabilities. The paper includes a comparative seakeeping study of two constructive versions for a large off-shore barge with a length of 189 m, having different breadths 40 m and 50 m. Both constructive versions are on the full cargo 23000 t condition. The seakeeping analyses are done with our own software DYN-OSC, developed by linear potential Lewis's strip theory. The seakeeping studies are done in oblique irregular waves with a maximum height of 12 m and for the off-shore barge maximum operation speed of 7 knots. The results of this comparative study reveal the differences in the seakeeping operation capabilities for the two off-shore barge constructive versions.

Keywords: seakeeping, large off-shore barge, linear oscillations, comparative study.

1. INTRODUCTION

This study includes the seakeeping capabilities evaluation for a large off-shore barge with two constructive versions at full load of 23000 t, having different breadths 40 m (B40) and 50 m (B50). The main data of the off-shore barge is presented in Table 1 and the offset lines for version B40 in Fig.1.

The off-shore barge, both versions, has a prismatic shape, with rounded bilge over 179.2 m, transom stern, and with slip shape at the fore-peak over 9.8 m (Fig.1).

The vertical gravity centre of the 23000 t cargo is considered in the range z_{GCMD}=2÷20 m, with respect to the main deck plane H. The off-shore barge speed is reduced for three trial values v = 0, 3.5, and 7 knots, representing the usual operation state at zero speed and the eventual transit state between locations, loaded at full cargo. The short-term oblique irregular waves are modelled by ITTC [3] spectrum, with maximum height H_{smax}=12 m.

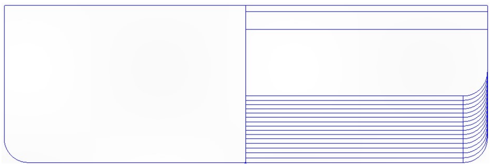

Fig.1.The off-shore barge B40 offset lines

Table 1. The large off-shore barge data

L[m]	189	*Vers:*	B40	B50
H[m]	11	Δ_{light}[t]	26586	33390
H_P[m]	1.5,1,2	Δ[t]	49586	56390
ρ[t/m^3]	1.025	V[m^3]	48377	55014
g[m/s^2]	9.81	L_{WL}[m]	189	189
stations	270	d_m[m]	6.586	6.000
points	5400	*trim*	0	0
v[knots]	0,3.5,7	x_G[m]	92.467	92.266
cargo [t]	23000	x_F[m]	94.497	94.489
z_{GCMD}[m]	2÷20	z_B[m]	3.345	3.044
μ [deg]	0÷360	r[m]	20.835	35.774
spectrum	ITTC	T_{heave}[s]	8.408	8.686
H_{smax}[m]	12	T_{pitch}[s]	8.316	8.664

For the roll oscillations analysis of the two constructive versions, B40, B50, several scenarios for the cargo vertical gravity centre are considered (z_{GCMD}), resulting the transversal stability diagrams (Fig.2 and Fig.3) and roll natural periods (Table 2).

Table 2 Large off-shore barge roll natural periods and stability maximum angle

Vers.	B40			B50		
z_{GCMD} [m]	z_{Gship} [m]	T_{roll} [s]	φ_{maxGZ} [deg]	z_{Gship} [m]	T_{roll} [s]	φ_{maxGZ} [deg]
2	8.979	10.729	23	8.559	7.335	22
4	9.906	11.146	22	9.375	7.559	21
6	10.834	11.610	22	10.190	7.787	20
8	11.762	12.130	21	11.006	8.022	20
10	12.690	12.715	20	11.822	8.263	19
12	13.617	13.378	19	12.638	8.512	19
14	14.545	14.136	19	13.454	8.771	19
16	15.473	15.014	18	14.269	9.039	18
18	16.400	16.043	17	15.085	9.319	18
20	17.328	17.273	17	15.901	9.611	17

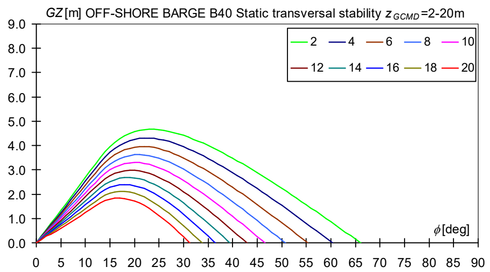

Fig.2 Barge B40, GZ[m], z_{GCMD}=2÷20 m

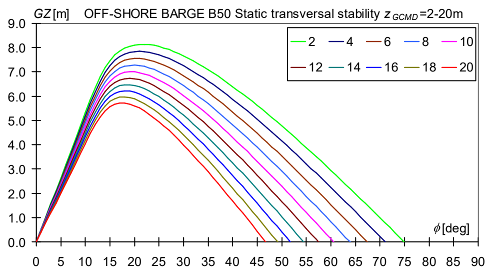

Fig.3 Barge B50, GZ[m], z_{GCMD}=2÷20 m

In table 3, there are presented the limit criteria for the evaluation of the seakeeping operation capabilities of the large off-shore barge with the two constructive versions.

Table 3 Seakeeping admissible criteria

Version	B40	B50
$RMS_{aft\text{-}combined}$[m]	5.614	6.200
$RMS_{mid\text{-}combined}$[m]	5.114	5.700
$RMS_{fore\text{-}combined}$[m]	6.114	6.700
RMS_{pitch}[deg]	3	3
RMS_{roll}[deg]	6	6
$RMS_{acc\text{-}heave}$[m/s^2]	0.981	0.981
$RMS_{acc\text{-}pitch}$[deg/s^2]	0.595	0.595
$RMS_{acc\text{-}roll}$[deg/s^2]	2.810	2.248

On average, the restoring terms are 2.856 times larger and total inertial terms are 1.128 times larger for barge B50 in comparison to B40. So, the natural roll period T_{roll} (Table 2) is on average 1.584 times larger for B40 in comparison to B50. Lower roll period will lead to lower roll damping.

The comparative seakeeping study is developed with in-house DYN-OSC program [2]. The code is developed by linear potential Lewis's strip theory with the theoretical fundaments presented in [2],[3],[5] and validation by experimental trials at the towing tank in [1],[4].

The numerical results are pointing out the seakeeping operation capabilities of the off-shore barge constructive versions.

2. OSCILLATION RESPONSE AMPLITUDE OPERATORS

The radio L/B is 3.780 (B50) and 4.725 (B40) so that the slender body potential flow strip theory approach can be applied for the oscillations response amplitude operators computations of both off-shore barge constructive versions. At this stage, as excitation, the oblique regular wave, with unit amplitude and maximum circular frequency of 3 rad/s (fine frequency step 0.001 rad/s), is applied.

2.1 Off-shore barge heave motion RAO's

This section includes the selected heave motion RAO_{heave}, Figs.4.1-4 for barge B40, and Figs.5.1-4 for barge B50.

The differences between both versions of heave RAO are very reduced, even for the natural periods 8.403 s (B40) and 8.686 s (B50). The heave motion is maximum for beam sea condition (Fig.4.1&5.1), where the barges' speed influence can be disregarded (Fig.4.3 & 5.3).

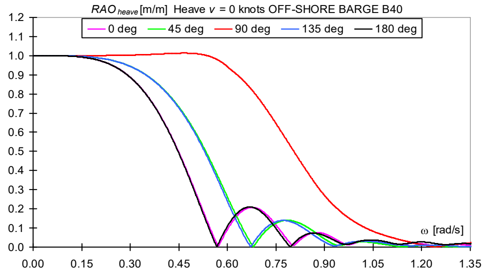

Fig.4.1 RAO_{heave}[m/m], B40, v=0 knots

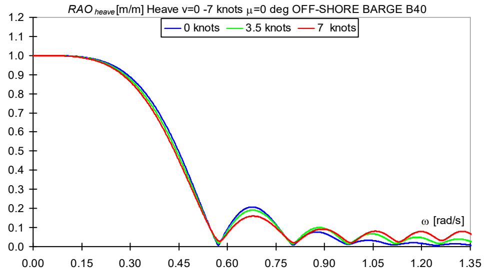

Fig.4.2 RAO_{heave}[m/m], B40, μ=0, v=0-7knots

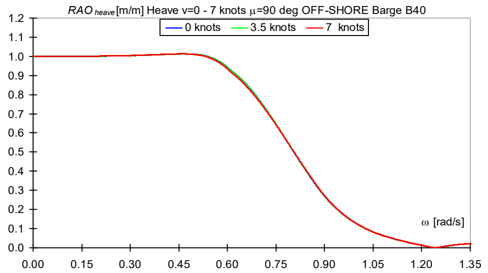

Fig.4.3 RAO_{heave}[m/m], B40, μ=90, v=0-7knots

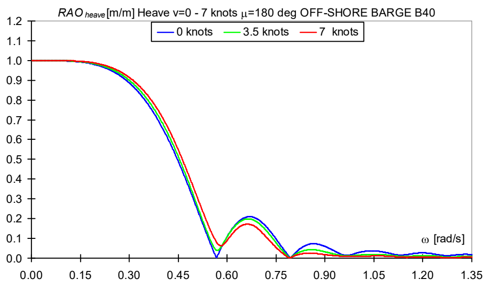

Fig.4.4 RAO_{heave}[m/m], B40, μ=180,v=0-7knots

For follow sea (Fig.4.2 & 5.2) and head sea (Fig.4.4 & 5.4) conditions the barges' speed influence on heave motion is reduced, due to the extended prismatic shape and vertical sides around the equilibrium water plane.

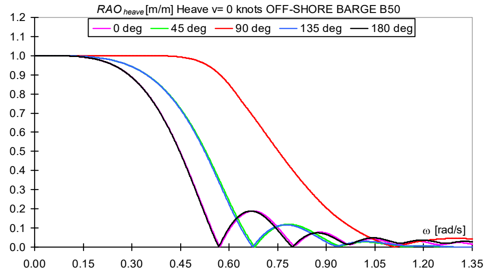

Fig.5.1 RAO_{heave}[m/m], B50, v=0 knots

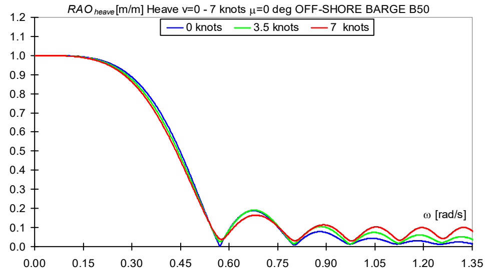

Fig.5.2 RAO_{heave}[m/m], B50, μ=0, v=0-7knots

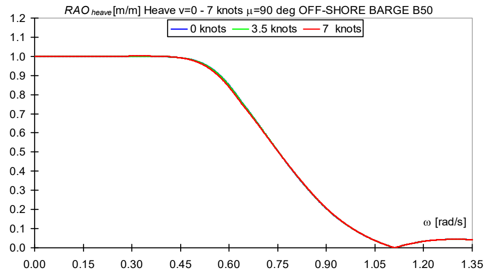

Fig.5.3 RAO_{heave}[m/m], B50, μ=90, v=0-7knots

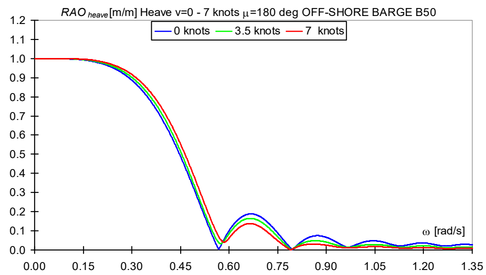

Fig.5.4 RAO_{heave}[m/m], B50, μ=180,v=0-7knots

2.2 Off-shore barge pitch motion RAO's

This section includes the selected pitch motion RAO_{pitch}, Figs.6.1-3 for barge B40, and Figs.7.1-3 for barge B50.

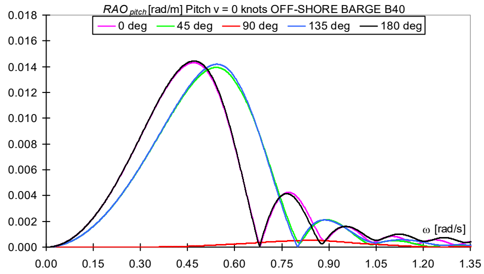

Fig.6.1 RAO_{pitch}[rad/m], B40, v=0 knots

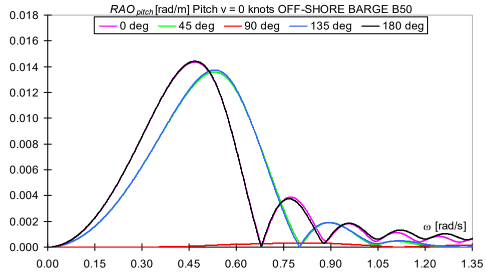

Fig.7.1 RAO_{pitch}[rad/m], B50, v=0 knots

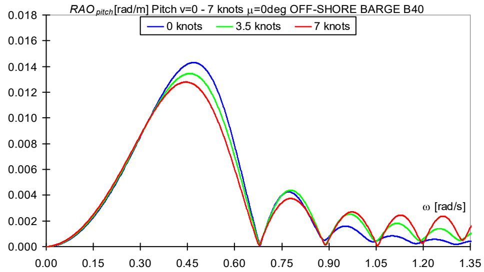

Fig.6.2 RAO_{pitch}[rad/m], B40, μ=0, v=0-7knots

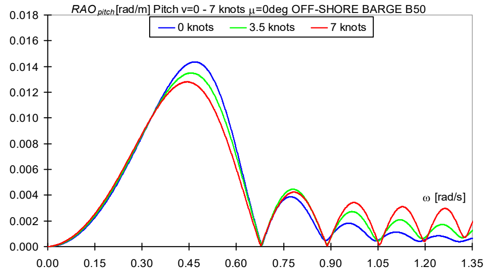

Fig.7.2 RAO_{pitch}[rad/m], B50, μ=0, v=0-7knots

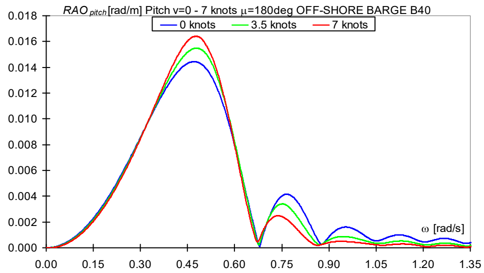

Fig.6.3 RAO_{pitch}[m/m], B40, μ=180,v=0-7knots

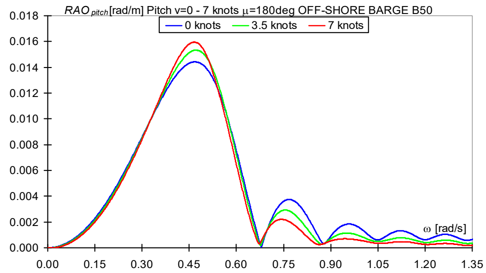

Fig.7.3 RAO_{pitch}[m/m], B50, μ=180,v=0-7knots

The differences between both versions of pitch *RAO* are very reduced, even for the natural periods 8.316 s (B40) and 8.664 s (B50).

At beam sea condition (Fig.6.1 & 7.1) the pitch motion has the minimum value, where the barges' speed influence can be disregarded, due to the linear potential approach.

At follow sea condition (Fig.6.2 & 7.2) the pitch motion decreases as the barges' speed increases. At head sea conditions (Fig.6.3 & 7.3) the pitch motion records the maximum values and is increasing as the barges' speed is increasing. The differences between follow sea and head sea conditions for pitch motions are due to the slip shape at the fore and U prismatic shape at the stern.

2.3 Off-shore barge roll motion RAO's

This section includes the selected roll motion RAO_{roll}, Figs.8.1-3 for barge B40, and Figs.9.1-3 for barge B50. The off-shore barge is designed to transport cargo only on the main deck, with an average cargo vertical gravity centre z_{GCMD}=8 m, so that results z_{GS}= 11.762 m (B40) and z_{GS}= 11.006 m (B50).

The differences between both versions of roll *RAO* are significant, having natural roll periods with distinct ranges 10.729÷17.273s (B40) and 7.335÷9.611s (B50) (Table 2).

At beam sea condition the roll RAO_{roll} has the maximum values for both versions (Fig.8.2 & 9.2). The barge speed influence is significant for the quarter sea conditions. The change of the barge-cargo vertical gravity centre has a significant influence on the roll RAO_{roll} (Fig.8.1 & 9.1). The second version B50 has higher values for the roll RAO_{roll} in comparison to the first version B40 (Figs.8&9), having lower hydrodynamic damping.

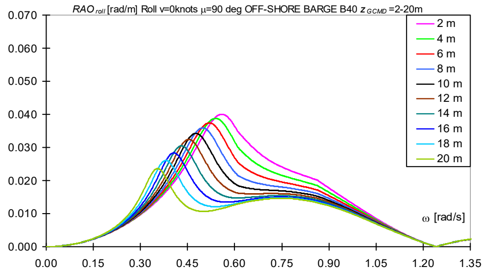

Fig.8.1 RAO_{roll},B40,μ=90,z_{GC}=2-20m,v=0kn

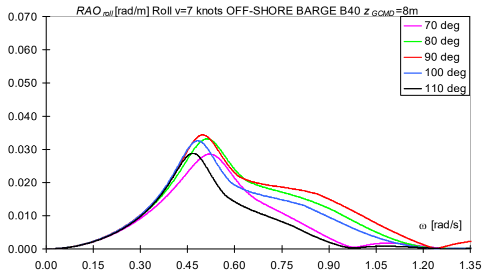

Fig.8.2 RAO_{roll}[rad/m], B40, z_{GC}=8m, v=7kn

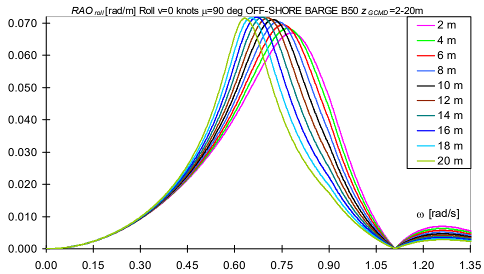

Fig.9.1 RAO_{roll},B50,μ=90,z_{GC}=2-20m,v=0kn

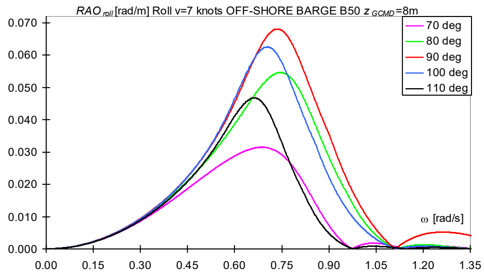

Fig.9.2 RAO_{roll}[rad/m], B50, z_{GC}=8m, v=7kn

3. SEAKEEPING SHORT-TERM RESPONSE

Based on the *RAO* motion functions from section 2, for irregular waves with ITTC spectrum [3] the seakeeping short-term responses [2] for both constructive versions are obtained. The seakeeping capabilities are evaluated by the admissible criteria (Table 3) formulated in terms of *RMS* motions and associated accelerations for the main oscillations degrees of freedom for the off-shore barge with two constructive versions, vertical otion (heave) and angular motions (roll and pitch), resulting in the seakeeping navigation limits polar diagrams [2],[5].

3.1 Off-shore barge short-term response

This section includes the selected short-term response *RMS*, Figs.10.1-7 for barge B40, and Figs.11.1-7 for barge B50.

The short-term response on combined vertical motions (Fig.10.1-2 & 11.1-2), pitch motions (Fig.10.4 & 11.4), heave (Fig.10.3 & 11.3) and pitch (Fig.10.5 & 11.5) accelerations have very reduced differences between the two barges' constructive versions, as it has been foreseen in section 2, with barges speed influence mainly on quarter-head and quarter-follow sea conditions.

The vertical combined motions $RMS_{combined}$ criteria, aft, mid & fore, are not satisfied, representing the only restrictions for both versions, even if the B50 barge has the free side by 0.586 m higher (Table 3). The RMS_{pitch}, $RMS_{acc\text{-}pitch}$, $RMS_{acc\text{-}heave}$ criteria are satisfied for both constructive versions.

The short-term response on roll motions (Fig.10.6 & 11.6) and roll accelerations (Fig. 10.7 & 11.7) have significant differences. The maximum roll short-term response is obtained for B50 barge, due to higher natural circular frequencies 0.654÷0.857 rad/s (B50) in comparison to 0.364÷0.586 rad/s (B40), leading to the reduction of the roll damping for the second off-shore barge constructive version. Even so, the RMS_{roll}, $RMS_{acc\text{-}roll}$ criteria are satisfied, taking as reference the maximum response at beam sea for both barge versions.

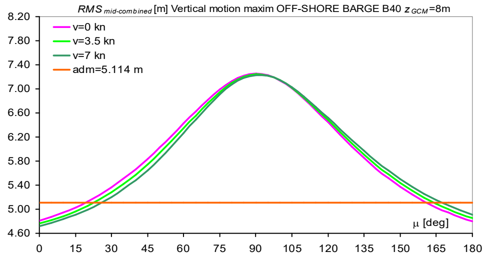

Fig.10.1 $RMS_{mid\text{-}combined}$[m], B40, z_{GCMD}=8m

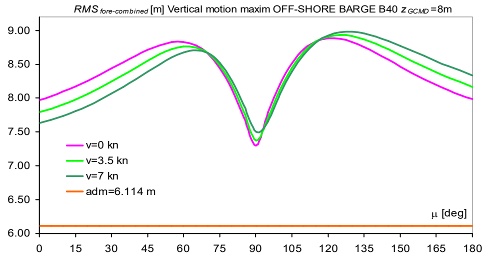

Fig.10.2 $RMS_{fore\text{-}combined}$[m], B40, z_{GCMD}=8m

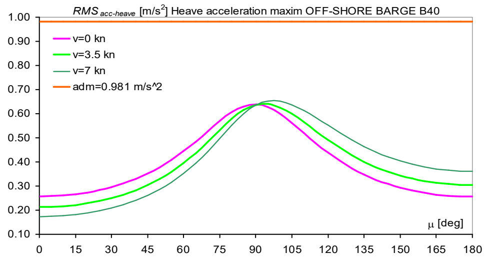

Fig.10.3 $RMS_{acc\text{-}heave}$[m], B40

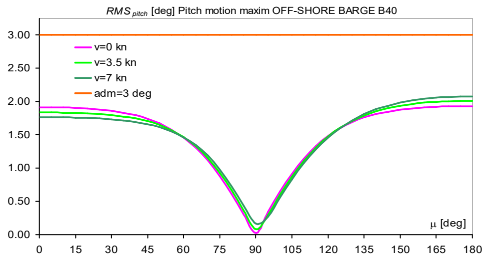

Fig.10.4 RMS_{pitch}[deg], B40

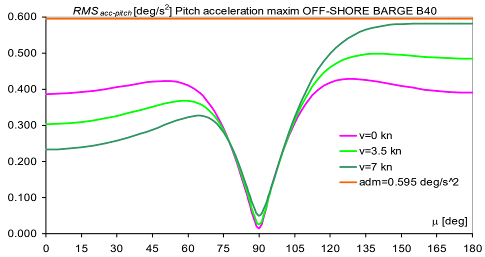

Fig.10.5 $RMS_{acc\text{-}pitch}$[deg/s^2], B40

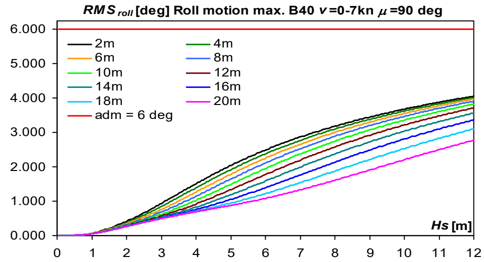

Fig.10.6 RMS_{roll}[deg], B40, μ=90 deg

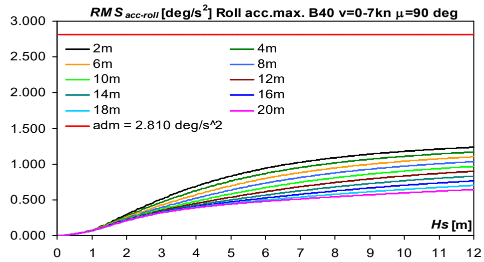

Fig.10.7 $RMS_{acc\text{-}roll}$[deg/s^2], B40, μ=90 deg

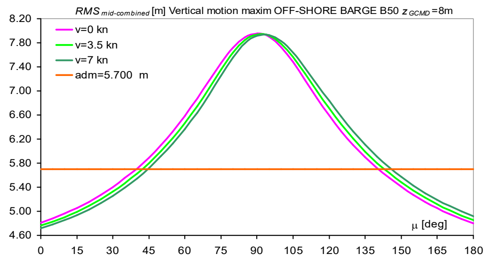

Fig.11.1 $RMS_{mid\text{-}combined}$[m], B50, z_{GCMD}=8m

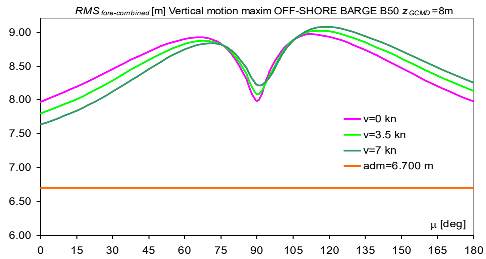

Fig.11.2 $RMS_{fore\text{-}combined}$[m], B50, z_{GCMD}=8m

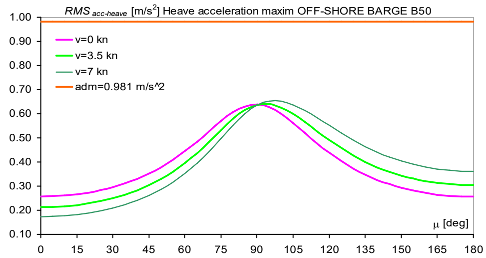

Fig.11.3 $RMS_{acc\text{-}heave}$[m], B50

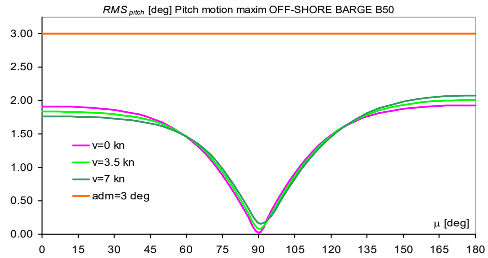

Fig.11.4 RMS_{pitch}[deg], B50

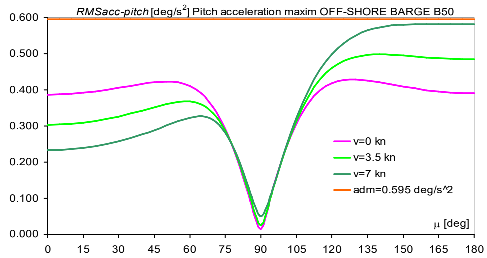

Fig.11.5 $RMS_{acc\text{-}pitch}$[deg/s^2], B50

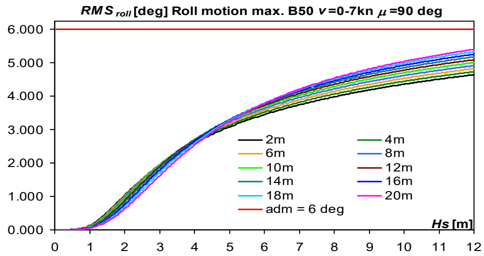

Fig.11.6 RMS_{roll}[deg], B50, μ=90 deg

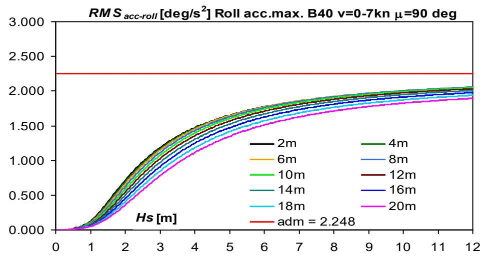

Fig.11.7 $RMS_{acc\text{-}roll}$[deg/s^2], B50, μ=90 deg

3.2 Off-shore barge seakeeping capabilities

This section includes the selected results for seakeeping capabilities evaluation, Fig.12,Figs.13.1-2 for barge B40, and Fig.14, Figs.15.1-2 for barge B50.

The influence of cargo z_{GCMD} is noticeable at beam sea (Fig.12 & 14) due to mid-combined vertical criteria where roll response is sensitive and maximum (Figs.10.6-7 & 11.6-7).

Figs.13.1-2 and Fig.15.1-2 present the operation capabilities by seakeeping criteria (Table 3), for average cargo z_{GCMD}=8 m, the trend is similar, except for the beam sea case.

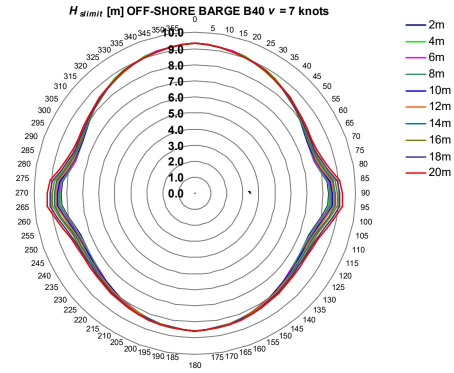

Fig.12 H_{slimit}[m], B40, v=7knots, z_{GCMD}=2÷20m

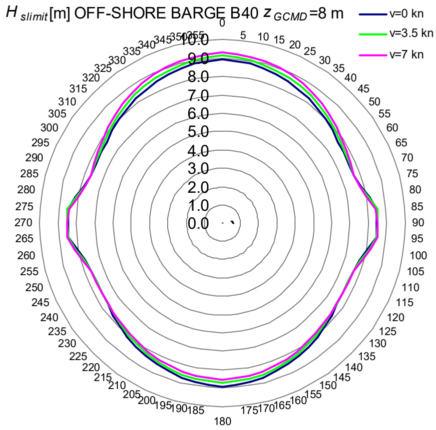

Fig.13.1 H_{slimit}[m], B40, z_{GCMD}=8 m

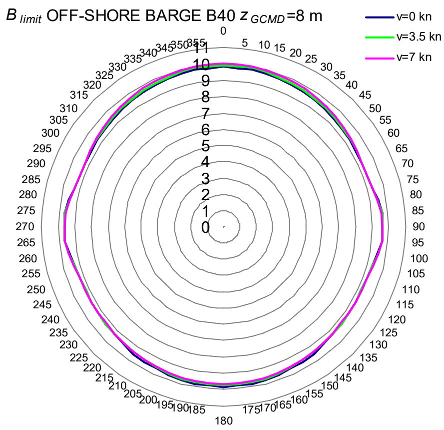

Fig.13.2 B_{limit}, B40, z_{GCMD}=8 m

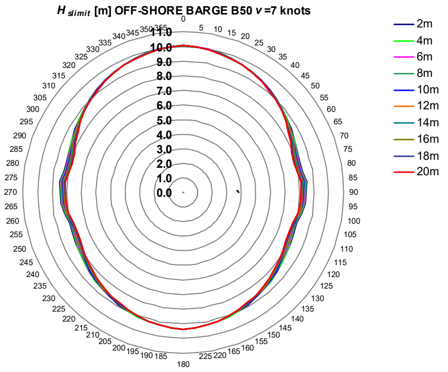

Fig.14 H_{slimit}[m], B50, v=7knots, z_{GCMD}=2÷20m

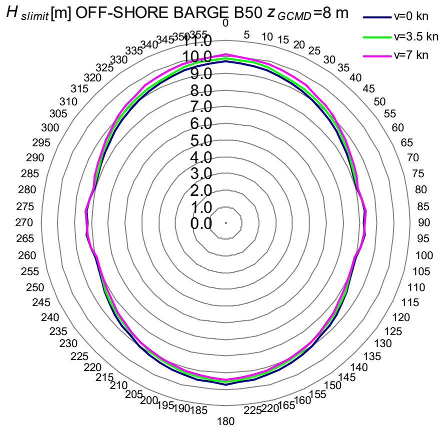

Fig.15.1 H_{slimit}[m], B50, z_{GCMD}=8 m

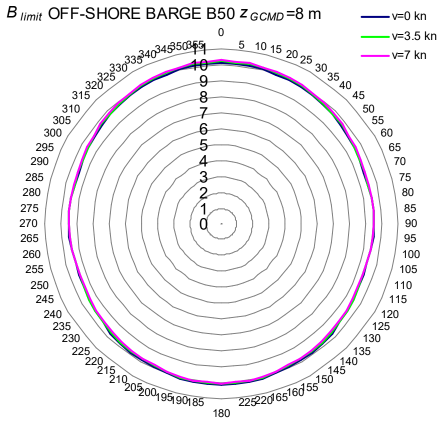

Fig.15.2 B_{limit}, B50, z_{GCMD}=8 m

Table 4 includes an average of the seakeeping operation capabilities for both barge versions, being similar. The higher free side for barge B50 leads to a smaller advantage.

Table.4 Seakeeping limits for off-shore barge

v[kn]	*vers.*	z_{GCMD}[m]	B_{limit}	H_{slimit}[m]
0	B40	2-20 Limits from vertical motion criteria	9.16÷9.96	7.520÷9.203
	B50		9.25÷10.14	7.724÷9.672
3.5	B40		9.15÷9.97	7.509÷9.212
	B50		9.26÷10.22	7.729÷9.875
7	B40		9.15÷10.01	7.510÷9.318
	B50		9.26÷10.29	7.744÷10.079

4. CONCLUSIONS

The response on regular waves points out that heave and pitch motions are similar for both versions, with speed influence on quarter-follow and quarter-head sea cases. The roll motions on regular waves have significant differences, with segregated natural frequencies and maximum at beam sea case.

The short-term response in oblique waves points out that pitch and roll motions, all accelerations, criteria are satisfied for the whole range of waves, barge's speed, and cargo conditions. The combined vertical motions criteria are not satisfied at aft and fore, partial at mid, leading to the only operation restrictions.

In conclusion, both off-shore barges have similar seakeeping capabilities B_{limit}≈9, acceptable for the design operational area.

Acknowledgments

This study is developed at the Naval Architecture Research Centre, "Dunarea de Jos" Univ. of Galati.

REFERENCES

[1]. **Burlacu, E., Domnisoru, L., Obreja, D.,** *"Seakeeping prediction of a survey vessel operating in the Caspian Sea"*, OMAE 2018-77126, ASME Conference, Madrid, 2018.

[2]. **Domnisoru, L.,***"Ship dynamics. Oscillations and vibrations",* E.T., Bucharest 2001.

[3]. **Journée, J.M.J, Pinkster, J,,** *"Introduction in ship hydromechanics"*, TU Delft, 2002.

[4]. **Obreja, D., Nabergoj, R., Crudu, L., Domnisoru, L.,** *"Seakeeping performance of a Mediterranean fishing vessel"*, IMAM, pages 483-491, Lisbon, 2017.

[5]. **Obreja, D.,** *"Ship theory. Concepts and methods for the navigation performances analysis",* E.D.P., Bucharest, 2005.

Paper received on November 5th, 2021

