ON THE RIVER BARGE OF 3000 T PRELIMINARY SEAKEEPING APPROACH

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ABSTRACT

This study concerns the preliminary seakeeping analysis of a river barge of 3000 T with length of 90 m and two main loading conditions: full cargo and ballast. As environmental conditions the maximum wave height is 2 m, with whole range wave-barge heading angle, specific for all the river navigation zone. The maximum speed of the river barge is 15 km/h. The numerical analysis involves a linear seakeeping code by strip-theory method and short-term irregular waves approach, representing a preliminary simplified evaluation of the navigation capabilities of the river barge.

Keywords: river barge, linear seakeeping, short-term analysis, irregular waves.

1. INTRODUCTION

For a river barge of 3000 T, the preliminary seakeeping analysis by linear strip-theory method [1] is developed in this study.

Table 1 presents the main characteristics of the 3000 T river barge [2], with two loading conditions: full cargo (F) and ballast (B). The river barge has an almost prismatic shape.

Table 1. The 3000 T river barge data [2].

| L [m] | 90 | Load: | Full (F) | Ball (B) |
|-------|----|-------|----------|----------|
| H [m] | 4.5 | ∆[t]  | 3620.73  | 507.73   |
| B [m] | 11  | dₚ [m]| 3.912    | 0.565    |
| v [km/h]| 0, 5, 8, 11, 15 | xₚ [m] | 43.145  | 42.252   |
| g [m/s²] | 9.81 | zₚ [m] | 1.932    | 0.287    |
| spectrum ITTC | r [m] | 2.000 | 1.643 | 16.675 |
| Hₚ [m] | 5.0 | Tₚ [s] | 5.457 | 3.692 |
| Jₓ [tm²] | F 32231 | Tₚ [s] | 5.102 | 3.828 |
| Jᵧ [tm²] | B 9756 | Tₚ [s] | 5.826 | 2.188 |

Figs.1,2 present the transversal stability charts, resulting in the peak healing angle φₚ=ζₓ equal to 13.50 deg (F) and 23.75 deg (B).
Table 2 presents the required seakeeping limit values used for the preliminary simplified evaluation of the river barge of 3000 T.

| Loading case | Full (F) | Ballast (B) |
|--------------|----------|-------------|
| $RMS_{Zpp-adm}[m]$ | 0.488 | 3.835 |
| $RMS_{Zm-adm}[m]$ | 0.602 | 3.835 |
| $RMS_{Zpv-adm}[m]$ | 0.716 | 3.834 |
| $RMS_{Rpitch-adm}[deg]$ | 1 | 1 |
| $RMS_{Rroll-adm}[deg]$ | 4 | 4 |
| $RMS_{Zacc-heave-adm}[m/s^2]$ | 0.491 | 0.491 |
| $RMS_{Racc-pitch-adm}[deg/s^2]$ | 1.248 | 1.175 |
| $RMS_{Racc-roll-adm}[deg/s^2]$ | 10.219 | 15.329 |

The preliminary seakeeping analysis of the 3000 T river barge is done by a linear strip theory approach implemented in own DYN(OSC) code [3], validated by several tests [4], [5].

2. FULL CARGO (F), 3000 T RIVER BARGE DYNAMIC ANALYSIS

2.1 RAO’s functions of the 3000 T river barge, full cargo loading case

The linear strip theory [3] applied to the river barge of 3000 T on full cargo loading case, with unit amplitude regular wave excitation, delivers the deterministic hydrodynamic response in the frequency domain:
- Fig.3, heave $RAO$, $v=0$ km/h, full;
- Figs.4.1-5, heave $RAO$, $\mu=0$-180 deg, full;
- Fig.5, pitch $RAO$, $v=0$ km/h, full;
- Figs.6.1-5, pitch $RAO$, $\mu=0$-180 deg, full;
- Fig.7, roll $RAO$, $v=0$ km/h, full;
- Figs.8.1-5, roll $RAO$, $\mu=70$-110 deg, full;

function to the $v$ barge speed, $\mu$ heading angle, and $\omega$ wave circular frequency.
The maximum heave $RAO$ is obtained at beam waves. The speed influence is reduced on following and stern oblique waves, being recorded mainly on fore oblique and head waves (Figs. 3,4).

**Fig. 5** Pitch $RAO$ [rad/m], $v = 0$ km/h, (F).

**Fig. 6.1** Pitch $RAO$ [rad/m], $\mu = 0$, $v = 0$-15 km/h, (F).

The maximum pitch $RAO$ is obtained at the fore oblique waves and minimum at beam waves. The speed influence is recorded for all the heading angles (Figs. 5,6).

**Fig. 6.2** Pitch $RAO$ [rad/m], $\mu = 45$, $v = 0$-15 km/h, (F).

**Fig. 6.3** Pitch $RAO$ [rad/m], $\mu = 90$, $v = 0$-15 km/h, (F).

**Fig. 6.4** Pitch $RAO$ [rad/m], $\mu = 135$, $v = 0$-15 km/h, (F).

**Fig. 6.5** Pitch $RAO$ [rad/m], $\mu = 180$, $v = 0$-15 km/h, (F).

**Fig. 7** Roll $RAO$ [rad/m], $v = 0$ km/h, (F).

**Fig. 8.1** Roll $RAO$ [rad/m], $\mu = 70$, $v = 0$-15 km/h, (F).

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2.2 Short-term response of the 3000 T river barge, full cargo loading case

The short-term statistical analysis of the dynamic response approach \[1,3\] applied to the river barge of 3000 T on full cargo loading case, with ITTC \[3\] irregular waves spectrum, delivers the most probable statistical response RMS for the oscillation components: -Figs.9.1-3, vertical combined motions, maximum short-term RMS\(_Z\), aft (pp), mid (m) and fore (pv), \(v=0-15\) km, \(\mu=0-180\) deg, full; -Figs.10.1-2, pitch and roll motions, maximum short-term RMS\(_R\), \(v=0-15\) km, \(\mu=0-180\) deg, full; -Figs.11.1-3, heave, pitch, and roll accelerations, maximum short-term RMS\(_{acc}\), \(v=0-15\) km, \(\mu=0-180\) deg, full.

The maximum roll RAO is obtained at beam waves when there is no speed influence. For follow and head waves roll is zero. The speed influence can be recorded for stern and fore oblique waves (Figs.7, 8).

The maximum roll RAO is obtained at beam waves when there is no speed influence. For follow and head waves roll is zero. The speed influence can be recorded for stern and fore oblique waves (Figs.7, 8).
In the full cargo case, from the short-term statistical analysis results that the navigation restrictions occur on vertical combined motions at aft and fore for the whole range of speed and heading angles (Figs.9.1,3), on vertical combined motions at midship for the whole range of speed and $\mu = 30-150$ deg (Figs.9.2), on roll motion for the whole range of speed and $\mu = 75-105$ deg (Figs.10.2), without restrictions on pitch and acceleration criteria (Fig.10.1, Fig.11.1-3).

Combining the seakeeping criteria (Table 2) results in the preliminary seakeeping capabilities of the 3000 T river barge on full cargo case (Fig.12), in terms of $H_s$ significant wave height.

Table 3 presents a synthesis of the $H_s$ limits for safe navigation of the 3000 T river barge on full cargo case (F) function to the speed in the range of 0 and 15 km/h.

![Fig.12](image_url)
3. BALLAST (B), 3000 T RIVER BARGE DYNAMIC ANALYSIS

3.1 RAO’s functions of the 3000 T river barge, ballast loading case

The linear strip theory [3] applied to the river barge of 3000 T on the ballast loading case, with unit amplitude regular wave excitation, delivers the deterministic hydrodynamic response in the frequency domain:

- Fig.13, heave RAO, \( v = 0 \) km/h, ballast;
- Figs.14.1-5, heave RAO, \( \mu = 0-180 \) deg, ballast;
- Fig.15, pitch RAO, \( v = 0 \) km/h, ballast;
- Figs.16.1-5, pitch RAO, \( \mu = 0-180 \) deg, ballast;
- Fig.17, roll RAO, \( v = 0 \) km/h, ballast;
- Figs.18.1-5, roll RAO, \( \mu = 70-110 \) deg, ballast.

RAO \([\text{m/m}]\) Heave \( v = 0 \) km/h Barge B3000 BALL

RAO \([\text{rad/m}]\) Pitch \( v = 0 \) km/h Barge B3000 BALL

RAO \([\text{rad/m}]\) Roll \( v = 0 \) km/h Barge B3000 BALL

Same as for the full load, the maximum heave RAO is obtained at beam waves. The speed influence is reduced on whole heading angle range for the heave RAO (Figs. 13, 14).

Fig.13 Heave RAO \([\text{m/m}]\), \( v = 0 \) km/h, (B).

Fig.14.1 Heave RAO \([\text{m/m}]\), \( \mu = 0 \), \( v = 0-15 \) km/h, (B).

Fig.14.2 Heave RAO \([\text{m/m}]\), \( \mu = 45 \), \( v = 0-15 \) km/h, (B).

Fig.14.3 Heave RAO \([\text{m/m}]\), \( \mu = 90 \), \( v = 0-15 \) km/h, (B).

Fig.14.4 Heave RAO \([\text{m/m}]\), \( \mu = 135 \), \( v = 0-15 \) km/h, (B).

Fig.14.5 Heave RAO \([\text{m/m}]\), \( \mu = 180 \), \( v = 0-15 \) km/h, (B).

Fig.15 Pitch RAO \([\text{rad/m}]\), \( v = 0 \) km/h, (B).
The maximum pitch RAO is obtained at head waves and very reduced at beam waves. The speed influence is mainly for fore oblique and head waves conditions (Figs. 15, 16).

Fig.16.1 Pitch RAO [rad/m], \( \mu = 0 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.16.2 Pitch RAO [rad/m], \( \mu = 45 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.16.3 Pitch RAO [rad/m], \( \mu = 90 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.16.4 Pitch RAO [rad/m], \( \mu = 135 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.16.5 Pitch RAO [rad/m], \( \mu = 180 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.17 Roll RAO [rad/m], \( v = 0 \text{ km/h} \), (B).

Fig.18.1 Roll RAO [rad/m], \( \mu = 70 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.18.2 Roll RAO [rad/m], \( \mu = 80 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).

Fig.18.3 Roll RAO [rad/m], \( \mu = 90 \), \( v = 0 \text{ - } 15 \text{ km/h} \), (B).
Same as for the full load, the maximum roll $RAO$ is obtained at beam waves. For other heading angles the roll motion is very reduced and becomes zero at follow and head waves. The speed influence is very reduced on oblique waves (Figs. 17, 18).

3.2 Short-term response of the 3000 T river barge, ballast loading case

The short-term statistical analysis of the dynamic response approach [1],[3] applied to the river barge of 3000 T on ballast loading case, with ITTC [3] irregular waves spectrum, delivers the most probable statistical response $RMS$ for the oscillation components:
- Figs. 19.1-3, vertical combined motions, maximum short-term $RMS_Z$, aft (pp), midship (m) and fore (pv), $v=0$-15 km, $\mu=0$-180 deg, ballast;
- Figs. 20.1-2, pitch and roll motions, maximum short-term $RMS_\theta$, pitch (pp), and roll (rr), $v=0$-15 km, $\mu=0$-180 deg, ballast;
- Figs. 21.1-3, heave, pitch, and roll accelerations, maximum short-term $RMS_{\Delta v}$, $v=0$-15 km, $\mu=0$-180 deg, ballast.
On ballast case, from the short-term statistical analysis results that the navigation restrictions occur only from the heave acceleration criteria (Fig.21.1), for whole speed range and $\mu \approx 85\text{-}100$ deg. The other seakeeping criteria lead to no restriction (Figs.19-21).

Combining the seakeeping criteria (Table 2) results the preliminary seakeeping capabilities of the 3000 T river barge on ballast case (Fig.22), in terms of $H_s$ significant wave height.

Table 4 presents a synthesis of the $H_s$ limits for safety navigation of the 3000 T river barge on ballast case (B) function to the speed in range of 0 and 15 km/h.

4. CONCLUSIONS

The change in the loading condition leads to different behavior in regular waves. The values of the natural oscillation periods are changed from 5.102-5.826 s on the full cargo case to 2.188-3.828 s on the ballast case (Table 1).

The navigation restrictions in irregular waves by short-term statistical analysis are different in the two loading cases of the river barge of 3000 T:
- on full cargo the vertical combined motions and roll criteria are leading to restrictions, with $H_{slimit}[m] = 0.804\text{-}0.841 m$ at $\mu \approx 80$ deg, corresponding to $\approx$ IN(0.8) (Table 3);
- on ballast only the heave acceleration criteria leads to restrictions, with $H_{slimit}[m] = 1.745\text{-}1.768 m$ at $\mu \approx 90$ deg, corresponding to IN(1.7) condition (Table 4).

In conclusion, the 3000 T river barge in full cargo navigation has higher restrictions as in ballast, and beam waves must be avoided.
Acknowledgments

The technical paper was developed at the Naval Architecture Research Centre, from “Dunarea de Jos” University of Galati.

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Paper received on November 4\textsuperscript{th}, 2022