SCACR2015
International Short Course/Conference on Applied Coastal Research

28th September – 1st October 2015
Florence, Italy

STUDY OF THE EFFLUX VELOCITY INDUCED BY TWO PROPELLERS

Anna Mujal-Colilles[1], X. Gironella[1], A.Jaquet[1], R. Gomez-Gesteira [2], A.Sanchez-Arcilla[1]

Abstract: Present analysis is related with seabed erosion caused during docking and undocking maneuvering. Twin propellers without rudder were studied using a physical model with a fixed clearance distance and three different rotating velocities. Experimental results were compared to theoretical expressions of the efflux velocity, axial velocity and finally maximum bed velocity. Efflux velocity equations overestimate the experimental results, whereas axial velocity computed using the Dutch method fits reasonably well the experimental data. However, when maximum bed velocity expressions are compared to experimental results, German method behaves better with an over estimation if a quadratic superposition of the single jets is used.

INTRODUCTION

Marine transportation industry and regular lines, in particular, have been increasing the last 20 years significantly. The increment of the ships' draft and the power of engines during the docking and undocking maneuvering is generating serious problems to harbors. Nowadays, the present propulsion systems are closer to the soil of the docks with higher power engines, causing sediment erosion close to toe of the docks which, in turn, may cause severe problems to the docking platforms. Moreover the eroded sediment is deposited along the inner harbor reducing the water level and operative zones for several vessels maneuvering. The docking and undocking maneuvers are the most effective in terms of erosion, in particular for vessels without the help of a tugboat or pilot.

Today, the equations used to compute the future erosion are based both in theoretical equations with hypothesis far from reality and experimental studies using one helix as the propulsion system. Efflux velocity is the first parameter needed to

1 LIM, UPC-Barcelona Tech, Jordi Girona, 1-3, 08028 Barcelona. Anna.mujal@upc.edu
2 EPHYSLAB, Environmental Physics Laboratory, Universidade de Vigo, Spain

analyze the seabed erosion, since all the theoretical equations developed so far, use this variable as a dependant variable. However, efflux velocity for twin propellers has not been analyzed in detail.

This contribution deals with experimental values obtained for twin propeller vessels as the main propulsion system, without rudder. Experiments are compared to theoretical equations developed during the last 50 years.

METHODOLOGY

Experimental setup

Physical experiments were performed at a facility located in the Laboratory of Marine Engineering (LIM) from Technical University of Catalonia (UPC-BarcelonaTech). LaBassA, Fig. 1, is a rectangular concrete tank of 12.5x4.6x2.5 m^3 with three lateral windows to facilitate the view of the experiments. Two helix, with $D_p = 25.4cm$, were located at the end of LaBassA with a clearance distance from the bottom of $h_p = 26cm$ (see Fig. 2).

Three different rotating velocities ($n = 300, 350, 400 rpm$) were measured using 5 ADV (Acoustic Doppler Velocimetry) hanging from an electronic moving reference system and located at several positions in order to have the magnitude of the velocity decay along the three axis. Table 1 shows the measuring points in the three coordinates assuming that the center of the reference axis is located at the axis of symmetry at the bottom of LaBassA.

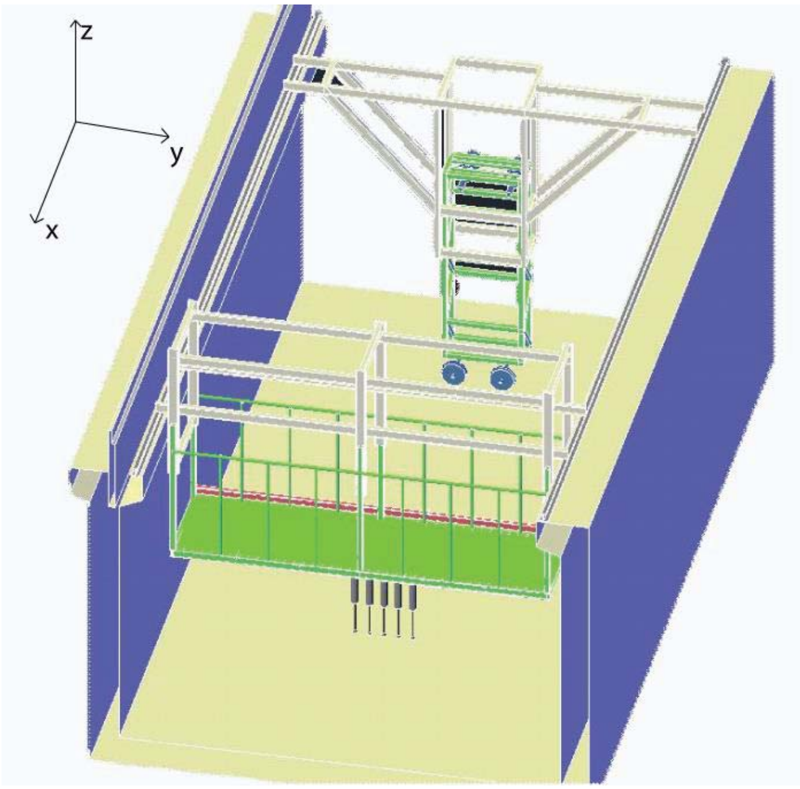

Fig. 1. Experimental setup in LaBassA (LIM/UPC-BarcelonaTech). The center of reference is located at the symmetry axis in the bottom of LaBassA.

Thrusters were located far from the opposite wall in order to study non-confined scenarios. However, the facility is designed to perform wall-scenarios in the future and different clearance distances.

Table 1. Scenarios and measuring points

n, rpm	x/D_p	y/D_p	z/h_p
300	2.5	0	0.2
350	5	±0.6	0.5
400	7.5	±1.2	1
	10	±1.7	1.4
	15	±2.3	

Fig. 2 plots the thruster system with the main distances used during the setup of the experiments. The rotating system was symmetric with right helix rotating in counter clockwise direction and left helix rotating in clockwise direction at the same speed. Errors in the speed rotation were of the order of 10% with a low difference of 3% from one propeller to the other: right thruster was rotating slightly faster than left thruster, but these errors have been corrected for future experiments.

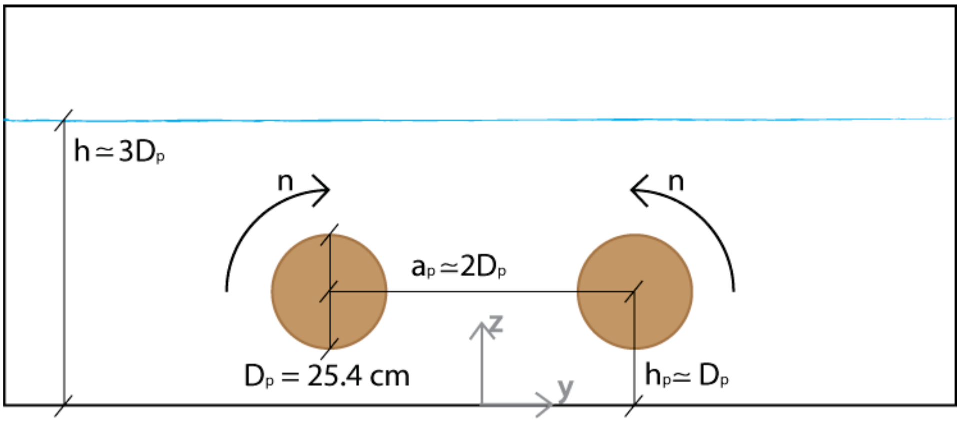

Fig. 2. Sketch of the thruster system

Theoretical aspects

(PIANC, 2015) was used as the reference document to compare results obtained at the physical model with theoretical formulas given by several authors during the past century (Bergh & Magnusson, 1987; Fuehrer, Pohl, & Römish, 1987; G. A. Hamill, Mcgarvey, & Hughes, 2010; G. A. Hamill, 1988; G. Hamill & Johnston, 1993; Johnston, Hamill, Wilson, & Ryan, 2013; Stewart, 1992).

Efflux velocity is defined as the mean axial velocity at the outlet of propeller systems without rudder, keel and wall influence. This velocity is defined for the initial zone of flow establishment, normally delimited for $x \approx 2.5D_p$.

Efflux velocity for free propellers when the thrust coefficient is not known, is detailed in Eq. (1), derived from theoretical formulas

$$V_0 = 1.48\left(\frac{f_p P_D}{\rho_w D_p^2}\right)^{\frac{1}{3}} \tag{1}$$

where

f_p = percentage of installed engine power, f_p=5-15%

P_D = maximum installed engine power (W)

ρ_w = density of the water

Other authors use the momentum based equation, Eq. (2) with the constant *C* varying for each author. However, Eq. (2) requires the thrust coefficient, K_t, which is, sometimes, difficult to obtain.

$$V_0 = CnD_p\sqrt{K_t} \tag{2}$$

Axial velocity along the centerline of the propeller in the flux direction is always described as a function of efflux velocity. Albertson (1950) proposed Eq. (3)

$$V_{axis}(x) = AV_0\left(\frac{D_p}{x}\right)^a \tag{3}$$

Where A = 6.17 and a=1. Other methods, like the German Method and the Dutch Method, use the same expression as Eq. (3) with different coefficients, which are detailed in Table 2. Both Albertson and Dutch method are used for single free propellers without a rudder, however, the German method proposes the equation also for twin screws like the case described in this contribution.

Table 2. Coefficients for Eq. (3) according to several methods

Method	A	a
Albertson (1950)	6.17	1
German	0.9	0.25
Dutch	1.95	1

Bed velocities, used mainly to compute the potential scouring due to main propeller effects are also a function of the efflux velocity. The German method for twin propellers with twin rudders is only applicable when the clearance distance is between 1 to 3 times the propeller diameter:

$$V_{b,\max} = 0.52V_0\left(\frac{D_p}{h_p}\right)^{0.275} \qquad 0.9 < \frac{h_p}{D_p} < 3 \tag{4}$$

The Dutch method for two propellers assuming linear superposition of flow velocities can only be used for the ratio of the clearance distance over the distance between the individual propellers, a_p, below 0.5,

$$V_{b,\max} = 2\frac{h_p}{r_p}V_{b,\max,\text{single}} \qquad 0.3 < \frac{h_p}{a_p} < 0.5$$
$$V_{b,\max,\text{single}} = 0.216 V_0 \frac{D_p}{h_p} \tag{5}$$

Where

$$r_p = \sqrt{h_p^2 + \left(\frac{a_p}{2}\right)^2}$$

Assuming a quadratic superposition of the two jets, and for $h_p / a_p < 0.5$

$$V_{b,\max} = V_{b,\max,\text{single}}\sqrt{2} \tag{6}$$

With

$V_{b,\max,\text{single}} = 0.42\,\mathrm{V}_0\left(\frac{D_p}{h_p}\right)$ if the German method is used and

$V_{b,\max,\text{single}} = 0.216 V_0 \frac{D_p}{h_p}$ if the Dutch method is used

RESULTS

Velocity distribution was analysed for all three components along the zone of established flow. Fig. 3 shows the axial component of the velocity for the planes parallel to the plane containing the propellers. In the efflux plane (x=2.5Dp) the two jets are clearly visible, although in the next plane, Fig. 3b they have already disappeared. It can also be observed how the jet is directed towards the bottom of the LaBassA at some point between 2.5Dp and 5Dp. Vertical velocities confirm in Fig. 4 this behaviour of the jet, although the vertical velocity component still holds a twin propeller influence at x=5Dp.

Fig. 3c shows how the influence of the jet at a distance 10Dp is negligible, confirming that the end of LaBassA is not an influence in the results shown herein.

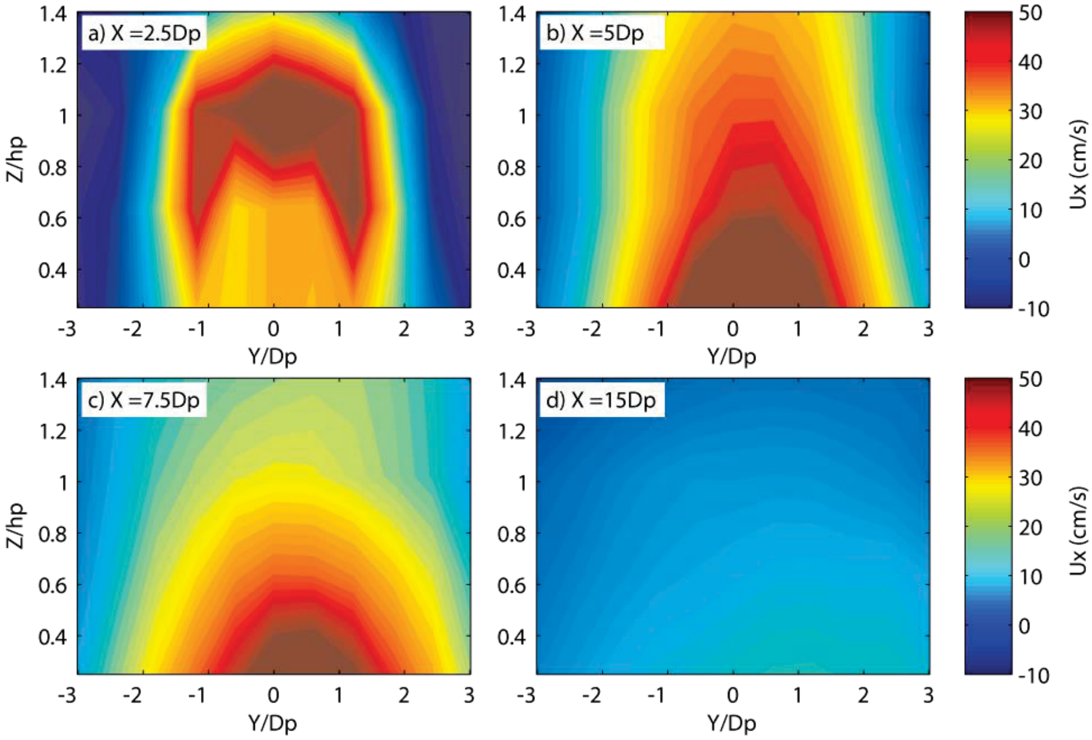

Fig. 3. Axial velocities, U_x, for n=400 rpm in planes parallel to the propellers plane.

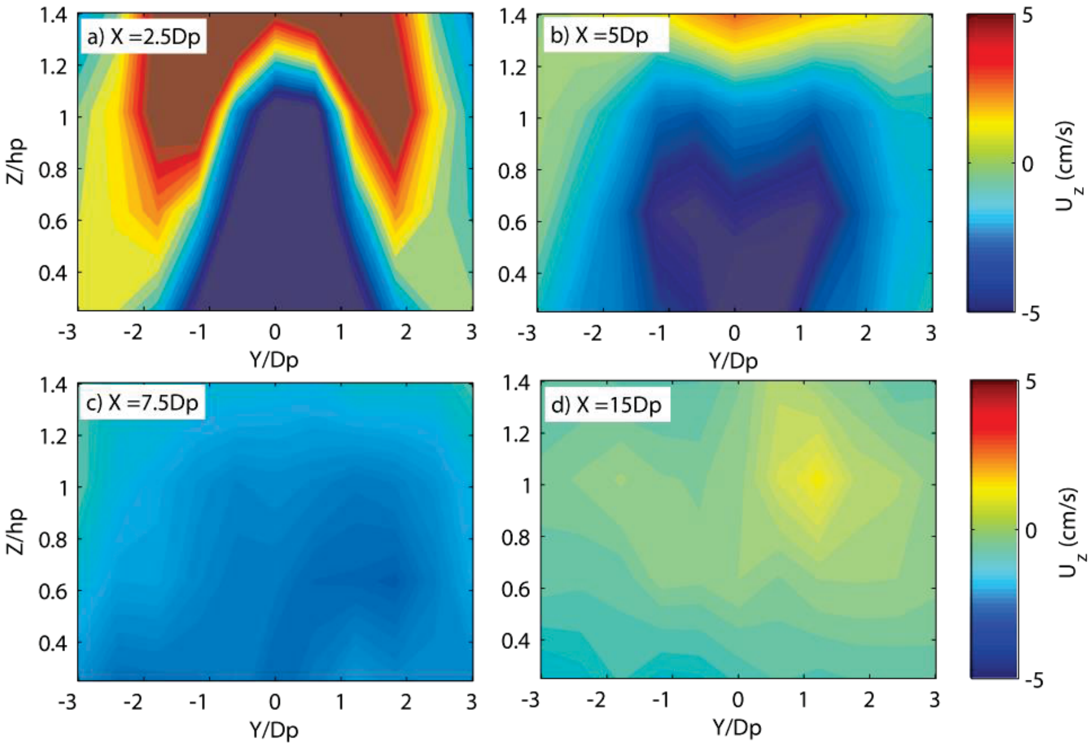

Fig. 4. Vertical velocities, U_z, for n=400 rpm in planes parallel to the propellers plane.

Axial velocities obtained at the center of symmetry are higher than axial velocities obtained at the center of each propeller, as shown in Fig. 5. Therefore only axial velocities at the center of symmetry will be compared to theoretical results described in the previous section.

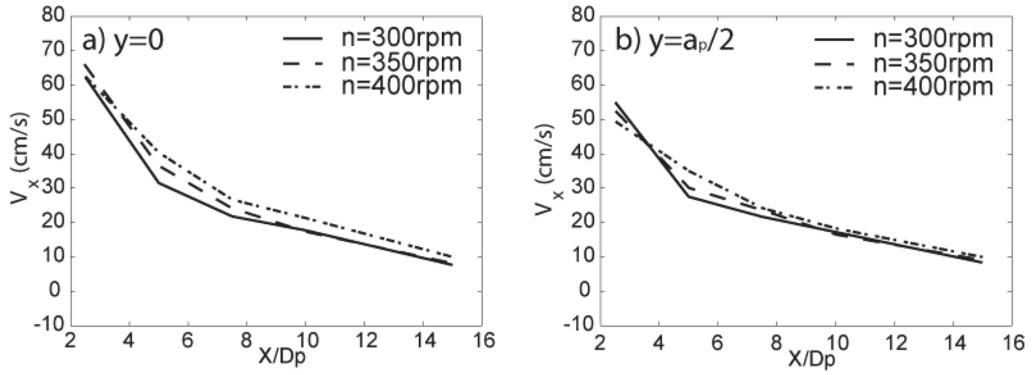

Fig. 5. Axial velocities. a) axis located at the center of symmetry *y=0*; b) axis located at the center of the right propeller *y=a$_p$/2*

Fig. 5a shows how the axial velocity at the axis of symmetry for the case of n=350 is slightly larger than axial velocity for the case of n=400. In Fig. 5b larger velocity values at x=2.5 Dp are obtained for low speed velocity scenarios. The first result combined with the second indicates that the small differences in rotation velocity of the propellers creates a non symmetric flux for which axis of symmetry between the propellers may not be the point with higher values. However it is important to point out that small errors in speed velocity will be corrected in the future to avoid these problems. On the other hand, Fig. 5b shows how velocity distribution is more homogeneous for lower values of the propeller rotation velocity. In Fig. 6 axial velocities in the efflux planes for the three scenarios are compared: the differences in rotation velocities are higher for low rotation velocities and Fig. 6 confirms that the larger the rotation velocity the less homogeneous is axial velocity at the center of the figures.

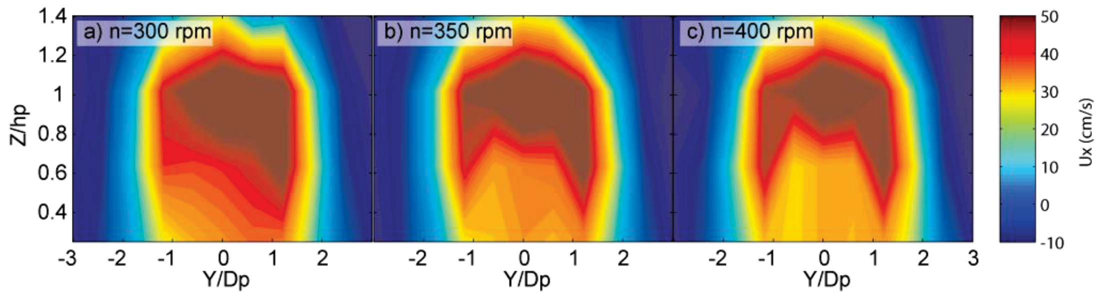

Fig. 6. Axial velocities at *x=2.5Dp* for a) n=300 rpm, b) n=350rpm and c) n=400rpm.

Comparing the present result of efflux velocity with maximum values obtained at the plane of flow establishment, Table 3Table 2, experimental results are not different between scenarios and it turns out that the scenario with 350rpm of speed revolution has a higher efflux velocity value than the scenario with a speed velocity of 400 rpm. This may be due to small errors in the exact location of the efflux velocity plane.

Table 3. Comparison between theoretical and experimental values of the efflux velocity.

V_0 (m/s)	n=300 rpm	n=350 rpm	n=400 rpm
Theoretical (Eq. (1)	1.04	1.20	1.34
Experimental	0.62	0.66	0.62

When axial velocities along the x axis is plotted in Fig. 7, comparing the experimental results, black line, with theoretical results detailed in Eq. (3) and Table 2, all the theoretical expressions overestimate the axial velocity. The axial velocity used in Fig. 7 is located at the axis of symmetry of LaBassA and the middle point between both propellers. If axial velocity along x axis located at the center of the propellers was used, this overestimation would be even larger. In any case, it seems that the Dutch method is the only one fitting the experimental data with reasonable accurate results, regardless of the low overestimation.

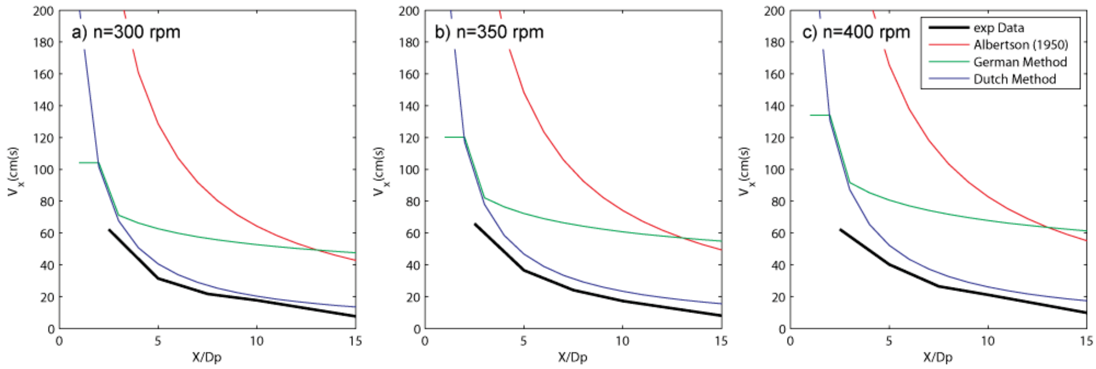

Fig. 7. Comparison between theoretical and experimental values of axial velocity along the axis of symmetry

Finally, the maximum bed velocities obtained in the experimental results are also compared to theoretical expressions. It is important to recall that theoretical expressions used herein, do consider the twin propellers. The German method is developed for seaborne vessels with twin propeller and twin rudder, although the rudder angle is not an independent variable in the function, Eq. (4). The Dutch method is used for twin propellers considering a linear superposition of two single propellers. According to (PIANC, 2015) with a linear superposition, Eq. (5), the total impulse increases, which is not comparable in the reality; however if the quadratic superposition is used, (PIANC, 2015), the total impulse of the jet remains constant but velocities are underestimated when both jets start to merge. Authors suggest the use of quadratic superposition is proposed with both methods, Dutch and German, because the maximum velocity at the bed for a single propeller is computed using each method, Eq. (6).

Maximum bed velocities are shown in Fig. 8, and in this case the German Method seems to predict the maximum bed velocities better. In contrast to the theory described in PIANC (2015) the quadratic approximation using the German Method overestimates the maximum bed velocity. Both superpositions of the jets when the Dutch method is used are clearly under predicting the experimental results.

Results shown in Fig. 8 are coherent with results obtained for axial velocities because the German method is always giving larger values than the Dutch method. However, the overestimation detected for axial velocities is not as large as the overestimation found for maximum bed velocities, indicating that the relation between axial and maximum bed velocities shall be further investigated for twin propellers.

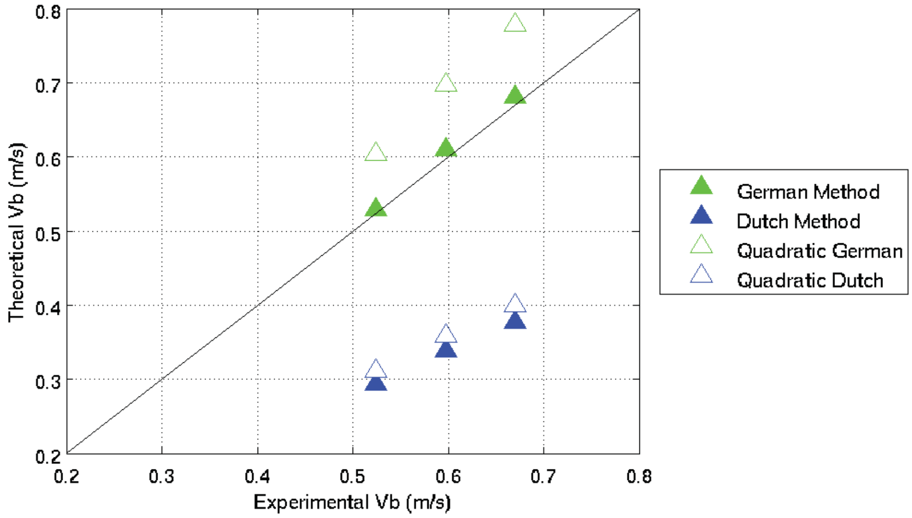

Fig. 8. Comparison between theoretical and experimental values of the maximum bed velocity, $V_{b,max}$

Experiments shown in this contribution are still being analysed and further scenarios will be studied with varying clearance distances, and adding sediment to investigate the erosion for twin propellers in the main propulsion system.

CONCLUSIONS

Main propulsion systems using twin propellers without rudder have been focus of the study presented in this contribution. Three different rotational velocities with a fixed clearance distance, fixed separation of the propellers and water height have been investigated using a physical model. Water velocities were obtained using ADV's configured to measure at different points. Experimental results compared to theory published so far indicate that:

- Efflux velocities obtained during the experiments were clearly lower than the predicted theoretical results.
- Formulas proposed in literature to obtain axial velocities over predict the experimental results.
- The Dutch method to obtain axial velocities can be used for twin propellers, although results are slightly larger for the theoretical results.
- Maximum bed velocities are under estimated when the Dutch method is used regardless of the superimposition method of the multiple jets.
- German method proposed for twin propellers to obtain maximum bed velocities is the most suitable for the experiments presented herein.
- The quadratic superimposition of the multiple jets, if the German method for a single jet is used, overestimates maximum bed velocities.

ACKNOWLEDGEMENTS

We greatly acknowledge the technical staff of the UPC CIEMLAB for their support throughout the experiments. This work has been supported by MINECO (Ministerio de Economía y Competitividad) and FEDER (Unión Europea- Fondo Europeo de Desarrollo Regional "Una Manera de hacer Europa") from Spanish Government through project BIA2012-38676-C03-01.

REFERENCES

Albertson, M.L., Dai, Y.B., Jensen, R.A., Hunter Rouse (1950). *Diffusion of submerged jets*, ASCE Transactions Paper no. 2409, New York, 639-664.

Bergh, H., & Magnusson, N. (1987). Propeller erosion and protection methods used in ferry terminals in the port of stockholm. *PIANC*, *58*.

Fuehrer, M., Pohl, H., & Römish, K. (1987). Propeller jet erosion and stability criteria for bottom protections of various constructions. *PIANC*, *58*.

Hamill, G. A. (1988). The scouring action of the propeller jet produced by a slowly manoeuvring ship (*). *PIANC*, *62*.

Hamill, G. A., Mcgarvey, J. A., & Hughes, D. A. B. (2010). Determination of the efflux velocity from a ship ' s propeller, (June 2004), 83–91.

Hamill, G., & Johnston, H. T. (1993). The decay of maximum velocity within the initial stages of a propeller wash. *Journal of Hydraulic Research*, *31*(5).

Johnston, H. T., Hamill, G. a., Wilson, P. R., & Ryan, D. (2013). Influence of a boundary on the development of a propeller wash. *Ocean Engineering*, *61*, 50–55. http://doi.org/10.1016/j.oceaneng.2012.12.033

PIANC. (2015). *Report n° 180 - 2015 Guidelines for protecting berthing structures from scour caused by ships*.

Stewart, D. P. J. (1992). *Characteristics of a ship's screw wash and the influence of quay wall proximity*.