SHIP PROPELLER EFFECTS ON HARBOURS

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INTRODUCTION

The increase in marine traffic during the last decades has led to important changes in ship designs. These changes have been directly affecting harbor structures designed to host smaller and less powerful ships. One of the most important consequences is the erosion of the seafloor close to the toes of the docking infrastructures which affects their stability. The World Association for Waterborne Transport Infrastructures published a guideline resuming the most used equations to solve the scouring problem (PIANC 2015). However most of the proposed formulas are empirical based using single propellers. Other common propulsion systems, such as the twin propeller, have been barely studied so far. Moreover, the propeller scouring action by a free developing jet has received much more attention in comparison with confined scour studies, i.e. nearby marine structures. Indeed, only one reference (Mujal-Colilles et al. 2018) with experiments on the effects of twin propeller in a confined scenario is found nowadays, although it is known that most of the ro-ro and ferry ships use this propulsion system when maneuvering near closed quays. This contribution aims to provide new insights about the effects that twin propeller propulsion system has over the seabed through a set of experiments with mobile sand bed. The effects of the propeller pitch ratio are also evaluated in an attempt to better reproduce the behaviour of ferry ships, since most of them use a Controllable Pitch Propeller (CPP) system.

EXPERIMENTAL SETUP

A set of 24 experiments were conducted in the Marine Engineering Laboratory at the UPC-Barcelona Tech University in a medium-scale water tank named LaBassa. The characteristics of the tank and the propellers are detailed in (Mujal-Colilles et al. 2017, 2018). A part of the propellers used in the mentioned communications, new propellers with a different pitch ratio (p'=1.0) were used to replicate the experiments and evaluate the effects of the propeller pitch change in the local scour. In this communication, only forward (FWD) propeller rotation results are shown. Table 1 summarizes all the experiments performed.

Table 1. Summary of experiments in LaBassa tank.

p'=0.9	X_w=7D_p	C_{min}=1D_p	n ({300,350,400}) rpm	t (0-30min)
		C_{max}=1.5D_p	n ({300,350,400}) rpm	t (0-30min)
	X_w=10D_p	C_{min}=1D_p	n ({300,350,400}) rpm	t (0-30min)
		C_{max}=1.5D_p	n ({300,350,400}) rpm	t (0-30min)
p'=1.0	X_w=7D_p	C_{min}=1D_p	n ({300,350,400}) rpm	t (0-30min)
		C_{max}=1.5D_p	n ({300,350,400}) rpm	t (0-30min)
	X_w=10D_p	C_{min}=1D_p	n ({300,350,400}) rpm	t (0-30min)
		C_{max}=1.5D_p	n ({300,350,400}) rpm	t (0-30min)

The measurement grid in (Mujal-Colilles et al. 2018) was enlarged to reduce the blanking distance between the Front Wall (FW) and its closest measure. The former experiments, with p'0.9 propellers, had a blanking distance of 0.25m, which was reduced to 0.05m in the new experiments with p'=1.0. The experiments performed have a total duration of 30 minutes with sand bed scanning every 5 minutes to analyze the evolution of bed morphology. The characteristics of the fluid flow were obtained with measurements of mean axial velocity at $X=0.5D_p$, named efflux velocity, U_0, and thrust coefficient K_T was later obtained from the disk actuator theory. A whole grid of 1.5Dp x 1.5Dp at steps of 0.08Dp was made to measure the mean axial velocity distribution behind the propeller plane. An average of the maximum mean velocity every 0.1667Π radians along the propeller plane is used as U_0, and the obtained K_T for p'=1.0 and p'=0.9 is 0.65 and 0.55 respectively.

RESULTS AND CONCLUSIONS

The results of this experiments are divided into 4 subsections:

1) Maximum scour depth positions.

The analysis of maximum scour depth positions show that the study of the central profiles can be used to analyze the evolution of the maximum depth in the scour hole, since the maximum depth is always measured nearby the axis of symmetry. The agreement between the maximum depth and the center-line (r^2 = 0.9962) show that differences are negligible.

2) Scour profiles categorization.

Previously performed studies in confined local scour already discussed the formation of two different scour holes downwards the propeller plane when rotating FWD: the first due to the direct impact of the jet boundary with the seabed because of its free expansion and before the jet impinges the vertical wall, and the second at the toe of the vertical wall due to the flow separation associated with the impingement (Hamill, Johnston, and Stewart 1999; Mujal-Colilles et al. 2018; Wei and Chiew 2019). As in (Mujal-Colilles et al. 2018), the first is named Harbor Basin (HB) hole, while the last is named Front Wall (FW) hole. In the mentioned article (Mujal-Colilles et al. 2018) is shown how in some of the experiments, after a variable time, the FW and the HB hole merge and become a sole bigger hole, usually associated with the higher depths. However, other scenarios still show a two-hole configuration after 30 minutes run, being the FW and the HB hole easily distinguishable and presumably reaching an asymptotic state. Since it is clear that some of the scenarios produce the seabed holes to end up merged after some time, while some others do not make the seabed to break its original two-hole shape, a third category is included to define the transition scenario. Thus, one of the following three different categories is assigned to each profile: *no-merged*, *transition to merge*, and *merged*. At the centerline, the depth-profile and the slope-profile are used to assign a category for each one, depending on how developed the HB hole is. If two holes (HB and FW holes) are easily distinguishable, then it is considered a non-merged profile; if there is just one big hole, then it is a merged profile. In the cases where the HB hole is not symmetric on its X-Z plane anymore, it is considered that the profile is in transition to merge. Figure 1 shows an example of each case. The HB hole is considered to be symmetric on its X-Z plane if Area1 is at least a 35% of the absolute sum of Areas 1 and 2.

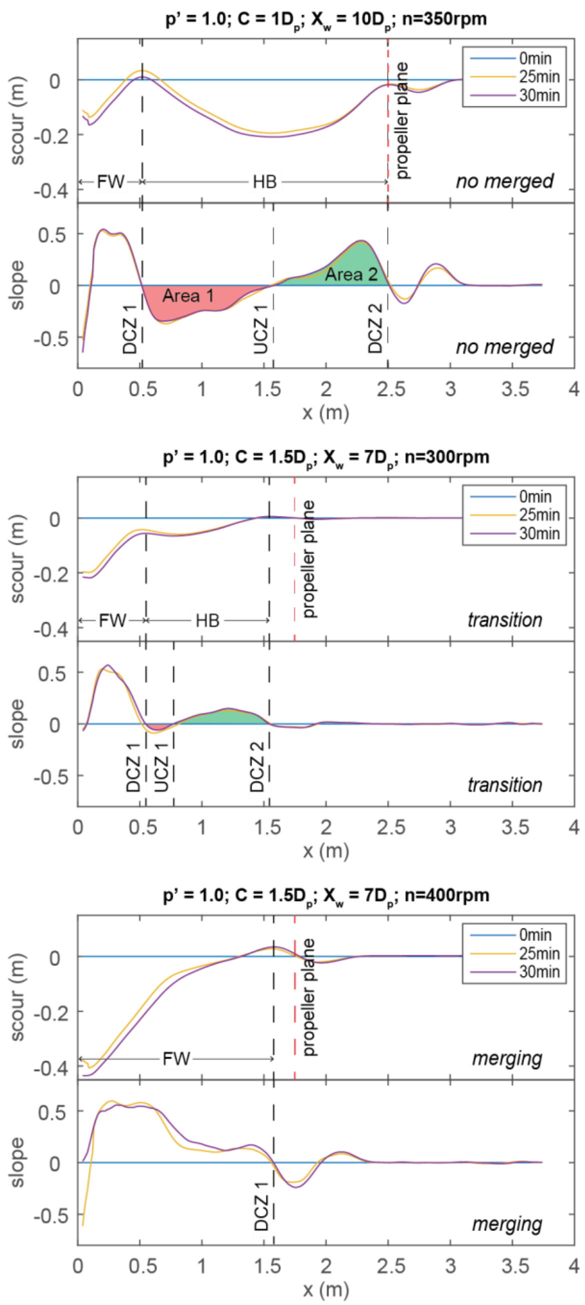

Figure 1. Examples of no-merged, transition and merged profiles.

As it is shown, the FW hole length is obtained by finding the first DCZ (Down-Crossing Zeros) from the FW upstream in the slope-profile, and the HB hole length is obtained by finding the DCZ before and after the first UCZ downstream the propeller plane.

3) FW profile in p'=0.9 experiments

Due to the larger blanking area in p'=0.9 experiments, as stated in the Experimental Setup section, direct comparison of maximum depth near the FW is not possible between p'=0.9 and p'=1.0 experiments. Then, a new fitted profile is obtained for every p'=0.9 profile, to fill the gap and allow the comparison. The dimensionless p'=1.0 scour profiles show that the FW hole of the *no-merged* and the *transition* cases are well fitted with a third-degree polynomial. The *merged* profile FW holes are fitted with a fifth-degree polynomial. The same behavior is expected for p'=0.9 profiles, in terms of shape, thus new curves for each p'0.9 profile are obtained in the blanking area based on the measured profile (0.25m<X<3.7m). Since the categories *merged*, *transition* or *no-merged* profile are obtained based on the HB hole -or the lack of it- most of p'=0.9 are properly categorized and the fitting polynomial degree is chosen accordingly. The fitting method is also applied in p'1.0 cases, where there is no blanking area, and the results yielded a very good agreement ($r^2 = 0.9843$) between predicted and measured maximum depth in the FW hole symmetry axis.

4) Maximum scour depth at FW

Comparison of time series between p'=0.9 and p'=1.0 yield no considerable differences in FW or HB scour due to the change of pitch. Maximum scour depths are measured in $X_w=7D_p$, C_{max}, n= 350rpm and n=400rpm experiments. Both profiles end up merged, so there is no distinction between HB and FW hole. A clear increase in the FW scour depth is observed with the increasing *n*, mostly linearly, in all cases. Based on the equation $T=K_T \cdot n^2 \cdot Dp^4 \cdot \rho$ (eq.1), higher *n* values are obviously causing an increase in the propeller thrust (T), leading to larger U_0 and making the propeller jet to impinge the FW with an important momentum. The change in the pitch leads to an increase in thrust too. However, this change causes negligible variations in the maximum scour depth in FW. Figure 2 show the calculated thrust per propeller and the obtained maximum eroded depth at FW for each experiment.

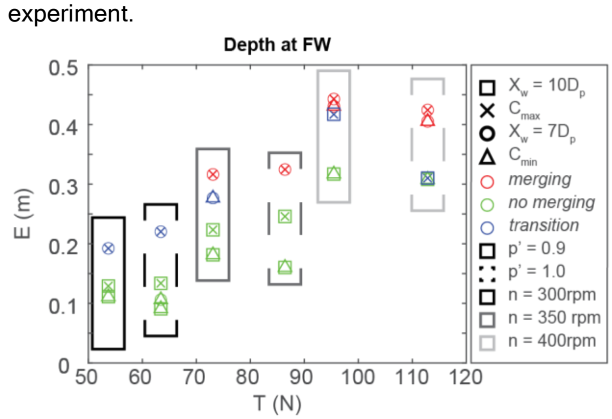

Figure 2. Results of maximum eroded depth (E) at t = 30min for all the experiments. Thrust (T) is calculated per each propeller according to (eq.1).

The lack of change in the maximum depth due to pitch is contradictory with the measured changes in U_0, and also with the change due to *n*. This leads to the hypothesis that higher pitches and lower *n* could be less harmful that lower pitches and higher *n*, as per the results observed from the experiments. However, a deeper analysis and more experiments with a lower pitch are still needed to confirm the observed trend.

NOTATION

- p' Pitch ratio (-);
- X_w Distance to the Front Wall (m);
- C Clearance distance from the hub (m);
- n Propeller speed of rotation (rpm);
- U_0 Efflux velocity ($m \cdot s^{-1}$);
- K_T Thrust Coefficient (-).

REFERENCES

Hamill, G., H.T. Johnston, and D. Stewart. 1999. "Propeller Wash Scour Near Quay Walls." *Journal of Waterway, Port, Coastal and Ocean Engineering* 125(4): 170–75.

Mujal-Colilles, A. et al. 2018. "Stern Twin-Propeller Effects on Harbor Infrastructures. Experimental Analysis." *Water (Switzerland)* 10(11).

Mujal-Colilles, A., X. Gironella, A. Crespo, and A. Sanchez-Arcilla. 2017. "Study of the Bed Velocity Induced by Twin Propellers." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 143(5): 04017013. http://ascelibrary.org/doi/10.1061/%28ASCE%29WW.1943-5460.0000382.

PIANC. 2015. *Guidelines for Protecting Berthing Structures from Scour Caused by Ships. Report N° 180*. The World Association for Waterborne Transportation Infrastructure.

Wei, Maoxing, and Yee Meng Chiew. 2019. "Impingement of Propeller Jet on a Vertical Quay Wall." *Ocean Engineering* 183(April): 73–86. https://doi.org/10.1016/j.oceaneng.2019.04.071.