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Motion Analysis of Scale Truncated Log Boom Structures Tested in a Towing Tank

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Abstract. *This work presents results from a series of physical experiments of a truncated log boom model structure, based on real equipment employed at Santo Antônio hidropower plant (HPP) to deflect debris and prevent their influence in plant machinery. All tests were designed and conducted at a towing basin. Tests aim to understand the hydrodynamics of these structures, more specifically their motion behavior. The experiments were carried out on several conditions of model length and curvature, upstream velocities, and log accumulation levels. To collect the data, a motion track system, based on infrared cameras and reflexive targets, was used. The tests focused on model movements of heave and pitch. These experiments have produced some awareness on the stability of model, which essentially sinks and rotates its float structure as flow velocity increases, even in the presence of debris. All procedures are part of a R&D project developed by Institute for Technological Research (IPT), request by Santo Antônio HPP.*

Keywords: *Log Boom, Towing Tank, Hydrodynamic Tests*

1. INTRODUCTION

The Madeira river, which is 3315 km long, borns in Bolivian Andes Mountains and contemplates Santo Antônio hydropower plant (HPP) through its course in Brazilian territory. Located nearby Porto Velho city, North of Brazil, Santo Antônio run-of-river HPP has 50 operational turbines with a total installed power of 3.5 GW. Climate and soil are advantageous factors to existence of a vast vegetation throughout the river extension, which during flooding season is dragged to its course. This natural phenomenon generates huge amounts of wooden debris floating on the river and reaching the dam machinery, affecting its power generation efficiency.

Countermeasures to avoid damages on the machinery and reduction in energy generation involve the arrangement of aligned float structures, called log booms, across the river (Fig. 1). Their purpose is to contain and deflect wood logs and other larger debris, even the ones located below the water surface.

Given the accessibility, their shape and size, and singular working conditions, a fully controlled reduced scale study shows itself as an useful alternative to investigate the conditions imposed to log booms and their performance during operation. Research of the hydrodynamics of log booms contributes to design process of fluvial and maritime hanging structures, which either or not have interactions to bodies on the stream. Since floating detritus tend to be deflected or retained, they present themselves as cost-effective solutions to be applied on ice holding (Abdelnour, 2001; Morse, 2001), litter containment (Slat, 2014), oil spill (Lo, 1996), or general river debris (Wahl, 1992).

Countermeasures to deal with debris accumulation depend on site dimensions. Bradley *et al.* (2005) classified them between structural and non-structural ones, which respectively consist on physical constructed structures, and maintenance, like removal of excess material. Among the structural measures, debris boom systems are appropriate to mitigate floating solid and liquid detritus. They are historically used on floating debris control on dams, where their first designs had simply tied up tree trunks as float devices, having walkways upon them (Perham, 1987).

Some recent studies about Santo Antônio log booms has been developed. Castro *et al.* (2017a) conducted a study covering the instrumentation methodology to collect load results on several scale log boom sets. The results were gathered through load cells attached on the extremities of the model, while being towed along IPT's Towing Tank, varying speed, length, and model curvature related to water flow, for tests without debris. Subsequently, Castro *et al.* (2017b) used strain gages instrumentation method to measure tension forces on the grid and reinforced beam elements for the same types of tests. Additionally, Castro *et al.* (2018) measured the force patterns for the same models and approach, but at this time in the presence of scale debris (Fig. 2).

Log containment structures are multibody mechanisms, that are not only subject to high loads, but also have an

Figure 1. Log boom structure shown in three perspectives: as a single module being prepared to be installed (left), connected with similar ones to form a line of approximately 600 m (upper right), and an aerial view of the accumulation phenomenon in some of the log boom lines placed upstream Santo Antônio HPP (lower right).

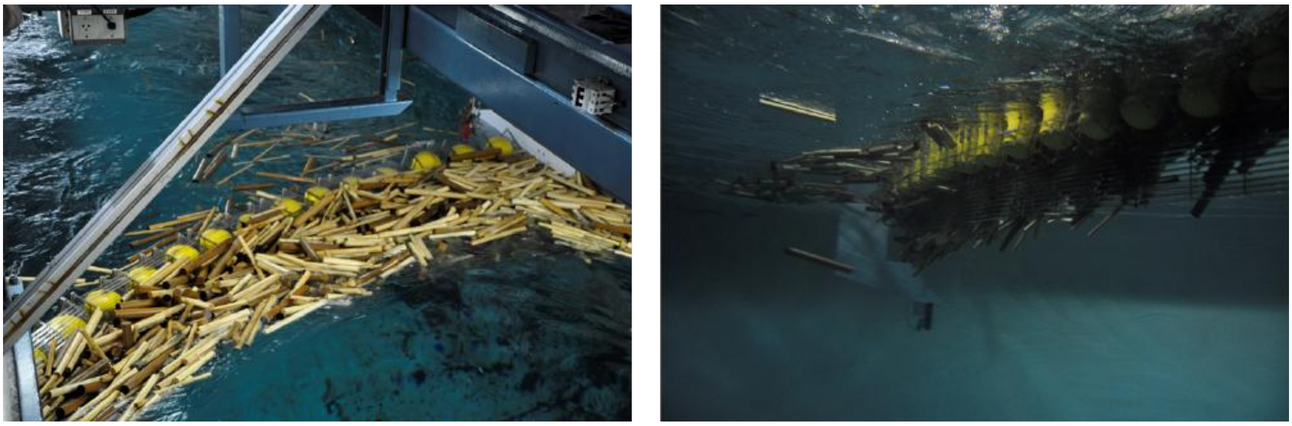

Figure 2. Scale truncated model line being test on IPT's towing tank.

unknown dynamic movement while in operation. This paper brings a complementary approach to fill the gap among the previous studies in terms of motion measurement. The plan is to simulate the log operation in less turbulent conditions compared to the real site, using scale model experimentation techniques and devices to track the system motion. The paper presents the chassis pitch and module heave motion results, on two unities, for two distinct line configurations and their relation with the increase of velocity and levels of debris accumulation.

2. METHODS

The main objective of this work is presenting measurements about the movements of a truncated scale log boom line, during tests in IPT's Towing Tank. The data is generated by dragging the models along the tank in several velocities and stages of debris accumulation. The collected results provide a better understanding of their dynamic behavior, necessary to comprehend the prototype operation and efficiency, in which the river conditions are not controlled and uniform.

2.1 FACILITIES

Experiments of this paper were conducted on the Towing Tank of the Naval Architecture and Ocean Engineering Laboratory (NAVAL) of IPT, which is a 280 m long facility equipped with a dynamometer carriage, usually used to perform tests of scale vessels and ocean structures (Fig. 3).

Figure 3. IPT's Towing Tank.

2.2 EXPERIMENTAL SET UP

Real size operational log boom line used by Santo Antônio HPP was designed as a system with several modules. The prototype modular set is composed of floaters that are framed on a rigid structure. This entire upper part is called chassis and is connected to a longitudinal reinforced beam, which in turn is connected to a grid, shown in Fig. 4. These unities are connected side by side, by the grid and reinforced beam, allowing them to rotate around their connection axes. Four shafts link the grid to the reinforced beam, where a rotational movement is permitted. Other four shafts connect the middle reinforced beam to the chassis, making it free to rotate while operates. Besides that, the design of the log boom line allows translational motion in the three main directions, assuming a curvature on the water plane during operation, as seen in Fig. 1.

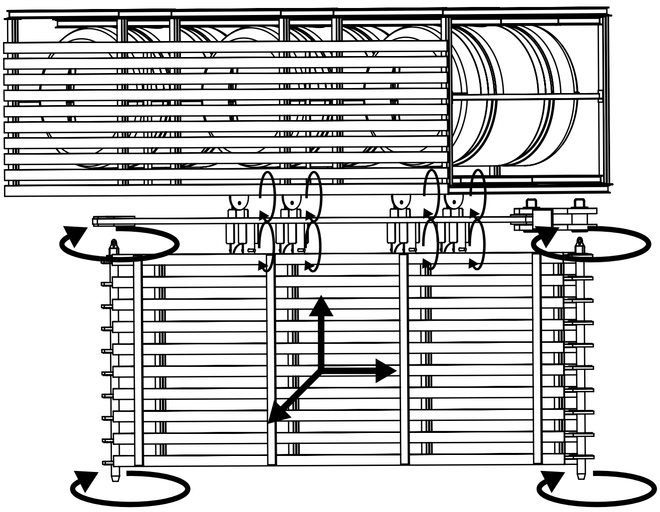

Figure 4. Log boom module detailing its rotational and translational motion axes.

Considering the geometrical limitations of the towing basin, assembly and handling of the model, quality of measured data, and magnitude of expected motion response, a 1:10 scale is assumed. In order to achieve the mentioned objectives, tests contemplating a truncated model of log booms being dragged on several velocities and levels of debris accumulation are performed. During these runs, the displacement of some modules are measured by reflexive targets placed on top of them by adapted rods (Fig. 5). The motion tracking apparatus consists on three infrared cameras by Qualisys, model Oqus 500, which are attached to the rig of the towing tank carriage. The acquisition software provides the real time position of the body defined by the reflexive targets on a Cartesian coordinate system, obtained on a calibration process. The origin of this body is then transported to the chassis rotational axis, which gives direct values for pitch and heave. Limited by the amount of cameras, only two modules are instrumented with the reflexive spheres of 35 mm of diameter.

From the geometry and specific mass of all components of the prototype, it was possible to define its center of mass and inertia. Based on that, a iterative calculation was done, equaling vertical forces of weight and buoyancy, as well the hydrostatic restoration and weight moments in order to define the static trim and draft, 13.4^{o} and 359 mm respectively, which are shown in more detail in Fig. 6. These values were adopted as the initial conditions for all modules in all experiments.

In order to reproduce their operational circumstances, the log boom modules were assembled forming a line. The series

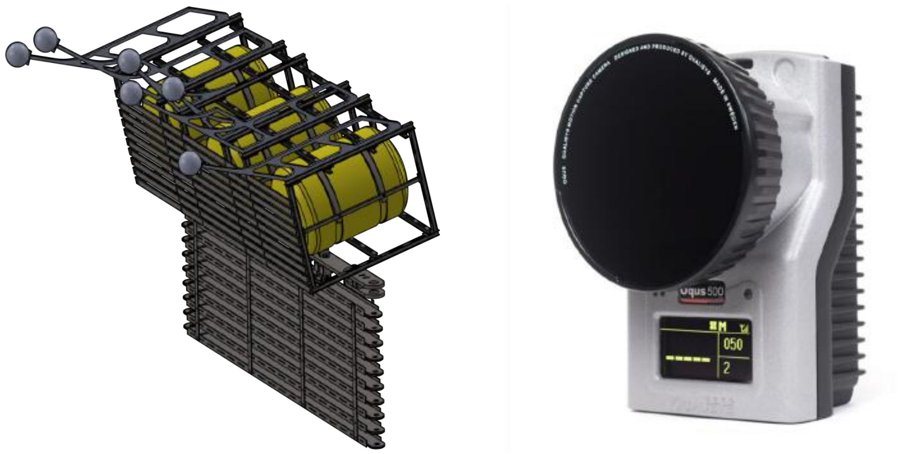

Figure 5. Perspective view of module with targets installed on top (left); Infrared camera used on tests (right).

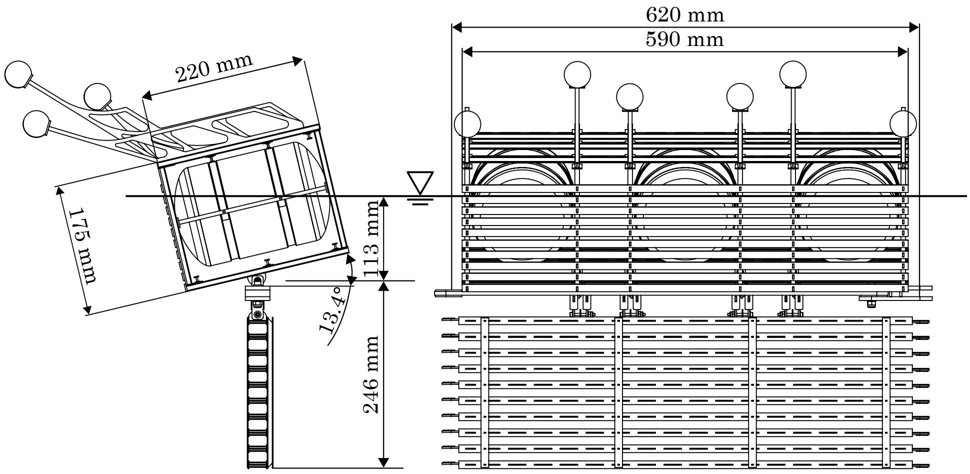

Figure 6. Scale log boom module particulars with the calculated static trim and draft.

of experiments considered two inclination conditions for this line related to the flow, which were obtained increasing both the number of modules and longitudinal distance of the anchoring points. The tests were performed with 5 and 7 modules of log booms. Table 1 details the geometric configuration of the truncated lines. The line had a symmetric form with 5 modules, while with 7, the modules adopted various yaw angles, as shown in the schematics of Fig. 7. The experiment velocities range from 0.158 m/s to 0.948 m/s. The tests were also set to measure tension forces at the model endings using uniaxial load cells, which were previously explored in Castro *et al.* (2017a,b, 2018).

Table 1. Geometric conditions of tests on the Towing Tank

Amount of Modules	**Translational Distance**	**Longitudinal Distance**
5	4.02 m	0.00 m
7	3.56 m	3.94 m

The effects of accumulation of debris over the model were investigated considering 4 increasing levels of log jamming, randomly disposed and located upstream, here named T1, T2, T3, and T4. The reference case, *i.e.*, without logs, was denominated H. The scale debris are cylinder rods and their quantity were based on aerial pictures of the HPP site, assuming some simplifications in terms of diameters. Table 2 describes quantities and volumes for each test.

3. RESULTS

The main set of results regarding log boom movements are shown in this section. During the tests, it was observed the expected heave and pitch motion of each module of the line on each test condition, better visualized in Fig. 8.

Among all degrees of freedom of a log booms line, sinking and rotation are those that presented significant values during operation and are related to their stability and log retaining purpose, being here analysed. Figure 9 presents static heave and pitch position for tests with no logs, on the central and lateral unity, considering its initial configuration de-

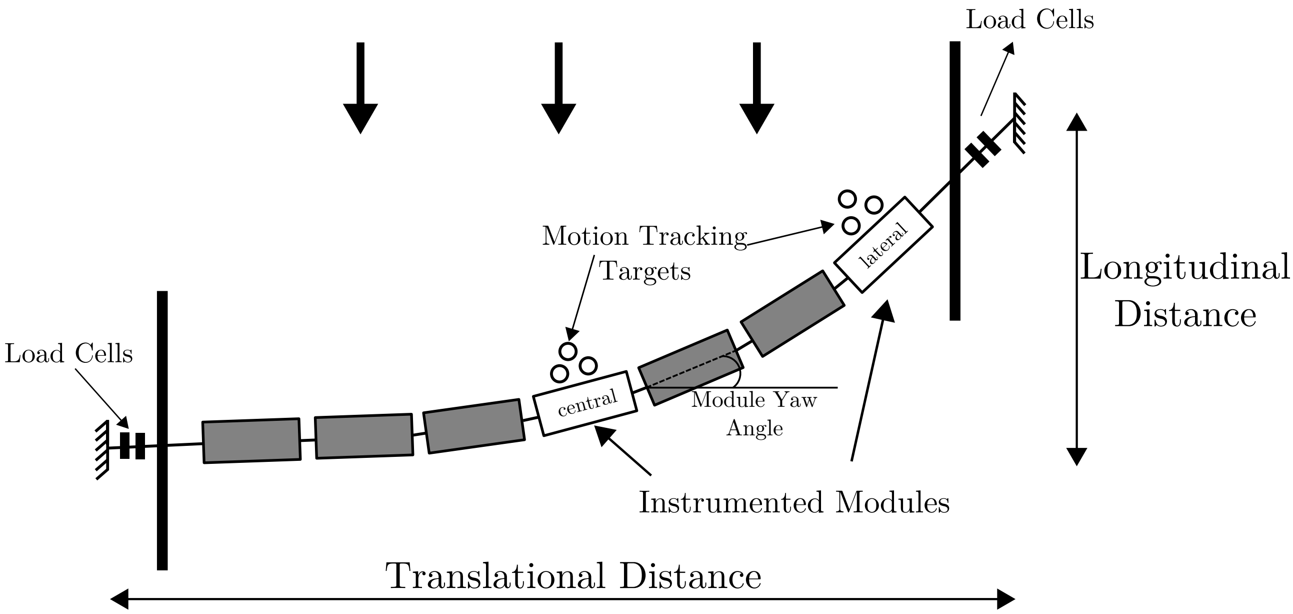

Figure 7. Test schematics for testes with 7 modules showing the main apparatus and flow direction.

Table 2. Amounts and volume of scale logs during the campaign of experiments.

Test	Total Pieces	Total Volume
H	0	0 m^3
T1	500	0.075 m^3
T2	1000	0.151 m^3
T3	2000	0.303 m^3
T4	3300	0.459 m^3

scribed in Fig. 6. Considering the tests with 5 modules, up to 0.75 m/s, both magnitudes tend to be linearly proportional to the towing speed, changing afterwards at maximum velocities. Experiments with 7 modules create an inclination of the line and generate a different yaw angle to the instrumented modules. Because of that, pitch measures were smoothly increasing with tow speed. An enhance on yaw angle decreases the variation on the pitch angle, observed on the measurements of the lateral module, mainly at the 7 modules line. At this condition, there is not an abrupt variation at 0.75 m/s. The heave comparison between tests with 5 and 7 modules is also shown in Fig. 9. On both configurations, the lateral module presented lower sinking values when compared with the central one. This effect is in fact reduced due to the flow incidence angle.

The dynamic heave, referenced on the condition of static balance of the central and lateral log boom module, for a 5 modules conditions in 3 levels of debris accumulation, is seen in Fig. 10. These data indicate a reduction of the line sinking in the presence of upstream debris, motivated by the hydrodynamic changing of grid and chassis which reduced the forces acting on them. At the same time logs are trapped beneath the floats, and since they have a lower specific mass, the log booms are lifted up. A greater dispersion is observed for the central module, compared with the tests without logs, showing how sensitive the runs were related to initial arrangement of debris. On the other hand, the lateral module data has a lower dispersion rate, mostly because the debris tend to accumulate at the center of the line, since its a symmetric configuration.

Debris make the pitch movement less predictable but still affected by the velocity increasing, compared to the heave results, which are more affected by the gain of buoyancy. The pitch results for the central and lateral modules, on tests with 7 modules, are shown in Fig. 11. Despite this dispersion for the central module, it possible to affirm that the rotation tendency is intensified with the velocity increase, as in the cases without debris. The debris tend to occupy void spaces of the log boom geometry and its adjacent connections, preventing its natural rotation. Given the random nature of this phenomenon, its repeatability is not guaranteed at the same test conditions. Again, the lateral module seems to be less affected by the debris, which accumulates on the opposite side with the increase of velocity, due to the curvature of the line, visualized in Fig. 8.

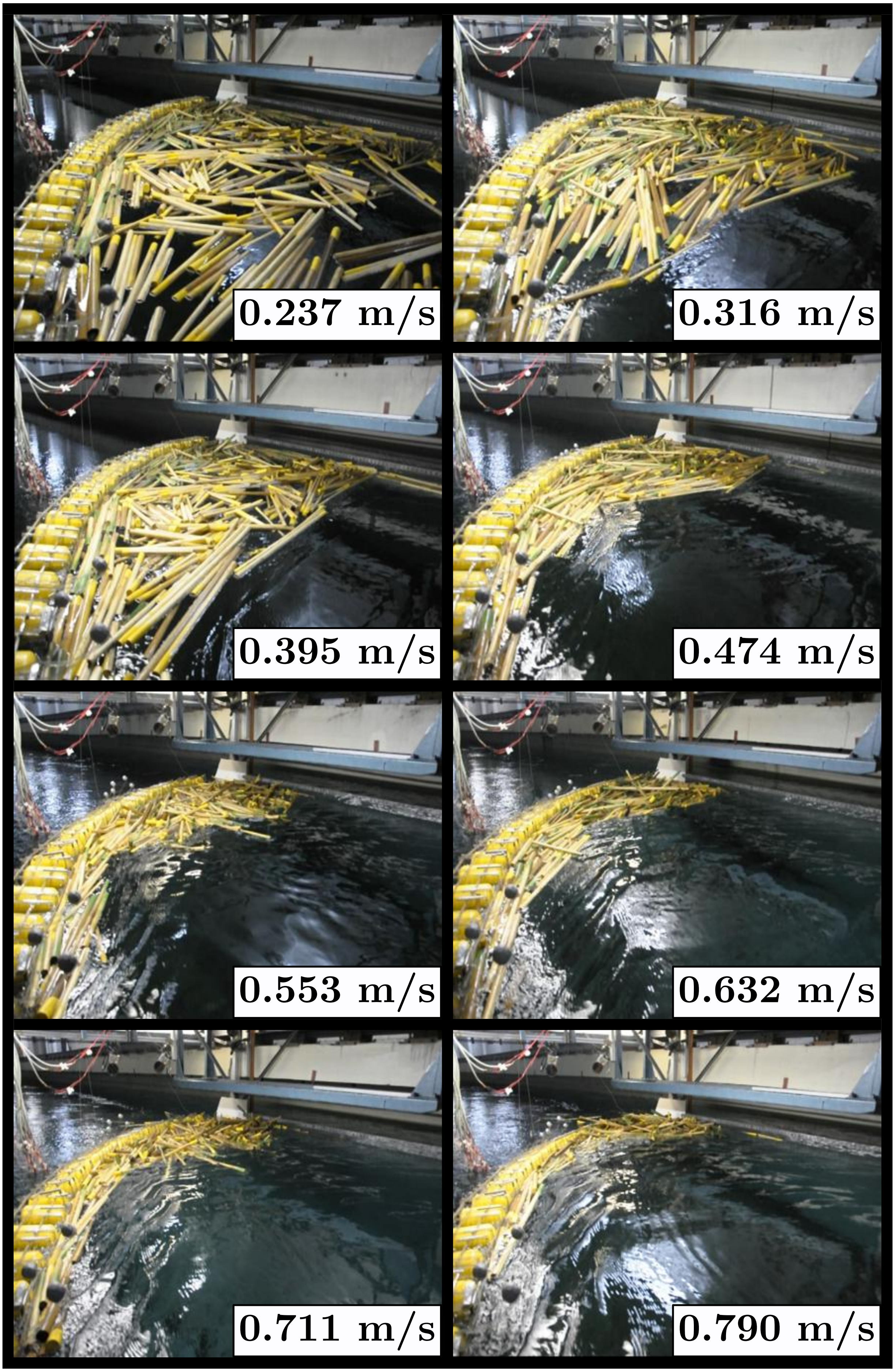

Figure 8. Picture of test with 7 modules and T2 level of debris accumulation. A notable sinking and rotation tendency is seen with the increase of towing velocity.

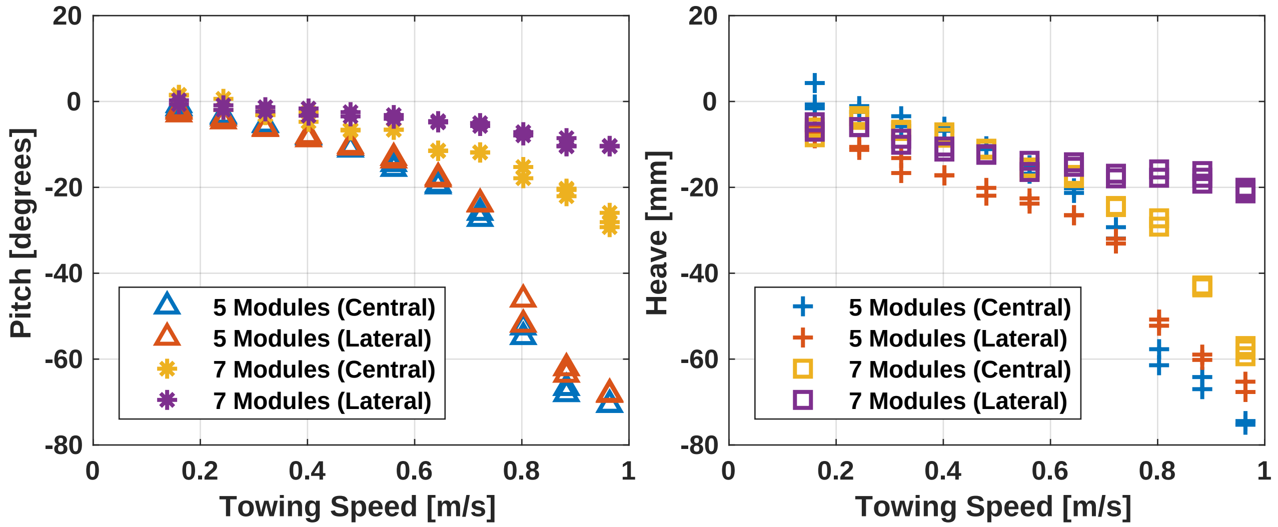

Figure 9. Pitch (left) and heave (right) results on the central and lateral module for 5 and 7 log booms unities.

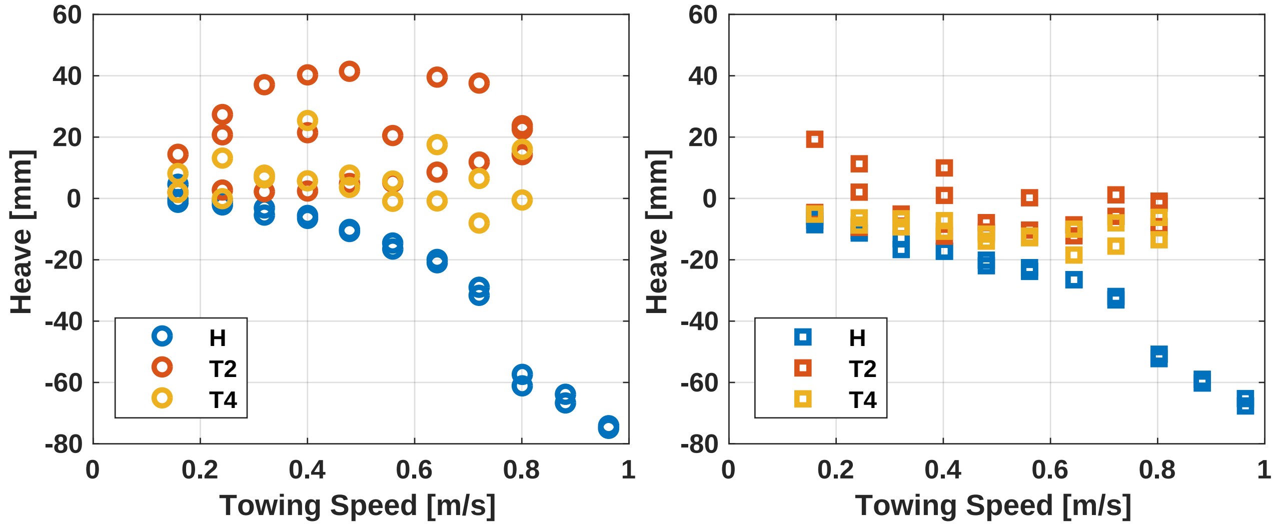

Figure 10. Heave data for central (left) and lateral (right) module, in a 5 modules configuration, on three debris accumulation levels: no logs, T2, and T4.

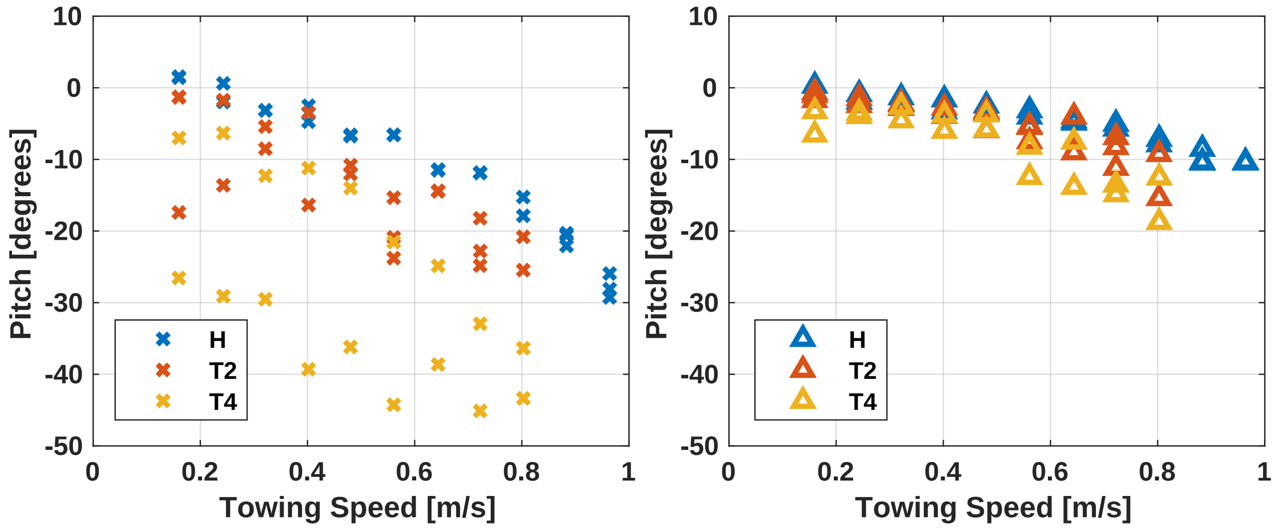

Figure 11. Pitch data for central (left) and lateral (right) module, in a 7 modules configuration, on three configurations: no logs, T2, and T4.

4. CONCLUSIONS

This work was developed to understand the dynamic motion of scale truncated log boom line, for different flow velocities and log accumulation levels. Given to the repeatability of the tests and the instrumentation process, the results demonstrated quite a qualitative acceptable precision.

Tests demonstrated that the truncated line sinks and rotates their chassis with the flow velocity, presenting a linear behavior up to 0.75 m/s, and quadratic afterwards. Sinking motion of the model is less affected by the debris accumulation compared to the pitch motion, possibly influenced by the uplift buoyancy created by the logs. In the asymmetric configuration, this effect was less intense due to the higher yaw angle with the flow.

5. ACKNOWLEDGEMENTS

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