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Analogical Manoeuvring Simulator with Remote Pilot Control for Port Design and Operation Improvement

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ABSTRACT: The use of an Analogical Simulator in shiphandling-manoeuvre tests (SIAMA) in waterways constitutes a useful tool for providing improvements in port design and manoeuvring rules, which, when enhanced with other relevant hydraulic studies of Froudian scale models, is a source of valuable statistical information. The time-scale of physical models fast-time runs complie with the square root of the linear scale, in this study-case the model time was 13.04 times faster than prototype. More than 1500 official tests having been undertaken since 1993 by 13 official pilots of three harbours, for manoeuvring and project optimization in 7 piers, with 10 berths, and radio-controlled ore carriers of 75,000, 152,000, 276,000 365,000, 400,000 and 615,000 dwt. The laboratory facilities belong to the Escola Politécnica of Sao Paulo University, Brazil. The port area studied comprised fairways, turning basins and berths. The ships and tugs were unmanned, with tug performance exerted by air fans.

1 INTRODUCTION

On optimizing a harbour lay-out, the relationship between changes in the lay-out, and the resulting changes in flow, wave pattern and the ship's path, should be reproduced as well as possible. In such cases, if small-scale modelling is required, the choice of a physical-model study of the port and adjacent sea area is used. A current or wave-pattern is generated to reproduce local conditions as well as possible. This is the case of SIAMA (Analogical Manoeuvring Simulator) of the Hydraulic Laboratory Harbour and Coastal Division of the São Paulo University, Brazil, which has been fully operational since December 1993. This Brazilian hydraulic centre has clients among governmental and private organisations, maritime authority (Brazilian Navy), port authorities and pilots.

Unfortunately, the risks involved in full-scale measurement, as a research technique, do not permit intense investigation of hazardous manoeuvres in confined channels. Furthermore, full-scale measurement can be undertaken only in existing situations. Excluding field tests, which, besides the high risk involved, are far too expensive, manning models, although requiring large areas, are ideal for training in shiphandling, especially of low-speed control without tug assistance. Real-time simulator studies in a Full Mission Bridge Simulator, although of extreme importance in the design process, only provide limited design-option evaluation, due to costs and time-consuming if multiple manoeuvre scenarios are to be covered. Consequently only a limited part of pilot experience and knowledge is used for assessing always too few of these options.

The SIAMA analogical concept, with ships and tugs unmanned, is a reliable cost-effective way of combining nautical studies with the hydraulic runs usual in scale-model port-study projects. In fact, this fast-time facility permits running a large amount of test statistics under various desirable environmental conditions (bathymetry, winds, waves, tides and currents), for different vessels and project lay-outs over a limited period.

The aim was to highlight the convincing usefulness of SIAMA, based on more than 1500 official recorded tests in almost 20 years of existence, and different case-studies, thereby encouraging its use in providing information and reducing the number of runs of a Full Mission Bridge Simulator. The ports studied are located in São Marcos Bay (Brazilian north coast): VALE Ponta da Madeira Maritime Terminal (PDM), which is the second in annul loading rate in Latin America (figures 100 Mt) with four piers and seven berths, ALUMAR Harbour (2 berths) and Itaqui Harbour (1 berth) were all studied at this facility.

2 ENVIRONMENTAL CONDITIONS

In Figure 1, it is possible to visualize a tidal current pattern validated through SIAMA. These are difficult conditions for approaching manoeuvres to PDM Pier II, since external currents are greater than those in the confined inner basin. According to Alfredini et al. (2006) and Alfredini et al. (2008), high tidal currents, due to tidal ranges up to 6.5 m, are present in the harbour site studied. The wave-climate is less important, with maximum heights of 1.0 m.

3 DESCRIPTION OF METHODS

The hydraulic model of SIAMA consists of a down-scaled undistorted 1:170 model with 1100 m^2 of the geometry of an estuarine area, in which tidal currents can be generated. In Figure 2A there is an aerial view of VALE PDM Piers I and III (South and North Berths).

Through the simulator, an attempt is made to sail a radio-controlled ship-model along a desired track, with a scenario similar to that in the prototype (see Fig. 2B), reproducing port facilities and navigation aids. Wind effects are provided by fans and tugboat force by air propellers mounted inside the hull of the ship model itself (see Figs 2C an 2D). The ship is steered by pilot-control from ashore (Fig. 2E), using radio-controlled rotating cameras mounted in position on the ship-model bridge (Fig. 2F). Thus, an incorrect visual picture of the waterway can, to a certain extent, be corrected. Since both the vessel and tugs are unmanned, the SIAMA concept is an analogical simulation modeling technique. Furthermore, there is the problem of time: the application of Froude's law to determine scaling factors is required in order to correctly represent total hydraulic influence. This implies that the time-scaling factor is equal to the square root of the linear-scaling factor. Thus, in the model, time will pass faster than in real life (13.04 times in SIAMA). This, depending on the difficulties arising from the quickness of the real manoeuvre, can be a hinderance to the model's pilot. Thus, an apprenticeship for pilot adaptation becomes necessary.

Tests to determine the effect of current forces on the navigation of vessels at port approaches are carried out at SIAMA, by using radio-controlled ships in hydraulic models. Control is exerted over one or two propellers and the ship's rudder. Tug force, when required, are simulated by the thrust of ducted air fans. Six variable speed fans, rigidly fastened inside the hull of the model ship, blow from windows opening thereon (see Fig. 2D). These are located at the bow and stern (longitudinal forces), fore starboard and portside (transversal fore forces), and aft starboard and portside (transversal aft forces). Each fan has an independent speed control, the maximum thrust being 750 kN (prototype). Engine and tugs speeds are calibrated according to prototype data, thereby providing dead slow, slow, half, full ahead, and reverse. In Figure 2G, one can see the propeller and rudder at the stern of a Panamax (75000 dwt) vessel model.

During a test run at SIAMA, a pilot manoeuvres the ship along a variety of courses using any of the available combination of forces. His orders are transmitted by radio communication (Fig. 2E) to a staff controlling tug force, engine speed and rudder angle (see Fig. 2H). Commands are transmitted by radio (see Fig. 2I) to a servo-mechanism on board the vessel model. Simultaneously, photographs are taken from overhead at timed intervals (see Fig. 2J), and video records made by cameras (overhead, vessel-bridge and port). These records show the position and orientation of the ship, as well as the settings of all controls. A later analysis of these records reveals, for example, how tugs need to be used to assist the passage of the ship through the prevailing currents, or whether the forces applied have exceeded those available in practice. Films produced of phenomena occurring in hydraulic models can be shown at reduced speed to enable a true comparison with the full-scale object.

The SIAMA facility has models of ore carriers of 75,000, 152,000, 276,000 365,000, 400,000 and 615,000 dwt. The model-calibration procedure includes turning circle tests compared with prototype data. In Figure 2K, one can see this procedure for a Panamax (75,000 dwt) vessel.

The tests were undertaken by the ports' pilots, with the co-operation and assistance of senior members of the marine departments of the companies concerned. This involved manoeuvres for berthing or departure under various tidal conditions.

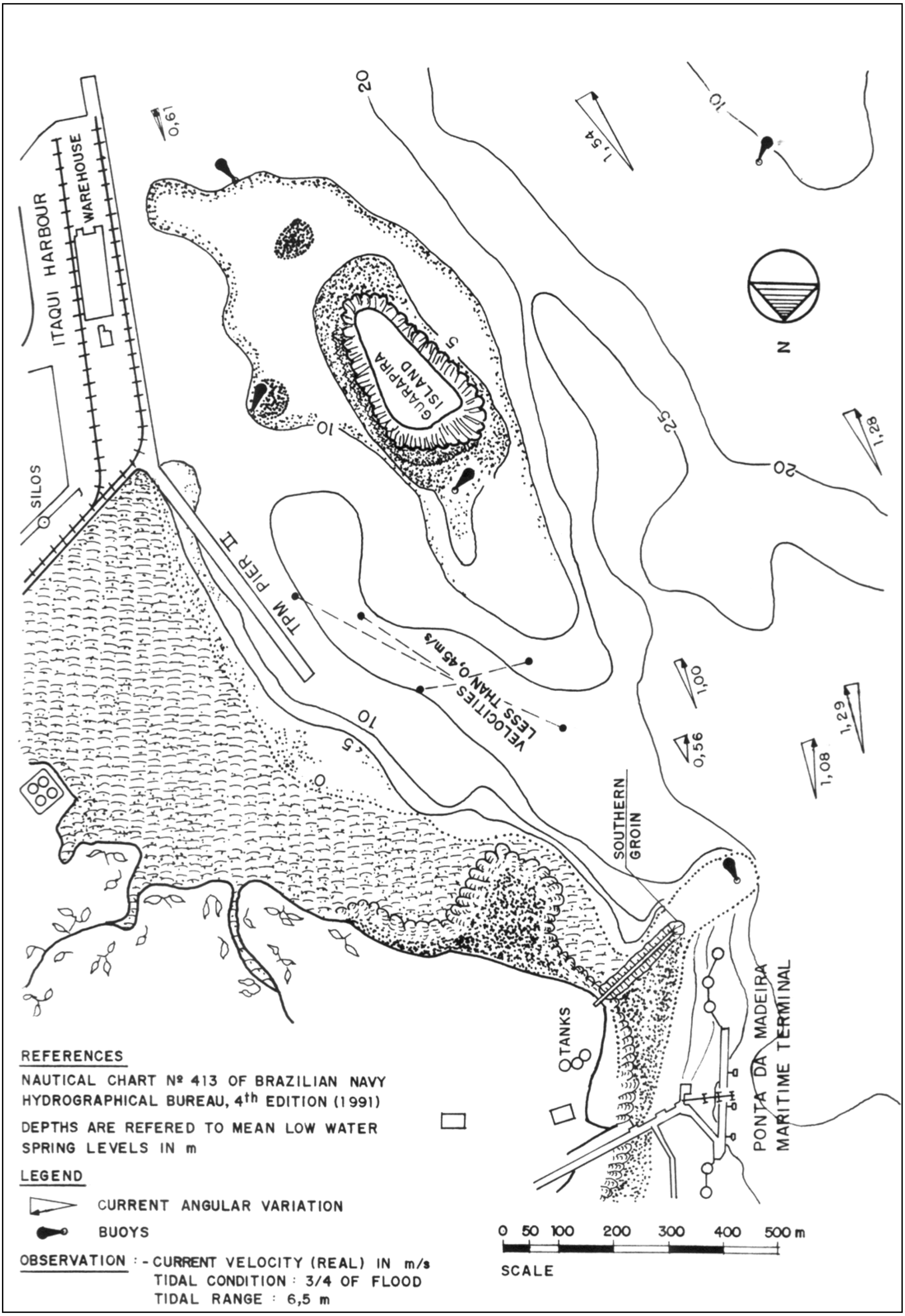

Figure 1. Tidal current conditions validated by SIAMA, for the end of extreme spring flood equinoctial tidal-range conditions, at Ponta da Madeira.

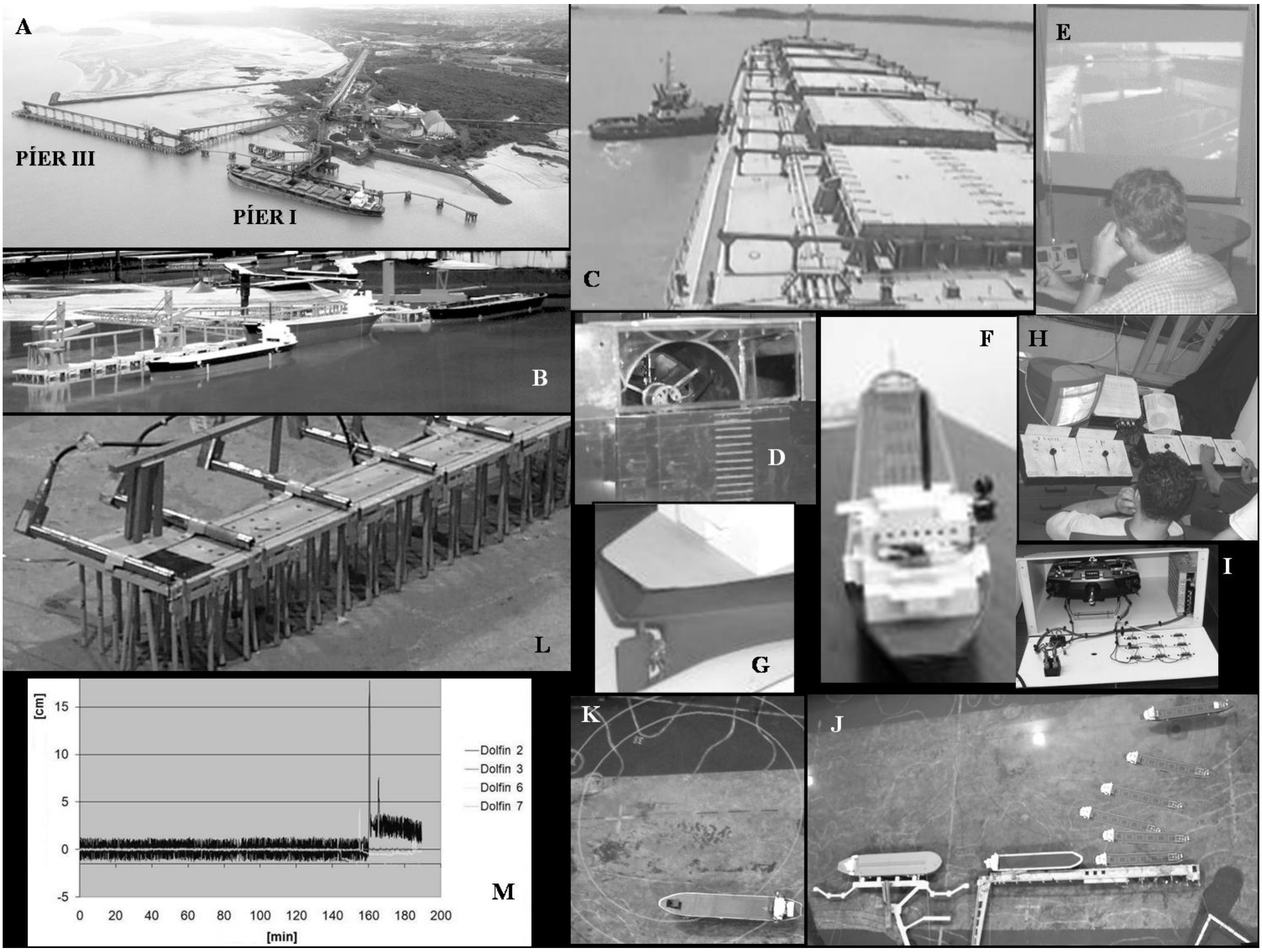

Figure 2. (A) Aerial view of VALE PDM Piers I and III (South and North Berths); (B) SIAMA run of a tug assisted manoeuvre at VALE PDM Pier III. Starboard berthing manoeuvre with a ballast Panamax-class ore carrier (75,000 dwt); (C) Tug assisted manoeuvre at VALE PDM Pier III starboard berthing manoeuvre with a ballast Capesize; (D) Window for an air fan blowing into the Capesize-class ore carrier (152,000 dwt) model hull at fore portside. The calibrated effect reproduces the pushing activity shown in Figure (C); (E) SIAMA run of a tug-assisted approaching manoeuvre for the starboard berthing of a ballast Capesize-class ore carrier (152,000 dwt) at VALE PDM Pier III. One can observe pilot vision from the bridge starboard micro-camera and his radio control device for remote rotating of the camera and for changing the image from the starboard (F) to the portside camera. Orders are also given by radio to tug-masters and engine/rudder (G) SIAMA controlling staff in another room (H); (F) Panamax-class ore carrier (75,000 dwt) vessel model. One can observe the rotating camera mounted in starboard position on the ship-model bridge; (G) Panamax-class ore carrier (75,000 dwt) vessel model stern. One can observe the propeller and rudder; (H) SIAMA controlling staff; (I) The SIAMA radio device; (J) Overhead sequence of photographs of the final stages of a VALE PDM Pier III (North Berth) starboard berthing of a ballast Panamax-class ore carrier (75,000 dwt); (K) SIAMA run turning circle calibration test for a Panamax-class ore carrier (75,000 dwt); (L) View of the gauges mounted on the VALE PDM Pier III North Berth for fender deformation measurement; (M) SIAMA recording of berthing conditions (test showed in J), given by fender deformation in the prototype (in cm), versus manoeuvring prototype time for VALE Pier III (North Berth) fenders;

In Figure 2, certain features of SIAMA devices are described (for further details see Alfredini et al. 2008). The similarities between bridge manoeuvring vision and prototype conditions are shown. An important issue regarding efficient berthing manouvring is berthing force impact, or the equivalent fender deformation, which is measured in gauges (accuracy of 0,01 mm) rigidly mounted into the deck of the pier (see Fig. 2L). Fender stiffness is scaled down by steel blades calibrated according to prototype specifications. The evaluation of impact force in SIAMA runs is used either as an input for fender projects or for pilot training purposes. A graph illustrating deformation in four fenders in a berthing test, is shown in Figure 2M.

Another interesting possibility is to study the conditions of night manoeuvres, since all luminous navigation aids are scaled, so as to comply with the flash time and colors of beacons, warning lights, lighthouses, vessel lights and port lights.

4 SOME RESULTS AND ANALYSIS

The results of some case studies with SIAMA are hereafter presented with details.

The exceptional conditions with a fairly high level of risk are to be studied: prevailing environmental conditions, the general situation of traffic and failures. Initially, the risk is related to the degree of circumstantial difficulties in the conditions for manoeuvring, e.g. a strong wind, waves and currents. Final risks are related to malfunction in procedures and communications, (misunderstanding, miscalculation and lack of attention) and technical malfunction (engine, rudder, or tug failures). The consequences, due to the probability of such initial events producing an accident (contact, collision, grounding, etc.) are damage, loss of lives, environmental impacts, etc.

Figure 3 contains a detailed description of the manoeuvring run of a ballast Capesize-class ore carrier (152,000 dwt), for approach and berthing to PDM Pier II, solely with tug assistance, thereby simulating the loss of both engine and rudder. The channel is strongly confined by PDM South Groin (jetty) and the shoals of an island and tidal currents conditions are difficult (see Figure 1). This serves as an example of the usefulness in evaluating the risks of hits or groundings involved in the failure of equipment, such as engine, rudder or tugs, in this case the engine and rudder. As described by Alfredini et al. (2008) and Gerent (2010), for each set of runs the peer group fills in a check-list based upon PIANC et al. 1997, for a de-briefing and open discussion of the following itens:

1 Tug Activity: number of tugs and orders, as well as force employed.
2 Engine Movements: frequency, number.
3 Assessment line and position maintenance: ability to keep the vessel to the intended track, and to assess its position.
4 Position: with relation to the pier and other ships.
5 Control and Safety: feeling of "in control" throughout: feeling of safety.

The following scores were attributed to each item:

10 - practicable, with ease and adequacy

5 - conditionally practicable with certain difficulty

0 – barely practicable

A Pairwise Comparison is obtained, based on this traditional questionnaire. The result of the comparison of every possible pair of alternatives gives a ranking of condition scenarios, viz., much easier, easier, as difficult as, more difficult than and much more difficult than.

From Figure 4, it is possible to gain a quantitative idea regarding the economic impact of a manoeuvring study. In the present case, the results provided an enlargement of daily tidal windows from 6 to 14 hours, with the consensus of a joint group of mariners, engineers and the Brazilian Naval Authority. This study involved all the 13 official pilots, the port captain and naval officers. With the improvements thus obtained, it is now possible to undertake combined manoeuvres (the coordinated approach and berthing of one vessel and the departure of another), by using two additional tugs with more bollard pull (750 kN) than the existing 500 kN. The SIAMA is prepared to make these concomitant manoeuvres with two pilots, with two sets of controls for two vessels. The immediate consequence of this optimization was an increase of 15% in the annual loading rate (equivalent to 10 Mt of iron ore).

Summarizing, SIAMA fast-time simulations comprised the study of more than 400 runs for PDM Pier III, more than 350 for PDM Pier I, more than 300 for the future PDM Pier IV, more than 200 for PDM Pier II, more than 100 for ALUMAR Harbour and more than 50 for Itaqui Harbour. Also important for these statistics was the ideal pilot adaptability to, and familiarisation and cooperation with, SIAMA features. In fact, all the runs were 13.04 times faster, according to the SIAMA Froude law of similitude. As regards the latter, it was also possible to reach a fine balance in the number of runs carried out by each of the official pilots (more than 100 manoeuvres in average). Only under these conditions was it possible to obtain a change in the official manoeuvring rules of the Naval Authorities.

5 CONCLUSIONS

Hydraulic scale-models have an extensive range of application, and it is quite possible that the model of a harbour or river-section is already being built to predict hydrodynamic patterns, pollutant dispersion, mooring conditions, silting, the general arrangement of jetties and breakwaters, etc. In such a case, the choice is whether it is worthwhile to use existing hydraulic models for manoeuvring investigation, that is the SIAMA concept.

An important aspect in design is the lay-out and dimensions of the harbour itself, as well as those of approach channels and turning basins. Harbour efficiency and safety is defined by its nautical accessibility and/or capacity, and hence, economic viability. The strategic dimensioning lay-out and operational-entrance windows in the early design phase can be optimized by fast-time simulations, as those with the SIAMA analogic concept.

In addition to its application as a training tool, SIAMA also facilitates risk analysis in a comparative sense, as a tool for port design. Nevertheless, the main reason for its use is the assistance in simulating the behaviour of those in charge of manoeuvring procedures, normally extremely difficult to simulate in mathematical or other descriptive models. Furthermore, results from fast-time simulator experiments can be incorporated into probabilistic design.

The results presented confirm the possibility of using the SIAMA concept as an cot-effective tool in optimizing port designs, as well as developing the empirical data sets required to sustain further developments in the investigation of manoeuvrability.

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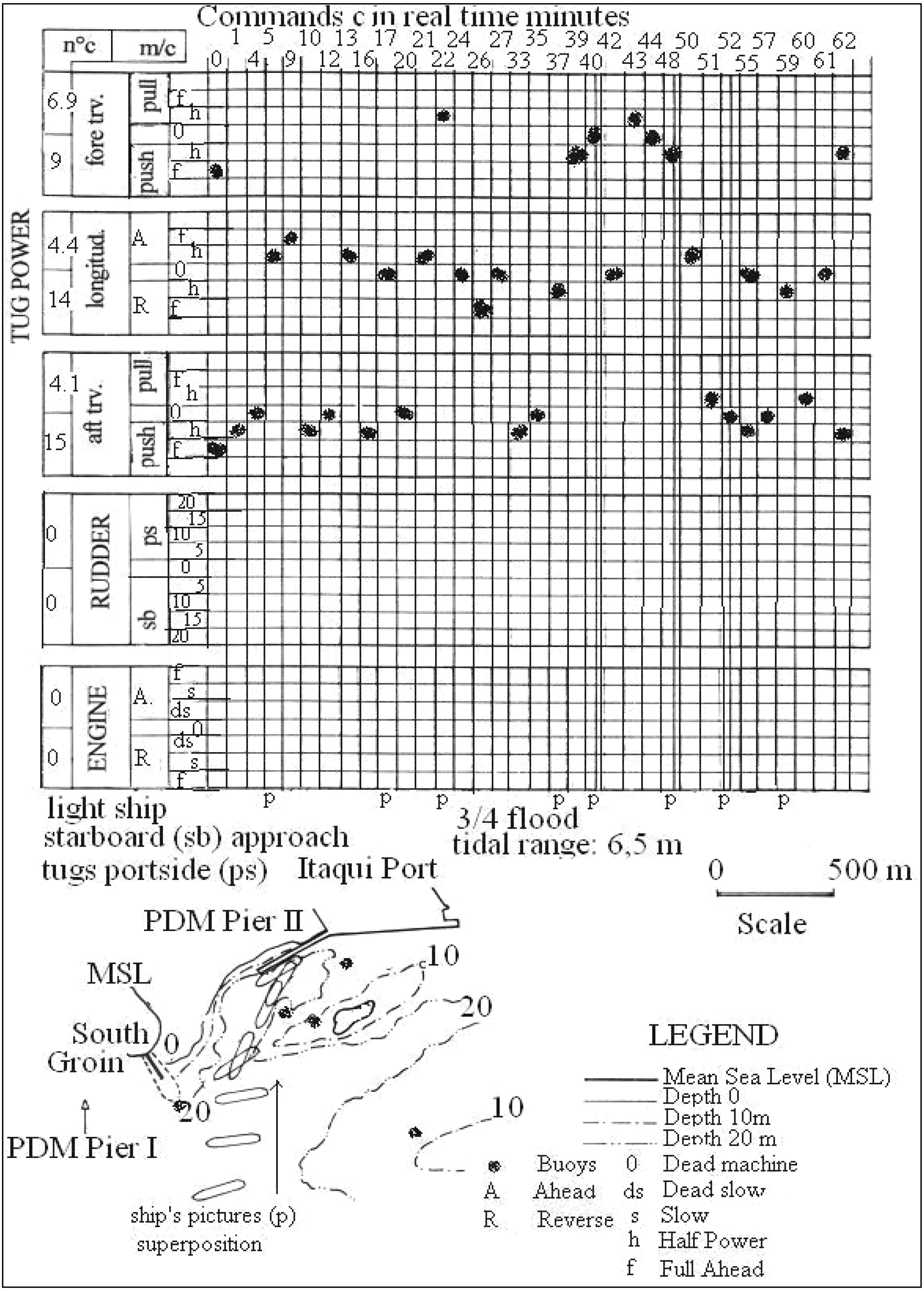

Figure 3. Example of SIAMA run detailed description of a ballast Capesize class ore carrier (152,000 dwt) approaching manoeuvre and berthing at PDM Pier II only with tug assistance, simulating a loss of engine and rudder.

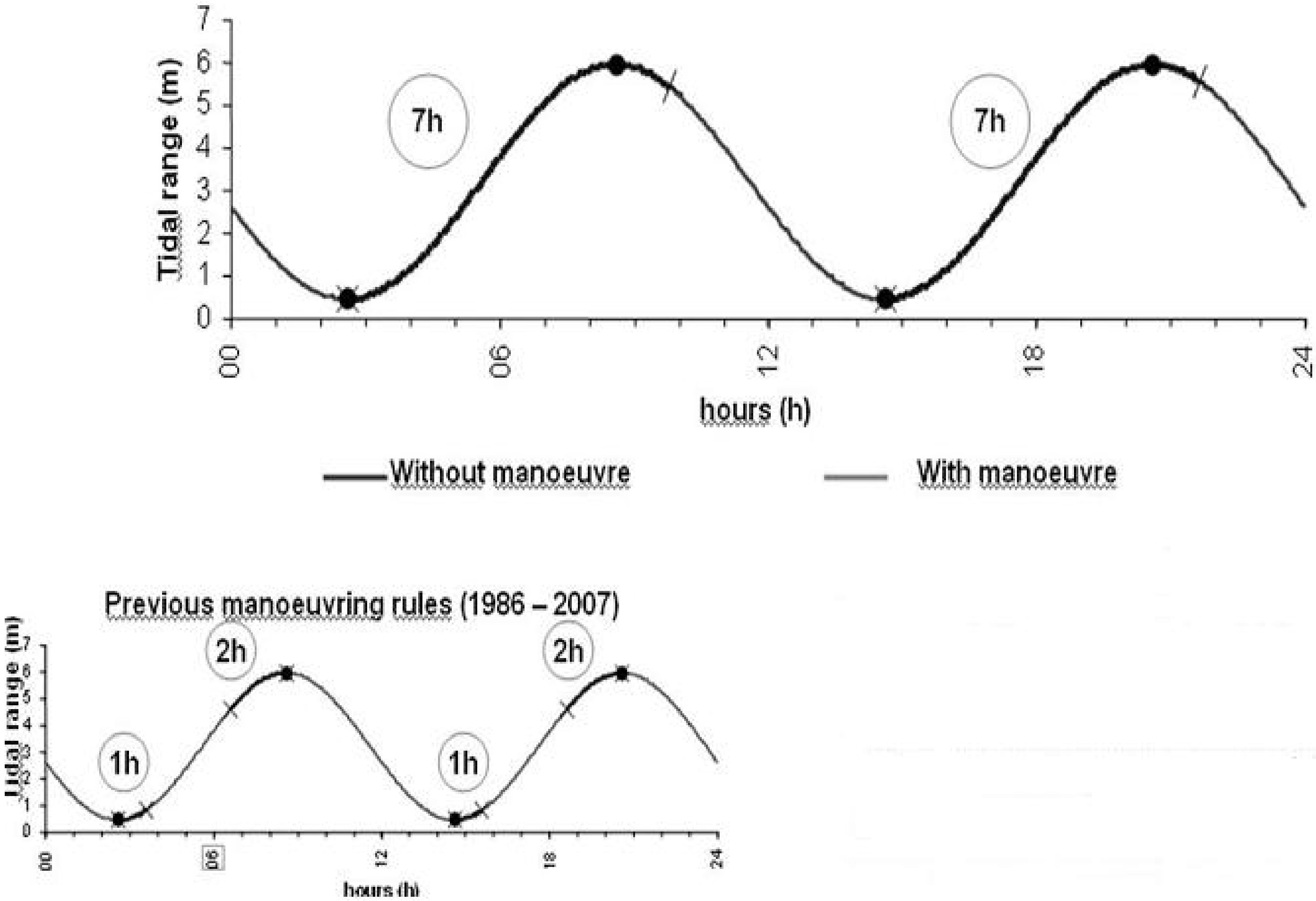

Figure 4. The enlarged tidal windows obtained at SIAMA for PDM Piers I and III. The manoeuvring tidal window was enlarged from 6 to 14 hours daily, thus improving berth simultaneous manoeuvring. The port loading rate increased by 10 million t|year, a 15% improvement