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International Standard for Bollard Pull Trials

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SYNOPSIS

Over the past three years, MARIN, together with 30 leading industry partners and class societies, has developed an international standard for the execution of bollard pull trials. Through model tests, CFD and full scale trials, the factors affecting tug performance during a bollard pull have been thoroughly investigated. The results have been used to develop a proven methodology that will deliver reliable, repeatable and transparent BP performance values for tugs. The paper gives a summary of the trial standard developed in the Bollard Pull Joint Industry Project.

INTRODUCTION

The bollard pull certificate plays a critically important role in the sale and delivery of a tug, as well as in commercial deployment and contracts. Although tugs have been around for a long time, a uniform standard for the conduct, measurement and analysis of a bollard pull trial is not available.[1] Several different bollard pull trial procedures are used in the towing industry with varying levels of detail. Many procedures have ambiguous definitions or requirements on reporting. Some incorporate correction factors to deal with non-ideal environmental conditions, and some describe trial requirements that contradict other procedures. In 2014, MARIN discussed the differences in trial execution with a number of tug operators. Their experience was that the available correction factors to date were over-estimating the influence of line length and shallow water, and some yards used the vagueness of reporting requirements to artificially increase the performance of their vessels. As part of a Dutch Maritime Innovation Impulse Project subsidy, model tests were conducted to evaluate the correction factors for water depth and line length as proposed by Steerprop in 2002.[2] The model tests indicated that the correction factors were strongly over-estimating the effects of line length and water depth on bollard pull.

With the objective of creating a scientifically based, transparent and unified bollard pull trial procedure, MARIN initiated the Joint Industry Project 'Bollard Pull' (BP-JIP). Stakeholders in the maritime towing industry were approached to join the project and share their knowledge in bollard pull testing. In November 2015, the BP-JIP kicked off with 31 companies participating. In alphabetical order, these were: ABB, ABS, ALP Maritime, Brunvoll, BV, Caterpillar, Cintranaval Defcar, CSSRC, Damen, JJ S&T, Kamome, Kawasaki, Keppel Singmarine, Kotug, LR, MAN, MTU Rolls-Royce, Nautican, Niigata, OSD, Robert Allan Ltd, Sanmar, Schottel, SMERI, Smit Lamnalco, Svitzer, UK MOD, Vroon, Wärtsilä and Wilson Sons.

In collaboration with the participating companies, a list was made of the different factors that could potentially affect the bollard pull performance. Investigations followed by evaluating the effect of the following factors on bollard pull trials:

- Line length
- Wind
- Water depth
- Waves
- Load cell characteristics
- Propeller roughness and hull fouling
- Current
- Air pressure and temperature
- Towing orientation to quay
- Draft and trim
- Sway and yaw
- Data logging characteristics
- Fuel quality
- Trial procedure
- Water density
- Reporting specifications, including definition of bollard pull and rated power

Line length and water depth are the most discussed aspects in literature, and received the initial focus. During the project, other factors proved to be even more relevant, such as the correct use of the load cell, current, and the definition of bollard pull and power rating. The effect of distance to shore and water depth

Figure 1: Model testing to investigate effect of water depth and line length in the MARIN offshore basin (lxb = 45x36m with movable floor 0-10m depth)

underneath the keel was investigated by means of 147 systematic model tests using a generic ASD tug with two Z-drives while towing over the bow and stern *(Figure 1)*. Systematic full scale trials on several tugs were performed to validate the model test results *(Figure 2)*. Open water tests in the same configuration and CFD calculations were done to evaluate the sensitivity of the hull shape on the results.

The effect of line length and water depth proved to be of secondary importance in comparison to the uncertainties found in load cells. During bollard pull trials with two recently calibrated load cells connected in series, large differences in line pull were found. This started investigations into the uncertainty of load cells. Five types of load cells were tested systematically in five calibration facilities in the UK and Netherlands. Investigations focused on quantifying their sensitivity to orientation, misalignment *(Figure 3)*, torsion *(Figure 4)*, shackle pin diameter, shackle pin cylindricity, temperature, bending and calibration procedure. Depending on the type of load cell, its connection to its accompanying shackles, type of towline, outside temperature and calibration practice, large uncertainties were found. These uncertainties by far exceed the uncertainties from water depth or line length. Based on the systematic tests and experience during bollard pull trials, a 'best practice' was made to reduce uncertainties in bollard pull measurement.

Current is another factor that affects nozzle performance, and consequently the pull efficiency. Simulations were done for several tugs and various current directions, such that the tug's propulsion system counterbalances the forces from the current, taking thruster-thruster interaction and nozzle/propeller efficiency into account. In practice, the searching for an equilibrium condition between hull forces and propeller thrust results in sway and yawing. This negatively affects nozzle efficiency.

The best performance can therefore be obtained in zero current. Due to the difficulty of quantifying current velocity, and to make the trial procedure

Figure 2: Systematic full scale trials to validate effect of line length

Figure 3: Systematic tests with load cells to evaluate the effect of misalignment

Figure 4: Systematic tests with load cells to evaluate effect of torsion when using steel stranded towlines

practical, a maximum threshold was defined to limit the uncertainties. The effects of current and sway were validated by means of full scale trials.

The effect of water density was determined using hydrodynamic calculations for fixed pitch and controllable pitch propellers. Next, systematic trials were done with a tug in different water densities to validate the calculations, resulting in requirements in terms of reporting. The following figures give an impression of some of the systematic model and full scale trials performed.

The effects of quay orientation *(Figure 5)*, fuel quality, draft and trim, trial procedure and data logging requirements were based on analysis of systematic full scale trials on nine tugs, ranging from ASD tugs to PSVs and ocean-going tugs. Reporting requirements and definitions were developed during six progress meetings of the JIP. Three years of research led to the development of a trial standard without the need for correction factors but with a strong emphasis on the correct use and calibration of the load cell. Unambiguous definitions and a clear trial procedure further reduce uncertainties during the trial and in the reporting.

Figure 5: Sailed track of full scale validation trials under restricted environmental conditions

SUMMARY OF INTERNATIONAL STANDARD FOR BOLLARD PULL TRIALS

The following sections provide a non-comprehensive summary of the trial standard. The full document can be downloaded free of charge on the website of the Vessel Operator Forum (www.vesseloperatorforum.com). In the planning of bollard pull trials, reference should always be made to the full document.

Objective

The standard has the purpose of ensuring that the reported bollard pull figure represents the realistic performance of the vessel that can be met in service conditions at an acceptable level of accuracy, irrespective of the specific conditions met during the execution of the bollard pull trial. The standard has been developed and is validated for harbour, escort, ocean and offshore tugs, including anchor-handling towing supply (AHTS) vessels with multiple propulsors, with or without nozzles. This excludes vessels where propulsors are mounted under a large flat bottom (eg, specialised ships with multiple thrusters for DP operation).

The trial standard assumes a sufficiently strong bollard is available on shore for testing. For re-certification of tugs where no sufficiently strong bollard is available, a special trial procedure is provided. For details of this procedure, reference is made to the full version of the International Standard for Bollard Pull Trials.

DEFINITIONS

Bollard pull

The vessel's bollard pull is the towing force provided by the specified propulsors recorded as being maintained in a steady state condition for a duration of not less than five minutes, performed at rated power at a speed through water of zero knots. Engine speed and brake power are to be measured simultaneously with towline force during the bollard pull trial, and shall be reported on the certificate. The steady state phase represents the highest consecutive five minute period, logged during a 15-minute trial under effectively constant trial conditions *(see Figure 6)*.

Bollard pull trials conducted in hybrid mode, where batteries or other supplementary power devices are used to provide additional power for a limited period of time shall be separately listed as 'Hybrid Bollard Pull (HBP)', and must have an associated time of validity for each operational mode of such HBP.

The issued bollard pull certificate is valid for five years.

Engine rating

Engine power and speed

The bollard pull trial is to be performed up to the maximum brake power the engine can deliver in service that corresponds to the power recorded during 100 per cent load testing at the factory acceptance tests (FAT) of the engine. For electric propulsion machines, the maximum brake power is the design power for normal service conditions defined at the electric motor, specified on the motor name plate. If the power availability is limited in time (eg, in hybrid mode when battery output depletes with time), the designed power availability duration shall be listed in the bollard pull certificate.

The engine speed shall be within the OEM specified speed range, which shall be consistent with the Type Approval of the engine and the certification of the propulsion train (eg, torsional vibration calculations).

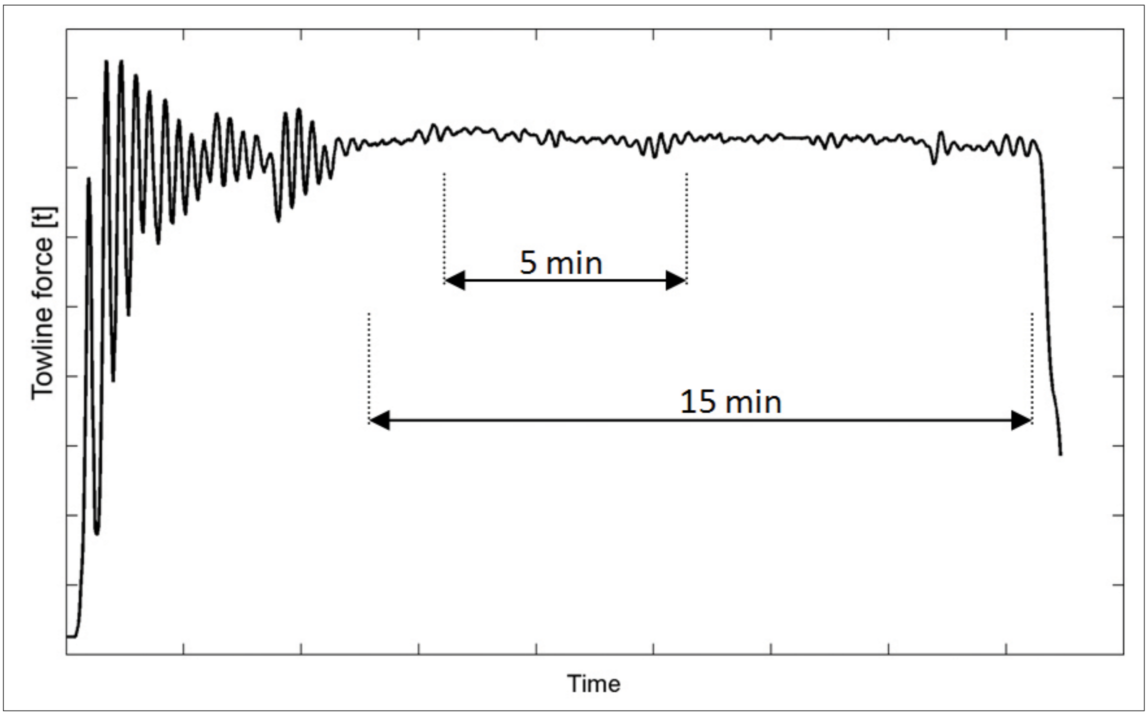

Figure 6: Definition of highest five minutes of 15min measurement period

Trial site and vessel requirements

Water depth and radius

The minimum total water depth, which shall be maintained at least in a radius of twice the ship's length around the towing vessel, is four times the propeller immersion depth (h_{imm}). The propeller immersion depth is defined as the distance between the water surface and the centre of the propulsion unit, as indicated in *Figure 7*.

Distance propeller to shore

The minimum distance between quay and centre of the propeller closest to shore – '*Lss*' in *Figure 7* – is 50 times the propeller diameter to avoid water circulation affecting the bollard pull.

Current

The current speed is to be less than 0.5 knots from the bow or sides. If the current is approaching the vessel from the stern, the current shall be less than 0.2 knots.

Wind and waves

Ideally the BP trial should be conducted in calm water conditions. If not achievable, the maximum significant wave height encountered during the BP trial period is to be not more than 0.5m. Wind speed during the bollard pull trial shall be as low as possible but not more than 10m/s (BF5).

Vessel orientation to quay

The heading relative to the quay side (assuming solid quay walls) shall be chosen such that propeller wash can freely move without being redirected in the direction of the vessel. Towing shall not be done in enclosed harbours, as recirculation is more likely to occur, resulting in unsteady performance *(Figure 8)*.

Draft and trim

The draft and trim of the towing vessel are to be representative for typical service conditions and shall be stated on the certificate.

Propellers

It is strongly recommended to clean/polish the propellers immediately before trials, as blade roughness and fouling negatively affects thrust and power efficiency.

Fuel

Fuel can have a significant effect on the available output power. The fuel used during the trial shall be representative for the normal service operation of the vessel. The fuel type and calorific value shall be stated on the certificate.

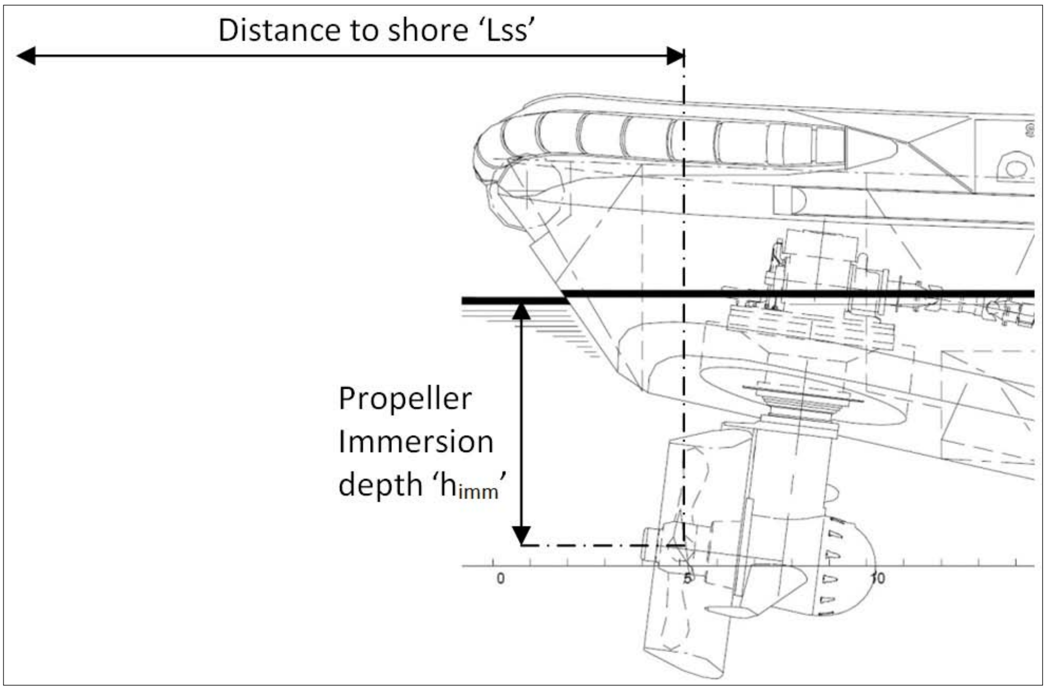

Figure 7: Definition of distance to shore and propeller immersion depth

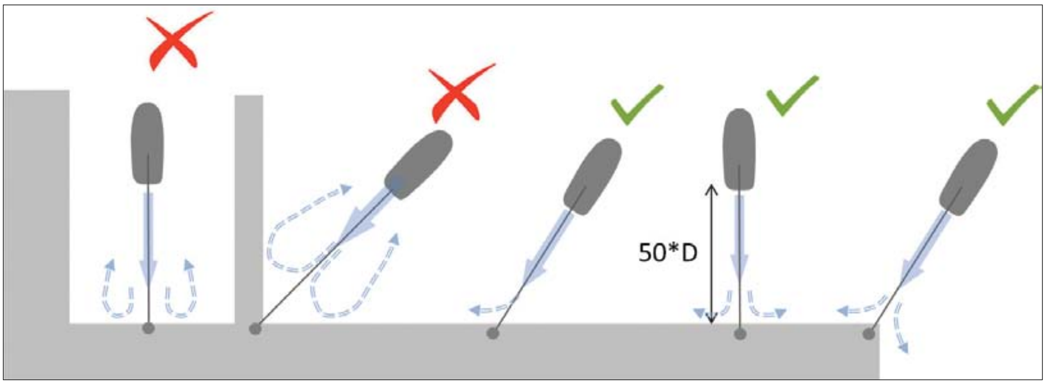

Figure 8: Positioning of the vessel during bollard pull trials. D = propeller diameter

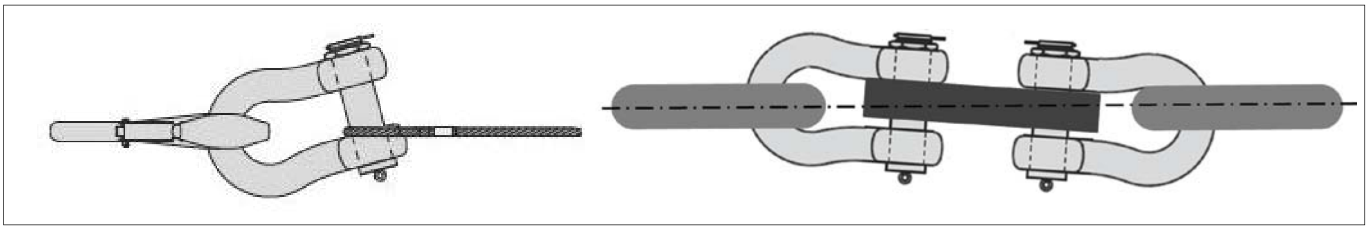

Figure 9: Load shackle and load cell misalignment

Instrumentation

Load cell

Systematic tests with different load cells indicated that they may be sensitive to drift over time, misalignment *(see Figure 9)*, torsion, temperature and connection type, and can be considered the most inaccurate aspect of a bollard pull trial. The load cell shall have a digital output and be capable of sampling at a rate of 1Hz or faster. To maximise accuracy, the following conditions shall be met:

- The load cell shall be calibrated following a specific calibration procedure (a modified version of ISO7500-1 as specified in Appendix 2 of the full trial standard) and be calibrated not more than 12 months prior to the trial
- When a steel stranded wire is used during the bollard pull trial, the load cell shall be proven to be torsion insensitive in accordance with the requirements set in Appendix 2 of the full trial standard
- Spacer rings – plastic rings specially made to fill the gaps between shackle ears and load cell – shall be installed between load cell and shackle ears to align the load cell
- The load cell and supporting shackles shall not touch the quayside edge or ground to avoid misalignment, bending and corresponding offsets in measurements
- The towline shall be connected first to a shackle, which is consecutively connected to a second shackle that holds the load cell *(Figure 10)*
- The load cell shall be set to zero prior to the trial, when the towline is not yet connected and free from any load.

Engine speed and power measurement

Engine brake power shall be measured using a dedicated shaft torque/engine speed measurement system for first and second ships of a series. The power measurement shall represent engine brake power as tested during shop tests. For the third and further of series, the engine management system can be used that is verified based on the first two vessels of a series.

If power cannot be measured directly on the engine's output shaft, it may be calculated by measuring power on the propeller shaft and correcting for power losses between engine flywheel and measurement point (ie, gearbox losses, PTO power etc). These losses are to be confirmed by their respective manufacturer and stated in the trial report.

Data logging

The readings of the towline force, engine speed and shaft torque shall be recorded continuously and automatically on a digital system with a sample frequency of at least 1Hz in order to capture the natural sinusoidal fluctuations in the forces. Each load cell reading shall be tagged with a time stamp and synchronised with the power measurements on the vessel.

Trial execution

During the trial, a visual observation of the load cell reading on the bridge is recommended, so that the commencement of the steady state phase can be judged. Minimal sway motion is recommended to avoid performance drops.

The test procedure should include testing of at least four power settings: 100 per cent, 85 per cent, 60 per cent and 40 per cent load, for a duration of 15 minutes for each setting.

1. Tare the load cell (set to zero) prior to the test when the load cell and shackles are not yet connected
2. Connect load cell and towline. Slowly put tension on the towline. Ensure correct alignment of the load cell and shackles. Re-align when necessary
3. Increase tension on the towline, until the defined maximum power is reached. When the vessel has a stable position and heading and line fluctuations are constant, start a 15-minute run recording the towline force, power and engine speed
4. Repeat step 3 for the other power ratings (85, 60, 40 per cent)
5. Repeat steps 2-4 for the other direction of towing (stern/bow), if applicable

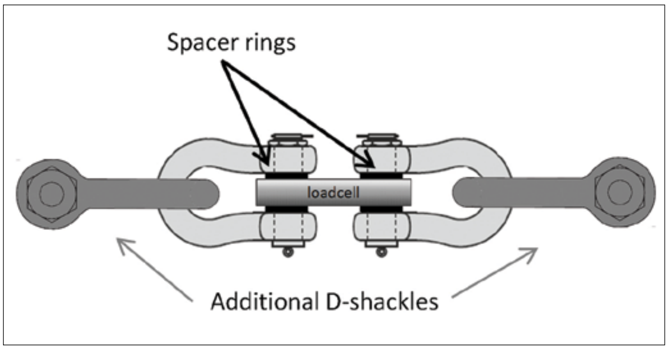

Figure 10: Recommended load cell arrangement with spacer rings and additional shackles

Data analysis and reporting

Validation of recorded data

The logged towline force shall be plotted on a time scale and evaluated for measurement errors, outliers and to identify the steady state period. The towline force shall have a smooth, sinusoidal character (for example, as shown in *Figure 11*) as a function of the mass-spring system of the towline and vessel. If the data quality is poor, indicated by stepwise data, missing data and large non-periodic fluctuations, the bollard pull trial shall be repeated.

Identification of steady state performance

The determination of the highest consecutive five minute period of stationary performance shall be performed after the trial using the logged data. The calculation of the average bollard pull over the five minute period is performed using a normal arithmetic average over the selected period (using at least: 1Hz sampled data x 5min = 300 consecutive data points).

Clear outliers due to sensor errors shall be removed prior to calculation of the average. The average of the propulsion power and engine speed shall be determined over the same five minute data period.

Reporting of test certificate

The bollard pull for tugs with conventional propulsion with no restrictions on power availability, shall be reported as following:

- _____ metric tonnes in ahead/astern pulling direction at a measured mean power of ______ kW and a mean engine speed of _____ RPM.

For bollard pull for tugs with prime movers with a diminishing supplementary power capacity, the bollard pull shall be reported as 'Hybrid bollard pull' as following:

- _____ metric tonnes in ahead/astern pulling direction at a measured mean propulsion power of ______ kW and a mean engine speed of _____ RPM. This pull is available for a designed minimal duration of _____ consecutive minutes.

Trial report requirements

The bollard pull test certificate shall be accompanied with a trial report. The report shall contain at least the following information:

- Characteristics of the vessel, propulsion system and main engines/propulsion motors, including OEM-defined consecutive periods of available maximum power
- The propulsion and engine configuration used during the bollard pull. This includes a specification of the sources of power, configuration of propulsion motors (mechanical, hybrid, number of propellers, use of (retractable) thrusters, etc) used during the bollard pull
- Used method of power measurement and used mechanical/electrical efficiency figures if applicable
- Fuel characteristics
- Location, water depth and line length during the trial
- Environmental characteristics: ambient temperature, wave height, water density, wind and current speed and direction relative to the vessel
- Towline and load cell-shackle arrangement and specifications
- Calibration certificate of load cell
- Log sheet with test results of each five-minute trial, including power, engine speed and towline force for all tested load cases
- Name and contact information for persons performing and witnessing the trial on behalf of shipyard, owner and main component manufacturers
- For re-evaluation trials at part-load operation, the original bollard pull – shaft power curve including the measured points at part load, and the calculation method to derive to the resulting extrapolated bollard pull at maximum power

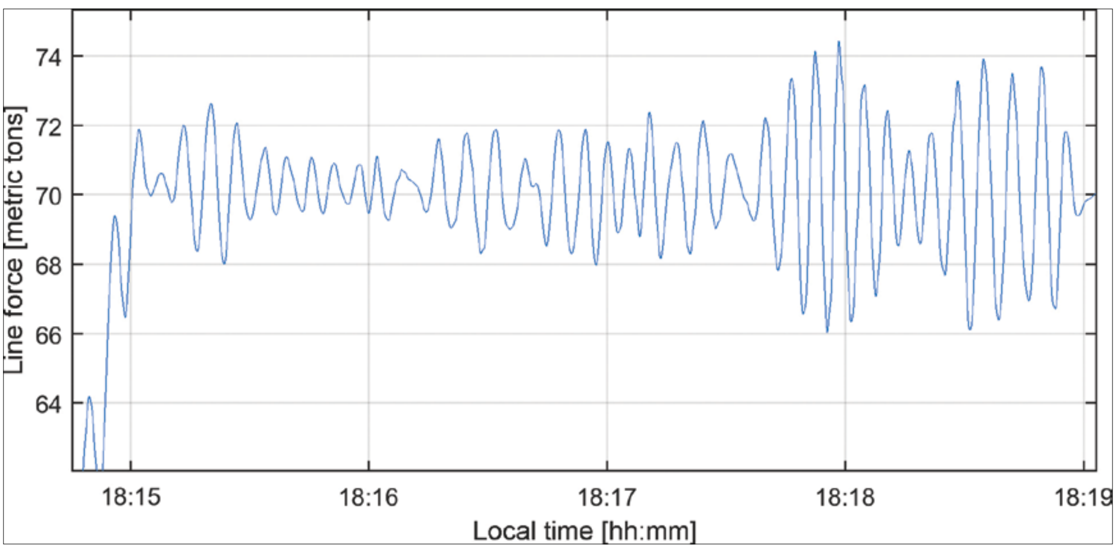

Figure 11: Example of typical sinusoidal towline fluctuations during bollard pull of a 70 tonne BP tug

CONCLUSION

Over the past three years, the factors affecting the bollard pull performance of tugs were investigated in significant detail. Model tests, CFD calculations and systematic full scale validation campaigns on nine tugs and five types of load cells were conducted to understand the behaviour of the tug in bollard pull conditions and the sensitivity of load cells. Based on the research conducted, a list of requirements and procedures was developed, leading to the recommended 'International Standard for Bollard Pull Trials'. This standard is supported by 31 leading industry partners in the towing industry and is the way forward in the reporting and certification of reliable, repeatable and transparent bollard pull performance figures. This paper provides a summary of the standard. For the planning of trials, reference is made to the full version of the standard which can be downloaded via www.vesseloperatorforum.com.

REFERENCES

[1] Stewart K, *It's all about bollard Pull*, *ITS 2016*, Boston

[2] Skogman, *Bollard Pull Trial Code Proposal*, *ITS 2002*, Bilbao