TUGTECHNOLOGY
25-26 October 2021
London

Operational experience of using the international standard for bollard pull trials

Thijs Hasselaar, MARIN

SYNOPSIS
In 2019 the International Standard for Bollard Pull Trials was launched. Over the past 2 years a great number of bollard pull trials have been executed according to this new standard. The paper describes the technical and operational experiences of applying the new standard to bollard pull testing. Guidance is provided to reduce the uncertainty caused by load cells and power measurement to get the most reliable and repeatable bollard pull test results.

Introduction
Bollard pull performance is the most scrutinised parameter of a tug. It is an important parameter for the commercial value of a tug, and therefore often subject to debate. Classification societies, shipyards and propulsion suppliers each have developed their own procedures and definitions to determine the bollard pull capability by means of trials. As a consequence of this multitude of procedures and definitions, there are large differences in bollard pull capability figures for similar tugs.

Due to commercial pressure the documented bollard pull figure is often higher than is available in service. This has led to a situation where end users of tugs use large safety margins in chartering contracts to make sure the chartered tug can deliver the minimum required pull. Furthermore, due to the wide spread in test procedures, there is a non-level playing field in the towing industry. Tugs are being set in the market with unrealistically high performance figures, creating unfair competition in an already competitive market.

In 2015 a group of 31 leading industry partners [1] started the development a uniform and scientifically proven method to test, document and define bollard pull. In May 2019 this procedure was presented at the Tugnology Conference in Liverpool, UK. Bureau Veritas (BV) has adopted this international standard for bollard pull trials into its own procedures, and other class societies are in the process of adopting it.

Over the past years MARIN performed over 20 bollard pull trials according to the new procedure. Many operators are aware of the new standard. Trial engineers, superintendents and masters on the other hand are not always up to date on the rationale behind the procedure. This paper attempts to provide a practical background to the procedure, and provides guidance to get a most reliable and repeatable trial. The paper starts with an overview of the new bollard pull standard, and how it compares with existing standards. Next, one of the most uncertain aspects of bollard pull trials is discussed, the load cell. Examples of poor practices are given, and suggestions given to improve the accuracy of measurements. Commercial and technical experiences are shared based on bollard pull trials performed internationally by MARIN.

Summary of trial standard
The standard is an elaborated document describing accurately the definition, boundary conditions, procedure and reporting requirements for bollard pull trials. It has been developed for harbour, escort, ocean and offshore tugs with multiple propulsors, with or without nozzles. Details of the procedure can be found in the full document, which can be downloaded from www.vesseloperatorforum.com. In a nutshell it can be described as following:

1. Bollard pull is defined as the mean towing force recorded as being maintained in a steady state condition for ≥5 minutes, performed at 100% power (as documented in FAT certificate) at a speed through water of zero knots. *It is documented as xxx metric tonne bollard pull at a measured mean engine power of xxx kW and an engine speed of xxx RPM.*
2. Towline tension, shaft power and shaft speed shall be synchronously recorded at 1Hz or more for the calculation of mean values. This means a digital sensor for towline tension and shaft torque and speed must be installed during the trial.
3. Water depth shall be > 4x propeller immersion depth. The distance to shore shall be more than 50x propeller diameter. There shall be no current, and wind lower than BF 5. In conditions lower than these thresholds, adverse effects on the achieved bollard pull can be expected. No

correction factors are applied for towing conditions lower than these thresholds.

4. The load cell shall be suitable for bollard pulls (a list of requirements is defined), not touch the ground, mounted to the bollard and towline using two shackles on each side, and be calibrated according to ISO7500:1
5. Four load settings shall be tested between 40-100% load with a duration of 15 minutes each. The highest five minute period, corresponding to the most steady performance, is documented on the bollard pull certificate

International standard compared to existing standards

Trial definition

The largest differences in trial requirements compared to existing standards is in the way power and bollard pull are defined and the way the load cell is used. Power and bollard pull are now both measured and reported, to avoid confusion and provide transparency. A clear definition for the power setting to be tested is explicitly included, representing the performance the vessel can deliver in normal service conditions without loading the engine beyond that is certified by class during FAT as 100% loading. This is an important change, as currently a multitude of definitions are in use, or temporarily overload trial conditions are used to report the maximum bollard pull for service conditions. By unifying and clearly documenting the definition of bollard pull, confusion definitions like 'sustained', 'maximum static', 'continuous', 'overload', 'steady' and 'maximum', are avoided.

Use of load cell

The load cell must be logged digitally with 1Hz sampling rate. Existing procedures allow manual readings to be taken every 30 seconds, which is subject to human errors (the eye tends to notice higher values more than lower), aliasing and is unreliable. Furthermore, systematic tests with load cells have shown that the load cell provides more uncertainty than the influence of shallow water or circulation from nearby quays. Where the load cell can introduce errors in the order of 5-15%, the error from water depth and line length does not reach higher than 4% in extreme conditions. To reduce the errors, a number of precautions are included in the standard.

Trial location

In terms of trial location requirements the procedure is less stringent than most existing procedures. Water depth, line length and towing orientation relative to the quay have been proven to be less sensitive than claimed by some procedures. For example, the minimum line length for a 28m, ASD tug is approximately 135m (50xD) according to the International Standard. Most existing standards state 200m or more (except ABS, who go down to 50m in their procedures). The minimal water depth for which no shallow water effects are expected is 16m for this tug (four-times propeller immersion depth), while most classification societies require 20m as minimum. This means that the implementation of the new standard would not affect the planning and execution of the bollard pull trial negatively.

Trial duration

Most procedures require the bollard pull trial to last for 5 or 10 minutes. In the standard, 15 minutes is recommended. The rationale for 15 minutes test period is that in this period there is a higher chance that the vessel reaches a constant steady state condition. In steady state conditions the bollard pull is highest. Any ship motion, such as sway or yaw, will result in a drop in performance. The consecutive 5-minute period with the highest bollard pull will represent the most steady state performance. A sensitivity study based on bollard pull trials executed in several environmental conditions was used to determine the optimal test period. Five minutes showed to be sufficient to capture the natural fluctuations in the line force, while minimising the chances of circulation development or environmental effects to affect the performance. Requirement hereby is that the line pull is measured at least with 1Hz sampling rate.

Load setpoints

The procedure describes the testing of four load set points, as it is general practice to evaluate and document more than one load setting. Other reasons are:

a) The availability of more than a single point allows a data check to be made. Figure 1 shows an example where tests were done at different times during the day on a river. For ships with a conventional propeller (FP or CPP), the curve of pull/kW should follow a more or less straight and decreasing line. Deviations from this line may indicate poor trial execution, such as due to currents, sway movement or other effects. This simple representation allows a direct check on site, so corrective measures may be taken.
b) it provides operational data to the ship owner and propulsion manufacturer on part-load performance. This can be used to estimate the line pull as function of throttle lever, calculate fuel consumption and validate measurement points etc.
c) The availability of a line pull – engine power curve allows the performance of the tug to be evaluated with future bollard pull tests. This provides insight in the state of the tug compared to its maiden voyage, and may be used to predict tug performance when only part-load tests are possible (see Appendix 3 of the International Standard). This is useful when no sufficiently strong bollards are available for testing.

Figure 2 shows tug efficiency curves for 19 tugs of various type (ASD, ocean going tugs, FPP and CPP) executed by MARIN according to the Intenational Standard for BP trials. The trials were executed in different parts of the world, but all satisfying the requirements stated in the standard. There appear to be large differences in efficiency. Some curves show deviations from a straight line. For most cases these deviations disappeared after repeating the specific loading condition later during the day. This showed the usefulness of plotting the efficiency directly after the trial as a quality check.

Load cell uncertainties

As part of the Bollard Pull Joint Industry Project several BP trials were performed with two load cells in series. During such trials deviations up to 5% between load cell readings were observed, while both load cells were calibrated. This

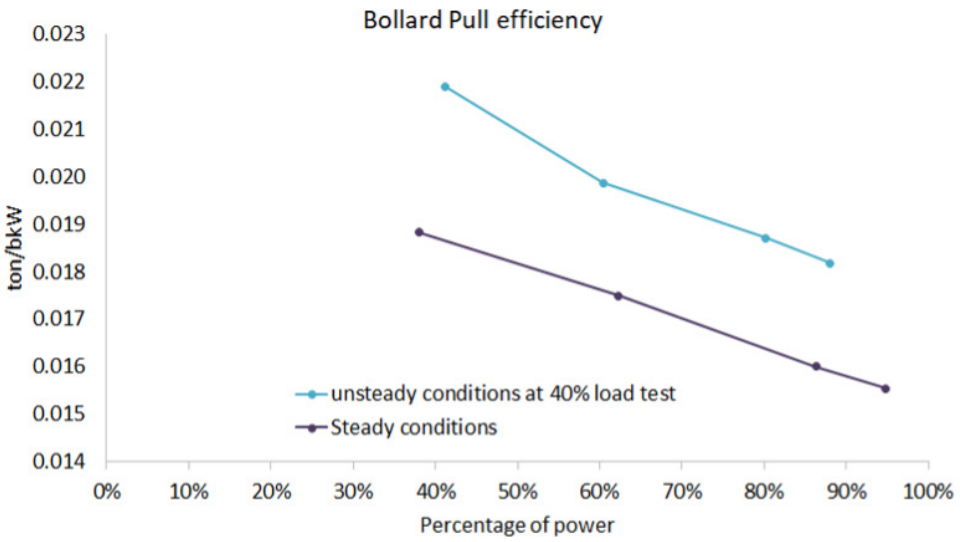

Figure 1: Tug's efficiency curve

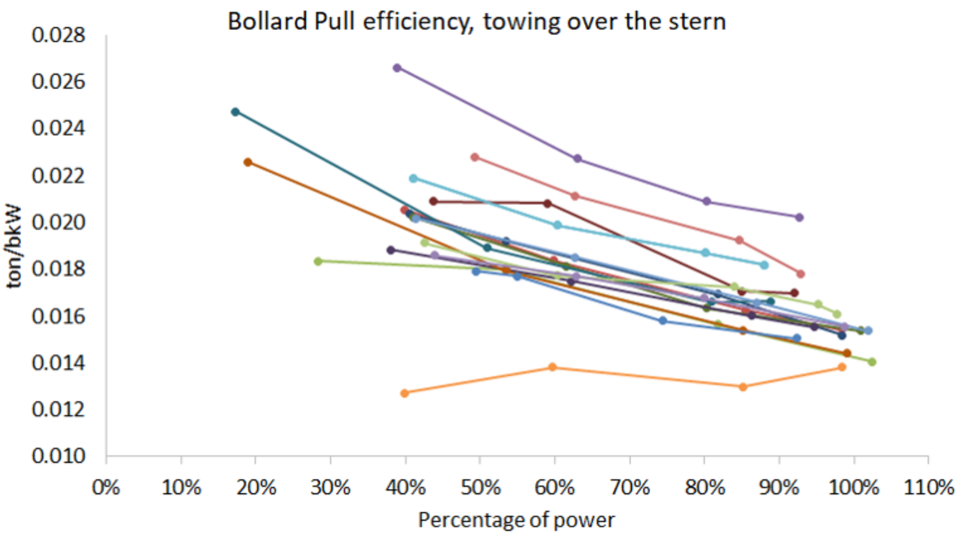

Figure 2: Bollard pull efficiency curves of 19 tugs

started investigations into the sensitivities of load cells. The investigations focussed on the following factors:

1. Temperature, as there may be large temperature deviations between installation of a load cell and the actual trial (for example due to the sun warming up the load cell)
2. Torsion. Most steel stranded towline wires have the tendency to unwind when a load is applied. As there is no freedom for the towline to unwind on the bollard, torsion is generated in the towline and transmitted through the load cell as a function of the towline force. For example, when a 70mm, 6x36WS+IWRC steel wire is tensioned with 70 tonnes during a bollard pull trial, the wire creates a torsion moment of 3.4kNm and wants to unwind approximately 20-30 turns. Most load cells are not designed for these load cases
3. Alignment of the shackle with the load cell. The space between the shackle ears and the load cell may be asymmetrical (Figure 6), resulting in an asymmetrical loading of the load cell
4. Alignment of the shackle with the towline (Figure 3, Figure 5), resulting in asymmetric loading of the load cell
5. Load cell touching the ground, which results in a normal force pushing against the load cell (Figure 7)
6. Pin diameter of the connecting shackle of the load cell, which affects the stress distribution through the load cell
7. Connection type on load shackle (shackle or synthetic towline, as shown in Figure 4) [2]
8. Calibration procedure
9. Repeatability
10. Hysteresis, as the line tension oscillates around the natural period of the tug-towline system

Systematic tests (Janse 2017, Hasselaar 2019) were performed with four different load cell brands of the type 'load link' (Figure 3) and 'load shackle' (Figure 4). All were calibrated by the manufacturer less than six months prior to testing, and all had a claimed error of 1% or lower. To evaluate calibration procedures, systematic tests were done at four testing facilities in the UK and Netherlands. All tests were performed with multiple repetitions to get reliable and statistically relevant results.

There appeared to be large differences in terms of sensitivity, repeatability and accuracy between the load cells. Some load cells showed sensitivities to temperature (2% deviation between -10..+50degC), torsion (4%), alignment (6%), connection type (17% between steel-steel or synthetic wire-steel), calibration procedure (3%) and/or repeatability (2%). Compared to the impacts of shallow water or circulation due to nearby quaysides, this showed that the load cell is the most uncertain factor during a bollard pull trial.

Figure 3 to Figure 7 show a number of examples of poor load cell practices found during bollard pull trials. Asymmetric loading appears often. Synthetic wires and eyes of steel stranded wires are often rough, which results in slight misalignments when brought under tension. A clear example is Figure 5, where the towline attaches to the shackle off-centre. Most often it is however difficult to see where the point of attachment of the towline is. Figure 3 and Figure 4 show cases where the load cell is likely to be loaded asymmetrical due to asymmetric connection of the towline to the load cell.

Systematic tests with slightly off-centre towline attachments have shown that load cells may be highly sensitive to this. A solution is by mounting an extra set

Figure 3: asymmetrical load distribution through load cell due to misalignment from towline

of shackles between load cell and towline, as shown in Figure 8. Shackle to shackle connections will align better under tension, avoiding asymmetric loading of the load cell. Misalignment caused by asymmetric spacing of the load cell between the shackle ears (Figure 6) can be solved by adding spacer rings.

Torsion is another invisible but important factor that may affect load cells. The effect of torsion moments through a load cell cannot be avoided when a steel stranded wire is used. The use of a swivel in an attempt to remove torsion moments is for most steel stranded wires not allowed. It will unwind the towline, which puts all tension on the inner strands of the towline. This will damage the cable and is therefore not allowed. To avoid the uncertainties, the manufacturer of the load cell should demonstrate the sensitivity of its equipment to torsion moments in combination with longitudinal forces.

Taking above considerations into account, the recommended setup is by using a load cell that is:

a) Proven to be insensitive to torsion moments
b) Calibrated with the same shackle pin diameter that is used during bollard pull testing
c) Proven to be insensitive to temperature variations
d) Calibrated according to the procedure described in the *International standard for bollard pull trials* (BP-JIP 2019)
e) Logged digitally using a wireless link with ≥1Hz store rate

Furthermore, the load cell and accompanying shackles should

f) Not touch the ground
g) Be connected to the towline using an additional set of shackles
h) Be set to zero prior to connecting the towline

The recommended setup is summarised in Figure 8. Using this setup and abovementioned quality checks the bollard pull can be determined with an estimated accuracy

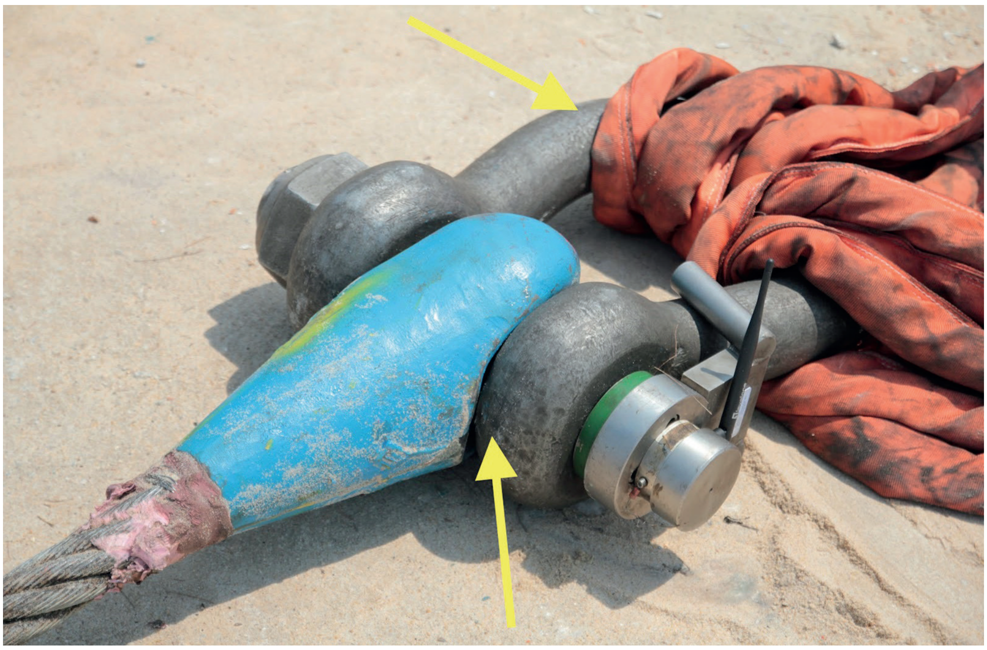

Figure 4: Poor mounting practice of load shackle

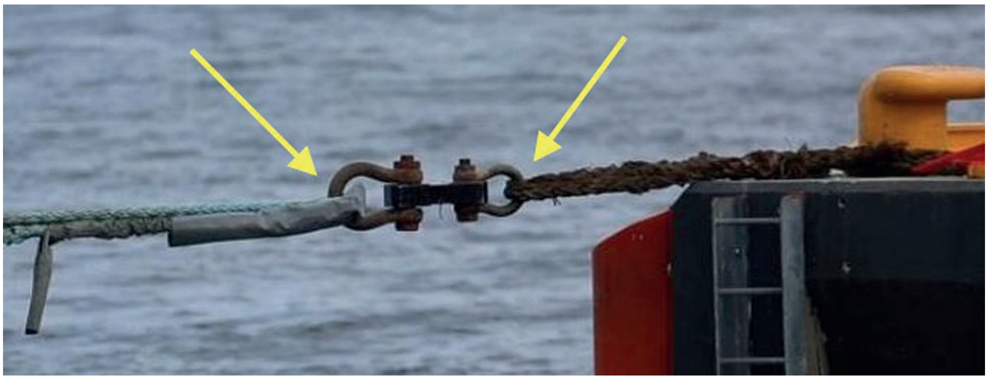

Figure 5: Asymmetric load distribution in load cell due to misalignment of shackle with towline

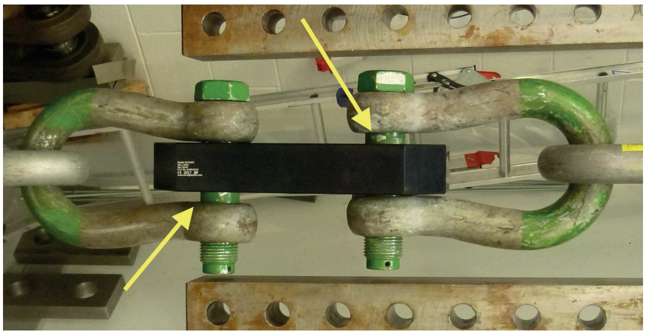

Figure 6: asymmetric load distribution due to misalignment of shackles with load cell

of ±2%. This is much higher than is practice during most existing bollard pull procedures and guidelines.

Finding a load cell that matches abovementioned conditions may not be easy. Load cell manufacturers test their equipment in laboratory conditions with pure longitudinal forces and are therefore sometimes unaware of the performance in typical bollard pull situations. If in doubt or in commercially sensitive situations, it is worthwhile to install two load cells of different brand in series so to evaluate the uncertainty from the load cell.

Uncertainties in shaft power

The engine power is a much-debated factor during trials. Generally, the engine manufacturer attends the trial and reads the engine output from the engine management system. For new engines this can be accurate. However, when the engine is worn, overhauled or operates with a different fuel quality, the uncertainty becomes large. For this reason it is required to measure shaft power using a dedicated torque and rpm measurement system on the output shaft of the engines.

The measured shaft power is used during the trial to test the 100% output setting. If the captain can request more power than the engine is certified for (100% load according to its EIAPP certificate and class approval), the throttle shall be reduced to 100% power for the bollard pull trial. Over-load conditions may be tested by the owner, but show on the certificate as over-load as the measured power is reported on the trial certificate. Generally, the available power of the engine is however lower after years of operation, while mostly the engine management system indicates no noticeable drop. Shaft power measurement provides here a useful measure to clarify performance drops.

Transition to transparent bollard pull testing and reporting

The bollard pull JIP was initiated by operators and yards with the objective of creating a level playing field and unified trial definition and procedure. Operators and yards experienced that tugs were being introduced in the market with unrealistically high performance figures, far exceeding performance that could be met in service. The introduction of a more transparent and technically correct definition will therefore probably result in lower performance figures, but representing true representations of the capabilities of the tugs during normal service operations, comparable to other vessels and repeatable.

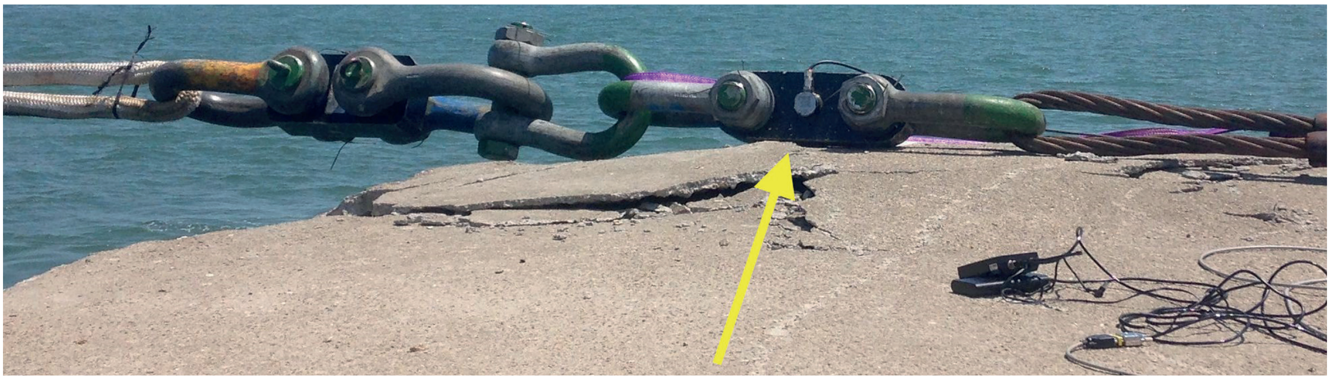

Figure 7: Loadcell touching ground affecting the loadcell

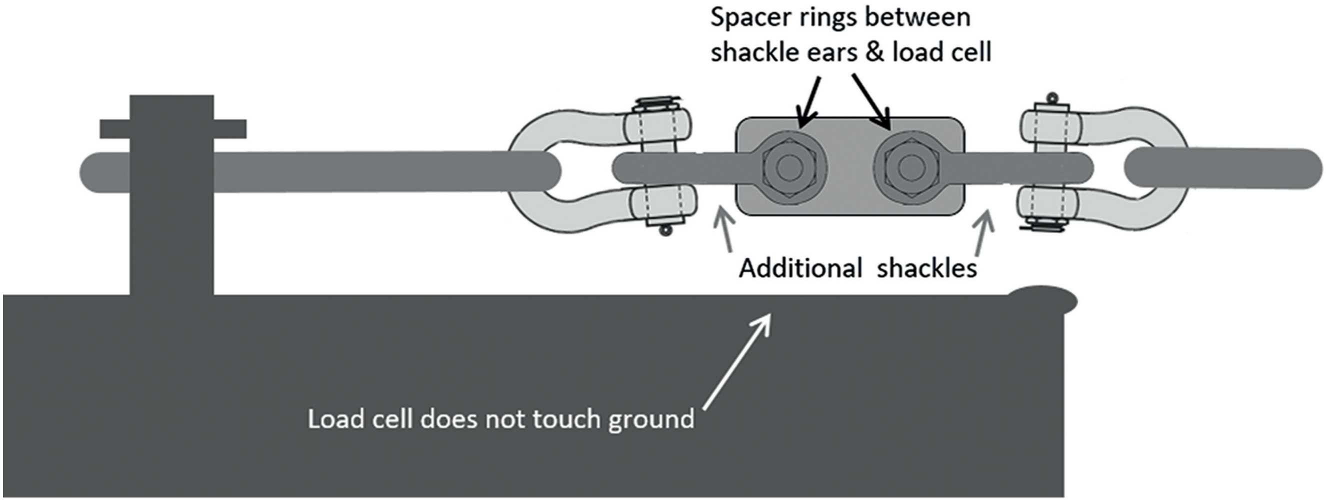

Figure 8: Recommended load cell setup

Over the past two years, MARIN conducted 24 bollard pull trials according to the new standard with various tug types. All trials were done after the first or second special survey dry docking. For some ships, especially those where in previous trials the power on the shaft was measured, the same performance was obtained when the new standard and definition was used.

For many other tugs however, the performance was lower. In many cases the engines could not deliver 100% power anymore, which resulted in lower absolute bollard pull figures. However, when correcting for the reduction in power, the average bollard pull was still about 7% lower to the claimed bollard pull from new build. This may be caused by a reduction in propeller efficiency, but most likely by the fact that previously the reported bollard pull and power were uncorrelated. The engine power (if at all reported) represented the power listed on the engine name plate, while the bollard pull represented the peak value when the engine was often temporarily over-loaded. The new definition does not include over-load conditions, which may therefore result in lower bollard pull figures.

On the other hand, charterers of tugs will recognise the transparency and procedure of the standard as a quality indicator. Tugs tested according to the standard have a proven performance that can be replicated in service conditions. The bollard pull trial data allows technical investigations to be made, operators can compare tugs, identify outliers in performance and initiate further actions. For some operators this leads to actions which lead to reductions in fuel consumption, improvement of maintenance schemes and improvement of vessel performance after repair.

Conclusion

Over the period 2015-2018, a large group of operators, yards, design offices and equipment suppliers of tugs have developed a scientifically sound methodology to define, test and document the bollard pull performance of tugs. Based on 3 years of research, a procedure was drafted that is not more stringent in terms of environmental requirements compared to most existing standards. New requirements are set on measurement of shaft power and line pull.

Line pull measurements have shown to be the most uncertain aspects of a bollard pull trial when power is measured. Using correct procedures and equipment, the uncertainty can be reduced to acceptable limits. Effects from non-ideal conditions can be evaluated on board by plotting the Pull/Power relationship. This can be used to evaluate the effect of unaccounted conditions and quality of the tests. Several classification societies have, or are in the process of adopting the procedure, which will accelerate the widespread shift in bollard pull definition from a purely commercial value into a technical representation of the bollard pull capabilities of the tug in service.

References

[1] Consisting of ABB, ABS, ALP Maritime, Brunvoll, Bureau Veritas, Caterpillar, Cintranaval Defcar, CSSRC, Damen, JJ S&T, Kamome, Kawasaki, Keppel Singmarine, Kotug, Lloyds Register, MAN, MARIN, Rolls-Royce Power Systems, Nautican, Niigata, OSD-IMT, Robert Allan Ltd, Sanmar, Schottel, SMERI, Smit Lamnalco, Svitzer, UK MOD, Vroon, Wärtsilä and Wilson Sons

[2] Picture obtained from https://prontosunray-tukun.blogspot.com/2012/02/bollard-pull-test-mv-setia-rentas.html, accessed on August 8, 2021

(Janse 2017), EFFECT OF ENVIRONMENTAL FACTORS ON LOADCELLS FOR BOLLARD PULL TRIALS MARIN Report No. : 26756-7-TM

(Hasselaar 2017), Calibration uncertainties for load cells used for Bollard Pull trials, MARIN report no. 26756-12-TM

(BP-JIP 2019), International Standard for Bollard Pull Trials, developed by the Bollard Pull Joint Industry Project. Available from www.vesseloperatorforum.com