It’s All About Bollard Pull

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SYNOPSIS

Have we ever heard a harbour master say he doesn’t want tugs with more bollard pull? Or an oil company knocks back an anchor-handler because of too much bollard pull? Unlikely. With bollard pulls approaching 300 tonnes, do we really appreciate the relevance of these figures? How much more do we need? Is 400 tonnes the limit?

Is there a disconnect between theoretical calculations and practical seamanship? Are empirical bollard pull formulae causing confusion? Can too much bollard pull be dangerous? This paper examines the history of bollard pulls and the impact on our industry today – the myths and confusion and even the misguided emphasis placed on bollard pulls.¹

INTRODUCTION

Previous studies have focused on how we measure or calculate bollard pull. This paper focuses on how we use (or misuse) this information, its validity and its relevance to real life towing operations. The theme of this paper is not to criticise or be judgmental, but to question the use of bollard pull figures as the arbitrary factor for decision-making on tug selection or design and to stimulate some discussions on the subject of bollard pull (Figure 1).

FOUR QUESTIONS

I would like to put forward four questions to consider as this paper proceeds:

1) Why is bollard pull the determining factor in decision making for tug selection? (how much is too much?)
2) Who makes these decisions?
3) How is bollard pull measured or calculated? (and are these methods valid?)
4) Are we ignoring the practicalities of towing skills over theoretical analysis?

BACKGROUND HISTORY

So when did bollard pull become significant? Early steam tugs were usually described by indicated horsepower (Figure 2). Single screw open propellers provided enough thrust to tow sailing ships and steamers into port.

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And then in 1932, quite by accident, Ludwig Kort was trying to find a way to cut down propeller wash erosion of canal walls when he fitted a nozzle around a propeller. The result: a 30-40 per cent improvement in thrust. After that, as they say, the rest is history.

Kort nozzles (Figure 3) revolutionised the tug’s propeller thrust and suddenly the industry began to speak in terms of propeller thrust rather than plain engine power.

Figure 3: Kort nozzle on a Towmaster rudder

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It is unclear when the term ‘bollard pull’ was coined to describe this propeller thrust, but as early as 1961, the British Ship Research Association had formulated a code of procedure for bollard pull trials.

Right through to the late 1960s, tug owners were describing their tugs by shaft power, but by the end of that decade they were advertising the tug’s bollard pull as well. Whether these figures were theoretical or the results of rudimentary bollard pull tests is unclear as records of formal third party verification are difficult to find. Certainly the figures were modest and reflect the fact that many tug operators opted for open propellers as a trade-off of speed versus bollard pull.

Figures ranging between 1 and 1.3 tonnes per hundred horsepower were common, but some tug builders brazenly claimed up to 2 tonnes per hundred horsepower! Never has such a propeller been built!

So as time passed and tugs gained in power, the classification societies began to set guidelines for bollard pulls. Det Norske Veritas led the way with guidelines formulated around about the late 1970s, and ABS and IMO suit followed suit, with Bureau Veritas most recently joining in, all with variances of the methodology of the tests.

With the advent of azimuthing stern drives (ASD) and ever-increasing engine power, more importance was placed on bollard pull figures and formal testing became the norm. But the results of these tests varied wildly.

It was possible to fudge figures by recording only momentary surges (maximum bollard pull) rather than sustained bollard pull readings over intervals of five minutes, 10 minutes or any other period of time.

Bollard pull sites varied with water depths and dockside reflection of thrust (Figure 4) and varying line lengths gave wildly varying results.

Figure 4: Quayside reflection of thrust

All things considered, the early bollard pull figures were indicative only and a certain amount of scepticism surrounded what was claimed to be the tug’s bollard pull. And to a greater or lesser extent this situation remains today.

We are now looking at many offshore vessels producing well over 200 tonnes, even 300 tonnes (Figures 5 and 6), and harbour tugs closing in on 100 tonnes bollard pull. And yet no internationally agreed-on common code for measurement has been established. To some extent the pace of tug design has overtaken the need to establish an internationally recognised code for bollard pull measurement.

Figure 5: Far Shogun 250-tonne BP

Figure 6: ALP Future 300-tonne BP
Yet we still have this fixation on bollard pull. What does it really mean to the industry as a whole? Static bollard pull measurements give us a figure which, if arrived at by a common method, enables us to compare tugs’ performance on a pound-for-pound basis. That’s all! It’s how we use that figure that’s important.

THE IMPORTANCE OF BOLLARD PULL

Bollard pull, what is it? Let’s define what we are talking about. During a bollard pull trial there is a maximum static or peak reading which occurs at the start of the trial when the tug takes up the tension on the tow line and exerts full power in ‘clean’ water. Then this stabilises back to a steady continuous or sustained reading. It’s the steady continuous (sustained) reading that we are interested in (Figure 7).

Figure 7: Typical bollard pull graph (note the spike at the start of the trial)

But tugs in service seldom will use all their maximum static bollard pull. This will happen in only a few circumstances:

- Harbour tugs berthing ships at very slow speed or arresting ship momentum (the braking effect) (Figure 8).
- Anchor-handlers breaking out anchors from a static pull or tensioning anchors at slow speed.

Figure 8: Stern tug arresting ship motion

At other times only a very small portion of a tug’s bollard pull capability is made use of. It’s the bollard pull that they have in reserve for emergency situations that gives comfort to operators.

SAFE IN SAFE HANDS

But is too much bollard pull dangerous in the wrong hands? In almost every accident there has been, with the benefit of hindsight, a way to avoid what happened – specifically, the human element:

- Poor decision making;
- Unfamiliarity with the tug;
- Incorrect use of the tools available;
- Inexperience.

Bollard pull, as a standard for the comparison of tug performance, seems to be the governing factor for tug selection today. But before all else is considered, a certified bollard pull for tugs must be consistent with an internationally recognised standard. In other words, we are comparing like with like. Research has found no fewer than six separate standards for conducting bollard pull trials, each having slight variations on the actual practices and duration of the trials.

The context of pure bollard pull figures alone must be tempered with the following considerations:

In harbour towage:

- Propeller immersion in shallow water operations, shallow water effects and the impact on bollard pull figures that have been established in ideal deep water trial sites.
- Reactions against ships hulls and losses of pulling power.
- Indirect pulls, loss of bollard pull when towing off direct fore/aft lines.
- Ahead verses astern pulls – designs are closing the gap with innovative configurations of azimuthing thruster configurations.
- The Voith concept; the advantage of constant pull in every direction at the sacrifice of draft and tonnes thrust per 100 horsepower of thrust.
- Dangerous situations; girting, snatch loads, line failures, collisions and running down, loss of power or loss of situational awareness.

All these considerations come down to the practical experience of pilots and tug masters.

In ocean towing, how much additional thrust is needed to push big blocky AHTS hulls through the water compared to the finer fully developed hulls of an earlier era? Compare the older United Towing or Selco/John Ross style hulls with the chunky parallel body anchor-handlers. (Figures 9 and 10, overleaf.)

There is a trade-off with these designs between free running speeds, towing speeds and fuel consumption on commercial tows versus the multi-discipline requirements of the offshore industry where perhaps fuel economy is not as important a factor.

How much bollard pull is needed? How is it used? What’s the difference between an ocean tug of say 80 tonnes BP and a harbour tug of 80 tonnes?
Bollard pull alone doesn’t define a tug. The tug’s purpose is the defining criterion. Let’s look at two 80-tonne BP tugs, one for harbour work and one for offshore (Figures 11 and 12). They’re both tugs? Yes. They have the same bollard pull? Yes. Can they do the same job? No.

A typical harbour tug:
• is about 30m long with a flush deck and a L/B ratio of 3:1;
• has ASD, Tractor, Rotor or Voith propulsion;
• the deckhouse is recessed inboard of the bulwarks for working under the flares of ships’ hulls;
• has fendering all round;
• render/retrieve towing winch and heavy towing staple on a radiused bow;
• is well suited to indirect towing (Figure 13) and resistant to girting.

A typical ocean tug:
• is about 60+m with a raised forecastle for weather protection of the aft deck and a L/B ratio of 5:1;
• has conventional twin screw configuration in Kort nozzles;
• stern roller, Shark jaws, Karmforks and hydraulic towing pins (Figure 14);
• a double drum towing winch and spare wire reel;
• cargo rails and wire stoppers;
• gobbing padeyes port and starboard.

The only similarity is the word ‘tug’ and the 80 tonnes bollard pull.
BOLLARD PULL AND DECISION MAKING

Who uses it and how is it used? This is the part where cold commercialism enters the discussion. Invariably with every tug contract, money raises its ugly head and decisions are made by commercial people: port authorities, oil company contract managers, P&I clubs—largely lay persons. Of course, they’ll ask for technical advice from their harbour masters or operations managers but they can’t keep their eyes off the bottom line figure. “Why is this 80-tonne tug better than that 80-tonne tug when it’s $5,000 a day more?” Technical people tend to stare open mouthed when they hear this question. “Isn’t it obvious?”

Towing contracts and port authority licences will specify the required bollard pull very early in the statement of duties, and contractors will immediately look for the cheapest compliant tug. But there is a serious danger in basing tug selection on bollard pull alone. A wrong decision will ultimately have a price to pay.

MYTHS AND CONFUSION

Often an exceptionally good tug with adequate bollard pull for a task will be overlooked in favour of a poorly maintained tug with a much higher claimed bollard pull.

Another misguided practice is to accept a tug based on bollard pull alone. We have seen contractors presenting a harbour tug of adequate bollard pull for an ocean tow. These tugs are poorly suited to open sea conditions. Yet if the bollard pull is adequate, an uninformed person will argue that this tug will do if the price is right.

I’m sure we all recognise that there is a worldwide skills vacuum, not just at sea, but ashore with the decision makers as well. So there is confusion about tug selection and a tendency to rely on bollard pull for making these decisions. This confusion is even evident in some contracts.

Then there are a number of rules of thumb, or time-tested practices, that are now coming under scrutiny, particularly with safety factors for towing equipment based on multiples of the bollard pull figure. There is confusion in the interpretation of MBLs (maximum break loads), proof loads, safe working loads (SWL) and working load limits (WLL) for towing equipment. For example, bridle chains are only ever rated by MBL and proof loads, whereas many shackles are rated by SWL (several factors of safety below the MBL). Naval architects are becoming confused and wary as to how to match gear for towing assemblies. And of course, the starting point for all their calculations is the bollard pull calculation.

Other myths still exist. For example, do all towing vessels have to have Kort nozzles? Many towing contractors contend that there is still a place for open propellers. One US contractor has stated that: “we sell speed, not (bollard) pull”. Single screw or twin screw? Big single screw propellers have deeper immersion in a seaway and the pitch and blade area ratio can be designed for specific thrust and speed combinations. I believe there was a time in the US when stainless steel propellers were ‘tweaked’ for particular jobs to give the best speed and fuel consumption figures to win jobs.

Conversely, can advances in propeller design provide even higher thrust figures than currently in use, say more than 1.3-1.4 tonnes/100hp (or 29-30 pounds/100hp in the US), and what sacrifice is there to speed?

Another great myth is the tonnes/100hp argument between Voith and ASDs (this is discussed later).

How about the practice of adding the thrust from retractable thrusters on anchor-handlers to enhance the bollard pull figures? Is that valid or misguided? Often shaft generators used for driving thrusters consume engine power and reduce the effective bollard pull. How do we interpret the true bollard pull in these circumstances?

These are just some of the myths and confusion that exist that originate from use or misuse of the bollard pull figure.

THE RELEVANCE OF BOLLARD PULL

As a stand-alone criterion, bollard pull surely can’t be considered a fair method for comparing different tugs.

Take, for example, a big blocky anchor-handler developing say 200 tonnes of static bollard pull and compare it to the finer body shapes of the likes of the Smit Amandla (John Ross) of the same bollard pull (Figure 15). Identical results on a static test. Put the boats to sea and there is an entirely different story. Fuel consumption is drastically less on the finer hulls.

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than the big single screw salvage tugs of an earlier era. These older boats could produce an astonishing turn of speed, up to 21 knots, which served their purpose well by reaching a casualty quickly (and beating the opposition to the job!).

So bollard pull alone is an unfair method of comparing two types of tugs which have entirely different purposes.

Similarly, with ship assist/escort tugs; compare an ASD of, say, 60 tonnes bollard pull with a Voith Schneider (Figure 16) of the equivalent rating. Both are identical on a direct in-line pull but when the ASD moves off line to an indirect pull the bollard pull drops away whereas the Voith tug can maintain its pull in almost any direction. Of course the age-old arguments arise that it requires much more horsepower to achieve 60 tonnes on a Voith Schneider than it does with an ASD; and horsepower translates into fuel consumption.

But when an ASD shears off line to an indirect pull it has to increase power to maintain position whereas by and large the Voith tug just stays at the same power setting. The net result: roughly similar fuel consumption.

So these examples of interpretive anomalies demonstrate that bollard pull alone does not define the tug.

HOW IS IT MEASURED?
Bollard pull measurement methods have remained fairly unchanged over the years. However, advances with digital and computer based equipment have refined the results and the recording procedures (and weeded out a lot of the overly optimistic results).

Firstly, it must be recognised that it isn't difficult to 'flog' the readings during a bollard pull trial. That's what originally brought about the introduction of independent third party verifications of trials results. There is a maximum static or peak reading that occurs during a trial and there is a continuous reading. It's the continuous reading that we are interested in.

Essentially, a load cell (Figure 17) is fitted in the towing assembly close to the shore side bollard. Load cells are usually tension link strain gauge types calibrated and rated for various load ranges. These were originally analogue to digital recorders, but modern load cells are improved in order to simplify the set-up and recording equipment (Figure 18).

Other early methods of load measurement were done using calibrated hydraulic cylinders, but the accuracy was questionable. Recalibration of instruments is recommended to be done annually to ensure an accuracy of +/-2 per cent.

Shaft power recordings were originally derived from torsion strain gauges on the shafts together with shaft rev/min measurements (Figure 19). Modern power recordings today can be taken directly from the main engines’ ECUs. The results are usually recorded through a range of engine power settings through to 100 per cent, and sometimes a 110 per cent overload reading is taken (often not required by ABS or IMO guidelines). The towing mediums have varied using either wire or synthetic ropes.
The shore side bollard should be adequately rated and proof loaded prior to testing. We experienced an embarrassing moment in the early days when a complete section of the mooring foundation (about 150 tonnes of concrete) was pulled out of the ground and across a road, tearing up water mains and underground power lines (Figure 20). Clearly there was some mismatch of figures!

Today, with bollard pulls approaching 300 tonnes, it is becoming increasingly difficult to find a suitable bollard pull site with adequate water depth to conduct these trials. There are some moves to use simulations and computational methods to determine bollard pulls, however, nothing compares to a true physical display of power.

And what codes are used? There are no fewer than six separate published guidelines, dating back to the British Ship Research Association code of 1961 (note that these are guidelines only, not rules). The length of time of the bollard pull trial under these codes varies: between five and 30 minutes to gather stabilised readings. The first recorded third party bollard pull trials were conducted in Australia in 1981 and in the UK only a few years before that. Historical US trials data wasn’t able to be sourced.

Testing procedures between the six different recommended guidelines for bollard pull testing are not less that the environmental conditions at the test site should be:

- Calm water;
- Wind speed less than 5 m/sec;
- Current less than 1 knot.

The water depth should be greater than 20m or, in the case of ABS, twice the tug’s draft. Is this a valid criterion when Voiths traditionally have much deeper drafts than equivalent powered ASDs?

Towline lengths are recommended to be greater than 300m but in the case of the IMO and ABS guidelines, not less than twice the tug’s length. In this day and age, with 80-tonne BP harbour tugs at 30m in length, this variance between 60m and 300m allows a fair range of error for the test results. On the laissez-faire side, Bureau Veritas only requires that the conditions of the bollard pull trial be agreed on by the society. Nothing more.

The test site location is vital to ensure that no reaction of propeller thrust from the quayside affects the readings. It’s normal for the thrust readings to ‘spike’ at the start of the trial as the propellers take up the ‘clean’ water not affected by turbulence at the site (known as maximum, static or peak bollard pull). This spike will level out to a lesser continuous reading as propeller slip and cavitation comes into play. This is when the recommended time interval should start to record the continuous bollard pull readings. In the early years some shipyards were keen to only record the maximum bollard pull to give the most impressive results. These spikes could be improved on even more by shearing the tug from side to side during the test to get surge loads as well (Figure 21). These unrealistic results were recorded on bollard pull certificates, much to the scepticism of experienced surveyors. Many other variables are factored into bollard pull results: air temperature affecting engine performance, seawater temperature, salinity and the tug’s trim and draft to name a few.

With so many variables and questionable methods of testing for bollard pull, the initiatives of the MARIN Joint Industry Project and their participating partners is commendable to finally harmonise testing and
trials procedures so that bollard pull certificates will be internationally recognised as uniform. So, what do we do with these results once they are recorded on a bollard pull certificate?

### HOW IS IT CALCULATED? (THEORETICAL VERSUS PRACTICAL)

This is where it gets really sketchy. In the words of Capt Zahalka of Hanseatic Marine Underwriters: “Bollard pull calculation is not an exact science”. This is something of an understatement given the wildly varying results depending on which method is used. Bollard pull calculations are a cocktail of arbitrariness. So many arbitrary constants, assumptions, correction factors and estimates are used to ‘guess’ the minimum bollard pull required for an ocean tow.

Like bollard pull testing, everyone has an opinion on how to calculate bollard pull. Again, I have found more than six different opinions on how to calculate the tug bollard pull necessary to conduct an ocean tow with a respectable margin of safety should things go awry.

It has been arbitrarily agreed by most parties that a tug’s bollard pull should be adequate to maintain zero headway in adverse conditions of:

- significant wave height (Hs) of 5m;
- a 40-knot (20m/sec) headwind and
- a 1- or 2-knot current (depending on whose guidelines are used).

All acting co-linearly against the direction of the tow. This is the first assumption that is questionable. There are many sea routes worldwide where tugs and tows frequently encounter conditions much worse than these. Furthermore, wind and waves often act co-linearly, but ocean currents do not necessarily fall in line with prevailing storm fronts. Most tug masters will attest to the fact that following or quartering seas are far more difficult to negotiate than head seas. And then there are the cantankerous tows:

- Those that shear from side to side (Figure 22) and no amount of line length and towing speed adjustment seems to correct.

There have been numerous tank tests done to verify resistance equations but not surprisingly these are often wide of the mark for the true life tow they simulate. Some years ago (17 in fact) Samsung conducted tank tests and CFD calculations for a very large FPSO tow from Singapore to the Timor Sea. The results of these tests (Figure 23) produced an excellent set of curves to estimate towline tension at various speeds. At 5.5 knots these curves estimated a towline tension of 48 tonnes.

The actual average speed for the whole tow was 5.56 knots but the towline tension was 75 tonnes! Bearing in mind that the on board winch tension meters resolve both the horizontal and vertical components of the towline tension, their figures do not even get close to the true life situation.

So having roughly agreed on the three environmental design conditions (5m Hs, 40 knots wind, 1-2 knots current) we next have to calculate the tow’s resistance to achieve nothing less than zero headway. Many of the resistance formulae make use of the Froude number calculation in some form or another (eg $F = \rho V^2 A/2$). However, there are so many inputs to these equations that are arbitrary.

For example, the DNV formula for wave drift force ($F_d = Hs^2 \times B \times (0.52L -13)/2$) makes use of the wave height but not the wave period. So the end result of this calculation for a tow in steep short pitched seas (5-10 seconds) is the same as in a long ocean swell (15-30 seconds)? Curiously if a barge of 25m is used in this particular equation the wave drift force comes out to be zero - something wrong there!

There are shape co-efficients, wave height effect factors, hull roughness coefficients or in some cases...
arbitrary reduction factors for the number of weeks since drydocking to be plugged into these formulae. Then there is the mysterious catch-all fudge factor: the tug efficiency co-efficient of 0.75 (0.85 for coastal waters). Surely this factor isn’t universal for all different hull shapes and propulsion layouts?

Depending on which method is used, the end result of these calculations will render a single figure for a required bollard pull that can vary up to 16 per cent (or more graphically; for an 85m barge, variances of between 5 and 10 tonnes in the required BP). This might not sound like much, but having twice experienced tugs being rejected by warranty surveyors that fell short of the calculated figure by a few tonnes the consequences were frustrating. This eleventh hour decision by the warranty surveyors caused the towing contractors a huge amount of financial grief.

So the question remains: how much bollard pull is enough for a particular tow? These formulae tend to allow for the worst case scenario which results in far more bollard pull than the tug will ever require: a good or a bad thing? Is too much power in the wrong hands a dangerous thing? Remember it only takes 11.3 tonnes to tow an Aframax sized tanker (112,000dwt) at 3 knots through calm water (OCIMF). So how much is really needed to control a tow in reality?

Some time ago a client asked me to calculate the bollard pull for a single 90m project cargo barge: something like 60 tonnes was needed according to the calculations. In actual fact a 55-tonne BP tug was used to double tow two of these barges down from Dampier when they struck a cyclone. The double tow was hove-to for 36 hours quite comfortably heading into 8m seas and severe storm force winds without incident.

Surely some of these theoretical methods have to be questioned, particularly in the context of the tug masters’ experience: theoretical versus practical?

THE FUTURE – WHERE WILL IT LEAD?
All of this discussion comes down to the actual purpose of the tug. Horses for courses: high thrust at slow speed for ship berthing work, steady thrust at a constant speed for open sea towing operations, or any number of combinations for the operational hybrids for the multifunctional tug:
- harbour tugs in a dual role as first response salvage tugs;
- anchor-handlers in multi-task roles of towing, anchor-handling, cargo carriers and firefighting response vessels.

So where do we go from here? We are already seeing bollard pulls of 100 tonnes on harbour tugs and 300 tonnes offshore. Is this the limit? Will we be seeing 150-tonne BP tugs in harbours and 400 tonnes offshore tugs? Is more bollard pull the answer for safety? Only in competent hands I would contend. So much power in inexperienced hands could be fatal.

Certainly ships are getting bigger. New box ships at 18,000 teu and with the current oil glut, tankers getting bigger, floating LNG plants almost half a kilometre long – will these be small ships in the next generation? The one thing to remember is that the increasing size of the towing connections have to be man-handled. The sheer size of this equipment is becoming a daunting and dangerous handling exercise already. More power means even bigger gear. bigger loads and exponentially more risk. If we haven’t got to the end of the line, let us at least have an internationally accepted method for conducting bollard pulls. A lot of food for thought there.

Figure 24: Food for thought

REFERENCES
1 This paper follows previous ITS presentations on this topic, including: Lloyd, The Noble Denton Towing Vessel Approvability Scheme, ITS 1990, Halifax, Nova Scotia; Jukola and Skogman, Bollard Pull, ITS 2002, Bilbao, Spain and Noble, Bollard Pull – Fact or Fiction, ITS 2004, Miami, US.