A RISK PROFILE FOR ESCORTED TANKERS AND THEIR RESISTANCE TO COLLISION DAMAGE

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SUMMARY

Perhaps no vessel poses a greater potential risk for causing environmental damage than a laden tanker. However since the ***Exxon Valdez*** incident in 1989, significant changes have been made making tankers inherently safer, most notably the adoption of mandatory double-hull construction. Major advances in the field of tanker escort towing have created a new generation of purpose-designed, powerful tugs in this service. One can therefore state with confidence today that an escorted tanker, subject to a well-managed set of escort procedures, has an absolutely minimal risk of a cargo oil spill. Regardless of these safeguards, many political and environmental spokespersons cite the ***Exxon Valdez*** and similar incidents as reasons today for not permitting the passage of tankers through coastal waters. Much has been written about the resistance of double hull structures to collision, nevertheless there is a need to present this material in a way which is accessible to an interested public so as to help debate proceed on the basis of fact. This paper distils some of that data to a level which will contribute to informed debate. This includes an analysis of the speed and direction of impacts involving tankers which would be required to breach the inner cargo tanks. Work from Estonia, the United States, and Korea is examined demonstrating the worldwide interest in this topic. Using the example of the Port of Vancouver (Canada), the authors present the scenarios used locally for safe tanker operations, safely escorting tankers, and identify the potential risks and the associated potential for a cargo oil spill.

NOMENCLATURE

ASD	Azimuthing Stern Drive
AMSA	Australian Maritime Safety Authority
BP	Bollard Pull
BV	Bureau Veritas
CSR	Common Structural Rules
FPSO	Floating Storage, Production and Offloading
FSO	Floating Storage and Offloading
HPP	Harbour Practices and Procedures
HTS	Higher Tensile Steel
IACS	International Association of Classification Societies
km	kilometres
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LOA	Length Overall
MARPOL	International Convention for the Prevention of Pollution from Ships
MRA	Movement Restriction Area
OPA90	US Oil Pollution Prevention Act 1990
PSPC	Performance Standards for Protective Coating
VHF	Very High Frequency
VLCC	Very Large Crude Carrier

1. INTRODUCTION

Perhaps no vessel poses a greater potential risk for causing environmental damage than a laden tanker. However since the ***Exxon Valdez*** incident in 1989, dramatic and significant changes have been made to make tankers inherently safer, most notably the adoption of mandatory double-hull construction. The phase-out of single hull tankers now means that the vast majority of the world's oil-carrying fleet is double hull. Only some single hull storage solutions remain. Concurrently, major advances in the field of tanker escort towing have created a new generation of purpose-designed, powerful tugs for this important service. One can therefore state with confidence today that a tanker under the watch of properly designed escort tugs, and subject to a well-managed set of escort procedures has an absolutely minimal risk of a cargo oil spill. Regardless of these safeguards, many uninformed political and environmental spokespersons continue to cite the almost thirty year old ***Exxon Valdez*** and similar incidents as reasons today for not permitting the passage of tankers through coastal waters. Much has been written about the resistance of double hull structures to collision, nevertheless there is a need to present this material in a way which is accessible to an interested public so as to help informed debate proceed on the basis of fact and not hysteria. The use of escort tugs for safeguarding tankers is a topic not at all well understood by the general public and also not always properly understood by many within the marine industry itself. The advances made in this technology are dramatic in the years since the introduction of OPA'90, and tugs which incorporate the best available technology in this field have the capability to provide an incredibly high level of safety and operational redundancy to a transiting tanker, when properly deployed and when used with trained crews at all levels of involvement. This paper sets out with the objective of presenting the current state of the art in both these critical areas of ship design in a manner which can readily be understood by those interested in the facts and science of these important aspects of safe tanker operations.

2. RISK MITIGATION IN TANKER MOVEMENTS

2.1 RISK MITIGATION FACTORS

Oil spills from a tanker, though extremely rare, can occur in any of several possible ways; it could suffer an engine or steering system failure and then run aground and rupture the inner cargo tanks; it could suffer a structural failure in heavy seas; it could be involved in a collision with another ship resulting in ruptured cargo tanks, or human error could cause a navigational error resulting in a grounding. The probability of any such incidents is extremely low, but can never reach zero. More probably an error in a loading or cargo transfer operation could result in a spill at a terminal. An incident in the open sea cannot be protected against other than through diligence and vigilance in vessel maintenance and operations. However on the positive side, if a mechanical failure does occur deep sea then there is ample time to either execute repairs or to call for a capable towing vessel to assist. Time is on the right side of the equation in such cases. However once a tanker enters coastal waters time becomes the enemy, and any disabling event has the potential to result in a grounding and become a potential spill if suitable safeguards are not in place. The obvious safeguards to minimize grounding and associated pollution risks, in order of importance, are:

a) Safe Routing:

Allow tankers to operate only on those routes which provide a maximum sensible distance from shore, so that a known available response capability such as a rescue tug can respond to a breakdown and be on site well before grounding might occur. The "safe offset distance" for tanker routing can be readily calculated by conducting a relatively straightforward drift analysis which calculates the time it would take a drifting tanker under a defined set of environmental and tidal conditions to reach a set boundary line (NOT the shoreline, but say 1 to 2 km off the coast). That is then the maximum allowable response time for a rescue towing vessel to reach the ship and get connected to take the ship under tow. Such drift analyses also clearly help to define where rescue towing assets can be most strategically deployed.

b) Operating Procedures:

Responsible port management will put in place controls over all shipping within the area in which a tanker will operate. This should include ship traffic controls and priorities, restrictions on movement conditions, speed controls, use of pilot vessels, the use of qualified pilots, restrictions on time of movements where tidal influences may be strong, and the use of capable escort-rated tugboats.

c) Tug Escorts:

In areas where there is not sufficient sea room or response time to prevent a disabled ship from grounding under typical ambient conditions, a tethered escort tug must be used to continuously be ready to act as the backup steering and braking device for the tanker. In those locations where there is sufficient sea room the tug may not necessarily have to be tethered, but the time then taken for connecting results in far greater off-track ship movement. Careful analysis of all the potential failures and associated escort scenarios must be done to ensure the correct tug force generating capability is specified.

d) Escort Procedures:

Because disabling events aboard modern tankers are relatively rare, the use of an escort tug to steer and brake the ship must be practised routinely such that the reactions of the ship and tug crews are instinctive if and when a real incident does occur. Tug Masters must understand in which instances it might be better to assist a turn rather than oppose it. They must also be acutely aware of the limits of safe operation for the tug itself.

e) Spill Response Capability:

As unfortunately no set of precautions can assure 100% risk reduction, one must ultimately be prepared to respond to a spill incident. This is more likely to occur due to human error than to a mechanical/structural breakdown of a tanker. In either case however it requires providing the equipment, response organizations and associated protocols, and the trained personnel to operate the equipment in the worst foreseeable conditions. Assets must be deployed in positions of maximum strategic benefit.

2.2 TANKER CONSTRUCTION

The physical cross section of a modern double hull oil tanker is largely defined by the requirements of both OPA 90 [1] and MARPOL [2]. OPA 90 sprang from the grounding of the ***Exxon Valdez***, a single hull VLCC, in Prince William Sound, Alaska in March 1989. The consequences of this accident, aside from the pollution, were long lasting changes to the design of oil tankers, principally increased protection of the cargo space by the introduction of a void space surrounding the cargo area. When the ship is light, in ballast without cargo, this space is used for ballast water so as to maintain a safe draft and allow the ship to operate efficiently.

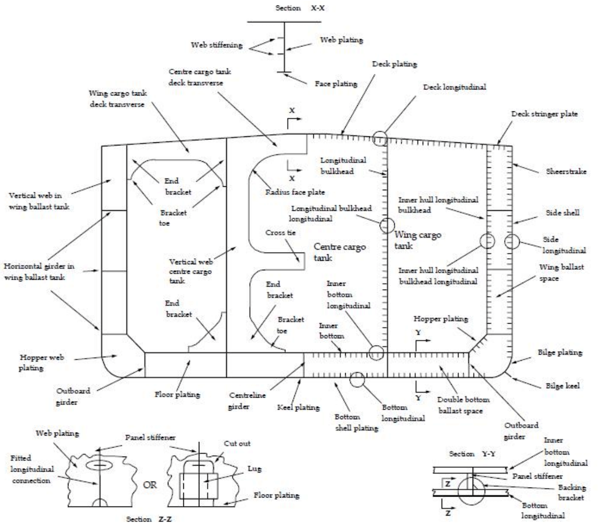


Figure 1: Typical double hull oil tanker midship section (source IACS)

Figure 2: Double hull tanker under construction

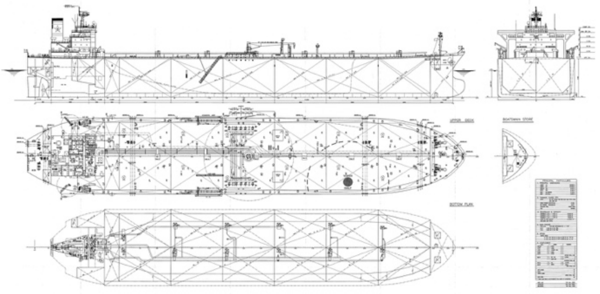


Figure 3: Typical general arrangement for a double hull tanker

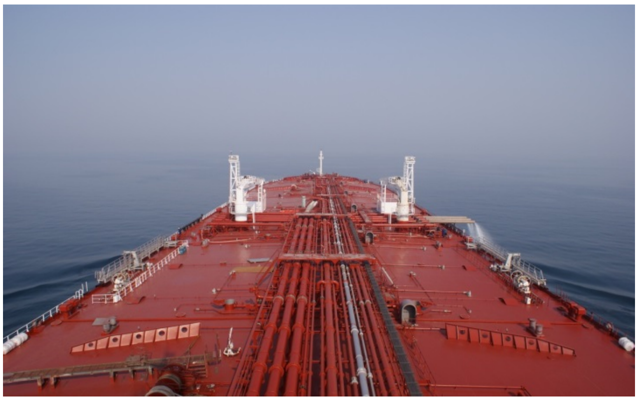


Figure 4: Typical view over fore deck of a double hull tanker, line of double side is about 2.5 m in from ships' sides, beam about 48 m

Figure 5: Typical oil tanker double bottom internals, about 2.5 m height

The effectiveness of double hull tankers in reducing the risk of pollution was heavily debated during the development of both OPA 90 and the MARPOL double hull amendments. The basic rationale used to support double hull requirements at both the federal and international level is that double hulls reduce the risk of oil spills that occur during a low energy grounding or collision. Because most accidents occurring in or near ports typically involve lower vessel speeds, and because the risk of grounding or collision is typically highest in port areas, double hull tanker designs offer a very reasonable option for reducing oil spill risks under these circumstances ([3] Elise DeCola, 2010).

A typical oil tanker of the type that might be seen to be loading at the Kinder Morgan terminal in Vancouver will have a double hull width of at least 2 m; that is 2 m at the side and 2 m at the bottom. The minimum, regardless of ship size, is 1 m for double hull and double bottom protection of cargo tanks. The minimum MARPOL requirement for double hull side width and bottom height is almost invariably exceeded in practise because of the need to carry adequate ballast in the double hull spaces.

2.3 TUG ESCORTS IN CONFINED WATERWAYS

The legislated use of tugboats as tanker escorts really began with the introduction of OPA 90 in the USA. Shortly thereafter many jurisdictions enacted similar legislation. However at that time the tug world really did not have a full appreciation of what was involved in tasking tugs to provide steering and braking capability of the magnitudes required to control large tankers at speeds of up to 10 knots. The topic was discussed at length at many International Tug Conferences. There was no shortage of those who stated that this simply could not be done. An example of just such a claim was from Ken Ross [4], at the time a senior executive in a major international towing company who stated emphatically; *"... the real crux of the problem ...is that in reality undue reliance is being placed on the escort tug to provide a cure-all.... such reliance is absolute pie-in-the-sky and will depend more on luck than good judgment and management.*" He went on to say; *"...there is virtually unanimous opinion that the tug which can always be relied upon to bale a runaway or disabled ship out of trouble does not exist.*"

Captain Ross' comments might still be accurate if the state of tug design had not evolved rapidly to accept head-on the challenge of safe tanker escort. Extensive private testing and research into better hull forms for escorting, and the associated generation of higher escort steering and braking forces while still ensuring tug safety certainly did take place over the ensuing years. Much of that work has been well documented in the proceedings of the International Tug & Salvage conferences, including extensive work by the Author's company. Important references in this context also include papers by Banks [5], Laible & Gray [6], Amundsen and Rokstad [7], and Allan and Molyneux [8].

The result of this work is a new generation of highly capable and efficient escort tugs, designed exclusively for this challenging work, and able to work safely in the "indirect mode" under high lateral forces without fear of capsize or girting. The use of sponsoned hulls such as the ***RAstar*** form developed by Robert Allan Ltd. in the mid-90's (Figure 6) enables these tugs to operate at heel angles of 12° to 15° with higher initial stability than they possess in the normal upright condition.

Figure 6: ***RAstar*** sponsoned hull form initiated with VSP escort tug – ***Ajax***

The use of properly-designed escort tugs in restricted waters thus offers the capability of providing emergency steering and braking capacity equal to that of the ship itself, in effect bringing a full degree of redundancy to the ship propulsion and steering systems in the event of a breakdown in critical areas. Ideally computer simulations should be conducted which define the vector forces to be applied by an escort tug in order to affect a "save" of a disabled ship within pre-determined constraints in the channels to be navigated. These forces may be greater than those which the ship itself could generate, particularly in very narrow channels.

2.4 CONTROLLED SHIP MOVEMENTS IN RESTRICTED AREAS

Most jurisdictions today have in place strict protocols around the movement of tankers, or indeed for any vessels carrying dangerous goods. The controls required vary naturally according to the individual port or terminal, but will generally include the following:

- Limitations on other vessel movements during tanker moves
- Speed controls on all ship movements
- Use of "pilot" vessels ahead of tankers to warn other vessel operators (especially small craft operators)
- Use of one or more qualified Pilots aboard the tanker
- Definition of shipping lanes for inbound and outbound traffic
- Defined use of properly rated escort tugs, with specified tug performance and tug deployment configurations
- Agreed communication protocols

2.5 TRAINED CREWS

All the best equipment in the world will neither prevent an accident nor facilitate a recovery if the persons involved in all aspects of the operation are not fully trained to deal with all foreseeable scenarios. Tanker rescue towing and indeed oil spill recovery are "firehall" scenarios; one hopes that these services will never be required but as long as there is some small potential for an incident the crews aboard these vessels must be fully trained to respond. Tanker escorts are in a different category: these are activities that take place regularly, thus providing the opportunity for the tanker crew, pilots and tug operators to conduct simulations of steering or propulsion failures and learn the best tactics to follow in response to each. They also learn the inter-dependencies of the actions by all these parties. These exercises make all involved aware of the expected response of the ship to the tug actions, and thus they know what can be expected should a real incident occur. Tug crews in particular must be ready to act at a moment's notice, and the response actions must be second nature to them. Such familiarity is only possible with: (a) proper training to understand the limits of the capability of the tug (b) training in the range of escort response strategies available, and then (c) conducting regular exercises and establishing clear communication protocols for all the potential scenarios to identify any sensitive areas of operation.

3. DOUBLE HULL STRUCTURES

Work looking at the collision resistance of ship structures is generally recognised as having been started by Minorsky [9] in 1959. This early work of course took no account of double hull tanker structures as these remained still to be invented. More recent studies related to the design technology of ship structures against collision and grounding have been reviewed by J.K. Paik [10] who has worked extensively in the field of damage resistance of ship structures. A brief review of key work in the field follows, there is certainly a lot that has been done.

Arita (1986) [11] carried out theoretical, numerical and experimental studies on the structural crashworthiness of nuclear powered vessels, LNG carriers and double hull tankers in collision. A theoretical approach to predict the energy absorption capability of the colliding and collided vessel structures was proposed and explored.

Kierkegaard (1993) [12] developed an analytical method for analysis of the internal collision mechanics of the bow structure in a head-on collision with icebergs or other objects.

Wang (1995) [13] obtained a simplified theoretical approach for predicting the damage of vessels in a head-on collision or in raking. A variety of failure modes were considered in Wang's work.

Lee (1997) [14] developed a theoretical formulation for estimating the damage of tanker structures in grounding with a forward speed or in stranding at standstill. The Lee method is formulated in closed form, and takes into account the vertical crushing caused by ship rigid body motions as well as horizontal raking (i.e. cutting) caused by the forward movement of vessel.

Simonsen (1997) [15] developed a mathematical model for predicting the loads and hull girder response of vessels in grounding on a soft sea bed or on a rock pinnacle. Simonsen's contribution is of value to the structural design of fast vessels against collision and grounding.

Chung and Paik (1997) [16] developed a theoretical approach for analyzing the damage and crushing strength of a ship's bow in a head-on collision. A series of crushing tests under quasi-static and dynamic loading were carried out on thin-walled square tubes with axial and/or circumferential stiffeners, and also on unstiffened specimen. More recently, Zhang (1999) [17] presented a comprehensive set of simplified formulations for the analysis of structural damage in ship collisions and grounding.

Further work was developed by Alan Brown [18] et al. examining structural response to collision and grounding and is particularly important to the current debate in western Canada because the size of ships examined is broadly in line with the types of ships that operate in the Salish Sea and Vancouver Harbour. Additional work carried out by Pollution Prevention & Control (POP&C) at Herbert Engineering in 2004 to 2006 [19] focused on Aframax tonnage and this is absolutely directly applicable to Salish Sea energy transportation. Work in the field has been brought up to date by Heinvee and Tabri [20] in Estonia in 2017. In addition Paik [21] has continued to work in this area and has published extensively including structural crash worthiness.

At its simplest the behaviour of ships' structures in a collision, a ship on ship impact, is best described in energy terms. Most of the discussion here will consider a bow from a striking vessel hitting the side of a struck vessel. Other collision types are possible, such as bow to bow (head on) or bow to stern in a failed overtaking manoeuvre or bow to accommodation (see Figure 7).

Figure 7: Accommodation damage from bow impact (RNLI)

However these scenarios are much less likely to result in penetration of the cargo space with consequent loss of oil than a bow to side collision. When the bow of a colliding vessel strikes the side structure of a collided vessel, the initial kinetic energy may be consumed in many ways. Part of the kinetic energy will be dissipated by damage of the colliding and the collided vessel structures, while the rest of the kinetic energy will remain in the form of various movements of the vessels together with the surrounding water.

4. PENETRATION LEVELS

Various technical efforts have been made to establish penetration distances after collision and grounding and some of those will be discussed here.

Sandia Report (Ammerman, 2002) [22], Sandia had previously conducted sophisticated finite element modeling of collisions of a series of ships with a double-hulled oil tanker similar in overall size, mass, and design to an LNG vessel. A summary of the analysis of a 90° collision of a large container ship (50,000 metric tonne class ship) and a double-hull tanker (80,000 metric tonne class) is shown in Figure 8 and collisions with smaller ships are shown in Figure 9 (Ammerman, 2002). The analysis tool included an approximately 250,000 finite element model of both the impacting vessel and the double-hulled tanker using PRONTO-3D run on a massively parallel computer with 256 processors. This is a transient dynamic, explicitly integrated, Lagrangian solver of the equations of motion. The analysis tracked the progressive failure of the struck ship as the striking ship penetrated. As noted in these figures, breaching of the inner hull does not occur until impact velocities exceed approximately 5 to 6 knots for large vessels. For small vessels, such as pleasure craft, kinetic energy is approximately one to two million N·m. Figure 9 shows that this level of kinetic energy is generally insufficient to penetrate the inner hull of a double-hulled vessel such as an LNG ship.

This analysis also calculated that penetration into a double-hulled tanker must be approximately three metres before a hole occurs in the inner hull. This, therefore, can be used to estimate the minimum size of an opening in the outer hull to likely cause a penetration in the inner hull and a spill in a grounding or collision event. The results for this analysis were compared with initial collision information from the ***Baltic Carrier*** collision in 2001 at approximately 12 knots. The results of these analyses over-predict, by about 15%, the external hole size measured for that collision. ***Baltic Carrier*** had adeadweight of about 37,000 tonnes, significantly smaller than an Aframax tanker and with a correspondingly reduced side protection.

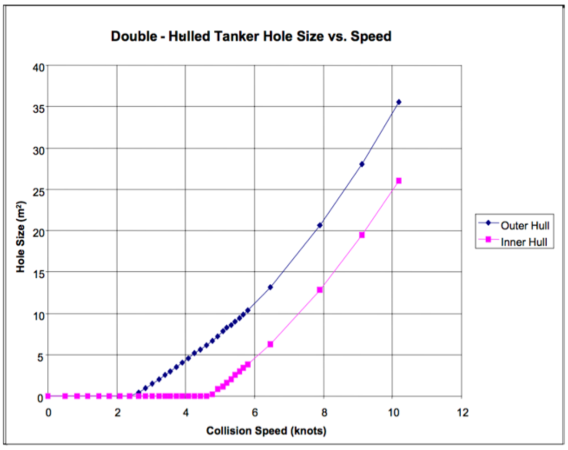


Figure 8: Study estimate of speed required to create a given hole size

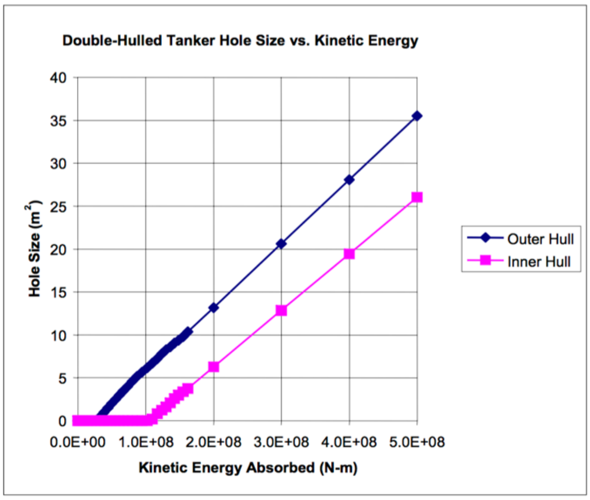


Figure 9: Double-hull tanker study of energy required to create a given hole size

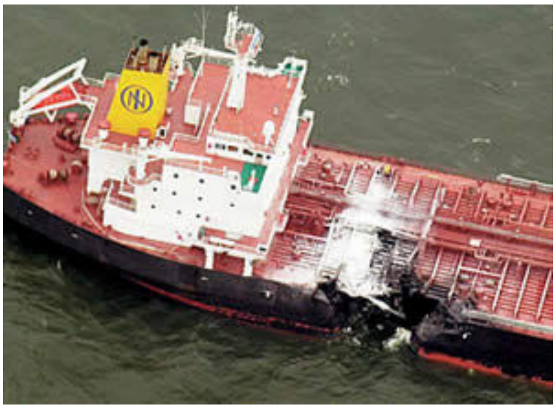


Figure 10: ***Baltic Carrier*** after collision, 2001 (photo ITOPF)

An additional element to consider in the accident scenario is that the hole size developed probably is not the size of the spill orifice. In many collisions between two ships, the ships can remain joined for several hours if significant penetration of one ship occurs. The analysis by Ammerman suggests that as little as 5 to 10% of the generated breach size is available for leakage. Therefore, the collision of a large ship with an oil tanker at even 12 knots is expected to produce an effective hole area of no more than approximately one square metre for an oil spill. If larger spills do occur, hole sizes could approach those calculated for intentional breaches. Grounding and terrorist attacks, for example, could produce holes that are effectively larger than in collision as the there is no ship to plug the opening in the initial stages. Analysis suggests that, in most cases, an intentional breaching scenario would not cause, in the case of LNG, an LNG tank breach of more than 5 to 7 m^2.

Table 1: Estimated LNG ship damage from potential tank breaches and spills

Breach Event	**Breach Size**	**Tanks Breached**	**Ship Damage**
Accidental collision with small vessel	None	None	Minor[b]
Accidental collision with large vessel	5-12 m^2 (Spill area 0.5-1 m^2)[a]	1	Moderate[c]
Accidental grounding	None	None	Minor
Intentional breach	0.5 m^2	1	Minor
Intentional breach	2 m^2	1	Moderate
Intentional breach	2 m^2	3	Moderate
Intentional breach	12 m^2	1	Severe[d]
Intentional breach	5 m^2	2	Severe

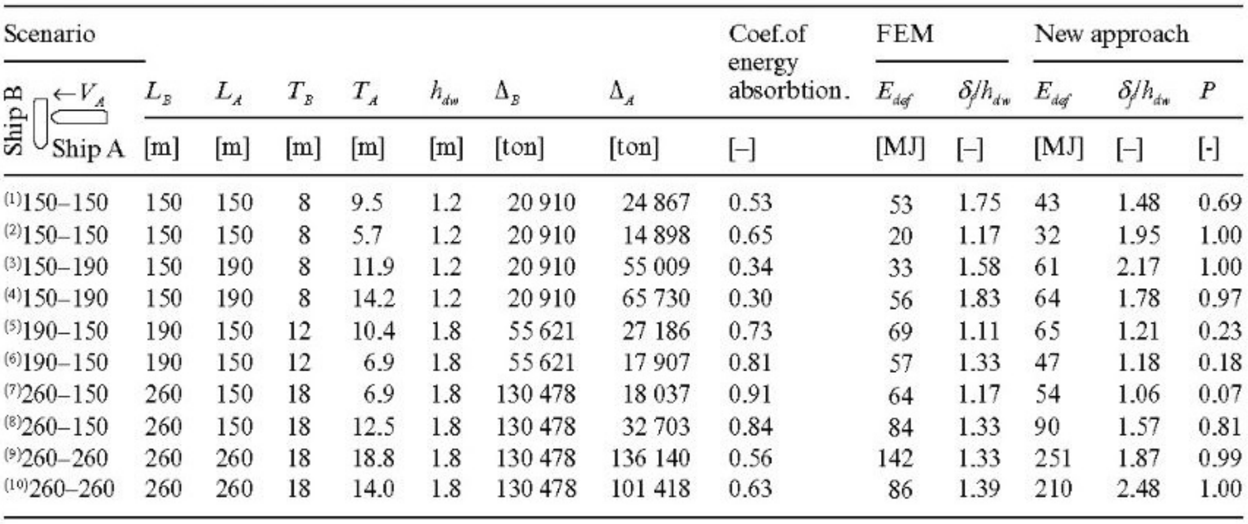
Notes:

a: Assumes vessels remain joined during spill event and breach is mostly plugged.
b: "Minor" suggests ship can be moved and unloaded safely.
c: "Moderate" suggests damage that might impact vessel and cargo integrity.
d: "Severe" suggests significant structural damage. Ship might not be able to be moved without significant difficulty and includes potential for cascading damage to other tanks. Cascading events are unlikely in oil spills, these can occur in LNGC because of the cryogenic temperatures involved and the effect on steel.

In LNGC the potential exists for progressive structural damage due to cold shock from the cryogenic liquid on the structural steel of the ship. The extent of the damage will depend on the volume and rate of LNG spilled and the ship areas that will be directly contacted by the liquid LNG. Such damage happens very quickly. Oil tankers are far less prone to cascading damage than LNGC since there is no mechanism for imparting sudden thermal shock to the structure. Based on the postulated breach events, attempts were made to estimate the potential level for ship damage from both accidental and intentional events. These are presented in Table 1 above. The conclusion from this table has to be that mitigating measures are required including tugs, VTS, collision avoidance and navigation since a double hull alone is not enough to prevent tank breaches, rather the double hull and escort towing and the other mitigation measures must work together to provide a virtuous circle of protection.

Heinvee and Tabri (2017), more recent work has been carried out by Heinvee and Tabri [20].This is interesting as it tries to take limited parameters such as length and displacement and then develop criteria to determine whether or not the inner hull of a double hull tanker ruptures in a collision. Part of the interest in the paper is to examine the impact of higher tensile steel on collision resistance. Contemporary ship designs are seeing increasing use of higher tensile steels. Increasing yield strength gives higher deformation energy however the consequence of using HTS is that plate is thinner, naturally. On the whole the yield strength does not have an impact on collision resistance, the effect is largely neutral. In principle this allows for ready comparison to be made between older pre CSR DH tankers and more modern tankers where HTS is being used in a much higher percentage than in the older ships.

Table 2: Results (striking ship velocity v_A 2.5 m/s, 4.9 knots) comparing FEM analysis with Heinvee and Tabri's new approach



Scenario								Coef.of energy absorbtion.	FEM		New approach		
Ship B ←V_A Ship A	L_B	L_A	T_B	T_A	h_{dw}	Δ_B	Δ_A		E_{def}	δ_f/h_{dw}	E_{def}	δ_f/h_{dw}	P
	[m]	[m]	[m]	[m]	[m]	[ton]	[ton]	[–]	[MJ]	[–]	[MJ]	[–]	[-]
(1)150–150	150	150	8	9.5	1.2	20 910	24 867	0.53	53	1.75	43	1.48	0.69
(2)150–150	150	150	8	5.7	1.2	20 910	14 898	0.65	20	1.17	32	1.95	1.00
(3)150–190	150	190	8	11.9	1.2	20 910	55 009	0.34	33	1.58	61	2.17	1.00
(4)150–190	150	190	8	14.2	1.2	20 910	65 730	0.30	56	1.83	64	1.78	0.97
(5)190–150	190	150	12	10.4	1.8	55 621	27 186	0.73	69	1.11	65	1.21	0.23
(6)190–150	190	150	12	6.9	1.8	55 621	17 907	0.81	57	1.33	47	1.18	0.18
(7)260–150	260	150	18	6.9	1.8	130 478	18 037	0.91	64	1.17	54	1.06	0.07
(8)260–150	260	150	18	12.5	1.8	130 478	32 703	0.84	84	1.33	90	1.57	0.81
(9)260–260	260	260	18	18.8	1.8	130 478	136 140	0.56	142	1.33	251	1.87	0.99
(10)260–260	260	260	18	14.0	1.8	130 478	101 418	0.63	86	1.39	210	2.48	1.00

Striking velocity is taken as 10 m/s in the numerical simulations which is about 19.5 knots. This is conservatively high for the confined waters of harbour approaches and some pilotage areas where speed controls can be expected. Salish Sea pilotage areas are considering reductions to 17 knots for large container ships and further reductions in congested areas according to the December 2016 Salish Sea Oil Spill Risk Mitigation Workshop held in Washington State.

In the four step process developed in Heinvee and Tabri's paper a model speed of 2.5 m/s is used, (Table 2), or about 5 knots which is below the maximum speed for pilot boarding in Puget Sound, Washington State according to the Puget Sound Harbor Safety Committee. The model can however take any speed and this would be useful for further investigation. The model would benefit from some more contemporary double hull models, for example there is no lower sloping hopper plate in the struck/striking ship model, the double hull itself is less than 2 m wide and the hull itself is rather slender; breadth to depth is 1.4 whereas more modern designs with a similar length to the T260 in the first column in Table 2 have B:D of about 2.2 with a double hull width of 2.7 m.

Some explanation of Table 2 will be helpful: ∂_f/h_w is penetration depth over double hull width; where this is greater than 1, penetration of the inner hull has taken place. Given the constraints imposed by the model type, slenderness and narrowness of double hull, then it is to be expected that running the model with more representative figures will show that the double hull can resist low speed collisions where the striking ship is up to 260 m long and striking at right angles. Other angles, relevant for passing ships should be examined.

Traditionally modelling has included a bulbous bow on the striking ship. Contemporary designs of bulk carriers, tankers and to a lesser extent LNGC feature a much reduced bulb and this is likely beneficial for impact.
POP&C (Pollution Prevention and Control) (Herbert Software Solutions, 2006) [19], this European Commission study which ran from 2004 to 2006 looked at survivability performance of medium-sized oil tankers and at the time of writing needed to be based on historical data dominated by single hull vessels. The database consisted of events such as collisions, contacts, groundings, fires and explosions. The study does show that medium size tankers have a high rate of survivability following loss of watertight integrity and this is known to be true intuitively. Where a fire occurs then there is a high probability of serious consequences and it can be seen that this is supported by the recent collision off Shanghai of the tanker ***Sanchi*** and bulk carrier ***CF Crystal***.

Of more interest is the commentary around outflow following collision. Among other things the report notes that Aframax tankers have a high rate of survivability following loss of watertight integrity and this accords with experience. The investigation performed case studies and compared historical data with analysis. Given that the historical database for this analysis stopped in 2003 it is high time that this study was updated. Interestingly though for all collisions/allisions examined there is a 0.68 probability of zero outflow, or conversely a 0.32 probability of some outflow. It can also be seen from the statistics presented in the report that double side or double hull significantly reduces the outflow/capacity ratio in any incident.

Some discussion of oil outflow is appropriate here where damage spans the waterline. In this case all oil in the damaged tank, provided it is lighter than water will eventually be lost. For the case where damage is all above the waterline then oil will flow out to the bottom of the damage. With damage entirely below the waterline this can be modelled simply, as outflow will continue until hydrostatic balance is reached.

5. ALLISION AND GROUNDING

Figure 11: Sideshell damage to moored tanker (allision), note inner hull remains intact

While most of the focus is on collision there are also incidences of allision where, for example, moored ships can be contacted by passing traffic or a ship can contact a bridge. There is a risk of a spill in both allision and grounding and these incidents should not be overlooked. For the case of the moored ship being the struck ship there is probably less likelihood of a spill than for an open sea collision. First of all, passing speeds are likely to be low and fully laden ships do not remain alongside so any accident is likely to involve a partly laden tanker.
The POP&C report [19] also discusses grounding and looks at the probability of zero outflow for a grounding incident. Here the probability of zero outflow is 0.42 however it also has to be said that all the ships that grounded and had greater than zero outflow were single hull. In bottom damage oil is constrained from flowing out by seawater hydrostatic pressure. There is also an element of dynamics at play in grounding and a high speed grounding can be expected to release oil immediately if the double hull is penetrated. Modern tanker designs have all oil tanks protected by void spaces, including bunker and service tanks in the machinery space, an additional environmental enhancement that was not fully considered by the authors of the POP&C report.

The report also discusses the development of a survival probability index, the greater the number the more survivable is the particular tanker design. Tankers with double bottom only fare particularly badly confirming the need for a full double hull where grounding and collision are possibilities. Conversely FSO/FPSOs could be built with a double side only where there is no possibility of a grounding while loaded.

Reference [18], Brown et al's 2000 work, notes that the further from the centreline of the ship that a rock is contacted the greater the damage, a function of relative motion. This can be directly translated into ensuring that navigable channels have adequate breadth and that survey lines are tight to avoid missing erratic rocks.

In the same work it was demonstrated that tank spacing and bulkhead characteristics have little effect on damage results whereas thickness of outer bottom plate did have an impact. Contemporary rule-based construction for oil tankers adds a corrosion margin to the design and together with PSPC requirements it can be expected that later double hull designs have an increased resistance to grounding damage simply by design, an unintended, though welcome side effect.

Further investigation of midship section enhancements showed that fitting two additional girders in the double bottom did have a marked effect on grounding resistance. This though comes at a steelweight penalty and a recent survey of a 120 ship tanker sample showed only four ships to have been fitted with additional girders.

6. TYPES AND CAPABILITIES OF MODERN ESCORT TUGS

In the early 1990's, as the concept of a true escort tug was just beginning to evolve, the use of Voith Schneider cycloidal propulsion was considered to be the "Best Available Technology" (B.A.T.) for escort tugs, and in many respects was considered to be almost the only available choice of propulsion. Owners however were seeking more flexibility in these large and relatively expensive tugs, and the use of Z-drive propellers in the "azimuthing stern-drive" (ASD) configuration was considered highly desirable in not only offering a higher unit thrust/kW but representing a configuration of tug which was more suited to other tasks such as long-distance towing or even anchor-handling in the event that an escort contract was terminated. Unfortunately the earliest generation of ASD escort tugs were not at all well-suited to escort service. Figure 12 from Aarts [23] shows an example of a typical ASD terminal tug of this era. While these were considered very good general towing and ship-assist tugs, they were not well-suited to the role of tanker escort. In fairness, these were not conceived to be so, but tugs of the same general configuration, only larger, were used in the early to mid-90's for tanker escort. They lacked any high-lift skeg to generate hydrodynamic forces; their aft-biased skeg, fitted for general course stability, was a significant hindrance to effective escort and the towing point was much higher than desirable for this service. Many of these "conventional" tugs also had stability characteristics much less and freeboard lower than necessary for safe escorting. The end result was that ASD tugs were by the late-90's deemed by many in the industry to be unsuitable for use as escort tugs. The rationale was incorrect; it was not the type of propulsion which was at fault but simply the wrong hull design being applied to the task.

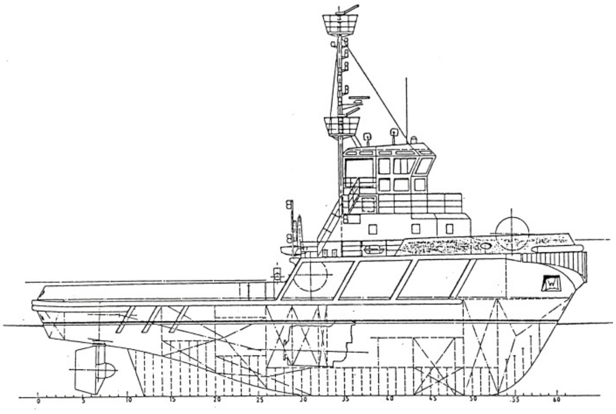


Figure 12: Typical ASD Terminal Tug circa 1990

Extensive research throughout the 90's by Robert Allan Ltd. gave rise to the use of much superior, sponsored hull forms for escort duty, for tugs with both VSP and Z-drive propulsion systems, namely the aforementioned ***RAstar*** hull form. The incorporation of large, high-lift, forward-biased skegs (previously unknown on ASD tugs) significantly increased the indirect force generating capability. Intelligent design increased freeboard and stability throughout the operating range for a new generation of ASD escort tugs which began to emerge in the late 90's, as illustrated in Figures 13 through 16. Most critically however, the early stigma attached to ASD escort tugs was erased and the latter have since become the norm in this field, with widespread acceptance internationally.

Figure 13: ***Z-Tech*** Class tug ***Indee*** indirect at 9 knots

Figure 14: ***RAstar 3400*** Class tug ***Svitzer Haven*** in heavy weather

Figure 15: ***RAstar 3900*** Class tug ***Svitzer Kilroom***

Figure 16: ***RAstar 4000DF*** Class dual fuel terminal escort tugs

Other hull form/drive configurations have also emerged latterly to fill needs in this market. The triple Z-drive Rotortug® has emerged as a powerful and effective option for tanker escort. After extensive evaluation and comparative simulations in studies for the proposed Northern Gateway Pipeline project in northern British Columbia a Rotortug® configuration was chosen as the best option for the route and conditions. The resulting design concept for the "***RAincoast*** Guardian" Class tugs (Figure 17) would have been the largest and most powerful escort tugs afloat anywhere. Political and environmental opposition however caused that project to be abandoned. The technical work which went into that design however has not been lost and is being applied to similar projects.

Figure 17: ***RAincoast Guardian*** Class escort tug concept for BC North Coast

Another significant development is the ***RAVE*** design concept for escort tugs. Based on observations made during various VSP tug tests, it was anticipated that using two VSP drives in an axial rather than in the typical side-by-side "tractor" configuration would provide better efficiency and higher escort performance. Collaboration ensued between Robert Allan Ltd. and Voith GmbH & Co. KGaA, including extensive CFD, simulation and model testing work to prove this unique concept. Although it is a very specialized configuration (Figure 18) the test results indicated very superior performance. The concept has also been adapted to more conventional ship-handling tug operations, and in early 2018 the first ***RAVE*** tug was delivered (Figure 19), also incorporating the patented Carrousel towline handling system [24]. While the latter mechanism is presently not sufficiently robust for large ship for escort service, the concept is certainly adaptable.

Figure 18: ***RAVE 3700*** Class escort tug

Figure 19: Carrousel ***RAVE*** tug on trials

As these new and much improved design concepts began to emerge, operators also began to examine and experiment with the most effective modes of tug operations for escort manoeuvres. The "science" of escort towing was gradually emerging and was being better understood. The forces involved in escorting are extremely speed dependent, and thus the mode of operation varies as the tanker speed increases. Obviously at zero speed a tug can only apply direct bollard pull, and up to about 5 knots a direct pulling mode produces the most net line pull. In the intermediate speed range however, say from 5 to 7 knots, ASD tugs can oppose their drive units and generate forces higher than direct thrust in the so-called "transverse arrest" mode. Finally, as speed increases to 8 knots and above tugs move into the "indirect" mode and use the hydrodynamic forces generated by the hull and appendages to produce forces which can frequently reach more than 1.50 x the bollard pull. The ability to achieve such high levels of line force is very dependent upon the stability characteristics of the tug however, and not all tugs are suitably designed to reach this level of performance.

Coupled with these design advances, there have been significant improvements and most thankfully some harmonization among Class Societies in the regulations associated with the stability of escort tugs, as attested to by de Jong [25]. The current basic regulatory requirements formally introduced in 2017 include the following:

- Establishing of service notations which distinguish the type and location of tug operations, with differing criteria for each
- Formalization of escort towing stability criteria based on righting energy, and accounting for all forces acting on the tug
- Accounting for the influence of the longitudinal separation of tow point and thrust point
- Acceptance for certification of valid escort simulations rather than a full-scale escort performance trial

- Formalization of the requirements for towing gear and the relative strength of each component of the towing system, and finally
- Specific mention of the requirements for adequate towing fittings on the attended ship

Of critical importance in the development of safer and more capable escort tugs is the development of hawser winches able to render and recover towline under high load, avoiding wave or manoeuvre-induced peak loads which might otherwise result in broken towlines. This reflects a significant change in philosophy for towline strength; in previous generations of tugs it was assumed that in the event of a tow getting into trouble, or indeed the tow putting the tug into trouble, the crew were given an axe with which to sever the towline, leaving the tow to its own fate! The futility of this regulated requirement can be attested to by many a tug girting in prior years, events which rarely if ever occurred in a controlled manner which would enable crew to deliver the required axe blows. Today's escort winches provide the ability to sustain defined line tension throughout a wide range of operating conditions at values which will not put the tug at risk of capsize, and which equally will not sever the connection between the tug and the attended tanker. If overloaded the winch simply lets line out at a controlled rate and then recovers to the desired length when tension is reduced. Of course the associated advances in high-strength towline technology have accompanied the improvements in winch design, and designers should be paying attention to the tug fittings required to take maximum advantage of new rope technology, as well as methods for coping with the high heat which can be generated in these lines under tension. Figure 20 illustrates a cooling water spray system installed on the dual aperture staple of a modern escort tug. The "wide-A" format of this staple (lower aperture) also reduces the heeling moment under load.

Figure 20: Escort towing staple on ***TRAktor-V 3600*** Class tugs

In summary, it is more than fair to state that the design of modern tanker escort tugs have evolved rapidly and significantly over the past 20 to 25 years to the point that the powerful machines available today represent the single greatest safeguard available to prevent a tanker mishap in confined waterways, when used within a properly planned and tested tanker escort plan. Escort tugs should be selected which can provide at the very least lateral and braking forces equal to those which can be generated by the attended ship's rudder and by the propeller respectively, or if available, equivalent to the forces shown by simulation/analysis as necessary to affect a "save" of a disabled ship within the confines of the channels to be navigated.

7. A WORKING EXAMPLE

There exist around the world today many examples of tanker escort systems which match the requirements stated above. Unfortunately there are also many which do not! One of the best examples of a fully integrated escort system is one of the very earliest, namely the Alyeska tanker escort systems in place both in Prince William Sound, Alaska and in Puget Sound at the southern terminus of that shipping system in Washington State. As a closed system the tankers are dedicated to that route and hence tug masters, ship masters, pilots and all other interested parties participate in regular reviews and tests of the system.

In Canada the scene is quite different and several proposed major pipeline/terminal projects receive much misguided resistance. The Port of Vancouver, Canada's largest port, currently only exports a modest amount of oil, with about 40 to 50 tankers per year transiting the harbour and associated sensitive waterways until they reach the open Pacific, a total distance of about 140 n. miles. A major oil pipeline project currently approved for construction and terminating within the Port boundaries will increase that volume of traffic to about 400 tankers per year…more than one per day on average. This increase has many local and Provincial government officials and environmentalists alike ranting about the risk of oil spills within the harbour as well as on any portion of the British Columbia coastline. Unfortunately these opponents often cite incidents such as the ***Exxon Valdez*** spill as examples of why such volumes of shipping or indeed any oil shipping should occur along this beautiful and sensitive coastline. While it is not unreasonable to insist that the very highest standard of precaution must be taken, it is too often the case that the need for "world class oil recovery systems" are cited by politicians and bureaucrats alike as the solution rather than placing an emphasis on preventing a spill in the first place. The facts of double-hulled tankers and the importance of escort tugs in this preventative role are rarely mentioned and certainly are much less understood. A review of the proposed operational guidelines and constraints follows with an assessment of its compliance with best practises.

Figure 21 illustrates the proposed voyage from tidewater to the open Pacific and the portions on which escort procedures will be in place.

Figure 21: Tanker escort route from Vancouver Harbour to open Pacific (source: https://www.transmountain.com)

The current "system" for safeguarding the Port of Vancouver waterways from potential pollution is defined within a document developed by the Vancouver Fraser Port Authority entitled "Harbour Practices and Procedures" (HPP). Section 8.13 of the HPP is the "Second Narrows Movement Restriction Area Procedures (MRA-2)", which includes the following most critical requirements for tanker movements within the "MRA" – (Movement Restriction Area). Figure 22 illustrates the MRA zone.

Figure 22: MRA-2 Zone in Vancouver Harbour

a) Transit Windows:

An MRA-2 Transit: is defined as a movement within MRA-2 that includes passing under the Second Narrows Iron Workers Memorial Bridge and the Second Narrows Railway Bridge. Transit windows are established on either side of high and low water slack tides and are based on predicted slack water or stemming a predicted limiting current of one or two knots.

b) Transit Restrictions:

The following specific transit restrictions and requirements apply:

- Tankers greater than LOA 185 metres and/or 40,000 Summer Deadweight (SDWT) and above are restricted to daylight transit of MRA-2 when in product
- Loaded tankers shall be trimmed to an even keel or by the stern and shall not be trimmed by the head.

c) Clear Narrows Restrictions:

The term "Clear Narrows" is defined as the transit of a vessel through MRA-2 unimpeded by any other vessel. MCTS will declare a "Clear Narrows" on VHF Channels 12 and 16 by means of a Sécurité call to ensure unimpeded transit of restricted vessels, examples being but not limited to:

- A vessel with LOA 230 metres and above and/or a moulded breadth of 35 metres or above
- A Tier 1 vessel (tanker) in product

d) Speed Restrictions:

Tier 1 vessels shall transit or manoeuvre within MRA-2 at a safe speed not to exceed six knots through the water, except when safety of navigation requires otherwise.

MRA-2 PILOTAGE REQUIREMENTS

Pilotage requirements within VFPA jurisdiction are governed by the Pacific Pilotage Authority Regulations, Section 9 and 10:

- Tankers of 40,000 summer deadweight tonnage (SDWT) and above in product require two pilots for an MRA-2 transit. Both pilots shall remain on the bridge throughout the transit. Two new pilots will replace the two shifting pilots in English Bay or other agreed location
- MRA-2 vessels with LOA 230 metres and above and/or a moulded breadth of 35 metres and above require two pilots for an MRA-2 transit

MRA-2 VESSEL ASSIST TUG REQUIREMENTS

MRA-2 vessels when transiting MRA-2, must comply with the standards for tug requirements included in Table 3 or 4 as appropriate, which detail the number of tugs and bollard pull requirements, reasonably spread between tug hulls. In addition:

- All vessel assist tugs employed on piloted MRA-2 vessels transiting MRA-2 must be tethered tractor/ASD tugs
- Vessel assist tugs capable of generating more than 40 tonnes of bollard pull shall have an operational tension meter that the tug operator can easily read from the conning position

- All vessels which require tethered tugs for an MRA-2 transit shall have them tethered prior to entering MRA-2 and shall remain tethered until clear of the Second Narrows Bridges unless, for operational reasons, they are required to remain tethered beyond MRA-2
- Tankers of LOA of 185 metres and above in product and/or 40,000 tonnes SDWT and above in product require a minimum of two tugs that, when inbound must be tethered prior to transiting MRA-1 and when outbound shall remain tethered until clear (west) of MRA-1

An interrupted passage between Second Narrows and First Narrows bridges, for whatever reason, shall not reduce the minimum escort tug requirements for the transit. For escort and tethered tug requirements related to tankers of 40,000 SDWT and above in product outside of VFPA jurisdiction, reference shall also be made to the relevant Pacific Pilotage Authority Notices to Industry.

Table 3: Second Narrows MRA (MRA-2) transit procedures deep sea vessels – summary matrix

Tankers in Product

Vessel Type	Night Time Allowed	Tidal Current Opposing	Tidal Current Following	Tugs	Pilots	Tugs First Narrows
Tankers LOA < 185m < 40,000 SDWT	Yes	< 1.0k	< 0.5k	T	1	-
Tankers LOA > 185m > 40,000 SDWT	No	< 1.0k	< 0.5k	T	2	T

T = Tethered Tug Required

Table 4: Second Narrows MRA (MRA-2) deep sea vessel – tug and bollard pull requirements matrix

LOA less than 200 m and moulded breadth less than 35 m

Vessel Draft	No. of Tugs	Bollard Pull Tonnes	No. of Tugs	Bollard Pull Tonnes
	Bow		Stern	
< 8m	1	20	1	30
> 8m < 10m	1	30	1	40
> 10m	1	30	1	50

LOA 200 to 229.9 m and moulded breadth less than 35 m

Vessel Draft	No. of Tugs	Bollard Pull Tonnes	No. of Tugs	Bollard Pull Tonnes
	Bow		Stern	
< 8m	1	30	1	50
> 8m < 10m	1	60	1	65
> 10m < 12m	1 or 2	60	1	80
> 12m	1 or 2	60	1	110

LOA 230 to 250 m and moulded breadth less than 45 m

Vessel Draft	No. of Tugs	Bollard Pull Tonnes	No. of Tugs	Bollard Pull Tonnes
	Bow		Stern	
< 10m	1 or 2	60	1 or 2	65
> 10m < 12m	1 or 2	60	1 or 2	80
> 12m	1 or 2	60	2	110

As well as the rule extract cited above, the HPP standard defines requirements for visibility, rights of way, shipping priorities, and numerous other logical safeguards for shipping.

So how does this comprehensive and very current (2017) standard measure up against the "state of the art" of tanker shipping safety? If one looks first at the overall procedures, they are quite thorough and reflect a great deal of input from many stakeholders. The results are generally empirical and reflect many years of experience from all sectors of the local maritime community. It reflects effectively what is known to work well, but is it enough in light of the heightened sensitivities omnipresent today re tanker shipping? Will the precautions called for stand the test of science?

Consider the escort tug requirements within the HPP:

- The requirements only call for tethered "Tractor/ASD tugs" defined erroneously as *"... a tug with either Z-drive (or azimuth thruster) or Azimuth Stern Drive (ASD) propulsion systems capable of generating all directional propulsions forces."* This definition confuses the type of drives used with the geometry of drive installation and

leaves no room for highly effective escort tugs with Voith-Schneider propellers or with novel propulsion geometry such as a Rotortug® or a ***RAVE*** tug. More accurate definitions are required
- No formal Class approved escort rating is stipulated; only the bollard pull, a value of little use at higher transit speeds. The line force which can be generated at the stipulated maximum transit speed of 6 knots is the operative performance parameter, and must be defined
- No stability requirements for the escort tugs are defined. Transport Canada is embarrassingly silent on this matter in their outdated regulations, not addressing the potential for externally applied forces on tugs whatsoever. This is a serious regulatory omission. The recently introduced international stability standard for tugs [26] should be invoked as a minimum requirement, without reference to any Canadian regulations as alternatives; there simply are no viable Canadian regulations for this type of vessel
- The HPP is silent on the type of winch and towline to be found on the escort tugs. The line strength must be commensurate with the duty, and the winch must be designed to sustain the required line force without use of the winch brake. This criteria is an integral part of all Class requirements for escort duty and is essential to the safety of the tug should a situation go awry. It is also vitally essential to the safety of the tanker because if the tug's towline breaks due to a sudden surge load, then the critical connection to the ship is lost. The "weak link" in any escort system must be the winch brake setting and not any structural component or the towline itself. Maintaining control over the tanker throughout any escort operation is of paramount importance. Again the new BV rules provide useful guidance.

Next, consider the defined transit speed of 6 knots:

- The HPP does not mention how this speed originated, but presumably it is a speed found by ship masters and the BC Coast Pilots themselves to be one that affords an appropriate degree of control over the ship and which also ensures that the ship can be accurately and safely controlled by attending tugs
- From a tug escort perspective this speed is rather "middle ground"; it is a bit fast for effective direct thrust operation, and too slow for effective use of the indirect mode. ASD type tugs are generally most efficient in transverse arrest mode at this speed

It can be seen from the previous discussions regarding tanker resistance to damage that controlling speed of both struck and striking ship can have a significant impact on the damage results. Angle of impact is critically important; it is unlikely that any double hull structure will resist a collision at full speed with angle of incidence of 90° without significant oil outflow. However it also virtually impossible within the geography of the Port of Vancouver, given the HPP requirements, that any ship of appreciable size could be operating at right angles to the primary tanker route.

Similarly for allision, reducing the speed of passing traffic will ensure that penetration of the double hull can be avoided.

The isolation of tanker traffic within Vancouver harbour limits is an extremely effective means of mitigating risk of collision. Coupled with the speed limits cited and the use of multiple escort tugs it is more than reasonable to conclude that a spill from a tanker within the harbour limits is almost impossible, if operated under current guidelines. In the outer reaches of the tanker passage to the open sea tanker escorts have been the norm for several years and are well-practised, and utilize well-found escort tugs. The proposed expansion of tanker traffic will result in the use of faster and larger rescue tugs (untethered) in the stretch of coast through Juan de Fuca Strait to off Cape Flattery. There is ample sea room in these waters such that tethered escorts are not necessary. One can therefore conclude that although slightly imperfect, the current procedures and plans will result in very safe transit of tankers through the Port of Vancouver and adjacent coastal waters.

It is noteworthy that other efforts are underway within BC to expand the understanding of all involved with respect to tanker escort operations. The Pacific Pilotage Authority has recently published a "Discussion Document on Escort/Rescue Tug Requirements on the West Coast of Canada" [27]. This is broader in scope than just port operations. It aims to address the potential for much expanded tanker operations and gas carrier operations on the west coast of Canada, and the need for suitably powered escort tugs and rescue tugs as a major mitigating factor against a grounding and potential oil spill. This is an important document however, as it clearly addresses the need for preventative measures rather than response measures as the single most effective way to prevent any oil spill. This report correctly starts out by basing projected tug force generation capability as a function of the attended ship size, speed and rudder angle. Such data is published by the Nautical Institute (Hensen [28]), but that study unfortunately refers to required Bollard Pull and does not correlate that to line forces required at the various speeds. The numbers will vary considerably as a function of the tug hull design and its stability characteristics. Any "brick" in the water can generate a stipulated BP, but only an extremely well-designed escort tug can safely develop and sustain line pulls comparable to or ideally greater than that same BP value at speeds of 10 knots.

8. SUMMARY

Since the almost global introduction of mandated tanker escort systems in the mid-90's, there have been very significant advancements in both the design and performance of escort tugboats. In addition during that same period there has been a general improvement within the towing and shipping industries in understanding how these powerful vessels can operate most efficiently. This includes better understanding of safer escort operations and the training and familiarization required by all personnel operating within the system to ensure the safest possible operations.

Tanker escort tugs today are large, powerful, very high performance tugboats. As they are generally purpose-designed for the demanding escort role they may not always be the best "multi-purpose" tug, however it is very common for escort tugs to be fully equipped for both fire-fighting and spill response. It is important to note however that the best escort tug may NOT be the best rescue tug, as the towing gear requirements and associated deck layouts are not the same and may not be entirely compatible. On larger tugs it is easier to fit both systems, but such large tugs may not be necessary. The requirements for both tasks must be carefully evaluated and then judgments made as to whether or not a single or different tug types are necessary for effective coastal protection.

It is likely that improvements in the resistance of double hull structures to collision, allision and grounding can be made by, for example, increasing the thickness of double bottom plating. However these structural additions would come at a price, heavier ships require more power or can carry a reduced cargo thereby increasing emissions per tonne carried and also costing more.

The studies reported on in this paper show that the current rules governing construction provide effective resistance to oil outflow but only in tandem with mitigating efforts such as speed reduction, avoidance of close quarters situations and the use of suitable well-designed escort tugs.

It should be noted that the referenced studies all broadly assume that the ship remains in its "as built" condition for its service life. There have been many studies on corrosion degradation of ships structures and while it would be relatively straightforward to model the impact on damage resistance of corrosion, by simply making the structure thinner, the authors of this paper are not aware of any explicit studies.

This leads to the inescapable conclusion that for the purposes of ensuring adequate resistance to oil outflow following impact of any type the hull structure must be maintained in a near "as new" condition. Fortunately the existence of the CAP (Condition Assessment Program) scheme, a voluntary scheme, although effectively almost mandatory, ensures that tankers over fifteen years old are maintained at, or very close to, the new build standard. In this respect it is concluded that oil tankers greater than fifteen years old trading into Vancouver harbour should be maintained to a standard of CAP2 or higher. While this is a voluntary standard and so cannot, under current arrangements, be enforced by Transport Canada, it can be enforced by terminals and charterers. The fifteen year cut off is important as experience tells us that corrosion is rarely significant until after fifteen and can be controlled effectively by the application of efficient coating repairs at Year 15 when the ship is in dock for routine dry docking.

An effective in-service inspection program operated by the ship owners themselves with regularly scheduled inspections by class and oversight from oil majors will ensure that structure remains effective throughout the life of a ship. The inspection routine can again be monitored by oil majors and flag state and it is known that some owners of conventional tankers have implemented a six monthly ballast tank inspection regime. Oilcos responsible for terminals can, and do, insist on seeing inspection records, both from Classification Societies and crew before granting terminal clearance and loading cargo. These audits are carried out each and every time a ship is to be cleared for cargo.

Based on the evidence available today, it is very clear that oil tanker movements can be made as safe as any type of shipping, reducing risk of spills to almost zero. This can be accomplished however ONLY by following a carefully developed Tanker Shipping Control Plan, which incorporates at least the following measures:

- Strict controls over all shipping in the vicinity of tanker movements to give priority and right of way to the tanker and their escorts
- Limits on the environmental conditions under which tanker movements can take place
- Limits on tanker movements to daylight hours and clear visibility conditions
- Limiting tanker speed to that at which any potential collision or allision (however unlikely) would not result in a breach of a cargo tank
- Analysis of the tug forces required to effect safe control over the ship (in terms of steering or braking in whatever is the most advantageous direction) at the limiting escort speed(s), OR as an absolute minimum, stipulating tug escort forces corresponding to those which could be generated by the size of tanker itself
- Use of properly certified escort tugboats which have:
  - the defined steering and braking force capability at the required speed
  - Class-approved stability certificates which correspond to the defined loads

  - towlines in good condition which have breaking strength ratings well above (minimum 3x) the rated line forces
  - hawser winches which can carry the rated line load on a "dynamic brake" rather than on a static or manual brake which cannot release in a controlled manner under load
- Use of properly trained personnel in every aspect of the escort operation
- A system which routinely practises all possible escort response strategies to ensure crew understanding and familiarization

9. CONCLUSION

There is undoubtedly sufficient good information in the technical arena to demonstrate clearly that double hull tanker structures themselves have adequate collision and grounding resistance but only in conjunction with other mitigating measures such as navigation, speed restrictions and escort towing. Some of the work would benefit from updating given the approximately twenty five years of double hull tanker operations, since the delivery of ***Eleo Maersk*** in 1993 and the increasingly high structural standards imposed by Classification Societies. Not only have structural standards increased but significant advances in escort tug design together with traffic management also contribute to high standards of tanker safety.

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