

## **NEW REGULATIONS FOR TOWING AND ANCHOR HANDLING VESSELS: THE FUTURE IS NOW**

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### **SYNOPSIS**

At the International Tug & Salvage Convention in 2010 (Vancouver) Bureau Veritas (BV) presented the first draft of the *Safety Guidelines for Design, Construction & Operation of Tugs*, which was developed in cooperation with Lloyd's Register of Shipping (LR) and the American Bureau of Shipping (ABS) under the umbrella of the SafeTug Joint Industry Project (JIP). Direct involvement of major stakeholders in the towing industry has proven to be vital to the successful realisation of the project. Following a period of industry feedback and further technical development the draft guidelines have been revised and extended by BV in order to arrive at a definitive document. Key items which have been further developed include towing stability, towing equipment, escort performance simulation and the operational interaction between the tug and the assisted ship. BV is now in the process of implementing the guidelines into the classification process for tugs.

In line with the recent technological and regulatory developments with regard to anchor handling, BV has also redeveloped the classification rules for anchor handling vessels, primarily focussing on intact stability during anchor handling and a holistic approach towards the assessment of anchor handling equipment in a similar way as has been done for the tugs. The rules are intended to improve operational safety and reliability by providing detailed guidance for taking into account the effect of the wire tension on the stability of anchor handling tugs and the deck equipment. Due to the comprehensive set-up the rules support and encourage the installation of reliable on-board decision support systems for the crew.

With the introduction of the new regulatory framework BV is setting future-proof standards for tugs and anchor handling vessels with regard to safety and reliability, taking into account innovative design solutions proposed by the industry.

### **INTRODUCTION**

Innovation is an integral feature of the towing industry. Continuously new designs and technological solutions are developed to improve the capability, safety, reliability and efficiency of tugs. As merchant ships have rapidly increased in size, the latest generation of harbour tugs effectively combines high bollard pull, good manoeuvrability and indirect towing/escorting capability. This is particularly necessary for assisting ultra large container ships, which feature large windage area and high minimum speed through the water (even at dead slow ahead), which pose significant operational and safety challenges to the tug and the crew.

For offshore terminal operations, a fast growing market due to the increasing capex in exposed oil and gas terminals, economic considerations require high deploy-ability of offshore terminal tugs in order to minimise operational downtime. As offshore terminal tugs perform assistance in more severe environmental conditions, including waves and current, and potentially in harsh environments (e.g. arctic), advanced designs have been developed and successfully deployed in operations. These designs typically feature high bollard pull and escort capability, as well as good manoeuvrability and seakeeping behaviour. To that end the towing equipment, in particular the winches and towlines, are designed according to high specifications. In addition, at offshore gas terminals special consideration is to be given to external fire-fighting equipment and gas safe operations (e.g. for emergency unberthing of gas carriers) of the tugs.

Also of interest is the diversification of tugs into multi-functional support vessels for the growing coastal engineering and renewable energy industries, such as offshore wind. New designs have been developed to perform towing/pushing, supply, installation and

maintenance support functions. Although bollard pull is usually not a major issue, the design and equipment have been adapted to effectively perform these tasks. Tugs are typically equipped with a special push bow, knuckle-boom crane(s) and/or deck equipment for shallow water anchor handling operations.

As fleet expansion and renewal are taking place around the globe, operators, designer and shipyards are facing challenges in coping with the wide variety of classification rules, flag state regulations and local government requirements, an issue which was most vocally expressed by Robert Allen in his 2006 ITS paper [1]. In response classification societies BV, LR and ABS have joined forces for the development of harmonised guidelines for the design and operation of tugs within the scope of the SafeTug II JIP, aiming to create a consolidated regulatory framework. The first draft was released and presented by BV at ITS 2010 in Vancouver [2]. On the basis of several rounds of industry review and feedback, involving leading tug operators, designers and shipyards, the guidelines have been further developed by BV. Major topics which have been revised and extended include towing stability, towing equipment and escort towage requirements. The guidelines are now being incorporated into the classification process.

In relation to the towing stability requirements BV has initiated a process of global harmonisation at IACS level, with a view to submitting a proposal to the International Maritime Organization (IMO) for inclusion into the International Code on Intact Stability (IS Code).

In the aftermath of the tragic accident with the anchor handling tug-supply (AHTS) vessel "Bourbon Dolphin" in 2007 much attention has been paid by the industry and regulators to operational safety, in particular with regard to intact stability during anchor handling and the characteristics of anchor handling equipment (e.g. emergency quick-release of anchor handling winches). In response to the accident the Norwegian Maritime Directorate (NMD) has issued guidelines on the implementation of specific measures to ensure a sufficient safety level during anchor handling operations carried out by supply ships or tugs and designers have developed a new generation of AHTS vessels with improved stability particulars and enhanced safety performance of anchor handling winches. Operators, designers and class societies have been working together to implement the NMD guidelines for both newbuildings as well as ships in service in order to determine the operational limits of the AHTS fleet. In addition, software makers have been keen to develop on-board decision support systems to facilitate safe operations, including on-board loading computers capable of direct anchor handling stability calculations.

In order to create an international regulatory framework covering anchor handling operations the IMO Sub-committee on Ship Design and Construction (SDC) has created an agenda item on anchor handling, which is addressed by the correspondence group tasked with proposing amendments to the IS Code (same as for towing mentioned above). Although the work is still in progress, important steps forward have been taken to make improve the practical implementation of the NMD guidelines on board.

Having in mind the progress at IMO level and drawing a parallel with the guidelines for the assessment of towing equipment for tugs, BV have redeveloped the classification rules for vessels engaged in anchor handling operations with a focus on intact stability and anchor handling equipment. To this end the service notation **anchor handling vessel** and associated technical requirements have been introduced in the Bureau Veritas Rules for the Classification of Steel Ships on 1 January 2014.

This paper provides an overview of the newly developed regulations for towing and anchor handling vessels together with their technical background and implications in terms of design and operation. Suggestions for further development of the regulations to further enhance safety, reliability are also provided. Furthermore, the latest status of the regulatory developments efforts at IACS and IMO level are highlighted.

## REVISED TUG GUIDELINES

The revised draft *Safety Guidelines for Design, Construction & Operation of Tugs* have been developed on the basis of industry feedback on the original draft. In fact, direct involvement of major stakeholders in the towing industry has proven to be vital to the successful realisation of the project. The main contributors to the discussion have been leading tug designers Robert Allan Ltd and Damen Shipyards. Valuable input was also provided from owner/operator perspective, in particular by Smit Lamnalco and Kotug.

The basic principles on which the draft guidelines were founded have been kept for the revised version. Throughout the document it has been attempted to adopt a pragmatic approach which is specific enough to create clear guidance for the design, construction and operation, while keeping maintaining an open mind towards the assessment of innovative technical solutions. The motto “one size fits all” is not a valid approach for the classification of tugs, which are characterised by a broad variation in assigned duties (or function) and operational profiles (or service) [2,3]. As differences between tugs can be very significant in terms of general arrangement design, hull lines, structural reinforcements, machinery and electrical systems, deck and towing equipment and safety systems, it is necessary to explicitly address these differences in the technical requirements, which effectively are a function of the selected class notation(s) which reflect the tug’s function and service. The main topics addressed on the basis of this approach are the definition of design loads for towing, escorting and pushing, stability requirements, towing equipment requirements and safety equipment requirements. The safety equipment requirements cover fire-safety, life saving appliances, radio installation, navigation equipment and anchor equipment for non-Convention tugs (< 500 grt). As SOLAS safety equipment requirements are not applicable to these small tugs, national requirements are to be applied instead. As these flag state requirements have not been harmonised and show a wide variation in technical requirements, the intent of the guidelines is to provide an alternative standard developed by class which can be proposed to the applicable flag state as a credible and adequate alternative standard. Acceptance of the standard would greatly facilitate the development of standardised tug designs [2].

The basic service notations introduced in the draft guidelines have been slightly amended to better reflect the performance characteristics:

- **harbour tug (Bollard Pull =  $[T_{BP}]$  kN,  $[T_{BP}/9.81]$  t)**, for tugs operating within port limits;
- **tug (Bollard Pull =  $[T_{BP}]$  kN,  $[T_{BP}/9.81]$  t)**, for tugs operating at sea;
- **escort tug (maximum steering force =  $[T_{Y,MAX}]$  kN,  $[T_{Y,MAX}/9.81]$  t; maximum braking force =  $[T_{X,MAX}]$  kN,  $[T_{X,MAX}/9.81]$  t; maximum escort speed =  $[V_{MAX}]$  kn)**, for tugs engaged in escorting.

The optional additional service feature **sailing time  $\leq 4$  h from safe sheltered anchorage**, which may be added to the class notations **tug** and **escort tug** in order to reflect the crew familiarity with the tug operating area as well as the associated required level of autonomy in case of an incident, has been maintained. This is particularly relevant to offshore terminal tugs, tugs engaged in coastal towage operations and tugs which are primarily designed for harbour towage operations (function), but which may also be engaged in ship assist at sea (e.g. port approach, anchorage, straits and estuaries) and can therefore not be assigned the service notation **harbour tug**.

The definitions of typical operational profiles and design arrangements, intended as general guidance for the application of applicable requirements included in the guidelines has been updated and extended to include innovative designs. The most notable changes are the refined definition of escorting and the explicit inclusion of salvage tugs and innovative tug designs, in particular designs with multiple omnidirectional thrusters distributed along the length of the tug.

For the purpose of the guidelines escorting is considered to include active (emergency) steering, braking and otherwise controlling of the escorted ship by the tug operating in indirect towing mode, whereby the ahead speed of the escorted ship is within a typical speed range of 6 to 10 kn. In indirect towing mode the towline force is the resultant of the (quasi-static) equilibrium condition reached between the forces and moments arising from the hydrodynamic lift and drag forces acting on the hull and appendices of the tug advancing through the water at a drift angle relative to the water flow, the thrust vector and the towline force. Different indirect towing modes can be identified, depending on the required action towards the escorted ship (e.g. steering, braking). The main indirect towing modes relevant for escort tugs are schematically shown in Figure 1. Where reference is made to “indirect steering” the objective is to maximise the steering force in indirect towing mode. Where reference is made to “indirect braking” the objective is to maximise the braking force in indirect towing mode.

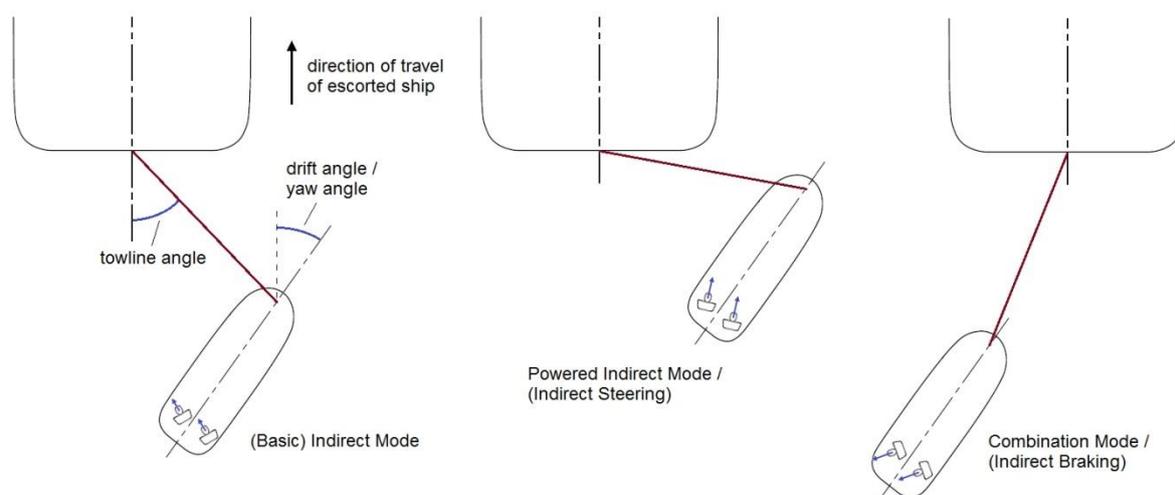


Figure 1: Schematic overview of indirect towing modes (escort tug)

In (basic) indirect mode the towline force is generated primarily by the hydrodynamic forces acting on the hull and skeg, with the thrust used solely to maintain the desired drift angle (also referred to as yaw angle). In powered indirect mode (indirect steering) the transverse component of thrust is used to maintain the desired drift angle, while a significant longitudinal component of thrust is applied in forward direction of the tug. Compared to the (basic) indirect mode, the tug is operating more sideways of the escorted ship with a relatively large towline angle, generating a higher steering force. In combination mode (indirect braking) the same principle as for the indirect steering mode is applied, except that the longitudinal component of thrust is applied in aftward rather than forward direction. Compared to the (basic) indirect mode, the tug is operating more behind the escorted ship with a relatively small towline angle, generating a higher braking force.

The revised guidelines recognise that escort tugs may operate in open sea areas as well as in sheltered (confined) waters, such as ports and estuaries. This is of importance as port authorities increasingly require certification as escort tug for tugs operating in ports. As the present escort tug rules have been set up for escort operations in waves. The revised guidelines provide specific requirements adapted to escort operations in calm water conditions, where dynamic oscillations of the towline are not likely to occur.

The reference (quasi-static) towline force ( $T$ ) is defined as the Bollard Pull ( $T_{BP}$ ) for towing and as the maximum steady towline force ( $T_{ESC}$ ) for escorting. The reference towline force ( $T$ ) is to be used for checking the intact stability criteria for towing and escorting. The Design Load ( $DL$ ) is defined as  $DL = DAF \cdot T$ , where  $DAF$  stands for Dynamic Amplification Factor, a coefficient which is directly dependent on the selected service notation as shown in Table 1.

The Design Load (DL) is to be used for checking the structural strength criteria for the towing equipment and the associated supporting structures. For towing winches and towing fittings used in conjunction with towing on a towing winch, as well as the associated supporting structures the winch brake holding load (BHL) is to be considered as an additional Design Load for strength assessment. For pushing operations in calm water (without bouncing) a Design Load (DL) equal to 1.5 times the Bollard Pull ( $T_{BP}$ ) is recommended [2].

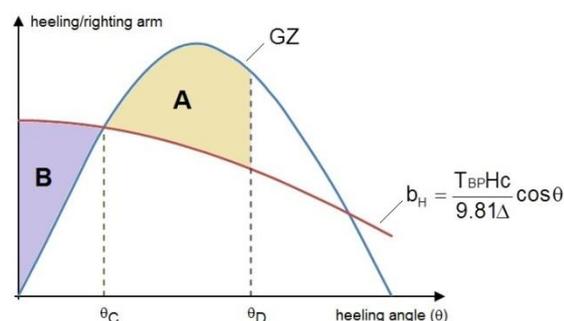
harbour tug		tug		escort tug	
Bollard Pull $T_{BP}$ [kN]	Design Load DL [kN]	Bollard Pull $T_{BP}$ [kN]	Design Load DL [kN]	Towline Force $T_{ESC}$ [kN]	Design Load DL [kN]
$T \leq 200$	$[2]T$	$T \leq 400$	$[2.5]T$	$T \leq 500$	$[3]T$
$200 < T < 800$	$\left[\frac{2600-T}{1200}\right]T$	$400 < T < 1000$	$\left[\frac{3400-T}{1200}\right]T$	$500 < T < 1000$	$\left[\frac{2000-T}{500}\right]T$
$T \geq 800$	$[1.5]T$	$T \geq 1000$	$[2]T$	$T \geq 1000$	$[2]T$

Table 1: Design Load definition (DAF values shown in square brackets)

In general, the requirements for safety equipment are a function of both the service notation and the additional service feature. In the draft guidelines the safety equipment requirements were presented by introducing a “safety matrix” (per topic) [2]. This practical format has been maintained, while some changes have been made to the requirements.

## STABILITY

A proposal for harmonised towing and escort stability criteria had already been included in the draft guidelines [2]. The proposed towing stability criterion requires that the available energy to right(en) the tug (area A) is to be equal to or greater than the energy released by the assumed heeling moment (area B), see Figure 2.



Criterion:  $A \geq B$

Figure 2: Intact stability criterion for towing

This self-tripping heeling moment is assumed to be exerted by a couple of forces made up of the towline force acting in transverse direction (due to an unintended event) and the thrust acting in the opposite (transverse) direction. The arm  $H$  between the two forces is the (vertical) distance between towing point (fairlead, staple, towing hook or equivalent fitting) and the horizontal centreline of the propulsion unit(s), as relevant for the considered towing situation. The area  $A$  is bounded by the down-flooding angle  $\theta_D$  (if less than the angle of the second intersection between the heeling and righting arms), as shown in Figure 2. As was already considered in the draft guidelines, it should be noted that ventilation openings of the machinery space and emergency generator room necessary to continuously supply these spaces should be considered as down-flooding points for the purpose of the stability calculations [2]. The general requirements of such openings have been slightly updated in the revised guidelines.

The key point is to set appropriate values for the transversely acting couple of forces (towline force and thrust force) generating the heeling moment on the tug. The considered force is usually expressed in terms of a percentage of the bollard pull  $T_{BP}$ , where the percentage is based on theoretical consistency and experience feedback on proven tug designs. For conventional tugs with fixed propulsion the percentage has been maintained at 50 per cent. For tugs with azimuth propulsion (e.g. ASD and tractor tugs) originally a percentage of 70 per cent had been proposed for all cases. Further theoretical considerations and investigations have shown that, while the proposed percentage is appropriate for ASD tugs towing over the stern, the percentage may be reduced when working over the bow. As the longitudinal distance between the towing point and the thrusters for ASD tugs towing over the bow is much larger compared to towing over the stern, a significant yaw motion is induced in ASD tugs when working over the bow. This yaw motion effectively dissipates energy and reduces the total (dynamic) heeling angle compared to the two dimensional case which underlies the theoretical stability model. This effect can be clearly observed in model tests, as shown in the video stills in Figure 3.



Figure 3: Simultaneous roll and yaw motion of ASD tug working over the bow (model test)

On the basis of the investigated cases a minimum value of 50 per cent for the effective percentage of the bollard pull acting in transverse direction to heel the tug has been derived. A similar reasoning as for ASD tugs can be applied to tractor tugs. That being said, the proposed “fixed” percentages may not be representative for other tug designs presently in operation, in particular where the (traditional) ASD and tractor concepts have been mixed. Therefore, a more generic formula for the coefficient  $c$  is proposed:

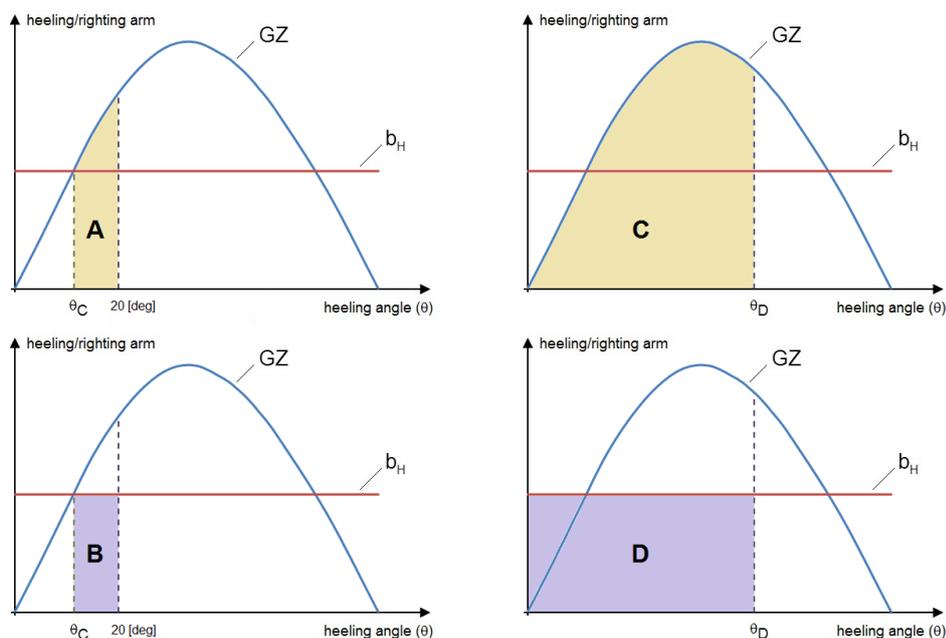
$$c = 0.9 / (1 + d / L_{LL}) \quad (1)$$

where  $d$  is the longitudinal distance between the towing point and the vertical centreline of the propulsion unit(s) and  $L_{LL}$  is the (freeboard) length as defined in the International Convention on Load Lines (ICLL) in force.

The formula has been calibrated on the basis of above referenced minimum percentages as proposed ASD tugs and can be used only for tugs with azimuthing thrusters installed at a single location along the length. In no case the coefficient  $c$  is to be taken as less than 0.70 for ASD tugs towing over the stern and tractor tugs towing over the bow and 0.50 for ASD tugs towing over the bow and tractor tugs towing over the stern, respectively.

The situation becomes more complicated when considering tugs equipped with multiple omnidirectional thrusters distributed along the length, which are becoming increasingly popular in the market [4,5]. Such tugs have the capability to generate relatively high transverse thrust compared to tugs with omnidirectional thrusters installed at a single location along the length. This aspect needs to be specially considered in relation to the anticipated effective towline forces acting in the transverse direction and the associated heeling moments in relation to the towing and/or escorting stability requirements.

With regard to escort stability the basic area requirements included in the draft guidelines have been maintained, see Figure 4 [2]. Experience feedback has demonstrated that the additional requirement for a positive minimum freeboard at the heeling angle corresponding to the (quasi-static) equilibrium, which is consistent with the experience feedback from tug masters on operability limits collected within the scope of the SafeTug JIP [6], is rather impractical and difficult to verify due to the complex dynamics involved and differences in modelling of free surface and water pile-up effects between escort simulation methods. Consequently, the revised guidelines include a modified and better defined operability requirement for the heeling angle corresponding to the (quasi-static) equilibrium to be not greater than 15 degrees, which is also included in the anchor handling stability requirements proposed by NMD in 2007 (which are now widely applied by classification societies and administrations) [7], as well as experience feedback on proven escort tug designs.



$$\text{Criteria: } A \geq 1.25B ; C \geq 1.40D ; \theta_c \leq 15 \text{ [deg]}$$

Figure 4: Intact stability criteria for escorting

### ESCORT PERFORMANCE ASSESSMENT

A key point in the draft guidelines was the explicit inclusion of criteria for the acceptance the results of escort performance simulations in lieu of full scale testing for the determination of the maximum towline forces and heeling moment induced under the combined action of the hydrodynamic forces (acting on the hull and appendices), the thrust forces and the steady towline force [2]. Based on experience feedback from escort simulations and model tests, the associated requirements for acceptance have been further developed and detailed in the revised guidelines. On the basis of these requirements developments BV has issued an Approval in Principle to the escort performance prediction methodology proposed by Robert Allan Ltd as presented by Smoker and Stockdill at the Tugology '13 conference in London [8].

In addition, a requirement for providing operating information regarding the design limitations of the escort tug has been added to facilitate the safe operation of escort tugs. This information, including the design operating area and environmental conditions, the maximum escort speed, a table with permissible values of (quasi-static) heeling angle and steady towline force as function of loading condition and escort speed and instruction to the master, is to be provided in the stability booklet. The instructions to the master are to detail the intended handling of the escort tug and the associated towing equipment, including the use

of the emergency quick-release device, and to demonstrate the implementation of effective means to limiting the steady towline force and heeling angle within the permissible limits.

### TOWING EQUIPMENT

The basic principles underlying the towing equipment requirements of the guidelines remain valid. The overall safety of the combined system of tug and assisted ship is to be considered. Consequently, the towline should not be considered as the weak link [2]. The guidelines cover the all towing equipment in a systematic way, including towing/escort winches, towing hooks, towline guiding fittings (fairlead, stable, etc.), towlines and the associated supporting structures. Fendering systems for pushing operations are also considered.

The key drawing underlying the assessment and verification of the towing equipment is the towing arrangement plan. The drawing is to include the location and general lay-out of the towing equipment, the range of anticipated lines of action of the towlines with the associated maximum static/steady towline forces and the corresponding points of application of the towline forces on the towing equipment. A comprehensive paper on a system approach to the design of the towing arrangement, highlighting the usefulness and relevance of the towing arrangement plan, was presented by Den Hertog and Allan at Tugology '13 [3].

Detailed drawings of the towing equipment are to be submitted for approval (by the maker), supported by design calculations (in particular for the towing winch and towline guiding structures). The basic strength criteria, including design loads and stress criteria which have been further developed on the basis of the draft guidelines, are shown in Table 2. The recommendation that the breaking strength of the towline should be not less than the greater of the Design Load (DL) and the winch brake Holding Load (BHL), respectively, has been maintained [2].

Towing equipment		Design Load	Stress criteria (N/mm <sup>2</sup> )
Towing winch		DL BHL	$\sigma_{VM} \leq R_e$ $\sigma_{VM} \leq 0.8 \cdot R_e$
Towing hook		DL	$\sigma_{VM} \leq 0.8 \cdot R_e$
Towline guiding fittings <sup>2,3)</sup>		MAX(DL <sup>1)</sup> ; BHL <sup>1)</sup> ; 2·SWL)	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
Supporting structures <sup>2)</sup>		MAX(DL <sup>1)</sup> ; BHL <sup>1)</sup> ; 2·SWL)	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
DL	Design Load	$R_e$	Material yield stress
BHL	Brake Holding Load (of winch)	$R_y$	235/k (k = material factor based on $R_e$ )
SWL	Safe Working Load (static)	$\sigma$ , $\tau$ , $\sigma_{VM}$	normal, shear, Von Mises stress, resp.
1) Force exerted by towline, considering the most unfavourable anticipated position of the towline			
2) Increase of permissible stress level by 10% in case of 3D finite element analysis (FEA)			
3) For wire stoppers and guide pins not made of welded construction $R_e$ may be used instead of $R_y$			

*Table 2: Strength criteria for towing equipment*

The reliability of the emergency quick-release on towing/escort winches and towing hooks is of key importance. To that end the guidelines require the capability of towline release under all operating modes, regardless of the direction of the towline and the position of the tug. The emergency quick-release function of winches is to be independent of the winch power supply. In all cases the emergency quick-release system is to be operable from the wheelhouse. The applicable quick-release procedures, including time delays and release speeds are to be communicated to the crew and displayed in the wheelhouse. The speed of paying-out the towline shall be such that the towline tension is reduced as fast as reasonable possible, but taking into consideration that paying out is to be done in a controlled manner. Spinning, defined as free and uncontrolled rotation of the winch drum, is to be avoided to

prevent the towline from getting stuck. For escort winches specific anti-spinning measures are to be taken to prevent spinning (anti-spinning device).

As described in the earlier in this section, escort operations in calm water conditions are specially considered in the revised guidelines. The requirements for escort winches have been further developed to take this into account. Escort winches intended to be used in conditions where dynamic oscillations of the towline are likely to occur, such as in open sea areas or other areas exposed to waves, are to be equipped with an active pay-out and haul-in system, capable to automatically and reliably pay-out the towline in a controlled manner when the towline force exceeds a pre-set (adjustable) level equal to 110 per cent of the rated towline force, and, as the towline force is reduced, actively haul-in the towline to prevent slack-line events and maintain a pre-set or adjustable towline force consistent with the rated towline force. The pay-out and haul-in speeds and pull capability shall be chosen taking into account the anticipated escort services and the dynamic characteristics of the escort tug. Escort operations in conditions where dynamic oscillations of the towline are likely to occur are not to be based on the use of the brakes of the winch drum.

Escort operations in calm water conditions, such as in ports and sheltered waters, may be based on the use of the brakes of the winch drum. As a minimum, the winch brake holding load BHL is to be equal to or greater than two times the maximum steady towline force. Long term experience feedback has demonstrated that such escort operations are viable and can be performed in a controlled manner, provided that tug crews are adequately trained for such operations. Taking into account that such escort operations are typically performed in confined spaces, the use of automatic towline release mechanism acting beyond the control of the master is considered not appropriate from a safety point of view. The heeling angle and towline force are primarily controlled by the power setting and thruster angle.

All escort winches are to be equipped with a calibrated towline force measurement system. In addition escort tugs are to be equipped with a calibrated heeling angle measurement system (inclinometer). The measured towline force and heeling angle are to be displayed in the wheelhouse next to the control desk. The readings are to be considered as information to the master in order to verify that the towline force and heeling angle remain within the permissible limits, which should also be displayed in the wheelhouse.

The revised guidelines pay special attention to the spooling of the towline on the escort winch. Proper spooling of the towline on the winch drum can generally be achieved by a suitable design of the fairlead or staple guiding the towline between the escort winch and the assisted ship. Where a spooling device is fitted, this device should be designed for the same Design Load and stress criteria as the towline guiding fittings.

Finally, the testing requirements for towing equipment have been updated. Three types of testing are considered. Load testing (at the Design Load DL) is to be performed at the manufacturer's workshop to verify the strength of the design, which is particularly relevant for novel designs. Function testing at the bollard pull is to be performed on board to verify the correct operation of towing equipment within specified limitations in accordance with the towing arrangement plan. Function testing is to be performed under normal operation and emergency modes, including dead ship condition. For safety reasons the emergency quick-release systems are to be function tested at a reduced tension. Operational tests are to be performed by the crew in order to ensure the satisfactory operation of the towing equipment, in particular the emergency quick-release system, in accordance with the operating manual. Records of operational tests are to be kept on board for verification during surveys.

## SAFETY EQUIPMENT

The approach taken in the draft guidelines to set up the safety equipment requirements as function of the selected service notation and additional service feature has been maintained in the revised guidelines [2]. The so called “safety matrix” for tugs of less than 500 grt, which contains recommendations for fire-safety, life saving appliances, radio installations and navigation equipment as function of the selected service notation and additional service feature (defining the operating area and therefore the required level of autonomy from shore-side support), has been slightly amended following industry feedback on the draft guidelines. The recommendations for anchor equipment have been kept the same as in the draft guidelines, except that the formula for the Equipment Number (EN) has been fully aligned with IACS UR A2 [2,9].

## ASSISTED SHIP

In the draft guidelines the issues regarding the strength of towing fittings (e.g. bollards) and the pushing areas of assisted ships were explicitly addressed. Attention was raised to the (too) small safety factors on the Safe Working Load (SWL) of towing bollards on the assisted ship to deal with dynamic amplification of the towline forces, a matter particularly relevant for towing operations at sea and for escort towing [2]. Moreover, as tugs are becoming more powerful, the static towline forces (bollard pull, steady towline force) the tugs can exert on towing fittings are increasing as well. It is therefore recommended to design the towing fittings on the assisted ship to the same design load and strength criteria as the towing equipment on the tug, taking into consideration the performance capabilities of modern tugs. The revised guidelines have been further developed on this basis.

The marking and strength of tug pushing areas were also already addressed in the draft guidelines [2]. In the revised version they have been slightly further developed. The key point is to ensure that the pushing areas are clearly marked and designed to the same design load and strength criteria as the fendering and pushing area of the tug. Again the increased power of tugs should be considered in relation to the static (push) force.

The above mentioned issues have also been addressed by the European Tugowners Association (ETA) and European Maritime Pilots Association (EMPA) in their joint position paper *Best Practice/Safety Harbour Towing and Pilotage* released in 2010 [10]. The paper also addresses the position of the (assisted) ships’ bollards, fairleads and winches, which in many cases have been found inadequate placed for harbour towing operations. A recommendation is made to explicitly consider harbour towing when designing the towing and mooring arrangement plans [2]. This recommendation has also been included in the revised guidelines.

The fourth, and perhaps most important, topic addressed by the ETA and EMPA is the speed of making fast. In particular (ultra) large container ships with high main engine power enter ports at relatively high (minimum) speeds of 6 up to 11 kn through the water [10]. Consequently, making fast by tugs would have to be performed at speeds close to the tug’s maximum speed (typically 11 to 12 kn). The paper refers to 8 kn as a limiting value for safety [10]. The guidelines recognise that making fast at high speed incorporates risk for the tug and its crew. Increased ships speed leads to stronger water flows between and around the ships and hence increases the risk of collision. In addition, at speeds close to the tug’s maximum speed the engines have no (or limited) reserve power, which reduces the tug’s ability to escape from a critical situation. Therefore it is advised to explicitly address during the design stage (of the assisted ship) the minimum speed through the water (propulsion configuration) as well as the proper location and strength of the towing fittings (bollards, fairleads, etc.) in relation to connecting to a tug. Furthermore, tug owners/operators and port authorities are recommended to specify an appropriate maximum speed for merchant ships in relation to making fast of tugs. Recent incidents and accidents with tugs have clearly demonstrated the relevance and importance of specifying and harmonising procedures and speed limits for tug assistance [11,12]. This has proven to be particularly important for bow-to-bow operations [13]. Aside from the capabilities of the tug (by design), good

communication between the tug and the assisted ship, as well as crew training, are necessary and crucial components for safe tug operations. Figure 5 illustrates a model test of a bow-to-bow operation with an ASD tug at 8 kn, where the master is trying to find the maximum towline and drift angle at which he can keep control over the tug's manoeuvrability.



Figure 5: ASD tug “bow-to-bow” at 8 kn with large towline and drift angle (model test)

#### FURTHER DEVELOPMENTS

With the revision of the guidelines the scheduled industry feedback rounds have come to a close. But as knowledge and technology in the towing industry are constantly evolving this by no means that the proposed regulations will be “frozen”. In fact, a number of further developments are envisaged.

Further development of the coefficient  $c$ , representing the effective percentage of the bollard pull acting in transverse direction for intact stability assessment, is considered. Consistent with the purpose of the guidelines, the current values have been proposed on the basis of experience feedback and continuity of the stringency of currently applied stability requirements. As mentioned before their applicability to innovative designs is not “a priori” obvious. Further research could support an extension of the proposed values of the coefficient  $c$  and further enhance the applicability of the guidelines. An interesting methodology to achieve the required insight in the dynamic behaviour of tugs exposed to a sudden transverse “jerk” of the towline, in particular the with regard to the heeling angle as a function of time, has been proposed by De Jong et al in a paper presented at Tugology '13 [14]. A dynamic simulation model combining a manoeuvring model for the horizontal plane motions with a one-degree of freedom model for the roll motion is applied to predict both the pathway and heeling angle of the tug in the time domain under different scenarios, including self-tripping, tow-tripping and engine failure in indirect towing mode [14]. Within the context of the guidelines self-tripping has been identified as the governing failure scenario for normal towing (zero or low speed direct towing) [2]. Therefore, the proposed methodology enables the further evaluation of the coefficient  $c$  of the guidelines by comparing the maximum (dynamic) roll angle for a given towline force to the heeling angle associated with down-flooding. A similar exercise can be performed to compare and further investigate the self-tripping and tow-tripping scenarios. Furthermore, an appropriate value for the coefficient  $c$  could be obtained for novel tug designs not explicitly covered by the present guidelines.

As also suggested by De Jong et al, the approach can also be applied to escort towing (indirect towing within speed range of 6 to 10 kn). By taking into account all relevant (failure) scenarios it becomes possible to evaluate the escort towing capability of tugs as function of the escort speed, whereby stability and strength limits define the maximum allowable speed. This creates the possibility to issue a table to provide a clear overview of a tug's capabilities

and limits which, as a matter of fact, is rapidly becoming and industry practice not in the least due to the increasing interest of port operators for the assignment of an escort tug class notation to (port) tugs engaged in indirect towing operations.

Another important topic for further investigation is the behaviour of the combined system of escort tug, winch and towline. The influence of the particulars of the winch (pay-out and haul-in characteristics) and the towline (elasticity and use of weak link) on the (dynamic) towline force are of key interest. Experience feedback shows that the use of toelines with high elongation values can be effective in absorbing energy associated with (short duration) peak loads. Further study into the dynamic behaviour of the holistically considered towing system in different configurations and under various environmental conditions may enable to further develop the guidelines with respect to the requirements for equipment used for escorting.

### HARMONISATION

Harmonisation has always been one of the main drivers behind the development of the guidelines. Ideally, harmonised regulations would be supported by both classification societies through IACS, as well as flag states through IMO. In order to move forward BV has proposed IACS to submit an information paper with a proposal for harmonised towing (and escort) stability criteria on the basis of the guidelines to the IMO for consideration and possible inclusion in the Intact Stability Code. Such submission would be in line with the work currently performed by the IMO Correspondence Group on Intact Stability, which is considering amendments to the Intact Stability Code for vessels engaged in towing operations. BV technical experts are also participating in this Correspondence Group, which has been made aware of the guidelines.

### **ANCHOR HANDLING REGULATIONS**

Anchor Handling Tugs (AHT) have been deployed ever since mobile offshore units have been moored at sea for oil exploration and production activities. Until the 1970s, AHTs remained small for manoeuvrability reasons, as bowthrusters were uncommon at the time. The vessels were used for shallow water anchor handling operations. A typical AHT would have a propulsion power of about 4,000 bhp delivering a bollard pull of about 48 t, while the main winch used for anchor handling would typically have a break holding load of about 150 t. A radical paradigm shift took place in 1975 when Ulstein introduced the concept of the Anchor Handling Tug Supply (AHTS) vessel on the market. The revolutionary UT 704 design effectively combined towing, anchor handling and platform supply functions into one hull with good seakeeping characteristics for operations on the North Sea, where conditions are typically more demanding than in the Gulf of Mexico. The design has the capability for deep water towing and anchor handling operations, a large working deck and underdeck cargo tanks for the carriage of drilling mud and brines in liquid bulk. Furthermore, a bowthruster was fitted to improve manoeuvrability. The propulsion power of a typical UT 704 would be in the range of 7,050 to 8,600 bhp, delivering a bollard pull in the range of 90 to 102 t. A sophisticated anchor handling winch with a brake holding load around 350 t would typically be installed. Other innovations, including the introduction of towing pins to contain the wire and the installation of a winch control unit on the bridge, have greatly contributed to the enhancement of operational safety. The success of the design is proven by the fact that 91 vessels were built between 1975 and 1986 [15]. And even today a significant number of them are still in active operation.

With the offshore oil and gas industry moving into deeper water and harsher environments, AHTS vessels and anchor handling equipment have become larger, more powerful (the largest AHTS have up to 400 t bollard pull and 600 t winch pull capacity), more sophisticated (e.g. multi-drum waterfall winches) and also more reliable. The required propulsion power, Bollard Pull and winch capacity are directly related to water depth and the operating area (in terms of environmental conditions, such as wind, waves and current). Modern AHTS vessels are typically equipped with dynamic positioning (DP) systems based on redundancy

principles, where the DP system on the latest generation of designs is typically IMO class 2 compliant. Other characteristics include large deck area for the handling and storage of anchors (with the use of additional deck equipment such as wire stoppers and tugger winches) and the transportation of deck cargoes (e.g. pipes, containers and specialised equipment). Furthermore, large underdeck capacity for carriage of liquid bulk cargoes, including oil products (e.g. fuel oil) and hazardous noxious liquid substances in bulk (e.g. drilling mud, brine and methanol) has become standard as well as centralised operational control from the bridge with full view on aft deck has become the standard. Building further on the idea multi-functionality, AHTS vessels are regularly designed to perform additional operational duties, including oil recovery, external fire-fighting and stand-by safety/rescue. An example of a modern versatile and multirole AHTS is shown in Figure 6.



Figure 6: Example of modern AHTS vessel (Damen AHTS 130 design)

### SAFETY ISSUES

Anchor handling is a highly specialised offshore operation involving an element of urgency due to weather windows and commercial pressure. As anchor handling operations are taking place in increasingly challenging environments with regard to water depth and weather conditions, high tension forces in the wire are to be expected, requiring high bollard pull and winch pull capacity. Moreover, the vessels are operating in a very dynamic environment due to ship motions, large rotating (deck) machinery and moving wires and anchors on the working deck. As a consequence, anchor handling operations are associated with risks. The two main categories of risk are related to strength and stability. The following strength related risks are identified:

- Overstressing of anchor handling equipment (winch, wire stoppers, guide pins and stern roller) due to excessive wire tension;
- Forces associated with unintended wire positions (loss of wire control);
- Forces associated with emergency quick-release (risk of free-spinning of the winch and jamming of the wire);
- Parting of the wire (e.g. due to dynamic effects in waves).

With regard to (intact) stability the following risks are identified:

- Excessive heeling (moment) associated with wire tension and position;
- Loss of stability due to water on deck (trim, heel, waves, insufficient bollard pull);
- Heeling (moment) associated with unintended wire positions (loss of wire control);
- Increase of vertical centre of gravity (VCG) during anchor handling operations (e.g. use of fuel stored in double bottom tanks, spooling of wire on drum).

Although everyone involved with anchor handling vessels is aware of these risks, somewhat surprisingly, until today there is no international regulatory framework in place to manage and mitigate them. The tragic accident with the Bourbon Dolphin, which capsized during anchor handling operations in the North Sea in 2007, has sadly but very clearly demonstrated this regulatory gap. Following the accident investigations the Norwegian Maritime Directorate (NMD) have issued *Guidelines on the implementation of specific measures to ensure a sufficient safety level during anchor handling (AH) operations carried out by supply ships or tugs* under [7,16]. The guidelines, which are mandatory to be followed by organisations and personnel involved in planning and carrying out of activities related to anchor handling operations, apply to all Norwegian supply vessels and tugs that are designed and equipped to provide anchor handling [16]. In the wake of the incident owners and operators of anchor handling vessels all over the world have begun to apply the guidelines to their fleets in order to better understand the anchor handling capabilities of their vessels and to prevent repetition of the accident and the major classification societies involved in the classification and certification of anchor handling vessels have incorporated the guidelines into their regulations, in particular with respect to stability during anchor handling.

### NMD GUIDELINES

The NMD guidelines require the preparation and documentation of vessel-specific anchor handling procedures covering vessel capabilities and limitations and requirements for risk assessment (by the operator/crew). The procedures are to include criteria for control limits (attention zones), interruption criteria and plans for handling critical situations [7,16].

With regard to stability the NMD regulations require calculations demonstrating the acceptable vertical and horizontal (transverse) tension to which the vessel can be exposed, considering the most unfavourable conditions for transverse tension. The vessel's maximum heeling angle is to be limited to one of the following angles, whichever occurs first (see Figure 7):

1. Heeling angle equivalent to a righting lever ( $GZ$ ) value equal to 50 per cent of the maximum righting lever ( $GZ_{MAX}$ );
2. Heeling angle which results in water on the working deck (deck is calculated as flat);
3. 15 degrees.

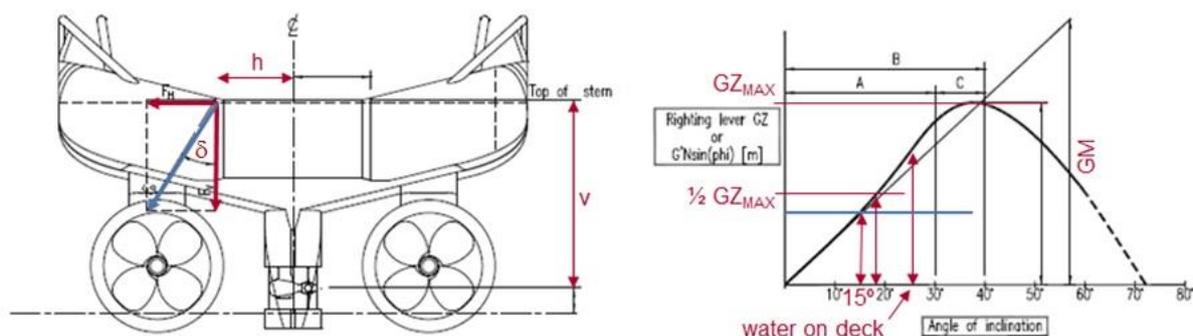


Figure 7: Reference for anchor handling stability calculations

The heeling moment is to be calculated on the basis of the combined effect of the vertical and horizontal components of the transverse tension (force) in the wire (or chain), as shown graphically in Figure 7. In this respect the (torque) arm of the horizontal force component  $v$  is to be calculated as the distance from the height of the work deck at the guide pins to the centre of main propulsion propeller or to centre of stern side propeller, if this projects deeper, while the (torque) arm of the vertical force component ( $h$ ) is to be calculated from the centre of the outer edge of the stern roller and with a vertical straining point on the upper edge of the stern roller (see Figure 7). The vertical tension force is to be included in the loading conditions and the righting arm curve used for the verification of the stability criteria. In

addition to the most unfavourable loading condition (in terms of draft, trim and vertical centre of gravity) other loading conditions for anchor handling are to be considered with prevailing practice with regards to loads on deck and winch reels. Information regarding the loading conditions and associated anchor handling stability limits is to be communicated to crew and displayed next to the control desk [16]. This is usually done in the form of diagrams showing the maximum wire tension as function of the angle of deviation  $\delta$ , which is defined as the angle between the transverse component of the wire tension and the vertical plane as shown in Figure 7. An example diagram is shown in Figure 8.

The NMD guidelines require that the maximum tension during a clean lift (no bollard pull) is to be limited by the anchor handling stability limits and that a curve showing the maximum available bollard pull for anchor handling as function of total (electrical) power balance (accounting for the power consumption of the anchor handling winch (e.g. pumps), as well as side and azimuth thrusters for position keeping) is to be prepared [16].

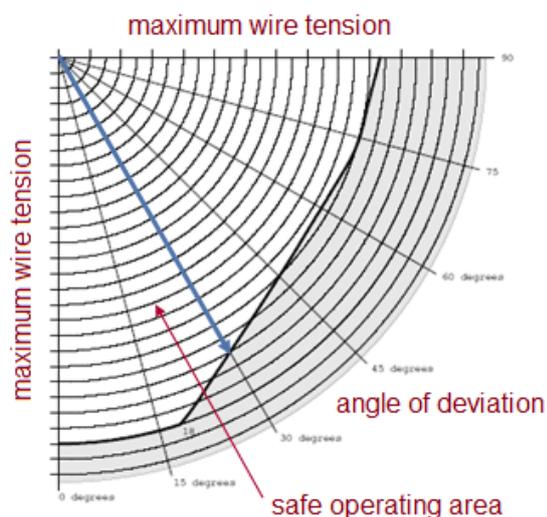


Figure 8: Example of diagram for maximum wire tension as function of the angle of deviation (for specific loading condition)

With regard to the anchor handling equipment a review of the effect of emergency release on the winch and other equipment is to be performed and procedures for unintended situations (emergency release methods, time delays and release speed) are to be communicated to vessel crew and displayed next to control desk [16].

Proper planning is of key importance for safe anchor handling operations. To that end calculations demonstrating the expected forces, taking into consideration the weight of the wire (or chain), the anticipated wire tension in any phase of the operation and the required tension to obtain sufficient anchor holding power, are to be performed. The vessel's capacity is to be assessed against expected forces in order to verify whether the operation can be carried out safely. The operation is to be stopped by releasing the gear and equipment if the vessel is exposed to forces greater than anticipated in the plans [16].

The NMD guidelines also cover additional requirements for tandem operations (quick disconnection in case of broken wire or and loss of bollard pull (propulsion power) in one vessel), the effect of roll reduction tanks on stability during anchor handling operations (calculations and documentation), fuel consumption plans with documentation for fuel oil and ballast water (considering the sequence for emptying and filling tanks and the associated impact on the vertical centre of gravity and free surface moments) [16].

## REGULATORY DEVELOPMENTS

Recognising the safety risks associated with anchor handling operations and having taken note of the NMD guidelines, the IMO Correspondence Group on Intact Stability has been given the task to proposed amendments to Intact Stability Code with respect to stability information for vessels engaged in anchor handling operations on the basis of the work performed by the NMD [7,16,17]. BV technical experts are participating in this Correspondence Group. One of the key items under consideration is definition of the path of the wire (between the anchor handling winch and the stern roller). The angle of deviation used in the NMD guidelines is difficult, if not impossible, to assess on board during anchor handling operations and does not consider that the towline may not be confined in the transverse plane at the aft end of the ship. In fact, it is common practice on large anchor handling vessels to break the anchor out by applying bollard pull, in which case the wire tension will have a component in the longitudinal direction (of the vessel). Splitting the angle of deviation into two separate angles at the “knuckle points” (guide pin and stern roller) provides the opportunity to improve the practical application of the stability requirements on board, providing an increased level of control. To this end the NMD has proposed to introduce the angle  $\alpha$ , defined as the angle between the ship’s centre line and the wire in the horizontal plane (at the guide pins), and the angle  $\beta$ , defined as the angle between the horizontal plane and the wire through the point of attack (point where wire leaves the vessel). The idea is that these angles can be determined on board. For angle  $\alpha$  this is relatively straightforward, while for angle  $\beta$  less so, as it requires consideration of the wire length, composition and distance between the point of attack on the vessel and the point where the wire leaves the rig [17]. The introduction of the two angles enables the calculation of the maximum permissible wire tension on the basis of table or curves, considering the relevant combinations of both angles for each loading condition (defined by displacement or draught and vertical centre of gravity).

Furthermore, the NMD guidelines consider that the wire will leave the vessel at the side of the stern roller, regardless of the arrangement. From a calculation point of view it is therefore favourable to have a stern roller with small width in order to limit the horizontal torque arm  $h$ , while a wide stern roller would lead to a higher heeling moment, even in case it is practically not realistic to have the wire at the side of the stern roller.

The applicable stability criteria are also being reviewed. Broadly speaking, the criterion that the heeling angle is not to be greater than the heeling angle corresponding to half of  $GZ_{MAX}$  is considered to represent a margin against capsizing, the criterion that the heeling angle is not to be greater than the heeling angle which results in water on deck is considered to be primarily related to the fact that crew members are working on deck to handle the anchors, while the criterion that the heeling angle is not to be greater than 15 degrees is considered as an operability limit low enough to enable the crew to perform corrective actions [17]. On the basis of test calculations the NMD has proposed to include an area requirement in the criteria in order to ensure an adequate level of reserve stability taking into account unpredictable variations in the forces acting on the vessel (due to waves, wind current and wire tension) as follows: the area between the heeling arm and righting arm up to the second intersection point, angle of down-flooding or 40 degrees, whichever is less, is to be not less than 0.055 mrad. The proposed area requirement is based on IACS Rec 24 (stability requirements for towing vessels), but adjusted for dynamic effects [17,18]. What is not clear from the NMD proposal is how the dependency between the heeling arm and the heeling angle is taken into account (a cosine distribution is applied in IACS Rec 24, whereas the NMD guidelines consider the heeling arm as constant). Also the nature of the dynamic affects, estimated at 40 per cent, requires further assessment, as also acknowledged by the NMD [17].

With regard to the loading conditions to be submitted the NMD has put additional emphasis on the effects of wires loaded on winch reels and the loading and unloading sequences of fuel oil and water ballast tanks on the centre of gravity and resulting stability particulars of the vessel during anchor handling operations.

### NEW BUREAU VERITAS CLASS NOTATION

Taking into account the on-going regulatory developments for anchor handling vessels, as well as the experience feedback obtained from applying the NMD guidelines to AHTs and AHTS vessels, Bureau Veritas (BV) has introduced the service notation **anchor handling vessel** in the Bureau Veritas Rules for the Classification of Steel Ships [19]. The service notation has entered into force on 1 January 2014 and is covering a full set of technical requirements for (intact) stability and strength of anchor handling equipment and their supporting structures. The stability requirements are based on the NMD guidelines, but already take into account the latest regulatory developments at IMO level, as discussed in the previous section. The strength requirements have been developed in parallel with the revised draft *Safety Guidelines for Design, Construction & Operation of Tugs* developed within the scope of the SafeTug JIP, as discussed earlier in this paper.

The service notation **anchor handling vessel** is intended for tugs and supply vessels designed with open stern and winches for the handling and decking of anchors, having appropriate thrust to perform the intended anchor handling operations. The technical requirements are included on Pt D, Ch 15, Sec 2, paragraphs 2 and 5 of the Bureau Veritas Rules for the Classification of Steel Ships [19]. The requirements of paragraph 5 are to be applied in addition to those included in paragraph 2, containing the basic class requirements for towing vessels (service notation **tug**), as applicable.

As a general requirement, procedures for unintended situations are to be established, with description of emergency release methods, time delays and release speed for each type of equipment in normal operating condition and dead ship condition. These procedures are to be communicated to crew and displayed next to the control desk.

As a basis for stability calculations loading conditions are to be prepared with 10% and 100% bunkers and all winches fully loaded with heaviest anticipated line type. The most unfavourable conditions for transverse tension are to be considered. Loading conditions other than most unfavourable ones are to be calculated according to prevailing practice with regard deck loads and winch reels [19].

As discussed in the previous sub-section, the (single) deviation angle  $\delta$  used in the NMD guidelines has been replaced by two angles  $\alpha$  and  $\beta$  in order to improve the practical implementation of the stability requirements on board. The angle  $\alpha$  is defined as the horizontal angle, in degrees, between the longitudinal axis passing through the inner part of the guide pin and the wire, the ship being in the upright position, taken positive starboard and varying up to 90 degrees, see Figure 9. The angle  $\alpha$  does not need to be taken less than 15 degrees for a vessel having a double pair of guide pins (PS and SB), and 25 degrees in the case of a single pair of guide pins located at the vessel centreline. The angle  $\beta$  is defined as the vertical angle, in degrees, between the waterline and the wire, varying between 0 and +90, see Figure 9 [19].

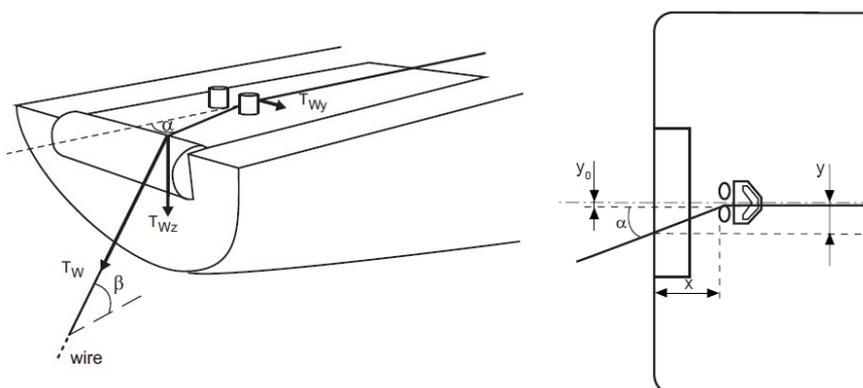


Figure 9: Wire tension and position of wire (single pair of guide pins) [19]

The wire tension  $T_w$  is decomposed into a vertical component  $T_{Wz}$ , considered to act at the point of attack of the wire, and a horizontal (transverse) component  $T_{Wy}$ , considered to act at the (top of the) guide pin.

The tension components are to be calculated as:

$$T_{Wz} = T_w \cdot \sin\beta \quad (2)$$

$$T_{Wy} = T_w \cdot \sin\alpha \cdot \cos\beta \quad (3)$$

The resulting heeling arm  $b_h$ , considered as constant, is to be calculated as:

$$b_h = (T_{Wy} \cdot h + T_{Wz} \cdot y) / D = T_w (h \cdot \sin\alpha \cdot \cos\beta + y \cdot \sin\beta) / D \quad (4)$$

where  $h$  is the (torque) arm of the transverse component of the wire tension,  $y$  is the (torque) arm of the vertical component of the wire tension and  $D$  is the vessel's displacement including the vertical component of the wire tension  $T_{Wz}$  considered at the vessel's centre line. The arm  $h$  is to be taken as the vertical distance from the uppermost part of the guide pins or the intersection of a line defined between the highest point of the winch pay-out and the top of the stern roller and a vertical line through the centre line of the guide pin, to the centre of the main propulsion propeller or the stern side propellers (whichever is projecting deeper). In case of azimuth thrusters,  $h$  is to be taken as the vertical distance from the uppermost part of the guide pins to the centre of the deepest drive. The arm  $y$  is to be taken as the transverse distance from the vessel centreline to the outboard point at which the wire tension is applied to the ship and is obtained by the formula

$$y = y_0 + x \cdot \tan\alpha \quad (5)$$

where  $y_0$  is transverse distance between vessel centre line and the inner part of guide pin and  $x$  is the longitudinal distance between the stern and the guide pin or any physical restriction. In any case  $y$  need not to be taken greater than half the breadth ( $B$ ) of the vessel and may be limited to a physical restriction of the transverse wire movement (e.g. cargo rails, crane, A-frame) [19].

The stability criteria included in the rules follow the NMD guidelines. For all loading condition intended for anchor handling operations, the maximum heeling angle is to be limited to one of the following angles, whichever occurs first:

1. heeling angle equivalent to GZ value equal to 50 per cent of  $GZ_{MAX}$ ;
2. angle of deck immersion;
3. 15 degrees.

Generally, when calculating the trim and the righting arm curve, the vertical component of the towing force is added as a weight in the loading condition located at the centre line and at the stern of the vessel (stern roller). Alternatively, in case the vertical and horizontal components of the tension are both included in the loading condition (e.g. by introducing a weight with offset), the righting arm curve is to be corrected as follows (before anchor handling intact stability calculations):

$$GZ = GZ_0 + b_h \cdot \cos\theta \quad (6)$$

where  $GZ$  is the righting arm after correction, so as to exclude the horizontal component of the towing force,  $GZ_0$  is the righting arm including both vertical and horizontal components of the towing force which vary with the heeling angle  $\theta$  of the vessel [19]. This specific requirement, related to the stability calculation method, has been introduced on the basis of experience feedback with actual designs, both in relation to the preparation of stability calculations as well as loading instruments for anchor handling [19].

For each relevant loading condition the calculation of the maximum heeling moment and corresponding maximum wire tension is to be provided for all possible combinations of angles  $\alpha$  and  $\beta$ , with a typical interval between two angle values of 5 degrees (10 degrees

when  $\alpha$  is greater than 50 degrees). The results are to be given in a table showing the maximum wire tension (corresponding to the maximum acceptable heeling moment) as function of the angles  $\alpha$  and  $\beta$  [19]. On the basis of these calculations curves or tables of the maximum permissible wire tension as function of the vertical centre of gravity (VCG) or metacentric height (GM) are to be provided for the draught (or displacement) and trim values covering the intended range of anchor handling operations. For each trim, two sets of curves (or tables) are to be provided, corresponding to the following ranges of angle  $\alpha$ :

- one set of curves (or tables) for  $0 \leq \alpha \leq 45$  degrees;
- one set of curves (or tables) for  $\alpha > 45$  degrees.

The draught (or displacement), trim and VCG (or GM) to be taken into consideration are those before application of the tension, see Figure 10 [19].

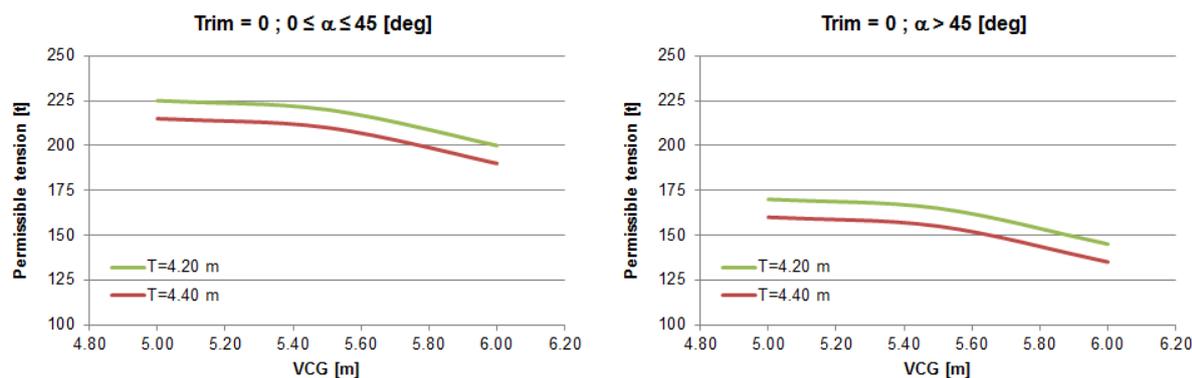


Figure 10: Example of maximum permissible tension curves

The choice for two permissible tension curves has been on the basis of practical considerations. The simplest solution for easy operation would be a single curve. In that case this curve will reflect the worst possible situation in terms of angle  $\alpha$ . As the permissible wire tension typically reaches the lowest value for an angle of 90 degrees, which is not realistic for actual operations, a single curve would be very restrictive, as can be seen from Figure 10 by comparing the left hand (normal operation) and right hand (unintentional situation) graphs. On the other end of the spectrum is the possibility to create bundles of curves for a range of angles, which in fact is quite similar to the wire tension diagram shown in Figure 8 (for a single loading condition). The drawback is that there will be many curves to consider, which is not very practical on board and may lead to human error. Moreover, as the angle  $\alpha$  is generally only approximately known and may vary due to dynamic effects (in particular ship motions in waves and current), it may be difficult to decide which curve to use during operation. Choosing a too optimistic curve would create a risk for overestimating the permissible wire tension.

Experience feedback from operators has shown that during anchor handling operations the angle  $\alpha$  normally does not exceed 45 degrees. On that basis it has been decided to require one curve for normal operating conditions ( $\alpha \leq 45$  degrees) and one curve for unintentional situations (unlimited  $\alpha$ , up to 90 degrees). The second curve, covering all possible combinations of angles  $\alpha$  and  $\beta$ , can be chosen by the master to maximise the safety margin. In this way a pragmatic solution for combining operational safety and flexibility can be provided.

As an alternative to include the maximum permissible wire tension curves in the stability booklet it is acceptable to install an (approved) on-board loading instrument (loading computer) capable of performing direct anchor handling stability calculations on the basis of the actual values of the angles  $\alpha$  and  $\beta$  [19]. BV technical experts have experience in supporting software makers for the development of loading instruments based on direct stability calculations.

In case technical means have been installed on board to measure the actual angles  $\alpha$  and  $\beta$  as well as the actual wire tension (anchor handling winch equipped with load cell), they can be directly coupled with the on-board loading computer to verify compliance with the relevant criteria. This integrated methodology is becoming more feasible with the increasing technical possibilities and reliability of on board measurement technologies. That being said, on-line verification of the wire tension during anchor handling operation should never replace the proper planning and preparation of the anchor operations.

With regard to the structure design principles included in the rules, longitudinal strength aspects to be considered for vessels with Rule length  $L$  equal to or greater than 65 m. As a minimum a loading condition corresponding to the chain lockers being fully loaded and the winches fully loaded with the heaviest anticipated line type is to be included in the loading manual [19].

With regard to the strength requirements for anchor handling equipment and the associated supporting structures a similar holistic approach as applied to tugs in the previous section is used. The rules cover the anchor winch, wire stoppers (shark jaws, fork, etc.), guide pins (towing pins) and stern roller, as well as their supporting structures.

Similar to the tugs the (anchor handling) arrangement drawing forms the basis of the design of the anchor handling system. Information shown is to be a detail arrangement of the handling deck equipment (wire stopper, guide pins, etc.), a typical arrangement of cargo on deck (anchors, wires, chain cables, etc.), the chain lockers used for mooring deployment, anchor handling/towing winch, tugger winches, the stern roller (including lateral limits on both ends), lifting appliances (if any) and the typical paths of lines between the winches and the stern roller showing the limit line sectors [19].

Detailed drawings of the anchor handling equipment are to be submitted for approval (by the maker). Similar to the tug guidelines a typical Design Load (DL) is defined for the relevant equipment on the basis of a reference load specified by the maker of the relevant equipment and a Dynamic Amplification Factor (DAF). In general, the Design Load (DL) is to be taken as not less than the maximum value wire tension resulting from the stability analysis. The winch Brake Holding Load (BHL) is to be considered as an additional design load (without DAF). The Safe Working Load (SWL) of equipment is associated with a safety factor of 2. Both the design loads as well as the associated stress criteria for anchor handling equipment and the associated supporting structures (foundations) are shown in Table 3.

AH equipment		Design Load (DL)	Stress criteria (N/mm <sup>2</sup> )
AH winch		MAX([1.5]·BP; [1.5]·RP) BHL	$\sigma_{VM} \leq R_e$ $\sigma_{VM} \leq 0.9 \cdot R_e$
AH winch foundation <sup>3)</sup>		MAX([1.5]·BP; [1.5]·RP; BHL)	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
Wire stoppers & foundation <sup>3,4)</sup>		MAX(2·SWL; [1.5]·RP; BHL)	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
Guide pins & foundation <sup>3,4)</sup>		MAX(2·SWL; [1.5]·RP <sup>1)</sup> ; BHL <sup>1)</sup> )	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
Stern roller & foundation <sup>3)</sup>		MAX(2·SWL; [1.5]·RP <sup>2)</sup> ; BHL <sup>2)</sup> )	$\sigma \leq 0.75 \cdot R_y$ ; $\tau \leq 0.47 \cdot R_y$ ; $\sigma_{VM} \leq 0.85 \cdot R_y$
BP	Bollard Pull	$R_e$	Material yield stress
RP	Rated (line) Pull (of AH winch)	$R_y$	235/k (k = material factor based on $R_e$ )
BHL	Brake Holding Load (of AH winch)	$\sigma, \tau, \sigma_{VM}$	normal, shear and Von Mises stress, respectively
BP	Safe Working Load (static)		
1) Force exerted guide pins by wire for wire angle of 45 degrees ( $\alpha = 45$ degrees)			
2) Force exerted stern roller by wire for wire angle of 120 degrees ( $\alpha = 0$ and $\beta = 120$ degrees)			
3) Increase of permissible stress level by 10% in case of 3D finite element analysis (FEA)			
4) For wire stoppers and guide pins not made of welded construction $R_e$ may be used instead of $R_y$			

Table 3: Strength criteria for anchor handling equipment (DAF in square brackets)

The strength of the anchor handling winch is to be checked on the basis of submitted calculations, in particular related for components directly exposed to the wire tension (drums, shafts, brakes and support frame). The associated supporting structure is to be checked with the wire on the most unfavourable layer of the drum and in the most unfavourable direction allowed by the anchor handling equipment [19].

The emergency quick-release is to be designed to allow drum release in all operational modes, including emergency more and dead ship condition, in the shortest possible time delay. The quick-release function is to be activated locally at the winch and from a position on the bridge with full view and control of the operation and is to be protected against unintentional operation. Spinning (free, uncontrolled rotation) of the winch drum is to be avoided [19].

The strength of guide pins, wire stoppers and their associated supporting structures is to be checked for the wire tension (Design Load based on RP or BHL) exerted in the most unfavourable directions at most severe vertical location and for the specified SWL. For this purpose a wire angle equal to 45 degrees, which is consistent with the maximum value for normal operating conditions specified for (intact) anchor handling stability ( $\alpha = 45$  degrees), is considered acceptable [19].

The strength of the stern roller and the associated supporting structure is to be checked considering the anchor hanging under the aftship at a negative angle. For this purpose a wire angle equal to 120 degrees, consistent with an angle  $\alpha$  equal to 0 and an angle  $\beta$  equal to 120 is considered acceptable. The wire tension is to be considered at any transverse position on stern roller as allowed by the guide pins and other deck equipment [19].

Testing requirements for anchor handling equipment similar to the requirements applied in the tug guidelines have been included in the rules and cover load testing at the manufacturer's workshop, function testing on board (normal operation and emergency mode) and operational testing (in particular for the emergency quick-release) [19].

#### FURTHER DEVELOPMENT

As described in the sub-section on regulatory developments there is an on-going work programme in IMO to amend the Intact Stability Code to include anchor handling stability criteria. BV technical experts will continue to participate in the Correspondence Group dealing with this subject and contribute to the developments. It is preferred to keep the BV rules in line with the regulatory developments at IMO level in order to achieve a harmonised international regulatory framework.

One of the key topics to be addressed by the correspondence group is the introduction of an area requirement for anchor handling stability. It is considered that the present requirement for an maximum heeling angle corresponding to a GZ value equal to 50 per cent of  $GZ_{max}$ , intended to maintain a safe margin against capsizing (through immersion of down-flooding points) is overly simplified and could effectively be replaced by a more precise and technically justifiable area requirement. Two interesting options are available from the tug guidelines, as described in the previous section:

1. Application of an energy balance requirement requiring that the amount of righting energy is to be equal to or greater than the available heeling energy on the basis of the anticipated heeling arm curve in analogy with the towing stability criterion, see Figure 2;
2. Application of comparative requirements between the areas under the heeling arm curve and righting arm curve in analogy with the escort stability criteria, see Figure 4.

The first option is to be considered as an emergency (survival) criterion, while the second option is to be considered as an operability criterion [2]. In order to apply either one for anchor handling a technically coherent formulation of the heeling arm as function of the heeling angle is to be derived. In fact, this is a necessary step for any area requirement, as the distribution of the heeling arm over the range of heeling angles greatly influences the

areas. It is considered that further research into this subject is required in order to come to a satisfactory stability criterion providing a safe margin against capsizing.

Another key topic requiring further development is the explicit inclusion of the available bollard pull during anchor handling in the assessment of the permissible wire tension. As described in the sub-section on safety issues, loss of stability due to water on deck caused by the vessel being pulled astern due to insufficient bollard pull is an important safety risk, which is also recognised and addressed by the NMD by requiring a vessel specific curve of the maximum available continuous bollard pull for anchor handling as function of the power balance, taking into account the power demand of the anchor handling equipment (e.g. winch pumps) and side propellers or azimuth thrusters for maintaining heading and/or position [7,16].

A logical way forward would be to connect the maximum available continuous bollard pull, or effective bollard pull, to the permissible tension tables/curves. This can be achieved by setting the effective bollard pull  $BP_{\text{eff}}$  as limit value for the longitudinal component of the wire tension  $T_{Wx}$  as follows, see Figure 11:

$$BP_{\text{eff}} \geq T_{Wx} = T_W \cdot \cos\alpha \cdot \cos\beta \quad (7)$$

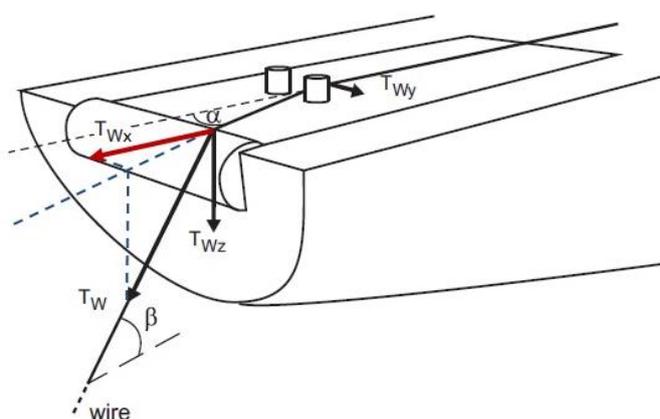


Figure 11: Effective bollard pull as limit value for the permissible wire tension

The implementation of this simple criterion requires that the electrical load balance (power balance) during anchor handling operation is known. This can be achieved by the development of typical load balances for different operating conditions. Particular attention is to be paid to the power demand of the anchor handling equipment and the propulsion units, which depend on the type of operation (e.g. type and weight of anchor, water depth) as well as the environmental conditions (e.g. waves, swell, current and wind). Loss of bollard pull associated with the orientation angle of azimuth thrusters is to be explicitly taken into account. In order to ensure sufficient margin against being pulled astern, a safe margin is to be included in the load balances.

A pragmatic way of implementing the effective bollard pull criterion would be to include the load balances in the on-board loading computer, whereby the master can select the appropriate condition suitable for the intended operation. A direct link with the actual (measured) values of the angles  $\alpha$  and  $\beta$  and the wire tension would provide an on-line decision support system taking into account both stability and bollard pull considerations.

## CONCLUSION

The draft *Safety Guidelines for Design, Construction & Operation of Tugs*, which had been issued in 2010 on the within the scope of the SafeTug JIP have been extensively revised on the basis of experience feedback received from key stakeholders in the towing industry and on-going technical developments. While the basic principles set out at the beginning of the project remain in place a greater level of applicability and practicality have been achieved. Important improvements have been made with respect to towing and escort stability criteria,

requirements for acceptance of escort performance prediction by computer simulation and requirements the functionality, structural strength and testing of towing and escorting equipment. The “safety matrix” with safety equipment requirements applicable to ships of less than 500 GRT has been slightly updated. The chapter on the interaction between the tug and the assisted ship has been rewritten to give more emphasis to the challenges encountered during actual operations. Important issues regarding the strength and location of towing fittings and pushing areas on the assisted ship, as well as the safe speed for making fast, require urgent attention and action from all stakeholders involved, both with regard to design (regulations) and operational procedures.

BV will proceed to incorporate the requirements into its classification rules for tugs. Furthermore, in order to meet the objective of harmonisation BV has proposed IACS to submit an information paper with a proposal for harmonised towing (and escort) stability criteria on the basis of the guidelines to the IMO for consideration and possible inclusion in the Intact Stability Code.

Even if the revised guidelines are considered to be on par with the needs of the towing industry and can effectively be applied, further developments are anticipated to provide extended guidance for innovative tug designs, in particular with regard to stability. Further development of the towing and escort stability requirements is envisaged with a view to link the operational capabilities to an associated safe (escort) speed on the basis of dynamic simulations. Furthermore, it is considered that the behaviour of the combined system of escort tug, winch and towline requires further study, with particular attention to the effect of the use of high elasticity towlines used for escorting.

With regard to anchor handling BV has introduced a new service notation **anchor handling vessel**. The class notation and associated technical requirements, which entered into force on 1 January 2014, address intact stability during anchor handling and structural design principles of anchor handling equipment and associated supporting structures, as well as testing requirements. The stability requirements incorporate the latest technical developments in the industry, as well as the relevant regulatory developments within the IMO, in which BV is actively participating. The structural design principles for the anchor handling equipment are based on the same holistic approach as applied for the tug guidelines (system approach), although the parameters considered and their values (e.g. dynamic effects) take into consideration the specific characteristics of anchor handling vessels and operations.

Same as for tugs, BV strongly supports the establishment of a harmonised international regulatory framework for anchor handling vessels. Therefore, BV technical experts will continue to participate to the regulatory developments at the IMO level, which will be taken into consideration for the further development of the rules. Another important topic for further development is the inclusion of the effective bollard pull during anchor handling operations into the criteria defining the permissible wire tension, as addresses the safety issues related to the vessel being pulled astern due to insufficient bollard pull. A brief outline of the work to be undertaken has been presented in this paper.

With the introduction of the new regulatory framework for towing and anchor handling vessels BV is setting future-proof standards with regard to safety and reliability, whereby a pragmatic approach is combined with an open minded attitude towards the innovative design solutions proposed by the industry. A key contributor to the successful implementation of these regulations has been the continuous involvement of major industry stakeholders.

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