INTACT STABILITY REQUIREMENTS

FOR TUGS

WITH APPLICATION TO FAIRPLAY 22

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1 Introduction

In this report the stability requirements as currently internationally applied to tugs are investigated and applied to the design of the tug Fairplay 22.

2 Summary

2.1 General

First the intact stability requirements are generally discussed, then the basic information and assumptions are given of the tug Fairplay 22, after which typical loading conditions are calculated and evaluated against the various stability requirements.

2.2 Intact stability requirements for tugs

Until recently, only a few Classification Societies or Flag Authorities had explicit requirements to the stability of tugs. However, in the mean time almost all major Classification Societies have formulated requirements.

In the case of stability of tugs the following aspects are determining the final safety:

a) The heeling moment occuring during towing
b) The applied safety margin to consider the tug 'safe'

It turns out that the opinion of the various Authorities differ on both aspects, so that the safety of the same tug is judged different by the various Authorities.

The heeling moment.

The heeling moment can be caused:

a) By the tow, this is called tow tripping, this happens when the tug is dragged by the tow, via the towline at a certain speed and a certain course through the water. Decisive are the lateral area of the tug, the speed of the tow and the angle of the tug with respect to the course of the tow.
b) By the tug, this is called self-tripping, the heeling moment is then caused by the combined action of rudders, propellers and the towline force or hydrodynamic lateral force on the hull. Decisive are the thrust forces or bollard pull of the tug
c) By a combination of tow and tug

Towed by the tow: Tow tripping. Speed of tow and breaking load of towline are decisive.


Towing on fixed object. Self tripping

Only few publications are available for the explicit calculation of the tow tripping moment, e.g. of US Coast Guard and of German Navy, while VBD (Versuchsanstalt für Binnenschifffahrt Duisburg) published a method to calculate the tow tripping moment as function of speed and water depth. The towing speed is shown to have a quadratic influence on the tow tripping moment.

The heeling moment, or heeling arm (heeling moment divided by displacement) is related by most investigated Authorities, to the bollard pull, as follows:

$$HA = \frac{c \cdot BP \cdot d}{\Delta} \cdot \cos^n \theta$$

where :

$c =$ factor to obtain lateral thrust as fraction of bollard pull

BP = bollard pull

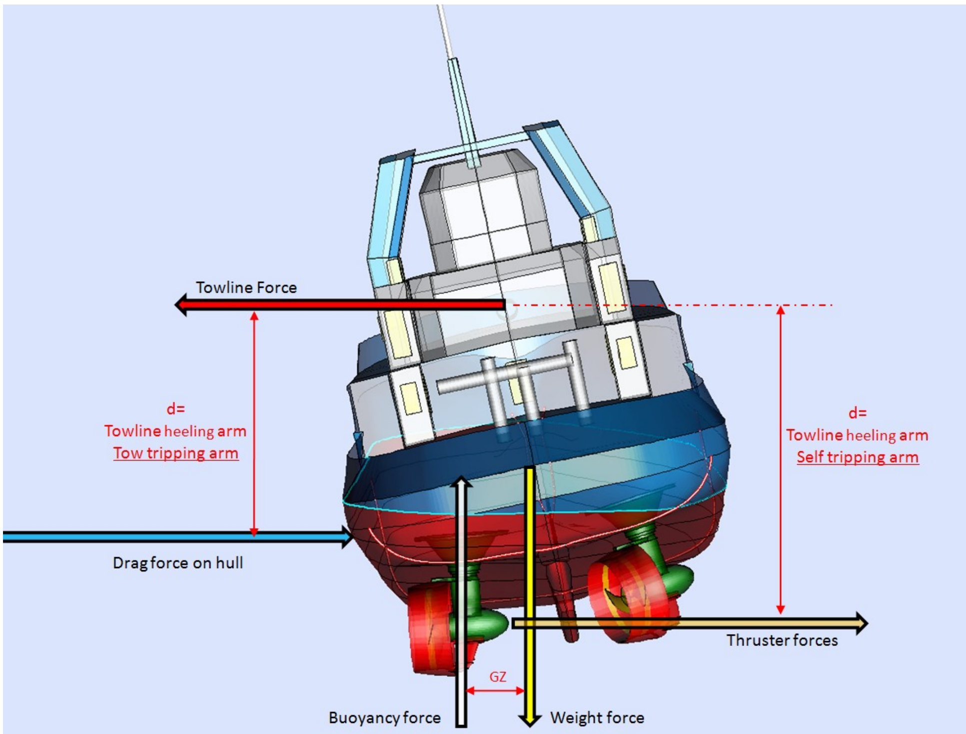
d= towline arm: distance between towing point and centre of effort: lateral area or propeller centre line

Δ = displacement

n= coefficient 0: horizontal line; 1: cosinus

θ = heeling angle

The meaning of d, the towline arm, is depicted in the following figure:



definition towline arm: distance between (highest) towing point and centre of thrusters (self tripping) or centre of lateral area (tow tripping)

d as tow tripping arm:

Some Authorities (ABS, BV, GL) have addressed the tow tripping danger, by choosing the centre of effort as function of the the lateral area (be it at ½ T or be at the VCB (vertical centre of buoyancy)).

d as self tripping arm:

Others Authorities (USCG, DNV, BV harmonized, IACS) have apparently chosen to address the self-tripping danger, by the choice of the centre of effort in the centre line of the propellers.

As can be seen in the figure, this can lead to considerable differences in the prediction of d.

However, in the current practice with azimuthing thrusters, there will be a combination of both the drag forces and the thrusterforces, which can work in the same direction. The tow tripping approach is therefore considered in case of demanding harbour towage as an underestimate of the heeling moment.

For the various investigated Authorities the properties of the heeling arm curve are summarized as follows, valid for azimuthing propellers:

	heeling arm curve		
	c: towline force = c x Bollard Pull	*d: towline lever towing bitt to*	*n curve*
IMO	**n.a.**	n.a.	n.a.
ABS Tug	**0.7**	½ T	1
USCG	**~1.2**	CL prop	1
DNV tug	**1.0**	CL prop	1
DNV escort tug	**1.0 (steering force)**	CL prop	0
BV Tug	**1.0**	½ T	1
GL tug	**0.7**	VCB	1
GL tug alternative	**0.7**	VCB	1
SBG (old)	**n.a.**	n.a.	n.a.
Harmonized proposal BV Tug	**0.7**	CL prop	1
IACS	**0.7**	CL prop	1

The following fractions of the bollardpull of 55 ton have been applied:

	c: fraction of bollard pull		
	100%	50%	10%
ABS Tug	0.700	0.700	0.700
USCG Towline pull criterion	**1.191**	**1.191**	**1.191**
DNV Tug	1.000	1.000	1.000
Bureau Veritas Tug	1.000	1.000	1.000
GL Tug	**0.700**	**0.700**	**0.700**
IACS Unified interpretation Tug	0.700	0.700	0.700
Harmonized proposal BV	0.700	0.700	0.700

When the appropriate values of T (draught), VCB (vertical centre of buoyancy) and CL prop (centre line propeller) are applied, the following centres of resistance are found. Taking into account the height of the towing point above base, also the values of *d* are found.

	vertical centre of resistance		
	100%	50%	10%
ABS Tug	2.298	2.061	1.865
USCG Towline pull criterion	**1.500**	**1.500**	**1.500**
DNV Tug	1.500	1.500	1.500
Bureau Veritas Tug	2.298	2.061	1.865
GL Tug	**2.757**	**2.473**	**2.238**
IACS Unified interpretation Tug	1.500	1.500	1.500
Harmonized proposal BV	1.500	1.500	1.500

	d towing fwd		
	100%	50%	10%
ABS Tug	6.953	7.190	7.385
USCG Towline pull criterion	**7.750**	**7.750**	**7.750**
DNV Tug	7.750	7.750	7.750
Bureau Veritas Tug	6.953	7.190	7.385
GL Tug	**6.493**	**6.777**	**7.012**
IACS Unified interpretation Tug	7.750	7.750	7.750
Harmonized proposal BV	7.750	7.750	7.750

Then, d is multiplied by the bollardpull to obtain the heeling moment, and then divided by the displacement, to obtain the towline heeling arm:

In meters:

	Heeling arm towing fwd loading condition:		
	100%	50%	10%
ABS Tug	0.277	0.334	**0.399**
USCG Towline pull criterion	**0.525**	**0.612**	**0.713**
DNV Tug	0.441	0.514	0.599
Bureau Veritas Tug	0.396	0.477	0.570
GL Tug	**0.259**	**0.315**	0.379
IACS Unified interpretation Tug	0.309	0.360	0.419
Harmonized proposal BV	0.309	0.360	0.419

As fraction of lowest value:

	Heeling arm towing fwd		
	100%	50%	10%
ABS Tug	1.07	1.06	**1.05**
USCG Towline pull criterion	**2.03**	**1.95**	**1.88**
DNV Tug	1.71	1.63	1.58
Bureau Veritas Tug	1.53	1.52	1.50
GL Tug	**1.00**	**1.00**	1.00
IACS Unified interpretation Tug	1.19	1.14	1.11
Harmonized proposal BV	1.19	1.14	1.11

The heeling arm predictions can be grouped as follows:

1. The lowest predictions are made by GL and ABS. GL uses the VCB (vertical centre of buoyancy) which is abt 2/3 of the draught, as centre of effort of the lateral forces, with 0.70xBollard pull as force. ABS uses 1/2T as centre of effort, with 0.70xBollard pull as force.
2. The second group consists of IACS and BVharmonized, which both use the centre of the propeller as centre of effort, and 0.70xBollard pull as force.
3. The third group consists of DNV and BV. DNV uses centre of the propeller and 1.00xBollard pull. BV uses half draught but also 1.00xBollard pull
4. The highest prediction is given by USCG, which uses the CL of the propeller, but uses a force of abt 1.19xBollard pull.

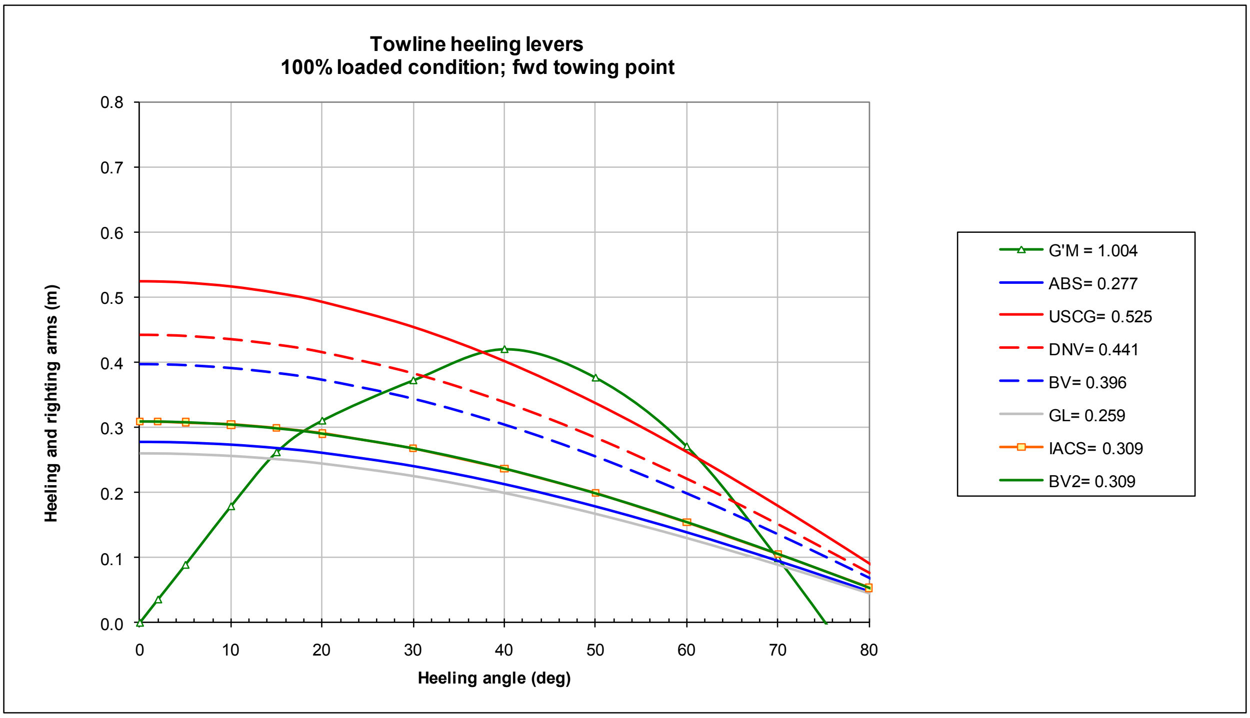
GL and ABS apparently assume tow tripping by lateral resistance of the hull, assuming a relation between bollard pull and transverse speed of the tug.

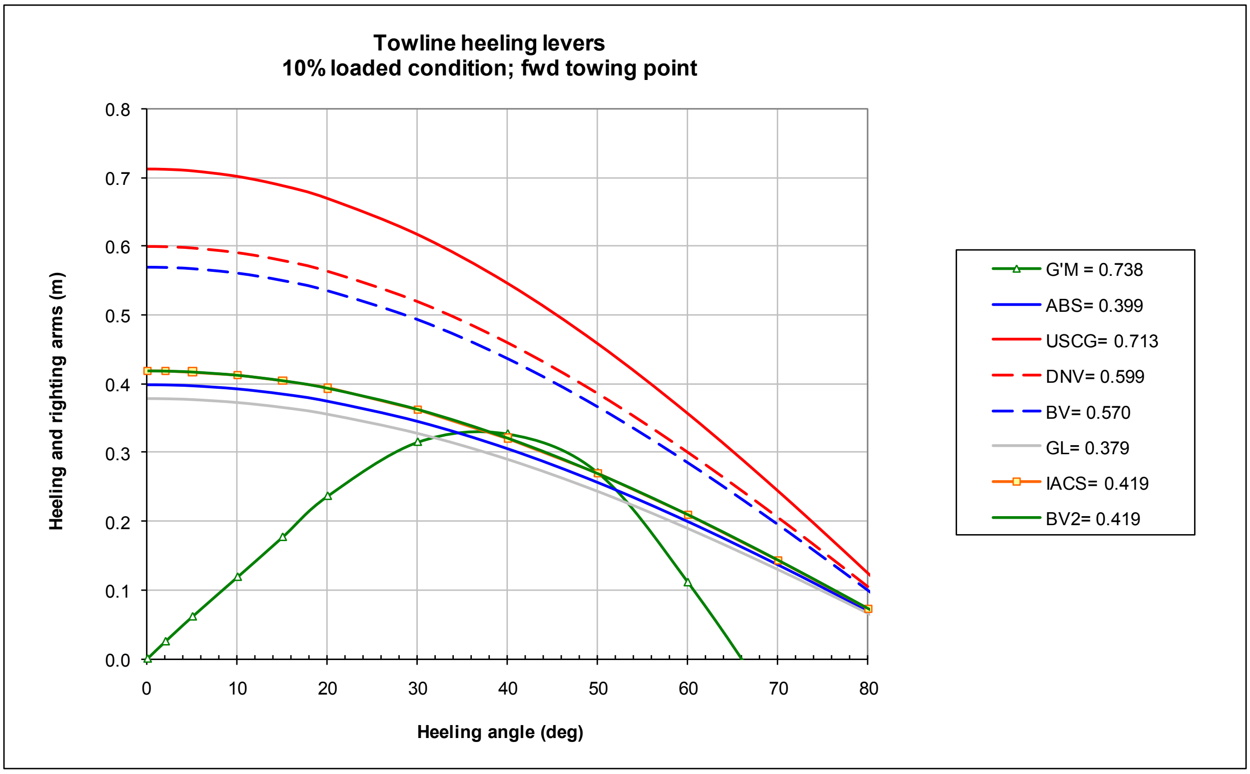
USCG can be assumed as consisting of a self tripping component of 1.0xbollard pull, plus a tow tripping component of 19% of the bollard pull.

For the 100% loaded condition and the 10% loaded condition this is summarized in the following diagrams, showing the stability curve GZ together with the towline heeling levers of the various Authorities and Classification Societies.

We see e.g. that the heeling angle predicted by USCG is close to 40º in the 100% condition, while no equilibrium is found in the 10% loaded condition.

The heeling angle predicted by e.g. IACS is close to 20º in the 100% loaded condition and 40º in the 10% condition.





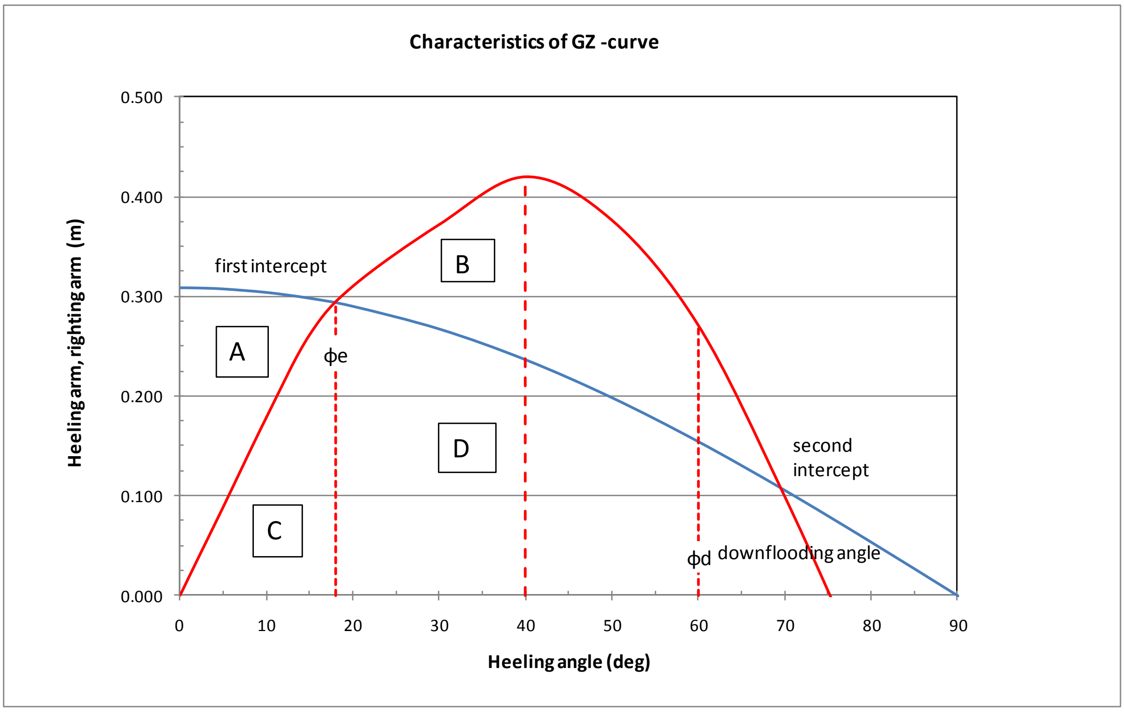
Conclusion Towline heeling arms:

There is a large difference in prediction of the towline heeling arm and subsequent heeling angle, between the various classification societies.

There is also a large difference between the 100% loaded displacement and the 10% loaded condition.

Requirements to safety margin:

The safety margins can be applied in two ways: as an absolute requirement expressed in meter x radian, or as a fraction or percentage of the area of the heeling arm curve. Further various upper limits are used, in all cases the downflooding angle, but also the second intercept, 40º, angle where GZ is maximal.



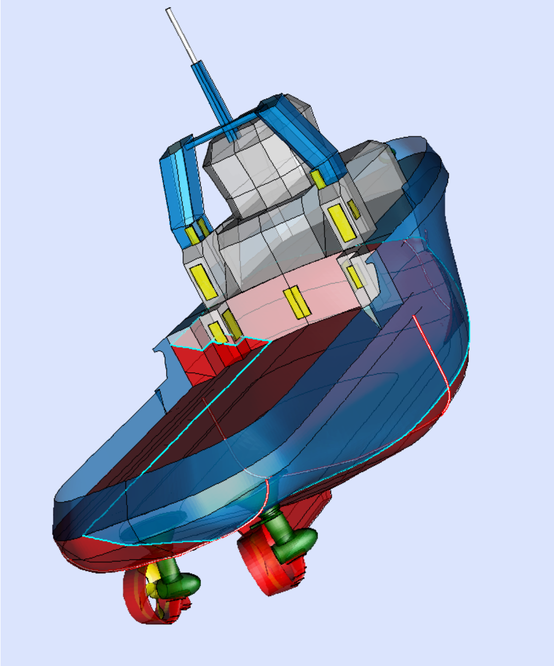
The requirements of the various Authorities are given in the next table:

	requirements to residuary stability		
	from:	*to the lesser of:*	*area:*
IMO			
ABS Tug	first intercept	a. first intercept + 40º b. downflooding	B>**0.09** mrad
USCG	first intercept	a. max arm b. 40º c. downflooding	B>**0.0106** mrad
DNV tug	first intercept	a. second intercept b. downflooding	>**0.09** mrad
DNV tug alternative	0º	a. second intercept b. downflooding	area righting curve > **1.40** x area heeling curve
DNV escort tug	first intercept	a. 20º	area righting curve > **1.25** x area heeling curve
	0º	a. 40º b. downflooding	area righting curve > **1.40** x area heeling curve
BV	first intercept	a. max arm b. 40º c. downflooding	B> **0.011** mrad
GL tug	first intercept	a. second intercept b. downflooding	B> **0.09** mrad
GL tug alternative	0º	a. second intercept b. downflooding	area righting curve > **1.40** x area heeling curve
SBG old			
Harmonized proposal BV	0º	a. second intercept b. downflooding	area righting curve > **1.00** x area heeling curve (B>A) Freeboard at first intercept >0
IACS	first intercept	a. second intercept b. downflooding	B>**0.09** mrad
IACS alternative	0º	a. second intercept b. downflooding	area righting curve > **1.4** x area heeling curve

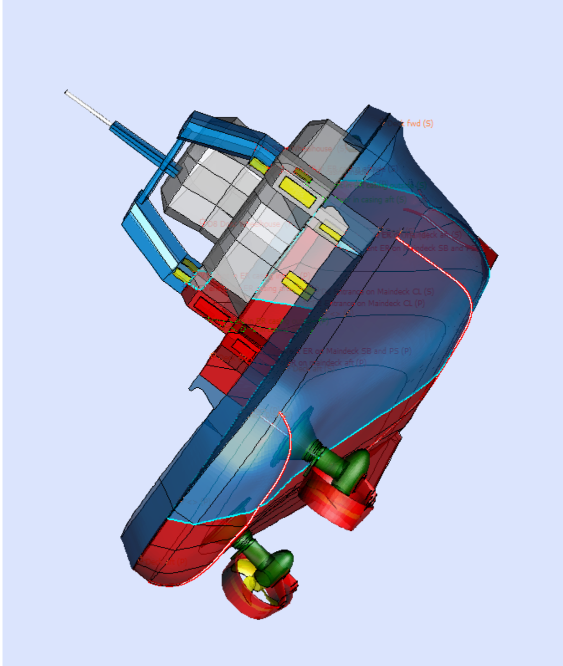
Before analyzing the safety margins according these requirements, first the limiting condition of downflooding and heeling angle is discussed.

2.3 Downflooding through ventilation openings

The ventilation openings and doors are shown in the following picture with an inclination of 30º and 60º, for the 100% loading condition.



100% loaded: downflooding starts at abt 30º when ventilation openings are not closed



100% loaded: downflooding starts at abt 60º when ventilation openings are closed

With reference to the ventilation openings two regulations need to be taken into account:

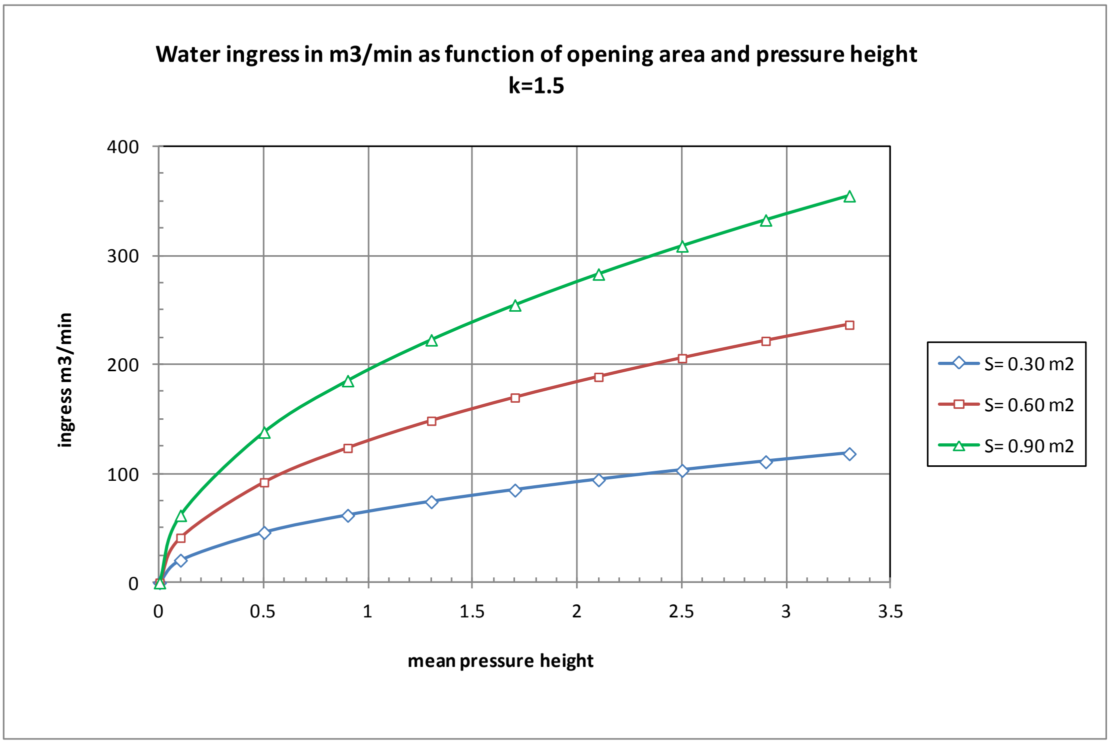
1. The Loadline Convention
2. The stability requirements, in this case those of SBG

According to the Loadline Convention Regulation 17 the ventilation openings need not be fitted with weathertight closing arrangements, when they are positioned more than 25% of the length abaft the forward perpendicular, and more than 2.3 m above the deck.

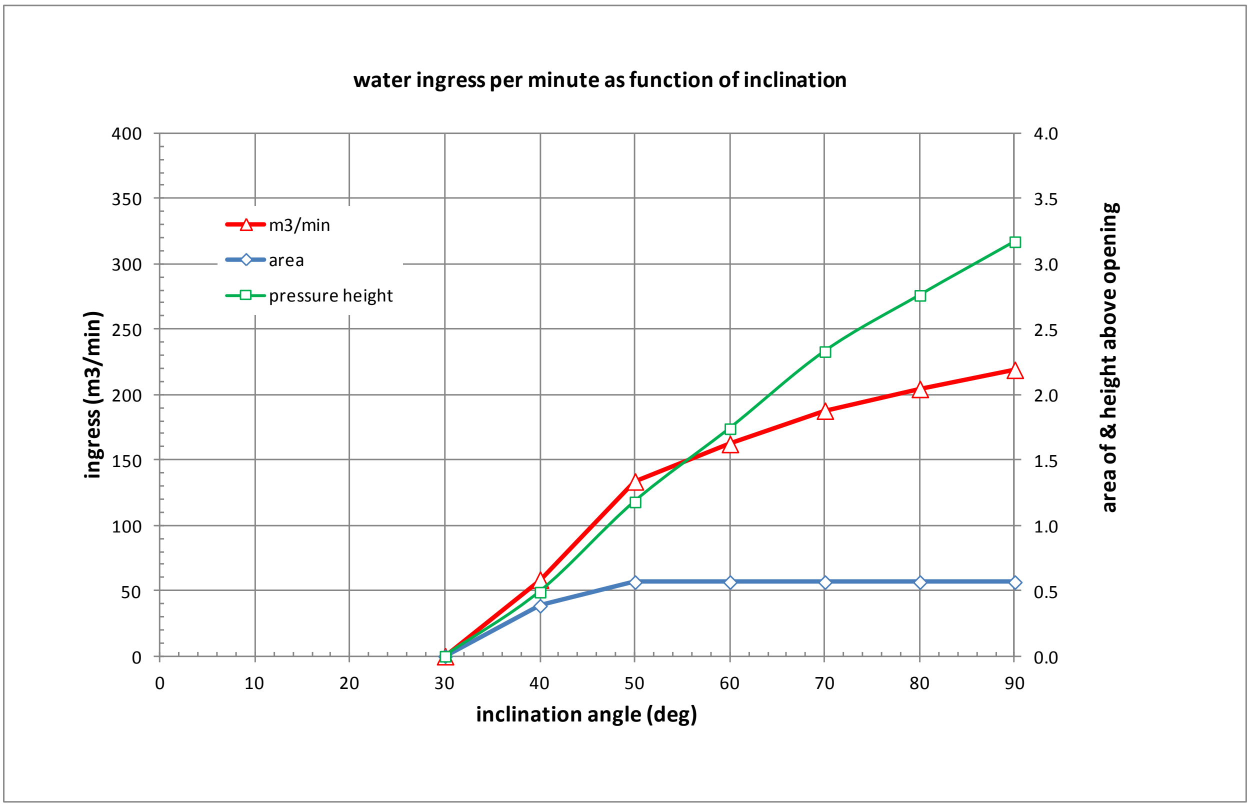
In this case all ventilation openings on the aftdeck are have a coamingheight of less than 2.30 m and are provided with weathertight closing devices. These weathertight closing devices should be used i.e be closed, in dangerous situations. Towing and the more towing in a storm has to be considered as such. Weathertight means: “that in any sea conditions water will not penetrate into the ship”. Or in Dutch: ‘zodanig dicht dat onder alle omstandigheden die zich op zee kunnen voordoen, geen water in het vaartuig kan binnendringen’.

According the stability requirements of SBG, the stability should have a range of 60º. This can only be achieved when all ventilation openings, with exeption of the upper ones, are closed. All other openings will enter the water at inclination angles between abt. 30º and 60º.

The amount of water that can enter the ship as function of pressure height and area of the opening is given in the following graph. The waterflow in m^3/h is given for various values of S (area of opening) and dh (pressure height in m above opening).



In the hydrostatic model the submerged opening area and the pressure height at teh engineroom ventilation casings was measured at angles between 30 and 90 degrees. These values are given in the next diagram, including the calculated waterflow per minute. E.g. at 80 degrees 200 ton/minute.



water ingress as function of inclination through engine room ventilator

2.4 Heeling angle

The equilibrium inclination angle that can be accepted, after applying the towline load, is mentioned by the following Authorities:

- DNV Escort Tug requirements requests a 25% reserve stability between equilibrium angle and 20º , this can not be achieved when the equilibrium inclination is much more than 10-12º
- The NMD (Norwegian Maritieme Directorate) Rules for anchor-handlers require a maximum angle of 15º
- BV/Harmonized proposal requires a freeboard>0 at equilibrium angle

Not all Authorities do stipulate requirements to the absolute equilibrium heeling angle and/or a positive freeboard at equilibrium.

However, for reasons of prudent design, good seamanship with respect to safety of the crew and the prevention of loss of controllability of the tug when the deckedge ships water, the additional requirement is applied in this report, that the angle of heel in the equilibrium condition, should be limited to 15º or to the angle where the deck immerges, whichever is the smallest. The lack of this requirement is considerd an omission in the concerning Regulations.

Inclination of abt 15º

With these additional assumptions an analysis is made of the requirements of the various Authorities.

2.5 Summary of evaluation of safety criteria

2.5.1 Extent

The safety criteria are evaluated for three significant loading conditions, without foam on board, and using the forward towing point, in the following variations:

With closed ventilation openings:

All ventilation openings and doors closed, exept V2 and V3, the two highest openings in the casing, submerging at an inclination of about 60º.

100% loaded
50% loaded
10% loaded

With opened ventilation openings:

Apart from V2 and V3, also the ventilation openings on the maindeck, V9 and V10, the door on CL, the doors in the casing and the ventilation opening in outside casing are considered open.

100 % loaded
50% loaded
10% loaded

With closed ventilation openings and ballast:

In the 50% and 10% condition, the ballasttanks in the double bottom and in the aft peak are filled to decrease the center of gravity.

50% loaded + ballast
10% loaded + ballast

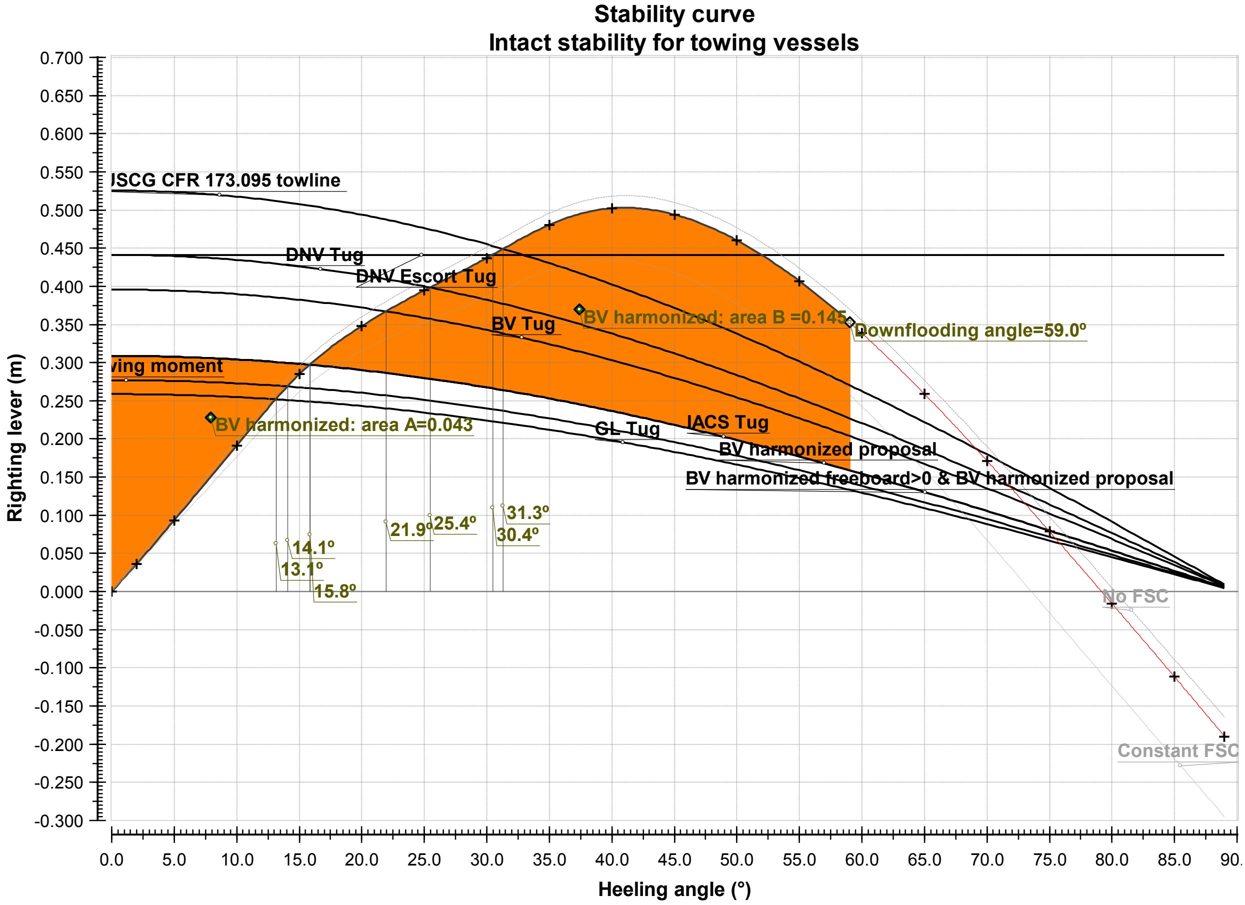
With opened ventilation openings and ballast:

50% loaded + ballast
10% loaded + ballast

These conditions are given in full in a separate volume, the final diagrams and evaluation of the criteria are given as summary in the next paragraph.

2.5.2 With closed ventilation openings

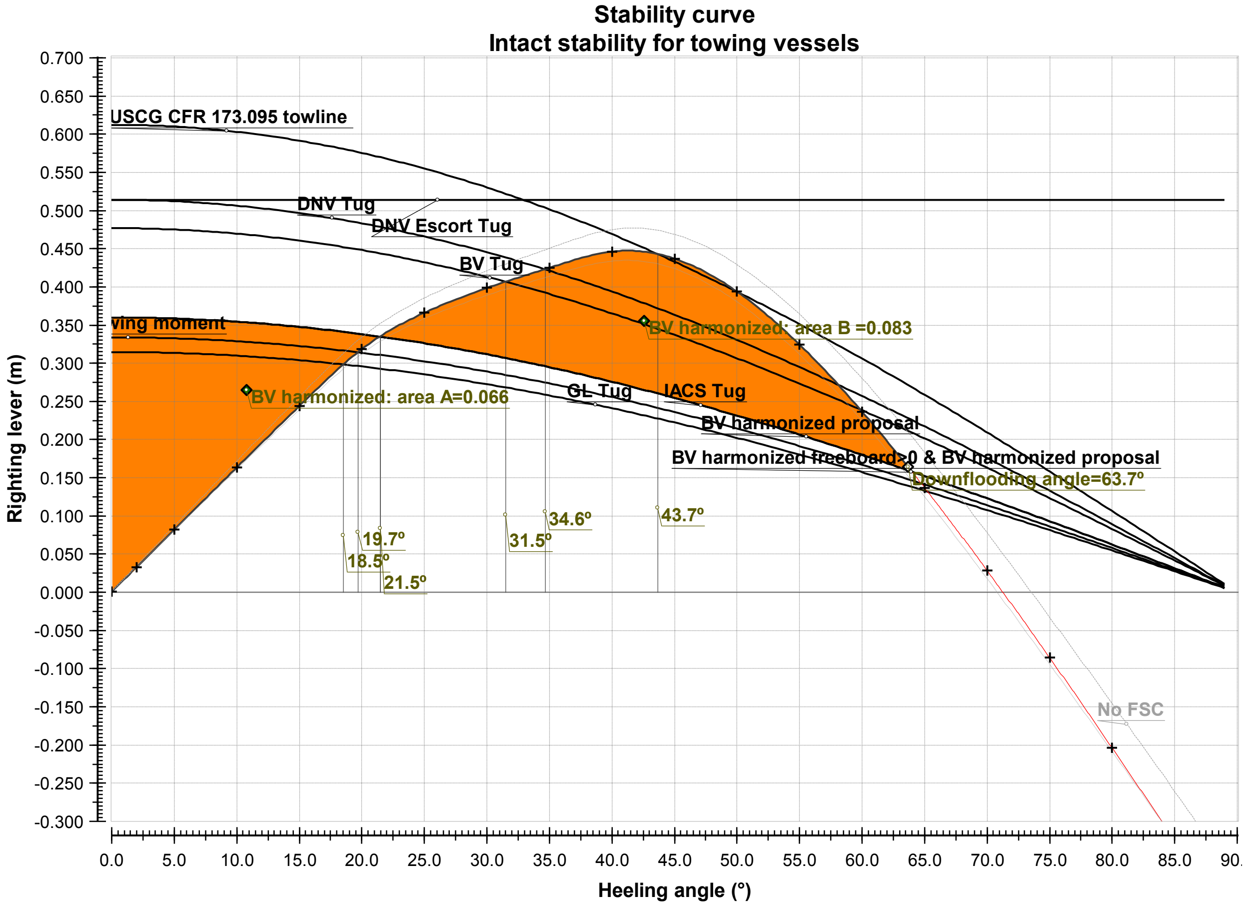
2.5.2.1 100% with closed ventilation



Intact stability for towing vessels						
Tugs						
Description	**Attained value**		**Criterion**	**Required value**		**Complies**
ABS Towing moment	14.1	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	267.65	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.1440	*(mrad)*	>=	0.0900	*(mrad)*	YES
USCG CFR 173.095 towline	31.3	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0103	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	25.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0778	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.3672	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.3782	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.9710		>=	1.4000		NO
DNV Escort Tug	30.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.2171	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.3080	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.7049		>=	1.4000		NO
BV Tug	21.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	382.36	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0333	*(mrad)*	>=	0.0110	*(mrad)*	YES
GL Tug	13.1	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	249.98	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.1756	*(mrad)*	>=	0.0900	*(mrad)*	YES
GL Tug area GZ 0-min(second intercept, downflooding)	0.3672	*(mrad)*	>=	0.0000	*(mrad)*	YES
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.2218	*(mrad)*	>=	0.0000	*(mrad)*	YES
GL Tug area GZ > 1.40 area heeling arm	1.6556		>=	1.4000		YES
IACS Tug	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.1451	*(mrad)*	>=	0.0900	*(mrad)*	YES
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.3672	*(mrad)*	>=	0.0000	*(mrad)*	YES
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.2648	*(mrad)*	>=	0.0000	*(mrad)*	YES
IACS Tugs area GZ > 1.40 area heeling arm	1.3871		>=	1.4000		NO
BV harmonized proposal	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0427	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.1451	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	3.4015		>=	1.0000		YES
BV harmonized freeboard>0	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	15.8	*(Degr.)*	<	11.7	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

ABS
BV Tug
GL Tug area yes, angle no
IACS
BV Harmonized

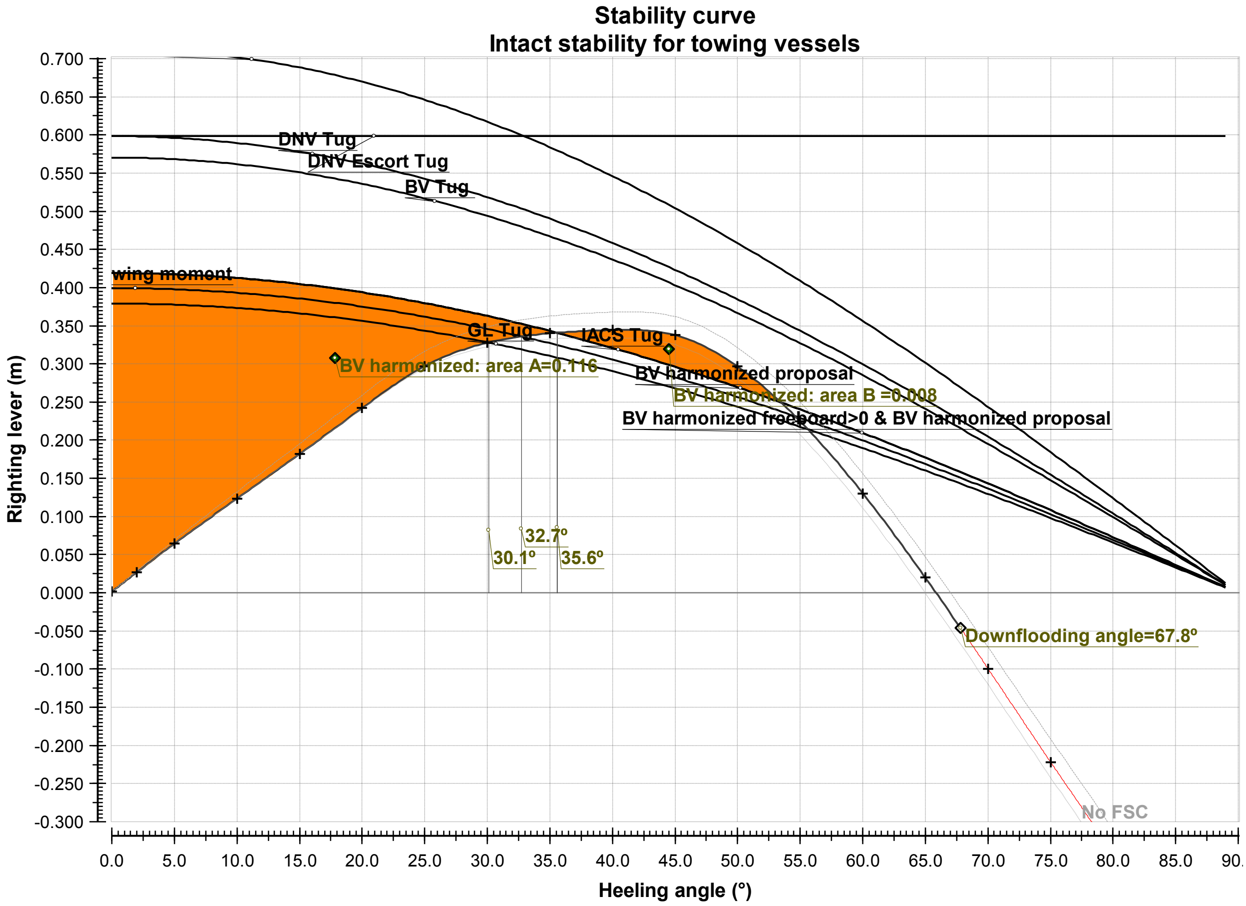
2.5.2.2 50% with closed ventilation



Description	Attained value		Criterion	Required value		Complies
Intact stability for towing vessels						
Tugs						
ABS Towing moment	19.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	276.78	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0936	*(mrad)*	>=	0.0900	*(mrad)*	YES
USCG CFR 173.095 towline	43.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	34.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0195	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.3174	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.4359	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.7281		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	NO
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	NO
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	31.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	395.39	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0062	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	18.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	260.91	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.1077	*(mrad)*	>=	0.0900	*(mrad)*	YES
GL Tug area GZ 0-min(second intercept, downflooding)	0.3387	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.2817	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	1.2023		>=	1.4000		NO
IACS Tug	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0826	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.3387	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.3221	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	1.0513		>=	1.4000		NO
BV harmonized proposal	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0661	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0826	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	1.2501		>=	1.0000		YES
BV harmonized freeboard>0	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	21.5	*(Degr.)*	<	16.7	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

ABS }
GL Tug } area yes, angle no
BV Harm }

2.5.2.3 10% with closed ventilation

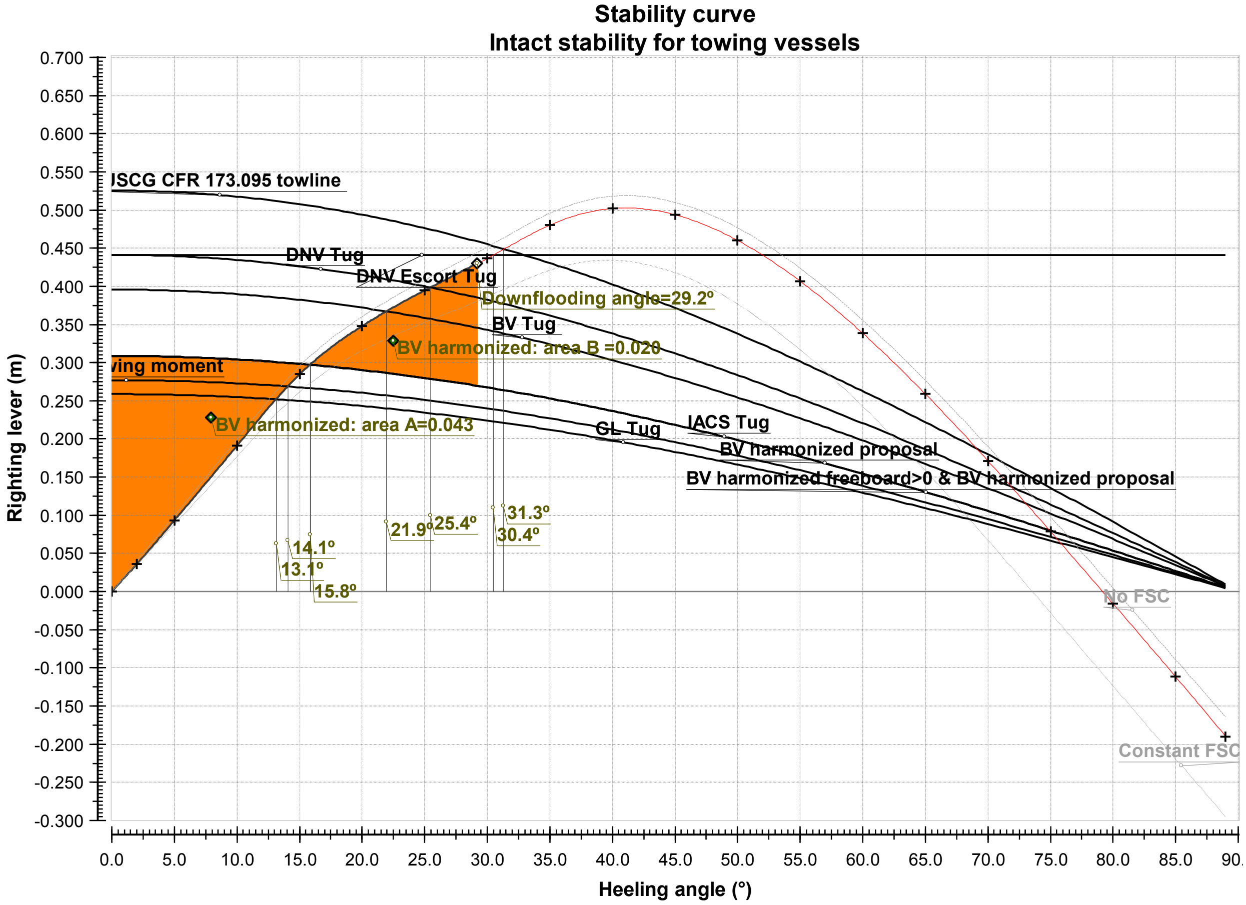


Intact stability for towing vessels						
Tugs						
Description	**Attained value**		**Criterion**	**Required value**		**Complies**
ABS Towing moment	32.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	284.32	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0130	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0000	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.0000		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	406.17	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0000	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	30.1	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	269.96	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0190	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.2363	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.3121	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	0.7571		>=	1.4000		NO
IACS Tug	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0081	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.2276	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.3358	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.6777		>=	1.4000		NO
BV harmonized proposal	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.1163	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0081	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.0692		>=	1.0000		NO
BV harmonized freeboard>0	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	35.6	*(Degr.)*	<	20.9	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

All no

2.5.3 With opened ventilation openings

2.5.3.1 100% with open ventilation



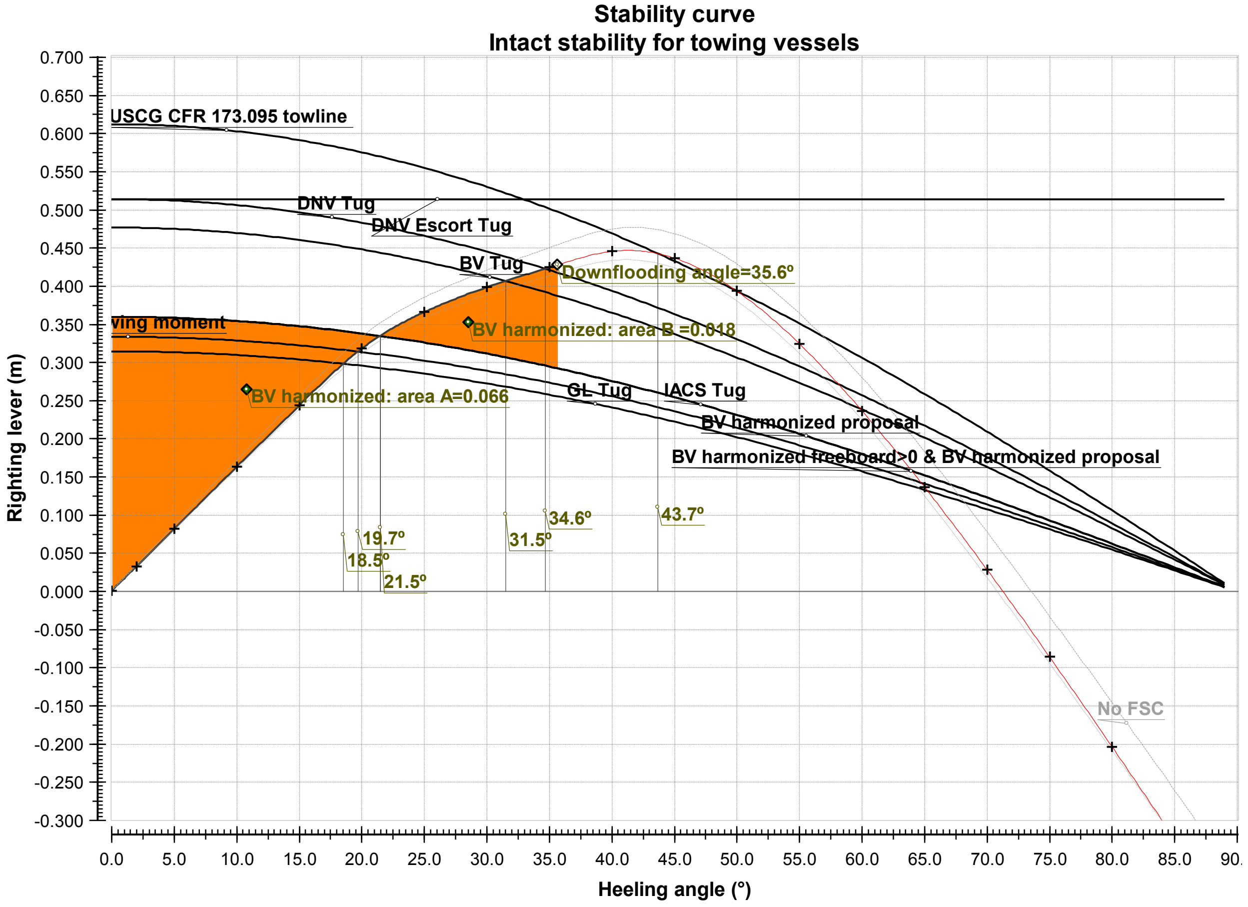
Intact stability for towing vessels

Tugs

Description	Attained value		Criterion	Required value		Complies
ABS Towing moment	14.1	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	267.65	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0272	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	31.3	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	25.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0015	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.1278	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.2152	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.5939		>=	1.4000		NO
DNV Escort Tug	30.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.1278	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.2248	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.5685		>=	1.4000		NO
BV Tug	21.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	382.36	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0054	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	13.1	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	249.98	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0318	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.1278	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.1262	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	1.0127		>=	1.4000		NO
IACS Tug	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0198	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.1278	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.1506	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.8485		>=	1.4000		NO
BV harmonized proposal	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0427	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0198	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.4651		>=	1.0000		NO
BV harmonized freeboard>0	15.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	15.8	*(Degr.)*	<	11.7	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

All no

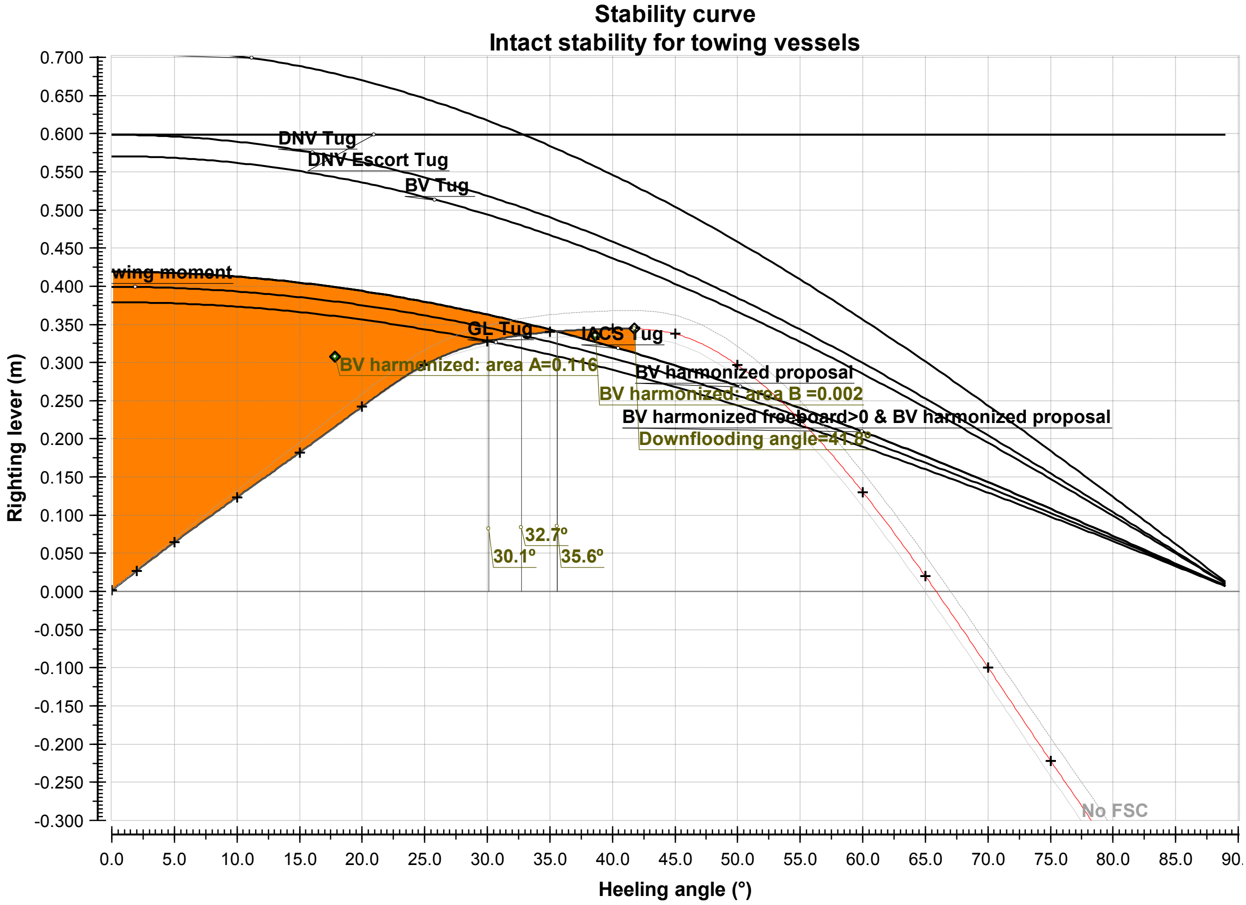
2.5.3.2 50% with open ventilation



Intact stability for towing vessels						
Tugs						
Description	**Attained value**		**Criterion**	**Required value**		**Complies**
ABS Towing moment	19.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	276.78	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0238	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	43.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	34.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0001	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.1609	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.2989	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.5385		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	31.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	395.39	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0015	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	18.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	260.91	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0287	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.1609	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.1829	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	0.8798		>=	1.4000		NO
IACS Tug	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0178	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.1609	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.2092	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.7693		>=	1.4000		NO
BV harmonized proposal	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0661	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0178	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.2695		>=	1.0000		NO
BV harmonized freeboard>0	21.5	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	21.5	*(Degr.)*	<	16.7	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

All No

2.5.3.3 10% with open ventilation



Intact stability for towing vessels

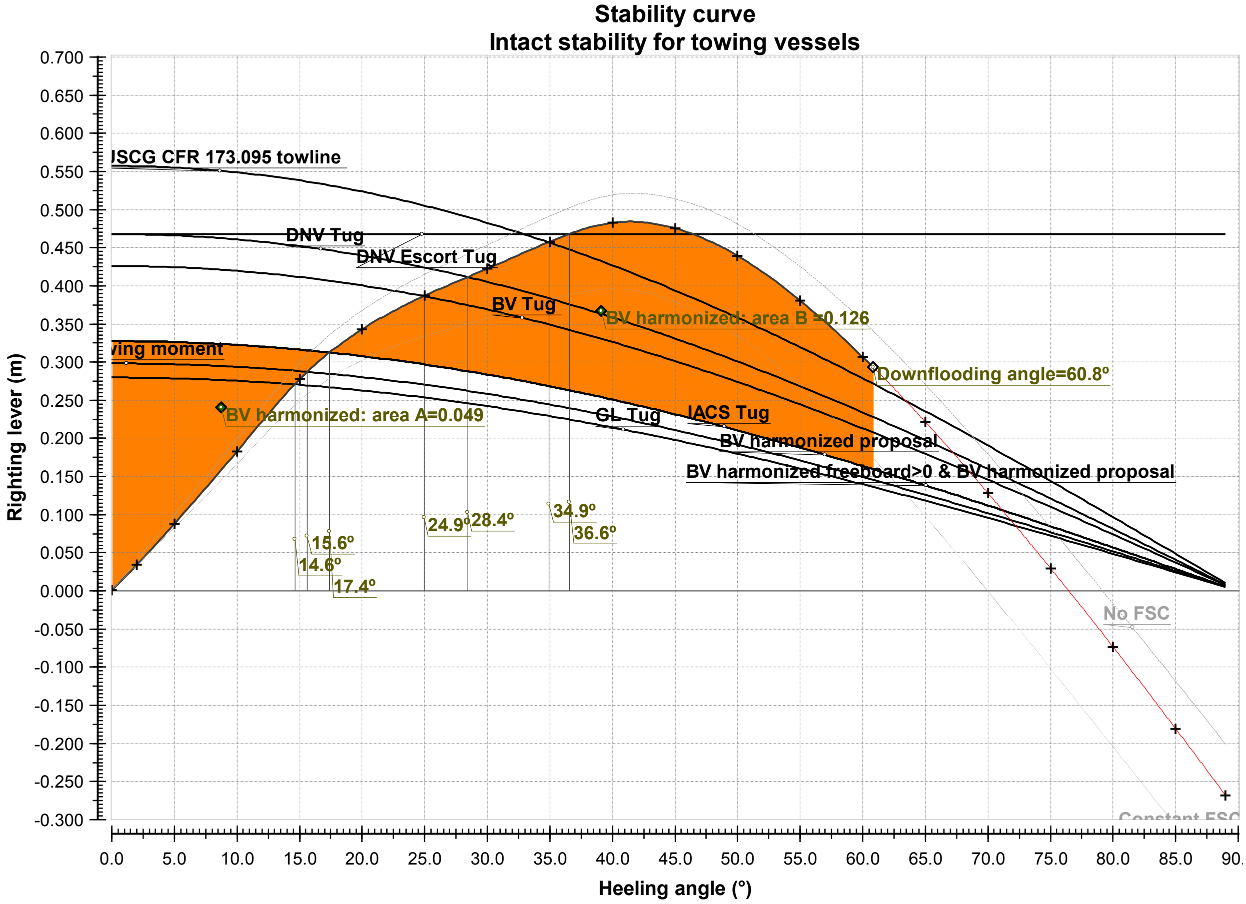
Tugs

Description	Attained value		Criterion	Required value		Complies
ABS Towing moment	32.7	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	284.32	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0038	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0000	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.0000		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	406.17	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0000	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	30.1	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	269.96	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0068	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.1637	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.2518	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	0.6504		>=	1.4000		NO
IACS Tug	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0018	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.1637	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.2783	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.5884		>=	1.4000		NO
BV harmonized proposal	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.1163	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0018	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.0153		>=	1.0000		NO
BV harmonized freeboard>0	35.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	35.6	*(Degr.)*	<	20.9	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

All NO

2.5.4 With closed ventilation openings and ballast

2.5.4.1 50% with closed ventilation + ballast



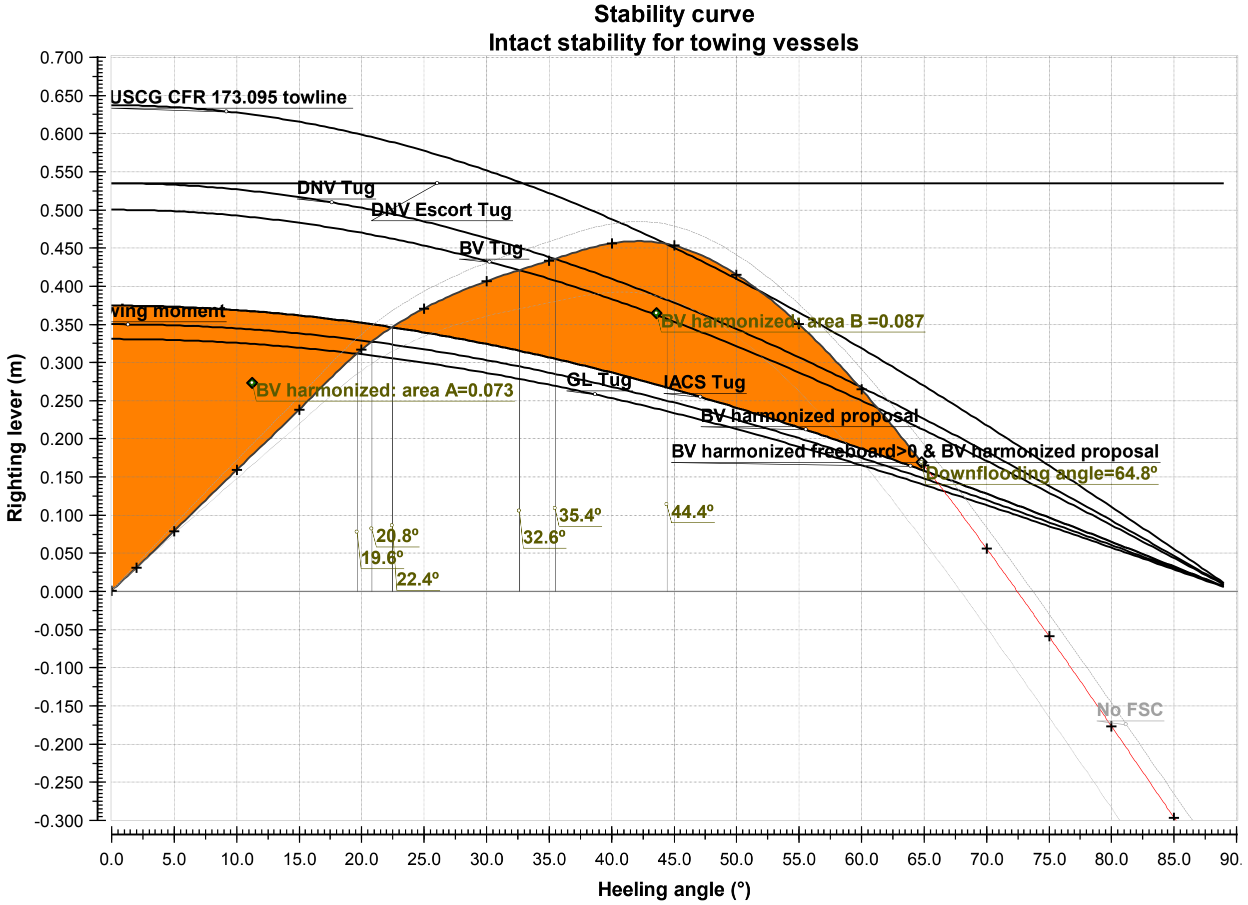
Intact stability for towing vessels

Tugs

Description	Attained value		Criterion	Required value		Complies
ABS Towing moment	15.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	271.69	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.1274	*(mrad)*	>=	0.0900	*(mrad)*	YES
USCG CFR 173.095 towline	34.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0041	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	28.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0578	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.3625	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.4081	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.8884		>=	1.4000		NO
DNV Escort Tug	36.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.2100	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.3261	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.6439		>=	1.4000		NO
BV Tug	24.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	388.14	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0212	*(mrad)*	>=	0.0110	*(mrad)*	YES
GL Tug	14.6	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	254.79	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.1549	*(mrad)*	>=	0.0900	*(mrad)*	YES
GL Tug area GZ 0-min(second intercept, downflooding)	0.3625	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.2439	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	1.4862		>=	1.4000		YES
IACS Tug	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.1263	*(mrad)*	>=	0.0900	*(mrad)*	YES
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.3625	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.2856	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	1.2691		>=	1.4000		NO
BV harmonized proposal	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0494	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.1263	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	2.5553		>=	1.0000		YES
BV harmonized freeboard>0	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	17.4	*(Degr.)*	<	13.5	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

ABS: area yes, angle no
BV Tug: area yes, angle no
GL Tug: area yes, angle no
IACS: area yes, angle no
BV harm, area yes, angle no
All no

2.5.4.2 10% with closed ventilation with ballast



Intact stability for towing vessels

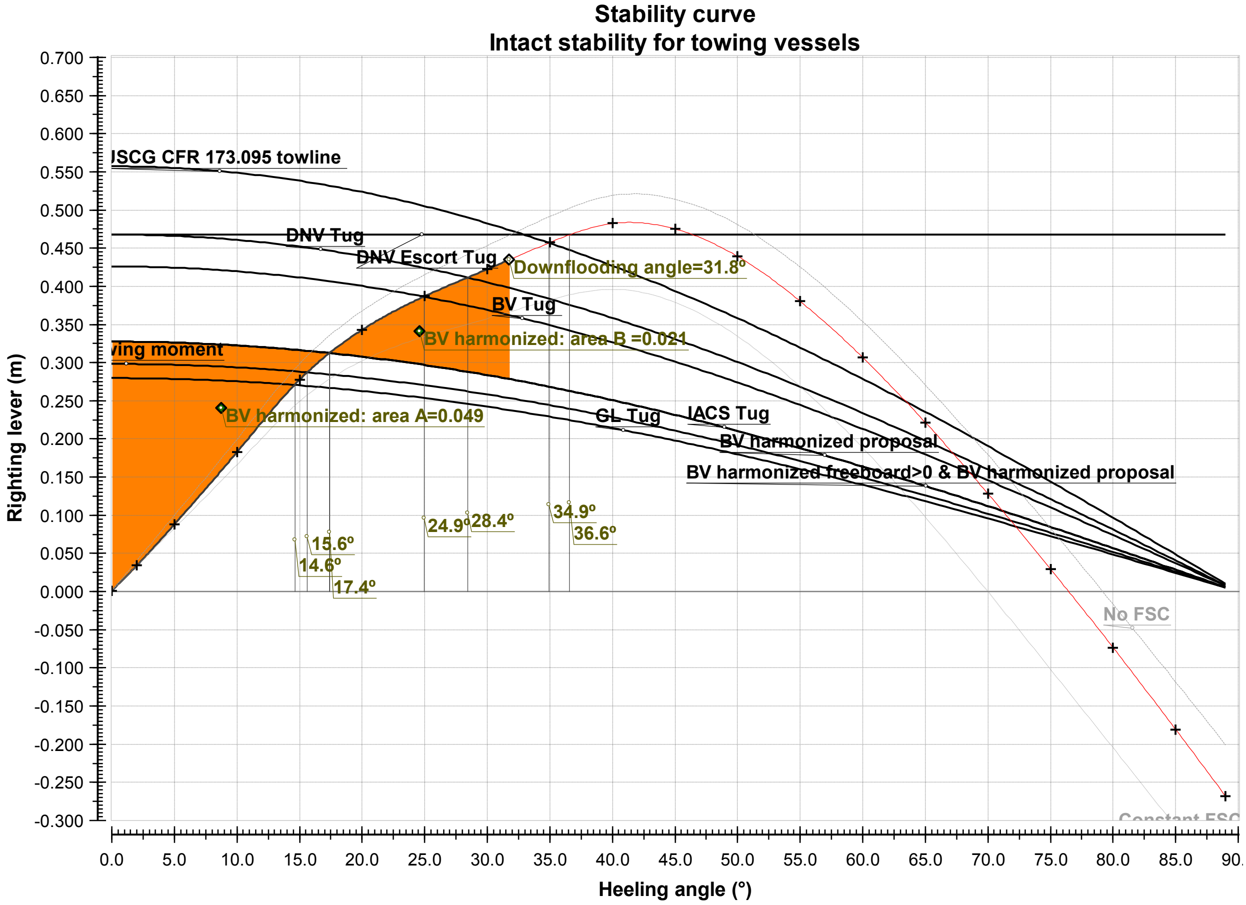
Tugs

Description	Attained value		Criterion	Required value		Complies
ABS Towing moment	20.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	278.93	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0962	*(mrad)*	>=	0.0900	*(mrad)*	YES
USCG CFR 173.095 towline	44.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	35.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0210	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.3326	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.4613	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.7211		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	32.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	398.47	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0048	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	19.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	263.53	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.1105	*(mrad)*	>=	0.0900	*(mrad)*	YES
GL Tug area GZ 0-min(second intercept, downflooding)	0.3522	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.2988	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	1.1786		>=	1.4000		NO
IACS Tug	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0866	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.3522	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.3384	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	1.0409		>=	1.4000		NO
BV harmonized proposal	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0727	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0866	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	1.1903		>=	1.0000		YES
BV harmonized freeboard>0	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	22.4	*(Degr.)*	<	17.9	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

ABS: area yes, deck submergence no.
GL: area yes, deck submergence no
BV harm: area yes, deck submergence no.

2.5.5 With opened ventilation openings and ballast

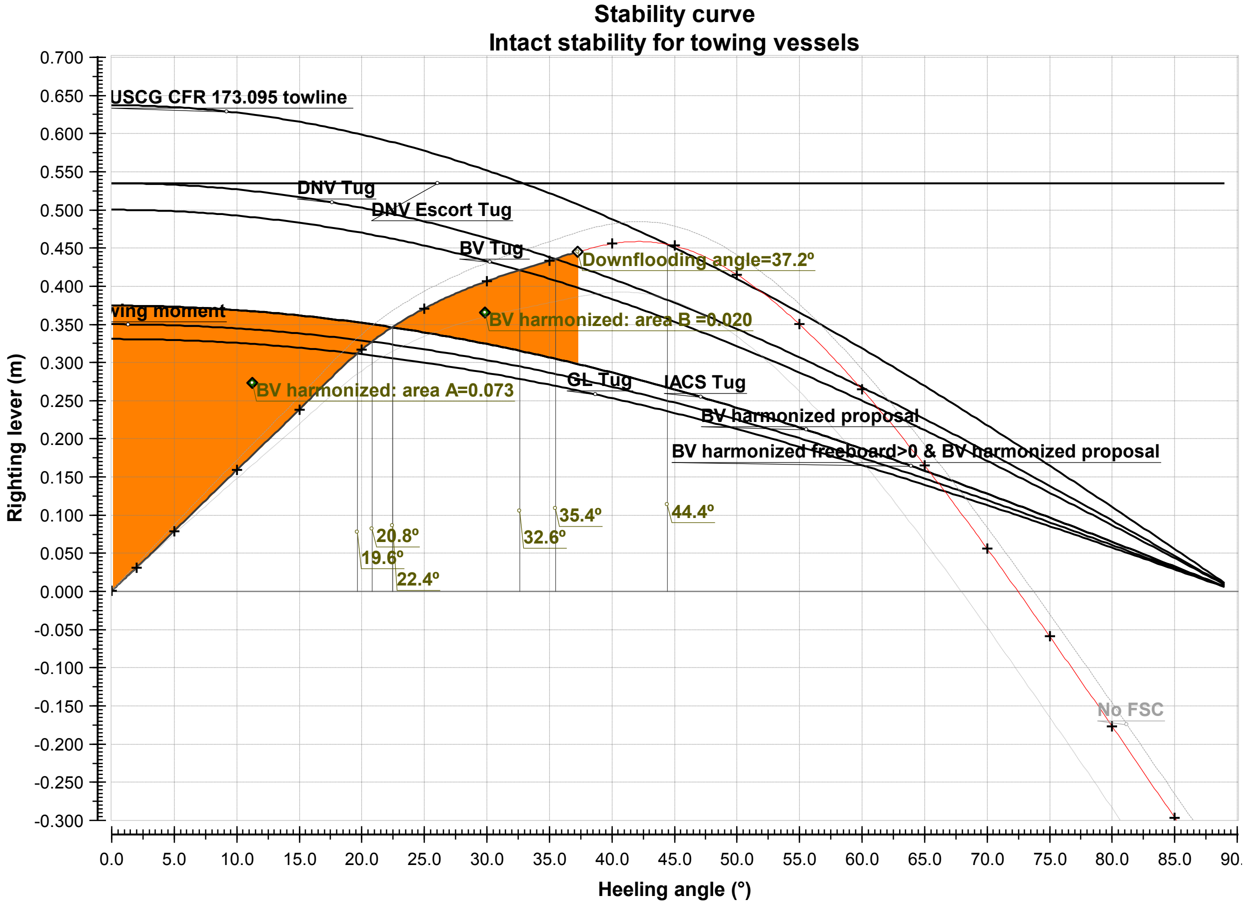
2.5.5.1 50% with open ventilation + ballast



Intact stability for towing vessels						
Tugs						
Description	**Attained value**		**Criterion**	**Required value**		**Complies**
ABS Towing moment	15.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	271.69	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0280	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	34.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	28.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0011	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.1435	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.2458	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.5840		>=	1.4000		NO
DNV Escort Tug	36.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.1435	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.2589	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.5545		>=	1.4000		NO
BV Tug	24.9	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	388.14	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0043	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	14.6	*(Degr.)*	<	15.0	*(Degr.)*	YES
Calculated heeling moment	254.79	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0330	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.1435	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.1469	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	0.9771		>=	1.4000		NO
IACS Tug	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0209	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.1435	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.1720	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.8343		>=	1.4000		NO
BV harmonized proposal	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0494	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0209	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.4233		>=	1.0000		NO
BV harmonized freeboard>0	17.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	17.4	*(Degr.)*	<	13.5	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

No for all.

2.5.5.2 10% with open ventilation + ballast



Intact stability for towing vessels

Tugs

Description	Attained value		Criterion	Required value		Complies
ABS Towing moment	20.8	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	278.93	*(t*m)*				
ABS area A1 first intercept to min (fi+40; downflooding)>0.090	0.0260	*(mrad)*	>=	0.0900	*(mrad)*	NO
USCG CFR 173.095 towline	44.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	507.63	*(t*m)*				
USCG area first intercept to min (40, max GZ, downflooding)>0.0106	0.0000	*(mrad)*	>=	0.0106	*(mrad)*	NO
DNV Tug	35.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Tug area first intercept to min(second intercept, downflooding)>0.090	0.0003	*(mrad)*	>=	0.0900	*(mrad)*	NO
DNV Tug area GZ 0- min(second intercept, downflooding)	0.1736	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area heeling arm 0-min(second intercept, downflooding)	0.3230	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Tug area GZ>1.40 Area heeling arm	0.5375		>=	1.4000		NO
DNV Escort Tug	180.0	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	426.25	*(t*m)*				
DNV Escort Tug area GZ first intercept-20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm first intercept -20	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ>1.25 area heeling arm	0.0000		>=	1.2500		NO
DNV Escort Tug area GZ 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area heeling arm 0-min(40, downflooding)	0.0000	*(mrad)*	>=	0.0000	*(mrad)*	
DNV Escort Tug area GZ > 1.40 area heeling arm	0.0000		>=	1.4000		NO
BV Tug	32.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	398.47	*(t*m)*				
BV Tug area first intercept to min(GZ max, 40, downflooding)	0.0019	*(mrad)*	>=	0.0110	*(mrad)*	NO
GL Tug	19.6	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	263.53	*(t*m)*				
GL Tug area first intercept to min(second intercept, downflooding)	0.0311	*(mrad)*	>=	0.0900	*(mrad)*	NO
GL Tug area GZ 0-min(second intercept, downflooding)	0.1736	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area heeling arm 0-min(second intercept, downflooding)	0.1997	*(mrad)*	>=	0.0000	*(mrad)*	
GL Tug area GZ > 1.40 area heeling arm	0.8693		>=	1.4000		NO
IACS Tug	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
IACS Tug area first intercept to min (second intercept, downflooding)	0.0202	*(mrad)*	>=	0.0900	*(mrad)*	NO
IACS Tug area GZ curve 0- min (second intercept, downflooding)	0.1736	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tug area heeing arm 0-min (second intercept, downflooding)	0.2261	*(mrad)*	>=	0.0000	*(mrad)*	
IACS Tugs area GZ > 1.40 area heeling arm	0.7678		>=	1.4000		NO
BV harmonized proposal	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	298.38	*(t*m)*				
BV harmonized: area A	0.0727	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized: area B	0.0202	*(mrad)*	>=	0.0000	*(mrad)*	
BV harmonized B/A>1	0.2783		>=	1.0000		NO
BV harmonized freeboard>0	22.4	*(Degr.)*	<	15.0	*(Degr.)*	NO
Calculated heeling moment	0.00	*(t*m)*				
Additional heeling moment:	BV harmonized proposal					
Total combined heeling moment	298.38	*(t*m)*				
Attained value smaller than deck immersion angle	22.4	*(Degr.)*	<	17.9	*(Degr.)*	NO
Weight	0.000	*(tonnes)*				
Trv. location of weight	0.000	*(m)*				

No for all

2.6 Conclusion

In the following table it is indicated wether the conditions comply with one or more of the requirements. To be distinguished are:

1. Area of reserve stability
2. Allowable heeling angle at equilibrium
3. Deck edge immersion at equilibrium

With closed ventilation openings:

	Area's:	Angle 15º:	Deck edge:	Total:
100% loaded	Yes	Yes	No	No
50% loaded	Yes	No	No	No
10% loaded	No	No	No	No

With opened ventilation openings:

	Area's:	Angle 15º:	Deck edge:	Total:
100 % loaded	No	No	No	No
50% loaded	No	No	No	No
10% loaded	No	No	No	No

With closed ventilation openings and ballast:

	Area's:	Angle 15º:	Deck edge:	Total:
50% loaded + ballast	Yes	No	No	No
10% loaded + ballast	Yes	No	No	No

With opened ventilation openings and ballast:

	Area's:	Angle 15º:	Deck edge:	Total:
50% loaded + ballast	No	No	No	No
10% loaded + ballast	No	No	No	No

This shows that in all investigated conditions the tug can not comply with the considered stability criteria, taking into account the safety criteria of no deck edge immersion and no inclination angle of more than 15º.

Herewith the summary of this report and the loading conditions ends.

3 Towing forces

3.1 Introduction

With reference to the intact stability criteria the following aspects need to be discussed:

1. What towline load is applied on the tug
2. What is the reaction of the tug on that load
3. What is the safety when subject to that load

Various towing situations can be distinghuised:

	
1. Towed by the tow, towing over aftship. Tow tripping. Speed of tow and breaking load of towline are decisive.	2. Steering the tow over foreship. Towline jerk can act at 90º. Steady heel not likely due to position of towing point.
	
3. Towing over foreship with need for stability	4. Towing over aftship on fixed object. Self tripping.

<u>Situation 1</u> The tugboat, with non-azimuthing propellers, is towing over the stern, but is overhauled by the tow, resulting in a athwarthship towline force, counteracted by the flowforces on the hull. The towline force is mainly determined by the speed of the tow. In the horizontal plane there is an equilibrium: unless the towing point is far aft, the tug will not be turned out of this potential dangerous situation.

<u>Situation 2</u> The tugboat, with azimuthing propellers, is towing over the bow, steering the tow. In this situation the towline force is determined by the thrust of the propellers. This can both be in the same direction as the towline force, then this force counteracts the heeling of the tug, or in the opposite direction of the towline force, then the propellerforce act together with the towline force to heel the vessel.

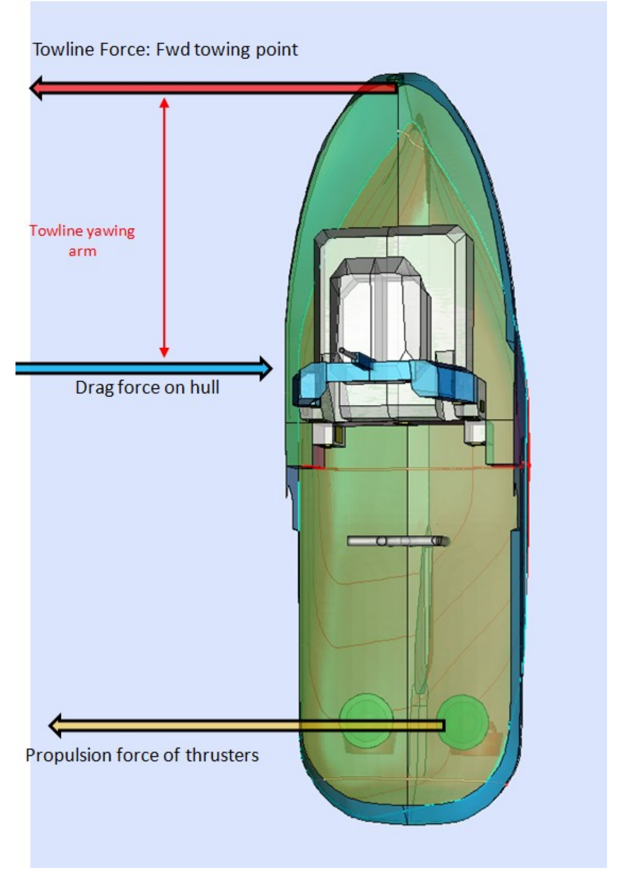
<u>Situation 3</u> Same situation with respect to the tow as 1., but now with Azimuting Stern Drive tug towing over the bow. Thrusterforces can act against - but also with - the towline force to heel the vessel.

<u>Situation 4</u> Azimuthing stern drive tugs towing over the aftship on fixed object, sheering from port side to starboard and vice versa, like a kite, creating atwarthship hydrodynamic forces on the hull, determined by the bollardpull of the tug.

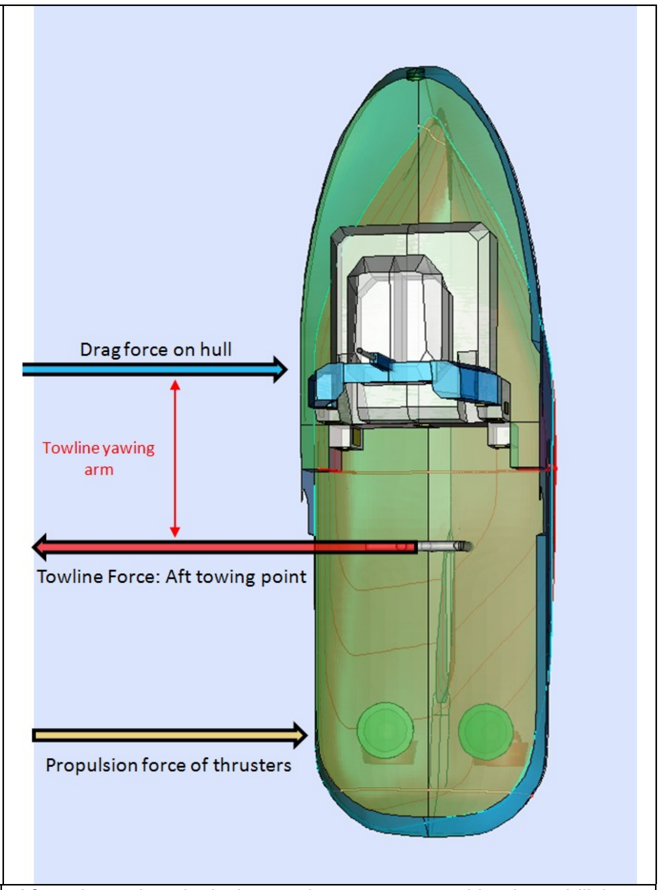
3.2 Forces during towing in a horizontal plane

The towline force has to be counteracted by the tug. This can be done by the thrusterforces or by the dragforces or by a combination of both.

With a forward towing point and aft positioned azimuthing thrusters, a thrusterforce in the direction of the towline is needed for horizontal equilibrium, while with an aft towing point a thrusterforce in the opposite direction of the towline is needed.



Forward towing point: counter clockwise yawing, counteracted by stabilizing thrusterforce



Aft towing point: clockwise yawing, counteracted by de-stabilizing thrusterforce

This means that, apart from the towline force, two other forces are acting on the ship: the dragforce and the thrusterforces. The thrusterforces can act in the same direction as the towline, then counteracting the heelingmoment, see figure, or in the opposite direction, then increasing the heelingmoment.

The towline yawing arm in general is higher for a forward towing tug than for an aft towing tug. This means that in case of a too large towline forces, the forward towing tug will be quicker turned in a safer position in the direction of the towline.

On the other hand, in case of failure of a propeller or of a human mistake, the angle of inclination of a forward towing vessel will increase suddenly due to the loss of the stabilizing moment - in a transverse plane- of the thrusters.

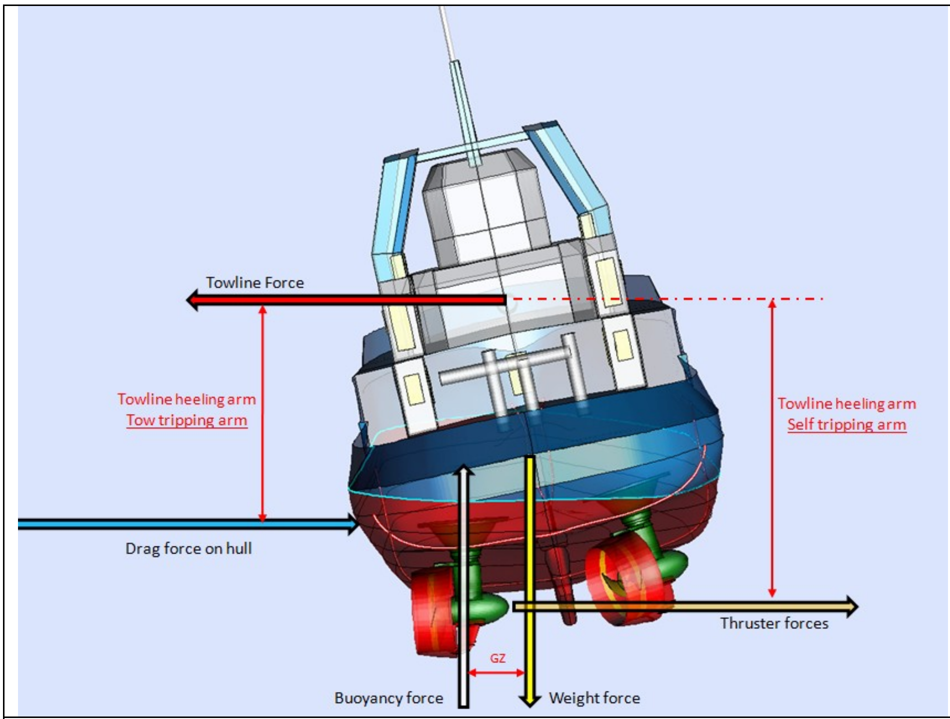
During manoeuvring thrusterforces can further be exerted in all directions, so that no distinction is made between forward or aft towing by the classification societies in the assessment of the stability.

Classification societies and/or Flag authorities have applied various approaches to estimate the heeling moment on a tug: some have applied the towline tripping approach, others the selftripping approach.

This is expressed in the formulation of the centre of application of the counteracting force of the towline force: as a function of draught, which assumes that the dragforce is determining, or taking the centreline of the propellers, which assumes that the thrusterforces are determining.

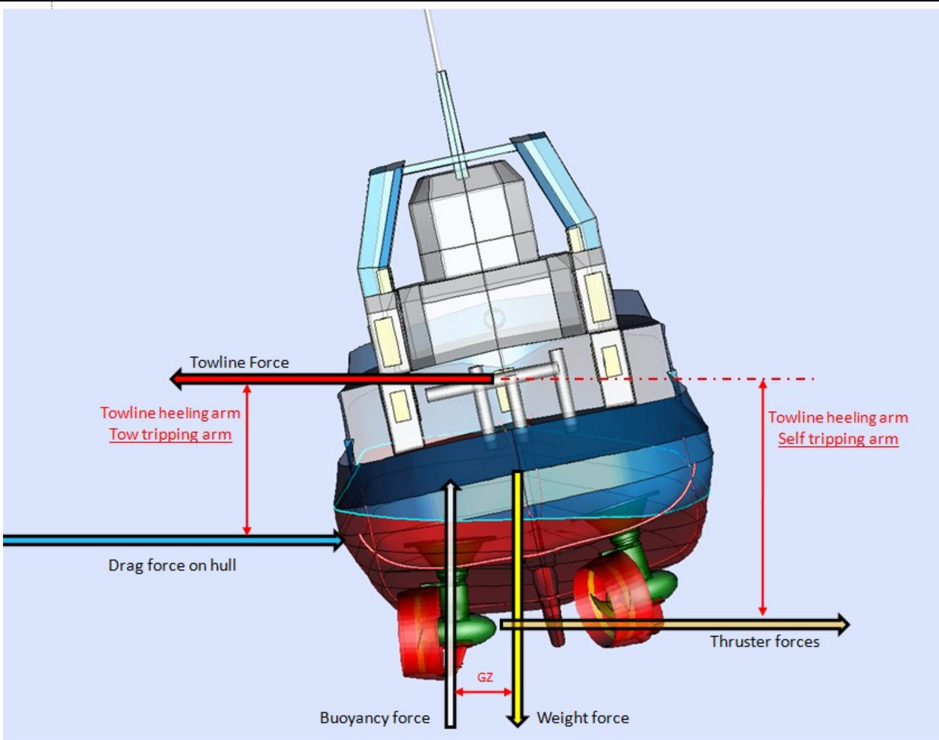
3.3 Forces during towing in a vertical plane

The horizontal forces are projected in a vertical plane as shown in the following diagram: The towline force and the drag- and thrusterforces cause a heeling moment which has to be counteracted by the transverse stability moment of the vessel.



Forces acting in transverse direction (drawn:forward towing point, start of portside turn)

This transverse stability moment consists of two forces in opposite direction: the downward vertical acting weightforce and the upward vertical acting buoyancy force. The lever of this moment is called GZ and will be explained in a following paragraph.



Forces acting in transverse direction (drawn:aft towing point, start of portside turn)

4 Stability characteristics

4.1 General

The approved by GL/SBG stability booklet of Fairplay 22 shows the following judged loading conditions:

1. Lightship
2. 100% consumables; 100% foam
3. 100% consumables, 0% foam
4. 50% consumables, 100% foam
5. 50% consumables, 0% foam
6. 10% consumable, 100% foam
7. 10% consumables, 0% foam
8. 60% fuel, 70 ton chains on deck

The lightship condition is not an operational condition, while condition 8 is an offshore anchor handling condition, further normal current operation of the tugs is without foam on board, therefore the following representative conditions have been further analysed:

1. 100% consumables, no foam onboard: (departure)
2. 50% consumables, no foam on board: (half way journey)
3. 10% consumables, no foam onboard: (arrival)

4.2 Characteristic loading conditions

The vessel including tankarrangement is modelled in Delftship, and these loading conditions have been calculated, taking into account the original lightship weight and centre of gravity as mentioned in the stability booklet. A reasonable agreement between Delftship and the stability booklet is obtained for draught and G'M value's as is shown in the following table:

			0% foam			stab booklet /0% foam		
			Loading condition Delftship			**Loading condition**		
			100%	50%	10%	100%	50%	10%
Displacement	Δ	[t]	966	829	712	967	830	715
Engine room tanks			1.8	9.1	9.0	1.8	8.96	8.96
Stores, crew & effects			9.0	8.3	7.7	9.0	8.25	7.65
Stores rope store			17.5	17.5	17.5	17.5	17.5	17.5
Foam			0.0	0.0	0.0	0.0	0.0	0.0
Lubricating oil			11.2	5.6	1.1	11.2	5.61	1.12
Fresh water			77.0	38.5	6.2	**77.0**	38.5	7.7
Fuel			198.4	99.1	19.8	198.6	99.24	19.85
Ballast water						0.0	0.0	0.0
Deadweight			314.9	178.1	61.2	315.1	178.1	62.8
Mean moulded draught	T_m	[m]	4.595	4.121	**3.730**	4.600	4.127	3.740
Draught APP			4.421	4.176	3.786	4.435	4.182	3.767
Draught FPP			4.769	4.067	3.675	4.764	4.072	3.714
Trim pp			0.348	-0.109	-0.111	**0.329**	-0.110	-0.053
Freeboard	fb	[m]	1.105	1.579	1.970	1.100	1.573	1.960
Estimate deckedge immersion atan (fb/0.5B)		[°]	11.6	16.3	20.0	11.5	16.2	19.9
KM		[m]	5.480	5.559	5.634	5.477	5.548	5.598
VCG		[m]	4.346	4.576	4.844	4.326	4.567	4.835
GG'		[m]	0.130	0.064	0.052	0.166	0.075	0.048
VCG'		[m]	4.476	4.640	4.896	4.492	4.642	4.883
G'M		[m]	**1.004**	**0.919**	**0.738**	**0.985**	**0.906**	**0.715**

4.3 Levers of stability GZ

4.3.1 General

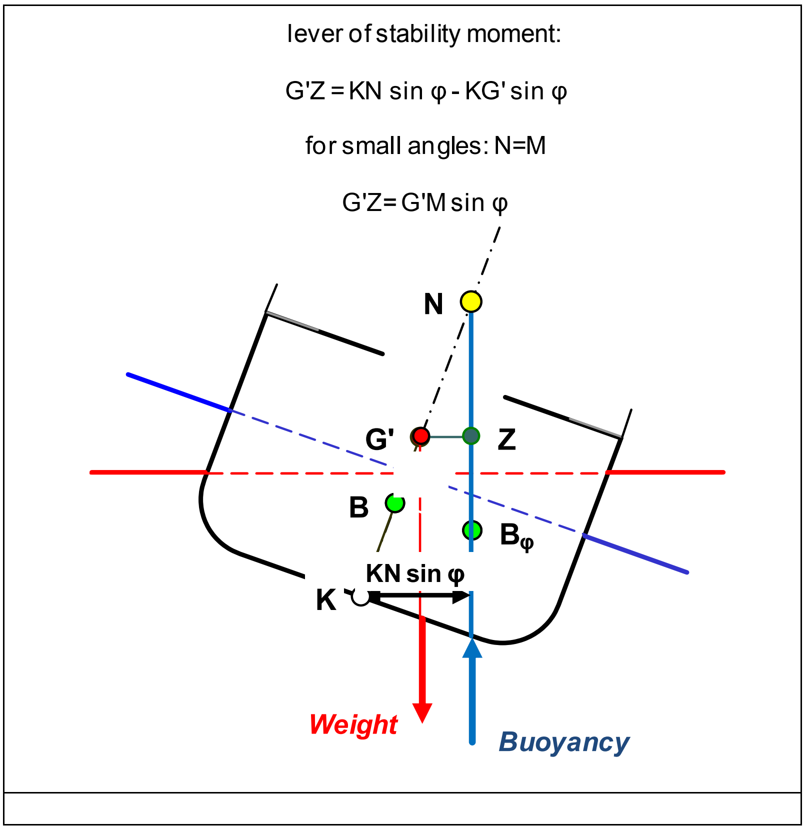
The stability of a ship is determined by the centre of gravity above the keel, KG, if applicable corrected for free surface effects with a distance GG', to the distance KG'.[1]

When given an inclination the weight of the vessel acting in G', tends to further incline the vessel. This is, in case of positive stability, counteracted by the buoyancy force which is acting in vertical direction and which is shifted from its location in upright position B to its inclined position B_{φ}. As long as the centre of buoyancy shifts more to the right than the centre of gravity, there is a positive moment of stability which tends to move the ship back to its original position. The stability of a ship is represented by the value G'Z, the righting lever of stability. The righting lever of stability G'Z = KN sin φ – KG' sin φ.

The value of KN sin φ depends on the hullform, the inclination, the draught and the trim. The value of KG' depends on the loading condition of the vessel.

For small angles the position of N (false metacentre) approaches the position of M, the metacentre. Then, for small angles, the stability lever can be approximated by G'Z = G'M sin φ and the upright heeling moment by M_{st} = G'M sin φ x Δ. Where Δ = displacement of the vessel.

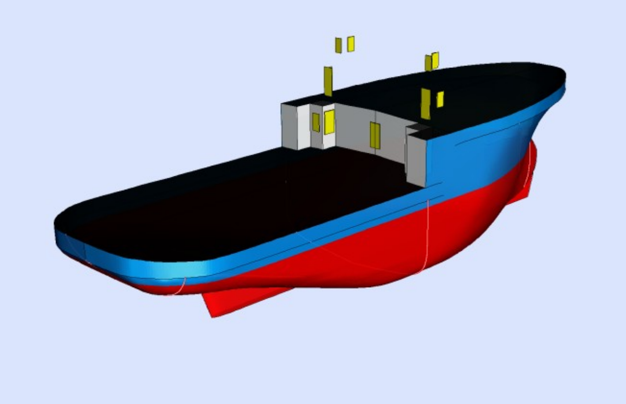
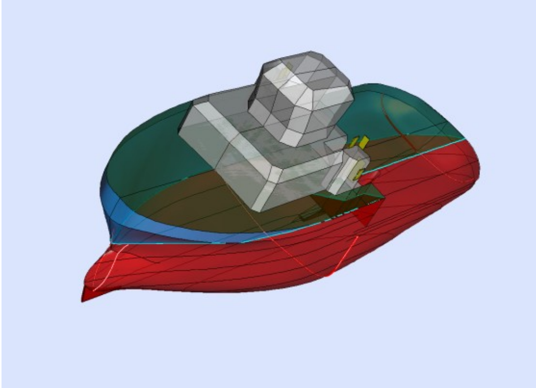
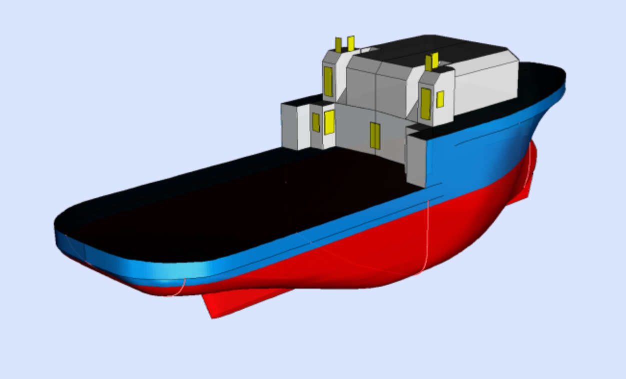
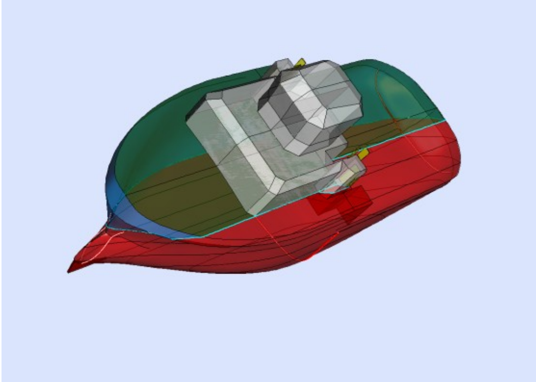
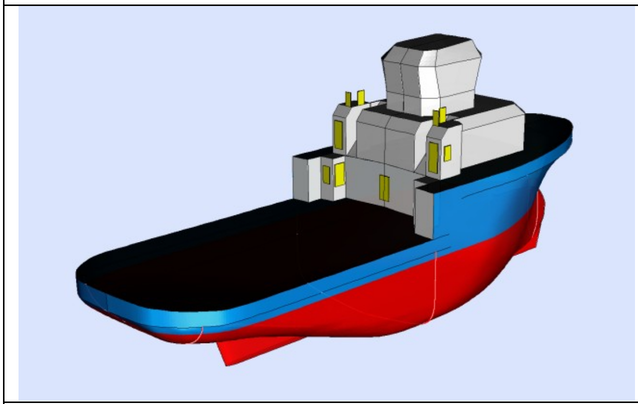
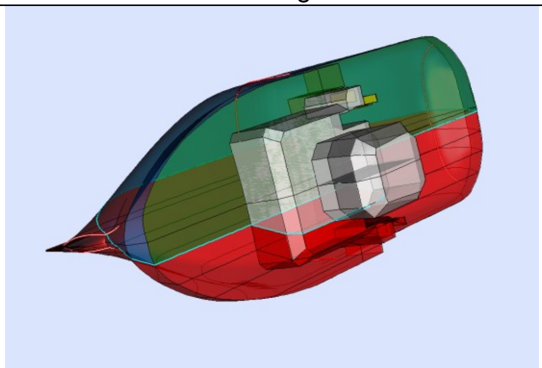
The G'Z-values as function of the inclination angle are given in the 'curve of righting arms'.



[1] This paragraph is intended to provide a general overview. The approach where the effect of the free surfaces is taken into account with a virtual increase of the centre of gravity GG' is an approximation. The actual calculations and analyses have been performed taking into account the actual centre of gravity of the moving content of the fluid in the tanks.

4.3.2 Volumes contributing to the stability

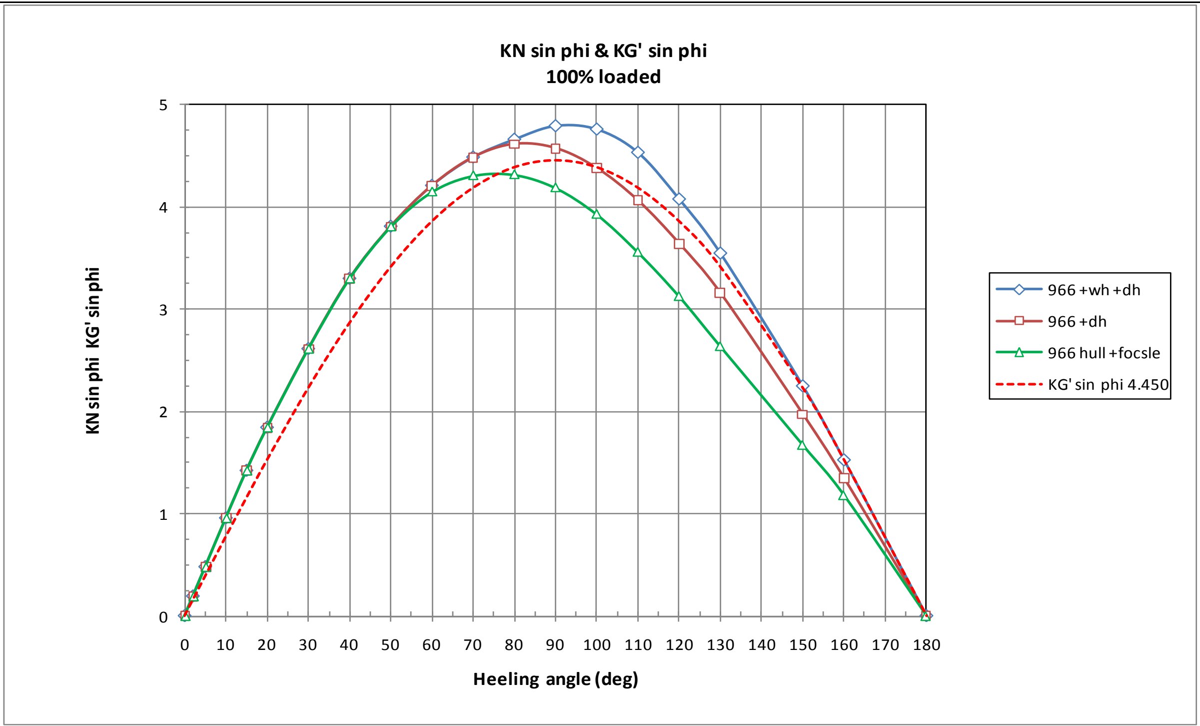
The parts of the vessel which can contribute to the stability and the angles at which they start to contribute (fully loaded coindition) are shown in the following picture.

	
Hull and forecastle (standard assumption)	Forecastle deck immerges at abt 33º
	
Hull, forecastle and deckhouse on forecastle	Deckhouse is contributing above abt 45º
	
Hull, forecastle, deckhouse, casing and wheelhouse	Wheelhouse is contributing above abt 70º

In general the hull plus the first layer of superstructure, in this case the forecastle, might be taken into account in the assessment of the stability. The standard IMO stability requirements are defined up to an angle of maximum 50º (wind criterium). In this case the SBG requests a minimum range of stabiltity of 60º. In this case above an angle of about 45º the deckhouse starts to contribute to the stability, while above about 70º the wheelhouse starts contributing.

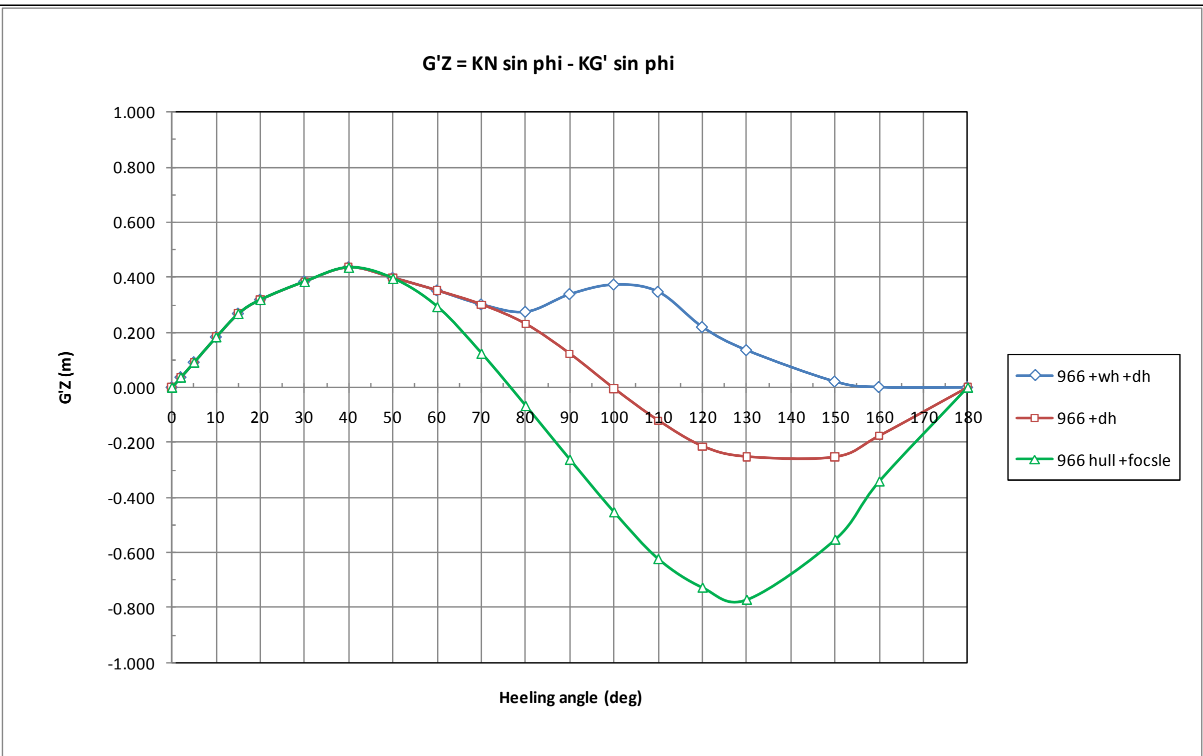
4.3.3 Levers of stability in considerd loading conditions

The upright lever of the buoyancy force and the heeling lever of the weight force are shown, and their difference, which is the G'Z-value. For the deepest draught with a KG' value of 4.45 m, corresponding with a G'M value of about 1.035 m, the KN sin φ and KG' sin φ values take the following shape at angles between 0º and 180º. The influence of taking into account the deckhouse and the wheelhouse in the buoyancy calculations is also shown.



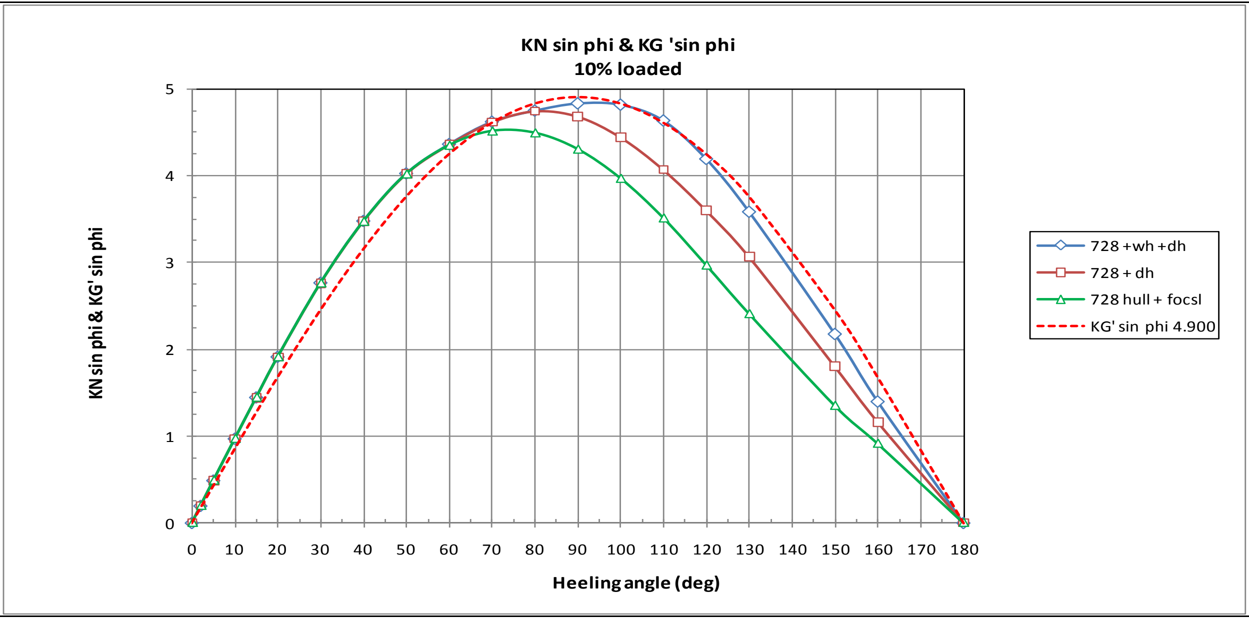
KN sin φ for Δ=966 ton; taking into account: green: forecastle; red: + deckhouse; blue: + wheelhouse; KG' sin φ for KG' = 4.45 m

After substraction of KN sinφ and KG' sinφ, the G'Z curve is obtained:

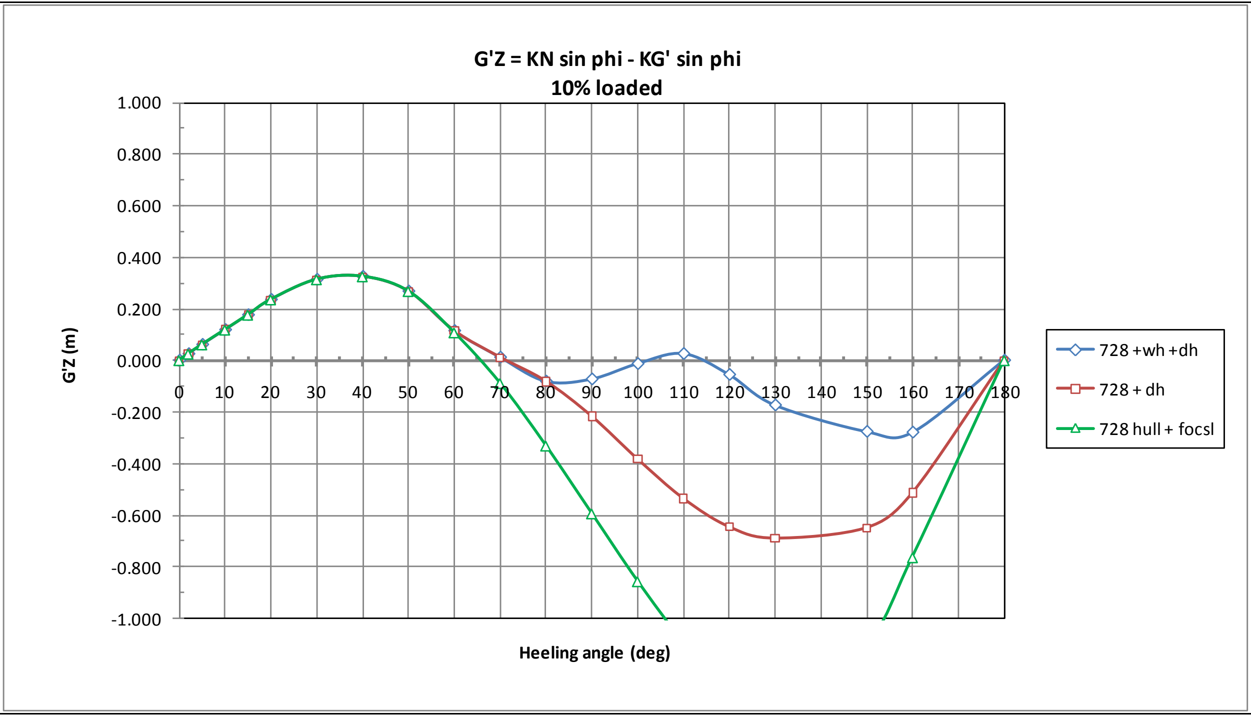


G'Z, showing influence of deckhouse and wheelhouse on righting lever, for KG' = 4.45 m

And at the 10% loaded condition with a KG'- value of 4.90 m, corresponding to a G'M value of about 0.74 m:



KN sin φ for Δ=728 ton; taking into account: green: forecastle; red: + deckhouse; blue: + wheelhouse; KG' sin φ for KG' = 4.90 m



G'Z, showing influence of deckhouse and wheelhouse on righting lever, for KG' = 4.90 m

The effect of including the buoyancy of the deckhouse and the wheelhouse in the stability at large angles, assuming all these volume's watertight, for:

1. Hull including forecastle (as applied in the stability booklet of Fairplay 22)
2. Hull including forecastle plus deckhouse on forecstle
3. Hull including forecastle plus deckhouse plus wheelhouse

This shows that the influence of buoyancy of the deckhouse and wheelhouse, is large when sufficient G'M is available, as in the 100% loaded condition, where a closed deckhouse can increase the range of stability up to 100º, while a closed wheelhouse, assuming windows strong enough, can increase this range up to 150º.

When the stability is already marginal –like in the 10% condition-, the additional buoyancy of deckhouse and wheelhouse does not improve the situation decisive.

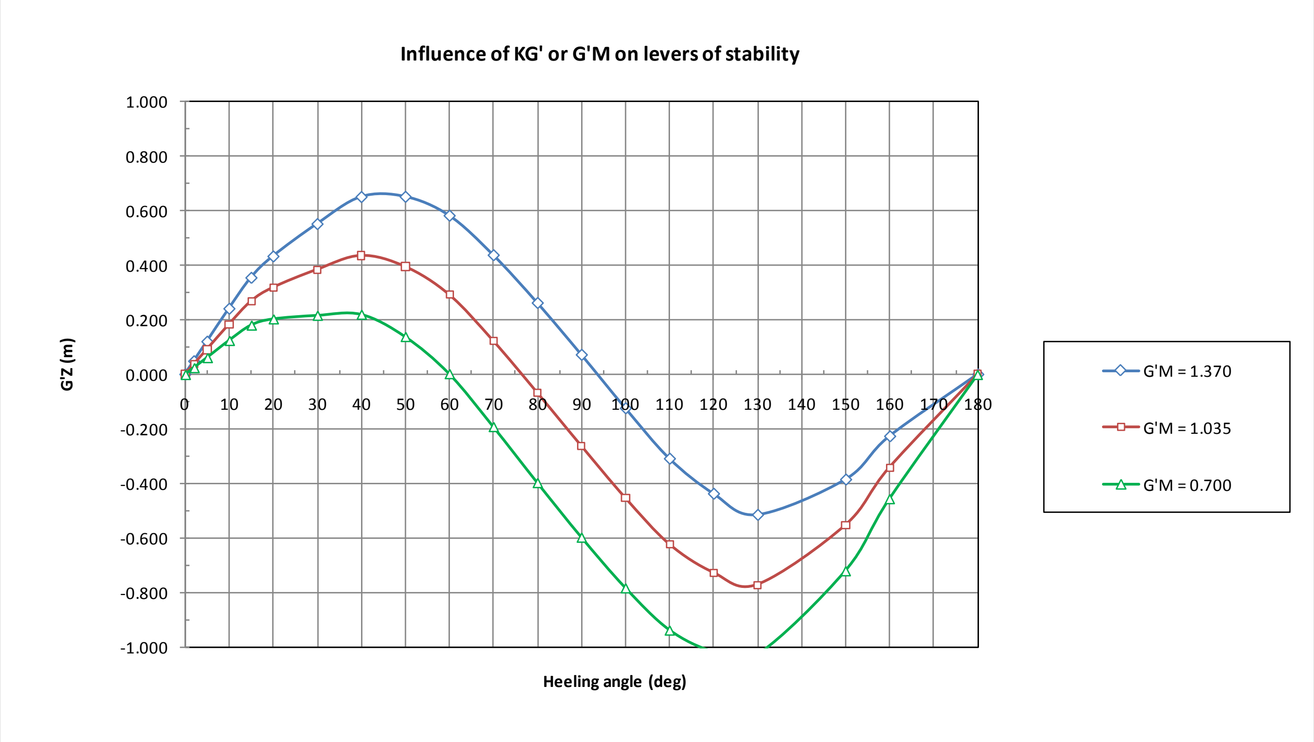
This means that -when sufficient stability is available- and when -the ship is watertight-, at least up to the 60º as required, the tug can be selfrighting or at least remain in a position to enable crew to abandon the ship.

Het gevaar bij conventionele sleepboten. De 'Buizerd' in een benarde positie.

4.3.4 Influence of vertical centre of gravity KG'

The large influence of apparantly small changes in the centre of gravity KG'[2] or G'M on the magnitude and range of the stability, is shown for the full loaded condition, only taking the forecastle (apart from the hull) as buoyant space. The KG' has been modified as follows:

KG' = 4.115 m: G'M = 1.370 m
KG' = 4.450 m: G'M = 1.035 m (basis condition)
KG' = 4.785 m: G'M = 0.700 m



Influence of G'M (KG') on range and magnitude of stability

This diagram shows the influence of the G'M (KG') value on the range and magnitude of the stability arms.

KG' = 4.115 m:	G'M = 1.370 m	range = 93°	lever at 30° = 0.553 m (144%)
KG' = 4.450 m:	G'M = 1.035 m	range = 76°	lever at 30° = 0.385 m (100%)
KG' = 4.785 m:	G'M = 0.700 m	range = 60°	lever at 30° = 0.218 m (57%)

This shows that a reduction of G'M from 1.035 m to 0.700 m, reduces the arm of stability at e.g. 30° with more than 40% and the range of stability with more than 20%.

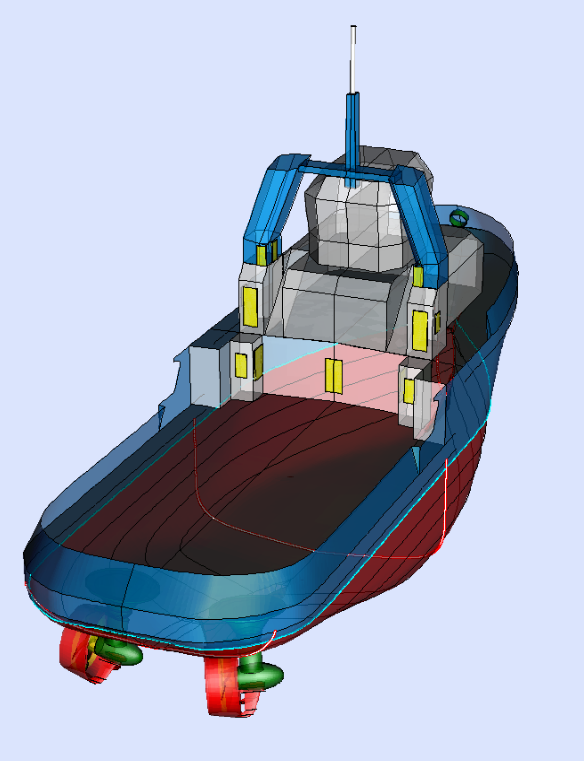
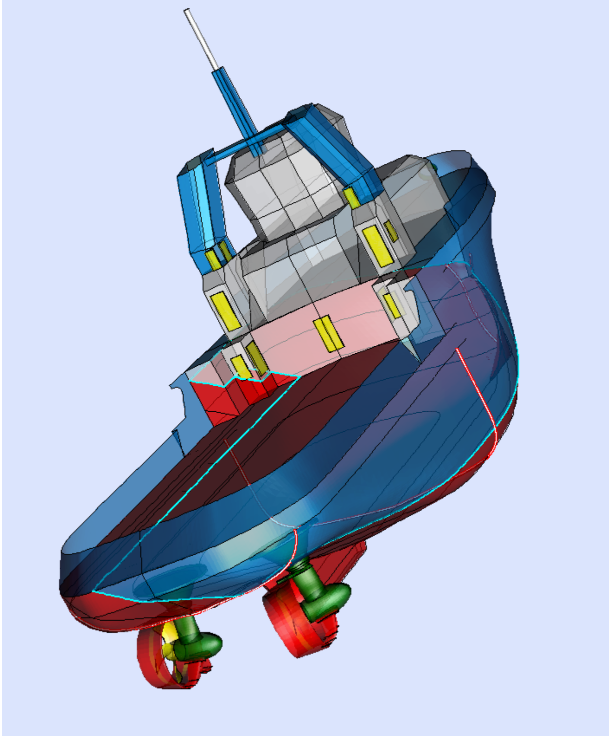
[2] Final analyses of stability are made with the actual centre of gravity of the moving surfaces of tanks as function of heeling angle .

4.4 Freeboard regulations and influence of openings

4.4.1 Position of openings

The status of the openings needs further clarification.

The position of the openings with respect to the waterline is shown in the following diagram at an inclination of 0 degrees and at 30 degrees in 100% loaded condition.

	
0 degrees	30 degrees

This is not an impossible position as is shown in the following picture in an emergency condition with an inclination of about 30 degrees, where apparently downflooding can start through one of the openings and worsen the situation rapidly.

Heeling angle abt 30º (picture showing sistervessel of Fairplay 22 in emergency condition) source internet.

4.4.2 Status of openings according Load Line Convention

Load Line Convention

Regulation 17(1):
Machinery space openings in position 1 or 2 shall be properly framed.. Access openings in such casings shall be fitted with doors complying with the requirements of regulation 12(1), the sills of which shall be at least 600 mm above the deck if in position 1, and at least 380 mm above the deck if in position 2.

Regulation 17(2), on machinery space openings:
17(2): Coamings of any fiddley, funnel or machinery space ventilator in an exposed position on the freeboard or superstructure deck shall be as high above the deck as is reasonable and practicable. Fiddley openings shall be fitted with strong covers of steel or other equivalent material permanently attached in their proper positions and capable of being secured weathertight.

Regulation 19(3) :
Ventilators in position 1 the coamings of which extend to more than 4.5 m above the deck, and in position 2 the coamings of which extend to more than 2.3 m above the deck, need not be fitted with closing arrangements unless specifically required by the Administration.

Regulation 19(4):
Except as provided in paragraph (3) of this regulation, ventilator openings shall be provided with weathertight closing appliances. In ships of not more than 100 m in length the closing appliances shall be permanently attached;…..
Ventilators in position 1 shall have coamings of a height of at least 900 mm above the deck; in position 2 the coamings shall be of a height at least 760 mm above the deck.

Regulation 13:
Position 1 –Upon exposed freeboard and raised quarter-decks, and upon exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular
Position 2 – Upon exposed superstructure decks situated abaft a quarter of the ship's length from the forward perpendicular

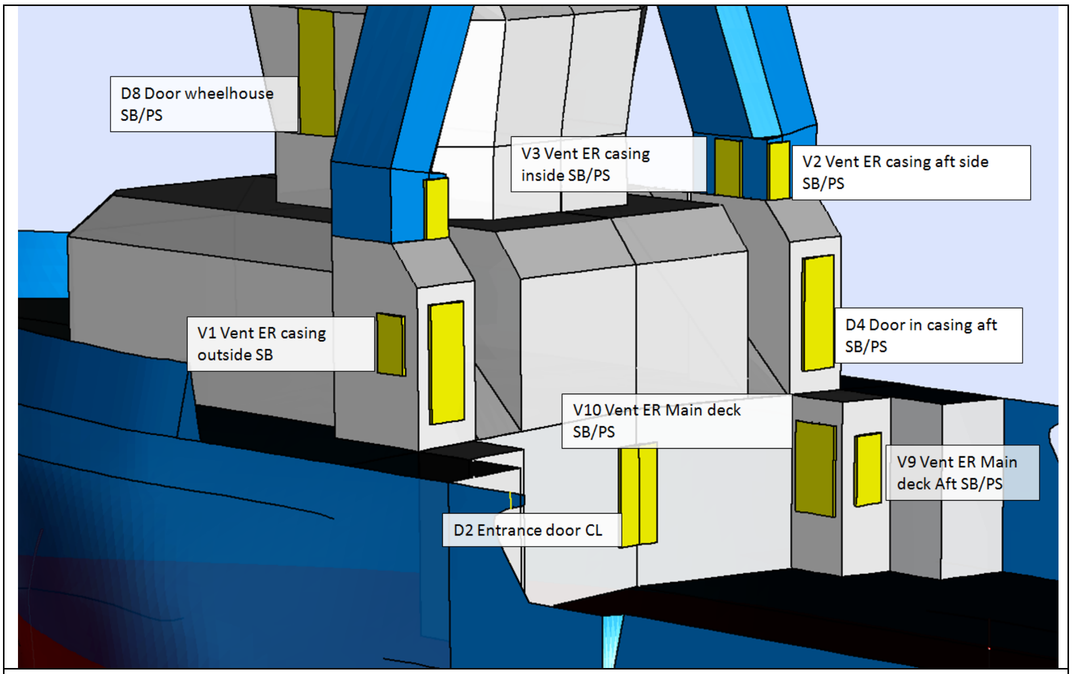
Unified interpretation of regulation 17(2), 19(3) and 19(4): (IACS interpretation LL.58)
Regulation 17(2) requires that the coamings of machinery space ventilators situated in exposed positions on the freeboard and superstructure decks shall be as high above the deck as is reasonable and practicable. In general, ventilators necessary to continuously supply the machinery space and, on demand, immediately supply the emergency generator room should have coamings which comply with regulation 19(3), without having to fit weathertight closing appliances.[3] However, where due to ship size and arrangement this is not practicable, lesser heights […] may be accepted with the provision of weathertight closing appliances in accordance with regulation 19(4) in combination with other suitable arrangements to ensure an uninterrupted, adequate supply of ventilation to these spaces.

Regulation 12(2):
(2) ..the height of the sills of access openings in bulkheads at ends of enclosed superstructures shall be at least 380 mm (15 inches) above the deck.

Regulation 18(3):
Unified interpretation Regulation 18(3)
.1 where access is provided from the deck above as an alternative to access from the freeboard deck in accordance with regulation 3(10)b then the height of the sills into a bridge or poop should be 380 mm The same should apply to deckhouses on the freeboard deck. .2 where access is not provided from above, the height of the sills to doorways in a poop bridge or deckhouse on the freeboard deck should be 600 mm.

[3] Weathertight means that in any sea conditions water will not penetrate into the ship. Or in Dutch: 'zodanig dicht dat onder alle omstandigheden die zich op zee kunnen voordoen, geen water in het vaartuig kan binnendringen'.

The size and coaming height of the openings have been derived from the freeboard plan:



position of openings

The following openings have been considered in the hydrostatic model:

	location of most outside, aftward and downward part of opening				properties for 100% loaded condition:	
	x from APP	y from CL	z above base	coaming height	distance to wl	submersion angle
V10 Vent ER on Maindeck SB and PS	17.125	3.050	6.635	**0.850**	2.030	33.2
V9 Vent ER on maindeck aft SB and PS	16.950	3.850	6.770	**1.030**	2.167	29.2
D2 Entrance door on Maindeck CL	17.950	0.350	6.500	**0.600**	1.887	73.0
D4 Door in casing aft SB and PS	17.930	3.900	8.600	0.400	3.986	44.8
V2 Vent ER in ER casing aftside SB and PS	18.400	3.600	11.000	2.800	6.381	59.4
V1 Vent in ER casing outside SB	18.250	4.100	9.244	1.000	4.627	47.6
V3 Vent in ER casing inside SB and PS	19.000	3.100	11.00	2.800	6.375	63.0
D8 Door Wheelhouse SB and PS	21.800	2.300	12.200	0.200	7.545	73.5

For the most important openings V10, V9, and D2 the following comments can be made:

V9 & V10: Engineroom ventilation openings on maindeck: According Regulation 19, and assuming position 2[4], with an opening which is less than 2.3 m above the freeboard deck, the opening should be provided with weathertight closing appliance and have a height of more than 760 mm above the deck in position 2 (in position 1 more than 900 mm). Actual: V9=1.030 m; V10=0.850 m.

D2: Entrance door on maindeck centreline: According Unified interpretation Regulation 18(3), height of sill should be at least 380 mm, or 600 mm when no alternative access is available from deck above. Actual: D2=0.600 m.

[4] In this case, where the tug is designed to tow both over the bow and over the stern, the exposure of the engine room ventilation openings is worse than anticipated in the regulations with incoming waves over a low stern, sailing in forward and aftward direction.

4.4.3 Estimate of flow of water entering the openings

It can be expected that the following quantities of water will enter the ship based on the following approach[5]:

The pressure drop over an opening:

$$\Delta p = \frac{1}{2}\rho \cdot v^2 \cdot \sum_i k_i$$

with that: $v = \sqrt{\dfrac{2 \cdot \Delta p}{\rho \cdot \sum_i k_i}}$

The associated flowrate: $Q = S \cdot v$

or: $Q = S \cdot \dfrac{1}{\sqrt{\sum_i k_i}} \cdot \sqrt{\dfrac{2 \cdot \Delta p}{\rho}}$

where:

$\Delta p =$ pressure drop

$\rho =$ density

$v =$ flow velocity

$\sum_i k_i =$ sum of resistance coefficients

$S =$ flow area

also:

$\Delta p = \rho \cdot g \cdot \Delta h$

with: $\Delta h =$ watercolumn

it follows:

$$Q = S \cdot \frac{1}{\sqrt{\sum_i k_i}} \cdot \sqrt{2 \cdot g \cdot \Delta h}$$

According[6] the pressure loss coefficient $\sum_i k_i$ can be taken between 1.5 and 2.0. With which the expression for Q reduces to:

$$Q = S \cdot \frac{1}{\sqrt{1.5}} \cdot \sqrt{2 \cdot g \cdot \Delta h}$$

$$Q = S \cdot 0.82 \cdot \sqrt{2 \cdot g \cdot \Delta h}$$

$$Q = 3.63 \cdot S \cdot \sqrt{\Delta h} \quad [m^3 / s]$$

In the following graphs the waterflow in m3/h is given for various values of S and dh.

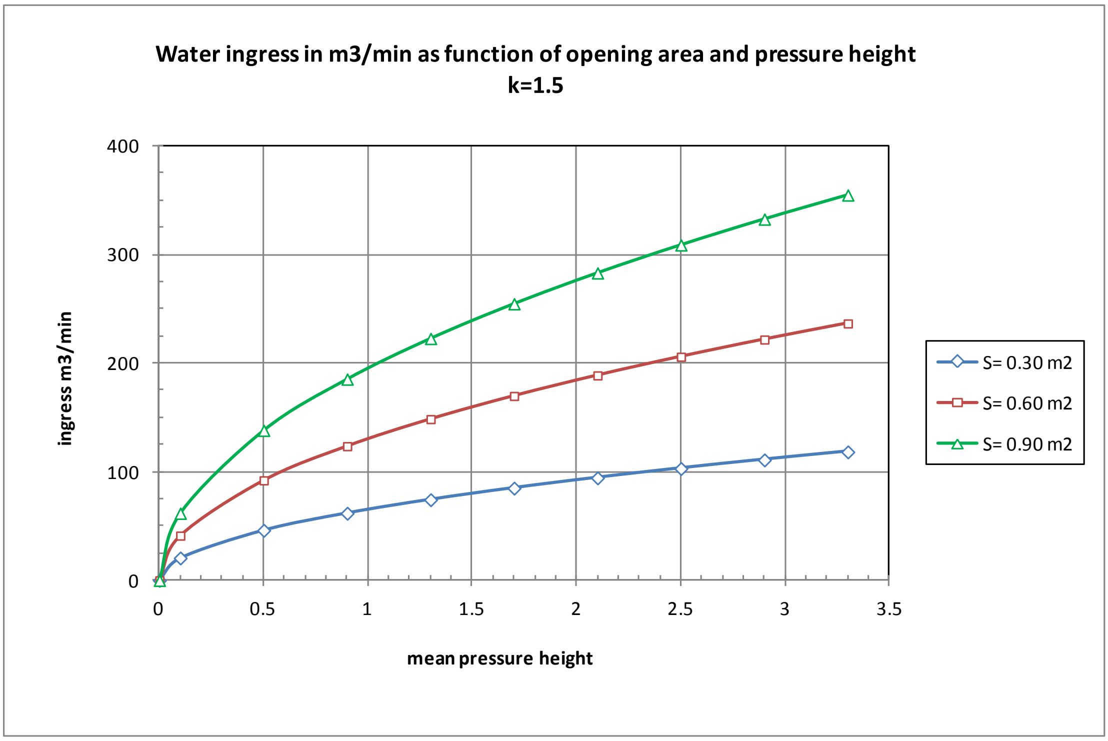
The area of the longitudinal opening is 0.75x1.30 =0.97 m^2, the area of the athwart ship opening is 0.50x1.00 = 0.5 m^2. The total gross inlet area to the ventilation casing is therefore 1.47 m^2.

The nett area of the ventilation casing is abt 0.90 m^2. The diameter of the air suction ventilator is estimated at 0.85 m, giving a suction area of 0.57 m^2.

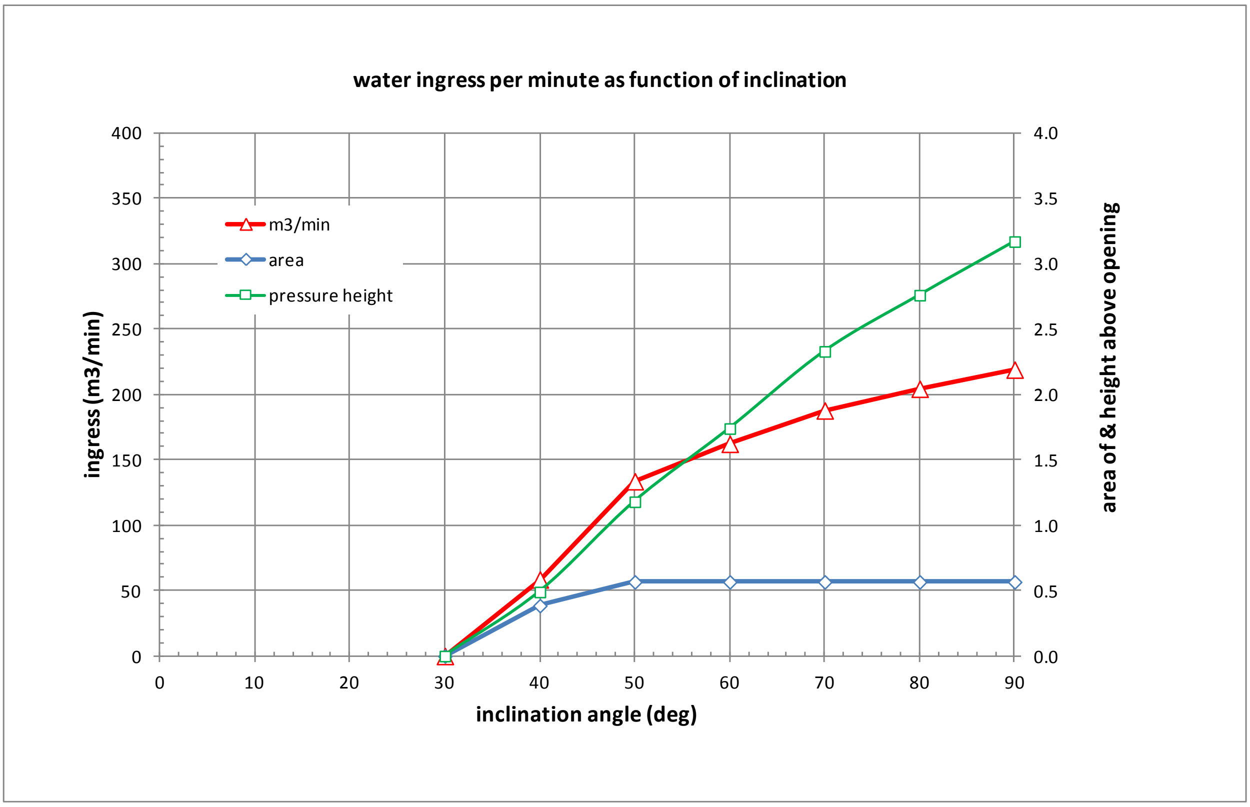
It is not taken into account that a ventilator might work as a pump as long as electricity is functioning.

[5] SLF 49/9 Annex 1 Recommendation on a standard method for cross flooding arrangements

[6] Vredeveldt, A.W., Journee, J.M.J., Roll motions due to sudden water ingress, calculations and experiments. RINA 1991.



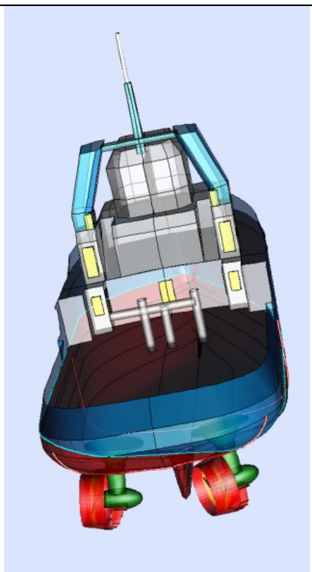
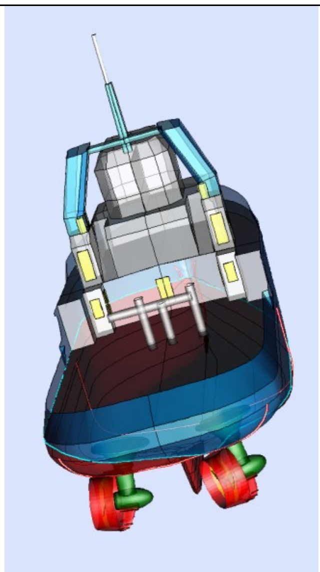
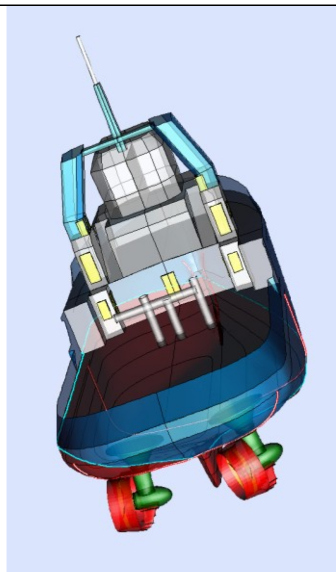
In the hydrostatic model the submerged area and the pressure height was obtained at heeling angles between 30 and 90 degrees. These values are given in the next diagram, with addition of the associated calculated waterflow per minute. E.g. at 80 degrees abt 200 ton/minute.



water ingress as function of inclination through engine room ventilator

4.5 Heeling angle

In the following picture the heeling angle is shown at which the deck enters the water in the 100%, 50% and 10% loaded condition.

		
100% loaded: water on deck at ~12º	50% loaded: water on deck at ~16º	10% loaded: water on deck at ~21º

The limiting equilibrium acceptable inclination angle is mentioned by the following Authorities:

- DNV Escort Tug requirements requests a 25% reserve stability between equilibrium angle and 20º , this can not be achieved when the equilibrium inclination is much more than 10-12º
- The NMD (Norwegian Maritieme Directorate) Rules for anchor-handlers require a maximum angle of 15º
- BV/Harmonized proposal requires a freeboard>0 at equilibrium angle

Not all Authorities do stipulate explicitly the maximum heeling angle and/or freeboard.

However, for reasons of prudent design, good seamanship with respect to safety of the crew and the prevention of loss of controllability of the tug when the deckedge ships water, the additional requirement is applied in this report, that the angle of heel in the equilibrium condition, should be limited to 15º or to the angle where the deck immerges, whichever is the smallest. The lack of this requirement is considerd an omission in the concerning Regulations.

Inclination of abt 15º

This additional requirement to the heeling angle is judged in the final stability calculations and analysis.

5 Tug stability requirements

5.1 Towline heeling lever

The heeling lever of the towline force with respect to the keelpoint K, with KH the vertical distance above the keel and b the horizontal distance from CL of the attachment of the towing line, amounts to:

$$\text{Lever towline} = KH \cdot \cos\varphi - b \cdot \sin\varphi$$

The heeling lever of the lateral resistance force (or thrusterforce) acting in the vertical centre of lateral resistance, amounts to:

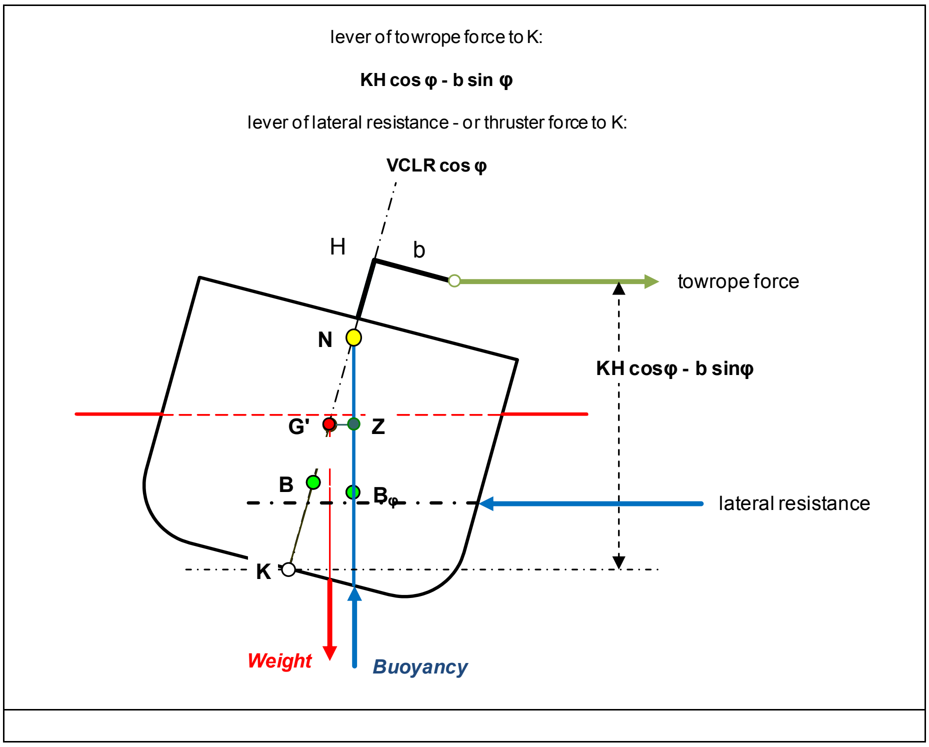
$$\text{Lever lateral resistance} = VCLR \cdot \cos\varphi$$

The total moment applied in the crosssection due to the towlineforce, counteracted by the lateral resistance force, amounts to:

$$\text{lever} = KH \cdot \cos\varphi - b \cdot \sin\varphi - VCLR \cdot \cos\varphi = (KH\text{-}VCLR) \cdot \cos\varphi - b \cdot \text{siin}\ \varphi$$

$$\text{Towline moment} = \text{lever} \cdot \text{towline force}$$

$$\text{Towline moment} = \{(KH\text{-}VCLR) \cdot \cos\varphi - b \cdot \sin\varphi\} \cdot \text{Towline force}$$



This moment can be transformed to an heeling arm in the diagram of righting levers, as follows:

$$\text{Towline lever} = \frac{\text{Towline moment}}{\text{Displacement}}$$

$$\text{Towline lever} = \frac{\{(KH\text{-}VCLR) \cdot \cos\varphi - b \cdot \sin\varphi\} \cdot \text{Towline force}}{\text{Displacement}}$$

Further in this chapter some methods are discussed to directly calculate the heelingarm as function of speed. Further the approach of the various Classification Societies is given to state the design- heeling arm of tugs.

5.2 Calculated towline heeling lever according US Coast Guard circular 12-02

US Coast Guard Circular 12-02 is one of the few publications providing a calculation of the towline heeling lever. The origin of capsizing due to the towline force is considered by USCG by two mechanism[7]:

1. tow tripping: the towline force is caused by the towed vessel
2. self tripping: the towline force is caused by the action of the towing vessel

In case of tow tripping, the speed of towing is determining the heeling moment.
In case of self tripping the magnitude and direction of the propellerforce is determing the heeling moment.

The heeling arm due to <u>tow tripping</u> according this reference is calculated as:

Heeling moment:

$$K = C_1 \cdot C_2 \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \; (\; h \cdot \cos\theta + C_3 \cdot H)$$

where :

$K =$ heeling moment

$C_1 =$ drag coefficient

$C_2 =$ correction to drag coefficient for heel angle

V= towing speed

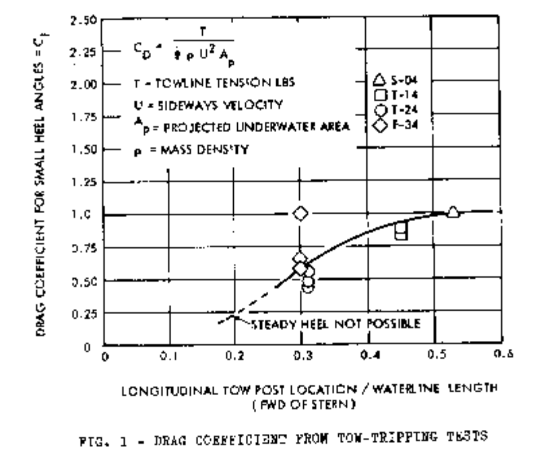
A = projected underwater lateral area

h = heigth of towing bitt above water line

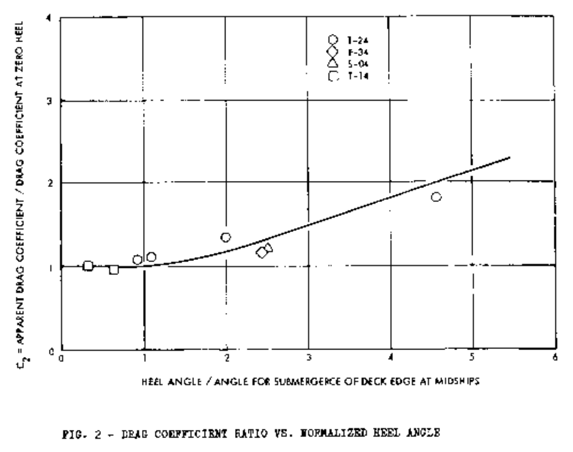
C_3 = location centre lateral force as fraction of draft below waterline

H = draft

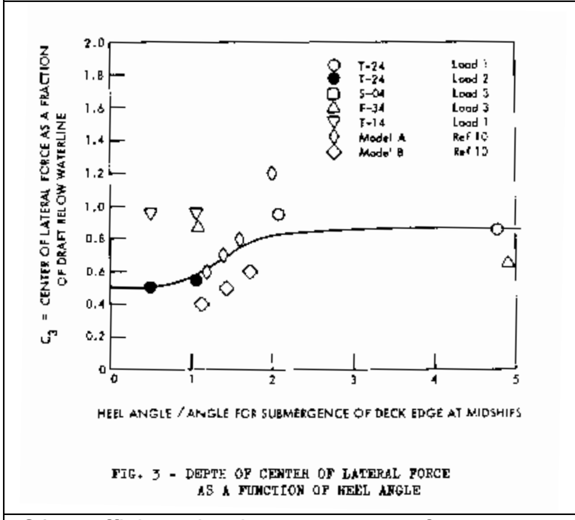
θ = heel angle



Drag coefficient C1



Correction drag coefficient C2



C3 coefficient depth center lateral force

[7] Navigation and vessel inspection circular N0. 12-83, 15 nov 1983, US Coast Guard

Apparently, a steady towline pull is assumed, not a sudden occuring jerk. Further, in this Navigation and Vessel Inspection Circular, the location of the towing point is taken into account, as no steady situation can remain when there is a large separation between towing point and the centre of transverse resistance.

In the current case, we have two towing points:

aft towing point : x = 12.25 m and z = 7.45
forward towing point: x = 33.25 m and z = 9.25

With a waterline length of (0.6 + 32.50) = 33.10 m (an LCG=16.65 m), this means:

Forward towing point:

Longitudinal towpost position/waterline length =1.00- (0.6+33.25)/33.10 = 1.00-1.022= -0.022 (towing over the bow). This would result in a C_1 = 0.00 for a steady heel.

However, it is very well imaginable that a tow jerk occurs with the towline fastened at the forward towing point, but the towline directioned in transverese or aftward direction. It would then take a 90º-135º turn of the tug before the towrope is in longitudinal direction. In that case the assumption C_1 = 0.00 is not correct.

Aft towing point:

Longitudinal towpost position/waterline length = (0.6+12.25)/33.10 = 0.388. This would result in a C_1 = 0.80 for a steady heel. C_2 at deck immersion = 1.00. C_3 for vertical location centre of lateral resistance at deck immersion = 0.55.

With these assumptions the properties towing with the aft towing point is analysed:

Heeling moment at 100% condition :

$$K= C_1 \times C_2 \times \frac{1}{2} \times \rho \times v^2 \times A \times (h \times \cos\theta + C_3 \times H)$$

$$K= 0.80 \times 1.00 \times \frac{1}{2} \times \rho \times v^2 \times (32.50 \times 4.60) \times ((7.45\text{-}4.60) \times \cos\theta + 0.55 \times 4.60)$$

With V=2.57 m/s (5.0 knots) :

$$K= 0.80 \times 1.00 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times (32.50 \times 4.60) \cdot ((7.45\text{-}4.60) \cdot \cos\theta + 0.55 \times 4.60)$$

$K=0.80 \times 3.39 \times 149.5 \times 5.38=2181$ kNm (for $\cos\theta=1.00$)

This is equivalent to a towline force of 405 kN and a vertical cenre of efffort of 2.07 above keel.

This is 405/550 = 0.74 of the nominal bollard pull of the vessel.

This represents a heeling arm at 100% condition of 2181/(966×9.81) = 0.231 m

Heeling moment at 10% condition :

$$K= 0.80 \times 1.00 \times \frac{1}{2} \times \rho \times v^2 \times (32.50 \times 3.79) \times ((7.45\text{-}3.79) \times \cos\theta + 0.55 \times 3.79)$$

With V=2.57 m/s (5.0 knots) :

$$K= 0.80 \times 1.00 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times (32.50 \times 3.79) \cdot ((7.45\text{-}3.79) \cdot \cos\theta + 0.55 \times 3.79)$$

$K=0.80 \times 3.39 \times 123.2 \times 5.75=1921$ kNm (for $\cos\theta=1.00$)

This is equivalent to a towline force of 334 kN and a vertical centre of effort of 1.71 m above keel.

This is 334/550 = 0.61 of the nominal bollard pull of the vessel.

This represents a heeling arm at 10% condition of 1921/(728×9.81)= 0.269 m

The quadratic influence of speed on the heeling arm (aft towing point) is shown in the following table.

speed (knots)	heeling arm 100% loaded	heeling arm 10% loaded
5	0.231	0.269
6	0.333	0.387
7	0.453	0.527
8	0.591	0.689

5.3 Calculated towline heeling lever according German Navy

The tow tripping criterion which is applied by the German navy reads:

Heeling moment:

$M = C_w \times \frac{1}{2} \times \rho \times v^2 \times A \times (z_a - T/2) \times \cos\theta$

where:

M=heeling moment

C_w=drag coefficient = 1.2

V= towing speed

A = projected underwater lateral area

z_a = heigth of towing bitt above base

T = draft

θ = heel angle

For v= 5 knots and 100% loading, aft towing point:

$M = 1.2 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times 149.5 \times (7.45 - 4.60/2) \times \cos\theta$

$M = 3127 \times \cos\theta$ kNm

Which means a heeling arm of:

$3127/(966 \times 9.81) = 0.330 \times \cos\theta$ m

5 knots, 100%, fwd towing point: $M = 1.2 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times 149.5 \times (9.25 - 4.60/2) \times \cos\theta = 4220 \times \cos\theta$

Heeling arm 5 knots, 100%, fwd towing point:: $4220/(966 \times 9.81) = 0.445 \times \cos\theta$ m

For v= 5 knots and 10% loading, aft towing point:

$M = 1.2 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times 123.2 \times (7.45 - 3.79/2) \times \cos\theta$

$M = 2780 \times \cos\theta$ kNm

Which means a heeling arm of:

$2780/(728 \times 9.81) = 0.389 \times \cos\theta$ m

For v= 5 knots and 10% loading, fwd towing point:

$M = 1.2 \times \frac{1}{2} \times 1.025 \times 2.57^2 \times 123.2 \times (9.25 - 3.79/2) \times \cos\theta = 3681 \times \cos\theta$

Which means a heeling arm of:

$3681(728 \times 9.81) = 0.515 \times \cos\theta$ m

Heeling arm German Navy As function of speed:

	heeling arm German Navy (aft towing point) (m)	
speed	100% condition	10% condition
5	0.330	0.389
6	0.475	0.560
7	0.647	0.762
8	0.845	0.996

	heeling arm German Navy (fwd towing point) (m)	
speed	100% condition	10% condition
5	0.445	0.515
6	0.641	0.742
7	0.872	1.009
8	1.139	1.318

5.4 Calculated towline heeling lever according VBD

At VBD extensive investigations on the transverse resistance of tugs including shallow water effects have been made.[8]

<u>The transverse resistance</u> is given by:

$$R_{Tq} = C_{wq} \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot A_L$$

<u>The vertical centre of drag</u> from waterline at rest:

$$z = T\left(f_z - 1\right)$$

C_{wq} can be approximated by:

$$C_{wq} = 1.95 \cdot k_q^{\frac{1}{3}}$$

$$\text{with:}$$

$$k_q = \frac{A_L}{L_{WL}\left(h - T\right)} \cdot C_M$$

$$\text{where:}$$

$$C_M = \frac{A_M}{B \cdot T}$$

The vertical distance of the centre of drag is estimated based on a parameter km:

$$k_m = \frac{B/2 - R}{T}$$

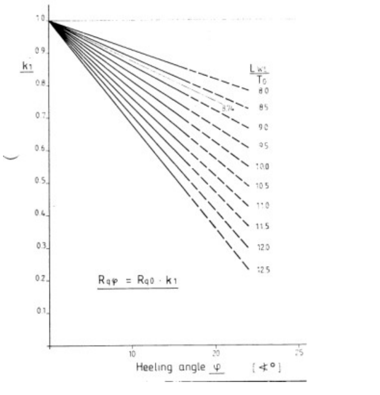
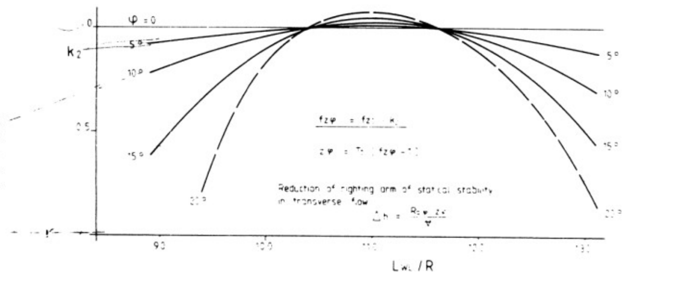
$$\text{where:}$$

$$R = \left(\frac{2 \cdot Vol}{\pi \cdot L_{WL}}\right)^{\frac{1}{2}}$$

f_z can then be approximated by:

$$f_z = 1.19 \cdot k_m^{0.23}$$

A coefficient k1 is applied for the transverse force corrections for angles deviating from 0 degrees. A coefficient k2 is applied to correct the vertical centre of drag for angels deviating from 0 degrees.

	
k1	k2

8 Heuser, H.H., Shallow water effects on a Tug's hydrodynamic qualities, 8th International Tug Convention, 1984

Applying this method, the following estimate of the resistance coefficient can be made:

		loading condition		
		100%	50%	10%
L_{pp}		32.50	32.50	32.50
L_{wl}		33.00	32.30	32.27
B		10.8	10.8	10.8
T		4.595	4.121	3.730
aft towing bitt above base		7.450	7.450	7.450
fwd twoing bitt above base		9.200	9.200	9.200
Displ		966	829	712
C_b		0.581	0.556	0.528
C_m		0.917	0.908	0.898
L/V^(1/3)		3.29	3.46	3.64
Lwl/B		3.06	2.99	2.99
B/T		2.35	2.62	2.90

A_l	Lateral area	138.2	122.1	108.8
LxT	Lateral area est.	149.3	133.9	121.2
Ratio Al / LxT	Al/(LxT)	0.93	0.91	0.90

h	waterdepth	**20**	**20**	**20**
(h-T)/h		0.770	0.794	0.814
k_q	$A_l/(L_{wl}(h-T)) \times C_m$	0.249	0.216	0.186
C_{wq} phi=0	1.95 kq^(1/3)	**1.227**	**1.170**	**1.113**

Lwl/T	heel:	7.18	7.84	8.65
	5	0.96	0.96	0.96
k_1 correction for heel:	**10**	**0.91**	**0.91**	**0.91**
	15	0.87	0.87	0.87
	20	0.82	0.82	0.82

	heel:			
	0	1.23	1.17	1.11
	5	1.17	1.12	1.06
C_{wq} corr for heel:	**10**	**1.12**	**1.06**	**1.01**
	15	1.06	1.01	0.96
	20	1.01	0.96	0.91

At a relevant heeling angle of 10 degrees a Cwq value is found of 1.12, which is higher then the 0.80-1.00 as found with the USCG approach, but lower than the 1.20 as found with the German Navy approach.

The vertical distance of the centre of lateral drag:

R eq	(2V/pi/Lwl)^0.5	4.32	4.04	3.75
km	(B/2 -R)/T	0.236	0.330	0.443
fz for phi=0	(T+z)/T	0.853	0.922	0.987
z	z to wl	-0.67	-0.32	-0.05
z %T above base, phi =0		**0.85**	**0.92**	**0.99**

Lwl/R	heel:	**7.6**	**8.0**	**8.6**
k2 (reduction for fz for phi)	0	1.000	1.000	1.000
	5	0.850	0.870	0.890
	10	0.520	0.610	0.680
	15			0.200
	20			

	heel:			
fz phi	0	0.853	0.922	0.987
	5	0.725	0.802	0.878
	10	0.444	0.562	0.671
	15			0.197
	20			

Which then gives:

	heel:			
CLR above base	0	3.922	3.799	3.681
	5	3.334	3.305	3.276
	10	**2.039**	**2.317**	**2.503**
	15			0.736
	20			

	heel:			
CLR above base as %T	0	0.853	0.922	0.987
	5	0.725	0.802	0.878
	10	**0.444**	**0.562**	**0.671**
	15			0.197
	20			

At the relevant heeling angle of 10 degrees, the centre of lateral resistance is at abt 50% of T above base, comparable with other formulations.

At a speed of 5 knots, the following forces and moments then results for the aft towing point at 7.45 m at a speed of 5 knots:

		Lateral force [kN]		
5 knots		100%	50%	10%
	0	575	485	411
	5	549	463	392
	10	523	441	374
	15	497	419	355
	20	472	397	337

		towline arm to keel		
		100%	50%	10%
	0	7.45	7.45	7.45
	5	7.42	7.42	7.42
	10	7.34	7.34	7.34
	15	7.20	7.20	7.20
	20	7.00	7.00	7.00

		centre lateral resistance to keel		
		100%	50%	10%
	0	3.92	3.80	3.68
	5	3.33	3.31	3.28
	10	2.04	2.32	2.50
	15			0.74
	20			

		towline heeling arm		
		100%	50%	10%
	0	3.53	3.65	3.77
	5	4.09	4.12	4.15
	10	5.30	5.02	4.83
	15			6.46
	20			

		towline heeling moment		
		100%	50%	10%
	0	2029	1769	1548
	5	2245	1905	1626
	10	2772	2213	1807
	15			2295
	20			

		towline lever		
		100%	50%	10%
	0	0.214	0.218	0.222
	5	0.237	0.234	0.233
	10	**0.293**	**0.272**	**0.259**
	15			0.329
	20			

This shows an increasing towline lever with inclination in stead of a decreasing as in other formulations.

As function of speed:

	heeling arm VBD (aft towing point) (m)	
speed	100% condition	10% condition
5	0.293	0.259
6	0.422	0.373
7	0.574	0.508
8	0.750	0.663

At a speed of 5 knots the following moments emerge for the <u>forward towing</u> point at 9.25 m:

		Lateral force [kN]		
5 knots		100%	50%	10%
	0	575	485	411
	5	549	463	392
	10	523	441	374
	15	497	419	355
	20	472	397	337

		towline arm to keel		
		100%	50%	10%
	0	9.20	9.20	9.20
	5	9.16	9.16	9.16
	10	9.06	9.06	9.06
	15	8.89	8.89	8.89
	20	8.65	8.65	8.65

		centre lateral resistance to keel		
		100%	50%	10%
	0	3.92	3.80	3.68
	5	3.33	3.31	3.28
	10	2.04	2.32	2.50
	15			0.74
	20			

		towline heeling arm		
		100%	50%	10%
	0	5.28	5.40	5.52
	5	5.83	5.86	5.89
	10	7.02	6.74	6.56
	15			8.15
	20			

		towline heeling moment		
		100%	50%	10%
	0	3036	2617	2267
	5	3203	2712	2310
	10	3674	2973	2451
	15			2896
	20			

		towline lever		
		100%	50%	10%
	0	0.320	0.322	0.325
	5	0.338	0.333	0.331
	10	**0.388**	**0.366**	**0.351**
	15			0.415
	20			

As function of speed for forward towing point acc VBD approach:

	heeling arm VBD (fwd towing point) (m)	
speed	100% condition	10% condition
5	0.388	0.351
6	0.559	0.505
7	0.761	0.761
8	0.993	0.993

5.5 Towline heeling lever and safety margins according IMO and Classification Societies

5.5.1 Introduction

The design towline heeling lever of the various classification societies and flag authorities is generally expressed as:

$$HA = \frac{c \cdot BP \cdot d}{\Delta} \cdot \cos^n \theta$$

where :

c = factor to obtain lateral thrust as fraction of bollard pull

BP = bollard pull

d= towline arm: distance between towing point and centre of effort

Δ = displacement

n= coefficient 0: horizontal line; 1: cosinus

θ = heeling angle

The following criteria are discussed with respect to the stability of tugs:

1. Minimum design criteria applicable for all ships according IMO
2. Intact stability criteria for tugs according ABS
3. Towline pull criterion USCG
4. Intact stability criteria for tugs according DNV
5. Escort tugs according DNV
6. Requirements of BV
7. UK Department of transport
8. Requirements of GL Tug
9. Requirements of GL Active Escort Tug
10. See Berufs Genossenschaft
11. Proposed harmonized criteria
12. IACS
13. NMD

5.5.2 IMO International Code on Intact Stability (2008 IS Code)

The current minimum design criteria which are applicable to all seagoing cargo and passenger ships of 24 m in length and over are regulated in Resolution MSC.267(85) which adopted the International Code on Intact Stability, 2008 (2008 IS Code):

1. The area under the righting lever curve (GZ curve) shall not be less than **0.055** metre-radians up to $\varphi = 30^o$ angle of heel and not less than **0.09** metre-radians up to $\varphi = 40^o$ or the angle of down-flooding φ_f ,if this angle is less than 40º.
2. Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30º and 40º, or between 30º and φ_f , if this angle is less than 40º, shall be not less than **0.03** metre-radians.
3. The righting lever GZ shall be at least **0.20 m** at an angle of heel equal to or greater than 30º.
4. The maximum righting lever GZ shall occur at an angle of heel not less than **25º**. If this is not practicable, alternative criteria, based on an equivalent level of safety, may be applied subject to the approcal of the Administration.
5. The initial transverse metacentric height GM_0 shall be noy less than 0.15 m
6. Severe wind and rolling criterion to be applied.

When compliance with the above is impracticable due to the vessel's characteristics: (offshore supply vessels with large B/D ratio) then the following equivalent set of criteria should be applied:

1. The area under the curve of righting levers should not be less than 0.070 metre-radians up to an angle of 15º when the maximum righting lever (GZ) occurs at 15º and 0.055 metre-radians up to an angle of 30º when the maximum righting lever (GZ) occurs at 30º or above. Where the maximum righting lever (GZ) occurs at angles of between 15º and 30º, the corresponding area under the righting lever curve should be : $0.055 + 0.001\ (30^o\text{-}\varphi_{max})$ metre-radians, where φ_{max} is the angle of heel at which the righting lever curve reaches its maximum
2. Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30º and 40º, or between 30º and φ_f , if this angle is less than 40º, should be not less than 0.03 metre-radians.
3. The righting lever GZ shall be at least 0.20 m at an angle of heel equal to or greater than 30º.
4. The maximum righting lever GZ shall occur at an angle of heel not less than **15º.**
5. The initial transverse metacentric height GM_0 shall be not less than 0.15 m
6. Severe wind and rolling criterion to be applied

Further, for offshore supply vessels, constructional precautions against capsizing are requested among others:

access to the machinery space should, if possible, be arranged within the forecastle. Any access to the machinery space from the exposed cargodeck should be provided with two weathertight closures. Access to spaces below the exposed deck should preferably be from a position within or above the superstructure deck.

5.5.3 Tug according ABS

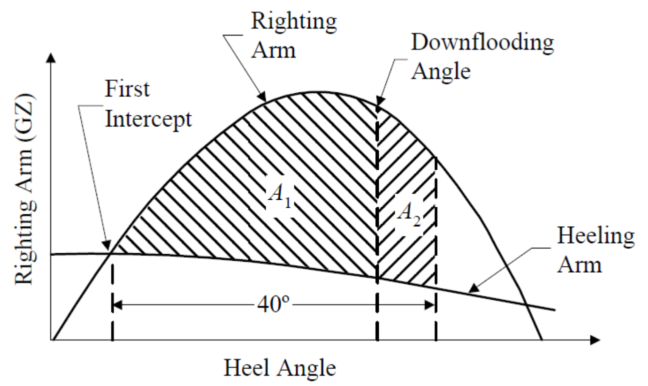
With reference to the ABS Rules for building and classing steel vessels under 90 m in length-2011, vessels intended for towing have to comply with Part 5, Chapter 8, Appendix 1 : Intact stability Guidelines for Towing Vessels.

1. The area under the righting lever curve (GZ curve) should not be less than **0.055** metre-radians up to an angle of heel of 30º and not less than **0.09** metre-radians up to an angle of heel of 40º or the angle of flooding if this angle is less than 40º.
2. The area under the righting lever curve (GZ curve) between the angles of heel of 30º and 40º, or between 30 and φ_f , if this angle is less than 40º, should be not less than **0.03** metre-radians.
3. The righting lever GZ should be at least **0.20 m** at an angle of heel equal to or greater than **30º**.
4. The maximum righting lever GZ should occur at an angle of heel not less than **25º**.
5. The initial transverse metacentre height GM_0 should not be less than **0.15 m**
6. The area of the residual dynamic stability (area between righting and heeling arm curves to the right of the first intercept) up to an angle of heel of <u>40º plus the angle of the first intercept</u> (A1+A2), or the angle of down flooding, if this angle is less than <u>40º plus the angle of the first intercept</u> (A1), should be not less than **0.09** meter-radians.

This set of criteria is equivalent to the IMO minimum design criteria to all ships, with exception of the weathercriterium, plus an additional requirement to the residual stability above the heeling arm curve, which should have a value of 0.09 meter-radian over the same range of 40º as a non-towing vessel, but then calculated from the first intercept between towline heeling arm curve and righting arm curve.

This approach assumes that the towing ship should be able to absorb an energy of wind and waves of 0.09 mrad over a range of 40º from the towing equilibrium, as for non-towing ships in upright position.

FIGURE 1
Righting Arm and Heeling Arm Curves



Righting arm and heeling arm curves (ABS part 5, 8, app 1)

The heeling moment due to the towline pull is calculated using a athwart ship towline pull as a percentage of the maximum bollard pull, depending on the type of propulsion. In case of azimuthing propellers, the towline pull force at 90º towline angle should be taken as 70% of the maximum bollard pull.

Example:
The bollard pull is taken as 55 ton. This means a transverse line pull of 0.70 x 55 = 38.5 ton.
The heeling arm is taken from the top of the towing bitt to the VCB (vertical centre of buoyancy) or to half of the draught of the vessel.

The towing bitt is 9.25 m above base. The draught is 4.60 m. The towing heeling arm is then 9.25 -0.5 x 4.60 = 6.95 m. The displacement is 966 ton. The heeling arm according ABS is then calculated as:

HA = {38.5 x 6.95} / 966 = 0.277 m.

Summary of heeling arm calculation:

			0% foam		
			Loading condition		
			100%	50%	10%
ABS Tug					
Bollard pull		[t]	55.0	55.0	55.0
Reduction factor to obtain transverse towline pull		[-]	0.700	0.700	0.700
Transverse line pull		[t]	**38.5**	**38.5**	**38.5**
Fastening point towing line / Towing bitt above base		[m]	9.250	9.250	9.250
Centre of effort above baseline (= 1/2 T)		[m]	2.298	2.061	1.865
Tow line heeling arm to centre of effort		[m]	6.953	7.190	7.385
Tow line heeling moment		[t m]	**268**	**277**	**284**
Heeling arm = Tow line heeling moment /Δ		[m]	**0.277**	**0.334**	**0.399**
Reduction function for heeling arm		[-]	**cos θ**	**cos θ**	**cos θ**
Residual dynamic stability from first intercept up to	**req:**		**0.090**	**0.090**	**0.090**
first intercept + 40^o or downflooding > 0.09 meter-radians	**actual:**				

5.5.4 Towline pull criterion USCG

5.5.4.1 Minimum GM according USCG CFR 173.095

USCG 46 CFR 173.095 towline pull criterion: either a minimum value to the GM value should be fullfilled or a requirement to the heeling arm.

$$GM > \frac{N\,(P \cdot D)^{2/3} \cdot s \cdot h}{13.93 \cdot \Delta \cdot f / B}$$

where :

$N =$ number of screws

P = shafthorsepower per shaft [kW]

D = propellerdiameter [m]

s = effective decimal fraction of propellerslipstream deflected

$s = \frac{1 + \cos\alpha}{2}$ for azimuthing propulsion units

$\alpha =$ angle between propulsion units if propeller stream of one unit is touching outer edge nozzle other unit

h = vertical distance from propeller shaft centerline to towing bitts [m]

$\Delta =$ displacement [t]

f = minimum freeboard along length of vessel [m]

B = molded beam [m]

Fairplay 22:

$N = 2$

$P = 0.95 \cdot 1650 = 1567$ kW

$D = 2.30$

$\alpha = 20^0$

$s = 0.97$

$h1 = 7.45 - 1.50 = 5.95$ (over aft ship)

$h2 = 9.25 - 1.50 = 7.75$ (over fore ship)

$f = 5.70 - 4.60 = 1.10$

$B = 10.80$

$\Delta = 968$ ton

Then :

$$GM1 > \frac{2\,(1567 \cdot 2.3)^{2/3} \cdot 0.97 \cdot 5.95}{13.93 \cdot 968 \cdot 1.10 / 10.80}$$

$$GM1 > \frac{32.7 \cdot 5.95}{968 \cdot 1.10 / 10.80}$$

$GM1 > 1.97$ (over aftship)

$$GM2 > \frac{2\,(1567 \cdot 2.3)^{2/3} \cdot 0.97 \cdot 7.75}{13.93 \cdot 968 \cdot 1.10 / 10.80}$$

$GM2 > 2.57$ (over foreship)

5.5.4.2 Dynamic stability criterion according USCG CFR 173.095

As an alternative criterion to the minimum GM criterion, the dynamic stability can be judged, with the following heeling arm:

$$HA = \frac{2 \cdot N\,(P \cdot D)^{2/3} \cdot s \cdot h \cdot \cos\varphi}{13.93 \cdot \Delta}$$

Example 100% loaded:

$$HA1 = \frac{2 \cdot 2\,(0.95x1646 \cdot 2.30)^{2/3} \cdot 0.97 \cdot \left(7.45 - 1.50\right) \cdot \cos\varphi}{13.93 \cdot 967}$$

$$HA1 = \frac{65.4 \cdot 5.95 \cdot \cos\varphi}{967}$$

$$HA1 = 0.402 \cdot \cos\varphi \quad (\text{ over aft ship})$$

$$HA2 = 0.524 \cdot \cos\varphi \quad (\text{ over foreship})$$

Apparently, in this criterion the factor for athwarthship fraction of the bollardpull amounts to 65.4/55=1.19.

The applied area criterion is then that the area between the righting lever and the heeling arm, between equilibrium and 40º or the angle of downflooding, whichever is less, shall be not less than 0.0106 meter-radian.

Summary heeling arm calculation:

				Loading condition		
				100%	50%	10%
USCG Towline pull criterion						
Number of screws		N	[-]	2	2	2
Shaft horsepower per shaft		P	[kW]	1568	1568	1568
Propellerdiameter		D	[m]	2.300	2.300	2.300
Fraction of propeller slipstream deflected		s	[-]	0.970	0.970	0.970
Transverse line pull			[t]	32.7	32.7	32.7
Dynamic transverse line pull	2 x tr. Line pull		[t]	**65.5**	**65.5**	**65.5**
Apparent f				**1.19**	**1.19**	**1.19**
Centre line propeller above base				**1.50**	**1.50**	**1.50**
Vertical distance from propellershaft to towing bitt		h	[m]	7.750	7.750	7.750
Tow line heeling moment			[t m]	**508**	**508**	**508**
Heeling arm		HA	[m]	**0.525**	**0.612**	**0.713**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to the		**req:**		**0.0106**	**0.0106**	**0.0106**
maximum righting arm, 40º , or downflooding > 0.0106 meter-radians		**actual:**				

5.5.5 Tug according DNV

The additional requirement for a tug, above the minimum requirements for all ships, according to DNV, Rules for Ships, July 2010, Part 5, Ch. 7, Sec 12, E100, has to be evaluated with a transverse heeling lever as follows:

$$HL_\theta = \frac{F_{thr} \cdot h \cdot \cos\theta}{g \cdot \Delta}$$

where :

$F_{thr} = BP \cdot C_T$

$BP =$ measured bollardpull [kN]

$C_T =$ reduction factor depending on propulsion arrangement

$C_T = \approx 1.0$ for azimuthing thrusters

h= towing heeling arm

h= vertical distance between centre propeller and fastening point towline

$\Delta =$ displacement in tonnes

The criterion which has to be fulfilled according DNV is then that the residual area between the righting lever curve and the heeling lever curve shall not be less then 0.09 metre-radians. The area is calculated between the first interception and the second interception or the angle of downflooding, whichever is less.

Alternatively, the area under the righting lever curve shall not be less than 1.4 times the area under the heeling lever curve, where the areas are determined between 0º and the angle of the second interception or the angle of flooding down, whichever is less.

Example:

Bollard pull = 55 tonnes; C_T = 1.0;

h = 7.75 m (over the bow)

With displacement = 967 tonnes, the heeling arm according DNV Tugs can then be calculated as:

Heeling arm = {55 x 1.00 x 7.75} / 967 = 0.441 m

Summary of heeling arm calculation:

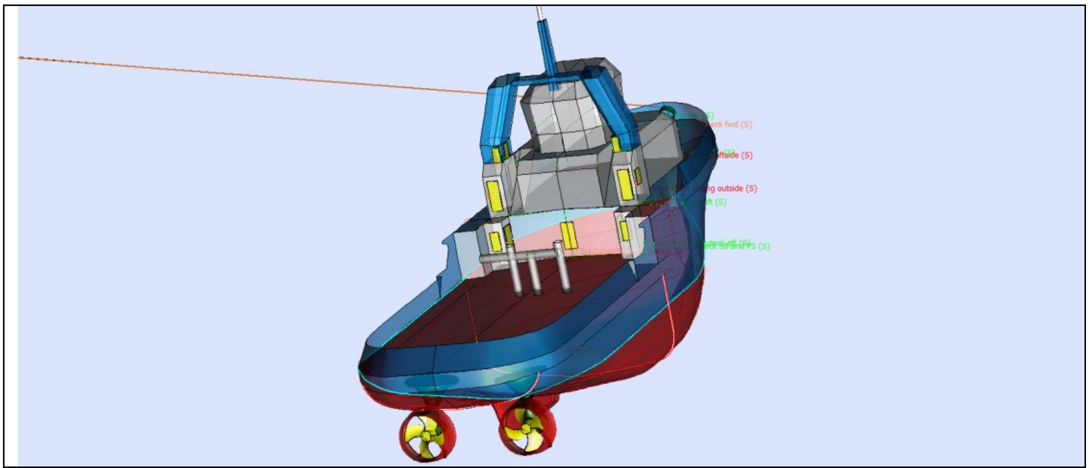
				0% foam		
				Loading condition		
				100%	50%	10%
DNV Tug						
Bollard pull		BP		55.0	55.0	55.0
Reduction factor to obtain transverse towline pull from bollard pull		C_T		1.000	1.000	1.000
Transverse towline pull	$F_{thr} = BP \times C_T$	F_{thr}		**55.0**	**55.0**	**55.0**
Fastening point towing line above base		FP		9.250	9.250	9.250
Centre line propellers above base		CL		1.500	1.500	1.500
Towing heeling arm	h = FP - CL	h		7.750	7.750	7.750
Towing heeling moment				**426**	**426**	**426**
Heeling arm = Towing heeling moment /Δ		HL_θ		**0.441**	**0.514**	**0.599**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to the second intercept, or downflooding > 0.09 meter-radians		**req:** **actual:**		**0.090**	**0.090**	**0.090**
Alternative: area righting curve not less than 1.4 times area of heeling lever curve, between 0° and second intercept or downflooding.						

5.5.6 Escort vessels according DNV

Forces during assisting at low speeds are mainly generated by the thrusters. At higher speeds, above 6-8 knots, the steering and braking forces on the assisted vessel are mainly generated by the hydrodynamic forces on the tug's hull. In that regime the notion escort service is used, for which DNV has developed separate requirements, formally applicable for speeds above 8 knots.

The heeling arm should be derived from the test where the steering force is achieved for which an escort notation is sought.

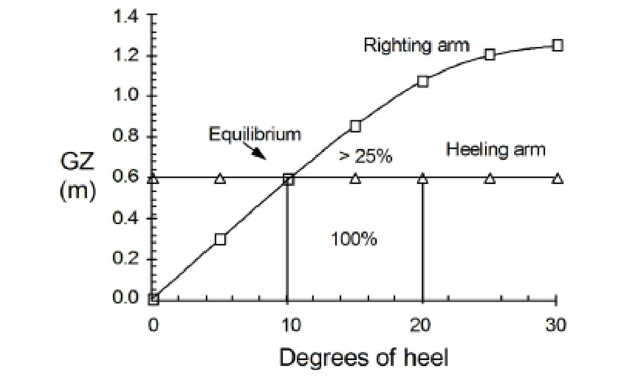
A practical approach in this case for the estimate of the value of the heeling arm is to take the heeling arm associated with the maximum angle which is expected to be allowed by the captain. This is or just before deckedge immersion or 12-13 degrees heeling.



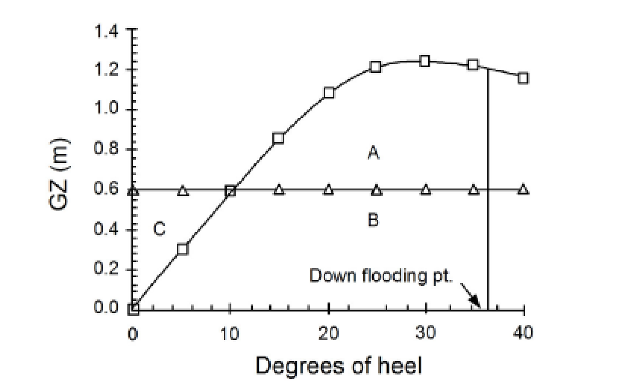
deck edge immersion at ~ 12 degrees at full draught

DNV, Rules for Ships, Pt. 5, Ch. 7, Sec 13, D, then requires for an escort tug:

1. a margin of 25% between the area below the righting arm and the area below the heeling arm between the equilibrium and 20º.
2. a margin of 40% between the area below the righting arm and the area below the heeling arm between 0º and 40º or the angle of downflooding, whichever is less



DNV D201 : ratio of areas between equilibrium and 20º



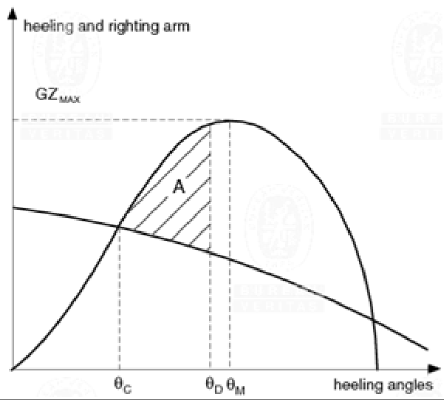
DNV D203: ratio of areas between 0º and 40º or downflooding

Summary of heeling arm calculation:

			Loading condition		
			100%	50%	10%
DNV Escort Tug					
Max steering force					
Steering force	F_{thr}		**55**	**55**	**55**
Centre line propellers above base	CL		1.500	1.500	1.500
Fastening point above base	FP		9.250	9.250	9.250
Towing heeling arm	h		7.750	7.750	7.750
Towing heeling moment			**426**	**426**	**426**
Heeling arm = Towing heeling moment /Δ	HL_{θ}		**0.441**	**0.514**	**0.599**
Reduction function for heeling arm			1.000	1.000	1.000
Requirement: ratio between righting and heeling areas between first intercept and 20° > 1.25 with maximum steering force	**req:**		**1.250**	**1.250**	**1.250**
	actual:				
Requirement: area righting curve not less than 1.4 times area of heeling lever curve, between 0° and 40° or downflooding.	**req:**		**1.400**	**1.400**	**1.400**
	actual:				

5.5.7 Bureau Veritas

Bureau Veritas adopts in its Rules for the classification of steel Ships, the following:



Residuary stability > 0.011 mrad

A tug may be considered as having suffcient stability, according to the effect of the towing force in the beam direction if

A > 0.011 [m rad]

A = area contained between the righting lever and the heeling arm curves between θ_c and θ_d

θ_c= heeling angle of equilibrium

θ_d= heeling angle to be taken as the lowest of:

- θ_m = angle corresponding to the position of GZ_{max}
- the angle of downflooding
- 40°

The righting lever is calculated according:

$$b_h = \frac{T \cdot H \cdot c}{9.81 \cdot \Delta} \cdot \cos\theta$$

where :

b_h = heeling arm [m]

T= maximum bollard pull [kN]

H= vertical distance between towing hook and half draught [m]

c = coefficient;

c = 1.0 for ships with azimuth propulsion

c= 0.65 for ships with non-azimuth propulsion

Δ = loading condition displacement i[t]

Example:

$$b_h = \frac{T \cdot H \cdot c}{9.81 \cdot \Delta} \cdot \cos\theta$$

T= 55x9.81=539.6 [kN]; H= 9.25-1/2 x 4.60 = 9.25-2.30 = 6.95 [m]; c = 1.0 for ships with azimuth propulsion

Δ = loading condition displacement=966 [t]

$$b_h = \frac{539.6 \cdot 6.95 \cdot 1.0}{9.81 \cdot 966} \cdot \cos\theta = 0.396 \cdot \cos\theta$$

Summary of heeling arm calculation Bureau Veritas:

				0% foam		
				Loading condition		
				100%	50%	10%
Bureau Veritas Tug						
Bollard pull		BP		55.0	55.0	55.0
Reduction factor to obtain transverse towline pull from bollard pull		CL		1.000	1.000	1.000
Transverse towline pull	T = BP x C	T		**55.0**	**55.0**	**55.0**
Fastening point towing line above base		FP		9.250	9.250	9.250
Centre of effort : half draught				2.298	2.061	1.865
Towing heeling arm	h = FP - CL	h		6.953	7.190	7.385
Towing heeling moment				**382**	**395**	**406**
Heeling arm = Towing heeling moment /Δ		HL_θ		**0.396**	**0.477**	**0.570**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to		**req:**		**0.011**	**0.011**	**0.011**
GZ max, downflooding, 40 > 0.011 meter-radians		**actual:**				

5.5.8 UK Department of Transport

The British Department of Transport has published in June 1993 the Merchant Shipping Notice No M.1531 :"Safety of Tugs While Towing". (Cancelled 30 August 1999, but included in Merchant Shipping (Load Line) Regulations 1998 for non-seagoing harbour tugs and seagoing tugs less than 80 tons).

This note was published as a reaction on a casuality with a tug, caused by girting, but where the following contributory causes were found: (i) small freeboard; (ii) poor curve of righting levers; (iii) closing appliances to spaces leading below not secured.

The following recommendations were made in this notice:

1. It is of the greatest importance that the design of the towing gear should be such as to minimise the overturning moment due to the lead of the towline and that the towing hook should have a positive means of quick release which can b erelied upon to function correctly under all operating conditions. …
2. Openings in superstructures, deckhouses and exposed machinery casings situated on the weather deck, which provide access to spaces below that deck, should be fitted with weathertight doors which comply with the requirements for weathertight doors contained in paragraph 1, Schedule 4 of the Merchant Shipping (Load Line) Rules 1968. Such doors should be kept closed during towing operations. Engine room ventilation should be arranged by means of high coaming ventilators and air pipes should be fitted with automatic means of closure.
3. Stability criteria for tugs not subject to the requirements of the Merchant Shipping (Load Line) Rules 1968:
    a. In the normal working condition, the freeboard should be such that the deck-edge is not immersed at an angle of less than 10º.
    b. The GM in the worst anticipated service condition should be not less than:
        i. (0.076xK)/(fxC_b)
        ii. where K =1.524+0.08xL-0.45r ; L=length perpendiculars; r=length of radial arm of towing hook; f=freeboard

Example:

$$GM > \frac{0.076 \cdot K}{f \cdot C_b}$$

Where :

$$K = 1.524 + 0.08 \cdot 32.50$$

$$f = 1.10 \text{ m}$$

$$C_b = 0.565$$

$$GM > \frac{0.076 \cdot 4.124}{1.10 \cdot 0.565}$$

$$GM > 0.50$$

which is an unrealistic low value for this type of tug.

5.5.9 Germanischer Lloyd Tug

The current Rules for Classification and Construction of Seagoing Ships 2011, Chapter 25, Tugs, of Germanischer Lloyds set the following set of requirements:

The intact stability shall comply with the following requirements:

1. the intact stability requirement of the International Code of Intact Stability (2008 IS Code), Chapter A 2
2. alternatively if applicable, the intact stability requirement of the 2008 IS Code, Chapter B.2.4
3. Additionally, the intact stability shall comply with one of the following requirements:
   a. The residual area between a righting lever curve and a heeling lever curve developed from 70 % of the maximum bollard pull force acting in 90° to the ship-length direction should not be less than 0.09 mrad. The area has to be determined between the first interception of the two curves and the second interception or the angle of down flooding whichever is less.
   b. Alternatively, the area under a righting lever curve should not be less than 1.4 times the area under a heeling lever curve developed from 70 % of the maximum bollard pull force acting in 90° to ship-length direction. The areas to be determined between 0° and the 2nd interception or the angle of down flooding whichever is less.

The heeling lever curve should be derived by using the following formula:

$$b_h = \frac{0.7 \cdot T \cdot z_h \cdot \cos\theta}{9.81 \cdot D} = \frac{0.071 \cdot T \cdot z_h \cdot \cos\theta}{D}$$

Where:

b_h = heeling arm [m]
T = maximum bollard pull [kN]
z_h = vertical distance [m] between the working point of the towrope and the centre of buoyancy
D = loading condition displacement [t]
Θ = heeling angle [°]

Example:

$$b_h = \frac{0.7 \cdot 52 \cdot 9.81\,(\,9.25 - 2.75) \cdot \cos\theta}{9.81 \cdot D} = 0.243 \cdot \cos\theta \quad (\text{ over the bow})$$

$$b_h = \frac{0.7 \cdot 52 \cdot 9.81\,(\,7.45 - 2.75) \cdot \cos\theta}{9.81 \cdot D} = 0.176 \cdot \cos\theta \quad (\text{ over the stern})$$

Summary of calculation heeling arm according GL:

				0% foam		
				Loading condition		
				100%	50%	10%
GL Tug						
Bollard pull		T		55.0	55.0	55.0
Reduction factor to obtain transverse towline pull from bollard pull		c		0.700	0.700	0.700
Transverse towline pull		F_{thr}		**38.5**	**38.5**	**38.5**
Fastening point towing line above base		FP		9.250	9.250	9.250
Vertical centre of buoyancy		vcb		2.757	2.473	2.238
Towing heeling arm	h = FP - vcb	h		6.493	6.777	7.012
Towing heeling moment				**250**	**261**	**270**
Heeling arm = Towing heeling moment /Δ		HL_θ		**0.259**	**0.315**	**0.379**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to the second intercept, or downflooding > 0.09 meter-radians		**req:** **actual:**		**0.090**	**0.090**	**0.090**
Alternative: area righting curve not less than 1.4 times area of heeling lever curve, between 0° and second intercept or downflooding.						

5.5.10 Germanischer Lloyd Active Escort Tug

The same Rules of Germanischer LLoyd, in case of an Active Escort Tug 'proof of stability has to be shown' without further specification, by using the heeling lever curve calculated by:

$$b_h = \frac{T \cdot z_h \cdot \cos\theta}{9.81 \cdot D}$$

Where:

b_h = heeling arm [m]
T = maximum tow rope pull [kN]
z_h = vertical distance [m] between the working point of the towrope and the centre of buoyancy
D = loading condition displacement [t]
Θ = heeling angle [°]

which results in heeling arms 10/7=1.429 higher than those for normal tugs.

					0% foam	
					Loading condition	
				100%	50%	10%
GL Escort Tug						
Towrope pull		T		55.0	55.0	55.0
Reduction factor to obtain transverse towline pul		c		1.000	1.000	1.000
Transverse towline pull		F_{thr}		**55.0**	**55.0**	**55.0**
Fastening point towing line above base		FP		9.250	9.250	9.250
Vertical centre of buoyancy		vcb		2.757	2.473	2.238
Towing heeling arm	h = FP - vcb	h		6.493	6.777	7.012
Towing heeling moment				**357**	**373**	**386**
Heeling arm = Towing heeling moment /Δ		HL_θ		**0.370**	**0.450**	**0.542**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to		**req:**		**0.090**	**0.090**	**0.090**
the second intercept, or downflooding > 0.09 meter-radians		**actual:**				
Alternative: area righting curve not less than 1.4 times area of heeling lever curve, between 0° and second intercept or downflooding.						

5.5.11 See Berufs Genossenschaft

The Seeberufsgenossenschaft (SBG) maintained the following requirement for tugs according the stability booklet : Directive on the application of stability rules, section 3:

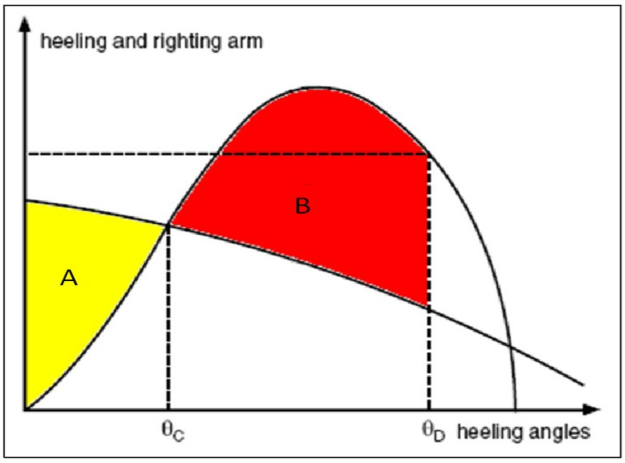
A. Area under the GZ-curve up to 30 degrees to be not less than 0.055 m rad
B. Area under curve up to 40 degrees not to be less than 0.09 m rad
C. Area between 30 degrees and 40 degrees to be not less than 0.03 m rad
D. Righting arm at 30 degrees inclination to be at least 0.30 m
E. Initial GM to be at least 0.60 m
F. Range of stability to be not less than 60 degrees

No requirement to towline heeling arm are given.

The analysis of this set of requirements is given in the report of SARC: Fairplay 22, of March 2011.

5.5.12 Bureau Veritas proposal for harmonised towing stability criteria

Recently a proposal was made by Bureau Veritas for a harmonized towing stability criterion.[9] This assumes that the heeling moment is suddenly applied and that the dynamic heeling angle is determined by equal area's A and B, representing performed labour.



Harmonized proposal: area B> area A

a. Area B > Area A
b. Freeboard at $\theta_c > 0$

θ_c = equilibrium
θ_d = lesser of heeling angle of second interception, and the angle of downflooding

$$b_h = \frac{T \cdot H \cdot c}{9.81 \cdot D} \cdot \cos\theta$$

T = bollard pull [kN]
H= vertical distance between towing point and centreline propeller
c = coefficient = 0.70 for azimuthing propellers; = 0.50 for non-azimuthing propellers

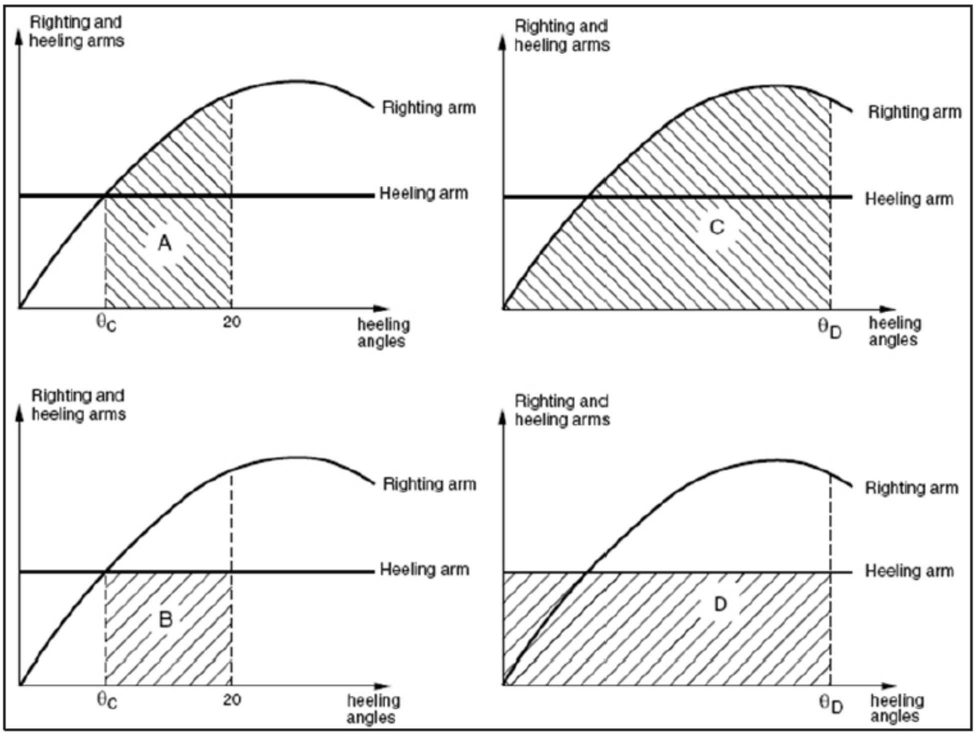
Summary proposal BV:

				0% foam		
				Loading condition		
				100%	50%	10%
Harmonized proposal BV						
Bollard pull		BP		55.0	55.0	55.0
Reduction factor to obtain transverse towline pull from bollard pull		c		0.700	0.700	0.700
Transverse towline pull	F_{thr} = BP x C	F_{thr}		**38.5**	**38.5**	**38.5**
Fastening point towing line above base		FP		9.250	9.250	9.250
Centre line propellers above base		CL		1.500	1.500	1.500
Towing heeling arm	h = FP - CL	h		7.750	7.750	7.750
Towing heeling moment				298	298	298
Heeling arm = Towing heeling moment /Δ		HL_θ		0.309	0.360	0.419
Reduction function for heeling arm				cos θ	cos θ	cos θ
Heeling angle for freeboard = 0				11.6	16.3	20.0
Maximum allowed heeling for safety on deck				15	15	15
Maximum applied heeling angle				12	15	15
Tow line force for indicated heeling angle	F = (Δ x GM sin θ) / h			25.1	25.4	17.5
% of actual towline force				0.65	0.66	0.46
area between heeling curve and righting curve up to first intercept not more than 1.0 times area of area between righting curve and heeling curve between first intercept and angle of downflooding						

[9] De Jong, G., The class answer to the rapidly developing tug industry, ITS 2010, Vancouver.

5.5.13 Proposal BV for harmonised escort towing stability criteria

The proposal for escorting made by Bureau Veritas is identical to the DNV criteria with an additional requirement that freeboard > 0 at the equilibrium angle.



A>1.25xB; C>1.40xD; f at θ_c >0

5.5.14 Unified interpretation IACS no 24

IACS the organisation of cooperating classification societies recommends the following requirements for towing vessels:

- The intact stability requirement of IMO Res. A.749(18), Chapter 3.1, as amended by MSC Resolution 75(69),
- alternatively, if applicable: the intact stability requirement of IMO Res. A.749(18) Chapters 4.5 as amended by MSC Resolution 75(69).

Additionally:

- The residual area between a righting lever curve and a heeling lever curve developed from 70% of the maximum bollard pull force acting in 90° to the ship-length direction should not be less than 0.09 mrad. The area has to be determined between the first interception of the two curves and the second interception or the angle of down flooding whichever is less.
- alternatively, the area under a righting lever curve should not be less than 1.4 times the area under a heeling lever curve developed from 70% of the maximum bollard pull force acting in 90° to ship-length direction. The areas to be determined between 0° and the 2nd interception or the angle of down flooding whichever is less.

The heeling lever curve should be derived by using the following formula:

$bh = 0.7 \times T \times H \cos\theta / (9.81 \times \Delta)$

where:

bh= heeling arm, in m
T = maximum bollard pull, in kN
H = vertical distance, in m, between the towing hook and the centre of the propeller
Δ = loading condition displacement, in t.

Summary IACS:

				0% foam		
				Loading condition		
				100%	50%	10%
IACS Unified interpretation Tug						
Bollard pull		T		55.0	55.0	55.0
Reduction factor to obtain transverse towline pull from bollard pull		c		0.700	0.700	0.700
Transverse towline pull		F_{thr}		**38.5**	**38.5**	**38.5**
Fastening point towing line above base		FP		9.250	9.250	9.250
Centre line of propellers above base		cl		1.500	1.500	1.500
Towing heeling arm	h = FP - vcb	h		7.750	7.750	7.750
Towing heeling moment				**298**	**298**	**298**
Heeling arm = Towing heeling moment /Δ		HL_θ		**0.309**	**0.360**	**0.419**
Reduction function for heeling arm				**cos θ**	**cos θ**	**cos θ**
Requirement: residual dynamic stability from first intercept up to the second intercept, or downflooding > 0.09 meter-radians		**req:**		**0.090**	**0.090**	**0.090**
		actual:				
Alternative: area righting curve not less than 1.4 times area of heeling lever curve, between 0° and second intercept or downflooding.						

5.5.15 Norwegian Maritime Directorate Circular

Finally mention is made of The Norwegian Maritme Directorate publication: RSV 04-2008: 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.

In those guidelines the maximum equilibrium heeling angle caused by the combined action of anchorchain/wire and propellers is determined by the following three requirements:

- Heeling angle equivalent to a GZ value equal to 50% of GZ max
- The angle which results in water on working deck when the deck is calculated as flat
- 15 degrees

The heeling moment must be calculated as the total effect of the horizontal and vertical transverse components of force/tension in the wire or the chain. The torque arm of the horizontal components shall 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. The torque arm of the vertical components shall 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.

The heeing moment is therefore calculated as the combined action of tow/anchorline and propellers and therefore in a comparable way as the calculation of the towline heeling moments.

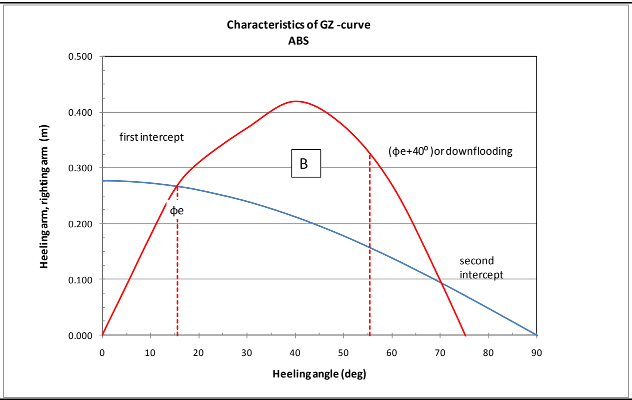
The safety approach of NMD could therefore also be used for tugs in judging the achieved heeling angle against the three criteria of NMD.

5.6 Summary requirements

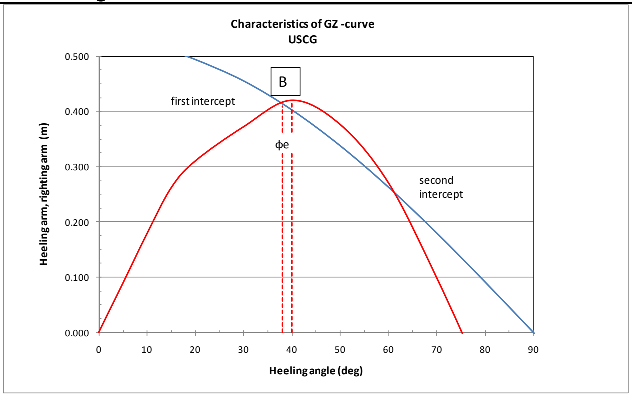
5.6.1 Safety margins

	requirements to residuary stability		
	from:	*to the lesser of:*	*area requirement:*
IMO			
ABS Tug	first intercept	# first intercept + 40º # downflooding	> **0.09** mrad
USCG	first intercept	# max arm # 40º # downflooding	>**0.0106** mrad
DNV tug	first intercept	# second intercept # downflooding	>**0.09** mrad
DNV tug alternative	0º	# second intercept # downflooding	area righting curve > **1.40** x area heeling curve
DNV escort tug	first intercept	# 20º	area righting curve > **1.25** x area heeling curve
+ DNV escorttug	0º	# 40º # downflooding	area righting curve > **1.40** x area heeling curve
BV	first intercept	# max arm # 40º # downflooding	> **0.011** mrad
GL tug	first intercept	# second intercept # downflooding	> **0.09** mrad (B>0.09)
GL tug alternative	0º	# second intercept # downflooding	area righting curve > **1.40** x area heeling curve
SBG old			
Harmonized proposal BV	0º	# second intercept # downflooding	area righting curve > **1.00** x area heeling curve (B>A) Freeboard at first intercept > 0
IACS	first intercept	# second intercept # downflooding	B >**0.09** mrad
IACS alternative	0º	# second intercept # downflooding	area righting curve > **1.40** x area heeling curve

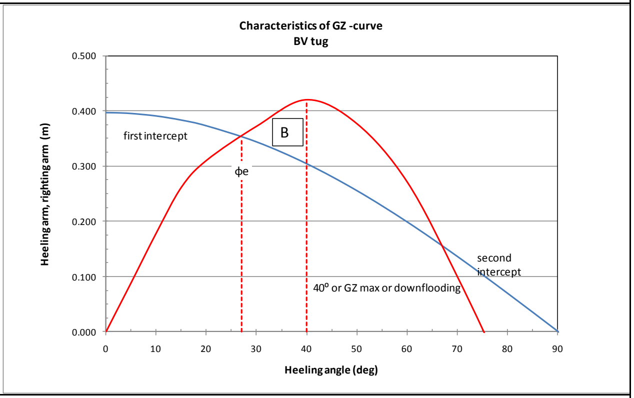
Schematic overview of requirements to reserve stability



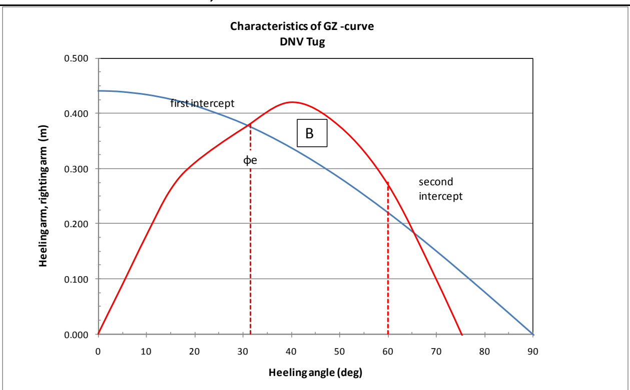
ABS Tug: B>0.09 mrad



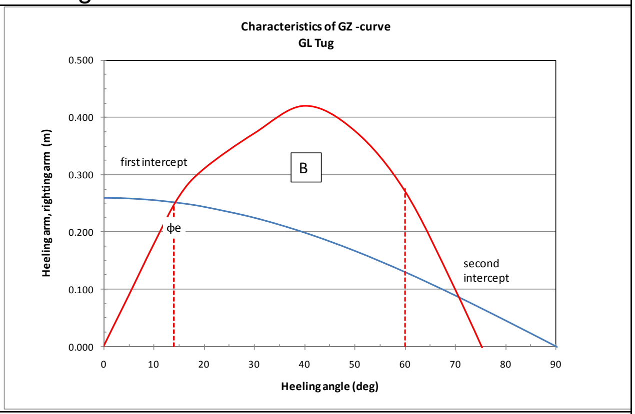
USCG: B>0.0106;



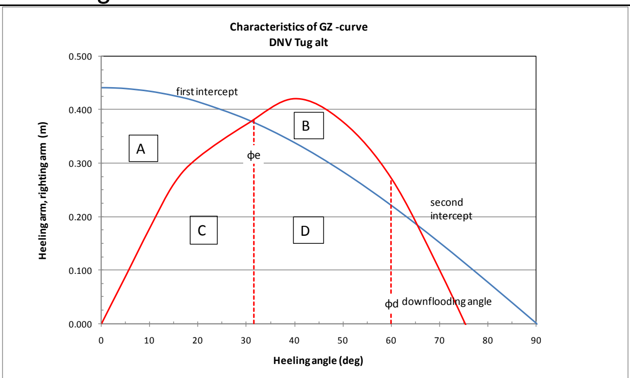
BV Tug: B>0.011 mrad



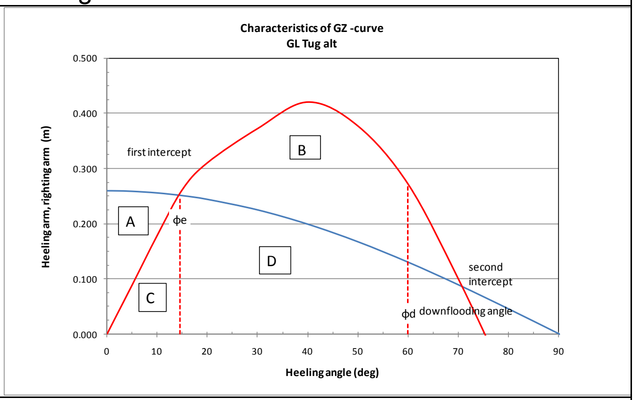
DNV Tug: B>0.09 mrad



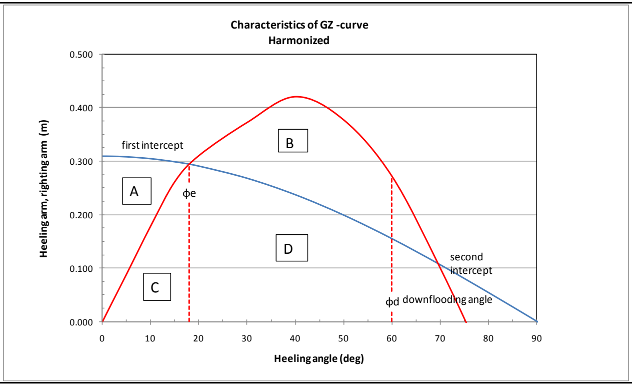
GL Tug: B>0.09 mrad



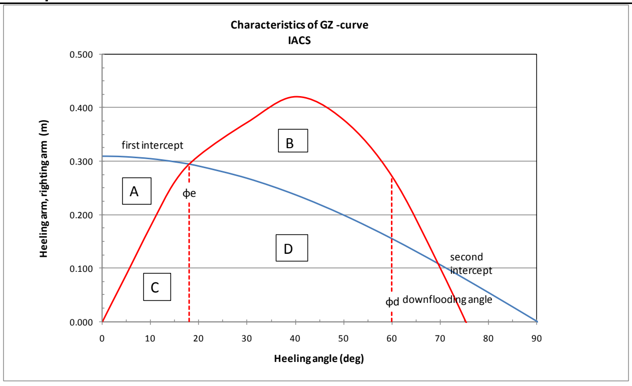
DNV Tug alt: (C+D+B)> 1.4 (A+C+D) :
B>1.4A+0.4(C+D)



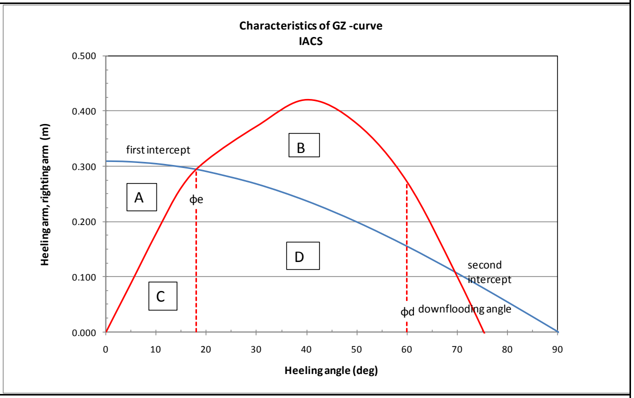
GL Tug alt: (C+D+B)> 1.4 (A+C+D) :
B>1.4A+0.4(C+D)



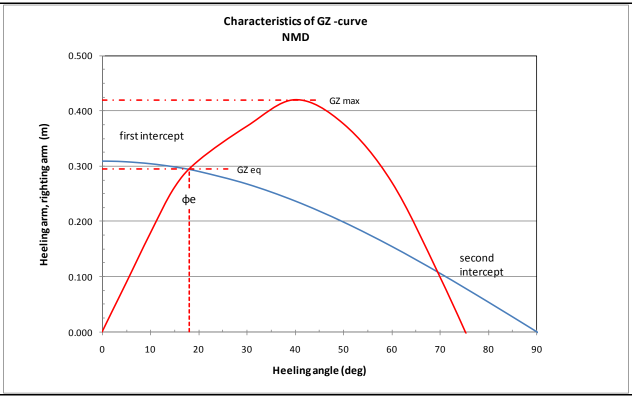
Proposal harmonized BV: B>A



IACS: B>0.09 mrad



IACS alt: (C+D+B)> 1.4 (A+C+D) :
B>1.4A+0.4(C+D)



NMD: $GZ_{eq} > 0.50xGZ_{max}$; $\varphi_e<15$; $\varphi_e< \varphi_d$

5.6.2 Summary of heeling arm formulations

	heeling arm curve		
	c: towline force = c x Bollard Pull	*d: towline lever towing bitt to*	*n curve*
IMO	**n.a.**	n.a.	n.a.
ABS Tug	**0.7**	½ T	1
USCG	**~1.2**	CL propellers	1
DNV tug	**1.0**	CL propellers	1
DNV tug alternative	**1.0**	CL propellers	1
DNV escort tug	**1.0 x steering force**	CL propellers	0
BV Tug	**1.0**	½ T	1
GL tug	**0.7**	VCB	1
GL tug alternative	**0.7**	VCB	1
SBG (old)	**n.a.**	n.a.	n.a.
Harmonized proposal BV Tug	**0.7**	CL propellers	1
IACS	**0.7**	CL propellers	1
IACS alternative	**0.7**	CL propellers	1

6 Heeling arm calculations applied

6.1 Elements of the calculation

	0% foam			0% foam + ballast		
	c: fraction of bollard pull			**c ballast**		
	100%	50%	10%	100%	50%	10%
ABS Tug	0.700	0.700	0.700	0.700	0.700	0.700
USCG Towline pull criterion	**1.191**	**1.191**	**1.191**	**1.191**	**1.191**	**1.191**
DNV Tug	1.000	1.000	1.000	1.000	1.000	1.000
Bureau Veritas Tug	1.000	1.000	1.000	1.000	1.000	1.000
GL Tug	**0.700**	**0.700**	**0.700**	**0.700**	**0.700**	**0.700**
IACS Unified interpretation Tug	0.700	0.700	0.700	0.700	0.700	0.700
Harmonized proposal BV	0.700	0.700	0.700	0.700	0.700	0.700

	vertical centre of resistance			**vclr ballast**		
	100%	50%	10%	100%	50%	10%
ABS Tug	2.298	2.061	1.865	2.298	2.193	2.005
USCG Towline pull criterion	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**	**1.500**
DNV Tug	1.500	1.500	1.500	1.500	1.500	1.500
Bureau Veritas Tug	2.298	2.061	1.865	2.298	2.193	2.005
GL Tug	**2.757**	**2.473**	**2.238**	**2.757**	**2.632**	**2.405**
IACS Unified interpretation Tug	1.500	1.500	1.500	1.500	1.500	1.500
Harmonized proposal BV	1.500	1.500	1.500	1.500	1.500	1.500

	h towing fwd			**h towing fwd ballast**		
	100%	50%	10%	100%	50%	10%
ABS Tug	6.953	7.190	7.385	6.953	7.057	7.246
USCG Towline pull criterion	**7.750**	**7.750**	**7.750**	**7.750**	**7.750**	**7.750**
DNV Tug	7.750	7.750	7.750	7.750	7.750	7.750
Bureau Veritas Tug	6.953	7.190	7.385	6.953	7.057	7.246
GL Tug	**6.493**	**6.777**	**7.012**	**6.493**	**6.618**	**6.845**
IACS Unified interpretation Tug	7.750	7.750	7.750	7.750	7.750	7.750
Harmonized proposal BV	7.750	7.750	7.750	7.750	7.750	7.750

	h towing aft			**h towing aft ballast**		
	100%	50%	10%	100%	50%	10%
ABS Tug	5.153	5.390	5.585	5.153	5.257	5.446
USCG Towline pull criterion	**5.950**	**5.950**	**5.950**	**5.950**	**5.950**	**5.950**
DNV Tug	5.950	5.950	5.950	5.950	5.950	5.950
Bureau Veritas Tug	5.153	5.390	5.585	5.153	5.257	5.446
GL Tug	**4.693**	**4.977**	**5.212**	**4.693**	**4.818**	**5.045**
IACS Unified interpretation Tug	5.950	5.950	5.950	5.950	5.950	5.950
Harmonized proposal BV	5.950	5.950	5.950	5.950	5.950	5.950

	Heeling arm towing fwd			**Heeling arm towing fwd (+ballast)**		
	100%	50%	10%	100%	50%	10%
ABS Tug	0.277	0.334	**0.399**	0.277	0.298	0.350
USCG Towline pull criterion	**0.525**	**0.612**	**0.713**	0.525	0.557	0.638
DNV Tug	0.441	0.514	0.599	0.441	0.468	0.535
Bureau Veritas Tug	0.396	0.477	0.570	0.396	0.426	0.501
GL Tug	**0.259**	**0.315**	0.379	0.259	0.280	0.331
IACS Unified interpretation Tug	0.309	0.360	0.419	0.309	0.328	0.375
Harmonized proposal BV	0.309	0.360	0.419	0.309	0.328	0.375

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6.2 Graphical presentation of the various heeling arms

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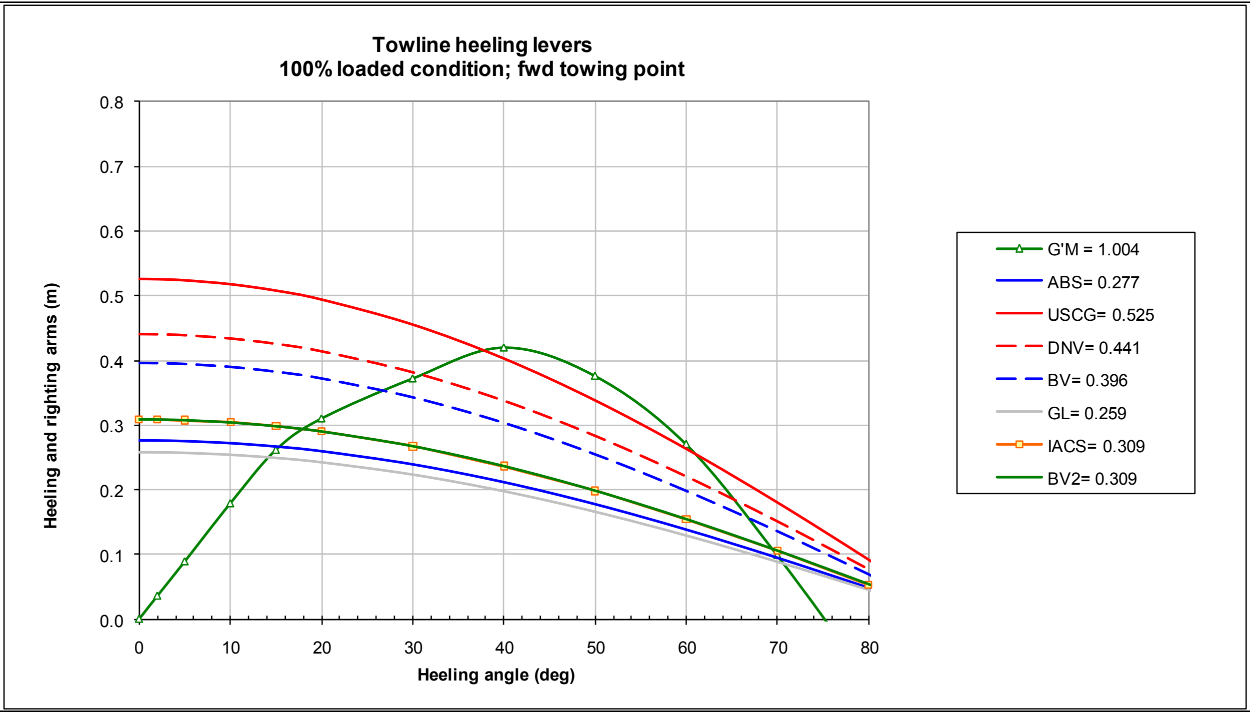

heeling arms in 100% loaded condition

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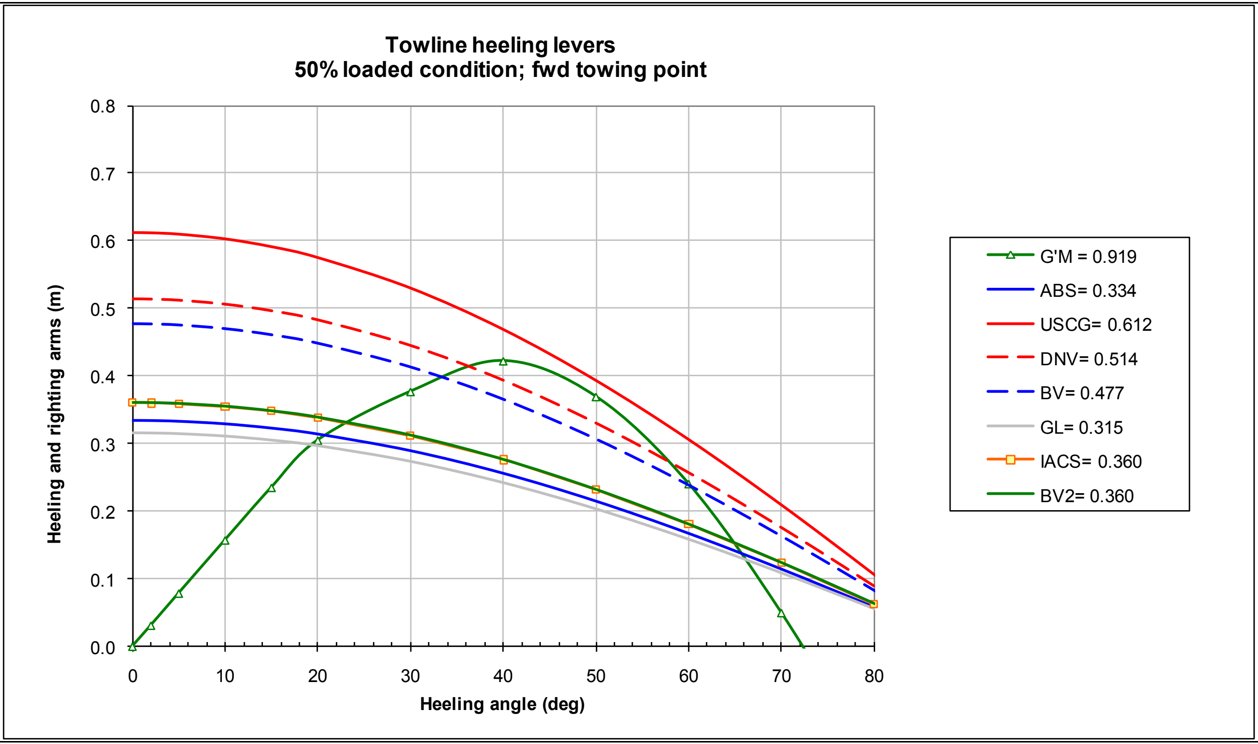
This shows that the highest heeling arm is predicted by USCG, while the lowest arm is predicted by Germanischer Lloyd.



heeling arms in 50% loaded condition

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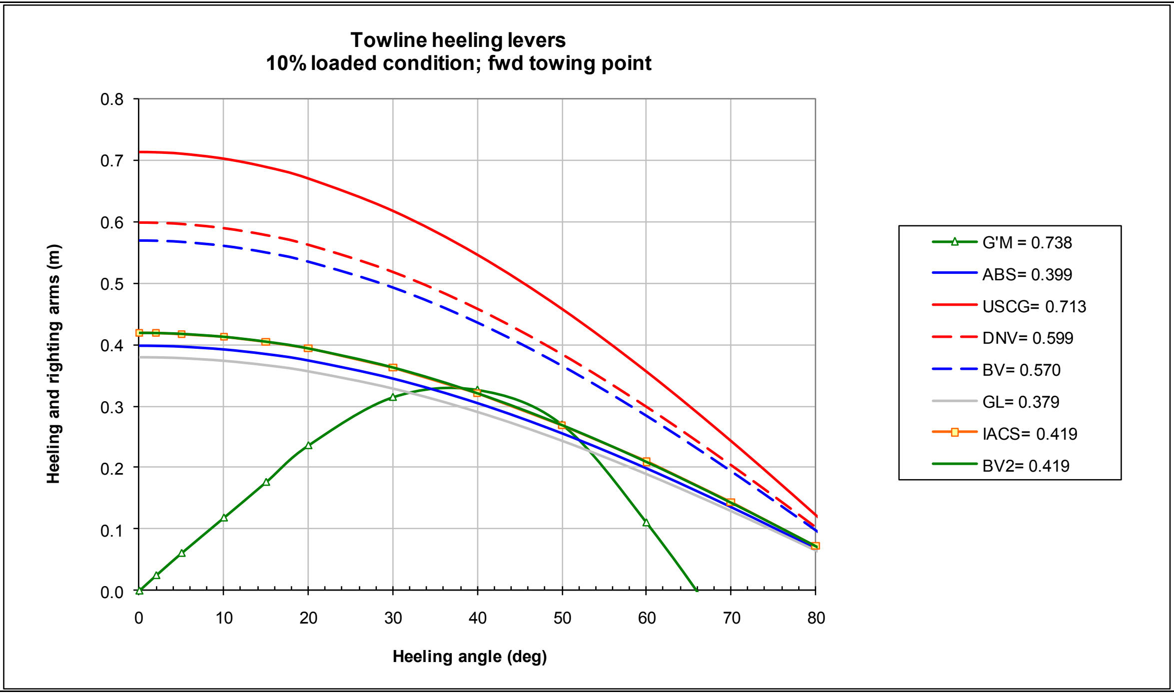


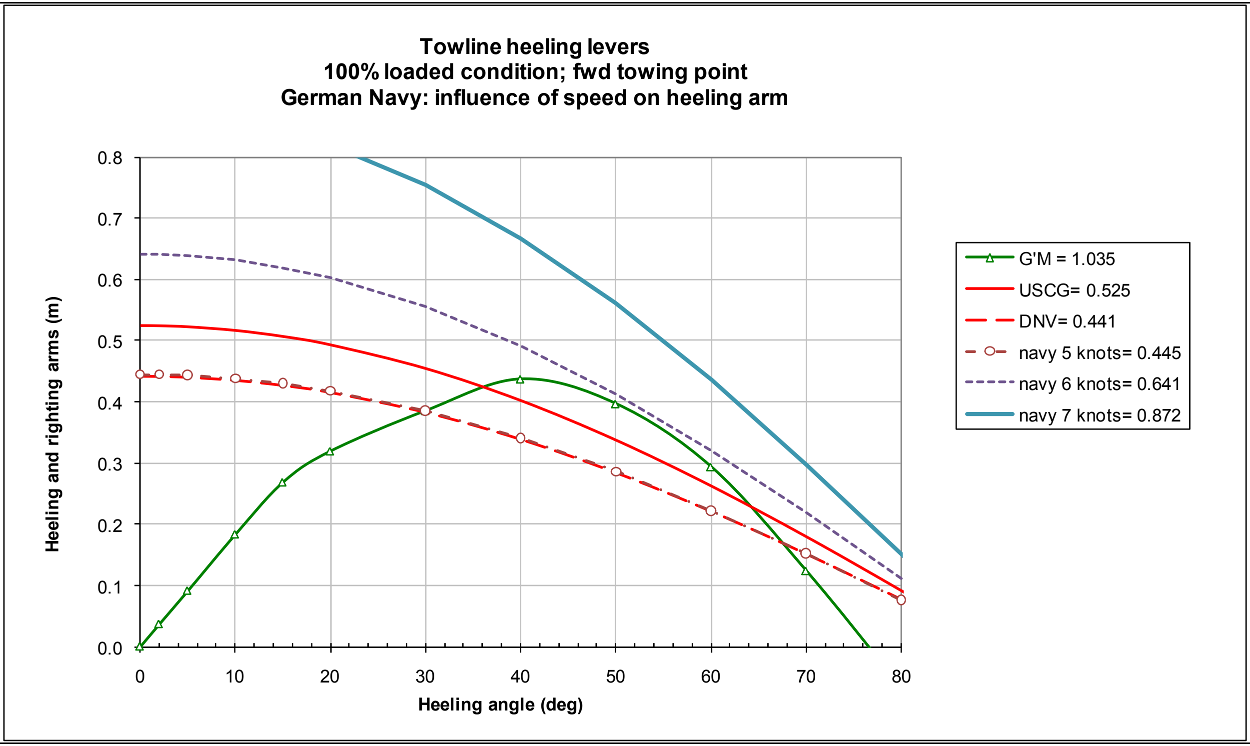
heeling arms in 10% loaded condition

In the 10% condition almost all heeling arm predictions exceed the available righting arm, which means capsizing already in static condition.

Influence of speed

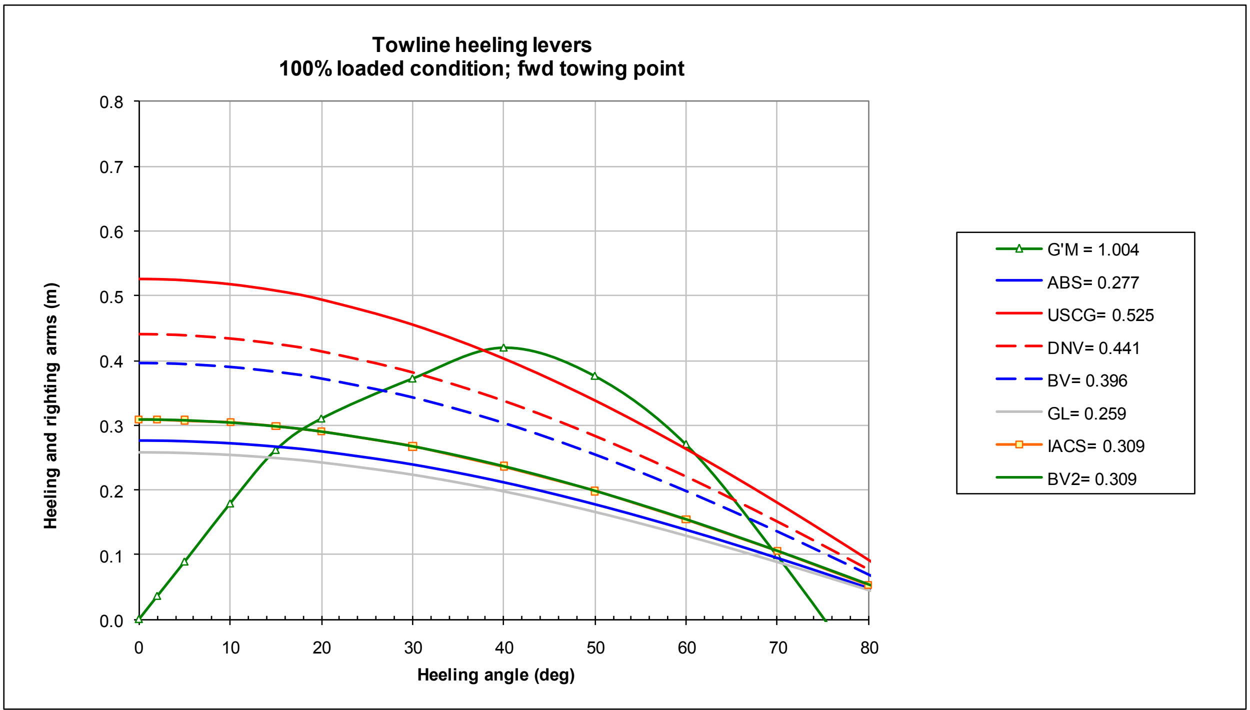
The influence of speed on the heeling arm is illustrated in the next figure, where the heeling arms according German Navy are added for 5, 6 and 7 knots. The 5 knots line appears to coincide with the DNV tug heeling arm, which is only based on bollard pull and a centre of lateral resistance at the centre line of the propellers.

This further shows that already at 5 knots a unacceptable large heeling angle of 30º is achieved.



heeling arms in 100% loaded condition, influence of speed , GL Navy assumptions

6.3 Evaluation heeling arm predictions



The heeling arm predictions can be grouped as follows:

5. The lowest predictions are made by GL and ABS. GL uses the VCB (vertical centre of buoyancy) which is abt 2/3 of the draught, as centre of effort of the lateral forces, with 0.70xBollard pull as force. ABS uses 1/2T as centre of effort, with 0.70xBollard pull as force.
6. The second group consists of IACS and BVharmonized, which both use the centre of the propeller and 0.70xBollard pull as force.
7. The third group consists of DNV and BV. DNV uses centre of the propeller and 1.00xBollard pull. BV uses half draught but also 1.00xBollard pull
8. The highest prediction is given by USCG, which uses the CL of the propeller, but uses a force of abt 1.19xBollard pull.

GL and ABS apparently assume tow tripping by lateral resistance of the hull, assuming a relation between bollard pull and transverse speed of the tug.

USCG can be assumed as consisting of a self tripping component 0f 1.0xbollard pull, plus a tow tripping component of 20% of the bollard pull.

7 Analysis of the loading conditions

The loading conditions are given in a separate volume: Intact Stability Requirements for Tugs: Loading conditions.