Comparative Investigation of Crane Effect on Intact Stability Criteria for Ships

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Abstract — *As it is known, investigating the stability of ships is the most important criteria for the safety of the voyage and the intact stability is the key to the full operability of ships. There are some special conditions in stability calculations, for instance the crane operation is a complex situation for stability processing and control. Therefore, crane operations for ships are limited by rules.*

In this paper, the comparison of the crane working limits that affect the vessels stability assessment according to naval and merchant vessel intact stability rules will be examined.

Keywords* — *Stability, Crane Operation, IMO, BV 1030, Navy Rules

I. INTRODUCTION

Maritime transport is essential to the world's economy as over 90% of the world's trade is carried by sea and it is, by far, the most cost-effective way to move goods and raw materials around the world. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo with over seventy per- cent as containerized cargo. There are also many platforms in the sea and support vessels that serving these platforms. One of the most important equipment of commercial and support ships is cranes used in loading-unloading and similar operations. These cranes have a significant effect on ship's stability, so there are strict rules about the effect of cranes on stability to ensure operations safety. For merchant ships, the International Maritime Organization (IMO) has a sub-committee to set the intact stability criteria. All the intact stability issues are debated in this sub-committee and determined as a recommendation. Intact Stability Code 2008 [1] is the latest recommendation rules for merchant ships and includes A and B part as mandatory and recommendation, respectively (Fig. 1).

On the other hand, for naval vessels, there is no international acceptance about stability criteria. Every country has special rules that were developed for its navy to comply. However, there are stability rules published by NATO to ensure a minimum level of safety for naval vessels, named as Naval Ship Code (NSC) [2]. And NSC has chapters to represent the safety limits (Fig. 2).

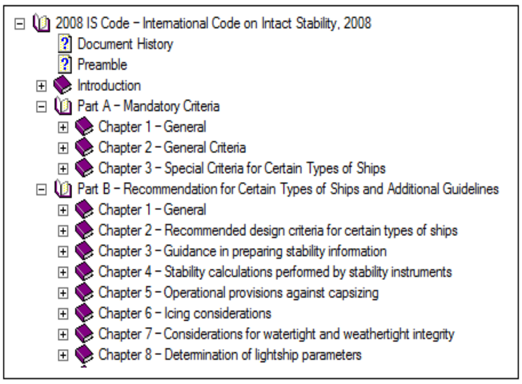

Fig. 1 2008 IS Code

Chapter 0 – Using the Naval Ship Code
Chapter I – Naval Ship Safety Certification
Chapter II – Structure
Chapter III - Buoyancy, Stability and Controllability
Chapter IV - Engineering Systems
Chapter V - Seamanship Systems
Chapter VI - Fire Safety
Chapter VII - Escape, Evacuation and Rescue
Chapter VIII - Communications
Chapter IX - Navigation
Chapter X - Dangerous Goods

Fig. 2 Arrangement of the Naval Ship Code

In this study, we will benefit from the commonly referred German Naval stability criteria, BV 1030, used as a reference for monohull naval surface ships of most of the countries [2]. In the last chapter, as an application, naval and merchant vessel's stability criteria will be compared on an auxiliary ship equipped with a crane affects it's stability limits.

A. BV 1030 German Naval Vessel Rules

This section presents the formulas to be used in calculations of BV 1030 criteria.

Vessel's loading condition is operational displacement condition. Operational displacement corresponds to the design displacement and means provisions (Loading Condition 0) with the contractually specified own and provisions as follows:

- 100% consumables, 100% provisions
- 100% fresh water
- 100% fuel oil
- 100% aviation fuel
- 100% lubricating oil and lubricants
- 100% foam compound
- 100% ammunition, of which torpedoes and missiles in the tubes/launchers as well as the ready-service lockers, loading magazines etc. filled, with the remainder in the ammunition magazines.
- Aircraft in stowed position
- 100% provisions or transported goods
- However without dirty oil, grey and black water in the collecting tanks

Vessel's operation group is E, that permitted operation in fair weather with a wind velocity of up to 20 knots as well as characteristic wave heights up to 1.0 m.

The heeling lever as a result of free surface liquids can be calculated approximately as follows:

$$k_F = \frac{1}{\Delta}\sum\left(p_i . b_{\varphi i}\right) \quad (1)$$

The heeling lever due to side wind pressure shall be calculated according to the following formula:

$$k_W = \frac{A_W\left(A_{W\Theta H} - 0,5T\right)}{\Delta . g} . P_W . \left(0,25 + 0,75.\cos^3\varphi\right) \quad (2)$$

The heeling lever due to crane effect shall be calculated according to the following formula:

$$k_K = \frac{w_1}{\Delta}\left(x_1\cos\varphi + y\sin\varphi\right) + \frac{w_2}{\Delta}\left(x_2\cos\varphi\right) \quad (3)$$

In here,

p_i: weight of the liquid load in the individual bunkers, tanks and cells [t]

$b_{\varphi i}$: deviation of the load centres of gravity compared with their loci when the ship is floating upright [m]

Δ: displacement [t]

φ: angle of inclination [°]

A_W: lateral projected area [m^2]
$A_{W\Theta H}$: vertical center of lateral projected area [m]

T: draught [m]

P_W: wind pressure [kN/m]

g: acceleration due to gravity [m/sn^2]

w_1: Crane maximum operation load [t]

w_2: Crane boom weight [t]

x_1: distance of the top point of the rope to the center line

x_2: distance of the center of gravity of the crane arm to the center line

y: distance of the top of the rope to the center of gravity of the ship

The corresponding necessary minimum righting lever is allocated to a particular heel angle and is measured for an associated reference angle[3]. Determination of the reference angle:

$$\varphi_{ref} = 2 \cdot \varphi_{stat} + 5\ [°] \quad (4)$$

The following limits have to be observed:

Heel angle $\varphi_{stat} \leq 15°$:

minimum residual lever = 0.1 m for a reference angle of $\varphi_{ref.} = 35°$

Heel angle $\varphi_{stat} > 15°$:
residual lever = (φ_{stat} – 5°) x 0.01 [m] at φ_{ref} (5)

B. MERCHANT VESSEL CRANE OPERATION STABILITY CRITERIA- IS CODE 2008

Criteria mentioned below is according to MSC.415(97) IS CODE 2008[4].

The maximum heeling angle of static equilibrium Θ_c is to be limited to one of the following angles, whichever occurs first:

- 10 degrees, or
- angle of deck edge immersion, or
- crane allowable values of list and trim (as obtained from manufacturer).

The area under the GZ curve measured from the position of the heeling angle of static equilibrium Θ_c up to the angle of downflooding or 20 degrees, whichever is less, shall be at least 0,03 mrad.

For ship shaped units, the area under the righting moment curve (A + B) to the second intercept or down flooding angle, whichever is less, is not to be less than 40% in excess of the area under the wind heeling moment curve (B + C) to the same limiting angle(Fig.3).

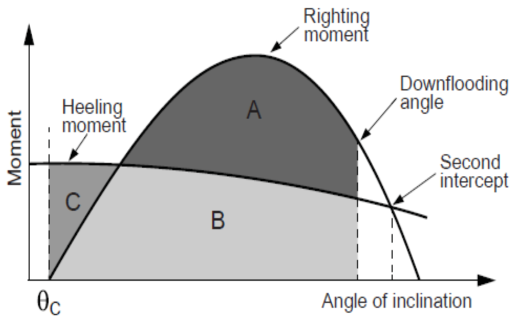

Fig. 3 Righting moment and heeling moment curves for ship shaped units

Intact stability criteria in the event of sudden loss of the lifted load:

The ability of a floating unit to withstand the effect of sudden loss of the lifted load when counter ballast is used shall be demonstrated, with reference to Fig. 4, as follows:

a- Prior to the loss of the lifted load the ship or unit is at heel of static equilibrium Θ_{C0}. After the sudden loss of the lifted load, the ship or unit is assumed to heel to the direction of the counter ballast to a new angle of heel at static equilibrium Θ_{C1}. $\Theta_{C1} \leq 15^{\circ}$

b- Under these circumstances, the area B, as indicated in Fig. 4, under the righting arm curve GZ_1 to the second intercept or downflooding angle is not to be less than 40% in excess of the area A under the righting arm curve GZ_1 to the heel at static equilibrium Θ_{C0} prior to the loss of the lifted load: $(B/A) \geq 1.40$

When, after the loss of the lifted load, the floating unit still heels to the same side, there is no need to comply with above criteria.

GZ_0: Righting lever curve for the loading condition which includes the weight and centre of gravity (LCG, TCG, VCG) of the lifted load and that of the counter ballast

GZ_1: Righting lever curve for the loading condition which excludes the weight and centre of gravity (LCG, TCG, VCG) of the lifted load and includes the weight and centre of gravity of the counter ballast

θ_{C0}: Heeling angle of static equilibrium before loss of the lifted load

θ_{C1}: Heeling angle of static equilibrium after loss of the lifted load

θ_f : Downflooding angle.

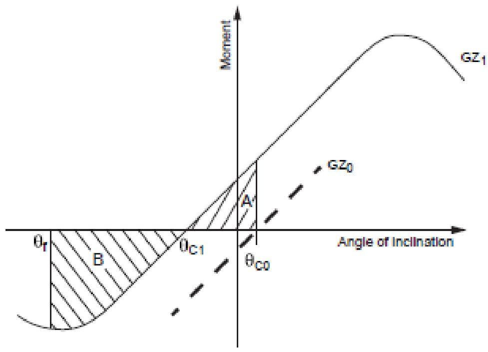

Fig. 4 Righting moment curve after sudden loss of the lifted load

II. SPECIFICATIONS OF THE SHIP AND INVESTIGATION OF CRANE EFFECT

Investigation of crane effect will be studying in this section. The general specifications of the auxiliary ship used for application and crane specifications are given in Table 1 and Table 2, respectively.

Table. 1 General specifications of the sample ship

General Specification		
Loa	83.10	m
Lbp	81.50	m
Bmax	16.80	m
D	7.40	m
T	6.00	m
Δ	6626.03	t

Table. 2 Crane and load specifications

Crane and Load Specifications		
Max. Load @ 10 m	50.00	t
x_1	15.00	m
x_2	9.50	m
w_1	50.00	t
w_2	45.20	t
Crane Hook from BL	16.90	m

All the calculations were run by at the most extreme crane operation case, via commercial stability software.

A. *IS CODE 2008 CRITERIA RESULTS*

Stability calculations have been performed according to IS CODE 2008 for loaded crane condition at maximum heeling position and obtained results was given in Table 3.

Table. 3 Result of stability calculations according to IS Code 2008

Results and Condition		
Δ	5442	t
Draft	5.05	m
Heel to Port	0.6	degrees
Trim by the stern	0.01	m
KGf	6.025	m
GMt	1.502	m
Criteria Results		
Criteria	**Actual**	**Result**
ϴc < 10 degrees	0.618	Pass
Lifting Criteria GZ > 0.03 mrad	0.09	Pass
Lifting Weather Criteria ≥ 1.4	4.276	Pass

Results of the sudden loss of the lifted load condition are given in Table 4.

Table. 4 Result of the sudden loss of the lifted load condition

Results and Condition		
Δ	5355	t
Draft	4.99	m
Heel to Starboard	7.5	degrees
Trim by the bow	0.3	m
KGf	5.85	m
GMt	1.78	m
Criteria Results		
Criteria	**Actual**	**Result**
ϴc < 10degrees	0.618	Pass
Lifting Criteria GZ > 0.03 mrad	0.044	Pass
Lifting Weather Criteria ≥1.4	6.734	Pass
$ϴc_1$ ≤ 15degrees	7.5	Pass
Sudden lose of load GZ Area ≥ 1.4 mrad	18.246	Pass

B. *BV 1030 CRITERIA RESULTS*

Stability calculations have been performed according to BV 1030 for loaded crane condition at maximum heeling position and obtained results was given in Table 5.

Table. 5 Result of stability calculations according to BV 1030

Results and Condition		
Δ	5442	t
Draft	5.05	m
Heel to Port	0.6	degrees
Trim by the stern	0.01	m
KGf	6.025	m
GMt	1.502	m

The results were evaluated according to the related stability criteria and obtained situation is given in Table 6.

Table. 6 Evaluation of the results

Stability Criteria (Crane Effect)				
Criteria	**Actual**	**Critical**		**Result**
$φ_{stat}$	10.824	≤	15	Pass
h_{rem}	0.227	≥	0.10	Pass

Obtained righting lever (GZ) values are given in Table 7 and related graph is given in Fig. 5.

Table. 7 Righting lever (GZ) values

Righting Lever (GZ) - Heeling Levers							
φ	KN	h_{SW}	k_F	k_W	k_K	k	h_{rem}
0	0.000	-0.020	0.000	0.044	0.217	0.261	-0.281
5	0.657	0.123	0.011	0.044	0.225	0.280	-0.157
10	1.315	0.271	0.022	0.043	0.231	0.296	-0.024
15	1.979	0.434	0.033	0.041	0.235	0.310	0.124
20	2.595	0.560	0.044	0.039	0.238	0.321	0.239
25	3.107	0.597	0.054	0.036	0.239	0.329	0.268
30	3.557	0.592	0.064	0.033	0.238	0.335	0.257
35	3.963	0.565	0.074	0.029	0.235	0.338	0.227
40	4.332	0.527	0.083	0.026	0.230	0.339	0.188
45	4.655	0.472	0.091	0.023	0.224	0.338	0.134
50	4.906	0.377	0.099	0.020	0.216	0.334	0.042
55	5.087	0.246	0.106	0.017	0.206	0.329	-0.083
60	5.203	0.087	0.112	0.015	0.195	0.322	-0.235
65	5.262	-0.090	0.117	0.014	0.182	0.312	-0.403
70	5.269	-0.278	0.121	0.012	0.168	0.301	-0.580
75	5.226	-0.474	0.124	0.012	0.153	0.289	-0.763

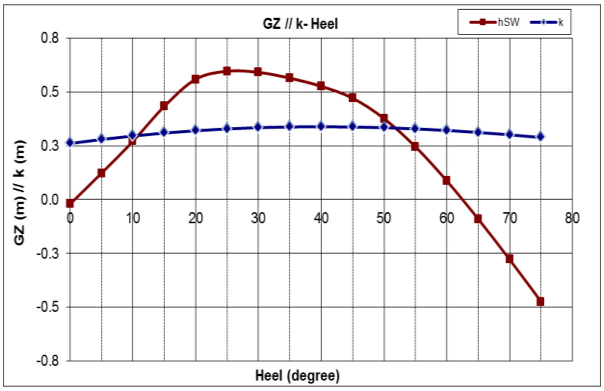

Fig. 5 Condition GZ – Heeling Curve

III. CONCLUSIONS

In this paper, the results of intact stability calculations of an auxiliary vessel have been compared according to different criteria. The vessels subject to IS code for crane operation meet the requirements of equal conditions, with a higher safety margin. On the other hand, BV 1030 has stricter rules for crane operations. Static heel angle and minimum residual lever levels that applied by the BV1030 are compelling the ship designers.

Due to the different operation fields of the ships, the differences between the rules requirements were investigated. It is concluded that the designers should shape their design according to both ship operation, operation area and rules to be applied when deciding on a design.

It is concluded that differences in crane operating rules are limited according to the intended use of ships. While operational limits aim to maximize crane operating conditions, it has been found that the ship will not be allowed to fall into any stability vulnerability.

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