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OPTIMIZATION OF HEAVY–LIFT OPERATIONS AND EFFECT ON SHIP'S STABILITY AND HEELING

Heavy–lift cargo operations are usually high–risk procedures. Normally before loading or unloading heavy cargo the vessel must be at even keel with lowering ship's center of gravity and therefore increasing metacentric height. In this article general procedures before loading and discharging heavy–lift cargo will be considered and also whilst the vessel has initial angle of heel. Main ship's stability aspects during heavy–lift operations will be pointed out.

Keywords: *stability, metacentric height, heavy–weight cargo, angle of heel, ship's center of gravity.*

The nowadays analysis of ship's operations shows that heavy–lift cargo operation by using the ship's cranes, especially during their simultaneous work can be dangerous, causing sometimes the serious circumstances for the ships and even capsizing due to large heeling angles in general.

Before carrying out cargo operations, particularly, when loading heavy-weight cargoes, special attention must be paid to the proper stowage to prevent excessive moments leading to accidents. In this case effect of cargo shifting on the ship's stability is well-known and must be checked continuously during operations.

While loading/discharging of heavy lifts by using ship's cranes the following points have to be considered.

1. The vessel's initial stability corrected for free surfaces is radical reduced when: opening the hatch covers (especially if the vessel is provided with folding system); hoisting the jib(s) from sea stowing position; hoisting the cargo from the berth (in that moment the vertical centre of gravity of the unit is fixed in the rope wheel at the jib's end up to 60m above the baseline dependent on the size of ship and cranes).

2. The vessel gets list which should not exceed 5^0 max (in this case sound alarm will be started) when: turning the jib over the berth in connection with the jib's outreach; hoisting the cargo from the berth.

The reason for that is suspending a cargo by a ship's crane so that the cargo just suspended transforms itself from a fixed (fastened) weight to an unfixed one with the sequent negative consequences. In addition, the procedure of lifting the heavy weights by the ship's cranes, requires the accurate and proper calculation of the changes in ship's stability and heeling. Such calculation should be performed before a such operations and it should be based on real figure of ship's metacentric height GM_{cor}.

When cargo is loaded or discharged from a ship, the numerical changes in the ship's stability and heeling are different; therefore, the processes of loading and discharging of heavy weight unit will be discussed separately. Thus, before heavy–cargo loading operations commenced, normally if vessel is berthed port side alongside, such general precautions must be carried out:

− take ballast in the double bottom tanks and also in some cases in the wing tanks but keep in mind arising heeling moments due to free surfaces;
− if possible tween deck panels must be put down in the holds tank top to make center of gravity as lower as practicable;
− pump the ballast water from heeling tanks starboard side to portside as much as possible;
− not fully open hatch covers giving space required only for heavy cargo operations;
− hoist the gangway and keep mooring lines tightened avoiding any slack;
− if necessary order port tugs or drop the starboard anchor;
− after connection of lifting wires/slings with unit it's necessary to make initial load on cranes hooks (just a few tons) and find the correct direction of lifting gear;
− heavy cargo must be as closer as possible to the ship's side (depending on unit dimensions and presence of pier fenders);
− constant communication by walkie–talkie must be performed between chief officer (captain) and crane operators;
− all deck crew must be familiar with crane operations and using of signals;
− before lifting of cargo it's recommended to leave some welded plates or stoppers at the bottom of heavy piece to prevent its shifting in any longitudinal and transverse direction, also guy–lines must be used at each cargo unit corner to keep them tight while hoisting up;
− start pumping ballast from the port side heeling tanks to the starboard side checking load on hooks;
− lift up the cargo unit only by ship's hooks controlling load steps continuously;
− swing cranes very slowly and all the time be in contact with crane drivers;

− commence pumping ballast from the starboard side to port side and check that heeling will not exceed 1^0 (if angle of heel is 2.5^0 sound alarm in the cranes will be raised and after 5^0 heel cranes automatically switching off);

− stow heavy–cargo in the hold in accordance to stowage plan and slowly decrease load on the hooks to take off all lifting accessories;

− make lashing meeting requirements of Cargo Securing Manual.

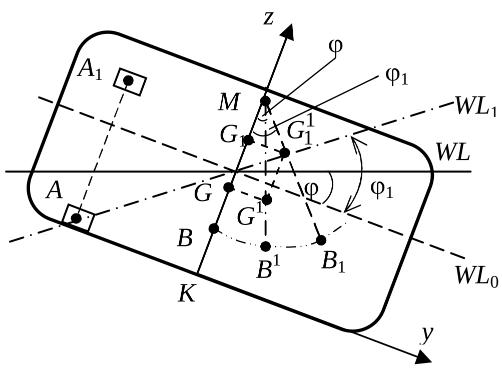
Discharging of heavy-cargo unit from the ship usually is carrying out vice-versa of above described procedures. Special attention must be paid to moving of cargo piece inside the hold and therefore arising additional heeling moments.

In this case, loss of ship’s stability is not usually caused by changing of metacentric height value as a distance between metacenter and center of gravity of the vessel. For that reason it’s necessary to input a correction, named *SWC* (Suspended Weight Correction).

Free suspended weight influenced the ship’s stability as cargo center of gravity is situated in the lifting point. In the other words, at the moment of lifting up cargo unit, its weight is instantly raising to the lifting point.

In this very moment ship’s stability is reducing. After further hoisting or lowering of freely suspended cargo due to changing the length of suspension will not affect the stability. Taking into consideration all information mentioned above, we can make a conclusion, that if free suspended unit is secured against the transverse movement (using guy–lines for example), then loss of stability in the moment of lifting cargo will not arise.

Let’s consider one case of loading/discharging heavy cargo based on the non-zero conditions, when the ship has initial angle of heel caused, for example, by strong wind or waves of passing by small vessels and sometimes the heeling may appear due to unsymmetrical positioning of cargo inside the holds in the view of centerline (as shown on pic.1).



Picture 1 — Aft view of vessel having initial angle of heel

This may cause additional heeling moment which may be found from below formula:

$$GG^I \times \cos\varphi = GM \times \sin\varphi,$$

where GG^I — distance between centers of gravity when the ship is on the even keel and after heeling [m]; φ — angle of heel [$^\circ$]; GM — metacentric height [m].

If cargo unit w shift from point A to point A_1 then ship’s center of gravity will be moved from point G^I to point G_1^I and metacentric height will be decreased.

Angle of heel will increase to the value φ_1 and new stability formula will be:

$$G_1G_1^I \times \cos\varphi_1 = (GM - GG_1)\times \sin\varphi_1;$$

$$GM \times \frac{\sin\varphi}{\cos\varphi} = (GM - \frac{w\cdot\delta z}{\Delta})\times\frac{\sin\varphi_1}{\cos\varphi_1};$$

$$\varphi_1 = \arctan(\frac{\tan\varphi}{1-\alpha}); \quad \alpha = \frac{w\cdot\delta z}{\Delta\cdot GM} = \frac{GG_1}{GM},$$

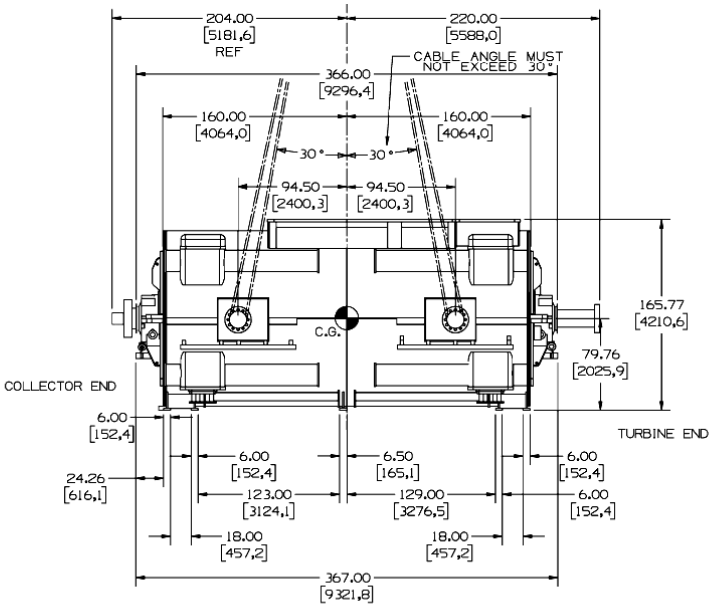
α is a coefficient equal to dividing the distance of vertical shifting the ship’s center of gravity to its metacentric height [1].

Further the example of heavy–lift procedure will be given down below.

Cargo description is follows:

316 mt turbine (pic. 2) to be loaded in US port Charleston with destination to Argentinian port Zarate

Length: 10.53 m;
Width: 4.95 m;
Height: 4.97 m



Picture 2 — Turbine dimensions

It should be noted that the position of the center of gravity (c.o.g.) can have a great impact on the lifting possibilities and lifting safety. And all parts (mounted inside or outside) of a cargo item, that could move or rotate during loading/discharging/sea transport must be secured properly by shipper.

The main vessel's technical data: Deadweight (Summer draft): 17000 mt; GT/NT: 12974/5334; Max summer draft: 9.7 m; Length o.a.: 143.14 m; Breadth moulded: 22.8 m; Depth to main deck: 13.3 m; Height above keel: 41.4 m.

Cranes: 3 NMF cranes situated portside (2x250 mt + 1x80 mt).

There are some port operations restrictions.

Loading / discharging operations of heavy lift will not start in case:

1) the wind-speed perpendicular to the direction of the ship is over Bf6 (Beaufort scale);
2) the wind-speed in the direction bow/stern of the ship is over Bf7;
3) significant wave height 0.5 m; swell is over 1 m or if captain considers planned operation as unsafe due to movement of crane hook/cargo;
4) current is over 6 kn in case a moored/anchored transshipment is performed;
5) light when working in poor lighting conditions;
6) visibility is less than 50 m daylight;
7) temperature is less than –15° C / above +50° C;
8) heavy–lift operations during hours of darkness are not allowed;
9) walkie–talkie hand–radios will be used for communication;
10) each morning prior to operations a toolbox meeting will be held with all involved parties in order to review local weather conditions and all scheduled operations for that particular day.

The following criteria can be used as a guideline, although the final decisions are at the discretion of the vessel's Master for sea voyage:

1) rolling angle over 15 degrees, ship must change wave heading and/or speed;
2) safe haven or sheltered region or area in case captain considers risk for men or ship too high to continue sea voyage due to heavy weather conditions;
3) master to ensure that instructions regarding navigation in reduced visibility are made up and complied with, notably when visibility reduces to 3 Nm. When visibility reduced to 6 Nm, activates additional radar equipment;
4) adjust vessel's speed as navigational circumstances require;
5) posting extra lookout/re–organize bridge team/orders full watch complement;
6) sounding of appropriate signals;
7) further measure to ensure safe navigation under specific situations [2].

Loading/discharging procedure of this heavy unit is shown on picture 5.

At the beginning of the discharging and hoisting the weight, the rope of the crane is gradually tensed up so that some portion of the weight mass belongs to the crane, but not to the deck at which this weight was originally placed. Finally, the entire mass of the weight will be applied to the rope of the crane, and the weight will become a freely suspended one by the rope.

Thus, during discharging a weight unit by a ship's crane, the ship's stability might be changed. The most dangerous moment is the first one at which the weight is just suspended from the deck, and the moment when the luffing angle of the jib is increased and, as a result, the point of suspension moves upward.

In the case of loading, the moment of suspending a weight is more dangerous than in the case of discharging the same weight. It happens because, in the first case, both the loss in the ship's stability and heeling the ship are much larger.

During lifting operation, if some unforeseen accidents occur (for instance, an abrupt and sudden heeling a ship happens), the weight that is suspended by the jib's rope must be immediately lowered and placed on the deck, the berth, or discharged into the outside water as soon as possible [3].

Picture 5 — Turbine loading/discharging operation

For the safe heavy–lift procedures preliminary calculations must be done in accordance with all stability criteria adopted by IMO (International Maritime Organization).

Normally, onboard the vessel, there are some stability computer programs. Let's consider the most preferable program to use by name COLOS.

But to make any conclusion regarding the degree of trust to such program, it's necessary to carry out own calculations using information regarding heeling the vessel with "non-zero" stability parameters, which is mentioned above (having initial angle of heel).

For instance, let's describe this particular case: The vessel has portside angle of heel (φ): 1.2^0; Displacement (Δ): 16065.2 mt; Cargo weight (w): 316 mt; Length of suspension (l): 45 m; Metacentric height corrected (GM): 3.11 m.

When cargo situated on board on tank top is lifted up to its maximum vertical position ship's angle of heel will be changed.

Distance between centers of gravity when the ship is on the even keel and after heeling:

$$GG_1 = \frac{w \cdot l}{\Delta} = \frac{316 \cdot 45}{16065.2} = 0.885\,\text{m}.$$

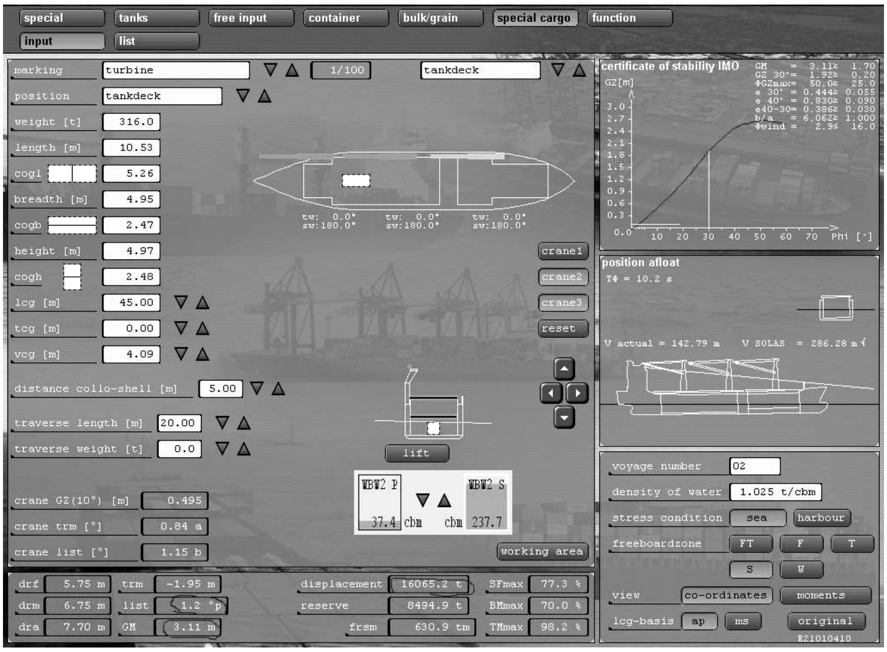
Non dimensional coefficient is:

$$\alpha = \frac{GG_1}{GM} = \frac{0.9}{3.11} = 0.289\,.$$

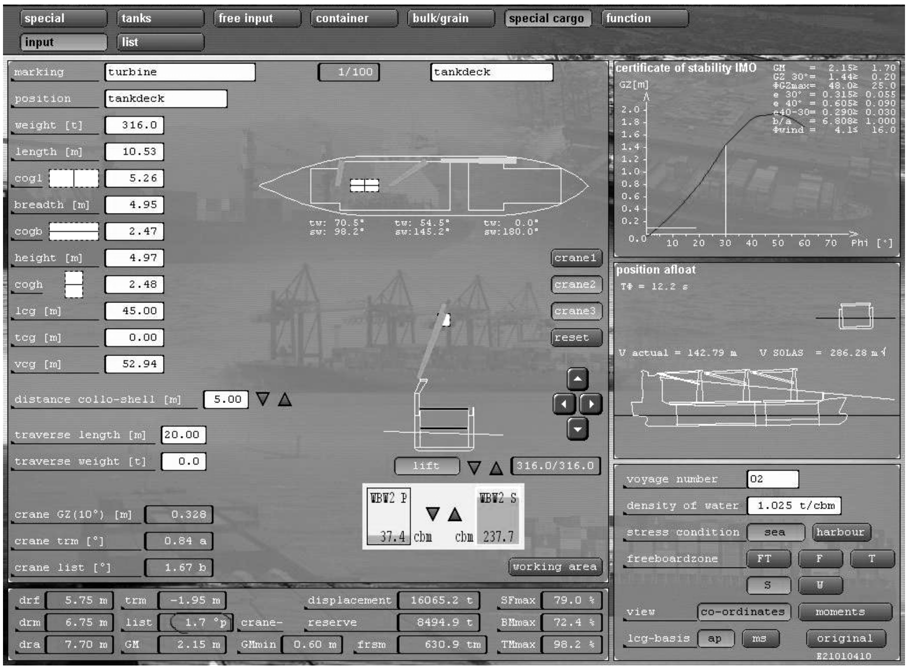
Thus new angle of heel will be:

$$\varphi_1 = \arctan\left(\frac{tg\varphi}{1-\alpha}\right) = \arctan\left(\frac{tg1.2}{1-0.289}\right) = 1.69^\circ\,.$$

Now as a comparison we can find calculations made by COLOS (pictures 6 and 7).



Picture 6 — COLOS calculations before lifting heavy–weight cargo from hold



Picture 7 — COLOS calculations after lifting heavy–weight cargo from hold

So, as you can see in this case, calculations made by this stability program and by–hand using stability information and formulas for ship with initial angle of heel are almost similar.

Further will describe situation when the same cargo is loading from the berth to weather deck of the ship with the same initial angle of heel.

The vessel has portside angle of heel (φ): 1.2°; Displacement (Δ): 15749.2 mt; Length of suspension (l): 50 m; Metacentric height (GM): 3.05 m; TPC (mass changing of draft per cm): 25 t/cm (from ship's stability booklet).

Draft mean (T): 6.62 m.

First, at the moment of suspending the weight by the ship's crane, this weight becomes to be a part of the ship as a whole and, as a result, the ship's displacement, its mean draught, and the coordinates of the center of gravity will change, consequently, the metacentric height of the ship will also change. Moreover, since the weight is just freely suspended, the ship's stability will further reduce in value of suspended weight correction as follows:

$$SWC = \frac{w \cdot l}{\Delta + w} = \frac{316 \cdot 50}{15749.2 + 316} = 0.983 \text{ m.}$$

Thus, the total change in metacentric height of a ship at the moment of suspending the weight will be as follows: $\delta GM - SWC$, where δGM — the alteration in metacentric height due to loading a weight as a fixed one at level z; z — distance between ship's keel and center of gravity of the cargo on pier (10.8 m).

As weight that loaded is small $w \le 0{,}1\Delta$, then value of δGM might be estimated as follows:

$$\delta GM = \frac{w}{\Delta + w}\left(T + \frac{\delta T}{2} - GM - z\right),$$

where δT — the increase in mean draught due to loading (suspending) a weight.

At the moment of suspending a weight stability of a ship momentarily reduces due to not only the SWC, but also loading the weight at level z which is above the actual water line of the ship.

Thus, the process of suspending a weight that is loaded on board is more dangerous than the one at which the weight is discharged. After suspending the weight, the metacentric height of the ship can be calculated as follows:

$$GM_{LO} = GM + \delta GM - SWC =$$
$$= GM + \frac{w}{\Delta + w}\left(T + \frac{\delta T}{2} - z - GM - l\right) =$$
$$= GM + \frac{w}{\Delta + w}\left(T + \frac{\delta T}{2} - z_1 - GM\right),$$

where z_1 — the height of the suspension point at the moment of the suspending the weight

$$z_1 = l + z = 50 + (13.3 - 2.5) = 60.8 \text{ m};$$

$$\delta T = \frac{w}{TPC} = \frac{316}{25} = 12.64 \text{ cm.}$$

Therefore: $GM_{LO} = 3.05 + \frac{316}{(15749.2 + 316)}(6.62 + \frac{0.1264}{2} - 60.8 - 3.05) = 1.925$ m.

It might be seen that the effect of suspending a weight by a ship's crane on stability of the ship is looked like this weight is loaded at the point of suspension. This fact is known very well. However, there is not broadly known that the stability of a ship would not dramatically reduce if a suspended weight were fixed transversally (for example, by means of ropes, chains, or so) because such a fixing the weight eliminates the value of SWC.

At the moment of suspending and discharging a weight from a berth, the heel angle of the ship might be roughly determined as follows:

$$\varphi_1 = 57{,}3 \times \frac{w \times y}{(\Delta + w)GM_{LO}},$$

where y — distance between center of gravity of cargo on pier and ship's centerline (18.9 m).

Finally:

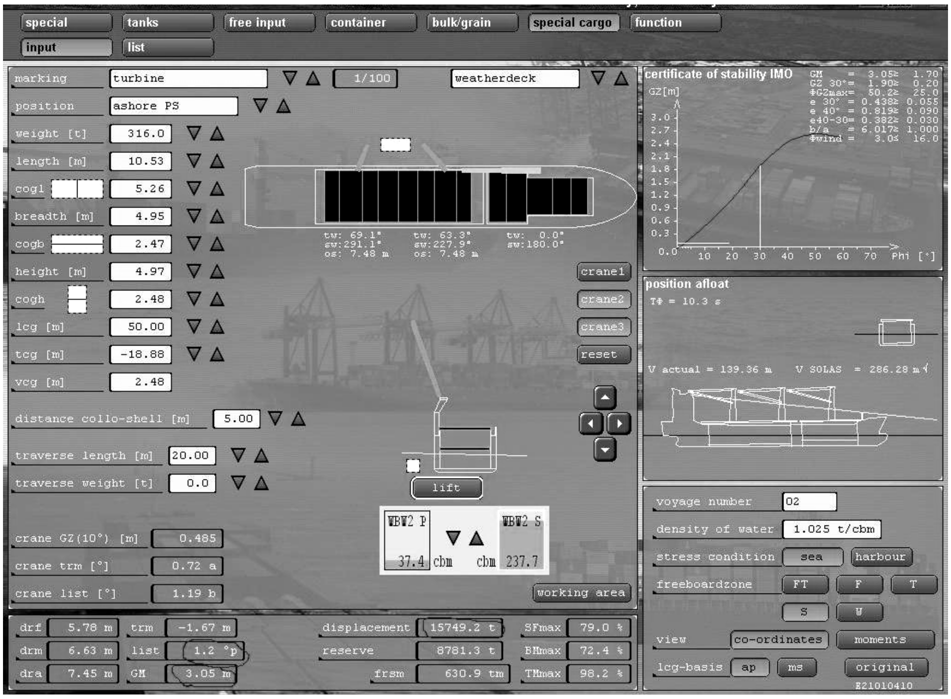
$$\varphi_1 = 57.3 \cdot \frac{316 \cdot 18.9}{(15749.2 + 316) \cdot 1.925} = 11.06^\circ.$$

This heel angle might be rather big because the weight, at this moment, is located too far from the centre plane of the ship. Therefore, in ship operation, discharging (suspending) a weight from a berth is normally performed by shifting transversally some ballast water between heeling tanks and, as a result, heeling the ship to the opposite side (the same operation like for unloading procedure from the ship).

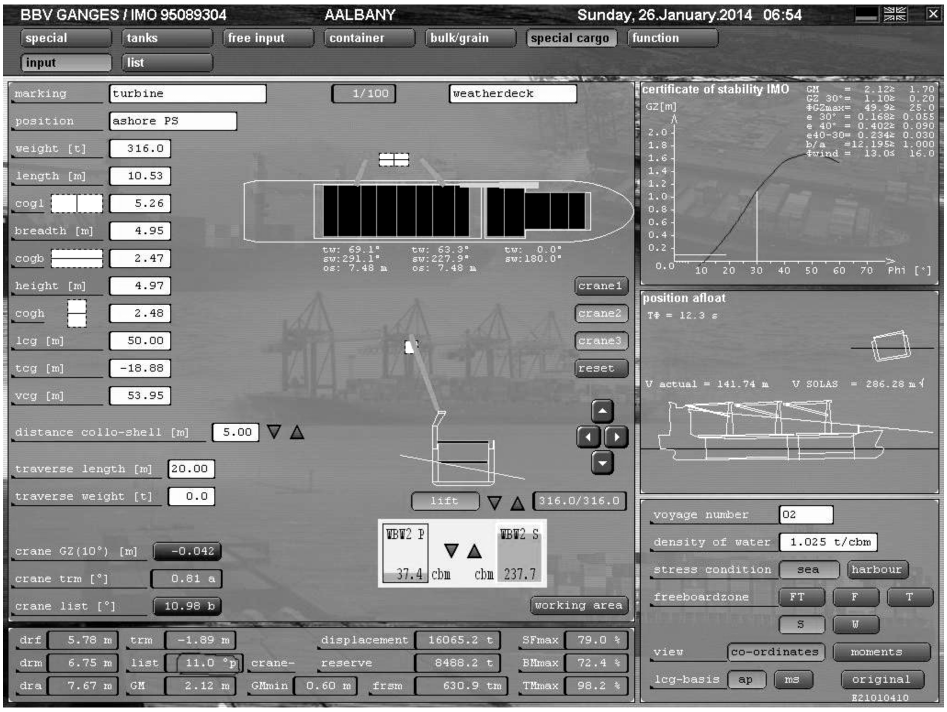
And now for comparison make a calculations by using again stability program COLOS as shown on pictures 8 and 9.

And at this time also all calculations have almost the same values.

That means that degree of trust to such program must be really high and using this system is much convenient and often saves time of cargo officer. Nevertheless, keep in mind there may be some mistakes input for example in ballast tanks capacities. Double checking of soundings and hand-made stability calculations are compulsory before heavy-lift operations not only for remarks but especially for own safety.



Picture 8 — COLOS calculations before lifting heavy–weight cargo from pier



Picture 9 — COLOS calculations after lifting heavy–weight cargo from pier

In conclusion several statements should be pointed out:

1. In the case of loading, the moment of suspending a weight is more dangerous than in the case of discharging the same weight. It happens because, in the first case, both the loss in the ship's stability and heeling the ship are much larger.

2. The process of a transversal shifting a suspended weight is comparatively unsafe because a ship's stability does not reduce (on condition that the point of suspension does not raise up). On the other hand, in this period, heeling the ship occurs, but it can be preliminary calculated and compensated by means of appropriate shifting some ballast water between heeling tanks.

3. The final period of placing the weight on a berth (or on board ship) is comparatively unsafe because a suspended weight is converted from freely suspended to the fixed one, and the ship's stability improves. In the

case of discharging a weight, the final period is especially convenient because the weight does not belong anymore to the ship and, as a result, it does not affect on the ship's stability and attitude at all.

4. The reduce or entire elimination of negative effect of a freely suspended weight by means of its restriction on spontaneous transversal movement is the reserve in the ships' stability improvement that is not still used for lifting operations performed by the ship's cranes. Preliminary assessments and calculations show that the loss in ships' stability can be reduced twice at least if this stability reserve would be used for, especially, during heavy lift operations.

5. The most effective way to prevent loss of ship's stability due to shifting of heavy cargo in transverse direction is its proper securing, for example, by guy-lines or chains and performing total control on the cargo operations as it's a high-risk procedure.

6. As one way for eliminating the problem of the stability loss during heavy-weight operations is changing the crane construction in such manner to prevent cargo shifting in suspended position (for example using triple slings to fix cargo in three planes simultaneously).

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Гембатий Є.В. Остійність судна й зміна кута крену при проведенні операцій з великоваговими вантажами

Операції з великоваговими вантажами є процедурами високого ризику. Як правило, перед навантаженням або вивантаженням важких вантажів судно повинне мати рівний кіль зі зниженим центром ваги й внаслідок цього зі збільшеною метацентричною висотою. У цій статті будуть розглянуті основні заходи перед навантаженням і вивантаженням великовагового вантажу, у тому числі з обліком того, що судно має початковий кут крену. Будуть виділені основні критерії остійності судна під час проведення великовагових операцій.

Ключові слова: остійність, метацентрична висота, великоваговий вантаж, кут крену, центр ваги судна.

Гембатый Е.В. Остойчивость судна и изменение угла крена при проведении операций с тяжеловесными грузами

Операции с тяжеловесными грузами являются процедурами высокого риска. Как правило, перед погрузкой или выгрузкой тяжелых грузов судно должно иметь ровный киль с пониженным центром тяжести и вследствие этого с увеличенной метацентрической высотой. В этой статье будут рассмотрены основные мероприятия перед погрузкой и выгрузкой тяжеловесного груза, в том числе с учетом того, что судно имеет начальный угол крена. Будут выделены основные критерии остойчивости судна во время проведения тяжеловесных операций.

Ключевые слова: остойчивость, метацентрическая высота, тяжеловесный груз, угол крена, центр тяжести судна.