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STABILITY OF SHIP'S CARGO SUSPENSION ARRANGEMENTS

Cargo lifting operations are considered as potentially dangerous especially when a metacentric height of the ship corrected due to freely suspended weight and free surfaces of ship's tanks is closed to zero or even negative. In this article we'll discuss the main aspects of the ship's stability regarding the safety cargo operations during loading or unloading heavy-lifts.

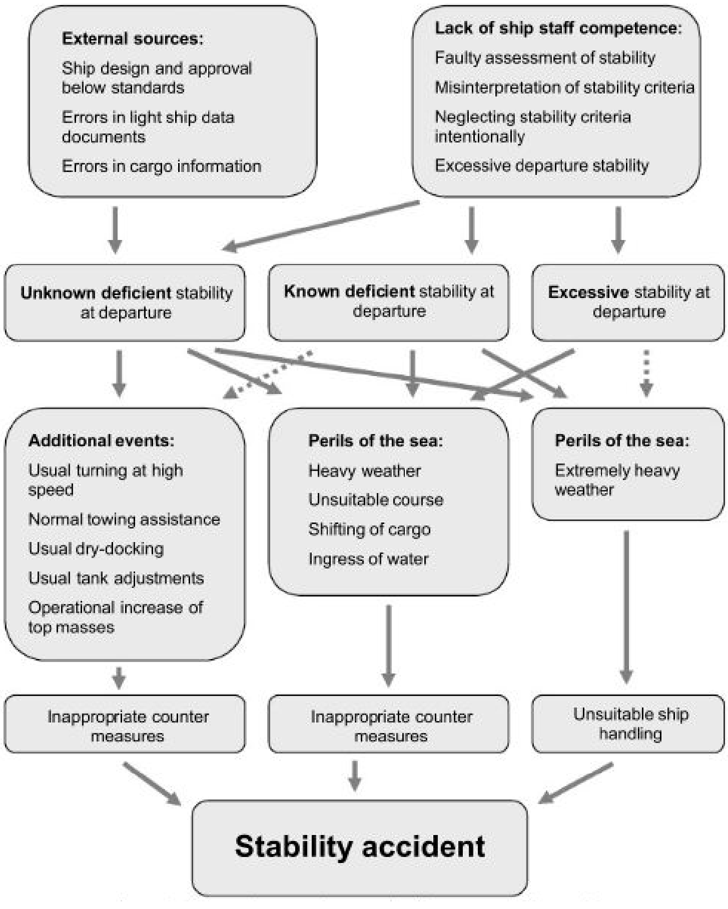
Keywords: *stability, heavy-cargo, suspension, center of gravity, metacentric height.*

The analysis of ship's operation shows that cargo lifting operations performed by ship's cranes could be unsafe and dangerous causing sometimes the serious circumstances for the ships. Such operations may cause a large heeling of ship or even its capsizing. In modern times capsizing is an accident that is not happening often, but if it happens, the consequences are usually catastrophic and ship is lost, quite often with all hands on board.

Generally, ship stability system is rather complicated. However, in most cases it could be considered as consisting of four basic elements: ship, environment, cargo and operation.

The analysis of ship's accidents during cargo operations shows that they are mostly happened as a result of loss the stability. In addition, the procedure of lifting the weights by ship's cranes requires the accurate and proper calculation of the changes in ship's stability and heeling. Such calculation should be realized before cargo operations and should based on the real figures of metacentric height GM_{corr}.

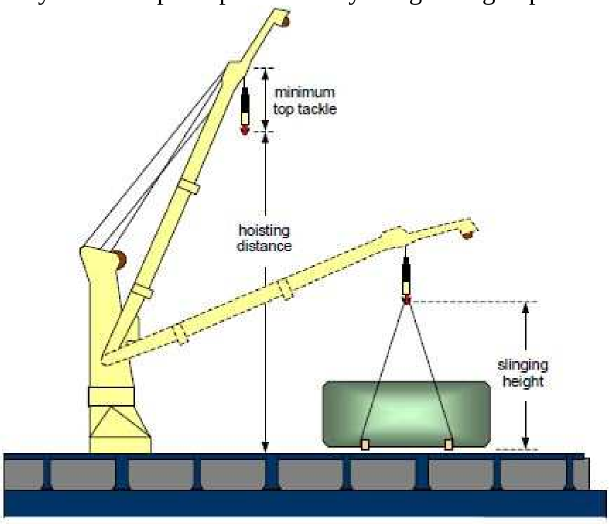
Picture 1 shows the main reasons of stability accidents.



Picture 1 — Stability accidents scheme

In order to achieve sufficient level of safety with respect of stability, all elements creating stability system have to be taken into account. Taking into account the fact, that less than 20 % of all casualties are caused by faulty or bad design of the ship, the existing safety requirements that refer mainly to design features of the ship can not insure sufficient level of safety, in particular with regard to ships having novel design features. The only way out of this would be to use risk-based approach [1].

Let's consider particularly the main principles of heavy-weight cargo operations.



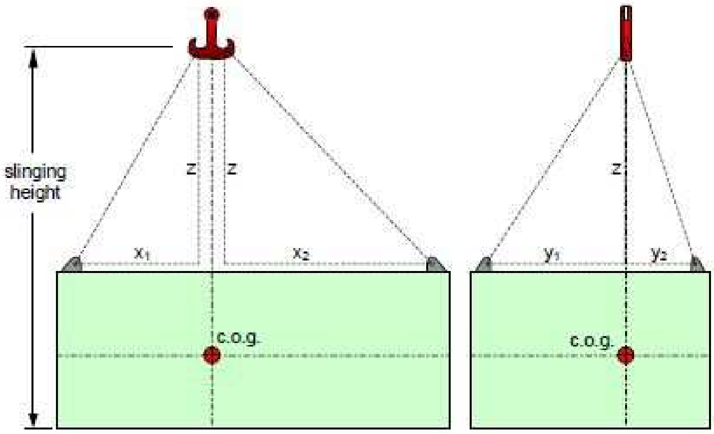
Picture 2 — Hoisting distance and slinging height of ship's crane

The vertical dimension of suspension arrangement is the slinging height. It may become critical as it must never exceed the available hoisting distance.

The hoisting distance is a vertical distance from the top of weather deck hatch covers to the upper most position of the crane hook. This distance is generally not critical for very heavy units because the working radius of the crane must remain small. But it should be checked against the slinging height.

The slinging height is the vertical distance from the bottom of a cargo unit to the crane hook. It depends on the length of the employed slings and spreader combinations in the suspension arrangement.

In cases where the slinging height is at the limit, the appropriate length of the slings must be determined accordingly. This may be of particular importance if the centre of gravity of the cargo unit is out of the geometrical center of the lifting points and sling length must be adapted individually.

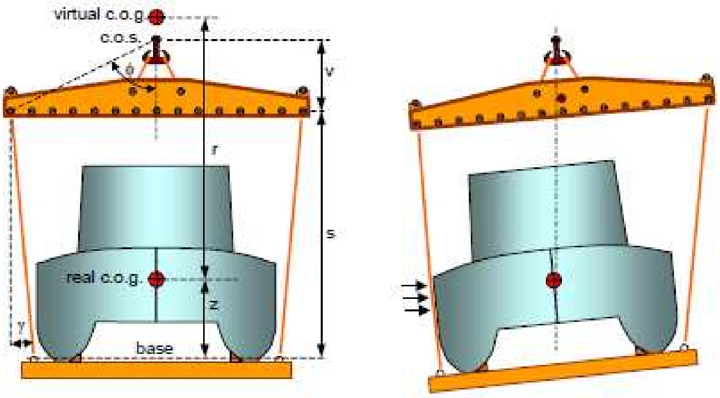


Picture 3 — Determination of individual sling length

The stability of suspension arrangement behaves in analogy to the stability of a ship. The center of gravity (c.o.g.) must always remain below the metacenter, which is the intersection of all buoyancy vectors at small angles of heel and may be looked at a static center of suspension of the ship.

The suspension where the cargo unit is directly connected to the hook by slings may be called a primary suspension. Such arrangements are definitely stable, if the fastening points at the cargo unit are above the c.o.g. If the unit is fastened below its c.o.g., the arrangement is still stable as long as the c.o.g. is kept below the center of suspension (c.o.s.) [2].

For this reason, the worst condition means: the heavy unit is hanging with its total weight under the cranes while the centre of gravity is located in the rope wheel at the end of the jibs with a maximum luffing angle of the jibs. If both cranes are in use this maximum luffing angle is reached when the cargo is just between the cranes (longitudinal in line with the cranes). If one crane is in use the maximum luffing angle of the jib is dependent on the location of the cargo ashore/on board.



Picture 4 — Unstable complex suspension arrangement

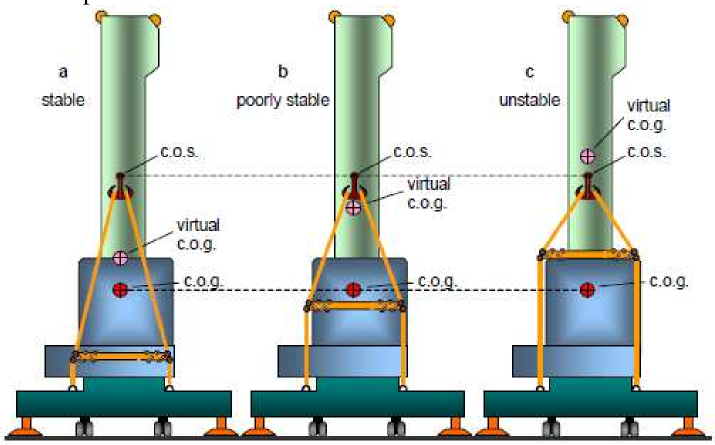
In a complex suspension arrangement, which includes spreaders or traverses hanging on a primary suspension, the cargo unit hangs on the secondary suspension. If there is a small horizontal offset of the c.o.g. in the cargo unit, the initial small heeling angle of the whole suspension will be amplified by the additional tilting of the secondary suspension. This effect is similar to the influence of the liquid free surfaces of a ship and may in the same way be understood and quantified by raising the c.o.g. to a virtual position.

The loss in value of the metacentric height (GM), is in fact, not real because the positions of the c.o.g. and the transverse metacenter of a ship above keel do not change. In other words, the loss of a ship's stability is not caused by the change in real value of GM as the vertical distance of the metacenter from the center of gravity of the ship. This expression would be reasonable to name suspended weight correction (SWC).

Hence, freely suspended weight affects on a ship's stability as so this weight is located at the point of suspension. In other words, at the very moment of suspending, the weight is as though spontaneously lifted up from the point of its original position to the point of suspension. At the same time the ship's stability is also decreased. After that the further actual hoisting up or lowering down the freely suspended weight (by the increasing or decreasing of the suspension length) will not affect on the ship's stability anymore.

Taking into account all the above, it might be stated if a suspended weight were transversally fixed (for example, this suspended weight were lifted by an elevator or it were fastened and secured by ropes, or so), then the ship's stability reduction, at very moment of suspension, would not occur.

The unstable suspension arrangement will not necessarily cause an accident, because the cargo unit is stabilized by contact to the slings. However if there is a situation where the unit may tilt over, extra care must be taken to provide the stable suspension.

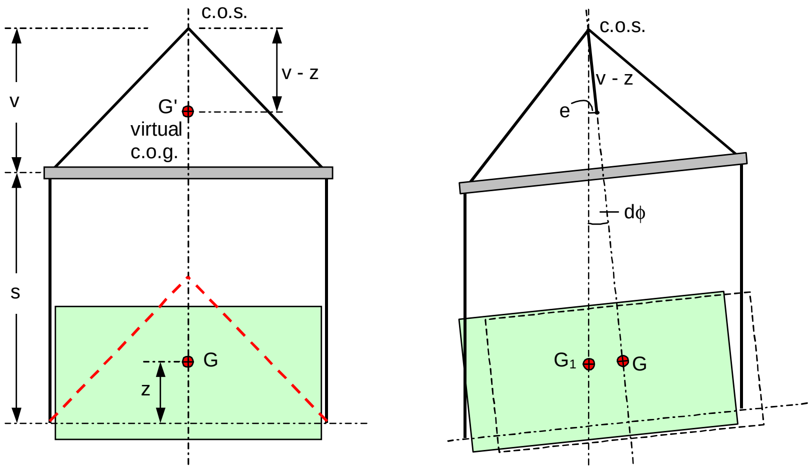


Picture 5 — Stability under variation of primary and secondary suspension

Suspension arrangements consisting of the primary suspension of a beam or traverse, connected to the cargo hook, and the secondary suspension of the cargo unit, connected to the beam or traverse, are more sensitive against small transverse deviations of the cargo centre of gravity than purely primary suspensions. They react with a greater tilting angle due to the tilting out of the secondary suspension. These also amplify any statical heeling of the ship and, moreover, may lead to an unstable condition.

Now we can analyse the vertical secondary suspension when the mass of traverse is ignored.

In the left part of Picture 6 the cargo unit hangs straight. In the right part it is tilted by the small angle $d\varphi$ caused by an initially unknown eccentricity e of the centre of gravity. This eccentricity shall be determined as the difference between the total shift of the centre of gravity and the slewing of the cargo unit, caused by the secondary suspension [3].



Picture 6 — Virtual position of the c.o.g with ignored mass of traverse

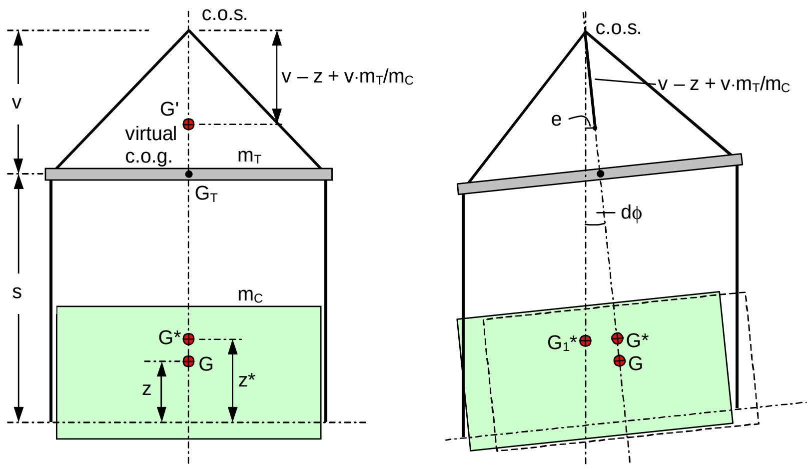
$$GG_1 = (v + s - z) \cdot d\phi \, ; \tag{1}$$

$$e = (v + s - z) \cdot d\phi - s \cdot d\phi = (v - z) \cdot d\phi \, , \tag{2}$$

v – vertical distance between spreader and the centre of suspension [m]; s – vertical distance between the fastening points on cargo unit and spreader [m]; z – vertical distance between the fastening points on cargo unit and real c.o.g. [m]; $d\phi$ – primary suspension angle [^{0}]; e – eccentricity of the c.o.g [^{0}]; GG_1 – distance between the c.o.g when the even keel of the ship and after heeling at small angle [m].

The distance ($v – z$) below the centre of suspension leads to a point, where the eccentricity e alone would create the new condition of equilibrium. This point is the virtual centre of gravity of the cargo unit within the suspension arrangement.

If the mass of the traverse is taking into account.



Picture 7 — Virtual position of the c.o.g. with consideration of the mass of the traverse

The level z^* of the common centre of gravity G^* of the cargo unit and the traverse is determined by:

$$z^* = \frac{m_C \cdot z + m_T \cdot s}{m_C + m_T} \, , \tag{3}$$

m_C – mass of cargo unit [t]; m_T – mass of spreader [t].

The common centre G^* moves in the tilted condition to G_1^*. The distance of this movement is:

$$G^* G_1^* = (v + s - z^*) \cdot d\phi \; . \tag{4}$$

This movement is the result of the unknown eccentricity e of the centre of gravity G and the slewing distance $s \cdot d\phi$ from the secondary suspension [4]. The eccentricity e may be determined by equalisation with:

$$G^* G_1^* = \frac{m_C \cdot (e + s \cdot d\phi)}{m_C + m_T} \; . \tag{5}$$

The solution is: $$e = \left(v - z + v \cdot \frac{m_T}{m_C} \right) \cdot d\phi \; . \qquad (6)$$

That means that the virtual centre of gravity is lower by the amount of $v \cdot m_T/m_C$. The distance to the real centre of gravity is:

$$GG_1 = s - v \cdot \frac{m_T}{m_C} \; . \qquad (7)$$

Thus, loading of cargo unit by own ship's lifting gear is quite dangerous lift operation because, at the very moment of hoisting the weight up from berth the dramatic decrease in the ship's stability take place. In addition the ship might be considerably heeled. Than higher a suspended point and heavier this weight than bigger the stability loss. In addition, than bigger the distance of the weight just suspended by the crane from the ship and heavier this weight than larger and more dangerous heeling might happen.

Consequently the tilting angle of the whole arrangement was always equal to the tilting angle of the secondary slings, namely dϕ. With a sloping secondary suspension the slewing angles of the secondary suspension are different causing an additional tilting of the cargo unit. This will influence the position level of the virtual centre of gravity in either way, up or down.

In conclusion, some recommendations for avoiding unstable suspended arrangements must be followed. They are: make the height "v" of the primary suspension as long as possible; make the height "s" of the secondary suspension as short as possible; avoid negative suspension angles, i.e. the secondary slings are narrowing at the base; if in doubt, make a calculation and give a margin of at least one meter for the position of the virtual centre of gravity below the centre of suspension.

The computations have also shown that there remains a problem in the existing safety regime, as there are in general no rules for stability in rough weather. There is further not a single stability rule which reflects the situation that also too much stability in unfavorable floating conditions is in fact a safety relevant problem that can lead to severe stability accidents.

The negative effect of unfixed cargo on a ship's stability might happen due to slackening or even breaking the chains or the ropes by which the cargoes were originally secured, during loading/unloading operations performed by ship's lifting devices. That's why the most effective way to prevent ship's stability reduction due to movement of an unfixed cargo is making it fastened and secured properly.

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Гембатий Є.В. Стійкість суднових систем з підвішеним вантажем

Операції з підйому вантажів є потенційно небезпечними, особливо коли метацентрична висота судна, виправлена завдяки вільно підвішеному вантажу та свобідної поверхні суднових танків, приближується до нуля або навіть негативна. У цієї статті розглянемо основні аспекти остійності судна щодо відношення до безпеки вантажних операцій протягом вантаження та розвантаження важковаговиків.

Ключові слова: остійність, важковаговик, підвіс, центр тяжкості, метацентрична висота.

Гембатый Е.В. Остойчивость судовых систем с подвешенным грузом

Грузовые операции на судне являются потенциально опасными, особенно когда метацентрическая высота, с учетом поправок на свободно подвешенный груз и свободную поверхность в балластных танках, близка к нулю или даже отрицательна. В этой статье рассмотрим основные аспекты касательно остойчивости судна в отношении безопасности при проведении грузовых операций с тяжеловесными грузами.

Ключевые слова: остойчивость, тяжеловесный груз, подвес, центр тяжести, метацентрическая высота.