# CALCULATION OF EFFECT OF FREE SURFACE OF LIQUID IN TANK ON STABILITY OF A SHIP

**Capt-Doctor DINH XUAN MANH**

*Vietnam Maritime University*

*Email: dxmanh@vimaru.edu.vn*

***Foreword***

*A sea going ship has various characteristics and there are some of them:*

- *Stability,*
- *Buoyancy,*
- *Ability of being steerable,*
- *Inertial …*

*Among above characteristics, stability is most important for a ship. It is a very essential task of deck officers is to maintain suitable stability of a ship. There are many facts, which may effect on stability of a ship while sailing at sea. This article is arming to describe the effect of free surface of liquid in tank on stability of a ship and calculate it based on ship technical documents.*

***Terminology***:

*Stability, Free surface of liquid, Tank, Ship's Center of Gravity, Center of Gravity of a Liquid Volume, Transverse Metacentric Height, Ship Stability, Moment of Inertia.*

## 1. Stability of a Ship

To maintain a ship in safety in operation is the most essential target of a ship Manager and seafarers. The safety of a ship is including not only technical but also operation meaning. A ship may impose to a risk or suffer an accident when seafarers fail to maintain her characteristics within required range.

Many activities onboard a ship can cause a ship unsafe: cargo handling, ballasting or deballasting, etc. These activities may adversely effect on ship characteristics as stability, inertia, ability of being steerable, buoyancy …

Among above characteristics, the **Stability** is the most important and to be maintain in required criteria all the time. The Stability of a ship can be fully controlled by ship officers. While planning a voyage, the stability of a ship should be calculated as for departure as for arrival conditions to ensure that the ship is always seaworthy. However, during a voyage the stability of a ship can be adversely effected under influence of weather conditions, shifting of cargo or free surface of liquid in tanks and so on … Among the said facts, influence of free surface of liquid in tanks to stability of a ship often occurs. Thus requires deck officers carefully to calculate the influence beforehand and ensure that the stability of ship be maintained in required range.

## 2. Influence of Free Surface of Liquid in Partly Filled Tanks on Stability of a Ship

### 2.1. Righting Moment and Metacentric Height (GM)

Stability of a ship is treated satisfactory for seagoing in case it is in compliance with requirements specified in **International Code on Intact Stability, 2008** (IS code 2008) of International Maritime Organization (IMO), which has come in force from 1/7/2010. These criteria are:

- *Graphic square under Static Stability Righting Arm for heeling angles up to $30^0$, $40^0$, $30^0$-$40^0$;*
- *Value of the Static Stability Righting Arm (GZ) at heeling angle $30^0$;*
- *The heeling angle respectively to Max. GZ and Min. GZ (Transverse Metacentric Height - GM).*
- *The Code set out the value of GM, which after correction for effect of free surface of liquid should be greater than 0.15 m (applied for cargo ships and passenger ships having length more than 24m).*

Therefor ship Master and Chief Officer should consider influence of free surface of liquid in tanks while checking or calculating GM, after that to compare with the criteria set out in the Code.

As illustrated in the figure, when a ship upright floating in the water, a whole ship acts to water with a force called Gravity (D) having the set point in ship's center of gravity (G), oppositely the water act to the ship with a force called the force of buoyancy (Fb) having set point in ship's center of buoyancy (B). The two forces are equal in value but having opposite acting directions. [1, 70-74].

When all tanks of liquid onboard are fully filled or empty, the ship is a unit in whole. While a ship is heeling at a angle (θ) under a force, the center of buoyancy B moves from transverse plane to the new position at the geometrical center of water volume displaced by ship while the center of gravity remains unchanged. Therefor a couple of forces (D) and (Fb) forms a moment called Righting Moment (Mhp) which tends to bring the ship back to upright position (Fig. 2.1).

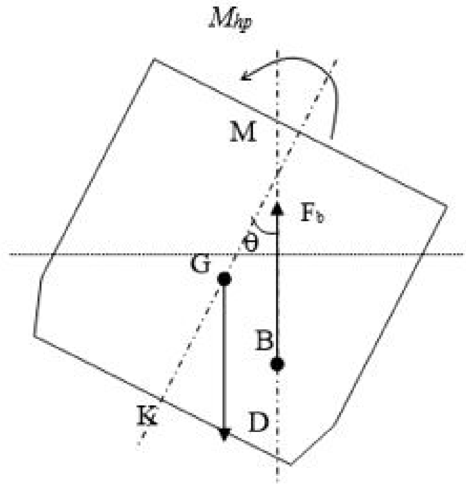


***Fig. 2.1. Righting Moment***

The value of the said moment is calculated as followed:

$$M_{hp} = D \times GM \times Sin\vartheta \tag{2.1}$$

Note: D is ship's displacement.

This formula showing that GM can represent the stability osf a ship at small heeling angles.

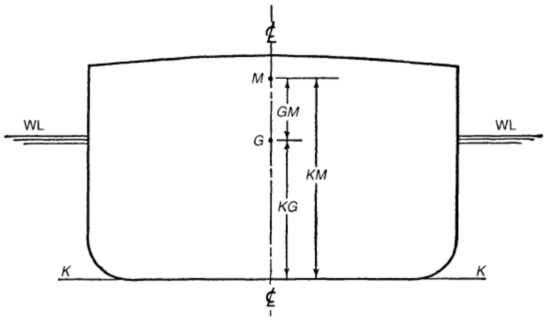


***Fig. 2.2. Transverse Metacentric Height***

From Fig. 2.2: GM = KM - KG (2.2)

With: KM: Transverse Metacentric Height above base line

KG: Height of Center of Gravity above base line

However, GM on formula (2.2) does not consider to effect of free surface of liquid in tank.

### *2.2. Calculation of Influence of Free Surface of Liquid in Tanks to Stability of a Ship*

A fully filled tank considers as a static weight with center of gravity at the center of the tank. The weight doesn't move when the ship is inclined. Therefor the center of gravity of the ship remains unchanged.

In case when a tank is partly filled, initial center of gravity of the water volume in tank is g and the center of gravity of the ship is G. When the ship is inclined at an angle (θ), the volume of water moves towards low side, center of gravity of the water volume g moves to position g1 causing the gravity of the ship to move to G1 in direction parallel with gg1 [2, 47-48] (Fig 2.3).

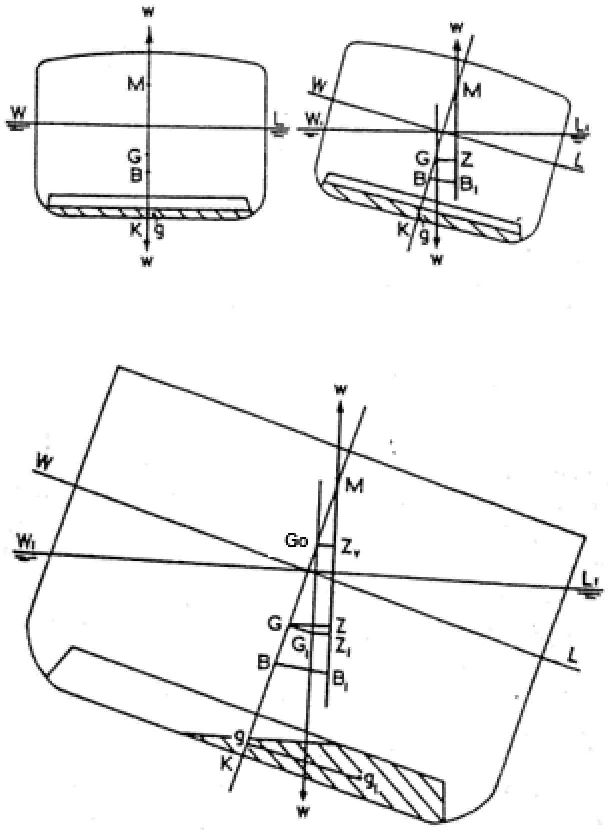


***Fig. 2.3. Fee Surface Effect***

Followed with Fig. 2.3, the value of Righting Moment is:

$$M_h = D \times G_1Z_1 = D \times G_0Z_v = D \times G_0M \times \sin\theta \qquad (2.3)$$

It is easy to see that Free Surface of Liquid decreases GM to value G0M. Therefor GG0 is decrement of GM due to free surface effect of partly filled tanks. Stability of a ship will decrease when she is in inclined position.

Obviously, when a ship have some partly filled tanks, the under formula (2.4) should be applied for calculation of GM instead of (2.2):

$$GM = KM - KG - GG_0. \qquad (2.4)$$

While: GG0 is decrement of GM due to free surface effect of partly filled, calculated by followed formula [2.5]:

$$GG_0 = \frac{\sum Ix \times \gamma}{D} \text{ (m)} \qquad (2.5)$$

While:

- $I_x$ is moment of innetia of liqiud free suface relatively to axis acrossing the center of the tank and parallelly with the longitudinal axis of the ship; its value can be detemined with under formula [2.6]:

$$I_x = \frac{l \times b^3}{K} \text{ (m}^4\text{)} \qquad (2.6)$$

While:

- *l* longitudinal length of the tank ;
- *b* beam length of the tank;
- K coefficient which is depent on the shape of a tank;

K= 12 for a tank with rectangular cross section shape ,

K= 36 for a tank with right-angled triangle cross section shape,

K= 48 for a tank with isosceles triangle cross section shape.

- $\gamma$ is density of the liquid in tank ($t/m^3$);
- D displacement of a ship

It is endemically that in the course of preparation of a voyage, Master/Chief Officer should take the influence of Free Surface of Liquid in tanks into account for stability of his vessel.

Practically, for the purpose of quick determination of GG0, some components of (2.5) are pre-calculated in ship stability booklet. Hereunder are some of the tables:

***- 1st Case***: Moment of Inertia *"$I_x$"*.

*Table 2.1:*

NO.1 UPPER W.B.T.(P/S)

| from B.L.(m) | Volume ($m^3$) | MG (m) | CLG (m) | KG (m) | Inertia ($m^4$) |
|---|---|---|---|---|---|
| 14.414 | 0.0 | 0.00 | 0.00 | 14.41 | 0.0 |
| 14.449 | 0.0 | −74.84 | 15.62 | 14.44 | 0.1 |
| 14.519 | 0.1 | −75.42 | 15.58 | 14.49 | 0.3 |
| 14.526 | 0.2 | −75.48 | 15.58 | 14.49 | 0.3 |
| 14.586 | 0.4 | −75.98 | 15.54 | 14.53 | 0.6 |
| 14.914 | 4.2 | −78.62 | 15.31 | 14.76 | 4.3 |
| 14.982 | 5.6 | −79.12 | 15.25 | 14.81 | 5.6 |
| 15.040 | 7.0 | −79.52 | 15.21 | 14.85 | 6.7 |
| 15.414 | 18.6 | −80.92 | 14.95 | 15.09 | 17.5 |
| 15.914 | 41.4 | −81.79 | 14.64 | 15.42 | 46.0 |
| 16.414 | 73.8 | −82.46 | 14.32 | 15.75 | 97.4 |
| 16.914 | 116.8 | −83.06 | 14.00 | 16.09 | 182.7 |

***- 2nd case***: **Max *"$I_x$"***

*Table 2.2 – Maximum Moment of Inertia*

| COMPARTMENT | | Maximum Moment of Inertia (I) in $m^4$ |
|---|---|---|
| FORE PEAK TANK (CR) | (C) | 3,891.2 |
| No.1 Water Ballast Tank | (P&S) | 2 x 4,340.8 |
| No.2 Water Ballast Tank | (P&S) | 2 x 17,740.9 |
| No.3 Water Ballast Tank | (P&S) | 2 x 10,442.1 |
| No.4 Water Ballast Tank | (P&S) | 2 x 3,475.2 |
| No.1 Upper Wing Water Ballast Tank | (P&S) | 2 x 1,329.6 |
| No.2 Upper Wing Water Ballast Tank | (P&S) | 2 x 1,473.6 |
| No.2 Upper Wing Water Ballast Tank | (P&S) | 2 x 1,470.2 |

**- *3rd case*: Heeling Moment*.***

*Table 2.3 - Max. Free Surface Moment*

| Fuel Oil Tanks | | | 98% Full S.G. = 0.944 | | | |
|---|---|---|---|---|---|---|
| Name of Tank and Frame Possition | | | Weight of Contents (t) | V.C.G. (m) | L.C.G. (m) | Max. Free Surface Moment (t-m) |
| No. 1 F.O.T. | (P) | 152-166 | 205 | 5.83 | 42.91 | 80 |
| No. 1 F.O.T. | (S) | 152-166 | 200 | 5.83 | 42.87 | 75 |
| No. 2 F.O.T. | (P) | 137-152 | 195 | 6.57 | 32.48 | 105 |
| No. 2 F.O.T. | (S) | 137-152 | 210 | 5.81 | 33.53 | 75 |
| No. 3 F.O.T. | (P) | 123-152 | 180 | 1.41 | 24.45 | 170 |
| No. 3 F.O.T. | (S) | 123-152 | 180 | 1.41 | 24.45 | 170 |
| No. 3 F.O.T. | (PC) | 119-152 | 345 | 1.28 | 24.02 | 700 |
| No. 3 F.O.T. | (SC) | 119-152 | 240 | 1.29 | 23.55 | 370 |

**- *4th Case*: Value $GG_0$**

*Table 2.4 – Loss of $G_0M$*

| LOSS OF $G_0M$ BY FREE SURFACE EFFECT (UNIT IN M) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lpp = 122.90 m Bm = 19.60 m Dm = 13.20 m | | | | | | | |
| TANK NAME | MAX. I $m^4$ | S.G. $t/m^3$ | MEAN DRAFT (m) & DISPALCEMENT (t) | | | | |
| | | | 2.00 3611 | 2.50 4590 | 3.00 5582 | 3.50 6585 | 4.00 7598 |
| FORE PEAK TANK | 119.7 | 1.025 | 0.034 | 0.027 | 0.022 | 0.019 | 0.016 |
| DEEP TANK | 443.9 | 1.025 | 0.126 | 0.099 | 0.082 | 0.069 | 0.060 |
| No.1 W.B.T. (C) | 4878.7 | 1.025 | 1.385 | 1.089 | 0.896 | 0.759 | 0.658 |
| No.2 W.B.T. (P/S) | 1881.3 | 1.025 | 0.534 | 0.420 | 0.345 | 0.293 | 0.254 |
| No.3 W.B.T. (P) | 256.3 | 1.025 | 0.073 | 0.057 | 0.047 | 0.040 | 0.035 |
| No.3 W.B.T. (S) | 265.9 | 1.025 | 0.075 | 0.059 | 0.049 | 0.041 | 0.036 |
| No.3 W.B.T. (C) | 1250.0 | 1.025 | 0.355 | 0.279 | 0.230 | 0.195 | 0.169 |
| No.4 W.B.T. (P/S) | 1508.3 | 1.025 | 0.428 | 0.337 | 0.277 | 0.235 | 0.204 |
| No.5 W.B.T. (P/S) | 636.3 | 1.025 | 0.181 | 0.142 | 0.117 | 0.099 | 0.086 |
| FRESH W.T. (P/S) | 24.0 | 1.000 | 0.007 | 0.005 | 0.004 | 0.004 | 0.003 |

*Note: Any cargo which may move crossly the deck while the ship is heeled can cause an effect same as Liquid.*

It is recommended, that tanks to be filled as full as possible or kept empty.

## 3. Conclusion

There are always some partly filled tanks on a vessel, Master/Chief Officer should load the tanks so that to minimize the effect of free surface of liquid in tanks. Stability of a ship should comply with IS Code 2008 before proceeding to the sea.

**REFERENCES**


[1] Captain A.R. Lester, Merchant Ship Stability, Butterworth & Co. Ltd, 1986.

[2] D.R. Derret, Ships Stability for Master and Mates, 4th edition (revised), Oxford, Heinemann Professional Publishing, 1990.

[3] W.E. George, J. La Dage and L. Van Gemert, Stability and Trim for the Ship's Officer, 4th edition, Centreville, Maryland, Cornell Maritime Press, 2005.

[4] Shin Kurushima Dockyard Co. Ltd, MV. GEMINI FOREST - Loading and Stability Information Booklet, 1998.

[5] Imabari Shipbuilding Co., Ltd. Imabari Shipyard, MV SANTA FRANCISCA - Stability Booklet

with Loading Guidance, 2001.

[6] Universal Shipbuilding Corporation, Maizuru Dockyard, MV CENTURY STAR - Trim & Stability Calculation, 2003.

[7] Đinh Xuân Mạnh, Xếp dỡ và bảo quản hàng hoá trên tàu biển, Trường ĐHHH, 2005.

[8] International Maritime Organisation, International Code on Intact Stability 2008, 2009 Edition.