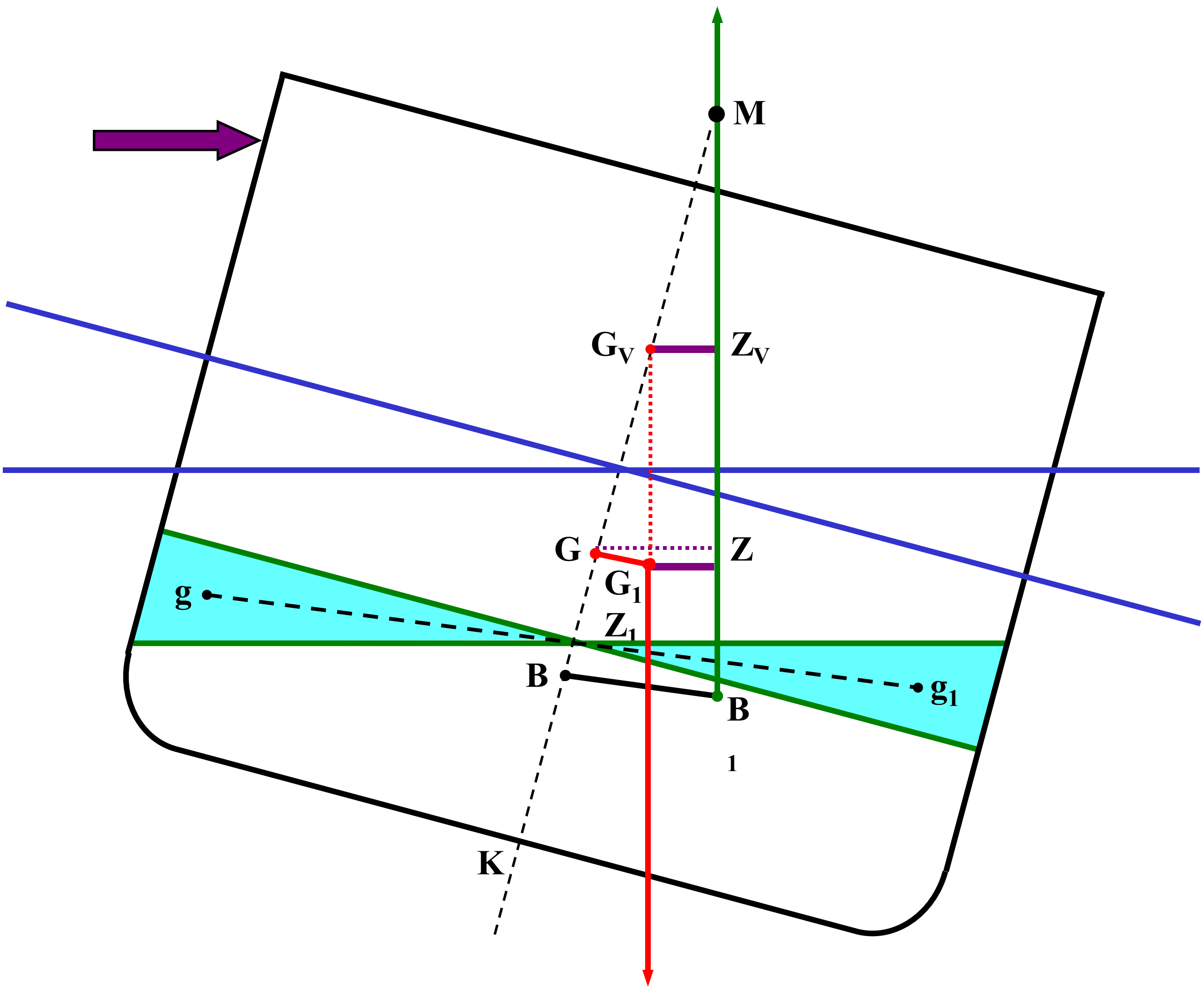
FREE SURFACE EFFECT



A ship has a slack tank as shown i.e. the tank is only part full.

External forces cause the ship to heel to some angle and liquid in the tank moves from the high side to the low side (gg_1).

This causes G to move off the centre-line to G_1.

As a result of the shift of liquid, ***righting lever is reduced from GZ to G_1Z_1.***

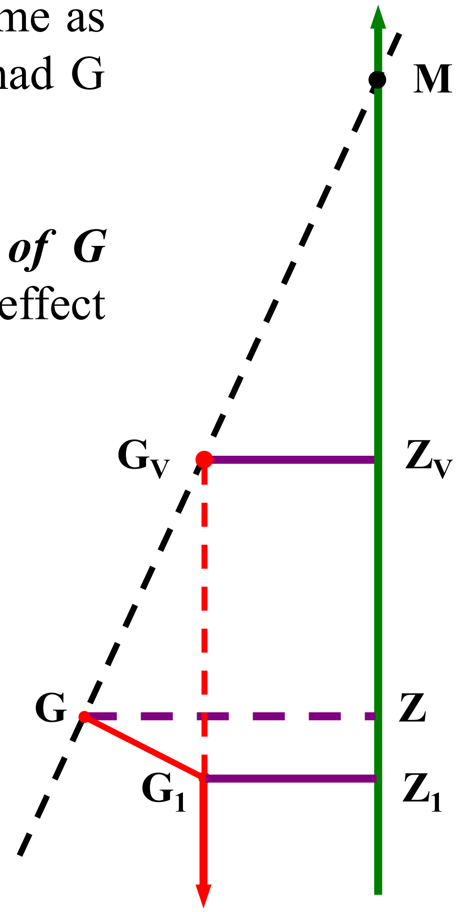
The righting lever G_1Z_1 is the same as the GZ that would have existed had G been raised to G_V.

GG_V represents the ***virtual rise of G*** that results from the free surface effect of the slack tank.

Thus:

GM is the ***solid GM*** ;

G_VM is the ***effective or fluid GM***.



When calculating the GM of the ship it is important that the effects of free surfaces are considered i.e.

IT IS ***ALWAYS*** THE ***FLUID GM*** THAT MUST BE DETERMINED TO TAKE ACCOUNT OF THE REDUCTION IN GZ VALUES THAT ARISES FROM LIQUID MOVEMENT WITHIN THE SHIP AS IT IS HEELED.

<u>Note</u>

When the ship is in the upright condition the centre of gravity (G) will move back to it's original position at G. Hence, it is termed a ***'virtual rise'*** of G since it does not actually move up to G_V.

To calculate the effect of free surfaces

For a tank that has a rectangular free surface the virtual rise of G can be calculated by:

$$\boxed{GG_V = \frac{lb^3}{12\nabla} \times \frac{dt}{ds}}$$

where: $\mathbf{GG_V}$ is the virtual rise of G in metres;
l is the tank length;
b is the tank breadth;
dt is the density of the liquid in the tank;
ds is the density of the water in which the ship floats (1.025 t/m^3);

and, ∇ is the volume of displacement of the ship.

Since: $$\Delta = \nabla \times ds$$

it follows that:

$$\boxed{GG_V = \frac{lb^3}{12\Delta} \times dt}$$

SAQ

A ship has an initial displacement of 10500 t and KG 7.60 m. A rectangular cargo oil tank of length 30 m and breadth 20 m is partly filled with 9600 t of oil (RD 0.86). If the Kg of the oil is 8.00 m calculate the effective GM if the KM for the final displacement is 8.80 m.

Answer

1. ***Taking moments about the keel, calculate the new solid KG.***

	WEIGHT (t)	KG (m)	MOMENTS (t-m)
Ship (+)	10500.00	7.60	79800.00
Cargo oil (+)	9600.00	8.00	76800.00
FINAL	20100.00	7.791	156600.00

2. ***Calculate the effect of free surface.***

$$GG_V = \frac{lb^3}{12\Delta} \times dt = \frac{30 \times 20^3}{12 \times 20100} \times 0.86 = 0.856 \text{ m}$$

3. ***Calculate the solid GM and then apply the free surface correction to obtain the fluid GM.***

KM	8.800
SOLID KG	7.791
SOLID GM	1.009
FSE (GGv)	0.856
FLUID GM	0.153

(Answer)

The determination of free surface data for use in stability calculations

The ***moment of inertia (I)***, often termed the ***second moment of area,*** of the free liquid surface must first be determined.

For a rectangular free liquid surface: $$I = \frac{lb^3}{12} \; (m^4)$$

If the value of I is multiplied by the liquid density then a value of 'Free Surface Moments' (FSM's) (t-m) is obtained.

$$\text{FSM's (t-m)} = \frac{lb^3 \times dt}{12}$$

In the previous free surface effect formula:

$$GG_V = \frac{lb^3}{12\Delta} \times dt$$

Therefore: $$GG_V = \frac{\text{FSM's}}{\text{Displacement}}$$

Since: $$\text{Final KG} = \frac{\text{Sum of moments}}{\text{Displacement}}$$

it is evident from the above that the greater the value of the free surface moments, the greater the loss of GM (GG_V) and the greater the value of the effective KG.

In calculating the effective GM it is usual to make allowances for free surfaces by incorporating the FSM's in the KG table where they must always be ADDED.

Consider the previous example.

1. ***Calculate the FSM's using:*** $FSM's\ (t\text{-}m) = \dfrac{lb^3 \times dt}{12}$

2. ***Taking moments about the keel, also adding the FSM's in the 'moments' column', calculate the fluid KG.***

	WEIGHT (t)	KG (m)	MOMENTS (t-m)
Ship (+)	10500.00	7.60	79800.00
Cargo oil (+)	9600.00	8.00	76800.00
FSM's (+)			17200.00
FINAL	20100.00	8.647	173800.00

3. ***Apply the fluid KG value to the final KM to obtain the final fluid GM.***

KM	8.800
FLUID KG	8.647
FLUID GM	0.153

(Answer)

Note

In tank sounding/ullage tables ***free surface moments (t-m)*** may be tabulated for an ***assumed value of liquid density***. If the actual liquid density is different then the ***FSM values must be corrected***.

Alternatively, free surface data may be tabulated in the form of ***I values (m^4)*** in which case the value of ***I must be multiplied by the liquid density to obtain free surface moments (t-m).***

ALWAYS CHECK!

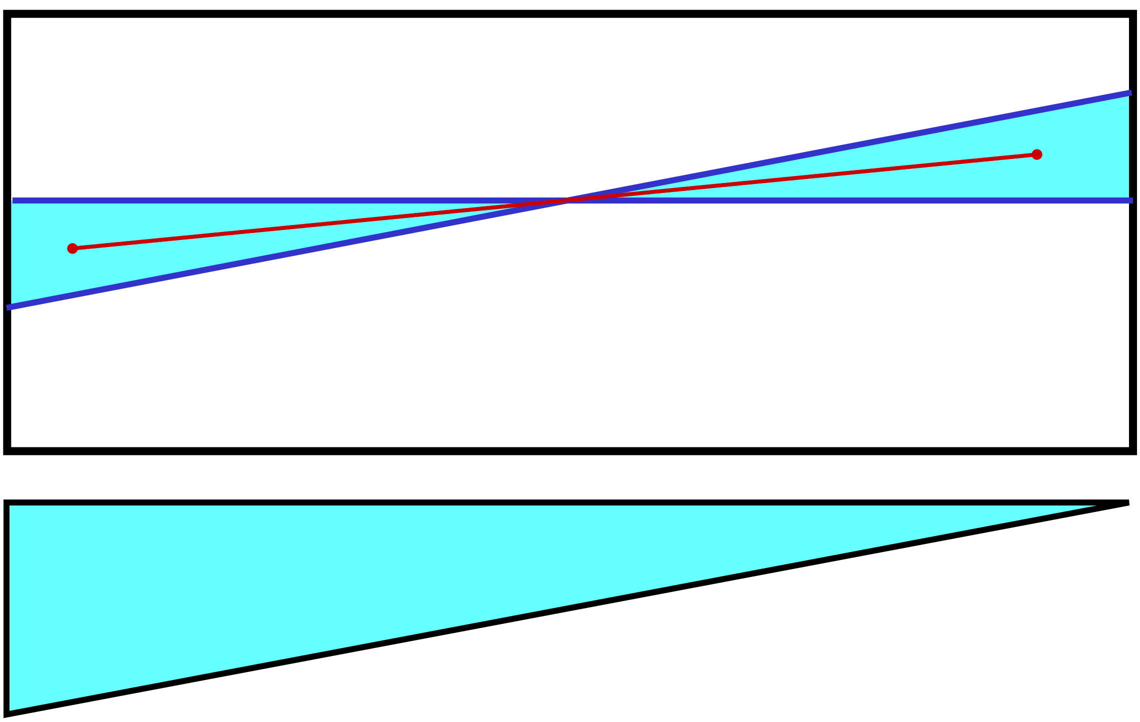
Factors affecting free surface effect

If the free surface formula is considered it is obvious that the ***breadth*** of the tank is the most important factor.

If a tank is subdivided the loss of GM can be greatly reduced.

Consider the rectangular tank shown below.

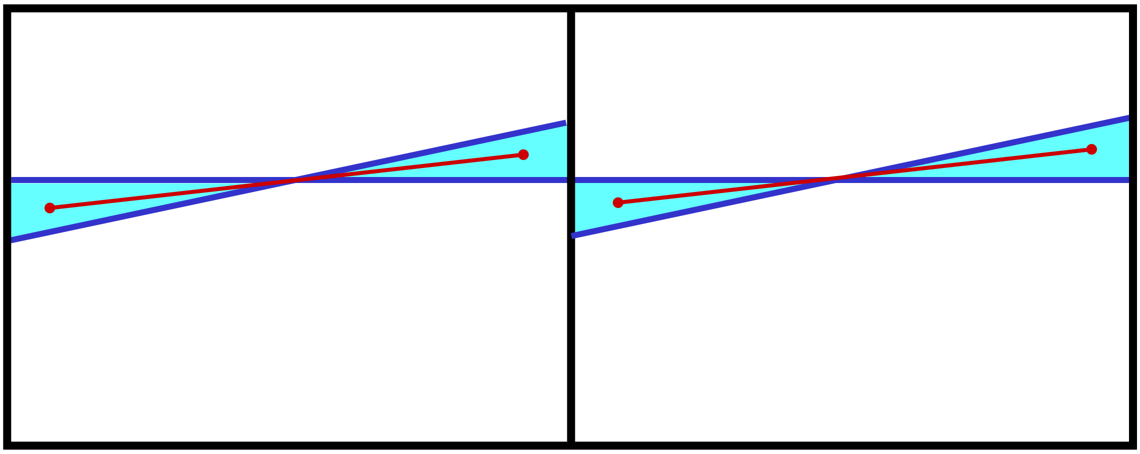
1. **With no subdivision**

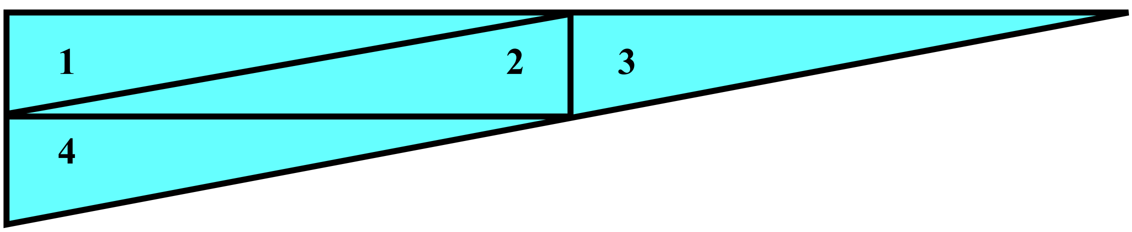


If the loss of GM due to the free surface of the tank is 0.64 m and the solid GM was found to be 0.70 m, say, the effective GM would be:

Solid GM	0.700 m
FSE (m)	0.640 m
Effective GM	0.060 m

2. With a single centre-line division





* The volume of liquid that has moved is halved.

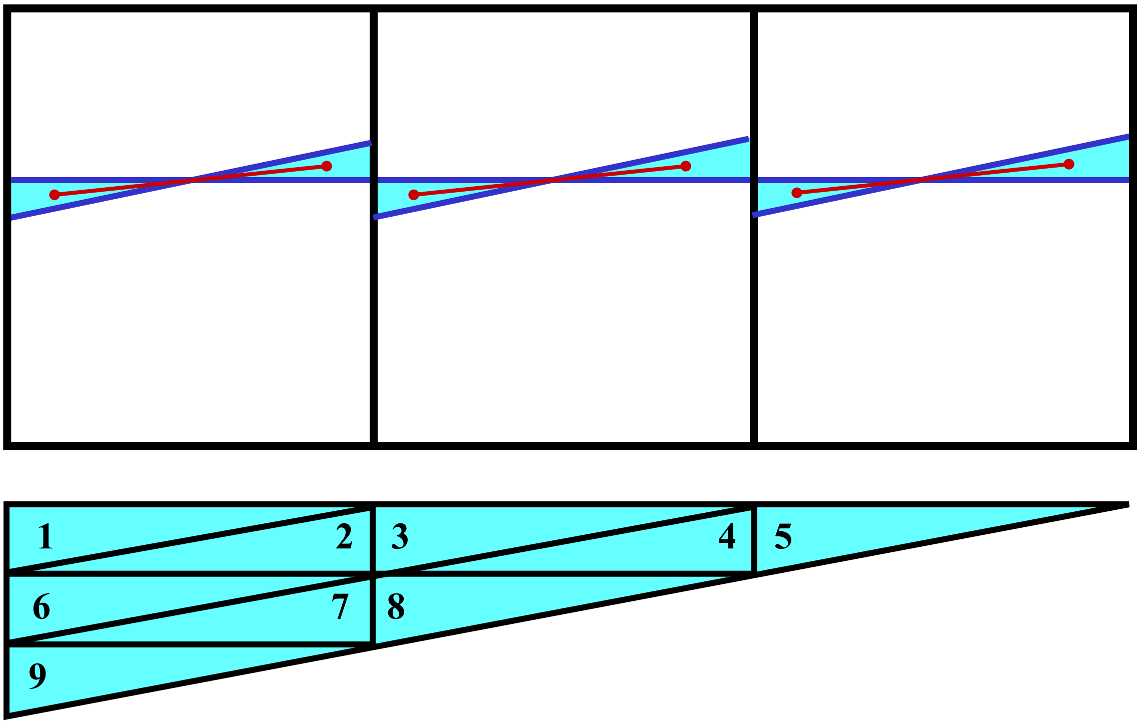
* The distance that the total volume of liquid has moved is also halved.

With a single centre-line division the FSE is reduced to a quarter of the original value

$\frac{0.64}{4} = 0.16$ m

Solid GM	0.700 m
FSE (m)	0.160 m
Effective GM	0.540 m

3. With two subdivisions



* The volume of liquid that has moved is now a third.
* The distance that the total volume of liquid has moved is also only a third.

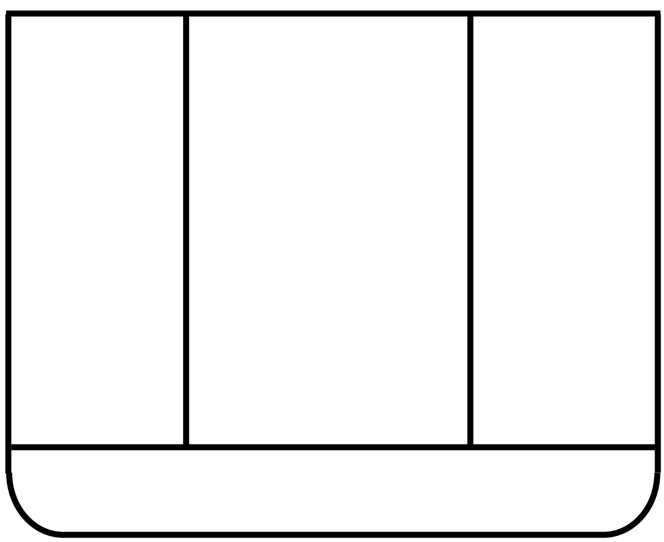
With the tank equally subdivided with two longitudinal bulkheads the FSE is reduced to a ninth of the original value.

$\frac{0.64}{9} = 0.071$ m

	Solid GM	0.700 m
	FSE (m)	0.071 m
	Effective GM	0.629 m

With ***three subdivisions*** i.e. dividing the tank into four ***compartments***, FSE would be reduced to ***one sixteenth*** and so on.

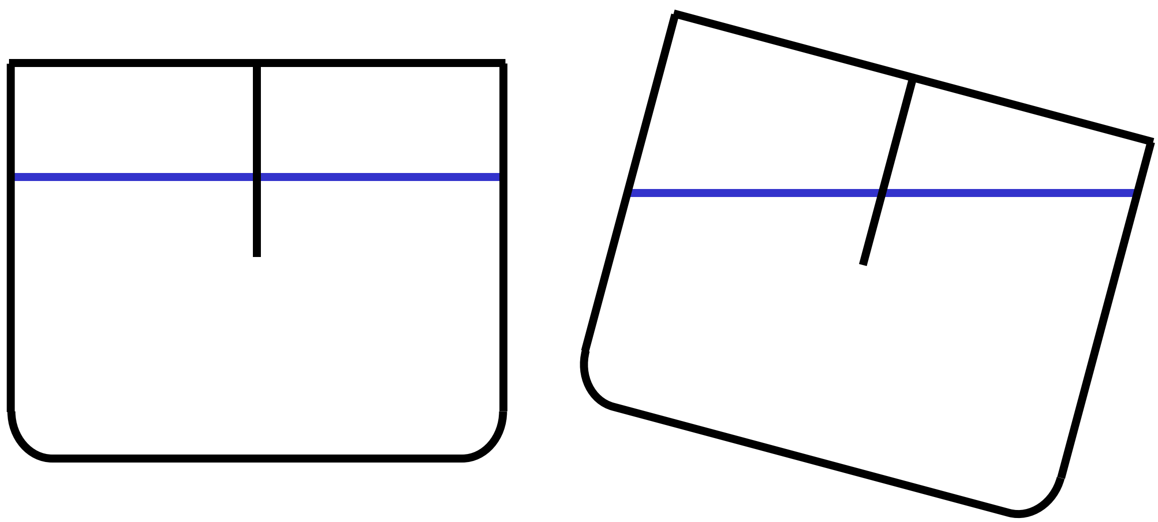
It is usual to subdivide tanks into three compartments at most as the benefit of any further subdivision would improve effective GM by a less significant amount each time (with the exception of product carriers/chemical carriers etc. where a ship is designed to carry a wide range of cargoes at any one time).



Typical oil tanker tank arrangement

Points to note

* For a tank to be considered subdivided it must be fitted with an 'oil-tight' or 'water-tight' bulkhead ensuring that there is no possibility of liquid transfer. This means that any valves in between the tanks must be capable of being fully shut.



A 'wash plate' is fitted to prevent damage to internal tank plating that may be caused by wave action ***within the tank***.

* The two tanks shown are exactly the same in size and both hold liquid of the same density but are filled to different levels.

The free surface moments for each are the same.