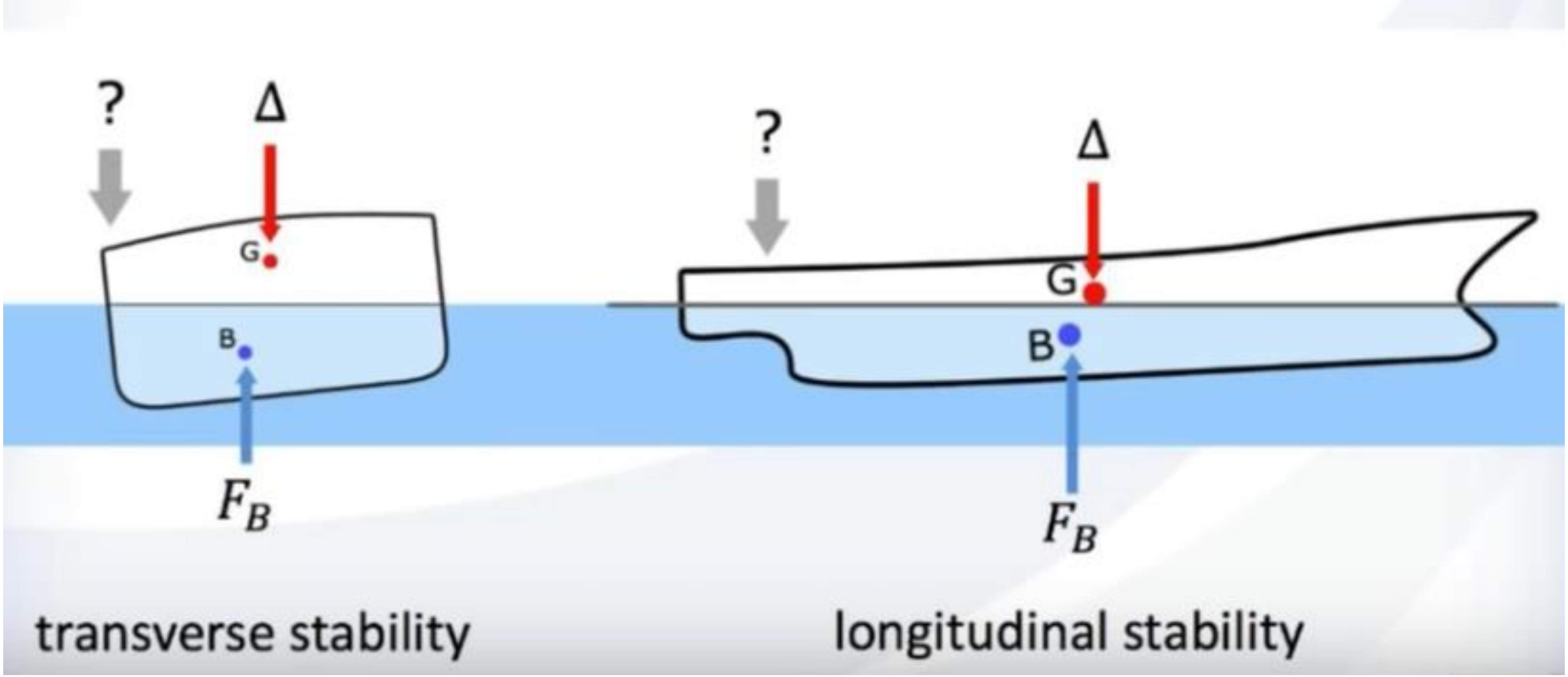
Ship Construction and Stability II

Calculating KB, BM and metacentric diagrams,

Final KG plus twenty reasons for a rise in G.

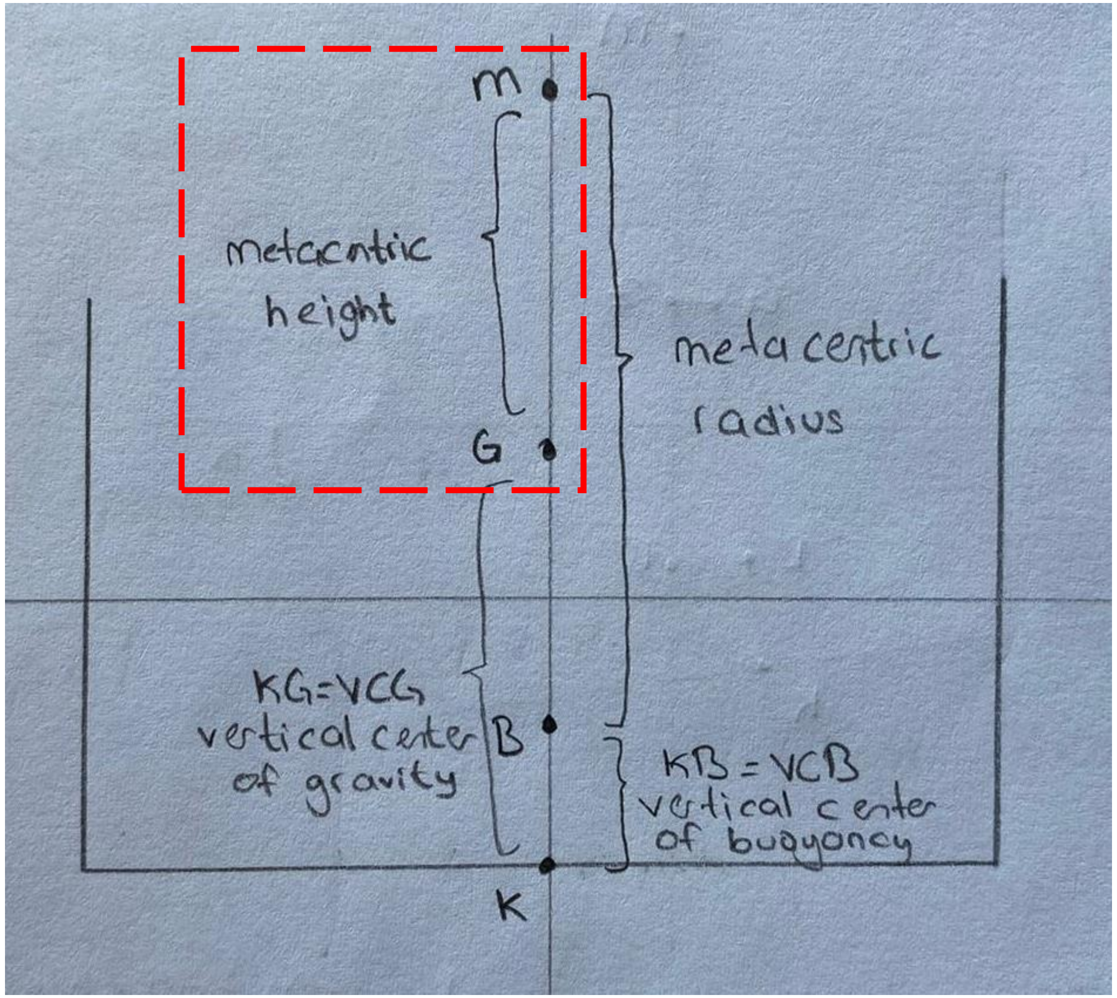
Ilgın Özgül

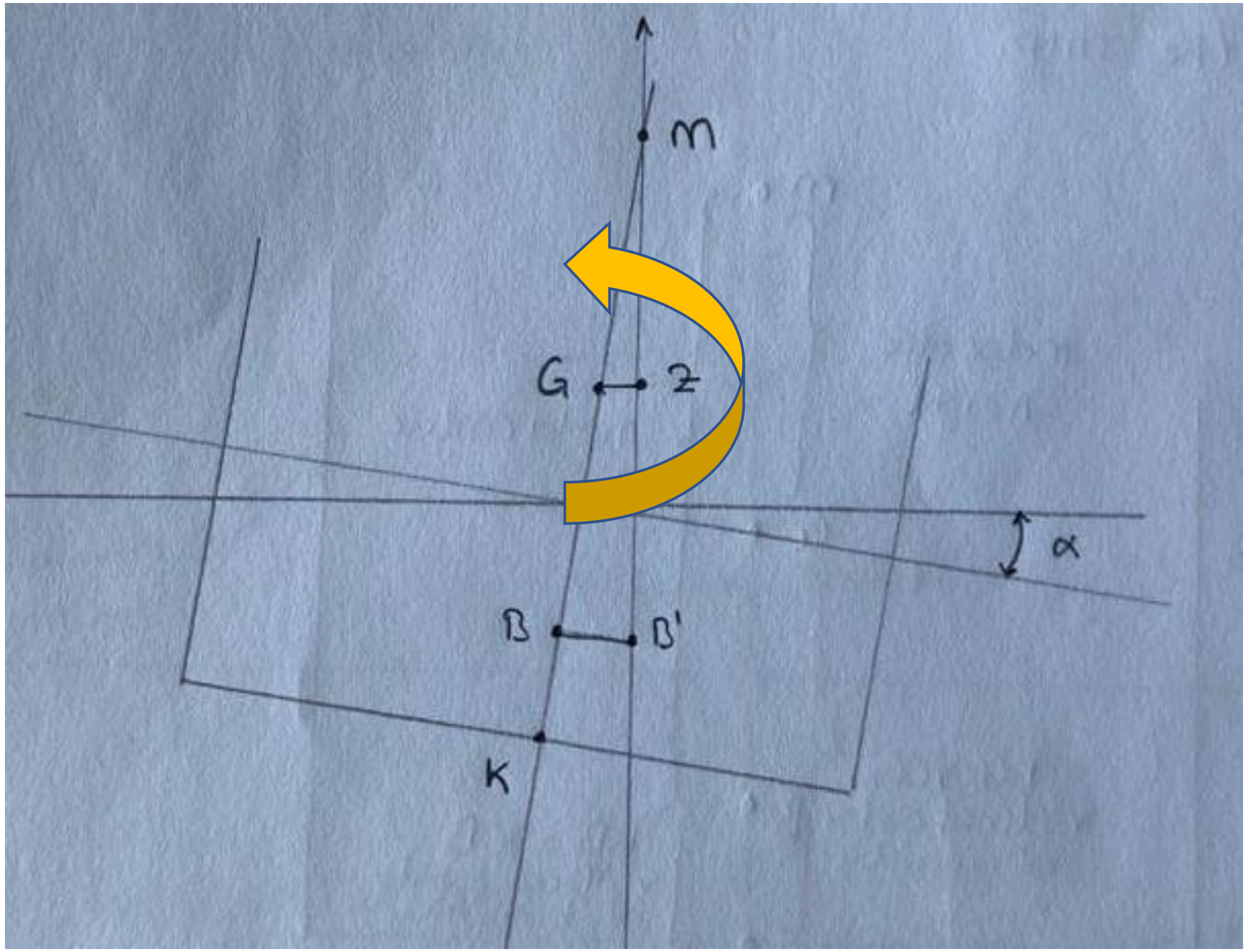
We will talk entirely about transverse stability:



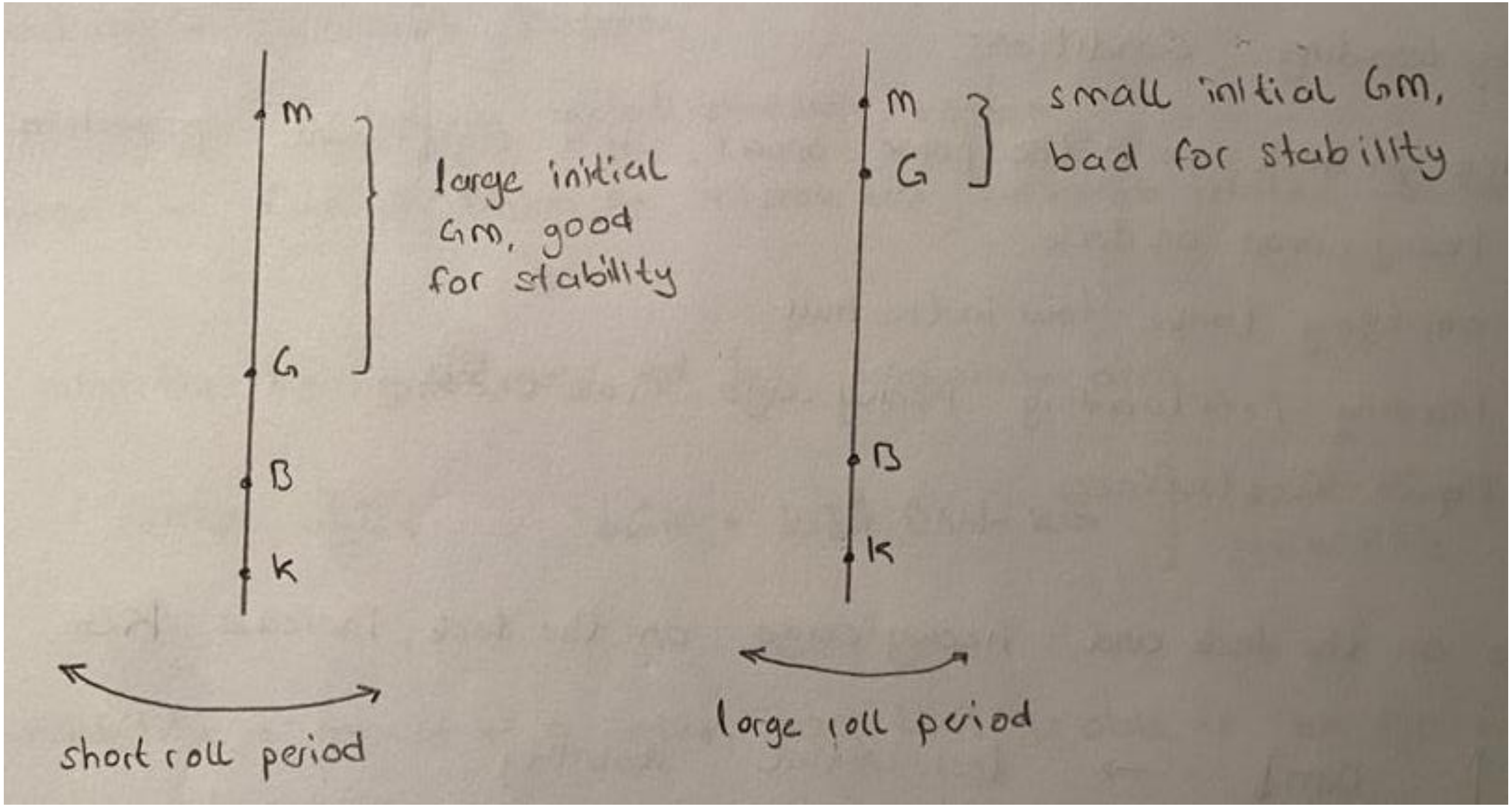
It’s all about GM.

GM is our measure of initial transverse stability. GM is what we are trying to get. It’s also known as «Metacentric Height».





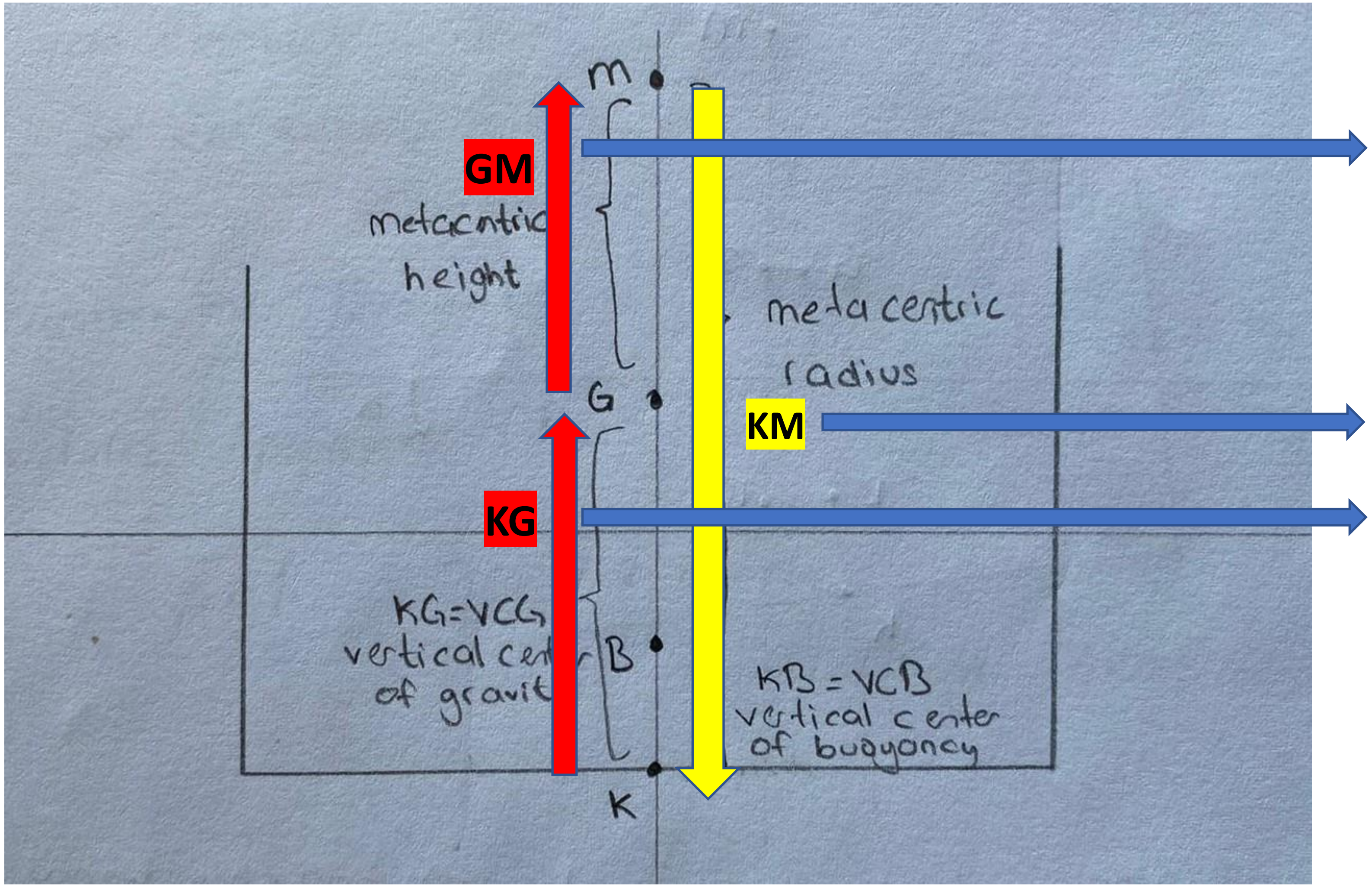
Simply,



M
G
B
K
large initial GM, good for stability
short roll period
M
G
B
K
small initial GM, bad for stability
large roll period

Well, how to find GM?

We can find GM if we know KM and KG.



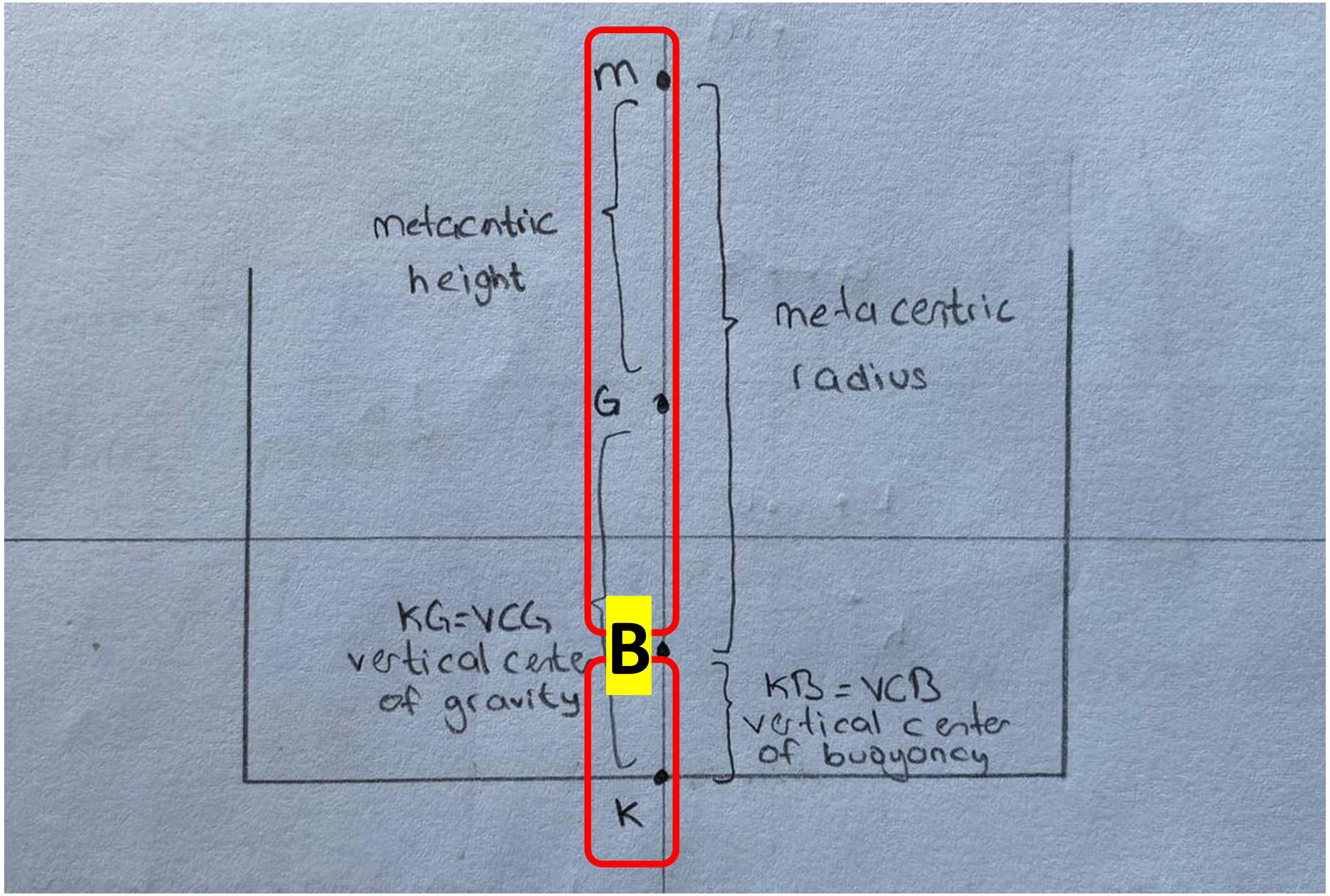
KG+GM=KM

KM provided in ship's hydrostatic curves.

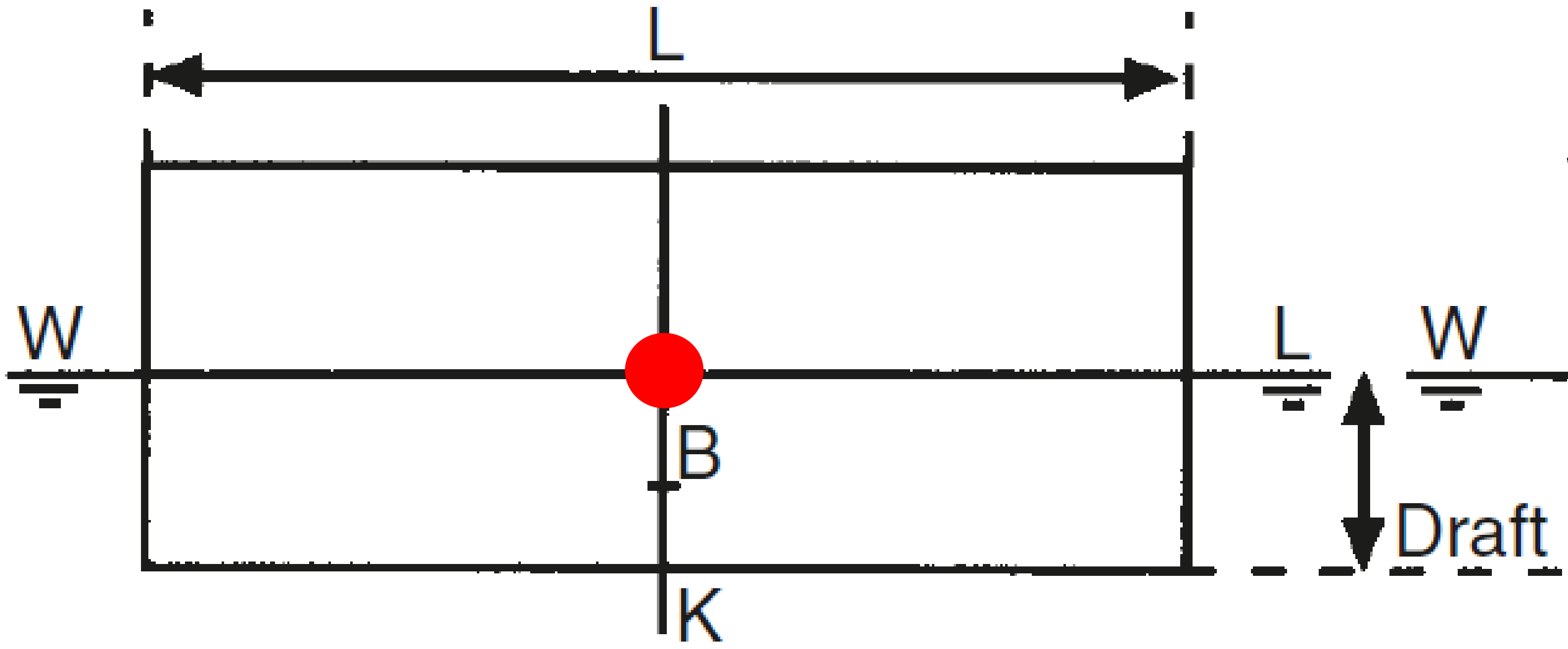
KG depend on the loading of the ship and determined by «weight and moment calculation».

Another way to find KM:

If we know KB and BM, then we can sum them and find KM. Actually, hydrostatic curves are drow by help of KB and BM.

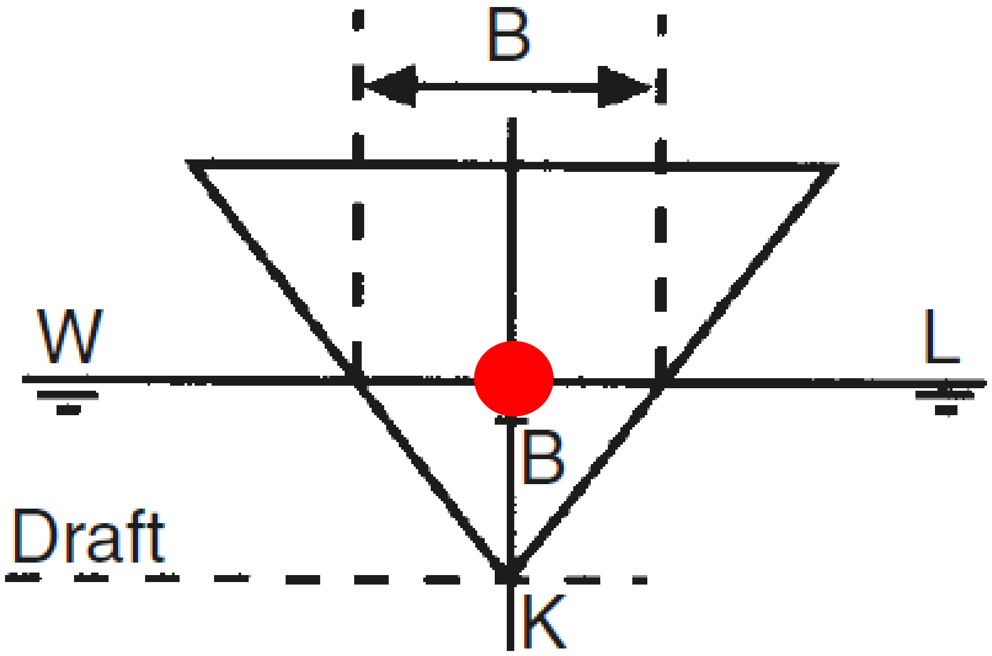


The centre of buoyancy is the centre of gravity of the underwater volume.



$KB = 0.5 \times Draft$

BOX SHAPED VESSEL

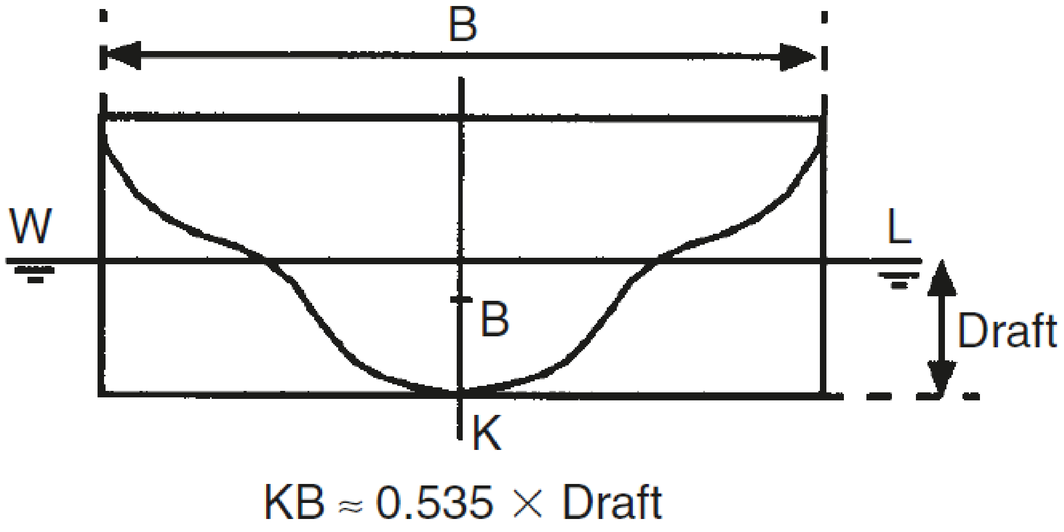


$KB = 2/3 \times Draft$

TRIANGULAR SHAPED VESSEL

COB (Centre of Buoyancy)

In the normal situation, we will not have a box shaped or triangular shaped vessels. We will have a ship shaped vessel.



SHIP SHAPED VESSEL

The approximate depth of the centre of buoyancy of a ship below the waterline usually lies between 0.44 x draft and 0.49 x draft.

COB (Centre of Buoyancy) Formula

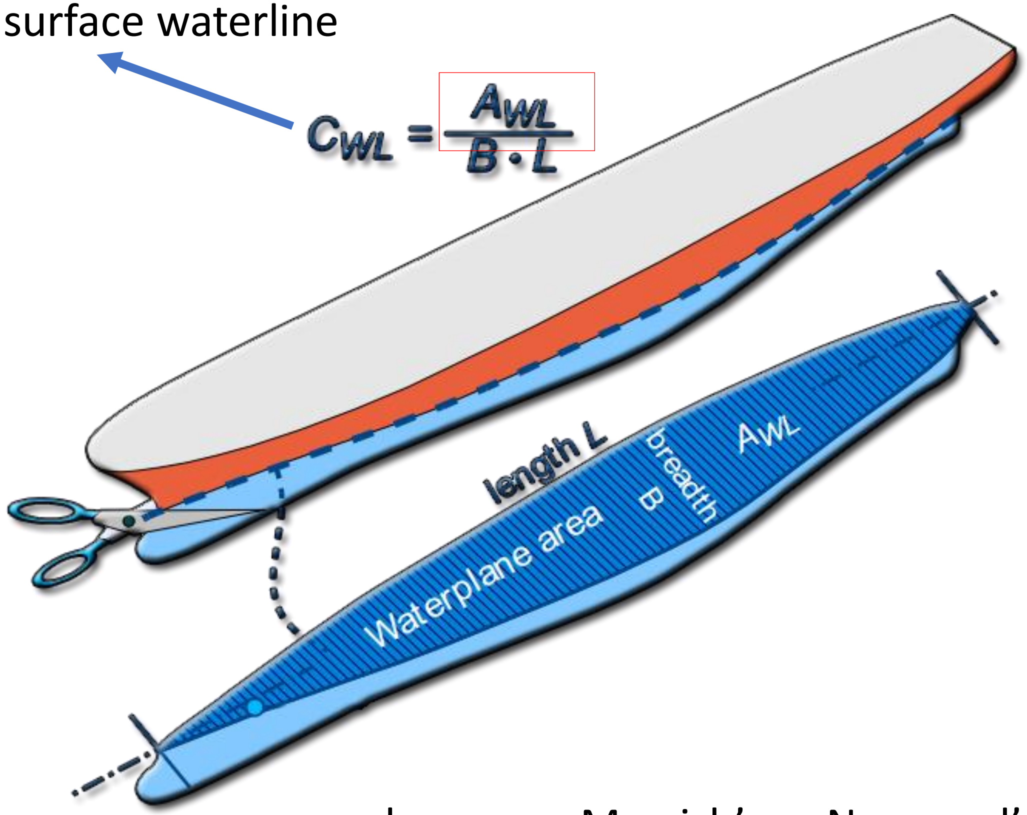
$$depth\ of\ centre\ of\ buoyancy\ \boldsymbol{below}\ waterline = \frac{1}{3}\left(\frac{d}{2} + \frac{V}{A}\right)$$

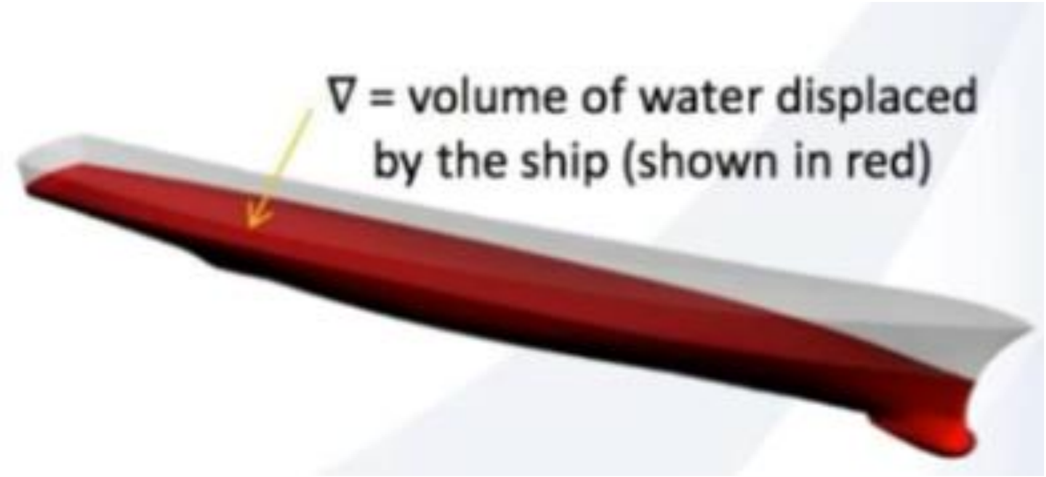
d=T= mean draft

V= volume of displacement

A= area of water plane

the coefficient of surface waterline



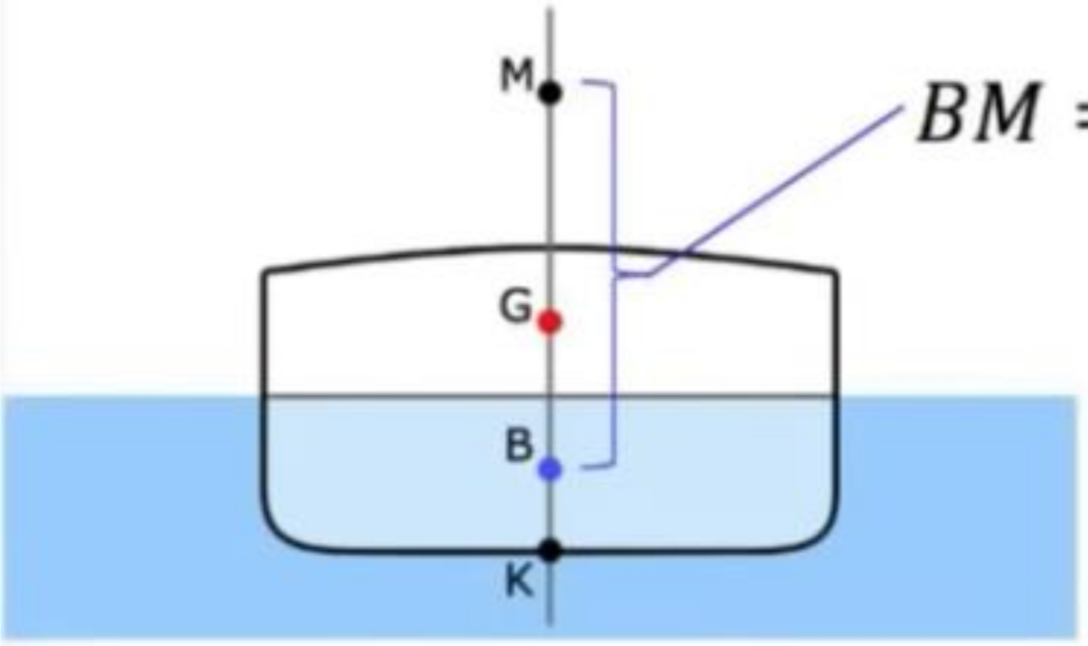


known as Morrish's or Normand's formula

How to find BM? (formula)

$$BM(metacentric\ radius) = \frac{second\ moment\ of\ the\ waterplane\ area\ about\ the\ centerline}{volume\ of\ the\ water\ displaced\ by\ the\ ship}$$

$$BM = \frac{I}{V}$$

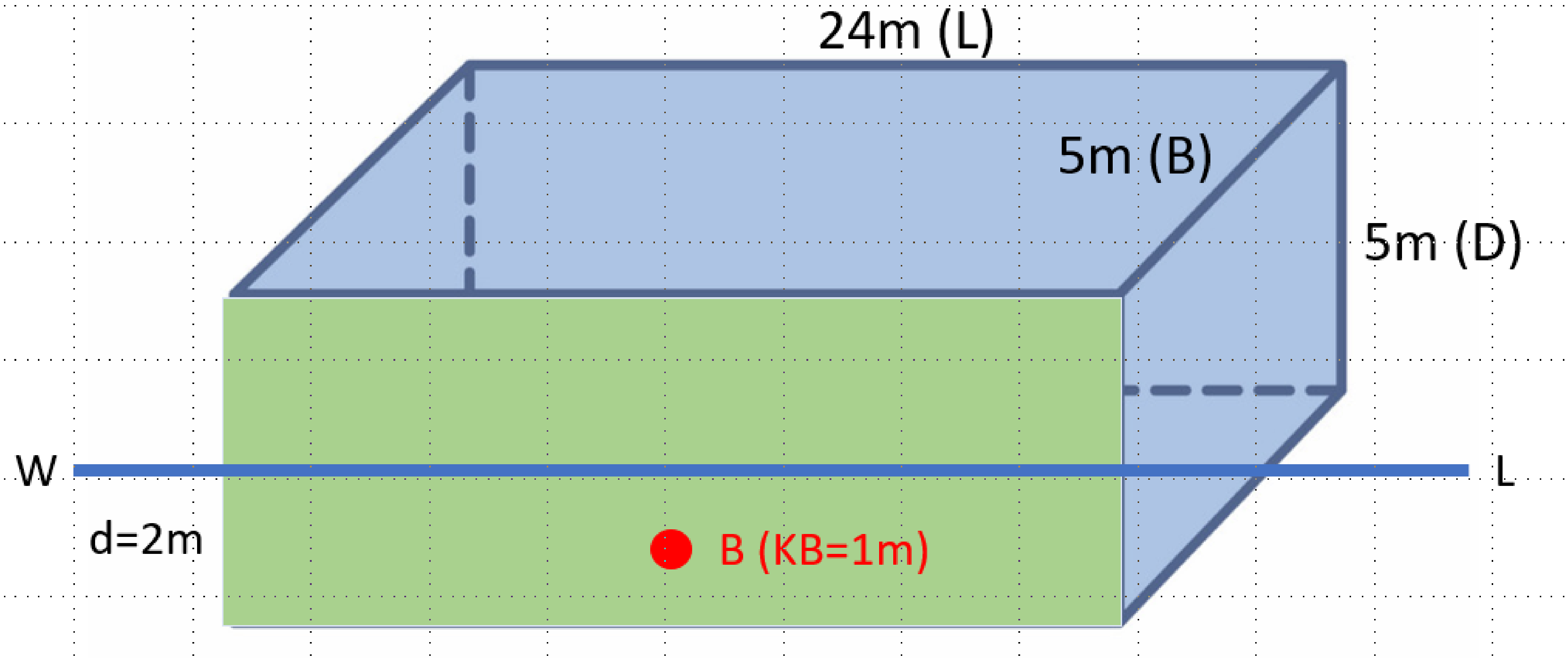


$$BM = \frac{I_T}{\nabla}$$

I_T: second moment of the waterplane area about the centerline

Let’s solve a basic problem: Example 1

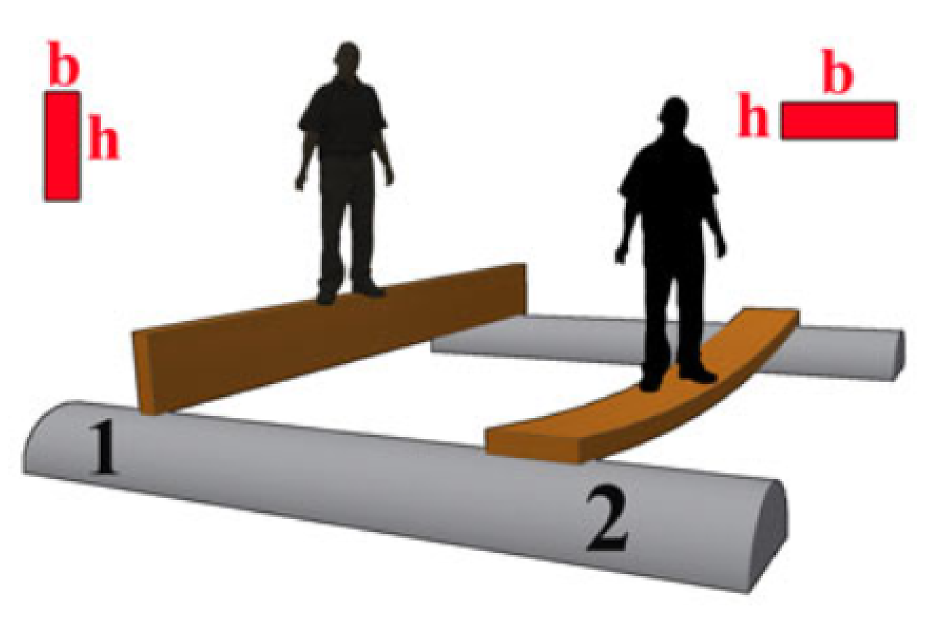
A box-shaped vessel is 24m 5m 5 m and floats on an even keel at 2m draft. KG 1.5 m. Calculate the initial metacentric height.



1- We found KB (1m) and now have to find BM to calculate all KM distance.

2- We need to know second moment of waterplane area (I) and volume of displaced water to calculate BM because formula of BM is I/V.

The **second moment of area** is also known as the **moment of inertia** of a shape. The second moment of area is a measure of the 'efficiency' of a cross-sectional shape to resist bending caused by loading.



Both beams have the same area and even the same shape.

Beam 1 is stronger than **Beam 2** because it has a higher *second moment of area* (I).

Orientation can change the *second moment of area* (I).

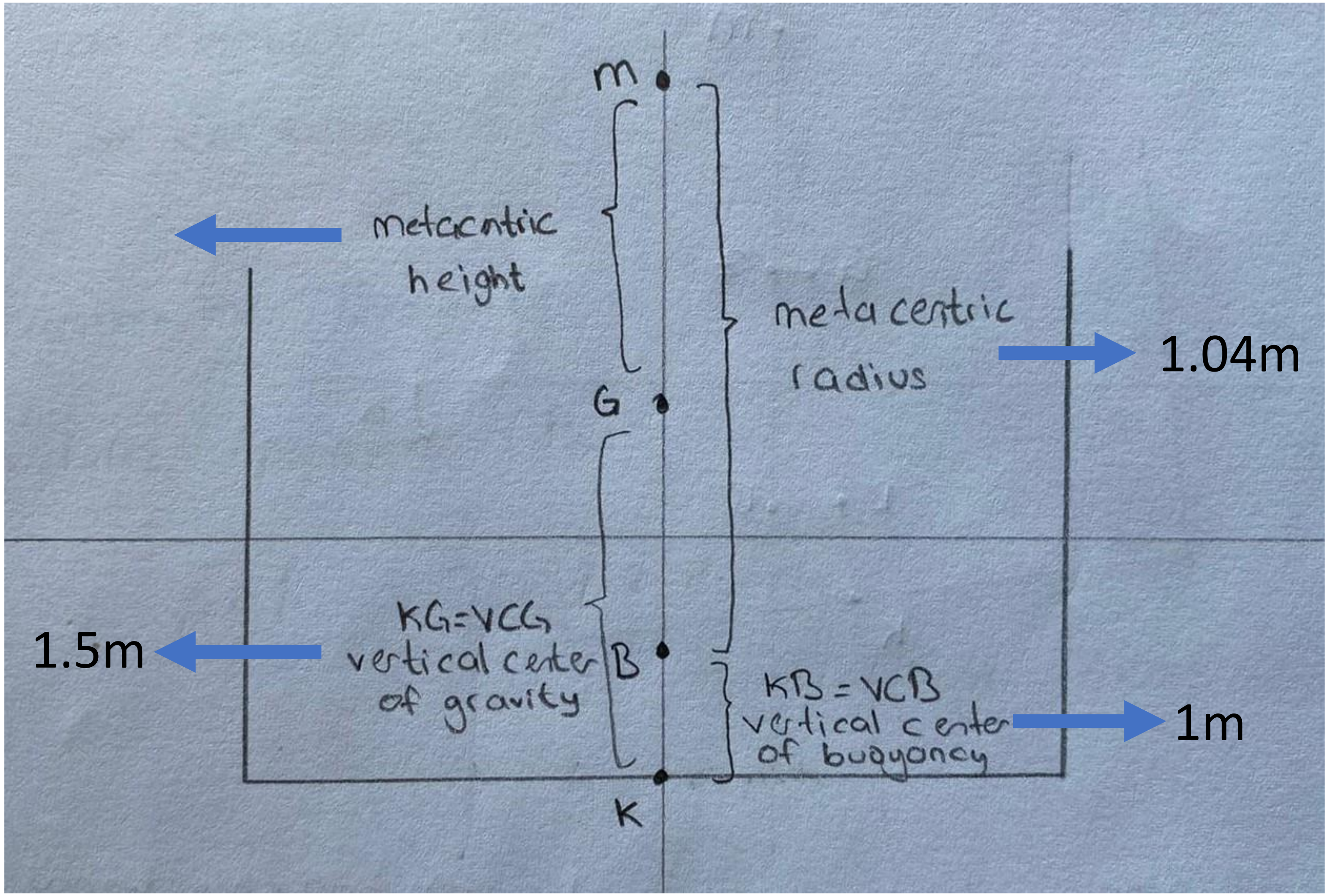
For a rectangle,

$$I_c = \frac{bh^3}{12}$$

*Where **b** is breadth (horizontal) and **h** is height (vertical) if the load is vertical - e.g. gravity load.*

(Image: Tim Lovett 2014)

$$BM = \frac{bh^3}{12V} = \frac{LB^3}{12 * L * B * d} = \frac{B^2}{12d} = \frac{5^2}{12 * 2} = 1.04m$$



1.5m

1.04m

1m

(This formula is only for rectangular-shape)

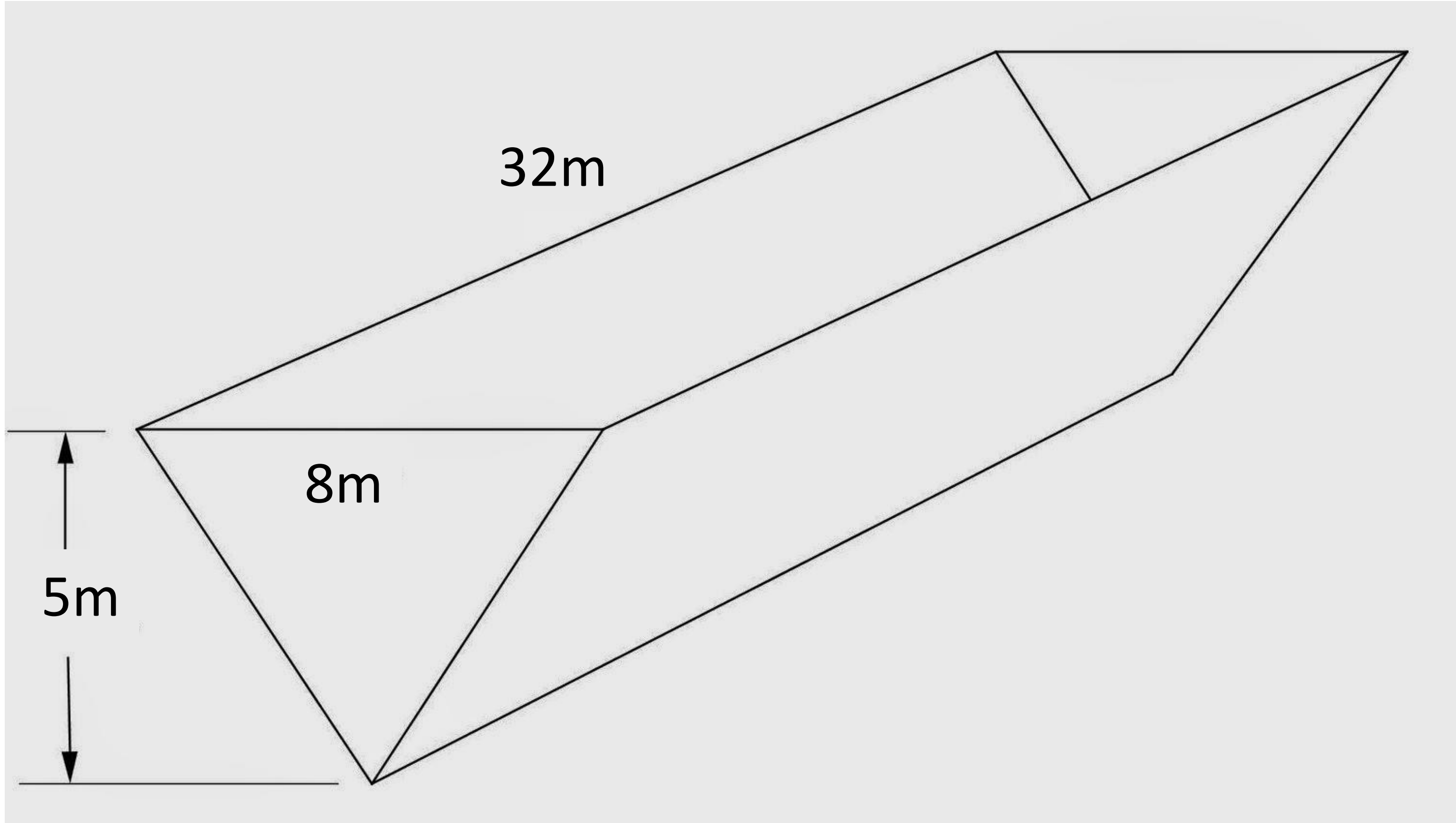
GM=KM-KG

KM=2.04m

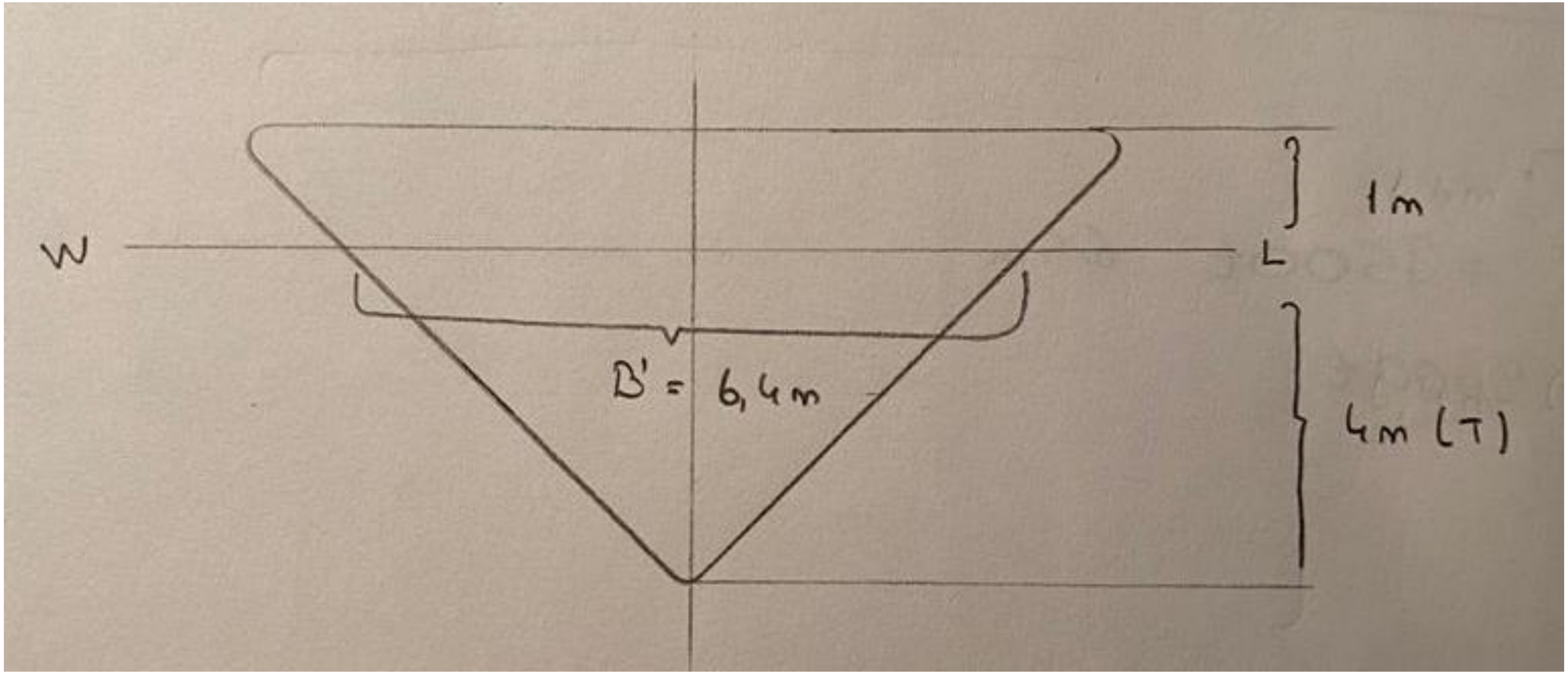
GM=2.04-1.5=+0.54m

Another example but «triangular shape»: Example 2

A vessel is in the form of a triangular prism 32 m long, 8 m wide at the top and 5 m deep. KG 3.7 m. Find the initial metacentric height when floating on even keel at 4 m draft.



If we proportion the beam depend to 4m of the draft then we find the beam about waterline is 6,4m.



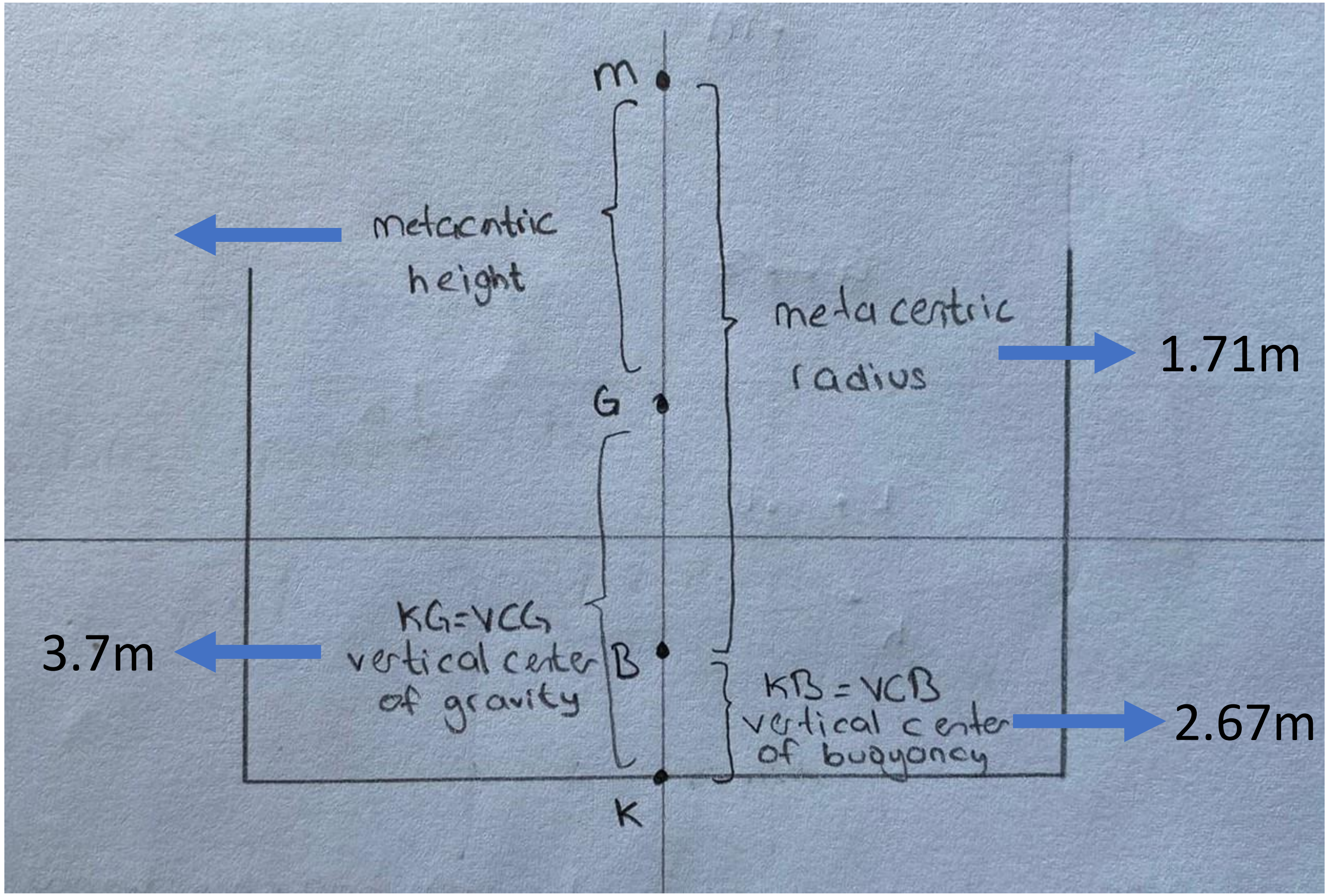
All the calculations will be the same except underwater volume. Since underwater volume is triangular, we are going to multiply ½ by volume.

$$BM = \frac{bh^3}{12V * 1/2} = \frac{LB^3}{6 * L * B * d} = \frac{B^2}{6d} = \frac{6.4^2}{6 * 4} = 1.71m$$

$$KB = d\frac{2}{3} = 4\frac{2}{3} = 2.67m$$

$$BM = \frac{bh^3}{12V * 1/2} = \frac{LB^3}{6 * L * B * d} = \frac{B^2}{6d} = \frac{6.4^2}{6 * 4} = 1.71m$$

(This formula is only for triangular-shape)



GM=KM-KG

KM=4.38m

GM=4.38-3.7=+0.68m

Metacentric Diagrams

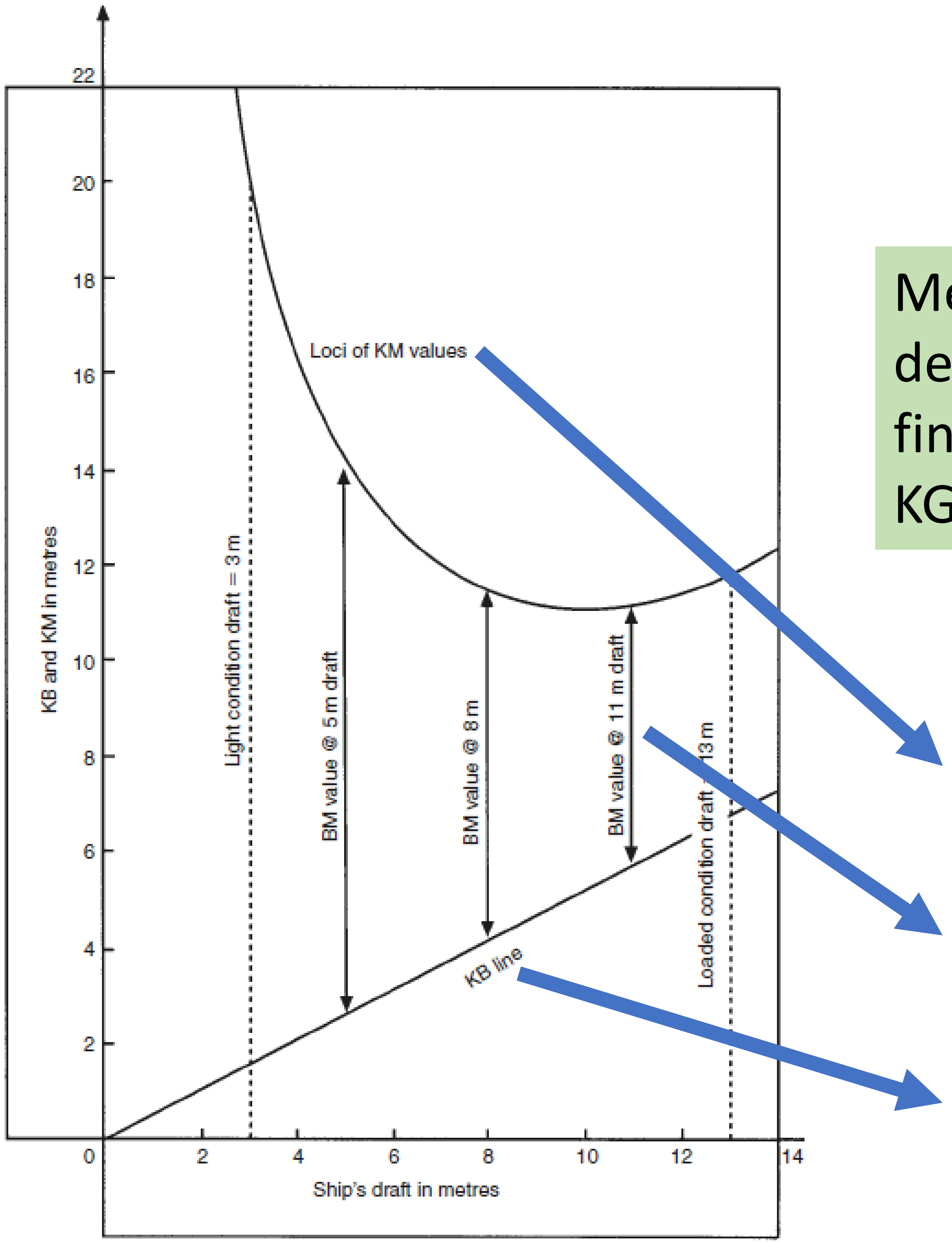


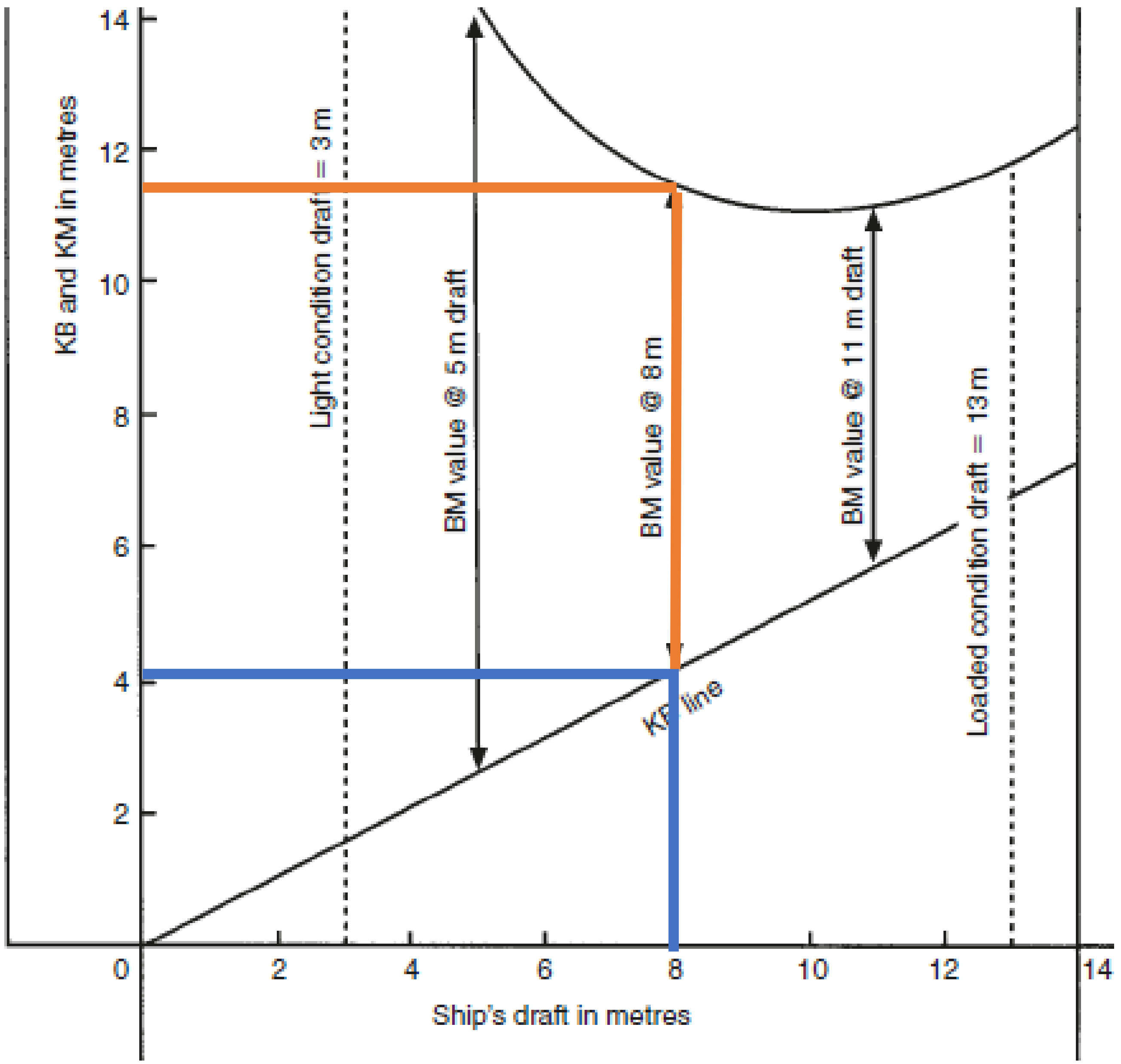
Fig. 12.5 Metacentric diagram for a ship-shaped vessel.

Metacentric diagrams are drawn by KB and KM values depend on a draft of the ship. As a chief officer, we can find the BM value and the GM value after finding the KG value with weights and moments calculations.

Graphic of KM values (it can ve read from left-scale).

Graphic of BM values (the distance between KM and KB graphics).

Graphic of KB values (it can ve read from left-scale).



For example,
KB value is ≈4,1m at 8m draft,
KM value is ≈11,5m at 8m draft,
thus
BM value is ≈7.4m.

GM can be calculated if we know KG.

I will not draw a diagram because it’s all about calculations and can be found in the book.

Example 3

Two box-shaped vessels are each 100 m long, 4 m deep, float at 3 m draft and have KG 2.5 m. Compare their initial Metacentric Heights if one has 10 m beam and the other has 12 m beam.

Situation 1: $BM = \frac{B^2}{12d} = \frac{10^2}{12*3} = 2.78$

$GM = KM - KG$

$GM = 2.78 + 1.5 - 2.5 = 1.78$

Situation 2: $BM = \frac{B^2}{12d} = \frac{10^2}{10*3} = 3.34$

$GM = KM - KG$

$GM = 3.34 + 1.5 - 2.5 = 2.34$

In situation 2 which when the beam is 12m, the initial metacentric height more than when the beam is 10m. That means a larger beam provides larger initial stability and smaller beam provides a smaller initial stability.

Final KG

GM should be determined after handling cargo. We learned how to find KM and BM. KG was given in the previous examples. It’s time to learn how to determine the final KG now. To calculate the final KG, weights and moments calculations are using.

$$Final\ KG = \frac{Final\ Moment}{Final\ Displacement}$$

Example 4

A ship of 6000 tonnes displacement kas KG=6m and KM=7.33m.

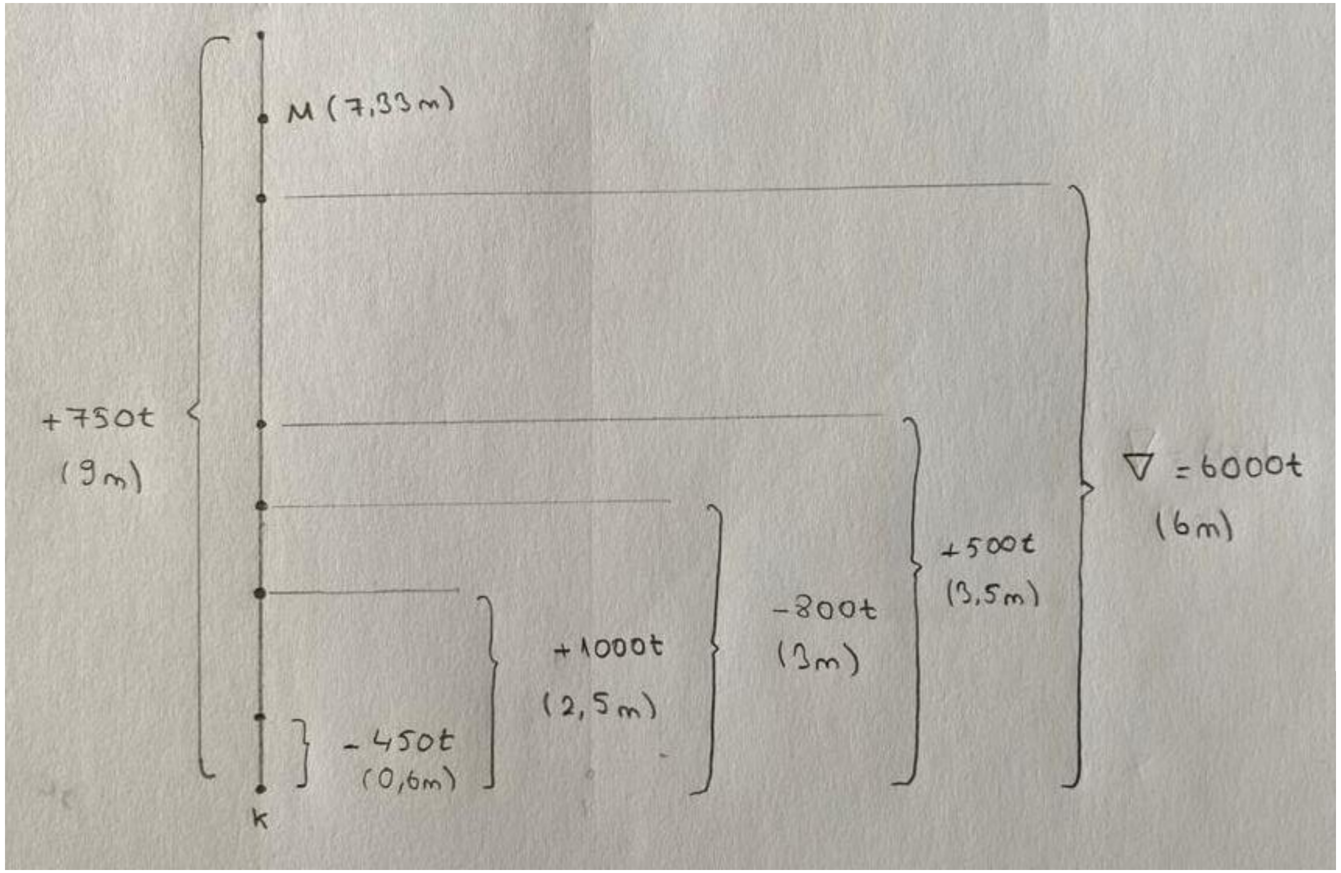
The following cargo is loaded:

1000t (KG=2.5m), 500t (KG=3.5m), 750t (KG=9m)

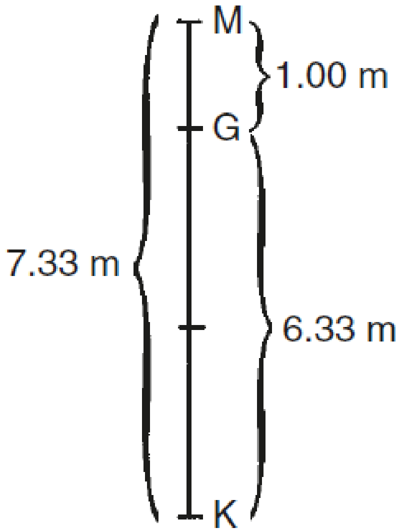
The following cargo is discharged:

450t (KG=0.6m), 800t (KG=3.0m)

What is the final GM?



Weight	*KG*	*Moment about the keel*
+6000	6.0	+36 000
+1000	2.5	+2500
+500	3.5	+1750
+750	9.0	+6750
+8250		+47 000
−450	0.6	−270
−800	3.0	−2400
+7000		+44 330



$$\text{Final KG} = \frac{\text{Final moment}}{\text{Final displacement}} = \frac{44\,330}{7000} = 6.33 \text{ m}$$

$$\text{GM} = \text{KM} - \text{KG}$$

$$\text{KM} = 7.33 \text{ m, as given}$$

$$\text{Final KG} = \underline{6.33} \text{ m, as calculated}$$

So we found the final KG and we already know KM, if we subtract 6.33 from 7.33, GM would be found as a +1m.

Example 8

A ship arrives in port with displacement 6000 tonnes and KG 6 m. She then discharges and loads the following quantities:

Discharge:
-1250 tonnes of cargo, KG 4.5 metres
-675 tonnes of cargo, KG 3.5 metres
-420 tonnes of cargo, KG 9.0 metres

Load:
-980 tonnes of cargo, KG 4.25 metres
-550 tonnes of cargo, KG 6.00 metres
-700 tonnes of bunkers, KG 1.0 metre
-70 tonnes of FW, KG 12.0 metres

During the stay in port 30 tonnes of oil (KG 1 m) are consumed. If the final KM is 6.8 m, find the GM on departure.

W	KG	M
+6000t	6m	+36000 tm
+980t	4.25m	+4165 tm
+550t	6m	+3300 tm
+700t	1m	+700 tm
+70t	12m	+840 tm
-1250t	4.5m	-5625 tm
-675t	3.5m	-2362 tm
-420t	9m	-3780 tm
-30t	1m	-30 tm
+5925t		+33208 tm

$$\text{Final } KG = \frac{33208\,tm}{5925\,t} = 5{,}6m$$

$$GM = KM - KG = 6{,}8 - 5{,}6 = 1{,}2m$$

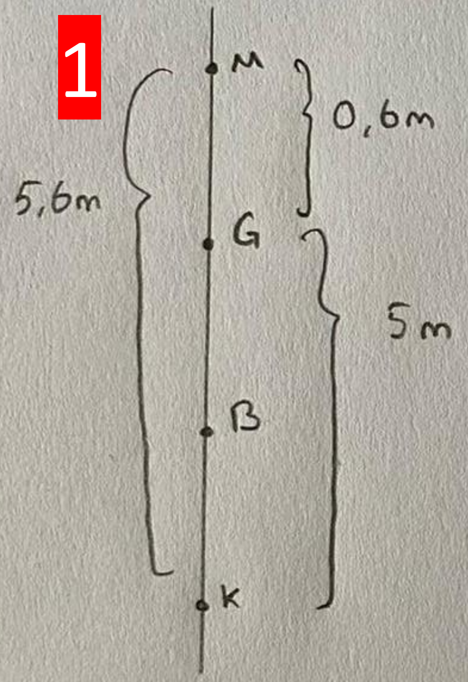
Example 9

A ship's displacement is 4500 tonnes and KG 5 m. The following cargo is loaded:

-450 tonnes of cargo, KG 7.5 metres
-120 tonnes of cargo, KG 6.0 metres
-650 tonnes of cargo, KG 3.0 metres

Find the amount of cargo to load in a tween deck (KG 6 m) so that the shipsails with a GM of 0.6 m. (The load KM is 5.6 m.)

1



2

W	KG	M
+ 4500t	5m	+ 22,500 tm
+ 450t	7,5m	+ 3375 tm
+ 120t	6,0m	+ 720 tm
+ 650t	3,0m	+ 1950 tm
+ x t	6.0m	+ 6x tm
(5720 + x) t		(28545 + 6x) tm

3

$$\text{Final KG} = 5\,m = \frac{(28545 + 6x)\ tm}{(5720 + x)\ t}$$

$$x = 55t$$

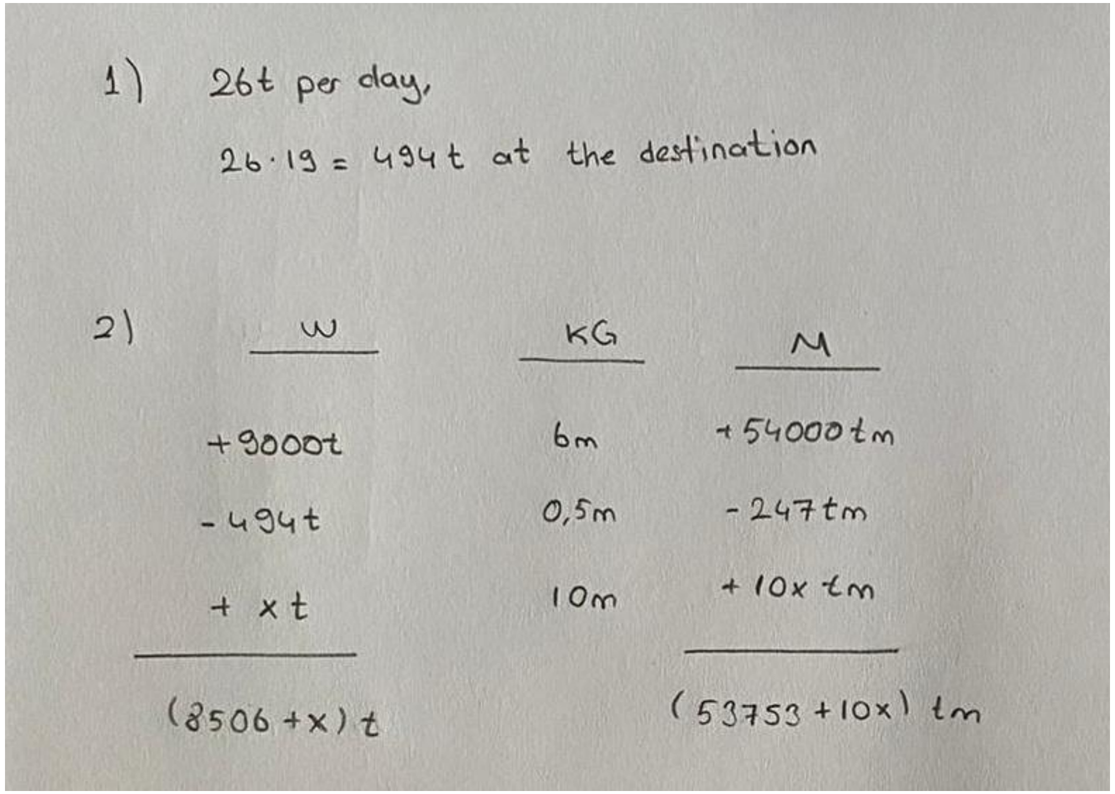
1 Find the final KG using the values given in questions.

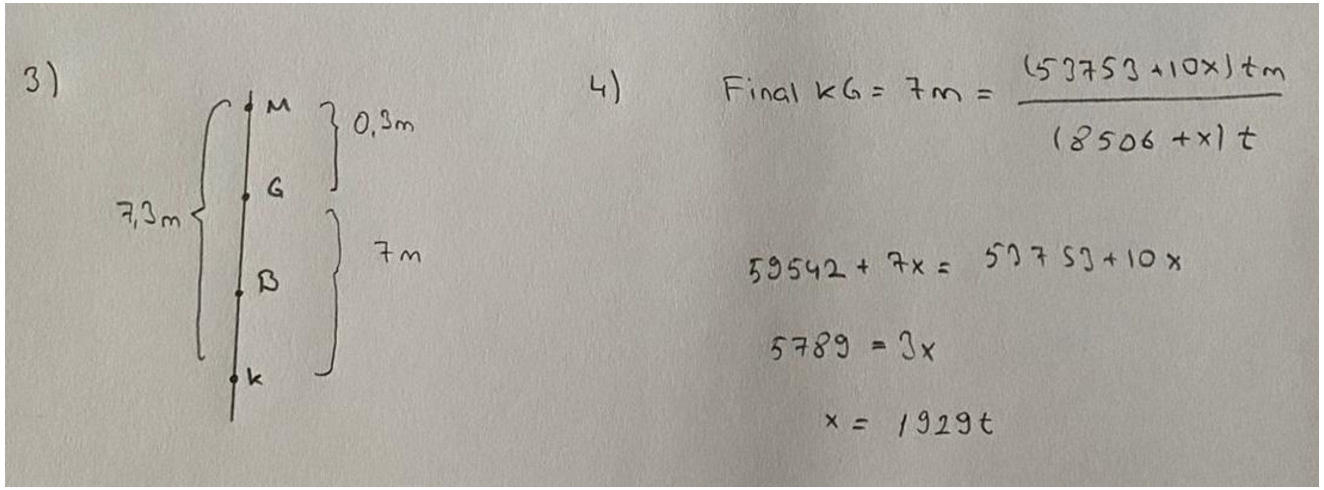
2 Weights and moments calculations with «x».

3 Find the x value using final KG.

Example 10

A ship is partly loaded and has a displacement of 9000 tonnes, KG 6 m, and KM 7.3 m. She is to make a 19-day passage consuming 26 tonnes of oil per day (KG 0.5 m). Find how much deck cargo she may load (KG 10 m) if the GM on arrival at the destination is to be not less than 0.3 m.

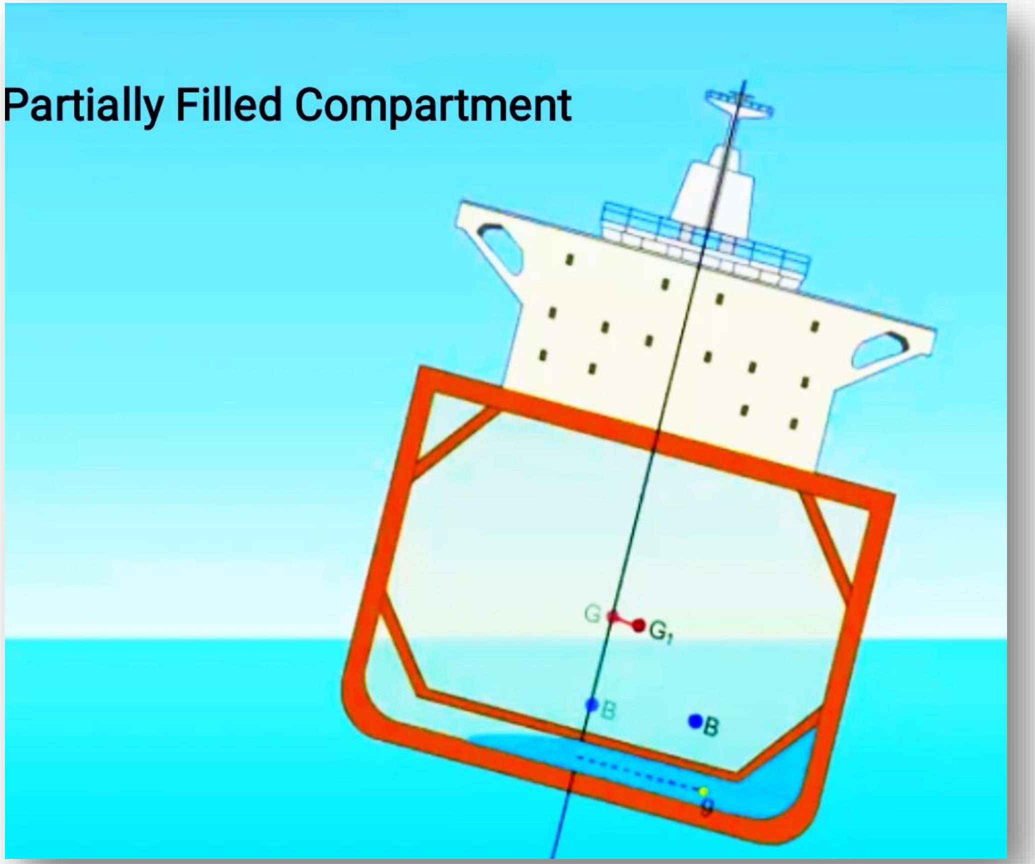




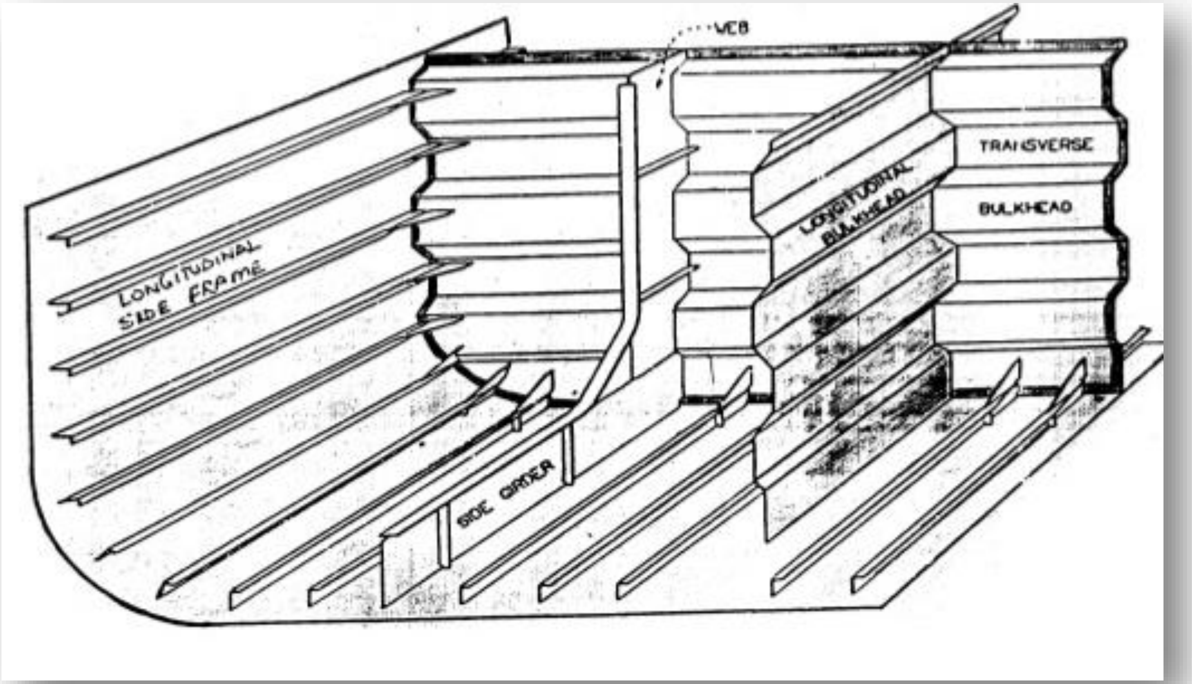
Twenty Reasons for A Rise in G

Since more metacentric height means more stability, master and mates need to be careful about the reasons rise G. It can even pass the M point and make the ship unstable.

1- Free-surface effects in partially filled tanks.



2- Collapse of a longitudinal division/bulkhead in a partially filled tank of liquid.



3- Icing up of superstructures.

4- Loading cargo in upper reaches of the vessel.

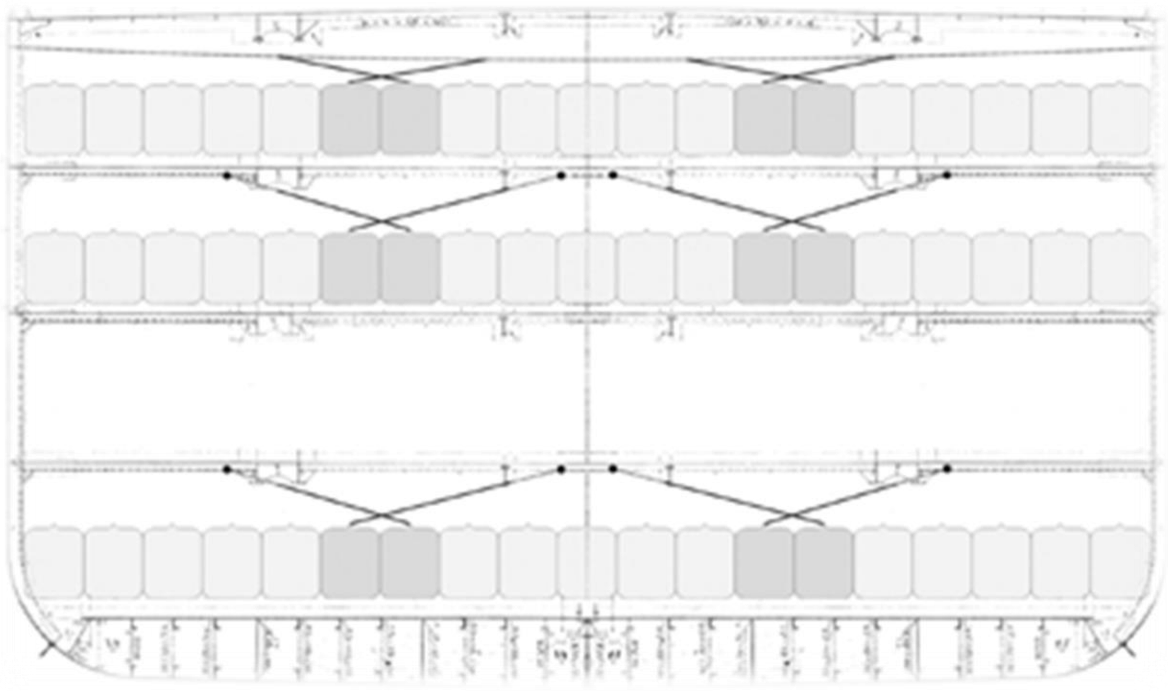
5- Water entering the ship through badly maintained hatches on upperdeck and flooding the tween decks.

6- Hatches or bow doors inadvertently left open on the main deck.

7- Water landing on the deck from the sea in heavy weather conditions.

8- Raising of a weight from a deck using a mast and derrick.

9- Raising a weight low down in the ship to a higher position within the ship.



10- Timber deck cargo becoming saturated due to bad weather conditions.

11- Vessel making first contact with keel blocks in a dry dock at the stern.

12- A ship's first contact with a raised shelf or submerged wreck.

13- The raising of the sails on a yacht.

14- A bilging situation, causing free-surface effects.

15- Passengers crowding on superstructure decks at time of departure or arrival.

16- Retrofits in accommodation decks and navigation spaces.

A collapse of grain-boards or fish-boards.

A blockage of freeing ports or scuppers on the upper deck.

Adding weight at a point above the ship's initial overall VCG.

Discharging a weight at a point belowthe ship's initial overall VCG.