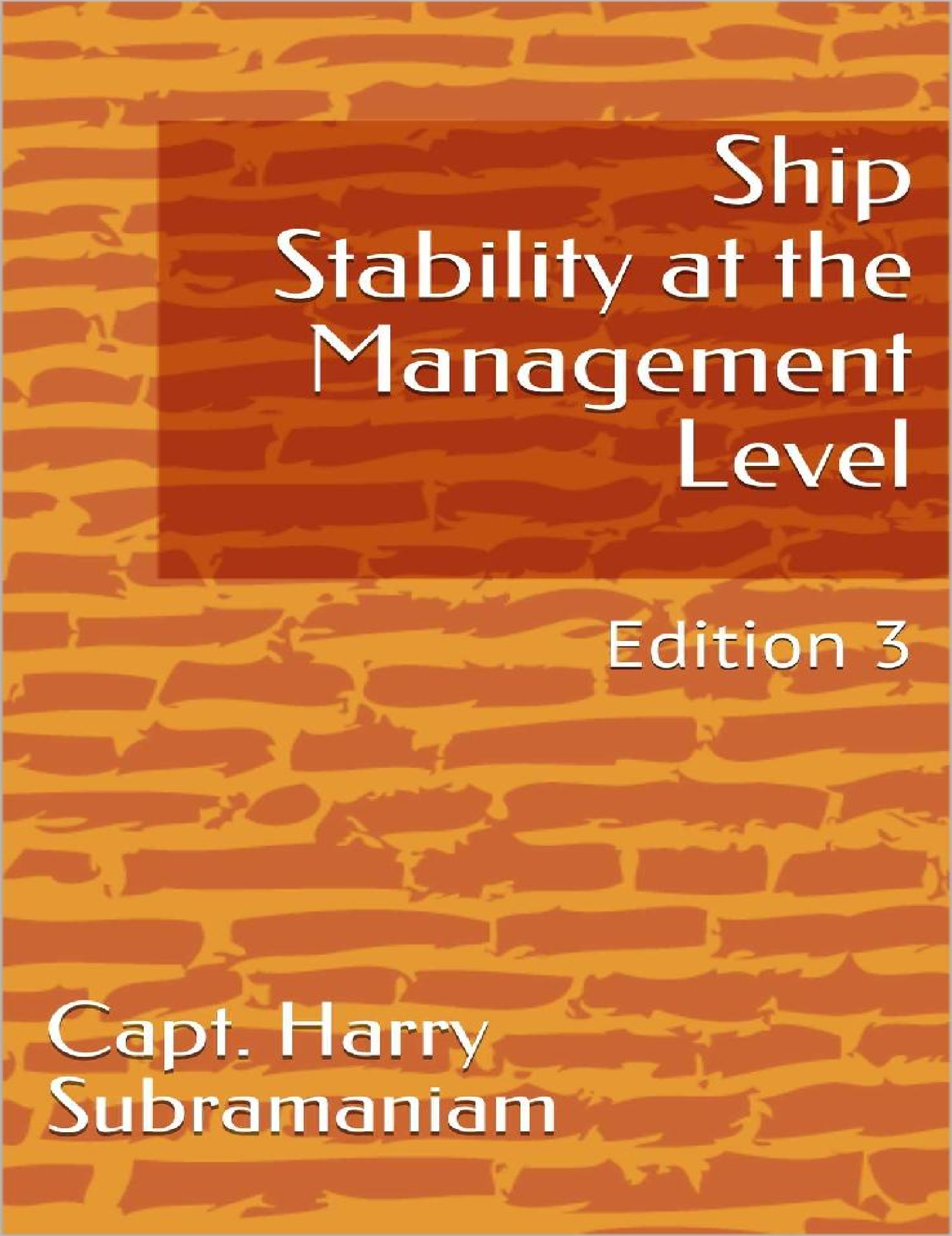

Ship Stability at the Management Level

Edition 3

Capt. Harry Subramaniam

SHIP STABILITY AT THE MANAGEMENT LEVEL

NUTSHELL SERIES

BOOK 6

BY

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DEDICATION

Mrs Vijaya Harry
11th April '26 -11th Jan '09
Founder, Vijaya Publications

Dedicated to my mother,
without whose patient and
constant encouragement,
this book would not have
been possible.

About the author

CAPT H SUBRAMANIAM

Born in Sept. 1942, Harry Subramaniam was educated in the Lawrence School, Lovedale, one of the best schools in India. He passed out of the Training Ship Dufferin in 1960 winning several prizes. He has about ten years of sea experience including Command of merchant ships. He has over fifty years of teaching experience at maritime training institutions and has thus been associated with all the four great nautical training institutions in Indian history - he was a cadet on T.S. Dufferin, the last Captain Superintendent of T.S. Rajendra, the first Captain Superintendent of T.S. Chanakya and Principal of L.B.S. College. He retired from Govt service in September 2002 after 34 glorious years including 12 years as head of maritime training institutions. He then sailed in command again for six months to satisfy himself that he was also a praticising Master, not merely a teaching Master! He has over three years of experience in making blended learning programmes with Executive Shipmanagement Co., Singapore, and ADUA in India. He is now a nautical training consultant in Mumbai. His achievements/distinctions include:

- Extra Master Certificate (UK).
- External Examiner of Masters & Mates for over forty years.
- The Chief Examiner of Extra Masters of India.
- Leader of the Indian delegation to the IMO on two occasions.
- Nautical Assessor in a formal investigation into a major ship collision.
- ‘Man of the year Award’ in 2001 by Sailor Today magazine for his ‘Conception and implementation of INDos (Indian National database of Seafarers)’.
- ‘Lifetime Achievement Award’ in 2002 by Marine World magazine.
- ‘Literary Distinction Award’ by Marex Bulletin in 2006.
- ‘Lifetime contribution to Maritime Training Award’ by GlobalMet in 2007.
- ‘Individual Innovation Award 2007’ by Sailor Today Magazine for the manner in which he conducted India’s first Maritime Quiz for Seafarers.
- ‘Outstanding Contribution to Maritime Education and Training Award’ by the Govt. of India on National Maritime Day 2013.
- Chairman of the Nautical Institute, India (West) Branch.
- Master (Chairman) of the Company of Master Mariners of India.

His qualifications, experience and devotion to teaching enable him to put each subject in a 'Nutshell'. All his books in the Nutshell Series have been great successes.

FOREWORD

Capt / Dr. P.S. VANCHISWAR
Ph. D., Extra Master

15th Feb 1986

Resident Professor,
World Maritime University,
Malmo, Sweden.

Enthusiasm, perseverance and dedication are the qualities that come to my mind when I think of Captain H. Subramaniam. Enthusiasm because of the way in which he goes about, not only his work, but also his ‘hobby’ of writing technical books! Perseverance because of his starting to write the next book as soon the earlier one is complete, thereby writing six books in less than ten years! Dedication to his work because he does not let his book writing interfere with his main occupation – teaching. In fact, I have heard from those who have had the good fortune to have been his students, that his dedication to teaching is total.

Capt. Subramaniam’s Nutshell Series of books are very popular today, especially among officers of developing countries, because of two reasons. Firstly, his books are written in simple, straightforward English. He has managed to avoid using difficult expressions and complex sentences. Secondly, he has maintained a practical approach throughout, bearing in mind the actual use to which the student can apply the knowledge gained from these books.

This book deals with the subject at the Management level. The author’s practical method of calculating the stability particulars of a ship in a damaged condition is unique. His chapter on stability of ships carrying bulk grain is certainly what a shipmaster needs to know. His decision to include chapters on shear force and bending moment, in this book on ship stability, will be welcomed by all students for the Certificates of Competency as Chief and Master F.G. The author’s expertise in teaching is clearly evident in this book.

I congratulate the author for his efforts and hope that he will continue to write on other maritime subjects.

(P.S. Vanchiswar)*

*Resident professor, World Maritime University, Malmo Sweden. Previously Nautical Adviser to the Govt. of India and Chief Examiner of Masters and Mates. Was Chairman of the Committee – "Master and Deck Department" – at the STCW Conference (1978) held by the International Maritime Organisation.

PREFACE

Ship Stability for mariners was formerly covered in three parts in ascending order - Navigational Watchkeeper, Chief Mate and Master.

The STCW Convention has only two categories of officers - Operational Level and Management Level. Hence the three volumes of Stability have been combined into two:

- 'Ship Stability I' second edition - was renamed 'Ship Stability at the Operational Level'. This has its original contents to which most of the contents of the erstwhile 'Ship Stability II' have been added at the end.
- 'Ship Stability III' third edition – renamed 'Ship Stability at the Management Level'. This has the original contents of Stability III to which the chapters carried over from Stability II have been added in the beginning. Eight new chapters have been added at the end, including Parametric Rolling, Squat, UKC and Draft Survey. These topics are important while complying with their ship owner's or ship operator's ISM manuals.

As far as possible, a practical approach has been maintained to enable ship's officers to put the knowledge to practical use on board ship.

Many Marine Engineers have thanked me saying that they found these stability books in the Nutshell Series very useful to them.

Mumbai (H. Subramaniam) 1st January 2011

Contents

1. COMBINED LIST AND TRIM

Sometimes, it may become necessary to cause a change of both, list and trim, by shifting fuel oil, FW, SW ballast or, as a last resort, by shifting cargo. In such cases, the problem could be split into two parts and each part may then be calculated separately, and in any order. In this book, change of list has been tackled first and then, change of trim. Having studied the earlier chapters on list and trim, you should find the calculations here, quite simple.

Example 1

A ship of W 8000 t, KM 8 m, KG 7.2 m and MCTC 150 tm, is listed 6° to port and trimmed 0.2 m by the head. You desire to bring the ship upright & trimmed 1 m by the stern by shifting heavy fuel oil between No: 2 DB tanks P & S and No: 6 DB tanks P & S. The COG of each tank is 8 m off the centre line of the ship. The distance between the centres of Nos: 2 & 6 tanks is 80 m. No: 2 DBT port and starboard have 300 t HFO each while No: 6 DBT port & starboard are empty. Find how much transfer of HFO should take place between the tanks and the final distribution.

(Neglect free surface correction).

To correct list

Tan θ = ILM / W.GM or ILM = W.GM.Tan θ

(ILM means Initial Listing Moment).

ILM = 8000 (0.8) tan 6° = 672.667 tm port.

To upright the vessel it is necessary to cause LM of similar value to starboard.

dw = 672.667 or w = 672.667 / 16 = 42 t.

Required to shift 42 t HFO to starboard.

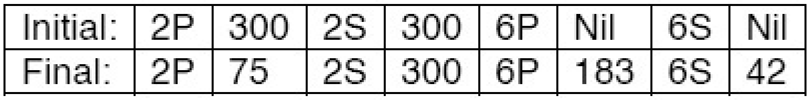
To change trim

<u>Present</u> trim: 0.2 m by head. <u>Desired</u>: 1 m by stern. So, Tc = 1.2 m = 120 cm by stern.

Tc = dw / MCTC **or** w = MCTC (Tc) / d

w = 150 (120) / 80 = 225 t HFO to go aft.

Final distribution in tonnes:



Initial:	2P	300	2S	300	6P	Nil	6S	Nil
Final:	2P	75	2S	300	6P	183	6S	42

Example 2

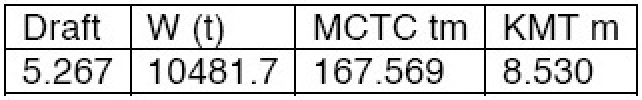
M.V. VIJAY, in SW drawing 4 m F & 6.6 m A, is listed 7° to port. KG = 8 m. How much HFO must be transferred between tank Nos: 2 P & S and 7 P & S to bring the ship upright & trimmed 1.2 m by the stern? The COG of the tanks are transversely 11 m apart & longitudinally 92 m. (Neglect free surface correction).

Fwd 4 m, aft 6.6 m, trim 2.6 m by stern.
Mean draft 5.3 m, for which AF = 71.800 m from hydrostatic table.

Corr = (AF / L) (trim) = (71.800 /140) (2.6) = 1.333 m

Initial hydraft = 6.6 – 1.333 = 5.267 m.

From hydrostatic table:



Draft	W (t)	MCTC tm	KMT m
5.267	10481.7	167.569	8.530

To correct list

Tan θ = ILM / W.GM **or** ILM = W.GM.Tan θ

ILM = 10481.7 (0.53) tan 7° = 682.105 tm

To upright the vessel it is necessary to cause LM of similar value to starboard.

dw = 682.105 **or** w = 682.105 / 11 = 62 t.

Required to shift 62 t HFO to starboard.

To change trim

Present trim: 2.6 m by stern. Desired: 1.2 m by stern. So, $T_c = 1.4$ m = 140 cm by head

$T_c = dw / MCTC$ **or** $w = MCTC (T_c) / d$

$T_c = 167.569 (140) / 92 = 255$ t.

Required to shift 255 t HFO aft to fwd.

Example 3

M.V. VICTORY is in DW, RD 1.015, drawing 12 m fwd & 14 m aft. KG is 12.6 m. The ship is listed 5° to starboard. Find how much oil transfer is required between the following tanks to bring the ship upright and trimmed 1 m by the stern: No: 2 P and S (HG 61 m fwd) and No: 5 P and S (HG 59 m aft). The COG of each tank is 16 m off the centre line of the ship. (Neglect free surface correction.)

Fwd 12 m, aft 14 m, trim 2 m by stern.

For mean draft 13.0 m, HF = 0.270 m aft from hydrostatic table.

$Corr = (HF / L) \times trim = (0.270 / 236) \times 2 = 0.002$ m

$Hydraft = 13 + 0.002 = 13.002$ m.

From hydrostatic table:

	Draft	W (t)	MCTC tm	KMT m
SW	13.002	84853.1	1159.167	13.180
DW	13.002	84025.2	1147.858	13.180

$GM = 13.180 - 12.600 = 0.580$ metre.

To correct list

$\tan \theta = ILM / W.GM$ or $ILM = W.GM.\tan \theta$

$ILM = 84025.2 (0.58) \tan 5° = 4263.7$ tm.

To upright the vessel it is necessary to cause LM of similar value to port.

$dw = 4263.7$ **or** $w = 4263.7 / 32 = 133.2$ t

Required to shift 133.2 t HFO to port.

To change trim

Present trim: 2.0 m by stern. Desired: 1.0 m by stern. So, Tc = 1.0 m = 100 cm by head

Tc = dw / MCTC **or** w = MCTC (Tc) / d

Tc = 100 (1147.858) / 120 = 956.5 t.

Required to shift 956.5 t HFO forwards.

Exercise 1
(Combined list & trim)

1. A ship of W 15,000 t, KM 9 m, KG 8 m, MCTC 200 tm, is listed 6° to port and trimmed 3 m by the stern. What oil transfer must take place between Nos: 3 P & S and Nos: 8 P & S to bring the V/L upright & trimmed 2 m by the stern? The COG of the tanks are transversely 10 m apart and longitudinally, 100 m.
(Neglect free surface correction).
Answer: 157.70 t to stbd, 200 t fwd.

2. A tanker of W 50,000 t, MCTC 650 tm, KM 11 m, KG 10.1 m, listed 7° to port and trimmed 5 m by the stern. Find the transfer of oil that must take place between Nos: 10 P & S and Nos: 2 P & S to bring the ship upright and trimmed 3 m by the stern. The COG of the tanks are transversely 14 m apart & longitudinally 140 m apart. (Neglect FSC).
Answer: 394.7 t to stbd, 928.6 t fwd.

3. M.V. VIJAY is upright in SW drawing 5.6 m fwd & 6.8 m aft. KG 7.16 m. Find how much oil transfer must take place between Nos: 2 P & S and Nos: 7 P & S, in order to list the ship 5° to port and bring it on an even keel. The COG of the tanks are transversely 10 m apart and longitudinally, 90 m.
(Neglect free surface correction).
Answer: 112.3 t to port, 232.7 t fwd.

4. M.V. VICTORY is in DW RD 1.009, drawing 13.6 m fwd & 12.6 m aft. KG 12.647 m. The ship is listed 8° to starboard. Find the oil transfer to be made between the following tanks to bring the ship

upright and trimmed 0.5 m by the stern: Nos: 2 P & S (HG 61 m fwd) & Nos: 5 P & S (HG 59 m aft). The COG of each tank is 16 m off the centre line.
(Neglect free surface correction).
Answer: 198.9 t to port, 1430.30 t aft.

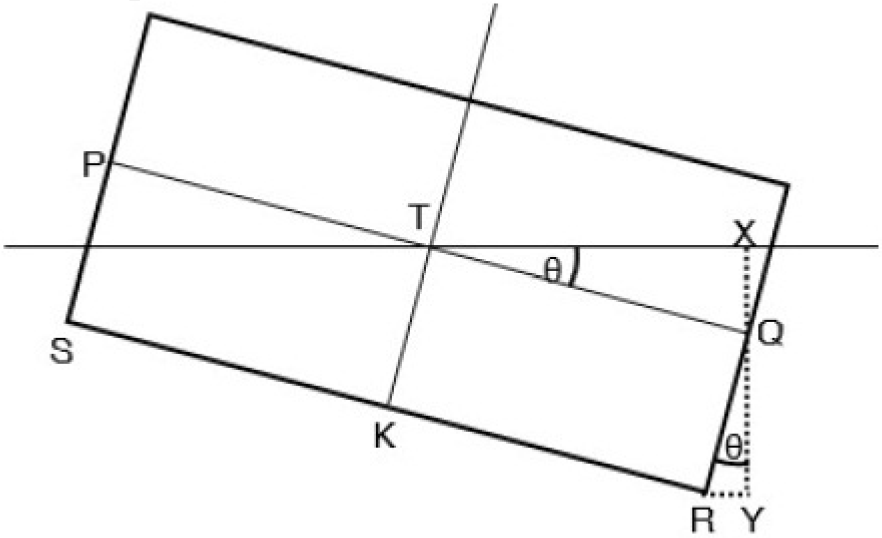
5. M.V. VIJAY is in DW, RD 1.017, drawing 7 m fwd & 6 m aft, listing 5° to port. KG is 7.4 m. How much FW must be transferred between the peak tanks (COG 132 m apart) and HFO between Nos: 2 P and S (COG 10 m apart) to bring the ship upright and trimmed one metre by the stern? (Ignore FSC)
Answer: 82.60 t to stbd, 266.6 t fwd.

-o0o-

2. DRAFT INCREASE DUE TO LIST

Draft is the depth of the lowest part of the ship below the waterline. When the vessel lists, the draft increases. Calculation of this increase can be done by simple trigonometry.

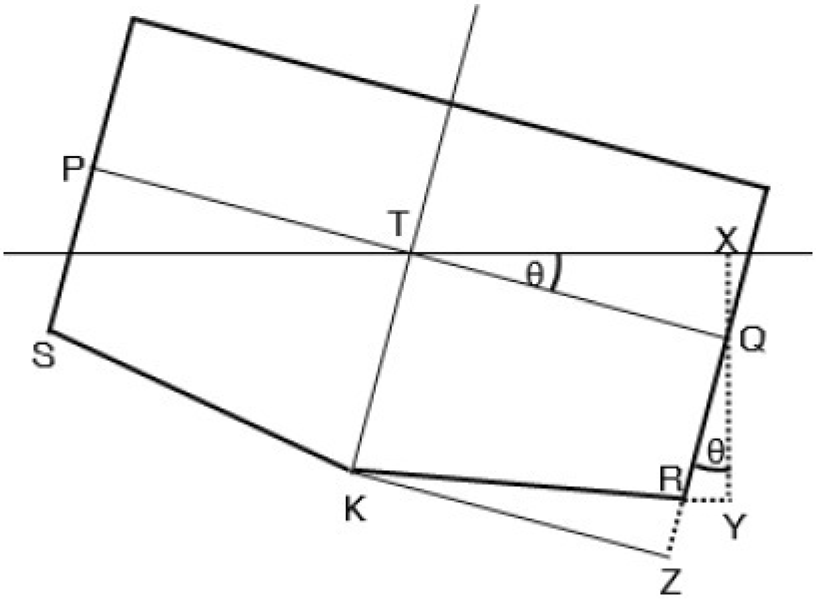
Box-shaped vessel



New d = XY = XQ + QY = TQ Sin θ + QR Cos θ
New d = Half beam Sin θ + old draft Cos θ

Ship-shapes

The amidships section of a ship resembles that of a box-shaped vessel except that the ship usually has a rise of floor. Rise of floor is the vertical distance between the keel and the bilge when the ship is upright. When pumping out a tank, rise of floor helps drain the liquid towards the suction pipe which is situated near the centre line of the ship.



New d = XY = XQ + QY = TQ Sin θ + QR Cos θ
= TQ Sin θ + (QZ – RZ) Cos θ

New d = Half beam Sin θ + (old d – R) Cos θ
(Where R = rise of floor of ship).

Note: Where there is no rise of floor, zero may be substituted in the foregoing formula which then becomes the same as the earlier formula.

Example 1

A box-shaped vessel 10 m broad floats upright & on an even keel draft of 6 m. Find the increase in draft if the vessel lists 15°.

New draft = Half beam Sin θ + old draft Cos θ

New draft = (5 Sin 15°) + 6 Cos 15° = 7.09 m

Increase of draft = 7.09 – 6.0 = 1.090 metres.

Example 2

A ship 18 m broad at the waterline is upright & floats at 8 m draft even keel. Rise of floor is 0.310 m. Find the new draft if the ship lists 12°.

New d = Half beam Sin θ + (old d – R) Cos θ

New d= 9 Sin 12° + (8 - 0.31) Cos 12°

New d = 9.393 metres.

Exercise 2

(Draft increase due to list)

1. A box shaped vessel, 100 x 20 x 8 m, floats upright at 5 m draft. Find the new draft if the vessel lists 16°. **Answer**: 7.563 m.

2. A ship, 32 m broad at the waterline, is upright and draws 12.3 m. The rise of floor is 0.34 m. Find the new draft at 15° list. **Answer**: 15.964 m.

3. A box-shaped vessel, 27 m broad, is upright at 9.00 m draft, in DW of RD 1.016. Find the increase in draft when listed 12°. **Answer**: 2.610 m

4. A ship 18 m broad is upright and draws 8.6 m in FW. The rise of floor is 0.15 m. Find the new draft when listed 18°. **Answer**: 10.818 m.

5. A flat bottomed barge is 12 m broad at the waterline and is upright. The draft is 5 m in SW. Find the increase in draft when listed 13°. **Answer**: 1.222 m.

-o0o-

3. DRY DOCKING AND GROUNDING

When a ship enters a graving type dry dock, she should be in stable equilibrium, upright and trimmed slightly by the stern. As far as possible, all tanks should be either empty or pressed up so as to reduce FSE to the barest minimum possible under the circumstances.

When the gate is closed and pumping out commences, the water level in the dock will drop gradually. Side shores consisting of large baulks of timber will be positioned loosely between the ship's sides and the sides of the dock, by shore personnel, at intervals of about five metres.

As the lower end of the stern frame nears the blocks, the rate of pumping will be reduced suitably while the ship is correctly positioned and aligned over the keel blocks. After the stern takes to the blocks, pumping out is continued. As the forward end nears the blocks, the side shores are wedged up tight, working from the after end towards forward, so that, by the time the bow also takes to the blocks, all the side shores would be tight thereby aligning the ship correctly over the keel blocks and preventing it from capsizing.

Until the stern has taken to the blocks, the ship is floating freely. Whatever trim, GM, etc. that it had while entering the dock will be unaffected until the stern touches the keel blocks. After the stern has taken to the blocks, part of the weight of the ship gets transferred to the blocks, say 'P' tonnes. This is equivalent to the discharge of weight from the location of the stern frame - both KG and AG of the discharged weight are zero metres. This results in:

(a) Decrease in the hydraft of the ship.

(b) Decrease in the trim by the stern.

(c) Virtual rise of COG of the ship and consequent virtual loss of GM.

The value of 'P' at the stern frame increases as the water level drops, until the bow also takes to the blocks. Thereafter, P acts along the entire keel and not only at the stern frame.

The interval, from the instant the stern takes to the blocks till the instant the bow also takes to the blocks, is called **the critical period**. This is because, during this period, the ship suffers steadily increasing virtual loss of GM, without the benefits of the side shores. The most dangerous time is at the end of the critical period, called the critical instant, when P, acting at the stern frame only, is maximum while the side shores are all not yet wedged tight.

Calculation of P

(1) During the critical period:

During the critical period, the force P acts only at the after perpendicular of the ship. So, its distance from the COF is the AF of the ship.

Trim in cm = TM / MCTC

Trim in cm = P**.** AF / MCTC

P = trim . MCTC / AF

(2) After the critical period:

After the ship has taken to the blocks at both ends, further drop in the level of water would cause further transfer of weight to the keel blocks but this would act all along the ship's length and not only at the stern frame. This increase of P, after the critical period, may be calculated by multiplying the drop in water level after the critical period by the TPC. The results obtained by this method are approximate as TPC of a ship is not constant but changes with draft.

(3) At any time:

Obtain the ship's displacement while entering the drydock – W1. At any time during the drydocking process, whether during the critical period or afterwards, obtain the hydraft and thence the displacement – W2. Then, at that time, P = W1 – W2 tonnes. The results obtained by this method are fairly accurate.

Virtual loss of GM

The virtual loss of GM, at any time during the process of drydocking, may be calculated by either of two formulae:

Formula	A	or	B
Virtual loss of GM = (in metres)	$\frac{P . KG}{W - P}$		$\frac{P . KM}{W}$

In both these formulae, the values of W and KG are those that the ship had while entering the drydock. Whenever sufficient data is available, the KM used should be that for the reduced displacement, (W – P). If sufficient data is not available, then the value of KM in formula B may be taken to be that with which the ship entered the drydock. Both formulae give fairly close results.

Formula A assumes that P is a transfer of weight to the keel blocks equivalent to the discharge of weight from the keel resulting in a virtual increase of KG. It is derived from the vertical GG_1 formula.

Formula B assumes that P is a transfer of buoyancy to the keel blocks resulting in a decrease of KM while the weight and KG remain constant.

While calculating the moment of statical stability (righting moment), at small angles of inclination during the drydocking process - multiplying W by GM.Sin θ - the displacement used in formula A should be (W – P) and in formula B, the original W. The GM used in both cases should be the virtual GM.

The virtual loss of GM, as calculated by the foregoing formulae, is approximate only. Therefore, the only practical solution, available to the Master/Chief Officer, is to ensure that the residual virtual GM at the critical instant, arrived at by using these formulae, is sufficiently large to accommodate the possible inaccuracy.

The calculation need only be done using either formula A or formula B. For illustration purposes, each example has been worked twice in this book, once with formula A and again with formula B.

Free surface correction

During the critical period FSC increases and may be calculated by the formula:

$FSC = FSM / (W - P)$, where FSM is in tm.

Once the ship is wedged up tight in drydock, without any possibility of roll, FSE ceases to exist. Hence, after the critical period is over, FSE may be ignored. However, if the ship is aground, she may roll due to wave action even though she may be sitting overall on the sea-bed. In such a case, FSE cannot be ignored – FSC must be applied.

Example 1

M.V. VIJAY enters a SW drydock drawing 3 m fwd and 5.2 m aft. KG 9 m, FSM 1200 tm. Calculate the virtual GM and the moment of statical stability at 0.5° heel, when she is just about to take to blocks fwd.

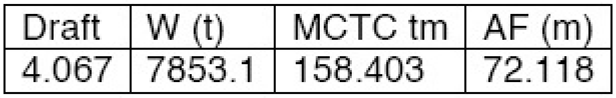
Fwd 3.0 m aft 5.2 m, trim 2.2 m by the stern

Mean draft 4.1 m for which AF = 72.113 m from the hydrostatic table.

$Corr = (AF / L)\ trim = (72.113 / 140)\ (2.2) = 1.133$ m

Initial hydraft $= 5.20 - 1.133 = 4.067$ m

From hydrostatic table:



Draft	W (t)	MCTC tm	AF (m)
4.067	7853.1	158.403	72.118

To find P and GM at the critical instant

$Trim\ in\ cm = TM / MCTC$

$Trim\ in\ cm = P.\ AF / MCTC$

$P = trim\ .\ MCTC / AF$

$P = 220\ (158.403) / 72.118 = 483.2$ tonnes

(W – P) = 7853.1 – 483.2 = 7369.9 t,
for which KM from hydrostatic table = 9.887 m

GM = KM – KG = 9.887 – 9.000	0.887 m
FSC = FSM/(W–P) = 1200/7369.9	0.163 m
GM fluid	0.724 m

Formula	A	or	B
Virtual loss of GM = (in metres)	$\frac{P \,.\, KG}{W - P}$		$\frac{P \,.\, KM}{W}$

	A	B
Virtual loss of GM	$= \frac{483.2\,(9)}{7369.9}$	$\frac{483.2(9.887)}{7853.1}$
Virtual loss of GM	= 0.590 m	= 0.608 m
GM fluid	= 0.724 m	= 0.724 m
Virtual GM	= 0.134 m	= 0.116 m

	Formula A	Formula B
RM @ 0.5°	(W–P)GM.Sin θ	W.GM.Sin θ
	= 8.618 tm	= 7.950 tm

Example 2

M.V. VIJAY has W = 7277 t in SW, KG = 9.1 m. Find the maximum trim with which she may enter drydock, if the virtual GM at the critical instant is to be not less than 0.25 metre.

From hydrostatic table

W (t)	MCTC tm	AF (m)	KM (m)
7277	156.0	72.141	9.950

Initial GM solid = 9.95 – 9.10	= 0.850 m
Minimum desired virtual GM	= $\underline{0.250}$ m
Permitted virtual loss of GM	= 0.600 m

	Formula A	Formula B
Virtual loss of GM	$= \frac{P.\ KG}{W - P}$	$\frac{P.\ KM}{W}$

0.6	$= \frac{P\ (9.1)}{W - P}$	$\frac{P\ (9.95)}{7277}$
Maximum P	= 450.1 t	438.8 t

Maximum trim	$\frac{P.\ AF}{MCTC}$	$\frac{P.\ AF}{MCTC}$
	$\frac{450.1(72.141)}{156}$	$\frac{438.8(72.141)}{156}$
Maximum trim	208.1 cm	202.9 cm

Note: Due to the nature of the problem, the value of P is available only towards the end of the calculation. Hence the KM used is for the original displacement (W) not for the reduced displacement (W – P). In reality, the KM for (W – P) would be more than the KM used above and hence the maximum safe trim would be more than the value calculated here. The error is thus on the safer side.

Example 3

M.V. VIJAY is at anchor drawing 4.9 m fwd and 6.7 m aft in SW. KG 7 m, FSM 1100 tm. During low water, the depth of water around the ship is expected to drop to 5.5 m. Assuming that the sea-bed is horizontal, find the virtual GM at LW.

Fwd 4.9 m aft 6.7 m, trim 1.8 m by the stern.

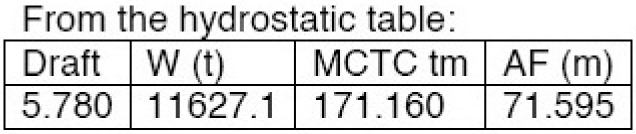
Mean draft 5.8 m for which AF = 71.586 m from the hydrostatic table.

Corr = (AF / L) trim = (71.586 / 140) 1.8 = 0.920 m

Initial hydraft = 6.70 – 0.920 = 5.780 m

Note: An interesting case develops here. At LW, when the depth of water becomes 5.5 m, if the ship is sitting overall on the sea-bed, then the hydraft of the ship would be 5.5 m, for which the displacement (W - P), and KM, can be obtained from the hydrostatic table. On the other hand, if at LW the ship is not sitting overall on the sea-bed, the aft draft would have reduced from 6.7 m to 5.5 m as a result of mean rise and the after proportion of trim (Ta). In such a case, the hydraft at LW would be < 5.5 m. The correct situation can be assessed by a simple calculation.

From the hydrostatic table:



From the hydrostatic table:

Draft	W (t)	MCTC tm	AF (m)
5.780	11627.1	171.160	71.595

To sit overall, P = (trim x MCTC) / AF

P = 180 (171.16) / 71.595 = 430.3 t

(W – P) = (11627.1 – 430.3) = 11196.8 t,
for which hydraft as per hydrostatic table = 5.588 m

The hydraft when sitting overall on the sea-bed will be 5.588 m. In other words, the depth of water at which the ship would sit overall on the sea-bed is 5.588 m. The depth at LW is 5.5 m. So, at LW, the ship is sitting overall and the hydraft then is 5.5 m, for which the displacement = 11000 t and KM = 8.417 m.

At LW, P = 11627.1 – 11000	= 627.1 t
GM solid = 8.417 – 7.0	= 1.417 m
FSC = FSM ÷ (W – P)	= 0.100 m
GM fluid	= 1.317 m

	Formula A	Formula B
Virtual loss of GM	$= \frac{P.\ KG}{W - P}$	$\frac{P.\ KM}{W}$
	$= \frac{627.1\ (7)}{11000}$	$\frac{627.1\ (8.417)}{11627.1}$

Virtual loss of GM	= 0.399 m	or 0.454 m
GM fluid	= 1.317 m	1.317 m
Virtual GM	= 0.918 m	or 0.863 m

Example 4

M.V. VIJAY enters a SW drydock drawing 3.6 m fwd and 5.8 m aft. KG 8.2 m, FSM 1000 tm. Find the virtual GM when the water level has dropped by 1 m after the stern has taken to the blocks.

Fwd 3.6 m aft 5.8 m, trim 2.2 m by the stern

Mean draft 4.7 m for which AF = 71.992 m from hydrostatic table.

Corr = (AF / L) x trim = 71.992 (2.2) / 140 = 1.131 m

Initial hydraft = 5.80 – 1.131 = 4.669 m

Note: When the stern takes to the blocks, the depth of water above the blocks will be 5.8 m. After a fall of 1 m in level, if the ship is sitting overall on the blocks, the hydraft will be 4.8 m. If, however, after the 1 m drop in level, the bow is still afloat, the hydraft will be < 4.8 m. The actual situation can be ascertained by a simple calculation.

Draft	W (t)	TPC)t)	MCTC (tm)	AF (m)
4.669	9164.1	21.918	163.252	71.998

To sit overall

P = (trim x MCTC) / AF= 220(163.252) / 71.998 = 498.8 t

(W – P) = (9164.1 – 498.8) = 8665.3 t,
for which hydraft as per hydrostatic table = 4.441 m

The depth of water above the blocks, at the given time, is 4.8 m. Therefore, the ship is still in the critical period. The draft aft has reduced from 5.8 m to 4.8 m as a result of mean rise and the after proportion of trim (Ta).

Decrease of draft aft = mean rise + Ta

100 = P / TPC + (AF / L) Tc

100 = P / 21.918 + P (71.998 / 163.252) 71.998 / 140
P = 367.1 t. (W – P) = 8797 t for which, from the hydrostatic table, KM = 9.086 m

GM solid = 9.086 – 8.200	= 0.886 m
FSC = FSM / (W – P)	= $\underline{0.114}$ m
GM fluid at required time	= 0.772 m

	Formula A	Formula B
Virtual loss of GM	$= \frac{P\ .\ KG}{W - P}$	$\frac{P\ .\ KM}{W}$
	$= \frac{367.1(8.2)}{8797}$	$\frac{367.1(9.086)}{9164.1}$

Virtual loss of GM	= 0.342 m	0.364 m
GM fluid	= $\underline{0.772}$ m	$\underline{0.772}$ m
Virtual GM	= 0.430 m	0.408 m

Example 5

M.V. VIJAY has W = 6849 t in SW, KG = 9.6 m, FSM = 900 tm. Find the maximum trim with which she may enter a drydock, if the GM at the critical instant is to be not less than 0.3 metre.

Note: This example is similar to example 2 but for one difference. Here, FSM has been given and has to be allowed for in the calculation.

W (t)	Draft (m)	TPC (t)	MCTC (tm)	AF (m)	KM (m)
6849	3.60	21.36	154.1	72.141	10.274

Initial GM = 10.274 – 9.600	= 0.674 m
Virtual GM @ critical instant	= 0.300 m
Permitted total loss of GM	= 0.374 m

Total loss of GM = FSC + loss due to P

Therefore 0.374 = FSM /(W – P) + drydocking loss

By formula A:
0.374 = 900 / (6849 - P) + P. KG / (W – P)

0.374 = 900 / (6849 – P) + P (9.6) / (6849 – P)

So, **P = 166.6 t**

Trim = 166.6 (72.141) / 154.1 = **78.0 cm**

By formula B:
0.374 = 900 / (6849 – P) + P. KM / W

0.374 = 900 / (6849 – P) + P (10.274) / 6849

So, **P = 159.6 t**

Trim = 159.6 (72.141) / 154.1 = **74.7** cm

Example 6

While drawing 3 m fwd and 7 m aft in SW, M.V. VIJAY runs aground lightly on a sandy coast. External soundings indicate that the depth of water near the after perpendicular is 2 m greater than near the fwd perpendicular. If KG is 8.1 m and FSM is 1200 tm, find (a) the drop in water level at which the ship would sit overall on the sea-bed;

(b) the virtual GM when the ship sits overall on the sea-bed; (c) The drop in water level at which the ship would become unstable.

Note: When sitting overall on the sea-bed, the trim would be 2 m by the stern.

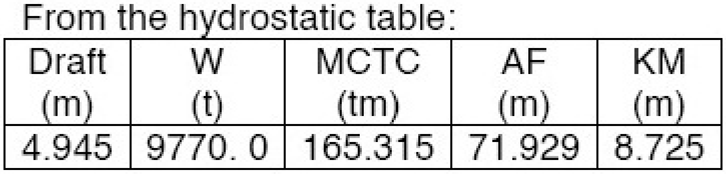
Fwd 3.0 m aft 7.0 m, trim 4.0 m by the stern

Mean draft 5.0 m for which AF = 71.913 m from the hydrostatic table.

Corr = (AF / L) trim = (71.913 / 140) (4.0) = 2.055 m

Initial hydraft = 7.00 – 2.055 = 4.945 m

From the hydrostatic table:



From the hydrostatic table:

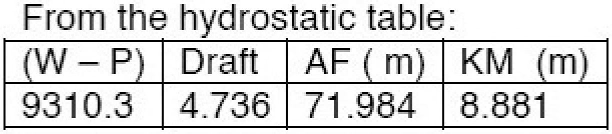
Draft (m)	W (t)	MCTC (tm)	AF (m)	KM (m)
4.945	9770. 0	165.315	71.929	8.725

Initial trim 4 m by stern. Final trim 2 m by the stern. So, Tc = 2 m by the head.

Tc = (P. AF) / MCTC or P = Tc (MCTC) / AF

P = 200 (165.315) / 71.929 = 459.7 tonnes

From the hydrostatic table:



From the hydrostatic table:

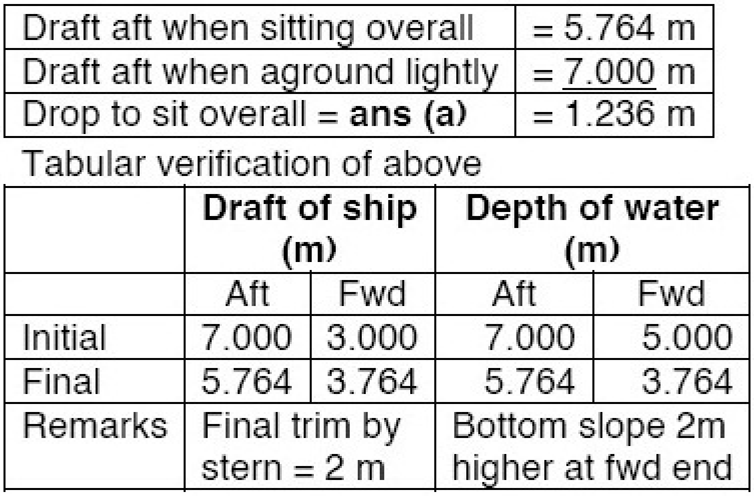
(W – P)	Draft	AF (m)	KM (m)
9310.3	4.736	71.984	8.881

Hydraft when sitting overall = 4.736 m and trim = 2 m by the stern. Draft aft =?

Ta = (AF / L) Tc = (71.984 / 140) 2 = 1.028 m

Draft aft = 4.736 + 1.028 = 5.764 m.

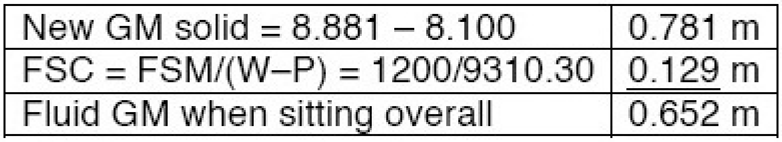
Draft fwd = 5.764 – 2.000 = 3.764 m.



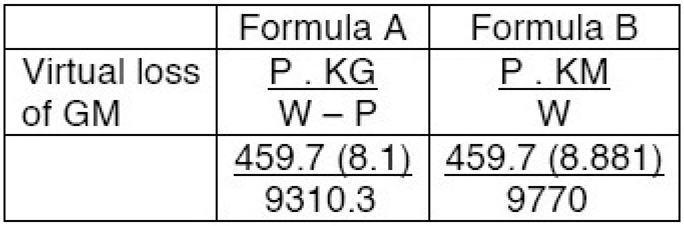
Draft aft when sitting overall	= 5.764 m
Draft aft when aground lightly	= 7.000 m
Drop to sit overall = **ans (a)**	= 1.236 m

Tabular verification of above

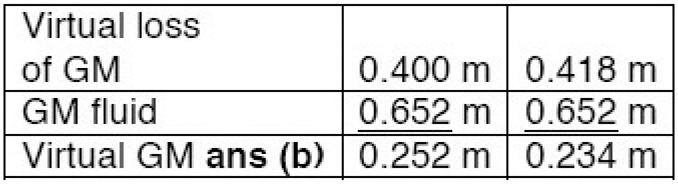
	Draft of ship (m)		**Depth of water (m)**	
	Aft	Fwd	Aft	Fwd
Initial	7.000	3.000	7.000	5.000
Final	5.764	3.764	5.764	3.764
Remarks	Final trim by stern = 2 m		Bottom slope 2m higher at fwd end	



New GM solid = 8.881 – 8.100	0.781 m
FSC = FSM/(W–P) = 1200/9310.30	0.129 m
Fluid GM when sitting overall	0.652 m



	Formula A	Formula B
Virtual loss of GM	$\frac{P . KG}{W - P}$	$\frac{P . KM}{W}$
	$\frac{459.7 (8.1)}{9310.3}$	$\frac{459.7 (8.881)}{9770}$



Virtual loss of GM	0.400 m	0.418 m
GM fluid	0.652 m	0.652 m
Virtual GM **ans (b)**	0.252 m	0.234 m

Initial GM = Initial KM – KG = 0.625 m, the loss of which will result in zero GM

Total loss of GM = FSC + loss due to P

Therefore 0.625 = FSM / (W – P) + drydocking loss

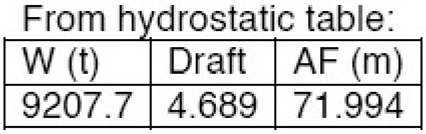
By formula A:

0.625 = 1200 / (9770 – P) + (P . KG) / (W – P)

0.625 = 1200 / (9770 – P) + P (8.1) / (9770 – P)

So, **P = 562.3 t**

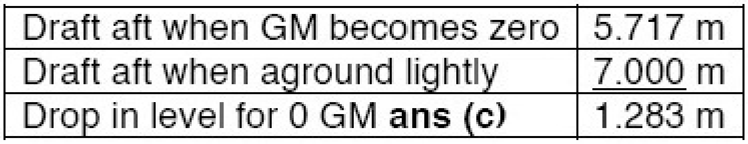
GM will be 0 when disp = (W – P) = 9207.7 t.



From hydrostatic table:

W (t)	Draft	AF (m)
9207.7	4.689	71.994

Ta = (AF / L) Tc = (71.994 / 140) 2 = 1.028 m.
Draft aft = 4.689 + 1.028 = 5.717 metres



Draft aft when GM becomes zero	5.717 m
Draft aft when aground lightly	7.000 m
Drop in level for 0 GM **ans (c)**	1.283 m

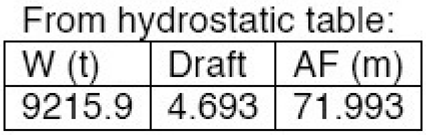
By formula B:

0.625 = 1200 / (9770 – P) + P. KM /W

0.625 = 1200 / (9770 – P) + P (8.725) / 9770

So, **P = 554.1 t**

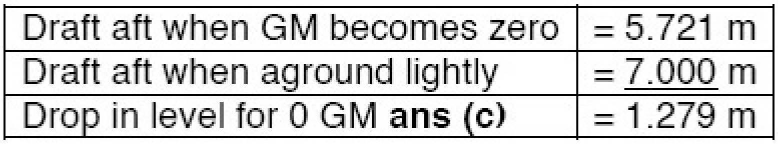
GM will be 0 when disp = W – P = 9215.9 t.



From hydrostatic table:

W (t)	Draft	AF (m)
9215.9	4.693	71.993

Ta = (AF / L) Tc = (71.993 / 140) 2 = 1.028 m,
Draft aft = 4.693 + 1.028 = 5.721 metres



Draft aft when GM becomes zero	= 5.721 m
Draft aft when aground lightly	= 7.000 m
Drop in level for 0 GM **ans (c)**	= 1.279 m

Note: Due to the nature of the problem, the value of P is available only towards the end of the calculation. Hence the KM used is for the original displacement (W) not for the reduced displacement (W – P). In reality, the KM for (W – P) would be more than the KM used above and hence the maximum safe trim would be more than the value calculated here. The error is thus on the safer side.

Example 7

M.V. VIJAY enters a SW drydock drawing 3 m fwd and 5.8 m aft. KG = 8.6 m, FSM = 800 tm. Find the new GM: (a) on taking to blocks overall and (b) after the water level drops by one metre thereafter.

Fwd 3.0 m aft 5.8 m, trim 2.8 m by the stern
Mean draft 4.4 m for which AF = 72.056 m from hydrostatic table.

Corr = (AF / L) trim = (72.056 / 140) 2.8 = 1.441 m

Initial hydraft = 5.80 – 1.441 = 4.359 m

From hydrostatic table:

Draft	W (t)	MCTC (tm)	AF (m)
4.359	8486.8	160.952	72.065

Tc = P. AF / MCTCor P = Tc (MCTC) / AF
P = 280 (160.952) / 72.065 = 625.4 tonnes
W – P = 7861.4 t, for which KM =9.570 m from the hydrostatic table.

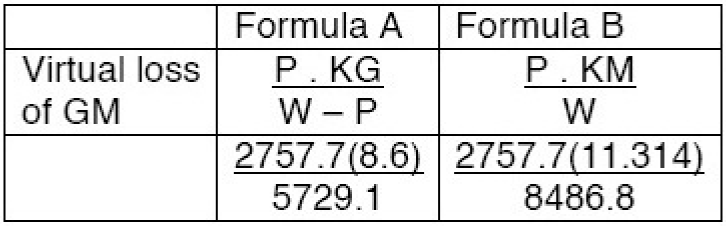
New GM = new KM - KG = 9.57- 8.6	0.970 m
FSC = FSM / (W – P) = 800/7861.4	0.102 m
GM fluid when sitting overall	0.868 m

	Formula A	Formula B
Virtual loss of GM	$\frac{P\ .\ KG}{W - P}$	$\frac{P\ .\ KM}{W}$
	$\frac{625.4(8.60)}{7861.4}$	$\frac{625.4(9.57)}{8486.8}$

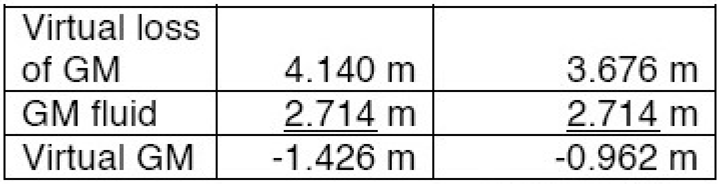
Virtual loss of GM	0.684 m	0.705 m
GM fluid	0.868 m	0.868 m
Virtual GM **ans (a)**	0.184 m	0.163 m

Note: After the critical period is over, the side shores would be in position and there is no possibility of roll. FSE can then be ignored.

On taking to blocks overall, W is 7861.4 t, for which the hydraft is 4.071 m. After a further drop of 1 m in water level, hydraft = 3.071 m for which W = 5729.1 t and KM = 11.314 m. Then GM solid = 11.314 – 8.600 = 2.714 m and P = 8486.8 – 5729.1 = 2757.7 t.



	Formula A	Formula B
Virtual loss of GM	$\frac{P . KG}{W - P}$	$\frac{P . KM}{W}$
	$\frac{2757.7(8.6)}{5729.1}$	$\frac{2757.7(11.314)}{8486.8}$



Virtual loss of GM	4.140 m	3.676 m
GM fluid	2.714 m	2.714 m
Virtual GM	-1.426 m	-0.962 m

Answer (b)

Example 8

M.V. VIJAY, drawing 5 m fwd and 6 m aft in SW, has KG = 7.6 m and FSM = 950 tm. She runs aground lightly on a reef at the fwd perpendicular. Internal soundings indicate that the hull is still watertight. If the tide is expected to fall by 0.5 m, find at LW:

(a) the upthrust exerted on the hull by the reef,

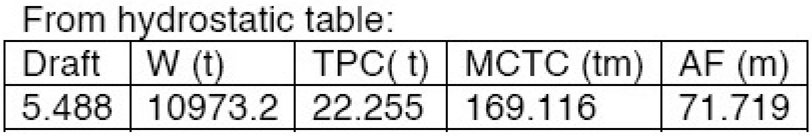
(b) the drafts fwd and aft and (c) the virtual GM.

Fwd 5.0 m aft 6.0 m, trim 1.0 m by the stern

Mean draft 5.5 m for which AF = 71.714 m from hydrostatic table.

Corr = (AF / L)trim = (71.714 / 140)1.0 = 0.512 m

Initial hydraft = 6.00 – 0.512 = 5.488 m



From hydrostatic table:

Draft	W (t)	TPC(t)	MCTC (tm)	AF (m)
5.488	10973.2	22.255	169.116	71.719

The draft fwd would decrease by 50 cm as a result of the upthrust P exerted by the reef at the fwd perpendicular.

Decrease of fwd draft = mean rise + Tf

50 = P/TPC + Tc (length forward of COF) / L

50 = (P / TPC) + P(L – AF) (L – AF) / MCTC / L

50 = (P/22.255) + P(68.281)(68.281) / (169.116)(140)

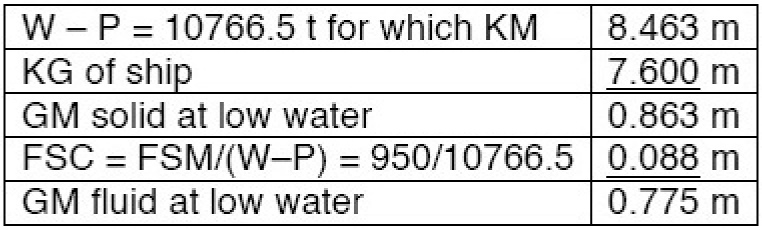
Upthrust P at LW = 206.7 t = **answer (a)**.

Tc = P (L – AF) / MCTC = 206.7 (68.281) / 169.116

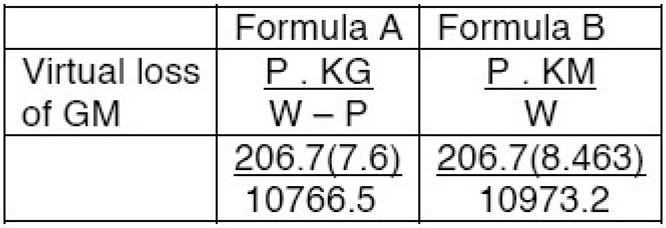
Tc = 83.5 cm

Trim at LW = original trim + Tc = 1.835 m

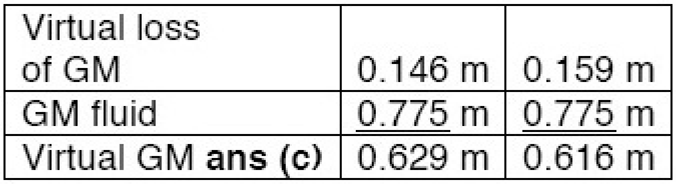
Draft fwd = 5.000 – 0.5 = 4.500 m at LW
Draft aft = 4.5 + 1.835 = 6.335 m **ans (b)**



W – P = 10766.5 t for which KM	8.463 m
KG of ship	7.600 m
GM solid at low water	0.863 m
FSC = FSM/(W–P) = 950/10766.5	0.088 m
GM fluid at low water	0.775 m



	Formula A	Formula B
Virtual loss of GM	$\frac{P \,.\, KG}{W - P}$	$\frac{P \,.\, KM}{W}$
	$\frac{206.7(7.6)}{10766.5}$	$\frac{206.7(8.463)}{10973.2}$



Virtual loss of GM	0.146 m	0.159 m
GM fluid	0.775 m	0.775 m
Virtual GM **ans (c)**	0.629 m	0.616 m

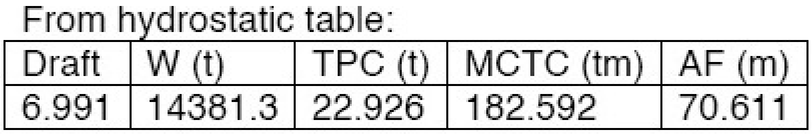
Example 9

M.V. VIJAY draws 6 m fwd and 8 m aft in SW. KG 7.04 m and FSM 1060 tm. She grounds lightly on a reef 30 m abaft the fwd perpendicular. The hull is still intact. The water level is expected to fall by 0.6 m. At LW, find: (a) the up thrust on the hull by the reef, (b) the drafts fwd and aft and (c) the virtual GM.

Note: This is similar to example 8 with the exception that the point of grounding is not at the forward perpendicular but 30 m astern of it.

Fwd 6.0 m aft 8.0 m, trim 2.0 m by the stern
Mean draft 7.0 m for which AF = 70.602 m from hydrostatic table.

Correction = 70.602 (2.000) / 140= 1.009 m
Initial hydraft = 8.00 – 1.009 = 6.991 m


From hydrostatic table:

Draft	W (t)	TPC (t)	MCTC (tm)	AF (m)
6.991	14381.3	22.926	182.592	70.611

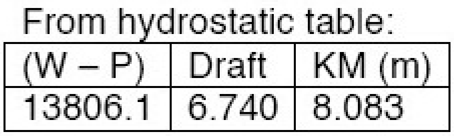
At R, the point of grounding, the decrease of draft, by tidal fall = 60 cm.
Let the distance of R from the COF = RF.
RF = AR – AF = 110 – 70.611 = 39.389 m.

Reduction of draft at R = mean rise + Tr
where Tr is the proportion of Tc, the trim caused, at point R.

$60 = (P / TPC) + P (RF) (RF) / MCTC / L$

$60 = (P / 22.296) + P (39.389)^2 / 182.592 / 140$

P = 575.2 t **answer (a)**


From hydrostatic table:

(W – P)	Draft	KM (m)
13806.1	6.740	8.083

Tc = P (RF) / MCTC = 575.2 (39.389) / 182.592

Tc = 124.1 cm

Trim at LW = original trim + Tc = 3.241 m

Ta = (AF / L) trim = 70.611 (3.241) / 140 = 1.635 m
Tf = trim – Ta = 3.241 – 1.635 = 1.606 m

Draft fwd = 6.74 – 1.606 =	5.134 m at LW
Draft aft = 6.74 + 1.635 =	8.375 m **ans b**

GM solid at LW = 8.083 – 7.040	1.043 m
FSC = FSM/ (W – P) = 1060/13806.1	0.777 m
GM fluid at low water	0.966 m

	Formula A	Formula B
Virtual loss of GM	$\frac{P \, . \, KG}{W - P}$	$\frac{P \, . \, KM}{W}$
	$\frac{575.2\ (7.04)}{13806.1}$	$\frac{575.2\ (8.083)}{14381.3}$

	A	B
Virtual loss of GM	= 0.293 m	0.323 m
GM fluid at LW	= 0.966 m	0.966 m
Virtual GM **ans (c)**	= 0.673 m	0.643 m

Example 10

M.V. VIJAY is in a SW anchorage drawing 5.4 m fwd and 6 m aft. KG 7.2 m, FSM 1100 tm. At LW, the ship rests on an uncharted rock and it is found that the drafts are then 6 m fwd and 5 m aft. Find (a) the upthrust exerted on the hull by the rock; (b) the distance, to the nearest metre, of the rock from the after perpendicular (c) the virtual GM and (d) the rise of tide required for the ship to refloat, assuming that it is aground at only one point surrounded by deep water.

Fwd 5.4 m aft 6.0 m, trim 0.6 m by the stern
Mean draft 5.7 m for which AF = 71.629 m from hydrostatic table.

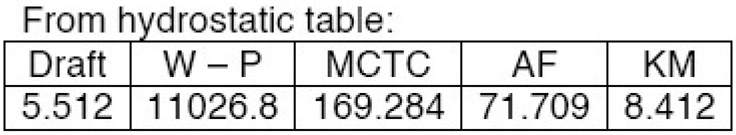
Corr = (AF / L) trim = (71.629 / 140) 0.6 = 0.307 m

Initial hydraft = 6.00 – 0.307 = 5.693 m for which the displacement W = 11431.8 t from hydrostatic table.

After grounding, Fwd 6.0 m aft 5.0 m, trim 1.0 m by head. Mean draft 5.5 m for which AF = 71.714 m.

Correction = (71.714 / 140) 1.000 = 0.512 m

At LW, hydraft = 5.000 + 0.512 = 5.512 m



From hydrostatic table:

Draft	W – P	MCTC	AF	KM
5.512	11026.8	169.284	71.709	8.412

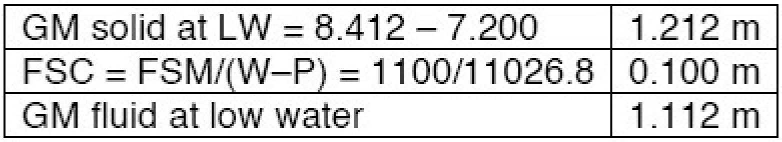
P = 11431.8 – 11026.8 = 405 t **answer (a)**

Original trim = 60 cm by stern. Trim at LW = 100 cm by head. Tc = 160 cm by head Hence rock is astern of COF. Let FR be the distance of the rock abaft COF.

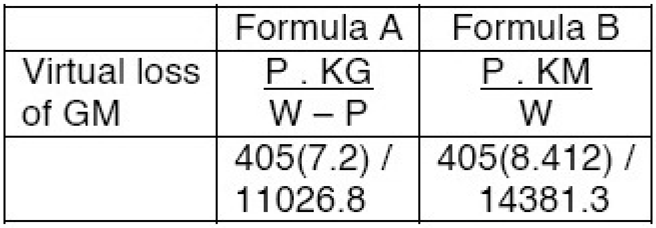
Tc = P (FR) / MCTC or 160 = 405 (FR) / 169.284

FR = 66.878. AF = 71.709. So, AR = 4.831

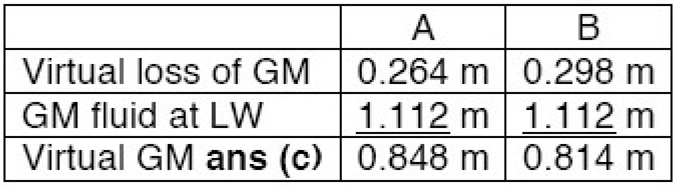
Distance of rock from the after perpendicular, to the nearest m, = 5 m **answer (b).**



GM solid at LW = 8.412 – 7.200	1.212 m
FSC = FSM/(W–P) = 1100/11026.8	0.100 m
GM fluid at low water	1.112 m



	Formula A	Formula B
Virtual loss of GM	$\frac{P\,.\,KG}{W - P}$	$\frac{P\,.\,KM}{W}$
	405(7.2) / 11026.8	405(8.412) / 14381.3



	A	B
Virtual loss of GM	0.264 m	0.298 m
GM fluid at LW	1.112 m	1.112 m
Virtual GM **ans (c)**	0.848 m	0.814 m

Let Tr be the proportion of trim at R.

Before grounding:

Tr = (FR / L) trim = (66.878 / 140) (0.600) = 0.287 m.

Since trim was by stern, and R was abaft COF, draft at R was > initial hydraft of 5.693 m by 0.287 m.

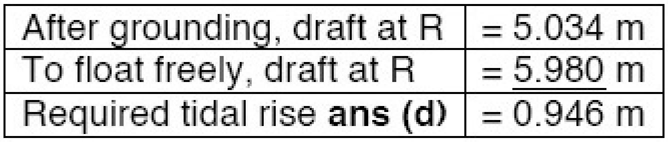
Draft at R = 5.693 + 0.287 = 5.980 m.

After grounding

Tr = (FR / L) trim = (66.878 / 140) 1.000 = 0.478 m.

Since trim is by head, and R was abaft COF, draft at R is < the LW hydraft of 5.512 m by 0.478 metre

Draft at R = 5.512 – 0.478 = 5.034 m



After grounding, draft at R	= 5.034 m
To float freely, draft at R	= 5.980 m
Required tidal rise **ans (d)**	= 0.946 m

FLOATING DRYDOCKS

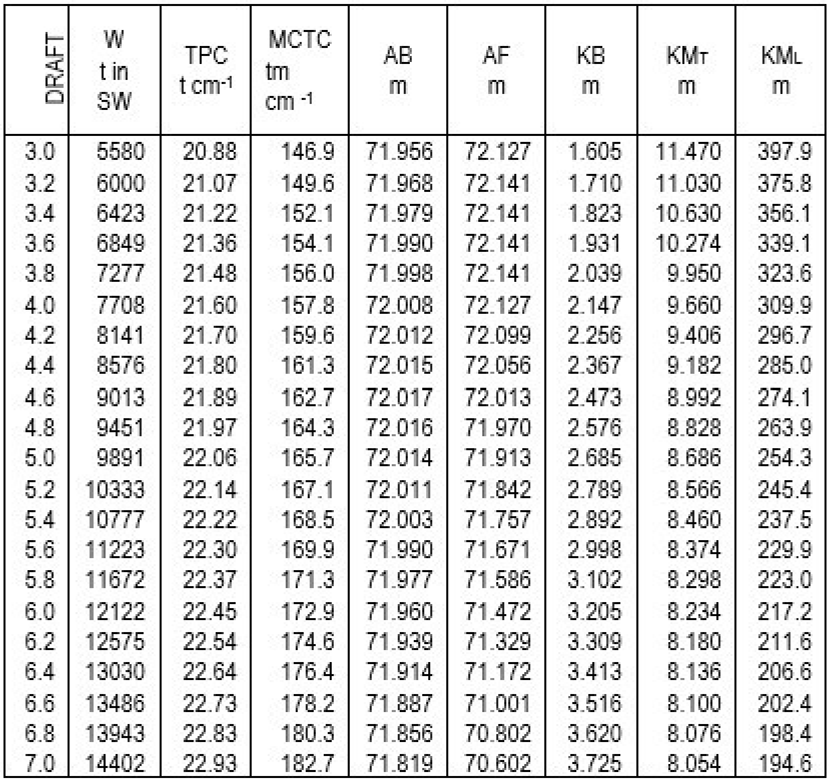
From the shipmaster's point of view, a floating drydock has one big advantage over a graving type drydock: the drydock itself can be made to have a trim in order to offset any adverse trim that the ship may have. Suppose the ship is trimmed one metre by the head. The drydock can be made to trim two metres by the head so that, when the ship's stern takes to the keel blocks, the relative trim is one metre by the stern. Thereafter, the ballast tanks of the drydock can be pumped out at a predetermined sequence to ensure that the stern frame of the ship always remains in contact with the keel blocks while the relative trim is gradually reduced. Once the bow also has taken to the blocks (relative trim zero) pumping out of the drydock can be completed, bringing the ship's keel above, and parallel to, the water surface.

If the ship is trimmed 3 m by the stern, the drydock can be made to trim 2 m by the stern so that the relative trim is only one metre by the stern, and so on.

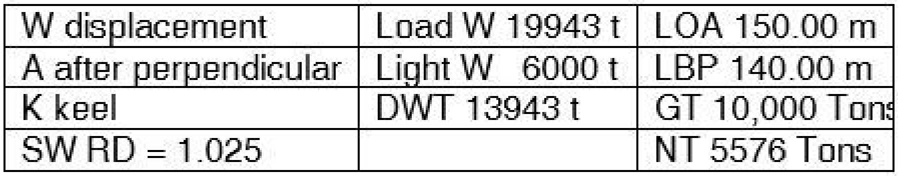
Exercise 3
(Drydocking and grounding)

Appendix 1 - Hydrostatic Table of M.V. 'VIJAY'
is reproduced here for easy reference.

Appendix I
HYDROSTATIC TABLE OF M.V. 'VIJAY'



DRAFT	W t in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6



W displacement	Load W 19943 t	LOA 150.00 m
A after perpendicular	Light W 6000 t	LBP 140.00 m
K keel	DWT 13943 t	GT 10,000 Tons
SW RD = 1.025		NT 5576 Tons

1. M. V. VIJAY enters a SW drydock drawing 6 m fwd and 8 m aft. KG 6 m. When it is just about to take to the blocks fwd, calculate the (a) virtual GM and (b) moment of statical stability at 0.5° heel.

Answer: (a) 1.856 or 1.789 m (b) 224.5 or 224.5 tm.

2. Rework Q1 given that FSM = 1180 tm.

Answer: (a) 1.771 or 1.704 m (b) 214.3 or 213.9 tm.

3. M.V. VIJAY has W = 10333 t, KG = 8 m. What is the maximum trim by the stern with which she may enter a SW drydock if the virtual GM at the critical instant is to be not less than 0.3 m?

Answer: 143 cm or 138 cm.

4. Rework Q3 given that FSM = 970 tm.

Answer: 92.5 cm or 88.3 cm.

5.M.V. VIJAY is at anchor in SW, drawing 7 m fwd and aft. KG 6.2 m. During low water, the depth of water around the ship is expected to drop to 6 m. Find the virtual GM at LW, assuming that the sea-bed is even and horizontal.

Answer: 0.868 or 0.730 cm.

6. Rework Q5 given that FSM = 1400 tm.

Answer: 0.753 m or 0.615 m.

7. While drawing 4.8 m fwd and 8 m aft in SW, M.V. VIJAY runs aground lightly on a sandy shoal, during a falling tide. Hand lead soundings indicate that the depth of water at the after perpendicular is 1 m more than at the forward perpendicular. If KG = 7.5 m, calculate the (a) drop in water level at which the ship will sit overall on the sea-bed; (b) virtual GM when just sitting overall and (c) drop in water level at which the ship would become unstable.

Answer: **(**a) 1.357 m (b) 0.369 or 0.354 m (c) 1.567 or more.

8. Rework Q7 given that FSM = 1300 tm.

Answer: (a)1.357 m (b)0.264 or 0.249 m (c)1.490 m or more.

9. M.V. VIJAY enters a SW drydock drawing 3.4 m fwd and 5.8 m aft. KG 8 m. Find the virtual GM when the level of water has fallen one metre after the stern has taken to the blocks.

Answer: 0.844 m or 0.81 m.

10.Rework Q9 given that FSM = 880 tm. (If, during drydocking, the critical period is over, FSC may be ignored).

Answer: 0.741 or 0.707 m.

11. M.V. VIJAY enters a SW drydock drawing 3.5 m fwd and 5.5 m aft. KG 7.1 m. Find the virtual GM after the water level has fallen to 4 m above the blocks.

Answer: 1.618 or 1.428 m.

12. Rework Q11 given that FSM = 820 tm. (If, during drydocking, the critical period is over, FSC may be ignored).

Answer: FSC 0.106 m – ignored: shores in place.

13.M.V. VIJAY drawing 5.6 m fwd and 8.4 m aft in SW, KG 7.2 m, runs aground lightly on shoal during a falling tide. At low water, the drafts are found to be 6 m fwd and 7.4 m aft. Find the virtual GM at low water.

Answer: 0.531 m or 0.506 m.

14. Rework Q13 given that FSM = 1400 tm.

Answer: 0.429 or 0.404 m.

15. M.V. VIJAY floating at 5.2 m fwd and 7m aft in SW, KG 7.4 m and FSM 1250 tm, runs aground lightly on a coral reef. Soon after grounding, the drafts are found to be 4.4 m fwd and 7.4 m aft. Find the (a) upthrust exerted on the hull by the reef; (b) point, to the nearest metre, where it acts; (c) virtual GM soon after grounding and (d) rise of tide required for the ship to refloat assuming that the reef is acting only at one point surrounded by deep water.

Answer: (a) 484.9 t (b) 114 m fwd of A (c) 0.467 or 0.445 m (d) 0.579 m

16. M.V. VIJAY, afloat in SW at 4.6 m fwd and 5.4.m aft, KG 7.8 m, FSM 1180 tm, runs aground lightly at the forward perpendicular. The stern is in deep water. The tide is expected to fall by 1 m. Find, at low water, the (a) upthrust exerted on the hull by the shoal; (b) drafts fwd and aft and (c) virtual GM.

Answer: (a) 407.7 t (b) F: 3.600 m A: 6.076 m (c) 0.564 or 0.535 m.

17. M. V. VIJAY floats at drafts of 5 m fwd and 7 m aft, KG 7.64 m, FSM 1086 tm, in a SW anchorage. During ebb tide, it sits on an uncharted rock 20 m abaft the fwd perpendicular. The hull is still intact. The tide is expected to fall another 0.5 m. Find at low water the (a) force exerted on the hull by the rock; (b) drafts fwd and aft and (c) virtual GM.

Answer: (a) 352.4 t (b) F: 4.359 m A: 7.349 m (c) 0.328 or 0.316 m.

18. M.V. VIJAY enters a FW drydock drawing 3.6 m fwd and 4.8 m aft. KG 8 m, FSM 960 tm. Find the virtual GM at (a) the critical instant (b) after a further drop of one metre in water level.

Answer: (a) 1.188 or 1.145 m (b) -0.023 m or -0.016 m after neglecting FSC.

19. M.V. VIJAY is in DW of RD 1.017. W is 9013 t, KG 8.02 m and FSM 810 tm. What is the maximum trim with which she may enter a drydock, of RD 1.017, if the virtual GM at the critical instant is to be not less than 0.3 m?

Answer: 2.571 or 2.459 m.

20.M.V. VIJAY is to be refloated in a SW drydock after a prolonged stay for structural repairs. Its displacement, KG and AG after repairs are calculated to be 8576 t, 8.1 m and 68 m. FSM is 900 tm. Calculate the virtual GM and the depth of water above the blocks (hydrostatic draft), when the bow just lifts off the blocks.

Answer: (a) 0.742 or 0.694 m (b) 4.180 m.

-o0o-

4. BILGING OF AMIDSHIPS COMPARTMENTS

A compartment is said to be bilged when it is holed below the waterline, the hole being large enough for water to pass freely in and out. Minor leaks are excluded as they can be tackled by the ship's pumps.

Bilging causes loss of buoyancy. A compartment, which was displacing water before, does not do so after bilging. So, the ship's draft increases until the loss of buoyancy is regained by the extra sinkage of intact spaces. By this line of thought, the displacement and KG remain unaffected by bilging. Though the draft of the ship increases, resulting in change of hydrostatic particulars, the volume of displacement is the same because the volume of buoyancy lost equals the volume of buoyancy regained. The increase of draft, denoted by 'S' metres, may be calculated as follows:

S = volume of lost buoyancy / intact water-plane area

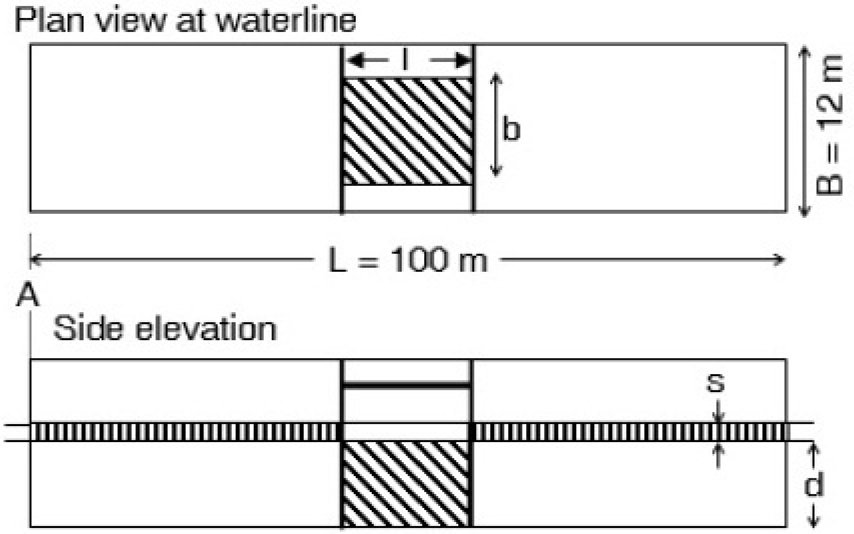
This chapter deals only with bilging of the amidships compartment of box-shaped vessels, resulting in parallel sinkage without causing any trim or list.

Water-tight flats restrict the entry of water into a bilged compartment. The volume of lost buoyancy, and hence the resultant sinkage, is less when the bilged compartment has a water-tight flat below the waterline. A good example of a water-tight flat is the tank top of the double bottom tanks of a cargo ship.

The following cases show the calculation of sinkage caused by bilging an amidships compartment. The advantage of having a WT flat is apparent by the limited amount of sinkage.

Consider a box-shaped vessel 100 m long and 12 m wide, floating at an even keel draft of 6 m in SW. It has an empty amidships compartment 10 m long and 8 m wide, on the centre line of the ship.

Case 1A: The amidships compartment has a watertight flat far above the waterline. If this compartment gets bilged, calculated the new draft.

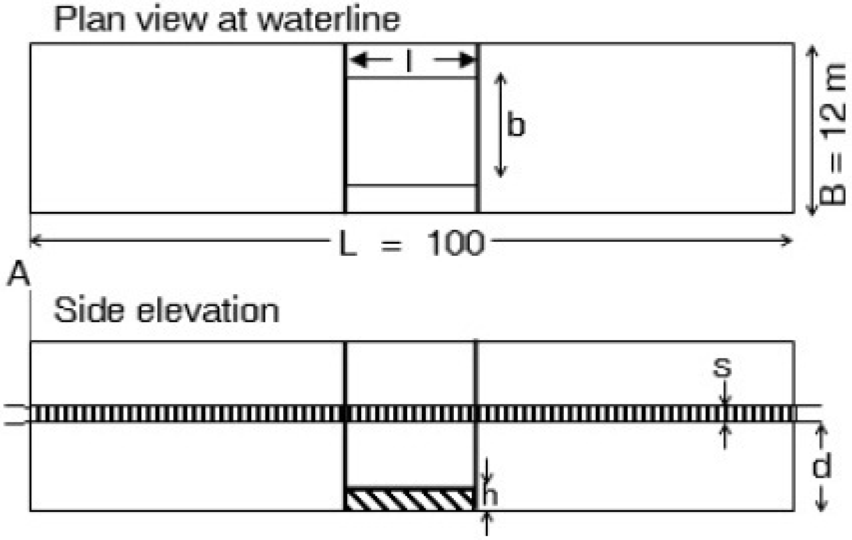


Note: Since the water-tight flat is far up, it will remain above the waterline after bilging. Its presence, therefore, makes no difference to the calculations.

S = volume of lost buoyancy / intact water-plane area
S = lbd / (LB–lb) = (10 x 8 x 6) / (1200 – 80) = 0.429 m

New draft = 6.000 + 0.429= 6.429 metres.

Case 2A: The amidships compartment has a WT flat 1 m above the keel. Find the new draft if the compartment is bilged below this flat. (Note: The bilged compartment is similar to the DB tank of a ship).



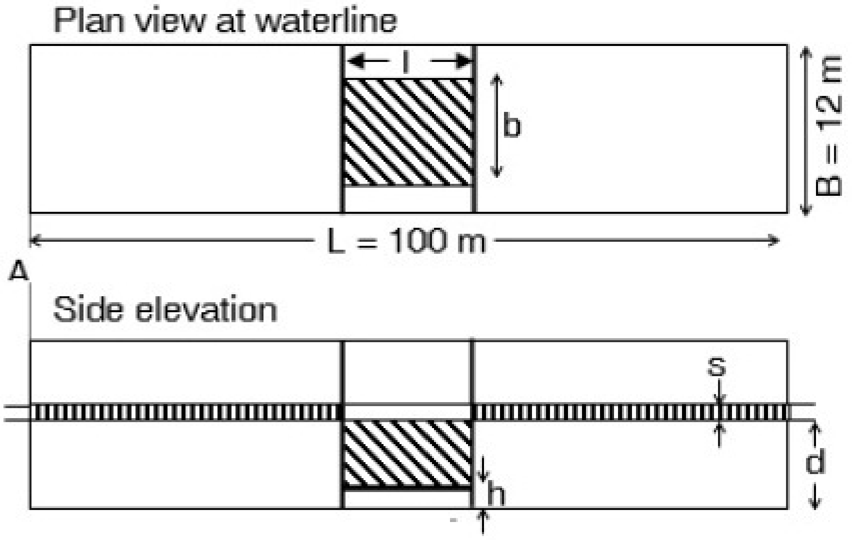
S = volume of lost buoyancy / intact water-plane area

S = lbh / LB = (10 x 8 x 1) / (100 x 12) = 0.067 m

New draft = 6.000 + 0.067 = 6.067 metres

Case 3A: The amidships compartment has a WT flat 1 m above the keel. Find the new draft if the compartment is bilged above this flat.

Note: You may wonder how such a protectively located compartment – bounded on all four sides & from below – can get bilged without damage to any of the adjoining compartments! Since this is a theoretical exercise, imagine that a large pipeline connected to the sea has burst and the ingress of water is beyond the capacity of the ship's pumps.

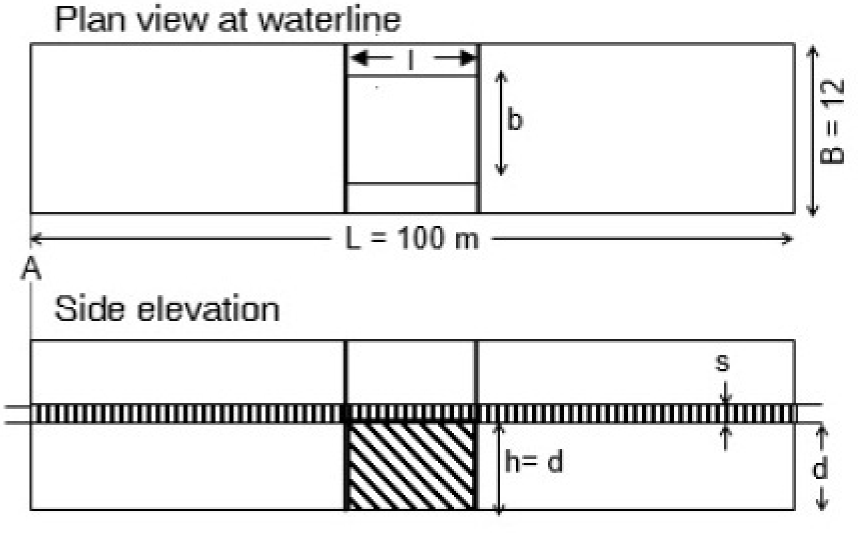


S = volume of lost buoyancy / intact water-plane area

S = lb (d –h) / (LB-lb) = (10 x 8 x 5) / (1200 – 80)
S = 0.357 m

New draft = 6.000 + 0.357 = 6.357 metres

Case 4A: The amidships compartment has a WT flat 6 m above the keel. Find the new draft if the compartment is bilged.



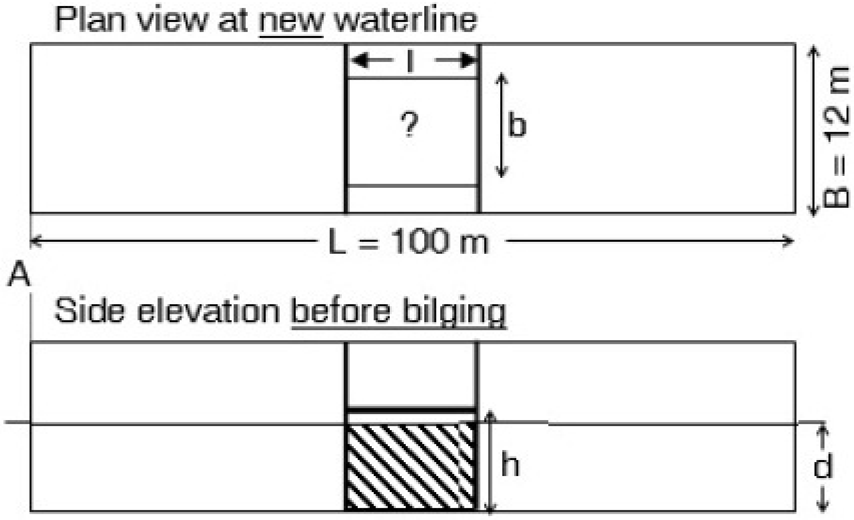
S = volume of lost buoyancy / intact water-plane area

S = lbd / LB = (10 x 8 x 6) / 1200 = 0.400 m

New draft = 6.000 + 0.400 = 6.400 metres

Case 5A: The amidships compartment has a WT flat 6.5 m above the keel. Find the new draft if this compartment is bilged.

Note: Since the WT flat is very near the waterline before bilging, it is not possible to judge, at a glance, whether the new waterline will be above or below the WT flat. The intact water-plane area will be (LB – lb) until the waterline reaches the level of the WT flat: thereafter, it will be LB.



Volume of buoyancy lost = 10 (8) 6 = 480 m^3.

If S = (h – d) = 0.5 m, volume regained = 0.5 (LB – lb) = 0.5 (1200 – 80) = 560 m^3

Since the ship cannot regain more buoyancy than what she lost, S < 0.5 m.
Hence the WT flat remains above the waterline after bilging.

The calculation is now similar to that of case 1A.

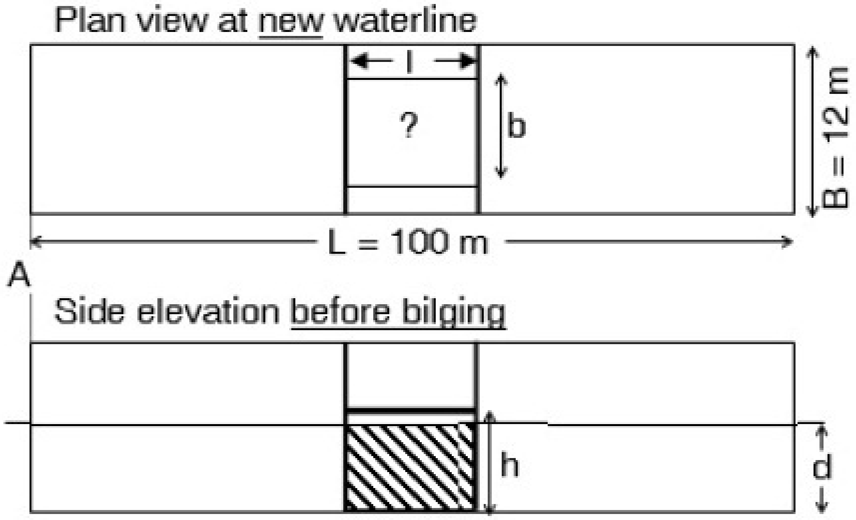
S = volume of lost buoyancy / intact water-plane area

S = 480 / (LB – lb) = 480 / (1200 – 80) = 0.429 m

New draft = 6.000 + 0.429 = 6.429 metres

Case 6A: The amidships compartment has a WT flat 6.2 m above the keel. Find the new draft if this compartment is bilged.

Note: Since the WT flat is very near the waterline before bilging, it is not possible to judge, at a glance, whether the new waterline will be above or below the WT flat. The intact water-plane area will be (LB – lb) until the waterline reaches the level of the WT flat: thereafter, it will be LB.



Volume of lost buoyancy = 10 (8) 6 = 480 m^3

If S = (h – d) = 0.2 m, volume regained = 0.2 (LB – lb) = 0.2 (1200 – 80) = 224 m^3

Volume yet to regain = 480 – 224 = 256 m^3 during which the intact WP area = LB.

Further sinkage = 256 / 1200 = 0.213 m.

New draft = 6.0 + 0.2 + 0.213 = 6.413 m.

Exercise 4

(Bilging amidships <u>empty</u> compartment)

A box-shaped vessel, 120 m long and 14 m wide, is afloat at 8 m draft even keel. Find the new draft if a central compartment 12 m long is bilged as under:

(Since ‘b’ is not given, assume b = B = 14 m)

1. It has a WT flat 11 m above the keel.

Answer: 8.889 m.

2. It has a WT flat 1.2 m above the keel & the compartment is bilged below it.

Answer: 8.120 m.

3. It has a WT flat 1.5 m above the keel & the compartment is bilged above it.

Answer: 8.722 m.

4. It has a WT flat 1.0 m above the keel. The compartment is bilged above and below this flat.

Answer: 8.889 m.

5. It has a WT flat 8.0 m above the keel.

Answer: 8.800 m.

6. It has a WT flat 8.9 m above the keel.

Answer: 8.889 m.

7. It has a WT flat 8.5 m above the keel.

Answer: 8.850 m.

PERMEABILITY

So far, the compartments bilged in this chapter were empty. If, however, they had cargo in them, that cargo would occupy space and only the balance space would be available for occupation by water in the event of bilging. In other words, cargo would restrict the space available for water, thereby reducing the volume of buoyancy lost due to bilging.

Permeability is the percentage ratio of the space available for the entry of water into a compartment, to the total volume of the compartment. The letter ‘p’ is used here to denote permeability. For an empty compartment, p = 100% and for a compartment so full that water cannot enter at all, if bilging occurred, p = 0%. For any compartment, p may be calculated by the formula:

$$p\ \% = (BS\ /\ SF)\ 100$$

where SF is the stowage factor in cubic metres per tonne & BS is the broken stowage per tonne of cargo.

Example: A compartment is full of coal in bulk (SF 1.3 $m^3/$ t). If RD of coal is 1.1, find p % of the compartment.

RD = 1.1 so density = 1.1 t / m^3, meaning that 1.1 t of coal should occupy 1 m^3, or 1 t of coal should occupy 1 / 1.1 = 0.909 m^3. But SF = 1.3 $m^3/$ t meaning that 1 t of coal actually occupies 1.3 m^3.

Broken stowage per tonne = 1.3 – 0.909 = 0.391 m^3.

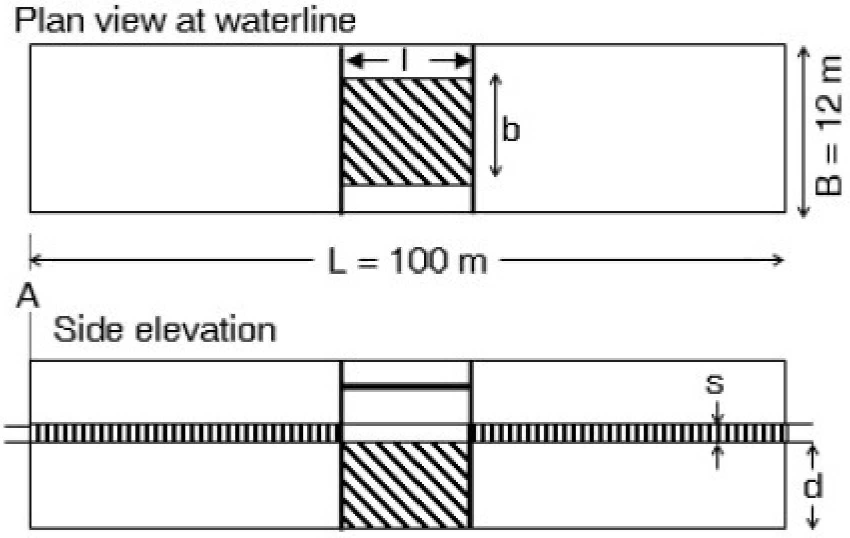
p% = (BS / SF) 100 = (0.391 / 1.3) 100 = 30.1%

Where the cargo in a compartment is heterogeneous, it is not possible to calculate the permeability to any degree of accuracy. In such a case, it is suggested that 60% may be used as a rough approximation at sea.

Permeability, once known or estimated, can be put to practical use as follows:

Consider the same box-shaped vessel and the six cases referred to earlier in this chapter, where L = 100 m, B = 12 m, d = 6 m, l = 10 m and b = 8m.

Case 1B: The amidships compartment has a WT flat far above the waterline. Find the new draft if this compartment is bilged, given that p = 35%.



Note: Since the water-tight flat is far up, it will remain above the waterline after bilging. Its presence, therefore, makes no difference to the calculations.

S = volume of lost buoyancy / intact water-plane area

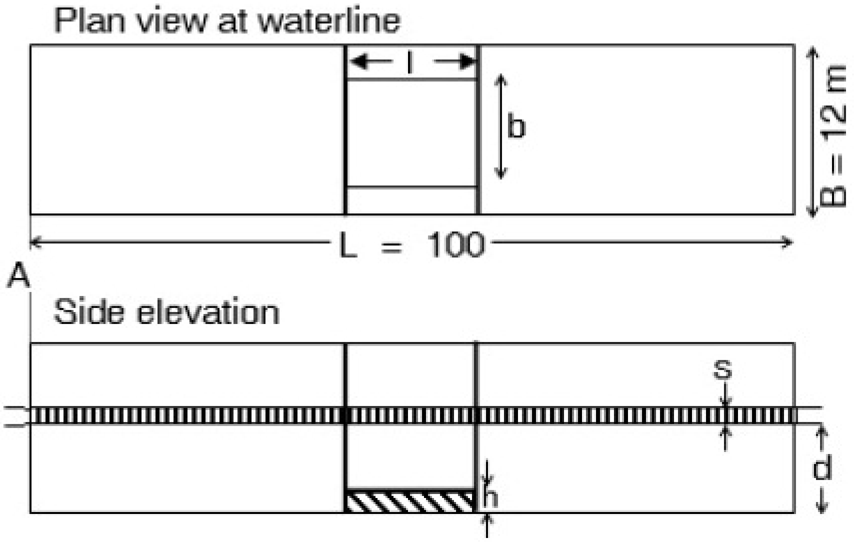
Note: Only 35% of (lbd) is available for entry of water as a result of bilging. The area of cargo also contributes to the intact water-plane area. So, the area of lost buoyancy = 35% of (lb).

S = lbd (p / 100) / [LB – (lb (p / 100))]

S = 10 (8) 6 (35 / 100) / [1200 - ([80 (35 / 100))] = 0.143 m.

New draft = 6.000 + 0.143 = 6.143 metres.

Case 2B: The amidships compartment has a WT flat 1 m above the keel. The space below the WT flat, full of SW ballast, gets bilged. Find the new draft.

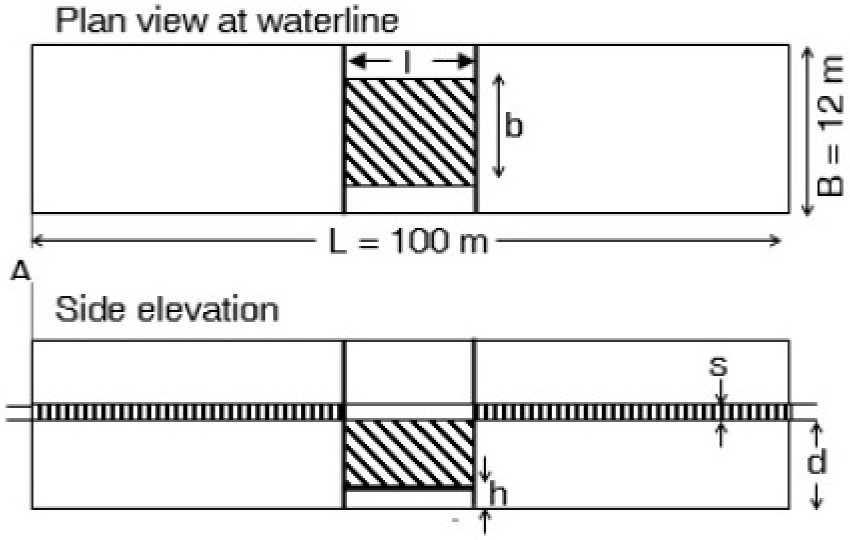


(Note: The bilged compartment is similar to the DB tank of a cargo ship).

Since the bilged compartment was full of SW, p = 0%; S = zero; new draft = 6.0 m.

Note: This is a short cut method which cannot be used if the contents of the bilged compartment had an RD different from that of the water outside. Solutions suitable for such problems have been explained in examples 5B and 6B few pages hence.

Case 3B: The amidships compartment has a WT flat 1 m above the keel. If the space above this flat, having p = 40 %, gets bilged, find the new draft.

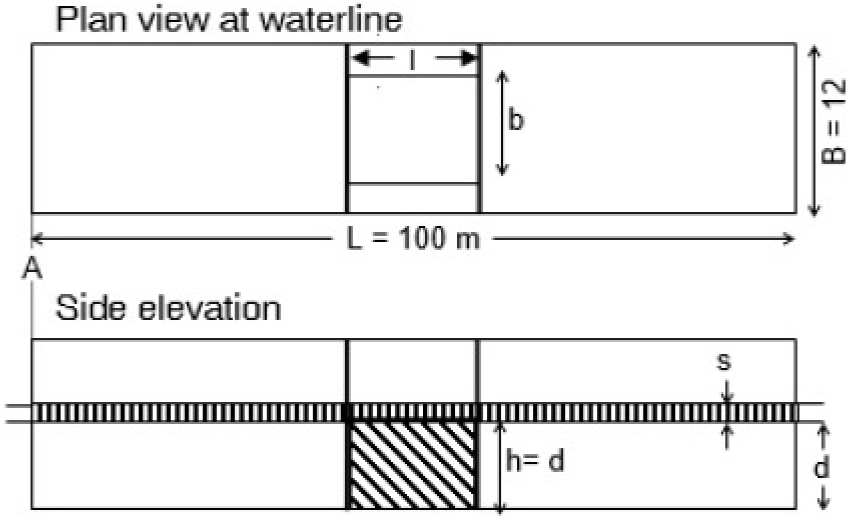


S = volume of lost buoyancy / intact water-plane area

S = lb (d – h) (p / 100) / [LB – (lb (p / 100))]
S = 10 (8) 5 (40 / 100) / [1200 – (80 (40 / 100))] = 0.137 m.

New draft = 6.000 + 0.137 = 6.137 metres.

Case 4B: The amidships compartment has a WT flat 6 m above the keel. Find the new draft if this compartment gets bilged, given that p = 30%.

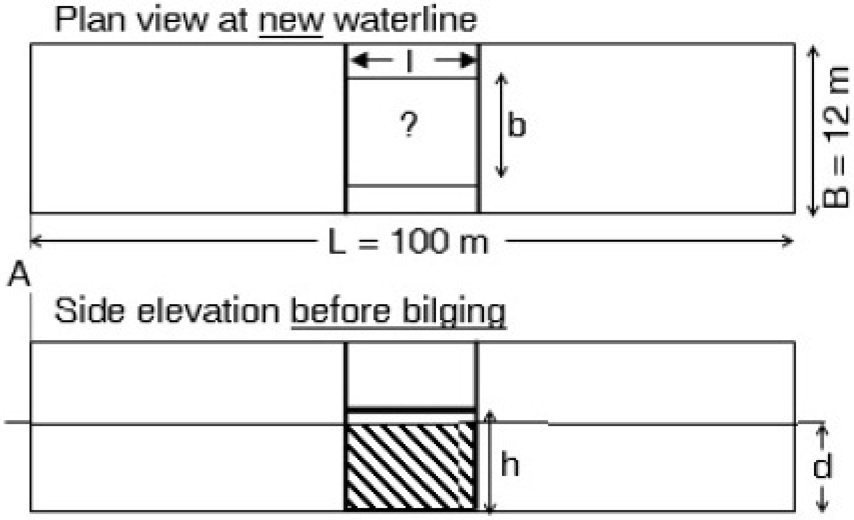


S = volume of lost buoyancy / intact water-plane area

S = lbd (p / 100) / LB = 10 (8) 6 (30 / 100) / 1200 = 0.120 m.

New draft = 6.000 + 0.120 = 6.120 metres.

Case 5B: The amidships compartment has a WT flat 6.2 m above the keel. Find the new draft if this compartment is bilged, given that p = 25%.



Volume of buoyancy lost = lbd (p / 100)
= 10 (8) 6 (25 / 100) = 120 m^3.

If S = (h–d) = 0.2 m, vol regained = 0.2 [LB–lb (p / 100)]
Vol regained = 0.2 [1200 – 80 (25 / 100)] = 236 m^3.
If S = 0.2 m, volume regained = 236 m^3.

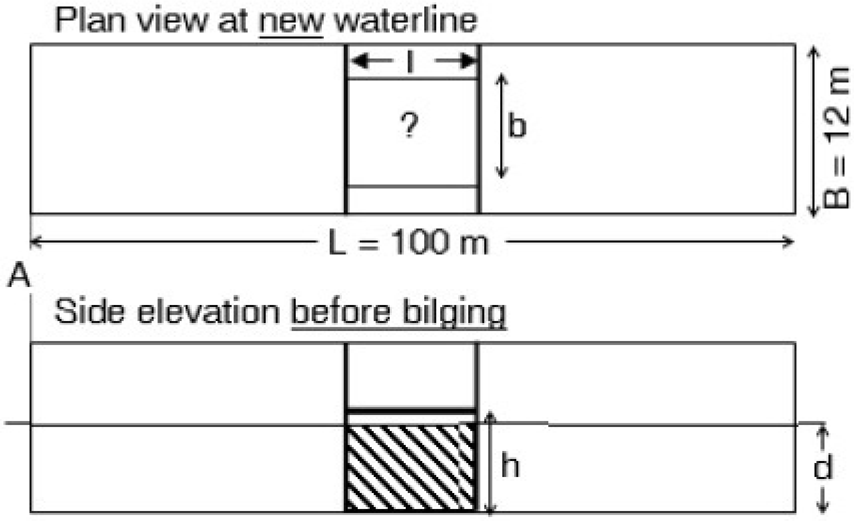
Since the ship cannot regain more buoyancy than what she lost, S < 0.2 m. The WT flat remains above the waterline even after bilging. The calculation is now similar to that of case 1B.

S = 120 / [LB – (lb (p / 100))]

S = 120 / [1200 – (80 (25 / 100))] = 0.102 m.

New draft = 6.000 + 0.102 = 6.102 metres

Case 6B: The amidships compartment has a WT flat 6.1 m above the keel. Find the new draft if this compartment is bilged, given that p = 80%.



Volume of buoyancy lost = lbd (p / 100) = 10 (8) 6 (80 / 100) = 384 m^3.

If S = (h–d) = 0.1 m, vol regained = [LB – (lb (p / 100))]

Vol regained = 0.1 [1200 – (80 (80 / 100))] = 113.6 m^3

Volume yet to regain = 384 – 113.6 = 270.4 m^3, during which the intact WP area = LB.

Further sinkage = 270.4 / 1200 = 0.225 m

New draft = 6.0 + 0.10 + 0.225 = 6.325 m.

Exercise 5
(Bilging amidships, loaded/filled compartment)

A box-shaped vessel, 120 m long and 14 m wide, is afloat at 8 m draft even keel. Find the new draft if a central compartment 12 m long is bilged as under:

(Since ‘b’ is not given, assume b = B = 14 m)

1. It has a WT flat 11 m above the keel. Compartment has p = 20 %. **Answer**: 8.163 m.

2. It has a WT flat 1.2 m above the keel, and the tank below, full of SW, it is bilged.
Answer: 8.000 m.

3. It has a WT flat 1.5 m above the keel and the compartment above it, with p = 30%, is bilged.
Answer: 8.201 m.

4. It has a WT flat 1.0 m above the keel. The compartment is bilged above and below this flat. Both have p = 50%.
Answer: 8.421 m.

5. It has a WT flat 8.0 m above the keel. The tank below has p = 40%.
Answer: 8.320 m.

6. It has a WT flat 8.9 m above the keel. The compartment below has p = 65%.
Answer: 8.556 m.

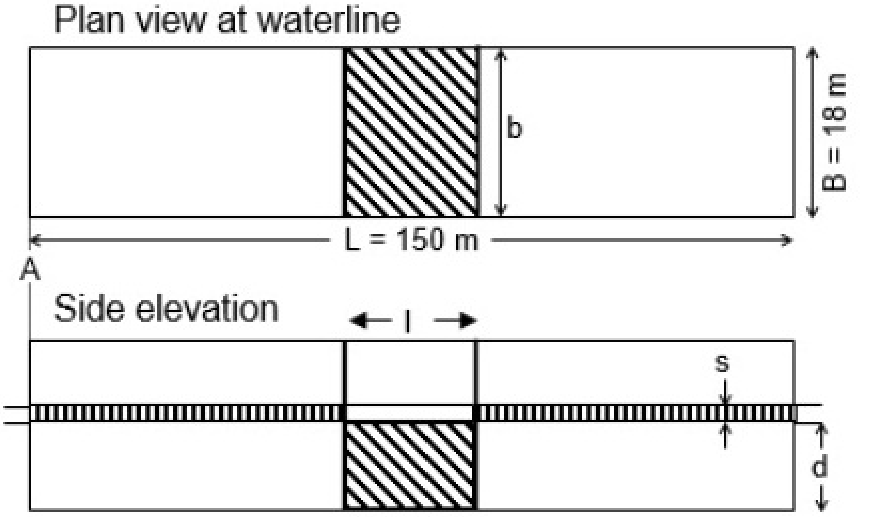
7. It has a WT flat 8.5 m above the keel. The compartment below has p = 80%.
Answer: 8.680 m.

-o0o-

EFFECT OF BILGING ON STABILITY

Since bilging causes a loss of buoyancy, resulting in an increase of draft, the KM of the ship would change. KG remains unaffected by bilging.

Example 1: A box-shaped vessel 150 x 18 m floats in SW at 5 m draft even keel. KG = 4 m. An empty amidships compartment 25 m long and 18 m broad gets bilged. Find the GM before and after bilging.



Before bilging
BM = I / V = LB^3 / 12V
BM = 150 (18 x 18 x 18) (12 x150 x 18 x 5) = 5.4 m

KM = KB + BM = 2.500 + 5.400 = 7.900 m
GM = KM - KG = 7.900 – 4.000 = 3.900 m **(answer a)**

After bilging
S = vol of lost buoyancy / intact WP area
S = (25 x18 x 5) / [(150 x 18) – (25 x18)] = 1 m.
New draft = 5.000 + 1.000 = 6.000 metres.

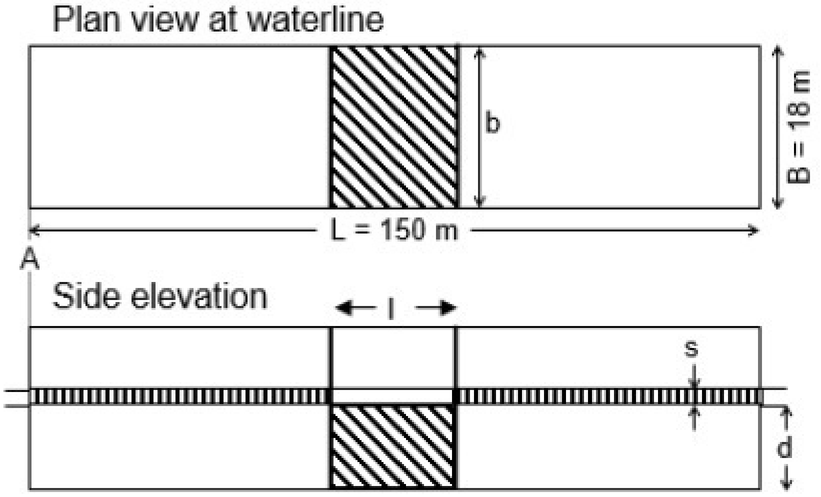
BM = I*CL intact WP area / vol of displacement.

BM = (LB^3 – lb^3) / 12V
BM = 150 (18^3) – 25 (18^3) / [12 (150 x 18 x 5)] = 4.5 m

Note: Volume of displacement is constant
V = 150 x 18 x 5 = 13500 m^3.
or V = 125 x 18 x 6 = 13500 m^3.

KM = KB + BM = 3.000 + 4.500 =7.500 m
GM = KM – KG = 7.500 – 4.000 = 3.500 m **(answer b)**

Example 2: A box-shaped vessel 150 x 18 m floats in SW at 5 m draft even keel. KG = 4 m. An amidships compartment 25 m long and 18 m broad, having p = 30%, gets bilged. Find the GM before and after bilging. **Note**: This is the same as example 1 except that permeability has been added.



Before bilging

BM = I / V = LB^3 / 12V

BM = 150 (18 x 18 x 18) (12 x150 x 18 x 5) = 5.4 m

KM = KB + BM = 2.500 + 5.400 = 7.900 m

GM = KM - KG = 7.900 – 4.000 = 3.900 m **(answer a)**

After bilging

S = lost buoyancy / Intact WP area

S = 2250 (30 / 100) / (2700 – 450) (30 / 100) = 0.263 m.

New draft = 5.000 + 0.263 = 5.263 metres.

BM = I*CL intact WP area / vol of displacement

BM = [LB^3 – (lb^3(30 / 100)] / 12V

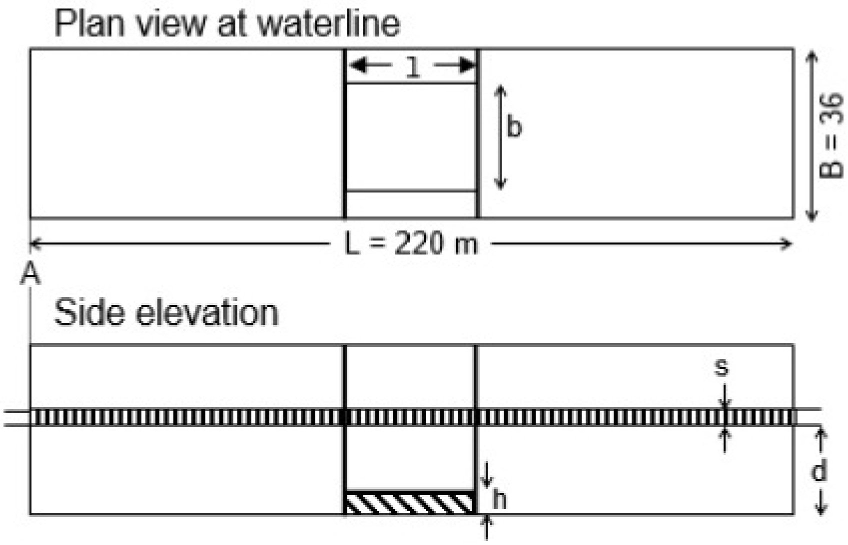
BM = 150 (18^3) – [25 (18^3) (30 / 100)] / 12 (150 x 18 x 5)

BM = 5.130 m

Note: Volume of displacement is constant

BM	= 5.130 m
KB = new draft/2	= 2.632 m
KM	= 7.762 m
KG	= 4.000 m
GM (answer b)	= 3.762 m

Example 3: A box-shaped vessel 220 x 36 m is afloat in SW at an even keel draft of 10 m. KG = 12 m. An empty DB tank 1.8 m high, 20 m long & 18 m wide, situated centrally, is bilged. Find the GM before and after bilging.


Plan view at waterline

Side elevation

Before bilging

BM = I*CL / V = $LB^3 / 12V$ = $220 (36^3) / 12 (79200)$

BM = 10.800 m

BM	= 10.800 m
KB = ½ draft	= 5.000 m
KM	= 15.800 m
KG	= 12.000 m
GM (answer a)	= 3.800 m

After bilging

S = buoyancy vol lost / intact WP area

S = 20 (18) 1.8 / (220 x 36) = 0.082 m

New draft = 10.0 + 0.082 = 10.082 metres.

Note: Here new KB is NOT = ½ new draft.

Taking moments of vol about K:

Final V (final KB) = original V (its KB) – vol lost (its KB) + vol regained (its KB)

Note: KB of vol regained = old draft + ½S

79200 (KB) = 79200 (5) – 648 (0.9) + 648 (10.041)

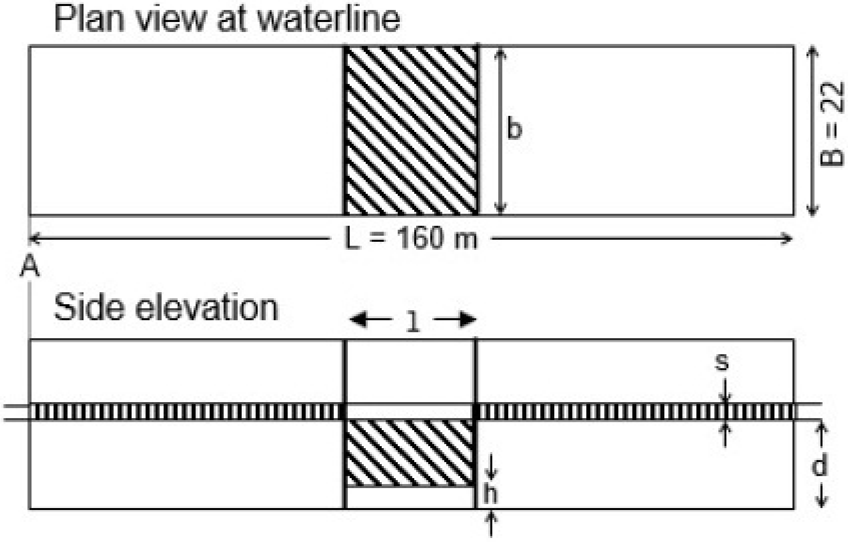
New KB = 5.075 metres.

Note: Since neither the water plane nor the volume of displacement is affected by bilging <u>in this case</u>, BM after bilging is the same as before.

KM = KB + BM = 5.075 + 10.8 = 15.875 m

GM = KM - KG = 15.875 - 12.000 = 3.875 m **(ans b)**

Example 4: A box-shaped vessel 160 x 22 m floats at 6 m SW draft. KG = 9 m. Its DB tanks are 1m high. Find the GM if a hold amidships, 26 m long and 22 m with p = 40%, gets bilged.



S = volume lost / intact WP area

S = 26 (22) 5 (40 / 100) / [160 (22) – 26 (40 / 100) 22]

S = 1144 / 3291.2 =0.348 metres

New draft = 6.000 + 0.348= 6.348 metres

Note: Here new KB is NOT= ½ new draft.

Taking moments of vol about K:
Final V (final KB) = original V (its KB) – vol lost (its KB) + vol regained (its KB)

Note: KB of vol regained = old draft + ½S
21120 (KB) = 21120 (3) – 1144 (3.5) + 1144 (6.174)

New KB = 3.145 metres.

BM = I*CL intact WP area / vol of displacement

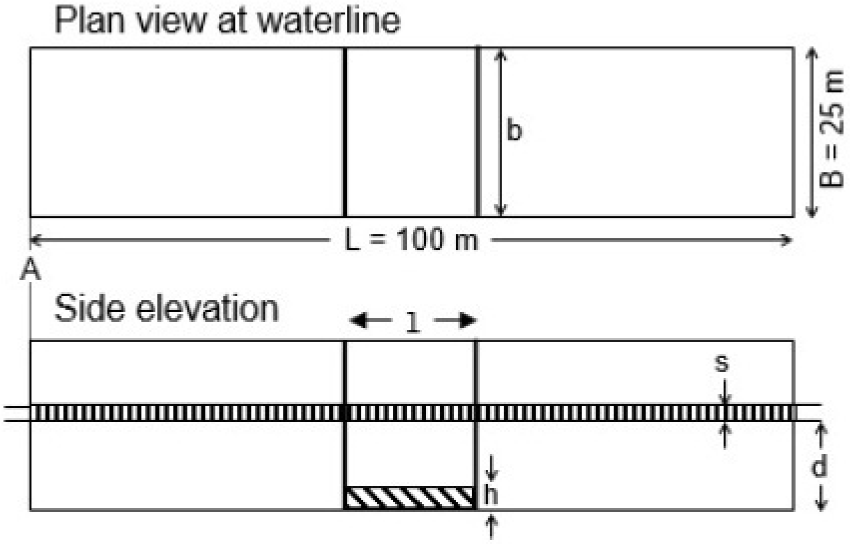
BM = LB^3– [lb^3(40 / 100)] / 12V
BM = 160(22^3) – [26(22^3)(40 / 100) / [12 (160 x 22 x 6)]

BM = 6.285 m

Note: Volume of displacement is constant

KM = KB + BM = 3.145 + 6.285 =9.430 m
GM = KM – KG = 9.430 – 9.000 =0.430 m **(answer)**

Example 5: A box-shaped vessel 100 m long and 25 m wide floats at 5 m SW draft. KG = 10 m. A DB tank amidships 20 m long, 25 m wide and 1.8 m high, full of SW, gets bilged. Find the GM before and after bilging.



Before bilging
BM = I / V = LB^3 / 12V = 100 (25^3) / 12(12500)
BM = 10.417 m

KB = d / 2 = 2.5 m
KM = KB + BM = 2.500 + 10.417 = 12.917 m
GM = KM – KG = 12.917 – 10.00 = 2.917 m **(ans a)**

Note: After bilging, the SW in the DB is no longer part of the ship. First assume that the SW was pumped out and calculate the new draft, KG & W. Then, bilge the empty tank & calculate as usual.

W = LBd (1.025) = 100 (25) 5 (1.025) = 12812.5 t
w = lbh (1.025) = 20 (25) 1.8 (1.025) = 922.5 t

Remarks	Weight	KG	Moment
Ship	12812.5	10.0	128125.00
SW	-922.5	00.9	830.25
Final	11890		127294.75

Final KG = 127294.75 / 11890 = 10.706 m.

New draft = 11890 / (100) 25 (1.025) = 4.640 m

After pumping out
W = 11890 t, V = 11600 m^3, d = 4.640 m

KB = 2.320 m, KG = 10.706 m.

After bilging
S = volume of lost buoyancy / intact water-plane area S = 900 / 2500 = 0.360 m

New draft = 4.640 + 0.360 = 5.000 metres.

Note: Here new KB is NOT half new draft.

Taking moments of vol about K:

Final V (final KB) = original V (its KB) – vol lost (its KB) + vol regained (its KB)

11600 (KB) = 11600 (2.32) – 900 (0.9) + 900 (4.82)

Note: KB of vol regained = old draft + S/2

New KB = 2.624 metres. <u>I*CL is unchanged</u>

BM = I / V = 130208.333 / 11600 = 11.225 m

KM = KB + BM = 2.624 + 11.225 = 13.849 m
GM = KM - KG = 13.849 - 10.706 = 3.143 m **(ans b).**

Example 6: If in example 5, the DB tank was full of DO of RD 0.88, find the GM before and after bilging.
The details in brief are: L = 100 m, B = 25 m, d = 5 m,
KG = 10 m, l = 20 m, b = 25 m, h = 1.8 m.

Before bilging
As calculated already in example 5:
KM = KB + BM = 2.500 + 10.417 = 12.917 m
GM = KM – KG = 12.917 – 10.00 = 2.917 m **(ans a)**

Note: After bilging, the DO in the DB is no longer part of the ship. First assume that the DO was discharged and calculate the new draft, KG & W. Then, bilge the empty tank & calculate as usual.

W = LBd (1.025) = 100 (25) 5 (1.025) = 12812.5 t
w = lbh (0.88) = 20 (25) 1.8 (0.88) = 792.0 t

Remarks	Weight	KG	Moment
Ship	12812.5	10.0	128125.00
DO	-792.0	00.9	712.80
Final	12020.5		127412.20

Final KG = 127412.20 / 12020.5 = 10.600 m.

New draft = 12020.5 / (100) 25 (1.025) = 4.691 m.

After pumping out

W = 12020.5 t, V = 11727.5 m^3, d = 4.691 m
KB = 2.345 m, KG = 10.600 m.

After bilging

S = volume of lost buoyancy / intact water-plane area
S = 900 / 2500 = 0.36 m.

New draft = 4.691 + 0.360 = 5.051 metres

Note: Here new KB is NOT half new draft.

Taking moments of vol about K:
Final V (final KB) = original V (its KB) – vol lost (its KB) + vol regained (its KB).
Note: KB of vol regained = old draft + S/2

11727.5 (Final KB) = 11727.5 (2.345) – 900 (0.9) + 900 (4.871)

Final KB = 2.650 metres. I*CL is unchanged.

BM = I / V = 130208.333 / 11727.5 = 11.103 m.

KM = KB + BM = 2.650 + 11.103 = 13.753 m
GM = KM - KG = 13.753 – 10.600 = 3.153 m **(ans b)**

Exercise 6
(Bilging amidships compartment - GM)

1. A box-shaped vessel 110 m long & 16 m wide floats in SW at 4 m even keel draft. An empty central compartment 16 m long & 10 m wide is bilged. Find the KM before and after bilging.
Answer: (a) 7.333 m (b) 7.344 m.

2. A box-shaped vessel 140 m long & 20 m wide floats in FW at 7 m even keel draft. KG = 8 m. An empty central compartment, 24 m long and 20 m wide, gets bilged. Find the GM before & after bilging.
Answer: (a) 0.262 m (b) 0.170 m.

3. A box-shaped vessel 150 m long & 25 m wide floats in SW at 6 m even keel draft. KG = 10 m. An empty amidships compartment on the centre line, 25 m long & 18 m wide, has a WT flat 2 m high. Find the GM before and after it is bilged below this WT flat.

Answer: (a) 1.681 m (b) 1.886 m.

4. A box-shaped vessel 200 m long & 26 m wide floats in SW at 8 m even keel draft. KG = 9 m. An empty amidships compartment, 28 m long and 26 m wide, has a WT flat 1.6 m above the keel. Find the GM before and after it is bilged above this flat.

Answer: (a) 2.042 m (b) 1.473 m.

5. A box-shaped vessel 210 m long and 25 m wide floats in SW at 10 m draft fwd and aft. KG is 10.6 m. An empty amidships compartment 30 m long and 25 m wide has a watertight flat 10.5 m above the keel. Find the GM if this compartment is bilged.

Answer: 0.433 m.

6. A box-shaped vessel 150 m long & 25 m wide floats in SW at 6 m even keel draft. KG = 10 m. An amidships compartment on the centre line, 25 m long & 18 m wide, has a DB tank below it, of same length and breadth and 2 m high. The DB tank is half full of HFO of RD 0.95. Find the GM before and after the DB tank gets bilged. No other tanks on the ship were slack.

(FSC to be allowed where applicable).

Answer: (a) 1.181 m fluid (b) 1.815 m (no FSC).

7. A box-shaped vessel 140 m long & 20 m wide floats in FW at 7 m even keel draft. KG = 8 m. A central compartment, 24 m long and 20 m wide, with p = 40%, gets bilged. Find the GM before & after bilging.

Answer: (a) 0.262 m (b) -0.107 m.

8. A box-shaped vessel 200 m long & 26 m wide floats in SW at 8 m even keel draft. KG = 9 m. An amidships cargo hold, 28 m long and 26 m wide, has a DB tank below it, 1.6 m high. Find the GM before and after the cargo hold gets bilged, given that the cargo hold was full of coal of SF 1.25 & RD 1.3.

Answer: (a) 2.042 m (b) p = 38.5%; 1.575 m.

9. A box-shaped vessel 110 m long & 16 m wide floats in SW at 4 m even keel draft. KG = 6 m. A central compartment 16 m long & 10 m wide, containing SW ballast to a sounding of 6 m is bilged. Find the GM before and after bilging.

Answer: (a) 1.144 m fluid (b) 1.382 m (no FSC).

10. A box-shaped vessel 210 m long and 25 m wide floats in SW at 10 m draft fwd and aft. KG is 10.6 m. An amidships compartment 30 m long and 25 m wide has a watertight flat 10.5 m above the keel. Find the GM if this compartment is bilged given that p = 50%.

Answer: Final GM (after bilging) = -0.008 m

5. BILGING OF AN END COMPARTMENT

The increase in draft, and the effect on GM, resulting from bilging an end compartment is the same as that caused by bilging an amidships compartment of similar dimensions. Since you would have studied the effects of bilging amidships compartments in the previous chapter, needless repetition has been avoided here.

The bilging of an end compartment causes the COB of the ship to be longitudinally displaced away from the bilged compartment. Since the position of the COG of the ship remains unaffected by bilging, the consequent longitudinal separation of the COB and the COG (i.e., BG) results in a trimming moment (W.BG). Bilging an end compartment, therefore, causes a change in the trim of the ship.

The foregoing statement can be illustrated simply by the worked examples that follow. However, before proceeding with the worked examples, it is necessary to know the 'theorem of parallel axes' as applicable to rectangles.

Note: The theorem of parallel axes with respect to other regular shapes is explained later in this book in the chapter titled 'Centre of pressure'.

Theorem of parallel axes: If I*GG (here * is used to indicate the word 'about') is the moment of inertia of an area about an axis passing through its geometric centre, and ZZ is an axis parallel to GG, then:

I*ZZ = I*GG + Ay^2 where 'y' is the distance between the axis GG and the axis ZZ.

Case 1

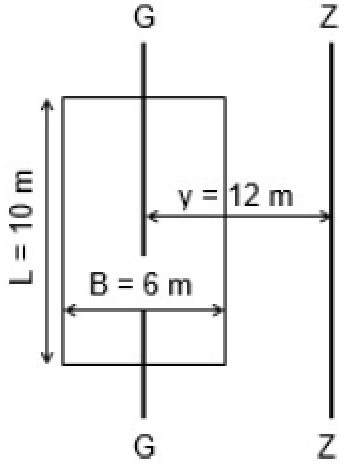
If L = 10 m, B = 6 m and
y = 12 m, I*ZZ =?

$I^*ZZ = I^*GG + Ay^2$

$= LB^3 / 12 + LB\,(y^2)$

$= 180 + 8640$

$= 8820\ m^4$.



Case 2

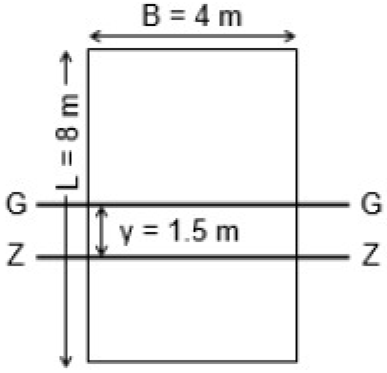
If L = 8 m, B = 4 m and
y = 1.5 m, I*ZZ = ?

$I^*ZZ = 1^*GG + Ay^2$

$= BL^3 /12 + LB\,(y^2)$

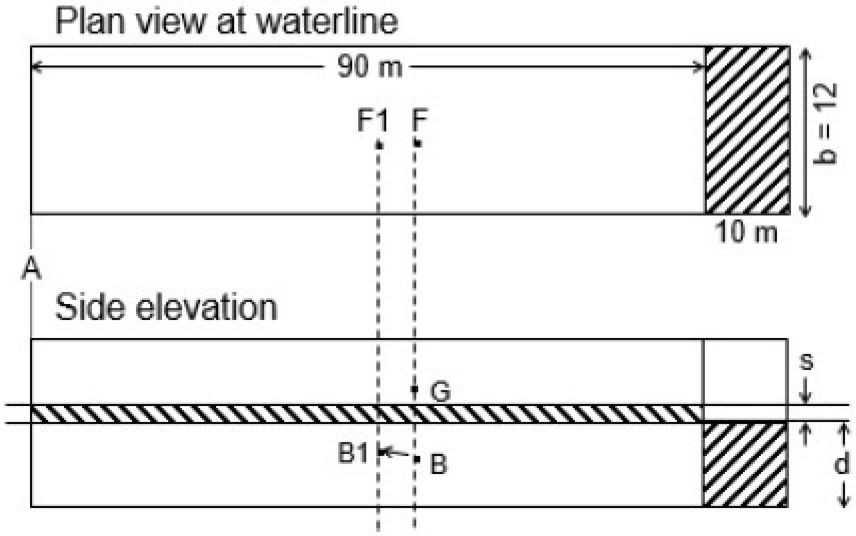
$= 170.667 + 72$

$= 242.667\ m^4$.



Example 1

A box-shaped vessel 100 m long and 12 m wide floats at an even keel draft of 6 m in SW. The compartment at the forward end, 10 m long and 12 m broad, is empty. Find the new drafts fwd and aft if this compartment gets bilged.



Before bilging, AB = AG = AF = 50 m.

V = 100 x 12 x 6 = 7200 m^3 (unchanged by bilging)
W = 7200 x 1.025 = 7380 t (unchanged by bilging)

S = volume of lost buoyancy / Intact water-plane area

S = lbd / (LB – lb) = 10 x 12 x 6 / (1200 – 120)

S = 720 / 1080 = 0.667 m

Final hydraft = 6.000 + 0.667 = 6.667 m.

Note: Since the intact underwater volume of the ship is rectangular and 90 m long, its AB and AF are both = 45 m.

BG = AG – new AB = 50 – 45 = 5 metres.
Since the new COB is aft of the COG, the trim caused will be by the head.

TM = W. BG = 7380 x 5 = 36900 tm by head.

Trim caused or Tc = TM / MCTC. However, the new MCTC has to be calculated.

MCTC = (W.GM_L) / 100 L or (W.BM_L) / 100L

$GM_L = KM_L - KG$. Since KG is not given here, BM_L may be used instead of GM_L.

Note: The 'L' to be used in this formula is the **total length** of the water-plane i.e., the LBP of the ship.

$BM_L = I*COF$ of intact WP / V = 12 (90^3) / 12 (7200)

$BM_L = 101.25$ m.

MCTC = ($W.BM_L$) / 100L = 7380 (101.25) / 100 (100)

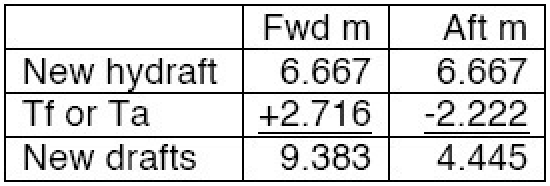
MCTC = 74.723 tm.

Tc = TM / MCTC = 36900 / 74.723 = 493.8 cm

Tc = 4.938 m by the head.

Ta = (AF / L) Tc = (45 / 100) (4.938) = 2.222 m

Tf = Tc – Ta = 4.938 – 2.222 = 2.716 m.



	Fwd m	Aft m
New hydraft	6.667	6.667
Tf or Ta	+2.716	-2.222
New drafts	9.383	4.445

Note: If the transverse GM in the bilged condition is asked, the method of calculation is the same as that explained under 'Bilging of amidships compartments' in the previous chapter.

Example 2

A box-shaped vessel 100 m long and 12 m wide floats at an even keel draft of 6 m in SW. The compartment at the forward end, 10 m long and 12 m broad, has p = 40% because of cargo in it. Find the new drafts fwd and aft if this compartment gets bilged.

Note: This is the same as example 1, except that the bilged compartment has p = 40%.

Before bilging, AB = AG = AF = 50 metres.

V = 100 x 12 x 6 = 7200 m^3 (unchanged by bilging)
W = 7200 x 1.025 = 7380 t (unchanged by bilging)

S = volume of lost buoyancy / Intact water-plane area

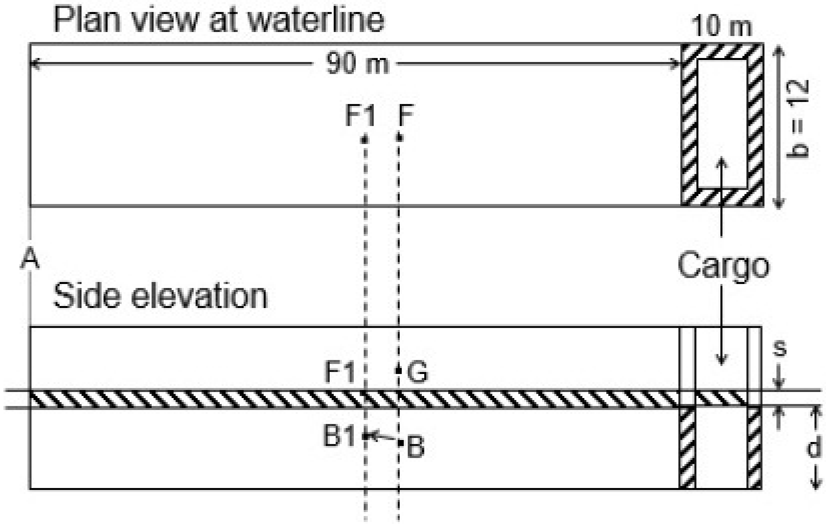
S = 10 x 12 x 6 (40 / 100) / [100 (12) – 10 (12)(40 / 100)]

S = 0.250 metre.

New hydraft = 6.000 + 0.250 = 6.250 m.

Note 1: The new COB will be the geometric centre of the combined volume of the rectangle 90 m long and the cargo immersed in the bilged compartment. AB is **not** 45 m as was in example 1.

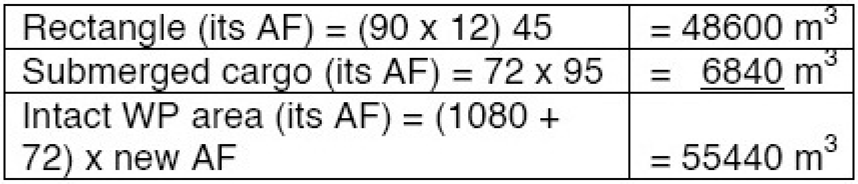
Note 2: Since the water-plane is uniform at all drafts after bilging, but before trimming, new AB = new AF.



As p is given as 40%, cargo must be 60%.
So, area of cargo = lb (60 / 100) = 72 m^2.
Volume of submerged cargo = 72 x 6 = 432 m^3.

To find new AF & AB (both are of same value here).

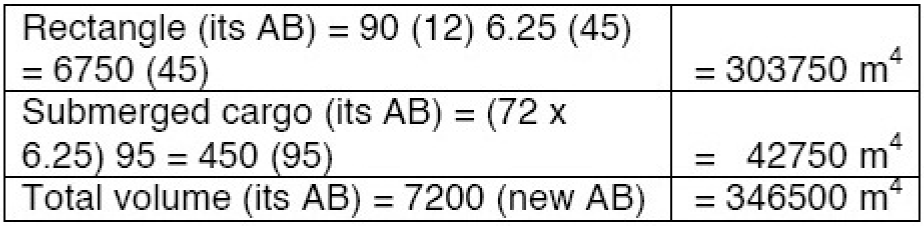
Alternative 1
Find new AF by taking moments of area about A.



Rectangle (its AF) = (90 x 12) 45	= 48600 m^3
Submerged cargo (its AF) = 72 x 95	= 6840 m^3
Intact WP area (its AF) = (1080 + 72) x new AF	= 55440 m^3

New AF = 55440 / 1152 = 48.125 m.

Alternative 2
Find new AB by taking moments of volume about A.



Rectangle (its AB) = 90 (12) 6.25 (45) = 6750 (45)	= 303750 m^4
Submerged cargo (its AB) = (72 x 6.25) 95 = 450 (95)	= 42750 m^4
Total volume (its AB) = 7200 (new AB)	= 346500 m^4

New AB = 346500 / 7200 = 48.125 m.

BG = (AG – new AB) = 50 – 48.125 = 1.875 m.

Since the new COB is abaft of COG, the trim caused will be by the head.

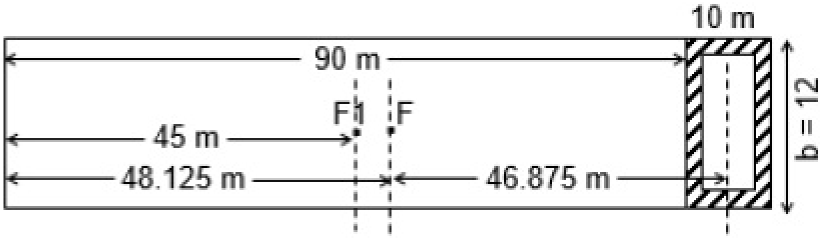
TM = W.BG = 7380 (1.875) = 13837.5 tm.

Tc = TM / MCTC. However, the MCTC in the bilged condition must be calculated.

MCTC = W x GM_L / 100L or W x BM_L / 100L.
Since KG is not given, BM_L is used instead of GM_L.
Note: In this formula, L represents LBP.

BML = (I*COF_1 of intact WP area) / V

Plan view at waterline



I^*COF_1 intact WP area = I^*COF_1 rectangle / I^*COF_1 of cargo area

I^*COF_1 rectangle = $[12(90^3) / 12] + (12)\ 90\ (3.125^2)$

= 729000 + 10546.875 = 739546.875 m^4.

I^*COF_1 cargo = $[12(10^3) / 12 + 120\ (46.875^2)]\ 60 / 100$

= (1000 + 2636710.88) (60 / 100) = 158803.13 m^4.

I^*COF_1 intact WP area
= 739546.875 + 158803.13 = 898350 m^4.

BML = 898350 / 7200 = 124.771 metres.

MCTC = (7380 x 124.771) / (100 x 100) = 92.081 tm.

Tc = TM / MCTC = 13837.5 / 92.081 = 150.3 cm

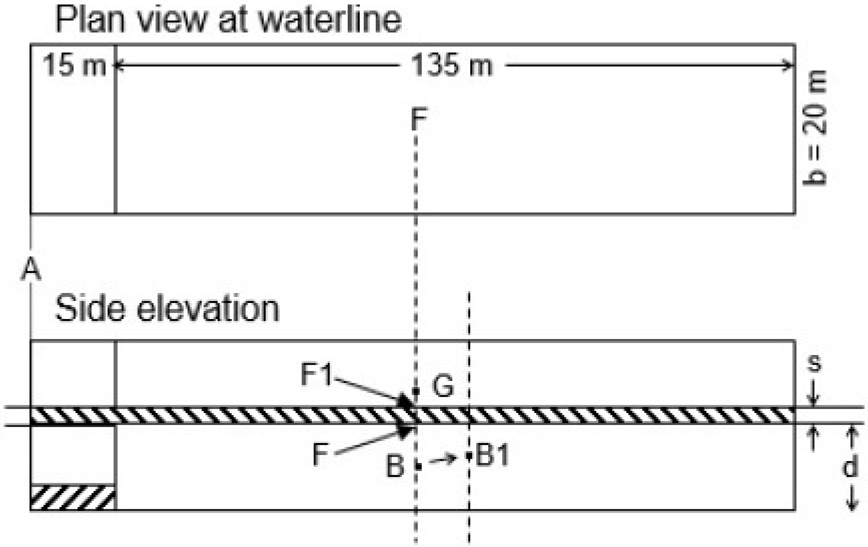
Tc = 1.503 m by the head.
Ta = (AF / L) Tc = (48.125 / 100) (1.503) = 0.723 m.

Tf = Tc – Ta = 1.503 – 0.723 = 0.780 m.

	Fwd m	Aft m
Final hydraft	6.250	6.250
Tf or Ta	+0.780	-0.723
Final drafts	7.030	5.527

Example 3

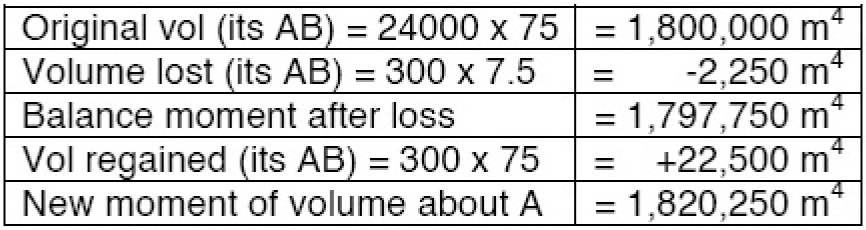
A box-shaped vessel 150 m long and 20 m wide floats at an even keel draft of 8 m in SW. The aftermost compartment, 15 m long & 20 m wide, has a water-tight flat 1 m above the keel, forming the top of the DB tank. Calculate the drafts fwd & aft if this empty DB tank is bilged.



$V = 150 \times 20 \times 8 = 24000\ m^3$ (unchanged by bilging)
$W = 24000\ (1.025) = 24600$ t (unchanged by bilging)
Before bilging AG = AB = AF = 75 metres.
After bilging AF = 75 m but new AB > 75 m

S = volume of lost buoyancy / Intact water-plane area $S = 15 \times 20 \times 1 / (150 \times 20) = 0.100$ metre.
New hydraft = 8.000 + 0.100 = 8.100 m.

To find new AB, moments of volume about A:



Original vol (its AB) = 24000 x 75	= 1,800,000 m^4
Volume lost (its AB) = 300 x 7.5	= -2,250 m^4
Balance moment after loss	= 1,797,750 m^4
Vol regained (its AB) = 300 x 75	= +22,500 m^4
New moment of volume about A	= 1,820,250 m^4

New vol (new AB) = 24000 x new AB = 1,820,250 m^4.
New AB = 1,820,250 / 24000 = 75.844 m.

BG = new AB – AG = 75.844 – 75 = 0.844 m

Since new AB > AG, Tc will be by stern.

TM = W.BG = 24600 x 0.844 = 20762.4 tm.

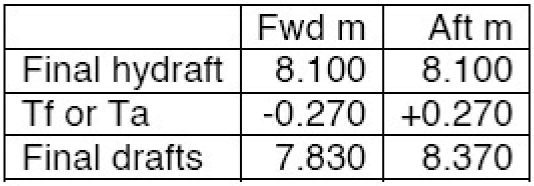
MCTC = W. GM_L / 100L or = W.BM_L / 100L
Since KG is not given, BM_L may be used.

BM_L = I*COF_1 intact WP area / V
BM_L = 20(150^3) / 12 (24000) = 234.375 m.

MCTC = 24600 (234.375) / (100 x 150) = 384.375 tm.

It is obvious from the foregoing calculation that, in this case, BM_L & MCTC are unchanged by bilging.

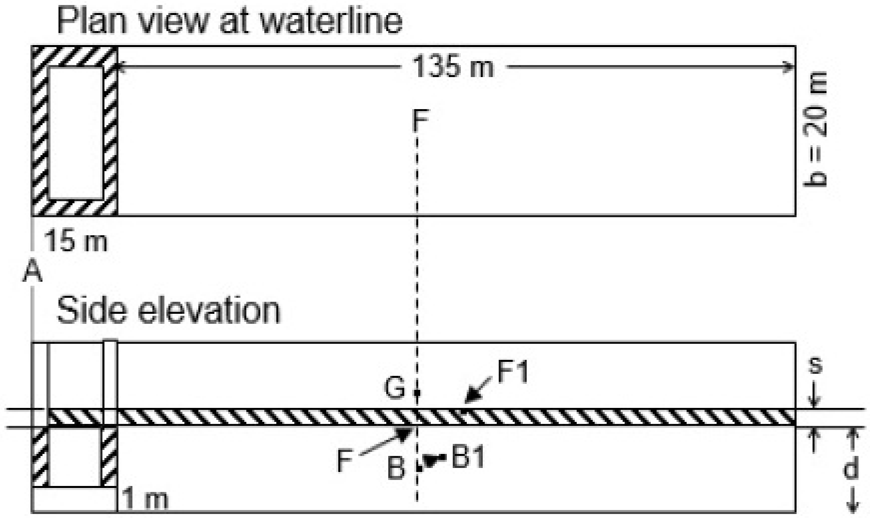
Tc = TM / MCTC = 20762.4 / 384.375 = 54.0 cm
Ta = (AF / L) Tc = (75 / 150) (0.54) = 0.270 metre.
Tf = Tc – Ta = 0.540 – 0.270 = 0.270 m.



	Fwd m	Aft m
Final hydraft	8.100	8.100
Tf or Ta	-0.270	+0.270
Final drafts	7.830	8.370

Example 4

A box-shaped vessel 150 m long and 20 m wide floats at an even keel draft of 8 m in SW. The aftermost cargo hold, 15 m long and 20 m wide, has a DB tank 1 m high, below it. Calculate the drafts fwd & aft if this cargo hold, with p = 60 %, is bilged.



Note: The AF_1 & AB_1 shown above are symbolic and can be ascertained only after actual calculation.

V = 150 x 20 x 8 = 24000 m^3 (unchanged by bilging)
W = 24000 (1.025) = 24600 t (unchanged by bilging)

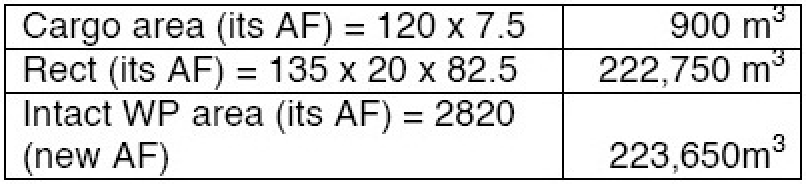
Before bilging, AG = AB = AF = 75 metres.
After bilging, $AB_1 > 75$ m, $AF_1 > 75$ m, but $AB_1 \neq AF_1$.

S = volume of lost buoyancy / Intact water-plane area

S = 15 x 20 x 7(0.6) / [(150 x 20) – 15 x 20(0.6)]
S = 0.447 m
New hydraft = 8.000 + 0.447 = 8.447 m.

As p is given as 60%, cargo must be 40%.
So area of cargo = 15 x 20 x 40/100 = 120 m^2

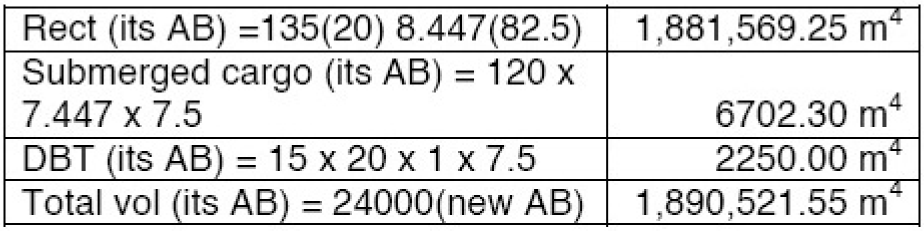
To find new AF, moments of area about A:



Cargo area (its AF) = 120 x 7.5	900 m^3
Rect (its AF) = 135 x 20 x 82.5	222,750 m^3
Intact WP area (its AF) = 2820 (new AF)	223,650m^3

New AF = 223,650 / 2820 = 79.309 m.

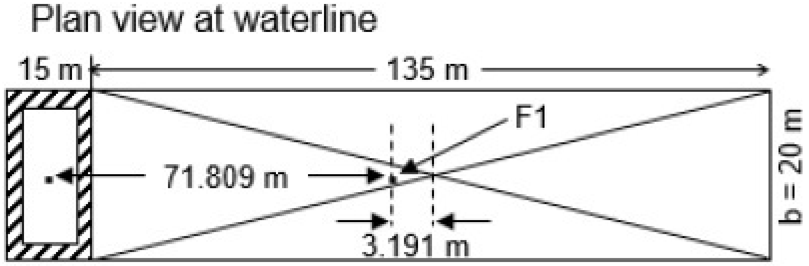
To find new AB, moments of volume about A:



Rect (its AB) =135(20) 8.447(82.5)	1,881,569.25 m^4
Submerged cargo (its AB) = 120 x 7.447 x 7.5	6702.30 m^4
DBT (its AB) = 15 x 20 x 1 x 7.5	2250.00 m^4
Total vol (its AB) = 24000(new AB)	1,890,521.55 m^4

New AB = 1,890,521.55 / 24000 = 78.772 m

BG = new AB – AG = 78.772 – 75 = 3.772 m
Since new AB > AG, Tc will be by the stern.



TM = W . BG = 24600 x 3.772 = 92791.2 tm.
Tc = TM / MCTC and MCTC = W.BM_L / 100L.

BM_L = I*COF_1 intact water-plane area / volume

I*COF_1 WP = I*COF_1 rectangle + I*COF_1 cargo

I*COF_1 rectangle = 20 (135^3) / 12 + (20) 135 (3.191^2)
= 4128117.698 m^4

I*COF_1 cargo area =
[20 (15^3) /12 + (20 x 15 x 71.809^2)] 40 / 100
I*COF_1 cargo area = 621033.898 m^4

I*COF_1 intact WP area = 4749151.596 m^4

BM_L = 4749151.596 / 24000 = 197.881 m

MCTC = 24600(197.881) / (100 x 150) = 324.525 tm
Tc = 92791.2 / 324.525 = 285.9 cm = 2.859 m

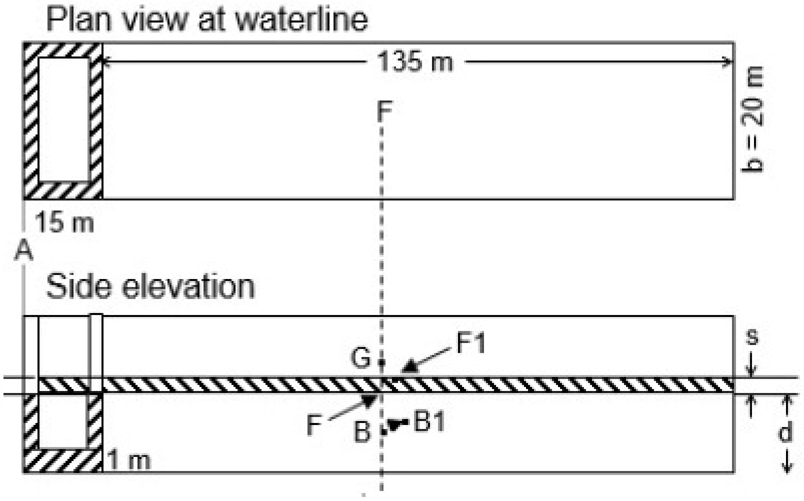
Ta = (AF / L) Tc = (79.309 / 150) (2.859) = 1.512 m

Tf = Tc – Ta = 2.859 – 1.512 = 1.347 m.

	Fwd m	Aft m
Final hydraft	8.447	8.447
Tf or Ta	-1.347	+1.512
Final drafts	7.100	9.959

Example 5

A box-shaped vessel 150 m long and 20 m wide floats at an even keel draft of 8 m in SW. The aftermost cargo hold, 15 m long and 20 m wide, has an empty DB tank 1 m high, below it. Calculate the drafts fwd & aft if this cargo hold, with p = 60 %, and the DB tank are bilge.
Note: Same as example 4, but DB tank also is bilged.



Note: The longitudinal positions of F_1 & B_1 shown above are symbolic & can be ascertained only after calculation of AF_1 & AB_1.

V = 150 x 20 x 8 = 24000 m^3 (unchanged by bilging)
W = 24000 (1.025) = 24600 t (unchanged by bilging)

Before bilging, AG = AB = AF = 75 metres.
After bilging, $AB_1 > 75$ m, $AF_1 > 75$ m, but $AB_1 \neq AF_1$.
S = volume of lost buoyancy / Intact water-plane area

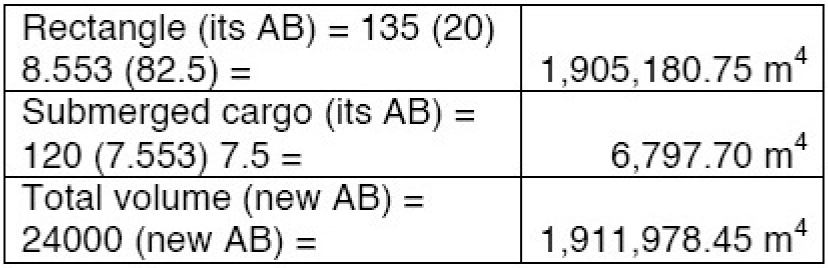
$$S = \frac{15(20)\ 1 + 15\ (20)\ 7\ (60/100)}{150\ (20) - 15 \times 20\ (60/100)} = 0.553 \text{ m}$$

New hydraft = 8.000 + 0.553 = 8.553m.

The following particulars of the vessel, already calculated in example 4, are applicable here without any change:

AF = 79.309 m, BM_L = 197.825 m, MCTC = 324.433 tm, cargo area = 120 m^2.

To find new AB, moments of vol about A:



Rectangle (its AB) = 135 (20) 8.553 (82.5) =	1,905,180.75 m^4
Submerged cargo (its AB) = 120 (7.553) 7.5 =	6,797.70 m^4
Total volume (new AB) = 24000 (new AB) =	1,911,978.45 m^4

New AB = 1,911,978.45 / 24000 = 79.666 m
BG = new AB – AG = 79.666 – 75 = 4.666 m

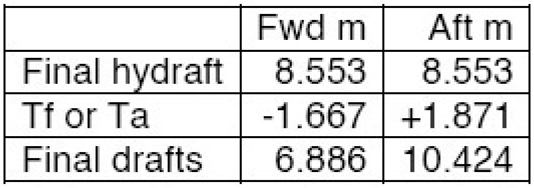
Since new AB >AG, Tc will be by the stern

TM = W.BG = 24600 x 4.666 = 114,783.6 tm

Tc = 114783.6 / 324.433 = 353.8 cm = 3.538 m.

Ta = (AF / L) Tc = (79.309 / 150) (3.538) = 1.871 m

Tf = Tc – Ta = 3.538 – 1.871 = 1.667 m.



	Fwd m	Aft m
Final hydraft	8.553	8.553
Tf or Ta	-1.667	+1.871
Final drafts	6.886	10.424

Exercise 7
(Bilging an end compartment)

1. A box-shaped vessel 200 m long & 25 m wide floats at an even keel draft of 9 m in SW. The aftermost compartment, 20 m long & 25 m wide, which was empty, gets bilged. Find the new drafts fwd and aft.

Answer: S 1.000 m, BM_L 270 m, MCTC 622.688 BG 10 m, Fwd 6.667 m, Aft 14.074 m.

2. A box-shaped vessel 180 m long & 18 m wide is afloat in SW at an even keel draft of 8 m. The forward-most compartment has a DB tank, 15 m long, 18 m wide & 1.5 m high, full of SW, Find the new drafts fwd and aft if this DB tank gets bilged.

Answer: Fwd 8.000 mAft 8.000 m.

3. A vessel 160 m long and 20 m wide is box-shaped and afloat in SW at an even keel draft of 7.6 m. The forward-most DB tank is 16 m long, 20 m wide and 1.2 m deep. Find the new drafts fwd and aft if this tank, which was empty, gets bilged. **Answer**: S 0.12 m, BM_L 280.702 m, MCTC 437.334, BG 1.137 m, Fwd 8.044 m, Aft 7.396 m.

4. A vessel 150 m long and 14 m wide is box-shaped and afloat in SW at an even keel draft of 8 m. The aftermost compartment, 18 m long and 14 m wide, is full of cargo. Find the new drafts fwd and aft if this compartment, having p = 30%, gets bilged.

Answer: S 0.299 m, BM_L 213.919 m, MCTC 245.579, BG 2.465 m, Fwd 7.463 m, Aft 9.192 m.

5. A box-shaped vessel 175 m long and 18 m wide is floating in SW at an even keel draft of 6.6 m. The forward-most compartment is 18 m long & 18 m wide and has a DB tank 1 m high. The LH, full of cargo, gets bilged. Calculate the final drafts fwd & aft, assuming p = 36%.

Answer: S 0.215 m, BM_L 350.626 m, MCTC 426.957, BG 2.565 m, Fwd 7.477 m, Aft 6.197 m.

6. A box-shaped vessel 175 m long and 18 m wide is floating in SW at an even keel draft of 6.6 m. The forward-most compartment is 18 m long and 18 m wide and has an empty DB tank below it, 1 m

high. The LH is full of cargo with p = 36%. Calculate the final drafts fwd & aft, if the cargo hold and the DB tank get bilged.

Answer: S 0.322 m, BM_L 350.626 m, MCTC 426.957, BG 3.833 m, Fwd 7.912 m, Aft 5.999 m.

7. A box-shaped vessel 200 m long & 20 m broad is afloat in SW at an even keel draft of 8 m. There is a DB tank at th%.e forward end, 18 m long, 20 m wide and 1.4 m high, which has HFO of RD 0.95 to a sounding of 0.5 m. Find the new drafts fwd and aft if this tank gets bilged.

(**Hint**: Bilging means that sea water can freely go in and out of the compartment and so can HFO. The HFO is NOT, therefore, in the ship anymore. So find the new W, the new AG and the new hydraft assuming that the HFO is pumped out. Then bilge the tank, find the new even keel AB, as in past questions, & complete the calculation).

Answer: S 0.126 m, BM_L 418.850 m, MCTC 683.333, BG 0.967 m, Fwd 8.315 m, Aft 7.853 m.

8. A box-shaped tank vessel, 200 m long and 20 m wide, is afloat in SW at an even keel draft of 6.2 m. The after-most tanks (No: 8 P, C & S) are each 16 m long. The wing tanks are 6 m broad each and the centre tank is 8 m broad. All three tanks are empty. Find the new drafts fwd & aft if both the wing tanks – No: 8 P & No: 8 S – get bilged.

Answer: S 0.313 m, BM_L 468.638 m, MCTC 595.638, BG 4.639 m, Fwd 5.569 m, Aft 7.549 m.

9. A box-shaped tank vessel, 160 m long and 18 m wide, is afloat in SW at an even keel draft of 9 m. The forward-most tanks (Nos: 1 P, C & S) are each 20 m long. The wing tanks are 5 m broad each while the centre tank is 8 m broad. No: 1 C, which had SW ballast to a sounding of 15 m, gets bilged. Find the new drafts fwd and aft.

(**Hint**: Find the new W, the new AG, and the new hydraft assuming that No: 1 C tank is discharged. Then bilge it, find the new even keel AB, as done in past questions, and complete the calculation).

Answer: S 0.480 m, BM_L 225.704 m, MCTC 340.079, BG 3.025 m, Fwd 7.520 m, Aft 9.664 m.

10. A box-shaped vessel, 100 m long & 12 m wide, floats at an even keel draft of 6 m in SW. The forward-most compartment, 10 m long and 12 m wide, full of general cargo, gets bilged. The drafts are then observed to be 7.03 m fwd & 5.53 m aft. By a simple calculation, find the approximate permeability of the compartment.

Answer: By one method 44.59 % and by another 46.7 %. So answer = approximately 46%.

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6. BILGING OF AN INTERMEDIATE COMPARTMENT

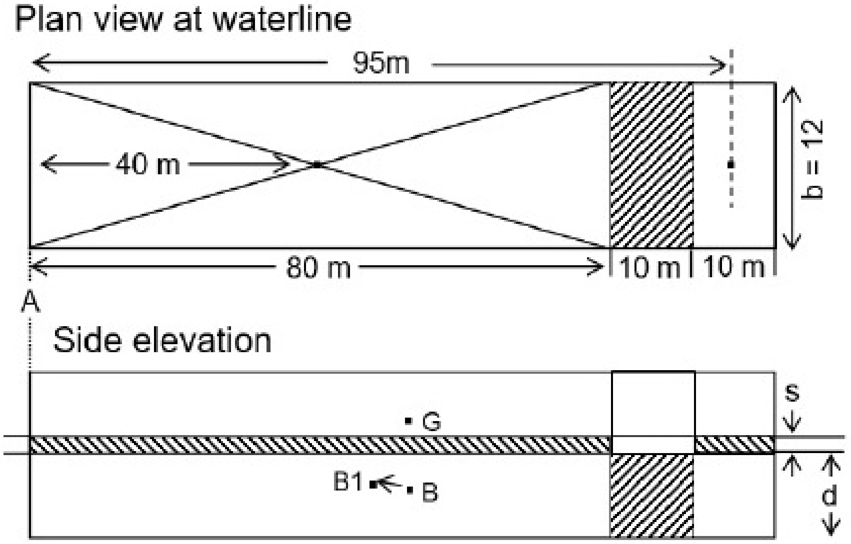
Having studied the effects of bilging amidships compartments and end compartments earlier in this book, you should have no difficulty in understanding the calculations involving the bilging of an intermediate compartment. Hence you have not been burdened by too many worked examples here.

The calculations in earlier chapters started with the vessel on an even keel. In this chapter, bilging of a compartment has been considered also when the vessel has an initial trim. This provides you with an interesting aspect to study.

Example 1

A box-shaped vessel 100 m long and 12 m wide floats at an even keel draft of 6 m in SW. No: 2 hold, 10 m long & 12 m broad, is empty. The forward bulkhead of this hold is 10 m from the forward end of the ship. Find the drafts fwd and aft if this hold is bilged.

$V = 100 \times 12 \times 6 = 7200\ m^3$ (Unchanged by bilging)
$W = 7200 \times 1.025 = 7380$ t (Unchanged by bilging)
Before bilging, AB = AG = AF = 50 metres.
After bilging, AB = AF and they are < 50 metres.
(See following diagram).



S = volume of lost buoyancy / Intact water-plane area

S = lbd / (LB-lb) = 10 x 12 x 6 / (1200 –120) = 0.667 m

Final hydraft = 6.000 + 0.667 = 6.667 m.

To find new AF, moments of area about A:

Large rect (its AF) = 80 x 12 x 40	= 38,400 m^3
Small rect (its AF) = 10 x 12 x 95	= $\underline{11,400}$ m^3
Intact WP (its AF) = 1080 (new AF)	= 49,800 m^3

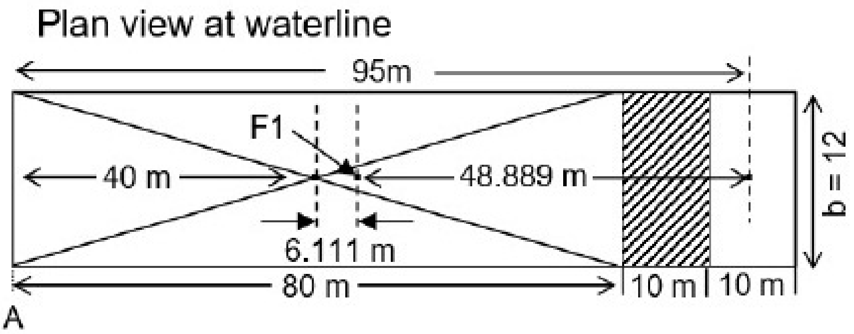
New AF = 49,800 / 1080 = 46.111 m.
In this case, new AB also = 46.111 m.

BG = AG – new AB = 50 – 46.111 = 3.889 m
Since new AB < AG, Tc will be by the head.

TM = W.BG = 7380 x 3.889 = 28,700 tm.
Tc = TM / MCTC and MCTC = W.BM_L / 100L.

BM_L = I*COF_1 intact WP / volume of displacement.

I*COF_1 intact WP area =
I*COF_1 large rectangle + I*COF_1 small rectangle.



I*COF large rectangle = 12 $(80^3)/12 + (12)\ 80\ (6.111^2)$ =	547,850.548 m^4
I*COF small rectangle = 12 $(10^3)\ /\ 12 + 120\ (48.889^2)$ =	287,816.119 m^4
I*COF intact WP =	835,666.667 m^4

BM_L = 835,666.667 / 7200 = 116.065 m.

$$MCTC = \frac{W.BM_L}{100L} = \frac{7380\ (116.065)}{100 \times 100} = 85.656 \text{ tm}$$

$$Tc = \frac{TM}{MCTC} = \frac{28{,}700}{85.6} = 335.1 \text{ cm} = 3.351 \text{ m.}$$

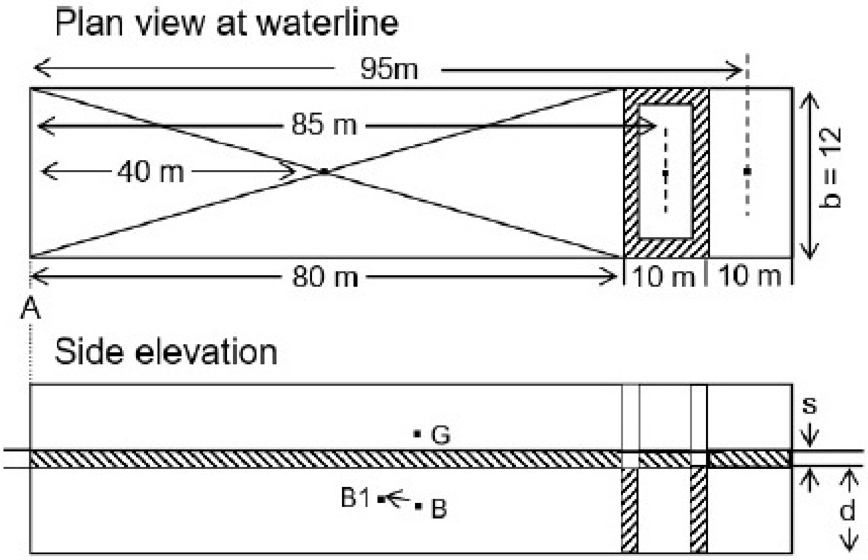
Ta = AF (Tc) / L = 46.111(3.351) / 100 = 1.545 m.

Tf = Tc – Ta = 3.351 – 1.545 = 1.806 m.

	Fwd m	Aft m
New hydraft	6.667	6.667
Tf or Ta	+1.806	-1.545
New drafts	8.473	5.122

Example 2

A box-shaped vessel 100 m long and 12 m wide floats at an even keel draft of 6 m in SW. No: 2 hold, 10 m long and 12 m broad, has p = 65%. The forward bulkhead of this hold is 10 m from the forward end of the ship. Find the drafts fwd and aft if this hold is bilged.



V = 100 x 12 x 6 = 7200 m^3 (Unchanged by bilging)
W = 7200 x 1.025 = 7380 t (Unchanged by bilging)

Before bilging, AB = AG = AF = 50 metres

S = volume of lost buoyancy / Intact water-plane area

$$S = \frac{10\,(12)\,6\,(65/100)}{1200 - (120)\,(65/100)} = \frac{468}{1122} = 0.417 \text{ m.}$$

New hydraft = 6.000 + 0.417 = 6.417 m.
Area of cargo = 120 x 0.35 = 42 m^2.

To find new AF, moments of area about A:

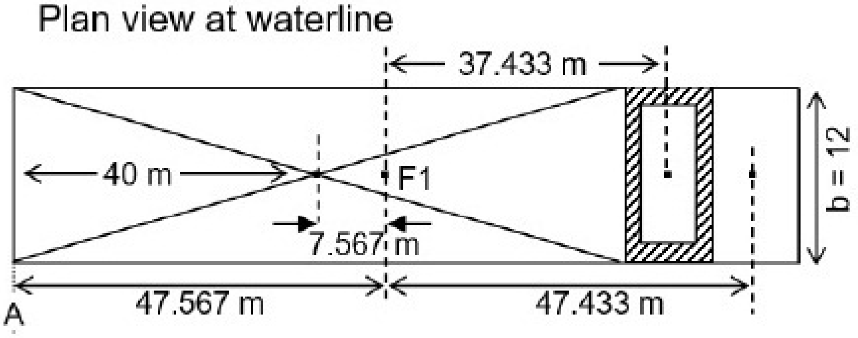
Large rect (its AF) = 80 x 12 x 40 =	38,400 m^3
Small rect (its AF) = 10 x 12 x 95 =	11,400 m^3
Cargo area (its AF) = 42 x 85 =	$\underline{3,570}$ m^3
Intact WP (its AF) = 1122 (new AF) =	53,370 m^3

New AF = 53,370 / 1122 = 47.567 m.
In this case, new AB also = 47.567 m.

BG = AG – new AB = 50 – 47.567 = 2.433 m

$$T_c = \frac{TM}{MCTC} \quad \text{and } MCTC = \frac{W.GM_L}{100L} \quad \text{or} \quad \frac{W.BM_L}{100L}$$

BM_L = I*COF$_1$ intact WP area / volume



I*COF$_1$ intact WP =
I*COF$_1$ large rect + I*COF$_1$ small rect + I*COF$_1$ cargo

I*COF$_1$ large rectangle = 12 $(80^3)/12 + (12)\ 80\ (7.567^2)$ =	566,969.109 m^4
I*COF$_1$ small rectangle = 12 $(10^3)/12 + 120\ (47.433^2)$ =	270,986.739 m^4
I*COF$_1$ cargo area = 12 $(10^3)/12 + 120\ (37.433^2)\ 35/100$ =	59,201.639 m^4
I*COF$_1$ intact WP =	897,157.487 m^4

BM_L = 89,7157.487 / 7200 = 124.605 m

MCTC = 7380 x 124.605 / (100 x 100) = 91.958 tm

$$Tc = \frac{TM}{MCTC} = \frac{7380\ (2.433)}{91.958} = 195.3\ cm = 1.953\ m$$

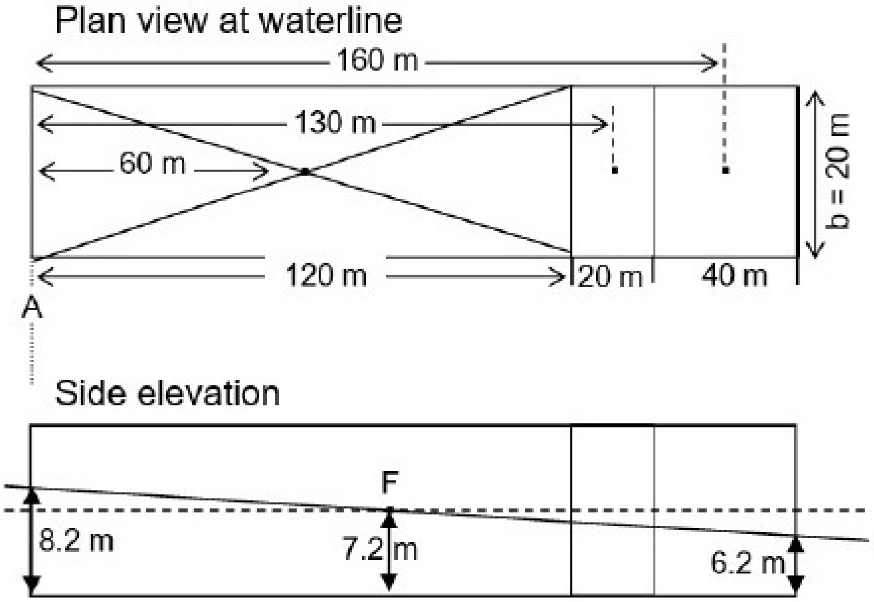
Ta = (AF/L) Tc = 47.567 x 1.953 /100 = 0.929 m.

Tf = Tc – Ta = 1.953 – 0.929 = 1.024 m.

	Fwd m	Aft m
New hydraft	6.417	6.417
Tf or Ta	+1.024	-0.929
New drafts	7.441	5.488

Example 3

A box-shaped vessel 180 m long and 20 m wide floats in SW at a draft of 6.2 m fwd & 8.2 m aft. No: 3 LH, beginning 40 m from the forward end is 20 m long and empty. Find the new drafts fwd and aft if this hold is bilged.



Note: As explained in 'Ship Stability at the Operational Level', trim is caused by the longitudinal separation of G & B and, in cases of bilging, we have considered that AG & KG do not change. Change of trim, due to bilging, is caused by the change in the AB of the ship.

In this example, where the vessel already has a trim at the commencement of the problem, we first work backwards and find the initial BG (before bilging) & thence the initial AB & AG which caused the initial trim. Then we bilge the compartment and find the new AB and thence progress as done in past examples.

V = 180 (20) 7.2 = 25920 m^3 (Unchanged by bilging)
W = 25920 x 1.025 = 26568 t (Unchanged by bilging)

$$\text{Trim in cm} = \frac{W.BG}{MCTC} \quad \text{or } BG = \frac{MCTC \times trim}{W}$$

$$BG = \frac{MCTC \times 200}{W} = \frac{W.BM_L}{100L} \times \frac{200}{W} = \frac{BM_L}{90}$$

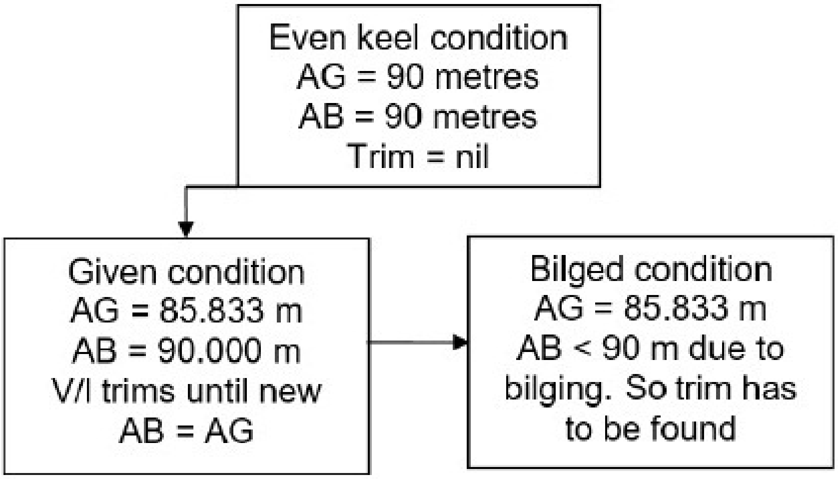
$$BG = \frac{I^*COF}{V\ (90)} = \frac{20\ (180^3)}{12\ (25920)\ 90} = 4.167 \text{ m}$$

Initial BG (before bilging) = 4.167 m

Since initial trim is by stern, AG < AB. When on even keel, the AB would have been 90 m.

So, AG of ship = 90 – 4.167 = 85.833 m.

The block diagram herein gives an over-view of the situation & the process followed:



Before bilging, AB = 90 m & AG = 85.33 m. If vessel is temporarily held on even keel draft of 7.2 m, we can find the final AB, final BG and proceed as in past examples.

S = volume of lost buoyancy / Intact water-plane area

$$S = \frac{20 \times 20 \times 7.2}{180\ (20) - 20\ (20)} = \frac{2880}{3200} = 0.9 \text{ m.}$$

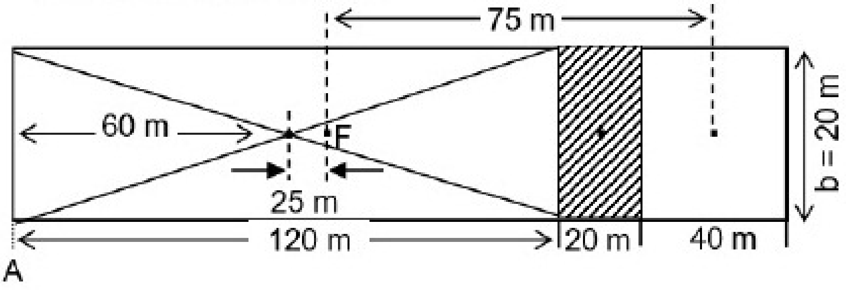
New hydraft = 7.200 + 0.900 = 8.100 m.
In this case, final AB & final AF are equal.

To find final AF, moments of area about A:
120 (20) 60 + 40 (20) 160 = 3200 (final AF)
Final AF = 85 m. Final AB also = 85 m.

Final BG = AG – Final AB = 85.833 – 85 = 0.833 m
Since AG > final AB, final Tc will be by the head.

TM = W.BG = 26568 x 0.833 = 22131.144 tm

$$Tc = \frac{TM}{MCTC} \text{ and } MCTC = \frac{W.GM_L}{100L} \text{ or } \frac{W.BM_L}{100L}$$


Plan view at waterline

BM_L = I*COF intact WP / Volume of displacement.

I*COF intact WP = I*COF large rect + I*COF small rect.

I*COF large rectangle = $20\ (120^3)/12 + (20)\ 120\ (25^2) =$	4380,000.000 m^4
I*COF small rectangle = $20\ (40^3)/12 + (20)\ 40\ (75^2) =$	4606,666.667 m^4
I*COF intact WP =	8986,666.667 m^4

BM_L = 8986,666.667 / 25,920 = 346.708 m.

$$MCTC = \frac{26568 \times 346.708}{100 \times 180} = 511.741 \text{ tm.}$$

$$Tc = \frac{TM}{MCTC} = \frac{22131.144}{511.741} = 43.2 \text{ cm} = 0.432 \text{ m}$$

Ta = Tc (AF) / L = 0.432 (85) / 180 = 0.204 metre.

Tf = Tc – Ta = 0.432 – 0.204 = 0.228 m.

	Fwd m	Aft m
Final hydraft	8.100	8.100
Tf or Ta	+0.228	-0.204
Final drafts	8.328	7.896

Example 4

A box-shaped vessel 180 m long and 20 m wide floats in SW at a draft of 6.2 m fwd & 8.2 m aft. No: 3 LH, beginning 40 m from the forward end is 20 m long and has p = 60%. Find the new drafts fwd and aft if this hold is bilged.

Note: This the same as example 3, except that p = 60% has been added. Hence the following particulars, already calculated in example 3, are unchanged by bilging:

$V = 25{,}920$ m^3, $W = 26{,}568$ t, $AG = 85.833$ metres.

S = volume of lost buoyancy / Intact water-plane area

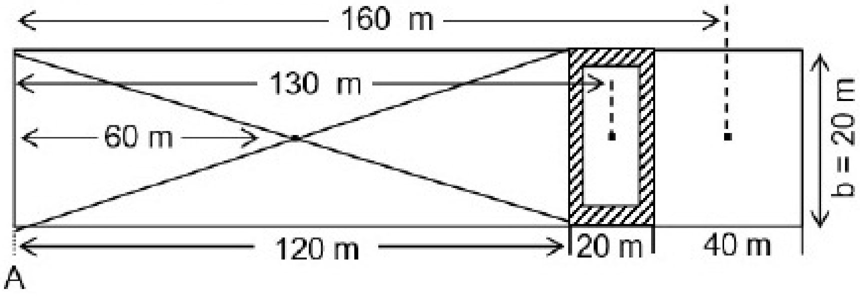
$$S = \frac{20 \times 20 \times 7.2 \times 60/100}{180\ (20) - (20)\ 20\ (60/100)} = 0.514 \text{ m.}$$

New hydraft = 7.200 + 0.514 = 7.714 m

In this case, new AF and new AB are equal.

Area of cargo = 20 x 20 x 0.4 = 160 m ^{2}.

Plan view at waterline



To find new AF, moments of area about A:
Intact WP area (its AF) =
(120) (20)60 + (40) (20)160 + (160)(130) = 292800 m^3

New AF = 292800 / 3360 = 87.143 m [also = new AB].

New BG = New AB – AG = 87.143 – 85.833

New BG = 1.310 m.

Since new AB > AG, Tc will be by the stern.

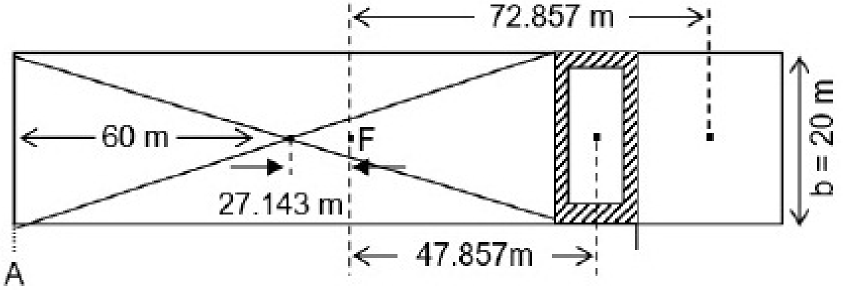
TM = W.BG = 26568 x 1.310 = 34,804.08 tm

$$Tc = \frac{TM}{MCTC} \text{ and } MCTC = \frac{W.GM_L}{100L} \text{ or } \frac{W.BM_L}{100L}$$

BM_L = I*COF intact WP / Volume of displacement

I*COF intact WP area =
I*COF large rect + I*COF small rect + I*COF cargo

Plan view at waterline



I*COF large rect = $[20(120^3)/12] + (20)120(27.143^2)$ =	4648181.877 m^4
I*COF small rect = $[20(40^3)/12] + (20)40(72.857^2)$ =	4353180.625 m^4
I*COF cargo area = $[(20(20^3)/12) + 400(42.857^2)]\ 40/100$ =	299208.925 m^4
I*COF intact WP area =	9300571.427 m^4

BM_L = 9300571.427 / 25920 = 358.818 m

$$MCTC = \frac{26568 \times 358.818}{100 \times 180} = 529.615 \text{ tm.}$$

$$Tc = \frac{TM}{MCTC} = \frac{34804.08}{529.615} = 65.7 \text{ cm} = 0.657\text{m}$$

Ta = AF (Tc) / L = 87.143 (0.657) / 180 = 0.318 m.
Tf = Tc – Ta = 0.657 – 0.318 = 0.339 m.

	Fwd m	Aft m
Final hydraft	7.714	7.714
Tf or Ta	-0.339	+0.318
Final drafts	7.375	8.032

Exercise 8
(Bilging an intermediate compartment)

1. A box-shaped vessel 180 m long & 24 m wide floats in SW at drafts of 9.5 m fwd & 8.5 m aft. An empty hold 22 m long & 24 m wide, whose after bulkhead is 50 m from the after end of the vessel, gets bilged. Calculate the new drafts fwd and aft.

Answer: S 1.253 m, BM_L 286.441 m, MCTC 634.180 BG 2.371 m, Fwd 9.541 m, Aft 11.031 m.

2. A box-shaped vessel 200 m long & 20 m wide is afloat in SW at drafts of 6 m fwd & 8 m aft. No: 2 LH, 24 m long & 20 m wide, has p = 70%. Its fwd bulkhead is 30 m from the fwd end of the vessel. Find the new drafts fwd & aft if this LH gets bilged.

Answer: S 0.642 m, BM_L 431.545 m, MCTC 619.267, BG 0.557 m, Fwd 7.778 m, Aft 7.520 m.

3. A box-shaped vessel 160 m long and 18 m wide is in SW drawing 6.4 m fwd and 7.2 m aft. No: 2 compartment, on the ship's centre line, is 25 m long and 12 m wide. Its forward bulkhead is 40 m from the forward end of the ship. Find the new drafts if this hold, having p = 80%, gets bilged.

Answer: S 0.618 m, BM_L 302.977 m, MCTC 380.115, BG 0.931 m, Fwd 7.672 m, Aft 7.180 m.

4. If the ship in question 3 had a DB tank 25 m long, 18 m wide & 1.6 m high, below No 2 hold, calculate the new drafts if the bilging occurred only in the hold and not in the DB tank. Note: Hold is only 12 m broad.

Answer: S 0.473 m, BM_L 302.977 m, MCTC 380.115, BG 0.340 m, Fwd 7.366 m, Aft 7.186 m.

5. If in question 4, the DB tank also got bilged, along with the hold, find the new drafts fwd and aft.

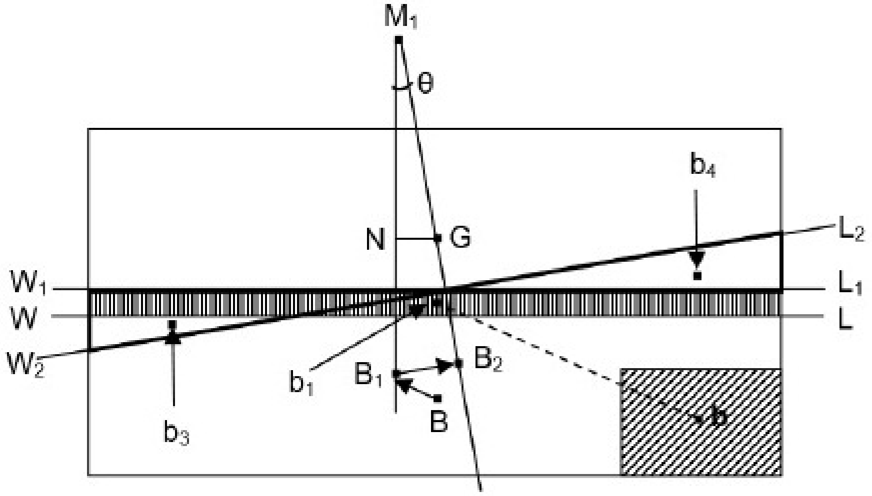
Answer: S 0.745 m, BM_L 302.977 m, MCTC 380.115, BG 1.450 m, Fwd 7.940 m, Aft 7.174 m.

7. BILGING OF A SIDE COMPARTMENT

Since you have studied the effects of bilging amidships compartments, end compartments and intermediate compartments (chapters 4, 5 and 6 in this book), the calculations involving bilging of a side compartment are just one more step.

In addition to sinkage, change of KB, possible change of BM and possible change of trim, bilging of a side compartment causes list.

Before bilging, the COB and COG of the ship were in a vertical line. Because of bilging of a side compartment, the COB of the ship shifts away from the bilged compartment and towards the volume of buoyancy regained. The COB is now transversely separated from the COG by the distance BG. This BG, divided by the new GM fluid, gives the tan of the angle of list, as illustrated in the following diagram:



WL is the transverse waterline before bilging.

B is the COB before bilging.

G is the COG of the ship – unaffected by bilging.

Diagonally shaded area is the volume of lost buoyancy and whose geometric centre is indicated by ‘b’.

Vertically shaded area is the volume of buoyancy regained by parallel sinkage and whose geometric centre is indicated by ‘b_1’.

W_1L_1 is the new waterline after bilging and parallel sinkage.

B_1 is the COB after bilging and parallel sinkage.

Note: BB_1 is parallel to bb_1.

GN is the transverse separation between B_1 and G after bilging and parallel sinkage – the moment so formed causes the ship to heel over to the side on which the bilging occurred.

b_3 and b_4 are the geometric centres of the emerged and immersed wedges.

B_2 is the final position of COB.

Note: B_1B_2 is parallel to b_3b_4 and B_2 is vertically below G.

W_2L_2 is the final waterline.

M_1 is the new metacentre after bilging.

NM_1 is the new metacentric height.

θ is the angle of list caused by bilging.

From the diagram, it is apparent that:

Tan θ = NG / NM_1. NG is generally known as BG and NM_1 is the new initial GM. The formula then becomes Tan θ = BG / New GM.

Calculation of list due to bilging a side compartment can be illustrated by the worked examples that follow:

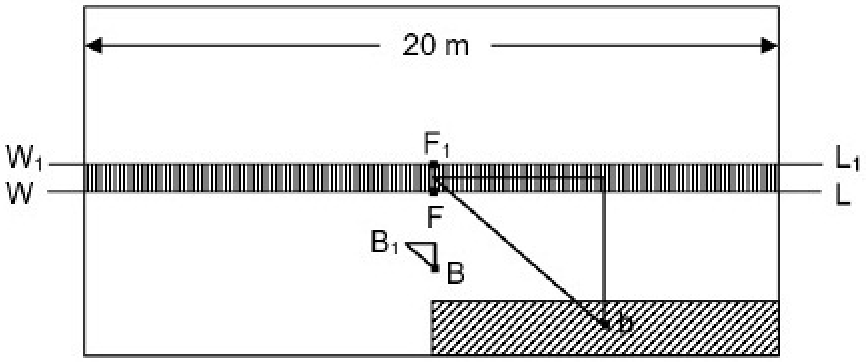
Example 1

A vessel 200 m long & 20 m wide is box-shaped and a float in SW at an even keel draft of 8 m. A DB tank on the starboard side is rectangular, 12 m long, 10 m wide, 1.2 m deep & empty. Calculate the list if this tank is now bilged, given that KG = 7.5 m and FSM of the other tanks of the ship = 820 tm.

$V = 200 \times 20 \times 8 = 32000\ m^3$ (Unchanged by bilging)

$W = 32000 \times 1.025 = 32800\ t$ (Unchanged by bilging)

End Elevation



S = volume of lost buoyancy / Intact water-plane area

$$S = \frac{12 \times 10 \times 1.2}{200 \times 20} = \frac{144}{4000} = 0.036 \text{ m.}$$

New hydraft = 8.000 + 0.036 = 8.036 m.

To find new KB, moments about keel:
32000(new KB) = 32000 (4) – 144 (0.6) + 144 (8.018)

New KB = 4.033 m.

BM_T = I*COF intact water-plane / volume

$$BM_T = \frac{LB^3}{12V} = \frac{200\,(20^3)}{12\,(32000)} = 4.167 \text{ m.}$$

KM_T = New KB + BM_T = 4.033 + 4.167 = 8.2 m.

GM = KM – KG = 8.2 – 7.5	= 0.700 m
FSC = 820 / 32800	= <u>0.025</u> m
GM fluid or GM_F	= 0.675 m

$$\text{Trans shift of B} = \frac{\text{Vol of buoyancy lost x dist off CL}}{\text{Vol of displacement of ship}}$$

Trans shift of B = 144 (5) / 32000 = 0.225 m.

Hence BG caused by bilging = 0.225 m

Tan θ = BG / GM_F = 0.0225 / 0.675 = 0.0333

θ = 1.91° or 1° 55’ to starboard.

Example 2

A box-shaped tanker 180 m long & 16 m wide is afloat in SW at an even keel draft of 7.5 m. The wing tanks are each 4 m broad and the centre tanks, 8 m. The KG is 5.5 m and FSM 1200 tm. Calculate the list if No: 3 starboard tank, which is 15 m long and empty, is now bilged.

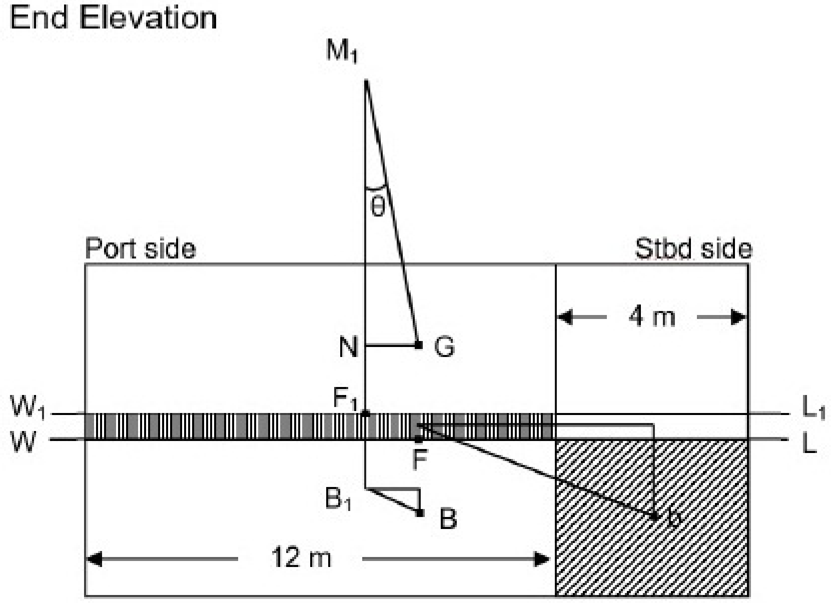
V = 180 x 16 x 7.5 = 21600m^3 (Unchanged by bilging)

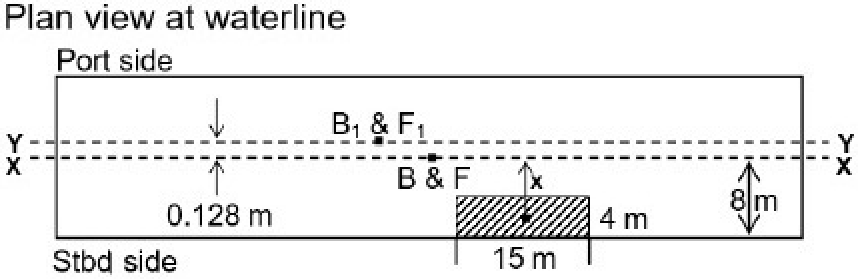
W = 21600 x 1.025 = 22140 t (Unchanged by bilging)

S = volume of lost buoyancy / Intact water-plane area

$$S = \frac{15 \times 4 \times 7.5}{2880 - 60} = \frac{450}{2820} = 0.160 \text{ m.}$$

New hydraft = 7.5 + 0.160 = 7.660 m.





After bilging and parallel sinkage, the area of the waterplane is constant at all drafts. **So, F_1 and B_1 will be in the same vertical line** and:

New KB = new hydraft / 2 = 3.830 m.

To find FF_1, the transverse separation between F and F_1, moments of area about the starboard side:

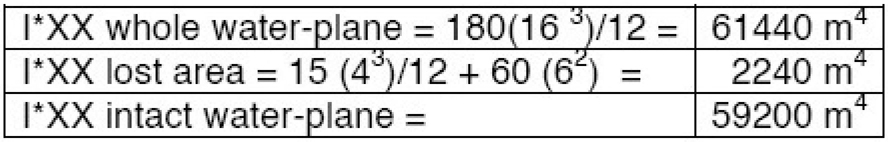
Total area (its distance) - area lost (its distance) = balance area (its distance).

(2880 x 8) – (60 x 2) = 2820 (its dist from stbd side)

Dist of F_1 from starboard side = 8.128 m

$FF_1 =$ 0.128 m.

In this case, $FF_1 = BB_1$.



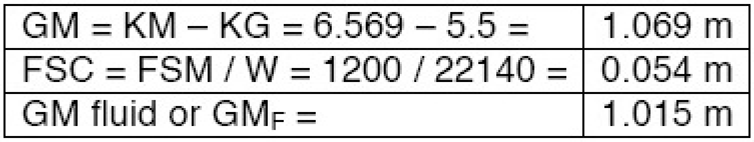
I*XX whole water-plane = $180(16^3)/12$ =	61440 m^4
I*XX lost area = $15(4^3)/12 + 60(6^2)$ =	2240 m^4
I*XX intact water-plane =	59200 m^4

I*YY intact wp area = I*XX intact wp area – Ay^2
= 59200 – 2820 (0.128^2) = 59153.797 m^4

Note: F_1 is the centroid of the intact area. Hence the minus sign in the formula.

BM_T = I*YY intact water-plane / volume
= 59153.797 / 21600 = 2.739 m.

$KM_T = KB + BM_T$ = 3.830 + 2.739 = 6.569 m



GM = KM – KG = 6.569 – 5.5 =	1.069 m
FSC = FSM / W = 1200 / 22140 =	0.054 m
GM fluid or GM_F =	1.015 m

Tan $\theta = BB_1 / GM_F$ = 0.128 / 1.015 = 0.12611

$\theta = 7.188°$ or 7° 11' to starboard.

Example 3

A box-shaped ship, 150 m long & 17 m wide, is afloat in FW at an even keel draft of 8 m. A rectangular compartment on the starboard side is 16 m long and 8.5 m wide. If KG = 6.0 m, FSM = 900 tm and permeability is 60%, find the list if this compartment gets bilged.

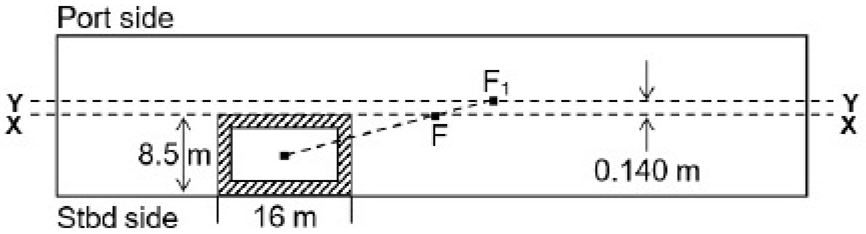
$V = 150 \times 17 \times 8 = 20400\ m^3$ (Unchanged by bilging)
$W = 20400 \times 1.000 = 20400$ t (Unchanged by bilging)

S = volume of lost buoyancy / Intact water-plane area

$$S = \frac{16 \times 8.5 \times 8 \times 60/100}{150\,(17) - 16\,(8.5)\,60/100} = \frac{652.8}{2468.4} = 0.265 \text{ m}$$

New hydraft = 8 + 0.265 = 8.265 m.

Plan view at waterline



After bilging & parallel sinkage, the area of the water-plane is constant at all drafts. So F_1 & B_1 will be in the same vertical line and KB_1 will be half the new draft.

Hence $KB_1 = 4.132$ m.

Area of cargo = $16 \times 8.5 \times 0.4 = 54.4\ m^2$

To find FF_1, the transverse separation between F & F_1, moments about stbd side:

Total area (its dist) – area lost (its distance) + cargo area (its distance) = balance area (its distance)

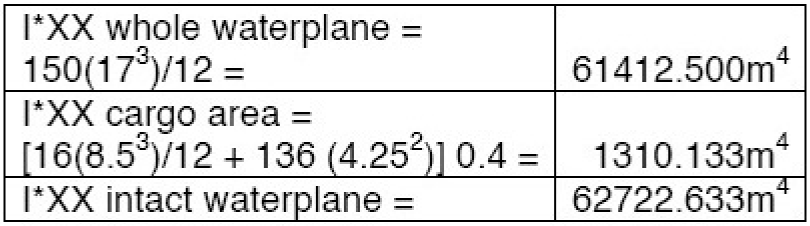
2550 (8.5) – 136 (4.25) + 54.4(4.25) = 2468.4 (its dist)

Dist of F_1 from stbd side = 8.640 m

FF1 = 8.640 – 8.500 = 0.140 m

In this case $FF_1 = BB_1$

To find the I*YY of intact waterplane and thence to calculate the the BM_T:

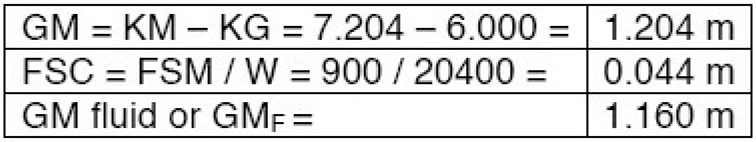


I*XX whole waterplane = $150(17^3)/12$ =	$61412.500 m^4$
I*XX cargo area = $[16(8.5^3)/12 + 136 (4.25^2)]\ 0.4$ =	$1310.133 m^4$
I*XX intact waterplane =	$62722.633 m^4$

I* YY intact wp area = I*XX intact wp area – Ay^2
= 62722.633 – 2468.40 (0.140^2) = 62674.253 m^4.
BM_T = I*YY intact waterplane / volume

BM_T = 62674.253 / 20400 = 3.072 m.

New KM = new KB + new BM
New KM = 4.132 + 3.072 = 7.204 m



GM = KM – KG = 7.204 – 6.000 =	1.204 m
FSC = FSM / W = 900 / 20400 =	0.044 m
GM fluid or GM_F =	1.160 m

Tan θ = $BB_1 / GM_{F\ 1}$ = 0.140 / 1.160 = 0.120690

θ = 6.88° or 6° 53’ to starboard.

Exercise 9
(Bilging a side compartment)

1. A box-shaped vessel 180 m long & 20 m wide is afloat in SW at an even keel draft of 7 m. A port side rectangular DB tank, 16 m long,

10 m wide & 1 m high, is empty. Calculate the list if this DB tank is bilged. KG = 7.5 m and FSM = 1000 tm.

Answer: List = 2.398° or 2° 24’ to port.

2. A box–shaped tanker 200 m long & 24 m wide is a float in FW at an even keel draft of 12 m. The wing tanks are 6 m broad and the centre tanks, 12 m. KG of ship = 8.5 m & FSM = 1800 tm. Find the list if number 4 starboard wing tank, 18 m long & empty, gets bilged.

Answer: List = 8.147° or 8° 09’ to stbd.

3. A box-shaped vessel 175 m long & 18 m wide is afloat in SW at an even keel draft of 10 m. A rectangular compartment 15 m long extends 6 m in breadth from the port shell plating. This compartment runs all the way from the keel up to the upper deck and has p = 40%. KG of ship = 6.8 m & FSM = 800 tm. If this compartment gets bilged, find the list.

Answer: List = 4.443° or 4°27’ to port.

4. A box–shaped vessel 150 m long & 16 m wide floats in SW at an even keel draft of 9 m. It has a longitudinal water-tight bulkhead on its centre line and DB tanks 1.2 m high. KG is 6.0 m and FSM is 900 tm. A hold 12 m long, on the port side, having p = 30%, gets bilged. Find the list.

Answer: List = 2.856° or 2° 51’ to port.

5. If in question 4, the empty port DB tank, directly below the hold, also gets bilged, find the list.

Answer: List = 4.127° or 4° 08’ to port.

6. A box-shaped vessel 120 x 14 m is in SW at an even keel draft of 8 m. KG 5.8 m, FSM 560 tm. A rectangular DB tank on the stbd side, 15 x 7 x 1 m, half full of HFO RD 0.95, is bilged. Find the list. Hint: After bilging, the HFO is not in the ship anymore. Calculate the GG1 to port, the new W, the new KG and new FSM, assuming that the HFO is discharged. Then bilge the tank, obtain BB1 to port, compute the final BG and thence the list. Assume KG of this tank = 0.5 m, regardless of sounding.

Answer: List = 3.205° or 3° 12’ to stbd.

8. BILGING OF SHIP SHAPED VESSELS

You would by now have a very clear idea of the effects on stability of bilging any compartment, after studying the earlier chapters on this topic. In those chapters, the ship was considered to be box-shaped so that the concept of the principles involved could be absorbed without the diversion that would have resulted from having too many variable parameters. It would not be proper to leave you at that, without orienting your conceptual knowledge towards ship shaped vessels.

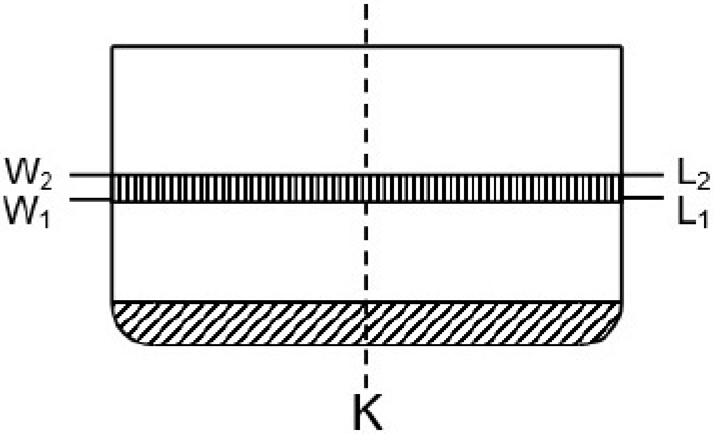
Bilging would affect the hydrostatic particulars of the ship. Hence you need to modify the hydrostatic table given in the Stability Booklet of the ship, before use after bilging. You can do this easily, using the knowledge gained by you in the earlier chapters on bilging of box-shaped vessels.

In this chapter, use has been made of appendix I of this book wherein suitable extracts of the hydrostatic particulars of an imaginary general cargo ship m.v. VIJAY have been given. Wherever necessary, extracts from the hydrostatic table are given in the solved examples for easy reference. The calculations have been divided into two parts – part A: bilging of a DB tank and part B: bilging of a cargo hold. A third part, Part C, explains the ‘Damaged Ship data’ supplied by the shipyard.

PART A – Bilging of a DB tank

Example 1

M.V. VIJAY is a float in SW at an even keel draft of 4.8 m. An empty DB tank of volume 430 m^3, KB 0.5 m & AB 60 m gets bilged. Using the particulars given (extracted from appendix I of this book), calculate the revised hydrostatic particulars for the bilged condition.



From the hydrostatic table, for draft of 4.8 m in salt water (SW), displacement (W) = 9451 tonnes.

Before bilging:

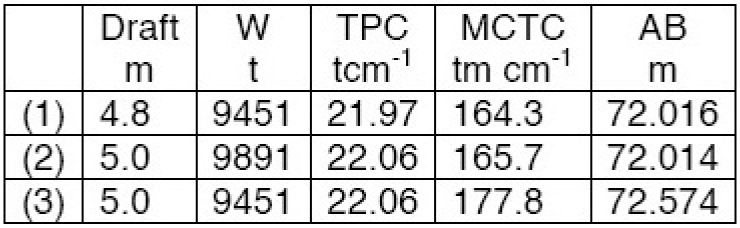
Draft in SW m	W t	u/w vol m^3	vol of disp m^3
4.8	9451	9220.488	9220.488
Due to bilging		+430.000	
After bilging	9451	9650.488	9220.488

To enter the hydrostatic table with Vol of 9650.488 m^3 we have to use W of 9891.8 t (i.e., 9650.488 x 1.025).

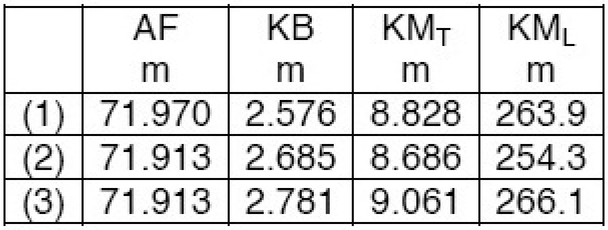
Entering hydrostatic table with new u/w volume of 9650.488 m^3 (i.e. W = 9891.8 t), new draft = 5.000 m.

After bilging, though the draft is 5.000 m, volume of displacement = 9220.488 m^3, and W = 9451 tonnes.

In the following table, (1) and (2) indicate the particulars for the intact hull in SW, as taken from the hydrostatic table, while (3) indicates the revised particulars for the bilged condition.



	Draft m	W t	TPC tcm^{-1}	MCTC $tm\ cm^{-1}$	AB m
(1)	4.8	9451	21.97	164.3	72.016
(2)	5.0	9891	22.06	165.7	72.014
(3)	5.0	9451	22.06	177.8	72.574



	AF m	KB m	KM_T m	KM_L m
(1)	71.970	2.576	8.828	263.9
(2)	71.913	2.685	8.686	254.3
(3)	71.913	2.781	9.061	266.1

Calculations in support of (3) above are as follows:

Draft & W: The method how the values in (3) have been arrived at has already been explained.

TPC & AF: These depend on the area and shape of the water-plane at the draft at which the ship is floating. In the bilged condition, the draft is 5 metres, corresponding to the waterline $W_2\ L_2$ in the foregoing figure.

New KB: Taking moments about the keel:

New volume (new KB) = Old volume (its KB) – volume lost (its KB) + volume regained (its KB)

$9220.488\ (\text{new KB}) = 9220.488\ (2.576) - 430\ (0.5) + 430\ (4.9)$

New KB = 2.781 m.

Note: The KB of the volume of buoyancy regained has been taken to be the mean of the two drafts 4.8 and 5.0 metres.

OR

$BB_1 = dv / V = (4.9 - 0.5)\ 430 / 9220.488 = 0.205$ m.

New KB = Old KB + $BB_1\uparrow = 2.576 + 0.205$

New KB = 2.781 m.

KM_T & KM_L: From hydrostatic table, for 5 m draft & intact hull, KM_T, KM_L & KB are extracted and BM_T & BM_L are obtained as follows:

KM_T	8.686 m		KM_L	254.300 m
KB	2.685 m		KB	2.685 m
BM_T	6.001 m		BM_L	251.615 m

BM = I / V or I = BM (V). In the intact condition, at 5 m draft, vol of displacement = W / 1.025 = 9649.756 m^3. The value of I is obtained by multiplying BM by V.

I*CL 57908.186 m^4 & I*COF 2428023.380 m^4.

The above values of I, for 5 m draft with hull intact, hold good in the bilged condition also - they depend only on the wp area W_2L_2 in the foregoing figure.

In the bilged condition, the vol of displ = 9220.488 m^3.

New BM_T = 57908.186 / 9220.488 = 6.280 m

New KM_T = new KB + new BM_T = 2.781+ 6.280

New KM_T = 9.061 m.

New BM_L = 2428023.380 / 9220.488 = 263.329 m

New KM_L = new KB + new BM_L = 2.781 + 263.329

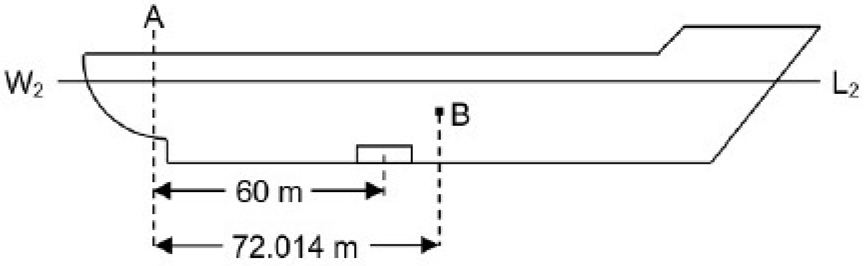
New KM_L = 266.110 m.

MCTC:

$$\text{New MCTC} = \frac{W\,(\text{new } BM_L)}{100L} = \frac{9451\ (263.329)}{100\ (140)}$$

New MCTC = 177.766 tm.

New AB:



Moments of volume about A,

New volume (new AB) = u/w volume at 5 m draft (its AB) – volume lost (its AB)

9220.488 (new AB) = 9650.488 (72.014) – 430 (60)

New AB = 72.574 m.

Example 2

Find the drafts fwd & aft in example 1.

Since the vessel was on an even keel at 4.8 m draft, AG = AB = 72.016 m before bilging. After bilging, AB = 72.574 m (calculated earlier in example 1).

BG = AB – AG = 72.574 – 72.016 = 0.558 m

Tc will be by the stern because AB > AG.

$$Tc = \frac{W.BG}{MCTC} = \frac{9451\ (0.558)}{177.8} = 29.7 \text{ cm} = 0.297 \text{ m}$$

Ta = AF (Tc) / L = 71.913 (0.297) / 140 = 0.153 m

Tf = Tc – Ta = 0.297 – 0.153 = 0.144 m.

	Fwd m	Aft m
Final hydraft	5.000	5.000
Ta or Tf	-0.144	+0.153
Final drafts	4.856	5.153

Example 3

If at the end of example 1, KG = 7.6 m, FSM = 1000 tm, and a heavy lift of 50 t is shifted 10 m to starboard, find the resultant list.

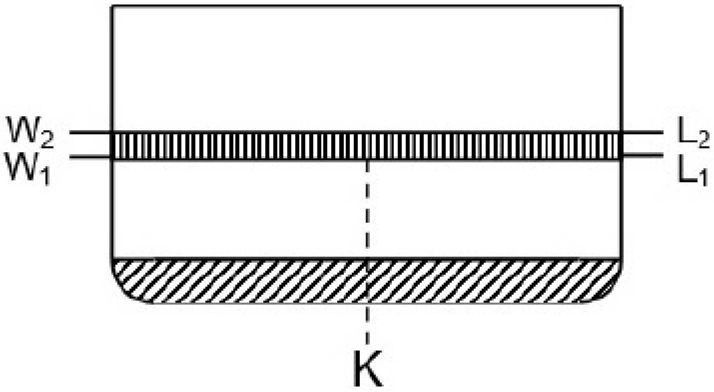
$GM = KM_T - KG = 9.061 - 7.600 =$	1.461 m
$FSC = FSM / W = 1000 / 9451 =$	0.106 m
GM fluid =	1.355 m

$$\text{Tan } \theta = \frac{dw}{W.GM} = \frac{10 \times 50}{9451\ (1.355)} = 0.03904$$

θ = 2.236° or 2°14' to starboard.

Example 4

M.v. VIJAY is afloat in FW at drafts of 5.6 m fwd and 6.6 m aft. A DB tank on the centre line has a volume of 396 m^3, KB 0.6 m & AB 100 m. Find the hydrostatic particulars, referring extracts given here from appendix I of this book, if this empty tank now gets bilged.



Fwd 5.6 m, aft 6.6 m; trim = 1.0 m by the stern

Mean draft = 6.1 m for which, from the hydrostatic table, AF = 71.401 m

Corr = (AF / L) (trim) = 0.510 m

Initial hydraft = 6.600 – 0.510 = 6.110 m

Line (1) below is from the hydrostatic table for SW.

Line (2) below has been derived from line (1) for FW.

Both lines (1) & (2) are for the intact hull condition:

		Draft m	W t	TPC t cm^{-1}	MCTC tm cm^{-1}
(1)	SW	6.110	12371.2	22.50	173.8
(2)	FW	6.110	12069.4	21.95	169.6

	AB m	AF m	KB m	KM_T m	KM_L m
(1)	71.948	71.393	3.262	8.204	214.1
(2)	71.948	71.393	3.262	8.204	214.1

$$\text{Trim} = \frac{W.BG}{MCTC} \text{ or } BG = \frac{100\ (169.6)}{12069.4}$$

Initial BG = 1.405 m.
Since the trim is by the stern, AB > AG.
AG of ship = AB – BG = 71.948 – 1.405 = 70.543 m.

	u/w volume	vol of disp
Before bilging	12069.4 m^3	12069.4 m^3
Due to bilging	+ 396.0 m^3	
After bilging	12465.4 m^3	12069.4 m^3

Entering the hydrostatic table with u/w volume of 12465.4 m in FW (i.e. 12465.4 x 1.025 = 12777.0 t in SW at constant draft), draft = 6.289 m.

Lines (3) & (4) below are derived from the hydrostatic table, assuming the hull to be intact. Line (5) is for the bilged condition, for which relevant explanations are given subsequently.

		Draft m	W t	TPC t cm^{-1}	MCTC tm cm^{-1}
(3)	SW	6.289	12777.0	22.584	175.4
(4)	FW	6.289	12465.4	22.034	171.1
(5)	FW	6.289	12069.4	22.034	183.5

	AB m	AF m	KB m	KM_T m	KM_L m
(3)	71.928	71.259	3.355	8.160	209.4
(4)	71.928	71.259	3.355	8.160	209.4
(5)	71.007	71.259	3.446	8.409	216.3

Explanations for line (5)

TPC and AF: These depend on the area & shape of the water-plane at the draft at which the ship is floating. In the bilged condition, the draft in FW is 6.289 m represented by W_2L_2 in the foregoing figure.

New KB: Taking moments about the keel,

New volume (new KB) = old vol (its KB) – vol lost (its KB) + vol regained (its KB)

12069.4 (new KB) =

12069.4 (3.262) – 396 (0.6) + 396 (6.2)

New KB = 3.446 m.

Note: KB of the volume of buoyancy regained has been taken to be 6.2 m which is the mean of the two drafts 6.110 and 6.289 m.

KM_T and KM_L: From the hydrostatic table, for 6.289 m draft, considering the hull to be intact:

KM_T	8.160 m		KM_L	209.400 m
KB	3.355 m		KB	3.355 m
BM_T	4.805 m		BM_L	206.045 m

I*CL 59896.247 m^4 & I*COF 2568433.343 m^4.

Note 1: BM = I / V or I = BM (V). I*CL & I*COF have been obtained by multiplying BM_T and BM_L by the volume of displacement at 6.289 m draft in FW with the hull considered to be intact.

Note 2: The above values of ‘I’ hold good for the bilged condition also as they depend only on the shape & area of the intact water-plane, corresponding to W_2L_2 in the foregoing figure.

In the bilged condition, vol of displ = 12069.4 m^3.

New $BM_T = I*CL / V = 4.963$ metres.

KM_T = new KB + new $BM_T = 3.446 + 4.963 = 8.409$ m.

New $BM_L = I*COF / V = 212.805$ m

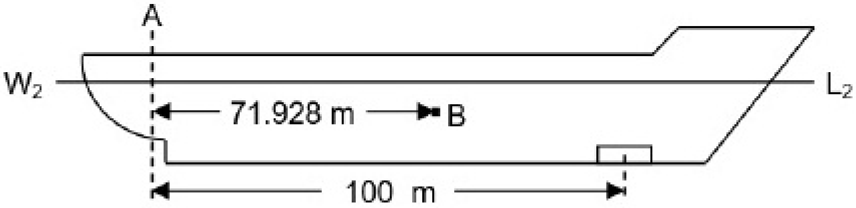
New KM_L = new KB + new $BM_L = 3.446 + 212.805$

New $KM_L = 216.251$ m.

$$\text{New MCTC: } = \frac{W.BM_L}{100L} = \frac{12069.4\ (212.805)}{100\ (140)}$$

New MCTC = 183.459 tm.

New AB:



Intact vol at 6.289 m draft in FW (its AB) – vol lost (its AB) = new vol (its AB)

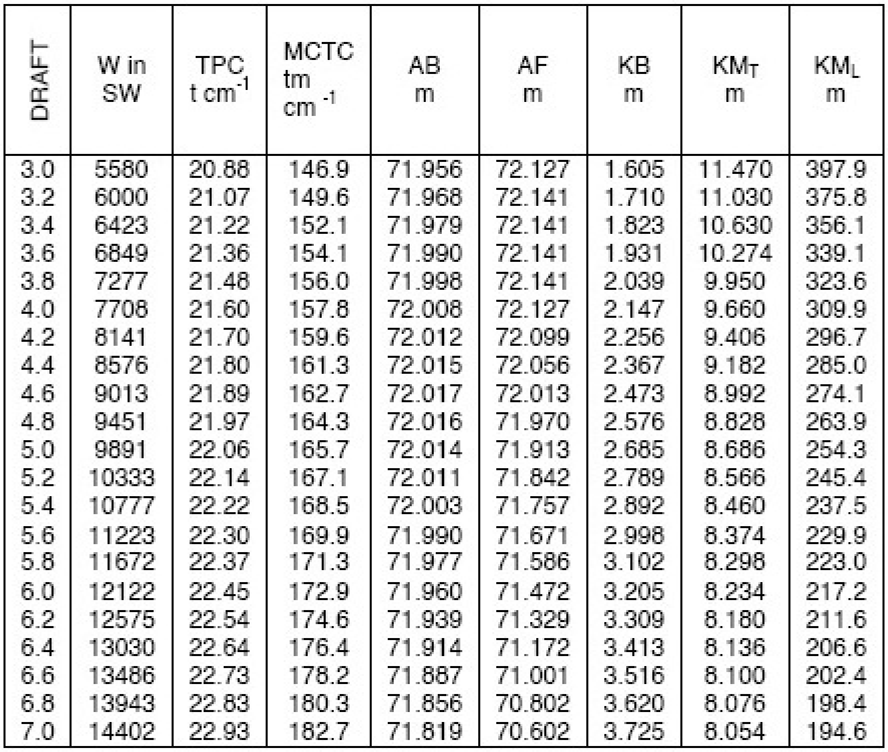
12465.4 (71.928) – 396 (100) = 12069.4 (new AB)

New AB = 71.007 m.

Exercise 10
(Bilging DB tank – ship shape)

NOTE: The hydrostatic table of m.v. VIJAY (Appendix 1 of this book) is reproduced here for easy reference while solving the problems in this exercise.

HYDROSTATIC TABLE OF M.V.’VIJAY’



DRAFT	W in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

1. M.V. VIJAY is afloat in DW of RD 1.015 drawing 4.6 m fwd and 5.8 m aft. A central DB tank of volume 432 m^3, AG 90 m & KG 0.6 m is empty. If this tank now gets bilged, find the new hydrostatic particulars using the hydrostatic table of the ship.

Answer: W 10197.2 t, RD 1.015, d 5.384 m, TPC 21.997, MCTC 176.989, AB 71.237 m, AF 71.764 m, KB 2.982 m, KM_T 8.808 m, KM_L 248.370 m.

2. In question 1, find the drafts fwd & aft after bilging.

Answer: Final drafts fwd 5.055 m, aft 5.730 m.

3. If in question 2, KG = 8 m, FSM = 1200 tm, and a weight of 50 t is shifted 10 m to stbd, find the list.

Answer: List = 4.071° or 4° 04’ to stbd.

4. M.V. VIJAY is in SW drawing 6.0 m fwd & 5.0 m aft. A central DB tank of KG 0.5 m, AG 20 m & volume 336 m^3, has 128 t of HFO in it. Calculate the new hydrostatic particulars, referring to appendix I of this book (reproduced in the previous page), if this tank now gets bilged.

Note: Assume that the KG of this tank is constant regardless of the sounding.

Answer: W 10899.1 t, RD 1.025, d 5.609 m, TPC 22.303, MCTC 181.973, AB 73.632 m, AF 71.667 m, KB 3.082 m, KM_T 8.620 m, KM_L 236.829 m.

5. In question 4, find the new drafts fwd and aft after bilging.

Answer: Fwd 5.763 m, aft 5.448 m.

6. If in question 5, KG of ship was 7.5 m and FSM of all other tanks of the ship was 8500 tm before bilging, find the list when a weight of 80 t is shifted 10 m to port.

Answer: List 4.752° or 4° 45’ to port.

7. M.V. VIJAY is in SW at an even keel draft of 4.6 m. A central DB tank is full of SW ballast. The volume of the tank is 240 m3, its KG 0.6 m & its AG 100 m. Find the new hydrostatic particulars if this tank gets bilged, referring to appendix I of this book, reproduced on the previous page.

Answer: W 8767.0 t, RD 1.025, d 4.600 m, TPC 21.890, MCTC 174.870, AB 71.232 m, AF 72.013 m, KB 2.526 m, KM_T 9.228 m, KM_L 281.775 m.

8. In question 7, find the new drafts fwd and aft.

Answer: Fwd 4.600 m, aft 4.600 m.

9. M.V. VIJAY at 6 m even keel draft in SW, collides with a barge. The fore peak tank, full with 102 t of FW (AG 135 m, KG 4 m) gets bilged. Since the top of this tank was below the original water line, the ship’s water-plane area is not adversely affected. Referring to Appendix I of this book, reproduced on the previous page, calculate (i) the new hydrostatic particulars and (ii) the new drafts fwd & aft.

Answer: (i) W 12020.0 t, RD 1.025, d 6.001 m, TPC 22.451, MCTC 185.303, AB 71.412 m, AF 71.471 m, KB 3.199 m, KM_T 8.271 m, KM_L 219.026 m.

(ii) Final drafts fwd 6.005 m, aft 5.997 m.

PART B – Bilging of a cargo hold.

Stability calculations, after a cargo hold gets bilged, are complex and tedious. Such calculations are not always solvable on board owing to the limitations of the information available to the shipmaster. However, an idea of the possible calculations that can be made, to a fair amount of accuracy, is given here in the following worked examples.

On modern ships, stability data of the ship in a variety of possible damaged conditions are calculated beforehand by the shipyard and made available on board in a separate booklet, as explained in Part C of this chapter.

Though an empty hold has been bilged in the worked examples that follow, the student who has studied the earlier chapters on bilging should be able to solve similar such problems even when the bilged compartment has cargo in it.

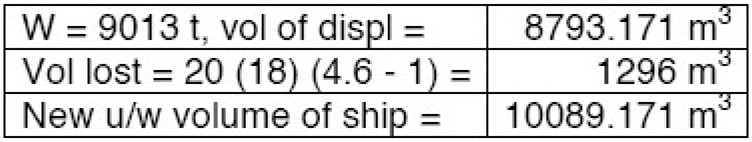
Example 5

M.v. Vijay is afloat in SW at drafts of 4.11 m fwd & 5.11 m aft. No 2 LH, AG 104 m, is 20 m long, 18 m wide & empty. No 2 DB tank, one metre deep, is situated directly below No 2 LH. While coming alongside, a tug collides with this ship causing No 2 LH to get bilged above DB tank. Calculate the hydrostatic particulars after the accident, assuming that No 2 LH is rectangular.

Fwd 4.11 m, aft 5.11 m, trim 1 metre by stern, Mean 4.61 m, AF = 72.011 m from the hydrostatic table.

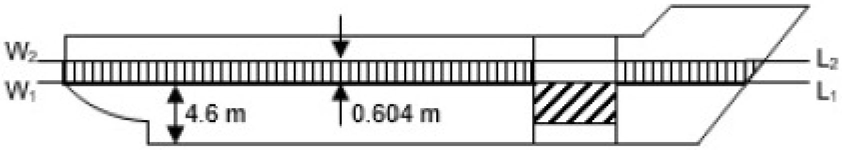
Correction = AF / L (trim) = (72.011 / 140) 1 = 0.51 m.

Initial hydraft = 5.11 – 0.51 = 4.6 m.
From hydrostatic table, W in SW = 9013 t.



W = 9013 t, vol of displ =	8793.171 m^3
Vol lost = 20 (18) (4.6 - 1) =	1296 m^3
New u/w volume of ship =	10089.171 m^3

If the hull was intact and the volume of displacement was 10089.171 m^3, W would have been 10341.4 t and the draft, as per hydrostatic table, would have been 5.204 m.



Actually, in No 2 LH the space between the waterlines at 4.6 m draft and 5.204 m draft, having a volume of 217.44 m^3 (i.e. 20 x 18 x 0.604), is dead space – it is neither lost nor regained as volume of buoyancy. So, the ship will sink in excess of 5.204 m draft in order to regain this 217.44 m^3. Since this sinkage in excess of 5.204 m draft will be very small, TPC may be considered to be constant.

During this sinkage, only the intact water-plane area will contribute to volume of buoyancy regained.

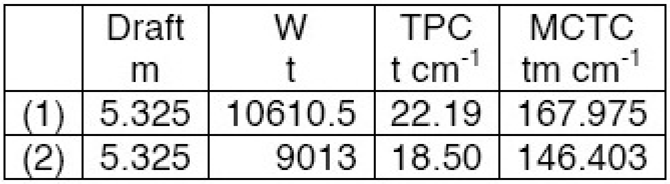
From hydrostatic table, considering the hull to be intact, TPC at 5.204 m draft = 22.142

TPC = 1.025 A / 100 or A = 22.142 (100) / 1.025

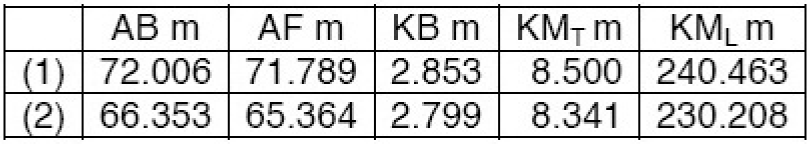
WP area at 5.204 m draft =	2160.195 m^2
Area lost in No 2 LH =	360.000 m^2
Intact water-plane area =	1800.195 m^2

Sinkage in excess of 5.204 m draft
= vol yet to regain / Intact WP area
= 217.44 / 1800.195 = 0.121 m
Final hydraft = 5.204 + 0.121 = 5.325 m.

Line (1) below contains the hydrostatic particulars for the intact hull at 5.325 m draft in SW while line (2) is for the bilged condition in SW at the same draft.



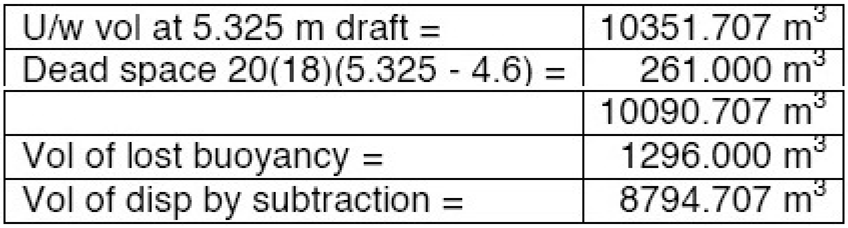
	Draft m	W t	TPC t cm^{-1}	MCTC tm cm^{-1}
(1)	5.325	10610.5	22.19	167.975
(2)	5.325	9013	18.50	146.403



	AB m	AF m	KB m	KM_T m	KM_L m
(1)	72.006	71.789	2.853	8.500	240.463
(2)	66.353	65.364	2.799	8.341	230.208

Calculations in support of line (2) above are given here:

W check:



U/w vol at 5.325 m draft =	10351.707 m^3
Dead space 20(18)(5.325 - 4.6) =	261.000 m^3
	10090.707 m^3
Vol of lost buoyancy =	1296.000 m^3
Vol of disp by subtraction =	8794.707 m^3

Vol of disp as per original hydraft is 8793.171 m^3. The difference is insignificant, indicating that the calculation is correct.

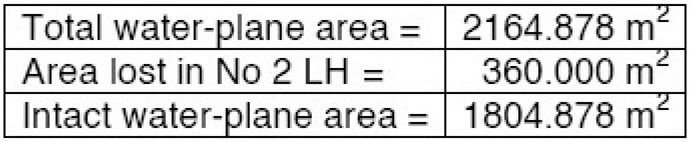
W = 8793.171 x 1.025 = 9013 t.

New TPC: TPC at 5.325 m draft, assuming that the hull is intact = 22.19 t cm^{-1}.

TPC = 1.025 A / 100 or A = 100 (22.19) / 1.025

A = 2164.878 m^2.

At 5.325 m draft:



Total water-plane area =	2164.878 m^2
Area lost in No 2 LH =	360.000 m^2
Intact water-plane area =	1804.878 m^2

New TPC = 1.025 (1804.878) / 100 = 18.500 t

New AF: Moments of area about A,

Intact WP area (its AF) = entire WP area (its AF) – area lost in No 2 LH (its AF)

1804.878 (its AF) = 2164.878 (71.789) – 360 (104)

New AF = 65.364 m.

New AB: Moments of volume about A,

Intact volume (its AB) = entire vol at 5.325 m (its AB) – u/w vol No 2 (its AB)

8793.171 (New AB) = 10351.707 (72.006) – 1557 (104)

Note: U/w volume in No 2 LH = 20 (18) (5.325 – 1)

U/w volume in No 2 LH = 1557 m^3.

New AB = 66.353 m.

New KB: Moments of volume about the keel,

Intact vol (its KB) = entire vol at 5.325 m draft (its KB) – u/w vol No 2 (its KB)

8793.171 (its KB) = 10351.707 (2.853) – 1557 (3.163)

Note: KB of u/w vol No 2 = (4.325 /2) + 1

New KB = 2.799 m.

New KM_T & KM_L:

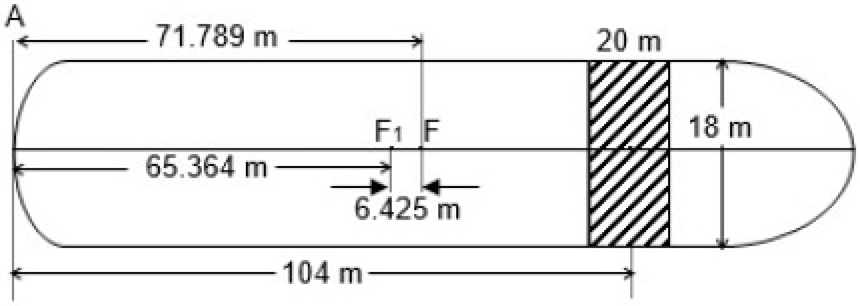
From hydrostatic table, at 5.325 m draft in salt water, assuming hull to intact, V = 10351.707 m^3 and:

	Transverse	Longitudinal
KM	8.500 m	240.463 m
KB	2.853 m	2.853 m
BM	5.647 m	237.610 m

BM = I / V or I = BM (V).

I*CL 58456.089 m^4 & I*COF 2459669.1 m^4.

Note: The I, so calculated for the intact WP, may be modified for the WP area in the bilged condition and divided by the actual volume of displacement to get the BM for the bilged condition.



I*CL intact WP = I*CL entire WP – I*CL area lost in 2#
= 58456.089 - 20 $(18^{3}) / 12$ = 48736.089 m^4.

$$BM_T = \frac{I}{V} = \frac{48736.089}{8793.171} = 5.542 \text{ m}$$

KM$_T$ = new KB + new BM$_T$ = 2.799 + 5.542 = 8.341 m
I*COF$_1$ entire WP = I*COF + Ah^2
= 2459669.1 + 2164.878 (6.425^2)
= 2549036.616 m^4.
I*COF$_1$ no 2 area = 18 (20^3) / 12 + 360 (38.636^2)
= 549386.579 m^4.
I*COF$_1$ intact WP = I*COF$_1$ full WP – I*COF$_1$ lost area
I*COF$_1$ intact WP = 1999650.038 m^4.
Double check of I*COF$_1$ above:
I*COF intact WP = I*COF entire WP – I*COF area lost
I*COF area lost = 18 (20^3) / 12 + 360 (32.211^2)
I*COF area lost = 385517.468 m^4.

I*COF intact WP = 2459669.1 – 385517.468
I*COF intact WP = 2074151.633 m^4.
I*COF$_1$ intact WP = I*COF – Ah^2
= 2074151.633–1804.878(6.425^2)
I*COF$_1$ intact WP = 1999645.142 m^4.

The difference in result is insignificant.

Resumption of calculation

$$BM_L = \frac{I^*COF_1}{V} = \frac{1999650.038}{8793.171} = 227.409 \text{ m}$$

KM$_L$ = new KB + new BM$_L$ = 2.799 + 227.409
New KM$_L$ = 230.208 m.

New MCTC:

$$\text{New MCTC} = \frac{W.BML}{100L} = \frac{9013\ (227.409)}{100\ (140)} = 146.403\ \text{tm}$$

Example 6

In example 5, find the drafts fwd & aft.

To find KG of ship:

Draft m	W t	MCTC tm cm^{-1}	AB m
4.600	9013	162.7	72.017

Trim = W.BG / MCTC or BG = trim (MCTC) / W
BG = 100 (162.7) / 9013 = 1.805 m.
Trim is by the stern, so AG < AB.
AG = AB - BG = 72.017 – 1.805 = 70.212 m

Final BG = AG – AB = 70.212 – 66.353 = 3.859 m.

Since AG > AB, Tc will be by the head.

$$Tc = \frac{W.BG}{MCTC} = \frac{9013\ (3.859)}{146.403} = 237.6\ \text{cm} = 2.376\ \text{m}$$

Ta = AF (Tc) / L = 65.364 (2.376) / 140 = 1.109 m.

Tf = Tc – Ta = 2.376 – 1.109 = 1.267 m.

	Fwd m	Aft m
Final hydraft	5.325	5.325
Tf or Ta	+1.267	-1.109
Final drafts	6.592	4.216

Example 7

If in example 6, 150 t of FW is transferred from the fore peak tank to the after peak tank through a distance of 130 m, and 150 t from No 2 DBT to No 8 DBT, through a distance of 80 m, find the new drafts fwd & aft.

$$Tc = \frac{150\ (130) + 150\ (80)}{146.403} = 215.2\ \text{cm} = 2.152\ \text{m}$$

Ta = AF (Tc) / L = 65.364 (2.152) / 140 = 1.005 m.

Tf = Tc – Ta = 2.152 – 1.005 = 1.147 m.

	Fwd m	Aft m
Initial drafts	6.952	4.216
Tf or Ta	-1.147	+1.005
Final drafts	5.805	5.221

PART C – Damaged Ship data

As per SOLAS 74, as amended, the shipyard provides ‘Damaged Stability Data’ for the ship. This consists of:

(a) Plans showing the piping diagrams for bilge and ballast lines for quick reference in case damage occurs resulting in bilging.

(b) A book referred to as the ‘Damage Stability Book’ which contains the data of the ship bilged under various assumed types of damage and the residual stability thereafter.

The ship’s Master and Mates should be familiar the various conditions depicted therein so that, in an emergent situation, see at a glance which condition matches or resembles the actual bilged situation and decide on the survivability of the ship and any corrective actions needed urgently. This saves a lot of time when urgency is of utmost importance. Many bulk carriers have foundered in a very short time wherein immediate corrective action may have helped to save the crew if not save the ship also.

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9. CALCULATION OF LIST BY GZ CURVE

You studied the calculation of list by use of the formula Tan θ = GG_1/GM in chapter 13 of the earlier book, 'Ship Stability at the Operational Level'. Use of that formula suffers from lack of accuracy because it assumes that the initial GM, and hence the transverse KM, remains constant despite changes in the angle of inclination, which assumption is reasonable ONLY for very small angles of inclination. A more accurate method of computing the angle of list is by use of the curve of statical stability (GZ curve). Wherever the list calculated by the formula exceeds 5° or so, you should use the GZ curve method for greater accuracy.

Your attention is invited to chapters 22, 23 & 24 of the earlier book, 'Ship Stability at the Operational Level' wherein you studied the curve of statical stability of a ship with a list. In those cases, the ship was in stable equilibrium such that GZ to one side was considered positive and to the other side, negative.

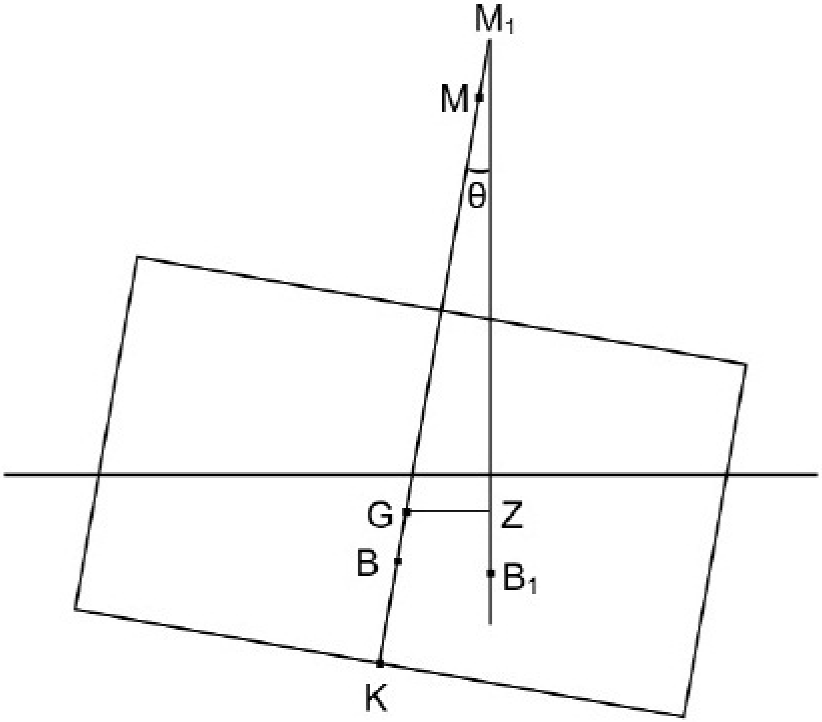
A transverse shift of the COG of the ship (GG_1) to one side causes a reduction of GZ when the ship inclines to that side and vice versa. This reduction of GZ or upsetting lever can be calculated by the formula:

Reduction of GZ or upsetting lever = $GG_1.\text{Cos}\ \theta$

Origin of the formula:

In the accompanying figure, let us consider the ship heeling over <u>only due to external forces</u>.

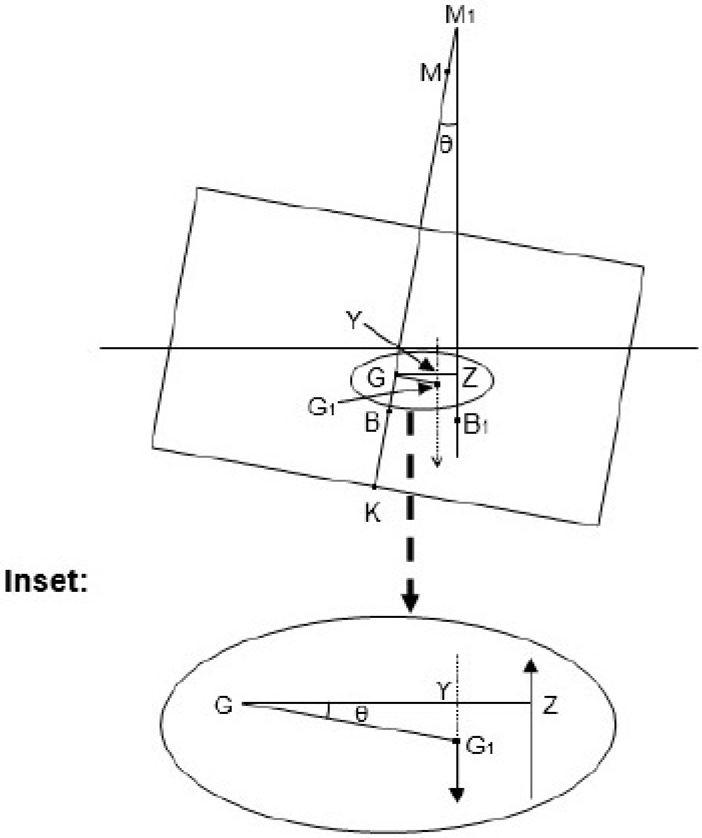
KG is the final fluid KG of the ship.
B is the COB when the ship is upright.
GM is the initial fluid metacentric height.
B_1 is the COB after the ship heels.
M_1 is the new metacentre after heeling.
GZ is the righting lever caused by heel.
θ is the angle of heel caused.



If the external forces were removed, the ship would return to upright. If, as shown in the following figures, the COG of the ship is then shifted transversely from G to G_1, parallel to the keel, and the vertical through G_1 cuts GZ at Y:

Angle Y = 90°, angle YGG_1 = angle of list = θ.

$GY = GG_1 (\text{Cos } \theta)$.



Since GY is the reduction of GZ due to transverse shift of G, the formula may be stated as:

Reduction of GZ or upsetting lever = GG_1 (Cos θ)

This upsetting lever may be allowed for in either of two ways:

Method 1

The curve of statical stability is drawn, as usual, for the final fluid KG of the ship, as explained in chapters 22 & 23 of the earlier book. The GG_1 sideways is calculated by the formula GG_1 = dw/W as explained in Chapter 13 of the earlier book.

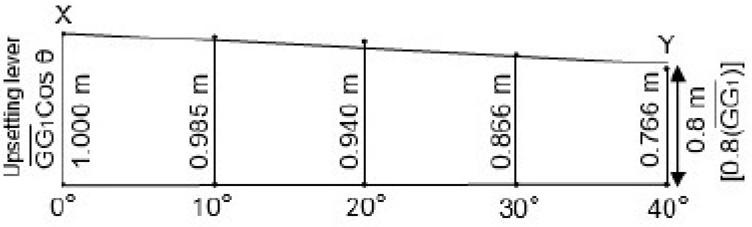
If GG_1 is assumed to be 1.000 m, GG_1(Cos θ) at 0° list = 1.000, at 10° = 0.985, at 20° = 0.940, at 30° = 0.866 & at 40° = 0.766 m. These ordinates are shown in the following diagram.

You will notice from the following diagram that this curve very nearly coincides with a straight line XY drawn from GG_1 at 0° heel to 0.8 (GG_1) at 40° heel.

Drawing of the upsetting arm curve:

Lay off GG_1 upwards from the 0° heel position on the x-axis, arriving at a point called X. Then lay off $0.8(GG_1)$ upwards from the 40° heel position on the x-axis, arriving at Y. Join points X and Y by a straight line which represents the upsetting lever at any angle of heel up to 40°. The angle of heel at which the righting arm (GZ) curve and the upsetting arm curve (line XY) intersect, is the angle of list.

This is the method used in the IMO Grain Code.



The foregoing method is further illustrated in the worked examples that follow.

Method 2

The curve of statical stability is drawn only after the value of GZ, at each angle of heel, is reduced by $GG_1(\text{Cos } \theta)$. The righting lever GZ at 0° heel would now necessarily be negative as it is trying to list the ship. The angle of heel at which the modified GZ curve cuts the x-axis is the angle of list. This is illustrated in the following worked examples:

Example 1

M.V. VIJAY is in SW displacing 13000 t. KG = 7.788 m, FSM = 1372 tm. A tractor, already on board, weighing 50 t is to be shifted 10 m to starboard. Calculate the resultant list.

FSC = 1372/13000 =	0.106 m
Solid KG =	7.788 m
Fluid KG =	7.894 m
KM (appendix I) =	8.139 m
Initial fluid GM =	0.245 m

$GG_1 = dw / W = 50 (10) / 13000 = 0.03846$ m.

$\text{Tan } \theta = GG_1 / GM = 0.03846 / 0.245 = 0.15699$

θ = 8.922° or 8° 55' to starboard.

Since the list exceeds 5°, it is preferable to obtain a more accurate answer by the GZ curve.

From appendix II,

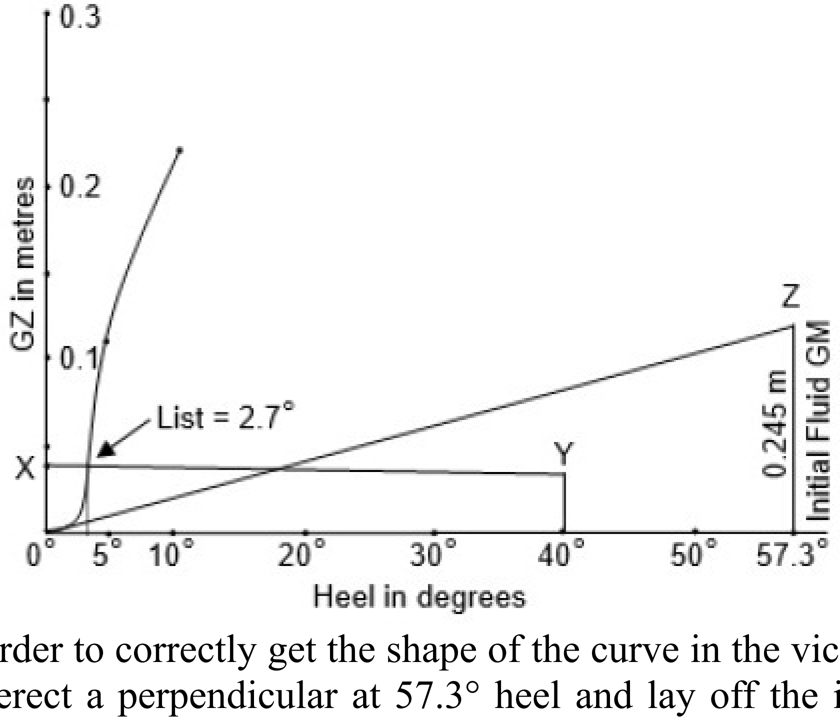
θ°	KN	- KG Sin θ	= GZ
0	0.000	-7.894 Sin 0°	= 0.000 m
5	0.798	-7.894 Sin 5°	= 0.110 m
10	1.595	-7.894 Sin 10	= 0.224 m

Note: It is not necessary to draw the entire curve of statical stability just to compute the value of list.

Method 1

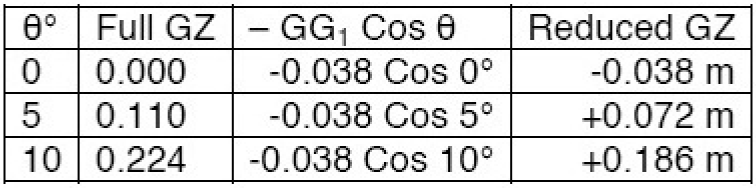
The upsetting levers at 0° and at 40° heel are GG_1 & 0.8 (GG_1) = 0.038 and 0.030 m respectively.

The accompanying graph shows both the righting arm and the upsetting arm curves. The value of list is readily apparent.



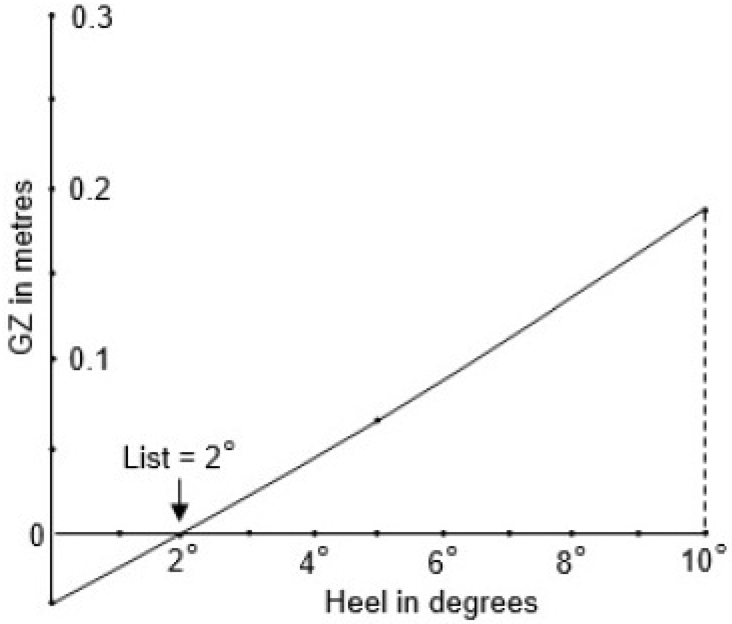
In order to correctly get the shape of the curve in the vicinity of the origin, erect a perpendicular at 57.3° heel and lay off the initial fluid GM upward to arrive at point Z. Join point Z and the origin by a straight line and, while drawing the curve of statical stability, ensure that the curve coincides with this line initially.

Method 2



θ°	Full GZ	$- GG_1$ Cos θ	Reduced GZ
0	0.000	-0.038 Cos 0°	-0.038 m
5	0.110	-0.038 Cos 5°	+0.072 m
10	0.224	-0.038 Cos 10°	+0.186 m

The accompanying graph shows the values of reduced GZ plotted against the corresponding values of heel.



The results by use of the formula become less accurate if the fluid GM is small.

In the case of this ship, the change of KM, due to change of angle of heel, is considerable even for small angles of heel.

Note: The above curves are only for starboard heel because GG_1 is to starboard.

You may, if you so desire, draw the entire curve for both, the starboard and the port sides, in order to understand the topic better. The correction to GZ, obtained by the formula GG_1 (Cos θ), would be additive to the port side because GG_1 is to starboard.

Example 2

M. V. VIJAY is in SW at a displacement of 13700 t. KG is 7.0 m and FSM 1400 tm. 300 t of cargo is loaded on the upper deck, KG 12 m, 6 m to port of the centre line of the ship. Calculate the list caused.

(Use appendix II for KN curves).

GG_1 = dw / W = 5(300) / 1400 = 0.107 m.

Final KG solid = 7.000 + 0.107 m =	7.107 m
FSC = FSM/W = 1400/14000 =	0.100 m
Final fluid KG =	7.207 m
KM from appendix =	8.073 m
Initial fluid GM =	0.866 m

GG_1 = dw / W = 6(300) / 14000 = 0.12857 m.

Tan θ = GG_1/GM = 0.12857 / 0.866 = 0.14846

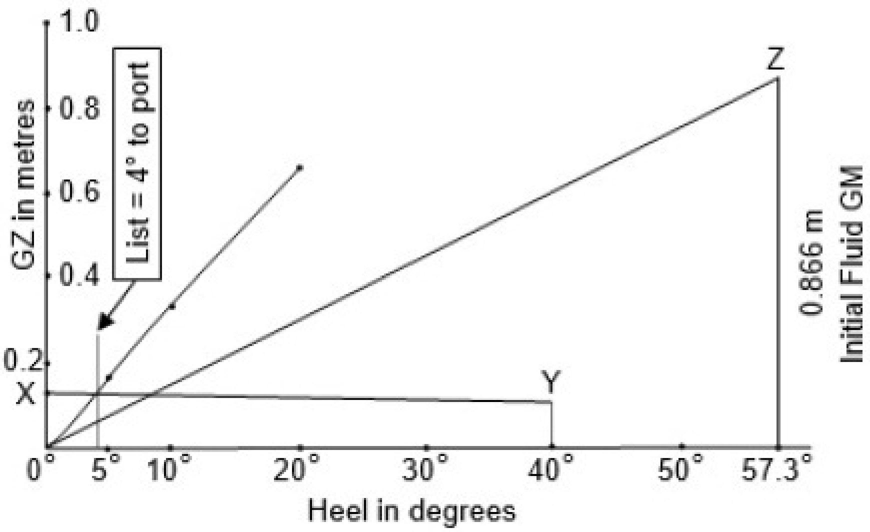
By formula, θ = 8.44° or 8° 27' to port.

Since the list exceeds 5°, it is preferable to obtain a more accurate answer by the GZ curve.

θ°	KN	-KG Sin θ	= Reduced GZ
0	0.000	-7.207 Sin 0°	= 0.000 m
5	0.793	-7.207 Sin 5°	= 0.165 m
10	1.581	-7.207 Sin 10°	= 0.330 m
20	3.130	-7.207 Sin 20°	= 0.665 m

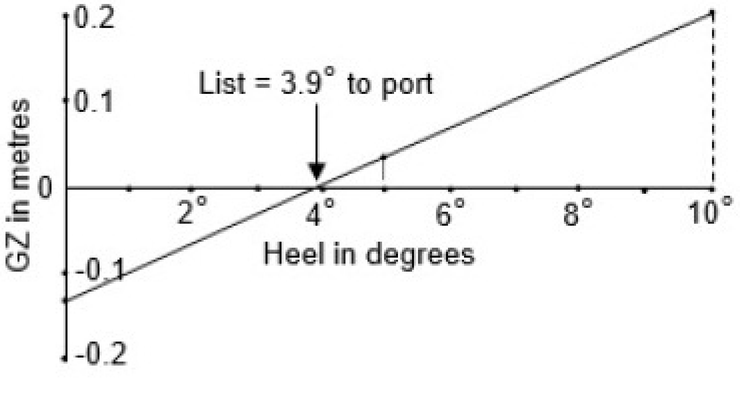
Method 1

Upsetting levers at 0° & 40° heel = GG_1 and 0.8 (GG_1) = 0.129 and 0.103 m respectively.



Method 2

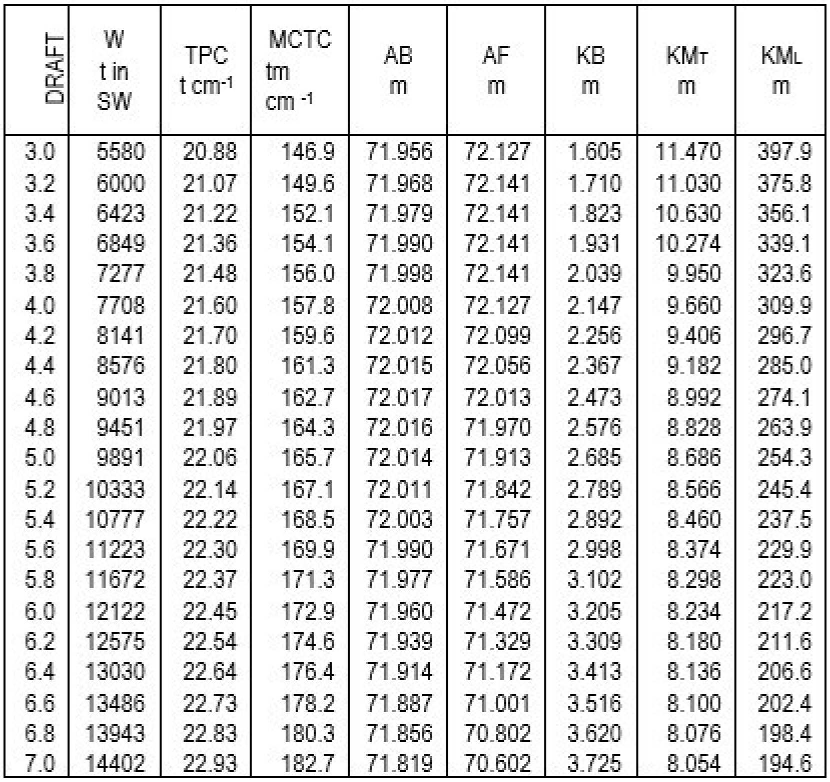
θ°	Full GZ	$-GG_1$ (Cos θ)	Reduced GZ
0	0.000	-0.129 (Cos 0°)	= -0.129 m
5	0.165	-0.129 (Cos 5°)	= +0.037 m
10	0.330	-0.129 (Cos 10°)	= +0.203 m
20	0.665	-0.129 (Cos 20°)	= +0.544 m



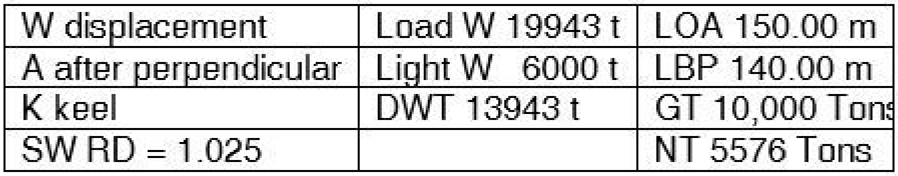
Exercise 11
(List by GZ curve)

(Appendices I & II are repeated here for easy reference)

Appendix I - Hydrostatic particulars - m.v. VIJAY

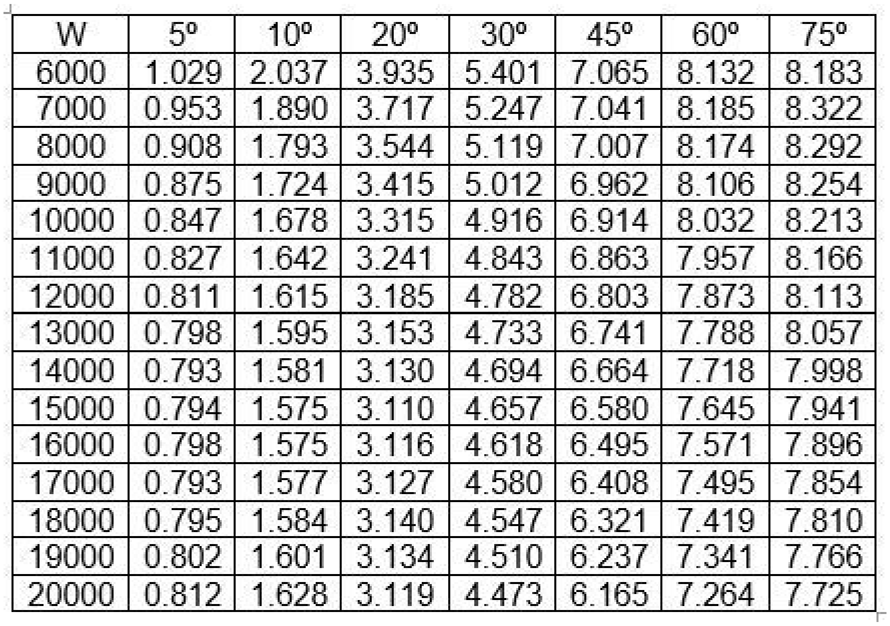


DRAFT	W t in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6



W displacement	Load W 19943 t	LOA 150.00 m
A after perpendicular	Light W 6000 t	LBP 140.00 m
K keel	DWT 13943 t	GT 10,000 Tons
SW RD = 1.025		NT 5576 Tons

Appendix II - KN Table - m.v. VIJAY



W	5°	10°	20°	30°	45°	60°	75°
6000	1.029	2.037	3.935	5.401	7.065	8.132	8.183
7000	0.953	1.890	3.717	5.247	7.041	8.185	8.322
8000	0.908	1.793	3.544	5.119	7.007	8.174	8.292
9000	0.875	1.724	3.415	5.012	6.962	8.106	8.254
10000	0.847	1.678	3.315	4.916	6.914	8.032	8.213
11000	0.827	1.642	3.241	4.843	6.863	7.957	8.166
12000	0.811	1.615	3.185	4.782	6.803	7.873	8.113
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896
17000	0.793	1.577	3.127	4.580	6.408	7.495	7.854
18000	0.795	1.584	3.140	4.547	6.321	7.419	7.810
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

1. M.V. VIJAY is in a SW dock, displacing 12,575 t; KG 7.6 m; FSM 1372 tm. Calculate the list, to the nearest degree, if a 125 t locomotive is loaded on the UD (KG 16 m) 6 m to stbd of the centre line.

Answer: By formula: 8.902°; by Curve: 3° stbd.

2. M.V. VIJAY has W = 8,000 t, KG = 7.354 m, FSM = 1082 tm. Cargo was shifted as follows:

200 t 4 m to starboard
100 t 2 m to port
100 t 4 m to port
200 t 15 m to starboard

Calculate the final list to the nearest degree.

Answer: By formula: 11.310°; by Curve: 8° stbd.

3. M.V. VIJAY has W = 10,000 t, KG = 6.814 m & FSM = 1420 tm. If 200 t of cargo is shifted 10 m down & 10 m to port, find the list to the nearest degree.

Answer: By formula: 6°; by Curve: 4° port.

4. M.V. VIJAY has KG = 6.3 m, FSM = 2148 tm & W = 12,000 t. A 200 t transformer is to be loaded by the ship's jumbo derrick whose head is 24 m above the keel. Find, to the nearest degree:

(i) The list when the derrick picks up the load from the wharf with an outreach of 15 m to stbd.

(II) The list after the load has been placed on the UD (KG 10 m) 7 m to starboard of the centre line.

Answer:

(i) By formula: 9.567°; by Curve: 3° stbd.

(ii) By formula: 3.889°; by Curve: not necessary.

5. M.V. VIJAY, having W = 14,212 t, KG = 7.4 m, FSM = 2026 tm, is listed 4° to port. It is proposed to discharge a 112 t locomotive from the upper deck (KG = 12 m) 8 m to starboard of the centre line. Find, to the nearest degree, the final list.

Answer: By formula: 10.126; by Curve: 4° port.

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10. ANGLE OF LOLL BY GZ CURVE

In chapter 11 of the earlier book, Ship Stability at the Operational Level, ‘Angle of loll’, and the behaviour of a ship in that condition, has been described. In chapter 21 of the same book, a formula to calculate the approximate value of the angle of loll was derived. The remedial action in such a condition was also discussed. In chapter 22 of the same book, the curve of statical stability of an unstable vessel has been illustrated. With a view to avoid needless repetition, this chapter is confined only to obtaining the angle of loll by constructing a part of the GZ curve and comparing the result with that by the formula.

Since the formula is based on the ‘Wall-sided’ formula (explained in chapter 21 of the earlier book), it is accurate only until the deck edge immerses.

Example 1

M.V. VIKRAM is in SW. W = 16635 t, KG = 8.69 m and FSM = 998 tm. The stability data book indicates that KM = 8.25 m, KB = 4.252 m and KN values as follows:

Heel °	0	5	10	15	20
KN (m)	0	0.756	1.501	2.227	2.974

Heel °	25	30	40	45	60
KN (m)	3.699	4.393	5.647	6.134	7.165

Find, to the nearest degree, the angle of loll by:
(i) Formula and (ii) GZ curve.

KG solid	8.690 m		KM	8.250 m
FSC = 998/16635	0.060 m		KB	4.252 m
KG fluid	8.750 m		BM	3.998 m
KM	8.250 m			
GM fluid	- 0.500 m			

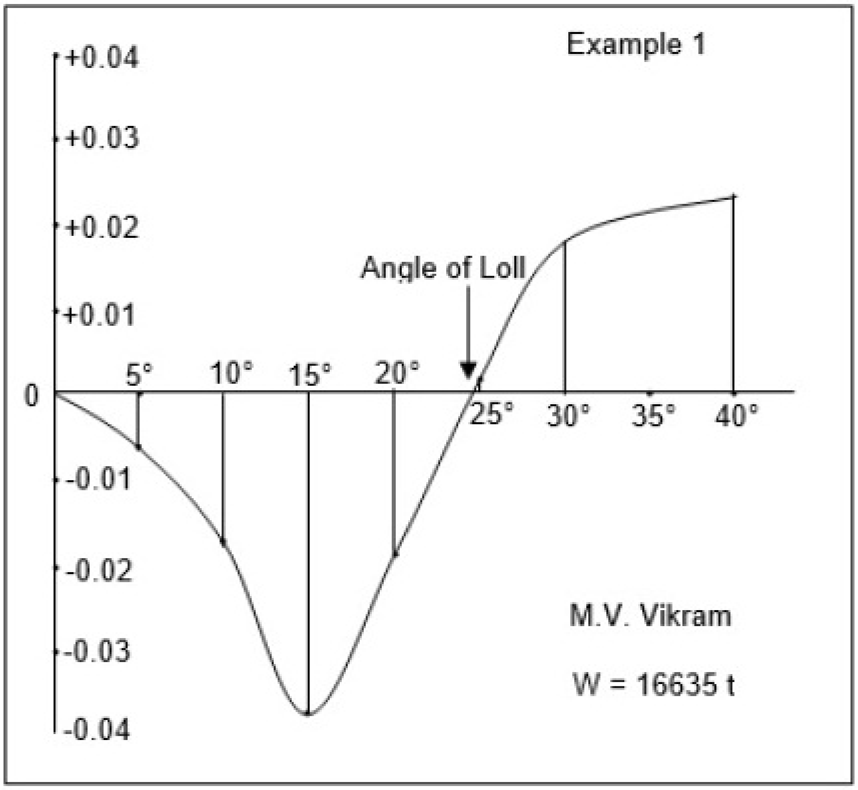
$\text{Tan } \theta \sqrt{(-2GM / BM)} = 0.50013$

θ by formula = 26.57° i.e., 27° answer (i).

θ	KN	KG Sin θ	GZ
0	0	0	0
5	0.756	0.763	-0.007
10	1.501	1.519	-0.018
15	2.227	2.265	-0.038
20	2.974	2.993	-0.019
25	3.699	3.698	+0.001
30	4.393	4.375	+0.018
40	5.647	5.624	+0.023
45	6.134	6.187	-0.053
60	7.165	7.578	-0.413 m

From the curve on the next page, the angle of loll = 24.9°.

Answer (ii) = 25°.



Exercise 12
(Angle of loll by GZ curve)

1. M.V. VINAYAK, W 12000 t, KG 8.660 m, FSM 4572 tm, KM 8.441 m, KB 3.20 m.

Heel	0	5	10	15°
KN	0	0.772	1.538	2.272 m

Heel	20	30	40	60°
KN	3.033	4.554	5.925	7.498 m

Find the angle of loll, to the nearest whole degree, by: (i) the GZ curve and (ii) the formula.

Answer: By curve: 26°; by formula : 26°.

2. M.V. VISHNU, W 9540 t, KG 9.2 m, FSM 1908 tm, KM 8.97 m, KB 2.623 m.

Heel	0	5	10	15°
KN	0	0.819	1.620	2.397 m

Heel	20	30	40	60°
KN	3.202	4.727	6.060	7.685 m

Find the angle of loll, to the nearest whole degree, by: (i) the GZ curve and (ii) the formula.

Answer: By curve: 22.5°; by formula : 20°.

3. M.V. VASUDEV, W 14300 t, KG 8.850 m, FSM 2145 tm, KM 8.258 m, KB 3.724 m.

Heel	0	5	10	15°
KN	0	0.755	1.504	2.227 m

Heel	20	30	40	60°
KN	2.974	4.459	5.799	7.330 m

Find the angle of loll, to the nearest whole degree, by: (i) the GZ curve and (ii) the formula.

Answer: By curve: 37.5°; by formula : 30°.

4. M.V. VASANTHY, W 17000 t, KG 8.550 m, FSM 2550 tm, KM 8.265 m, KB 4.331 m.

Heel	0	5	10	15°
KN	0	0.755	1.502	2.229 m

Heel	20	30	40	60°
KN	2.978	4.362	5.620	7.138 m

Find the angle of loll, to the nearest whole degree, by: (i) the GZ curve and (ii) the formula.

Answer: By curve: 20°; by formula : 25°.

5. M.V. VENUGOPAL, W 70000 t, KG 13.95 m, FSM 3500 tm, KM 13.254 m, KB 5.563 m. From the cross curves, for assumed KG of 10 m, the following were obtained:

Heel	0	10	20°
GZ	0	0.600	1.380 m

Heel	30	45	60°
GZ	2.250	3.130	2.580 m

Find the angle of loll, to the nearest whole degree, by: (i) the GZ curve and (ii) the formula.

Answer: By curve: 20°; by formula : 24°.

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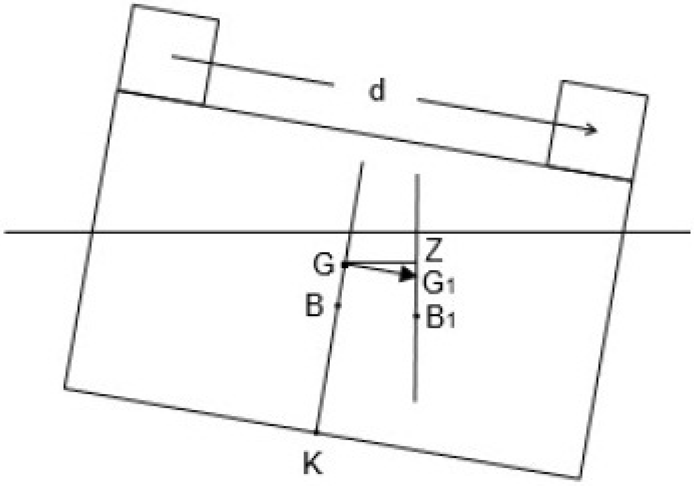
11. LIST WHEN INITIAL GM IS ZERO

When the initial GM fluid is zero, and a weight is shifted transversely, the approximate list caused can be calculated by formula:

$\text{Tan } \theta = \sqrt[3]{(2GG_1 / BM)}$

The derivation of the formula is as follows:



In the above figure, B and G are the initial positions of the COB and the COG. G_1 is the position of the COG after the transverse shift of weight. The ship will now incline transversely until the COB shifts to B_1, which is directly under G_1.

If you now insert the horizontal line GZ, you will notice that GZ represents the listing lever which is similar to the righting lever!

As per the 'Wall-sided formula' (see Chapter 21 in the earlier book, 'Ship Stability at the Operational Level'):

$GZ = \text{Sin } \theta \, [GM + \tfrac{1}{2}(BM \text{ Tan}^2 \theta)]$

But, as you will see from the foregoing figure,

$GZ = GG_1 \text{ Cos } \theta$

So $GG_1 \text{ Cos } \theta = \text{Sin } \theta \, [GM + \tfrac{1}{2}(BM \text{ Tan}^2 \theta)]$

Inserting GM = 0, and dividing both sided by Cos θ:

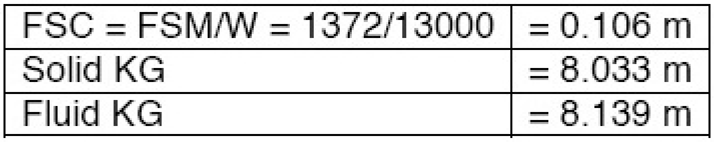
$GG_1 = \tfrac{1}{2}(BM \text{ Tan}^3 \theta)$ or $\text{Tan } \theta = \sqrt[3]{(2GG_1 / BM)}$

However, this formula is based on the 'Wall-sided formula' - applicable only where the ship's sides are parallel & that too, only until the deck edge immerses.

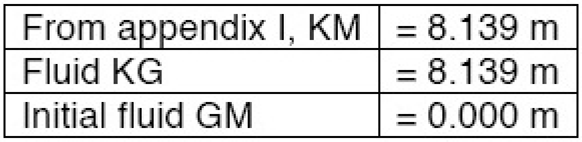
You would obtain a more accurate result by drawing the GZ curve for the fluid KG and displacement of the ship and applying the GG_1 Cos θ correction as done in chapter 9 of this book.

Example 1

M.V. VIJAY is in SW displacing 13,000 t. KG = 8.033 m, FSM = 1372 tm. Find the list if a weight of 25 t is shifted 10 m to starboard. (Use appendices I and II).



FSC = FSM/W = 1372/13000	= 0.106 m
Solid KG	= 8.033 m
Fluid KG	= 8.139 m



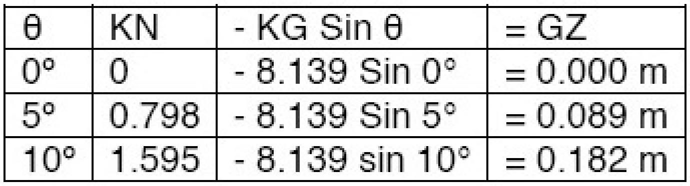
From appendix I, KM	= 8.139 m
Fluid KG	= 8.139 m
Initial fluid GM	= 0.000 m

BM = KM – KB = 8.139 – 3.406 = 4.733 m

$GG_1 = dw / W = 10\,(25) / 13000 = 0.01923$ m.

$\text{Tan } \theta = \sqrt[3]{(2GG_1 / BM)} = 0.20105$

List = 11.37° by formula.



θ	KN	- KG Sin θ	= GZ
0°	0	- 8.139 Sin 0°	= 0.000 m
5°	0.798	- 8.139 Sin 5°	= 0.089 m
10°	1.595	- 8.139 sin 10°	= 0.182 m

Upsetting lever at 0° heel = GG_1 (Cos 0°) = 0.019 m

Upsetting lever at 40° heel = GG_1 (0.8) = 0.015 m

By constructing part of the GZ curve and inserting the upsetting lever, as shown in chapter 9, you find the list to be only 2°, as against 11.37° obtained by using the formula.

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12. DYNAMICAL STABILITY

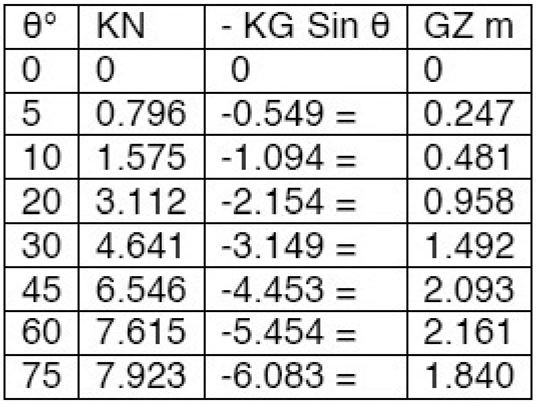
Dynamical stability, at any angle of heel, is the work done in heeling the ship to that angle. It is expressed in tonne-metre-radians (tmr). It is the product of the displacement of the ship and the area (mr) under the curve of statical stability up to the angle of heel for which it is desired to calculate the dynamical stability.

It may be possible to calculate the area under the curve by Simpson's Rules, directly from the GZ values without actually drawing the GZ curve, provided sufficient values of GZ are available at constant intervals of heel. However, if the given ordinates are too few or at irregular intervals, the curve of statical stability would have to be drawn and the values of GZ read off at the desired intervals of heel for the application of Simpson's Rules.

Example 1

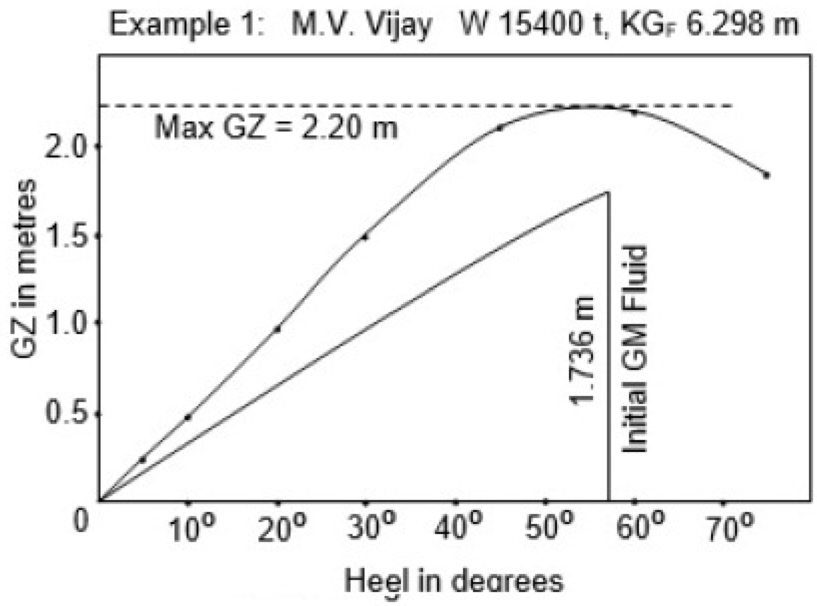
M.V. VIJAY is in SW at a displacement of 15400 t, KM is 8.034 m, KG 6.1 m and FSM 3050 tm. Calculate the dynamical stability at 40° heel. (Use appendix II).

KG fluid = 6.100 + 0.198 = 6.298 m.



θ°	KN	- KG Sin θ	GZ m
0	0	0	0
5	0.796	-0.549 =	0.247
10	1.575	-1.094 =	0.481
20	3.112	-2.154 =	0.958
30	4.641	-3.149 =	1.492
45	6.546	-4.453 =	2.093
60	7.615	-5.454 =	2.161
75	7.923	-6.083 =	1.840

Curve of statical stability drawn from foregoing data:



Extracted from the above curve:

Heel	GZ	SM	Product for area
0	0	1	0
5	0.247	4	0.988
10	0.481	2	0.962
15	0.725	4	2.900
20	0.958	2	1.916
25	1.225	4	4.900
30	1.492	2	2.984
35	1.800	4	7.200
40	1.975	1	1.975
		SOP	23.825

Area up to 40° = 5 (23.825) / 3 metre-degrees
= 5 (23.825)/ 3 (57.3) metre-radians

Note: It is suggested that the area under the curve be kept as a fraction until the final answer. If it is rounded off to three decimal places and then multiplied by W, a certain amount of inaccuracy would creep in.

Dynamical stability at 40° = 15400 (5) 23.825/3 (57.3)

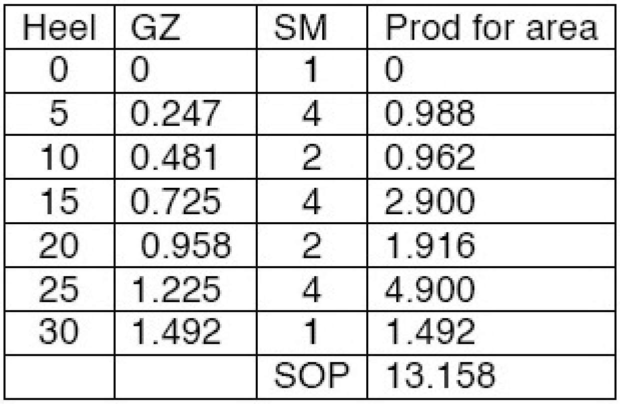
= 10672.048 tonne-metre-radians.

Note: With a common interval of 10°, the accuracy of the calculation would have been less and the answer would have been found to be 10556.033 tmr.

Example 2

In example 1, find the dynamical stability at 30° heel.

The values of GZ at 15° & 25° heel are taken from the curve of statical stability drawn for example 1.



Heel	GZ	SM	Prod for area
0	0	1	0
5	0.247	4	0.988
10	0.481	2	0.962
15	0.725	4	2.900
20	0.958	2	1.916
25	1.225	4	4.900
30	1.492	1	1.492
		SOP	13.158

Area up to 30° = 5 (13.158) / 3 (57.3) mr.
Dyn stability at 30° = 15400 x 5 x 13.1580 / (3 x 57.3)
= 5893.927 tonne-metre-radians

Note: A less accurate result would be obtained by using a common interval of 10°, & applying Simpson's Second Rule, giving an answer of 5854.620 tonne-metre-radians.

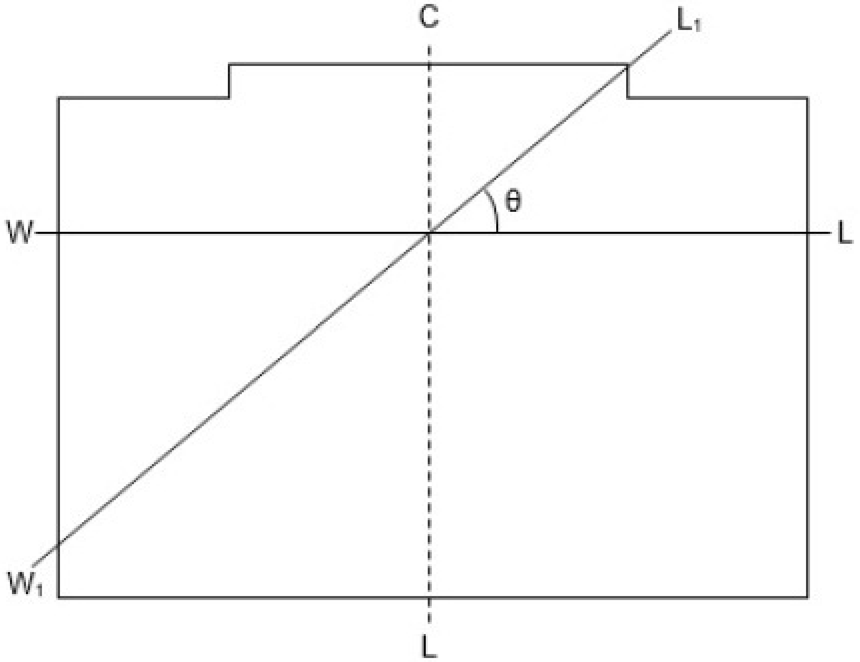
STABILITY REQUIREMENTS AS PER IMO 'INTERNATIONAL CODE ON INTACT STABILITY, 2008' (**Intact Stability Code or ISC**):

1) Initial GM to be not less than 0.15 m
2) Maximum GZ to be not less than 0.20 m at 30° heel or more.
3) Max GZ to occur at a heel of not less than 25°.
4) The area under the GZ curve, in metre radians, shall be not less than: (a) 0.055 up to 30° heel; (b) 0.090 up to 40° heel or the angle of

flooding, whichever is less; (c) 0.030 between 30° & 40° or the angle of flooding, whichever is less.

The angle of flooding is that angle of heel at which any non-watertight openings in the hull would immerse. Small openings through which progressive flooding cannot take place are excluded. The angle of flooding is usually well over 40°. If it is less than 40°, it would be clearly stated in the ship's stability information booklet supplied by the shipyard.

In most ships, the non-watertight openings that would immerse first, as a result of heel, would be the hatch coamings. Hatch covers are weathertight, not watertight. Coamings of cowl type ventilators, whose tops are likely to immerse before the hatch coamings, are usually provided with metal/wooden lids and canvas covers which may be put on, after unshipping the cowls, to prevent progressive flooding.



Some shipyards state the value of the angle of flooding in the GZ or KN tables against the displacement of the ship. An idea of the value of the angle of flooding may be obtained by inspecting the cross-sectional drawings of the ship but

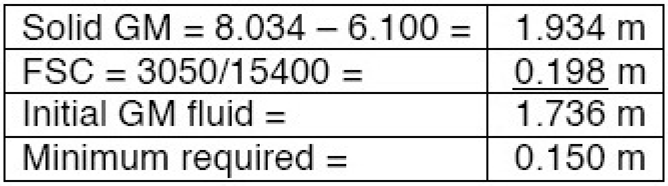
(i) The volume of displacement must be constant at both the waterlines – the present and the listed one;

(ii) Changes in the breadth of the ship at various points along her length, superstructure, etc would make considerable difference.

Example 3

Verify whether, in example 1, M.V. VIJAY meets all the stability requirements under the ISC.

1. Minimum GM needed:

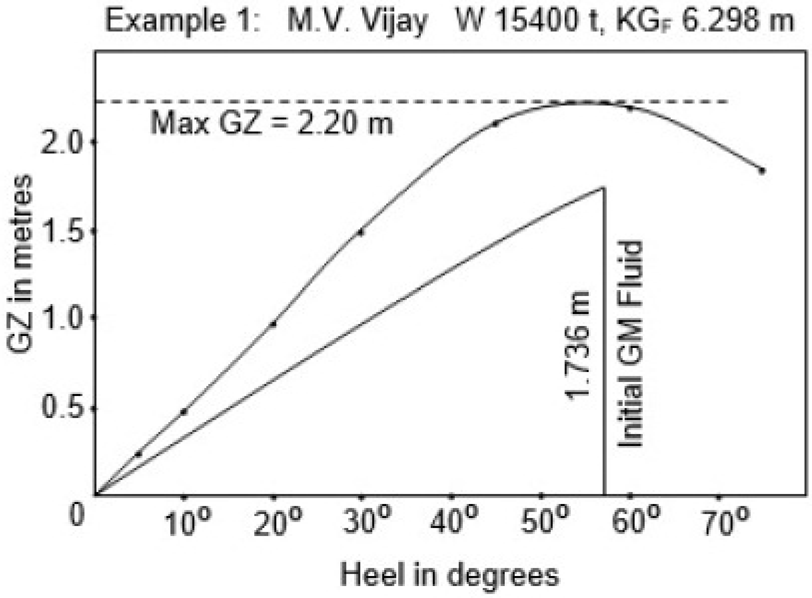


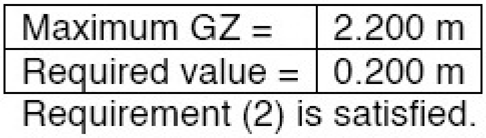
Solid GM = 8.034 – 6.100 =	1.934 m
FSC = 3050/15400 =	0.198 m
Initial GM fluid =	1.736 m
Minimum required =	0.150 m

Requirement (1) is satisfied.

2. Maximum GZ

As per curve drawn in example 1, repeated here:





Maximum GZ =	2.200 m
Required value =	0.200 m

Requirement (2) is satisfied.

3. Angle at which Maximum GZ should occur:

As per curve drawn in example 1, repeated at example 2:

Maximum GZ occurs at	55°
Maximum GZ should occur	= or > 25°

Requirement (3) is satisfied.

4. Area up to 30°, up to 40°and between 30° and 40° As calculated in examples 1 and 2:

		Actual	Criteria
(a)	Area up to 30° heel	0.383 mr	0.055 mr
(b)	Area up to 40° heel	0.693 mr	0.090 mr
(c)	Area between 30° & 40°	0.310 mr	0.030 mr

The ship complies with all the stability requirements of the ISC.

Example 4

If, in example 3, the angle of flooding was given as 30°, state whether the ship complies with the stability requirements of the ISC.

The rules require that the area under the curve between 30° & 40° or the angle of flooding, whichever is less, is at least 0.03 mr. In this case, the area between 30° & the angle of flooding (i.e. 30°) is zero!

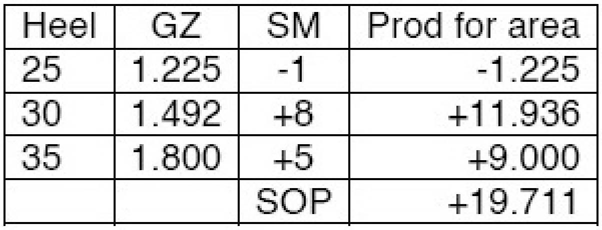
Hence, in this example, the ship does NOT satisfy all the stability requirements under the ISC. She complies with requirements 1, 2, 3, 4(a) and 4(b) but not 4(c).

Example 5

If, in example 1, the angle of flooding was given as 35°, state whether the ship meets all the stability requirements under the ISC.

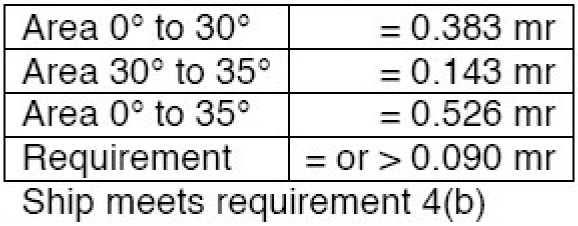
Referring to the calculations made in example 1, 2 & 3, the ship complies with requirements 1, 2, 3 & 4(a)

Requirement 4(b): Area under the curve, up to the angle of flooding, to be at least 0.09 mr.



Heel	GZ	SM	Prod for area
25	1.225	-1	-1.225
30	1.492	+8	+11.936
35	1.800	+5	+9.000
		SOP	+19.711

Area 30° to 35° = 5 (19.711) / 12 (57.3) = 0.143 mr



Area 0° to 30°	= 0.383 mr
Area 30° to 35°	= 0.143 mr
Area 0° to 35°	= 0.526 mr
Requirement	= or > 0.090 mr

Ship meets requirement 4(b)

Requirement 4(c): Area between 30° and the angle of flooding to be at least 0.03 mr. Here, it is 0.143 mr. The ship complies with 4(c).

The ship meets all the stability requirements of the ISC.

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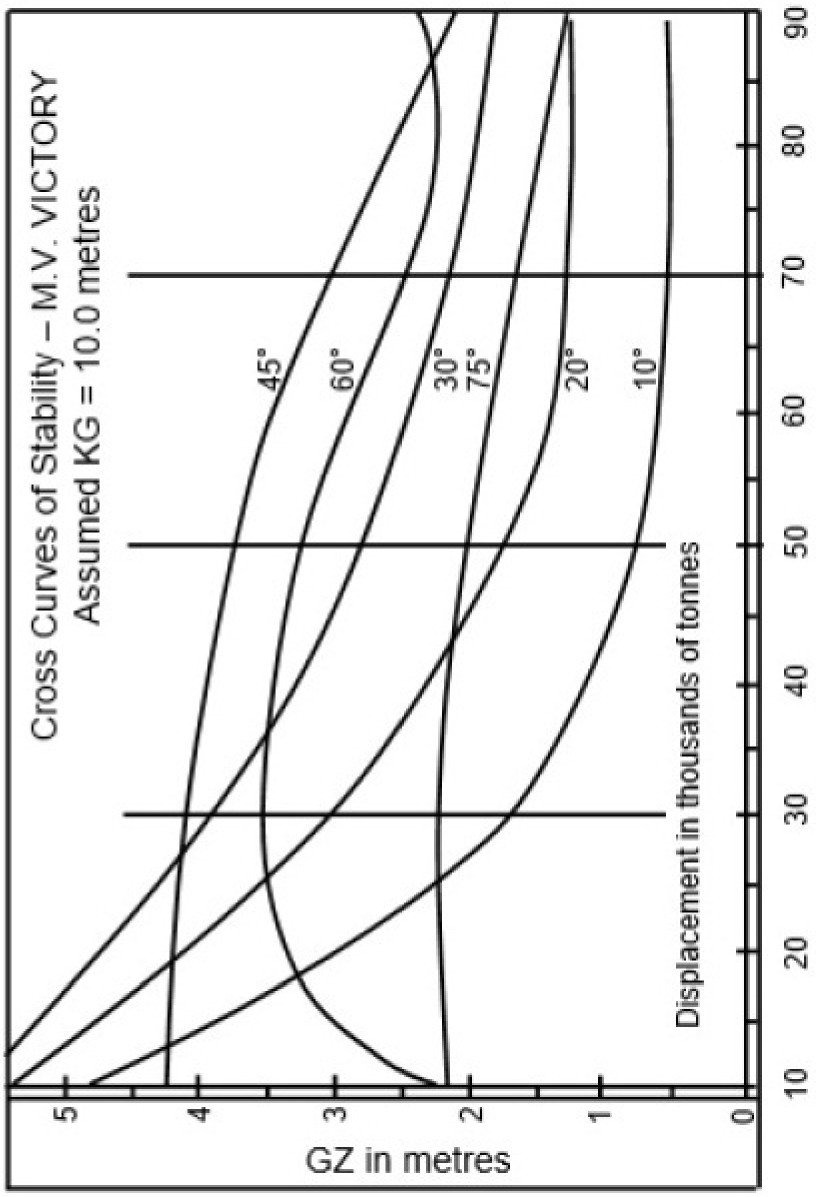
Exercise 13

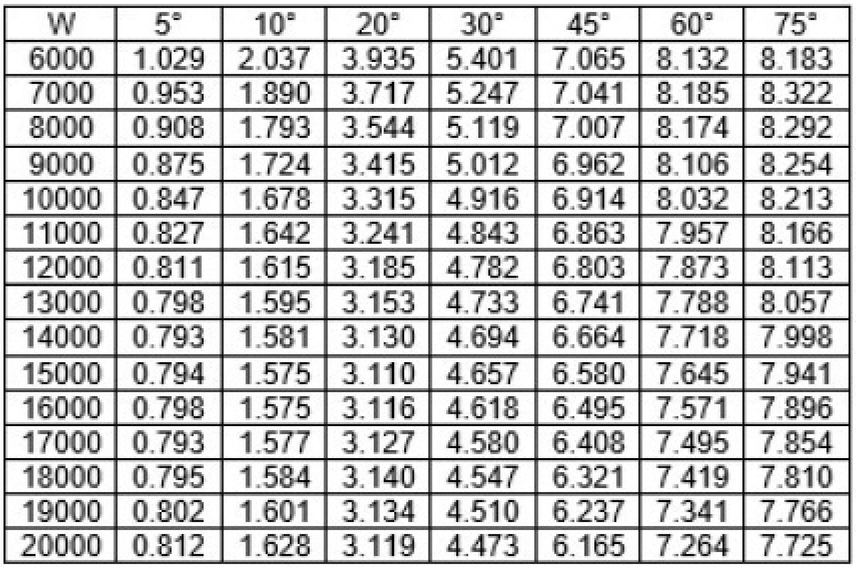
(Dynamical stability)

Appendices IV (m.v Victory) and II (m.v. Vijay) and are reproduced here for easy reference.

Appendix IV – m.v. Victory – Cross Curves



Appendix II – m.v. Vijay – KN Table

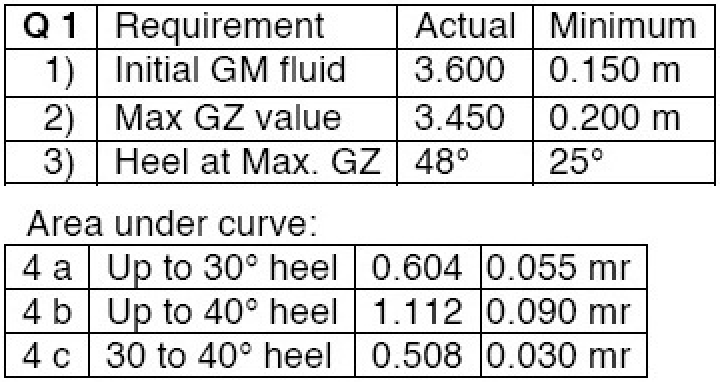


W	5°	10°	20°	30°	45°	60°	75°
6000	1.029	2.037	3.935	5.401	7.065	8.132	8.183
7000	0.953	1.890	3.717	5.247	7.041	8.185	8.322
8000	0.908	1.793	3.544	5.119	7.007	8.174	8.292
9000	0.875	1.724	3.415	5.012	6.962	8.106	8.254
10000	0.847	1.678	3.315	4.916	6.914	8.032	8.213
11000	0.827	1.642	3.241	4.843	6.863	7.957	8.166
12000	0.811	1.615	3.185	4.782	6.803	7.873	8.113
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896
17000	0.793	1.577	3.127	4.580	6.408	7.495	7.854
18000	0.795	1.584	3.140	4.547	6.321	7.419	7.810
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

Exercise 13
(Dynamical stability & requirements of ISC)

In the following cases, verify which of the stability requirements under the ISC have been met and which have not. Use the appendices of this book, where necessary. Where the angle of flooding is not mentioned, assume that it is over 40°.

1. M.V. VICTORY, W 70,000 t, KG 9.41 m, FSM 6300 tm, KM 13.1 m. State also the dynamical stability at 40° heel. **Answer**:



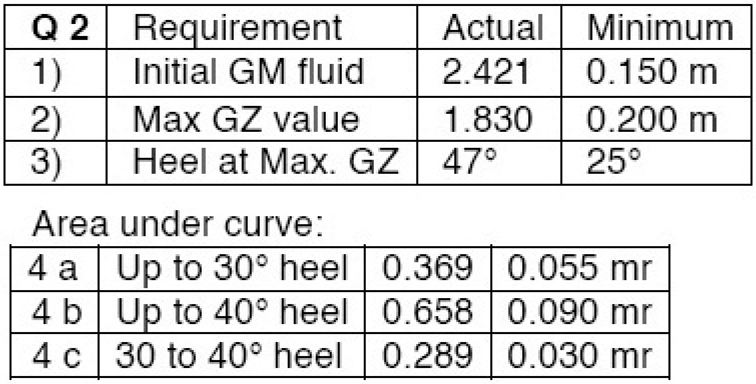
Q 1	Requirement	Actual	Minimum
1)	Initial GM fluid	3.600	0.150 m
2)	Max GZ value	3.450	0.200 m
3)	Heel at Max. GZ	48°	25°

Area under curve:

4 a	Up to 30° heel	0.604	0.055 mr
4 b	Up to 40° heel	1.112	0.090 mr
4 c	30 to 40° heel	0.508	0.030 mr

Vessel meets all the requirements.
Dynamical stability at 40° heel = 77881.617 tmr.

2. M.V. VICTORY, W 85,000 t, KG 10.68 m, FSM 6761 tm. State also the dynamical stability at 30° heel. **Answer**:



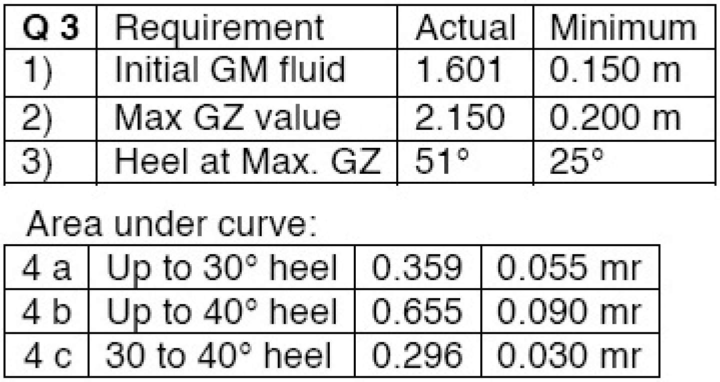
Q 2	Requirement	Actual	Minimum
1)	Initial GM fluid	2.421	0.150 m
2)	Max GZ value	1.830	0.200 m
3)	Heel at Max. GZ	47°	25°

Area under curve:

4 a	Up to 30° heel	0.369	0.055 mr
4 b	Up to 40° heel	0.658	0.090 mr
4 c	30 to 40° heel	0.289	0.030 mr

Vessel meets all the requirements.
Dynamical stability at 30° heel = 31329.843 tmr.

3. M.V. VIJAY, W 13,250 t, KG 6.427 m, FSM 1200 tm. **Answer**:



Q 3	Requirement	Actual	Minimum
1)	Initial GM fluid	1.601	0.150 m
2)	Max GZ value	2.150	0.200 m
3)	Heel at Max. GZ	51°	25°

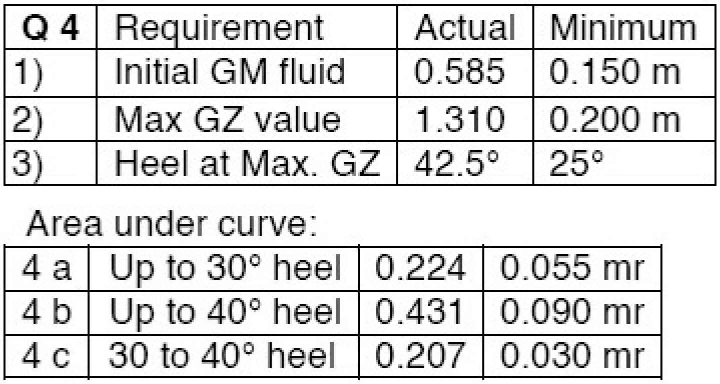
Area under curve:

4 a	Up to 30° heel	0.359	0.055 mr
4 b	Up to 40° heel	0.655	0.090 mr
4 c	30 to 40° heel	0.296	0.030 mr

Vessel meets all the requirements.

4. M.V. VIJAY, W 10,777 t, KG 7.8 m, FSM 800 tm. State also the dynamical stability at 40° heel.

Answer:



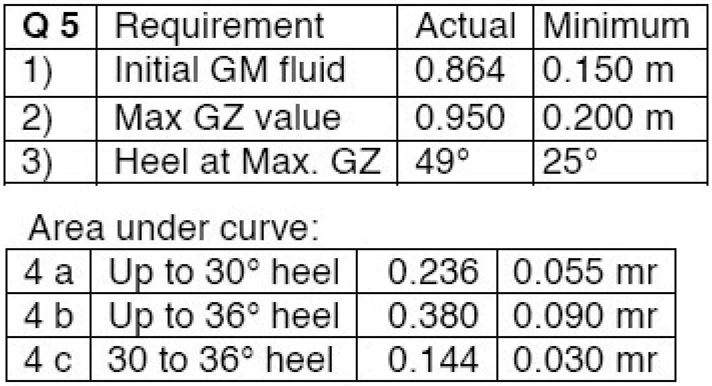
Q 4	Requirement	Actual	Minimum
1)	Initial GM fluid	0.585	0.150 m
2)	Max GZ value	1.310	0.200 m
3)	Heel at Max. GZ	42.5°	25°

Area under curve:

4 a	Up to 30° heel	0.224	0.055 mr
4 b	Up to 40° heel	0.431	0.090 mr
4 c	30 to 40° heel	0.207	0.030 mr

Vessel meets all the requirements.
Dynamical stability at 40° heel = 4645.583 tmr.

5. M.V. VIJAY, W 19,943 t, KG 7.326 m, FSM 1342 tm, KM 8.257 m, angle of flooding 36°. **Answer**:



Q 5	Requirement	Actual	Minimum
1)	Initial GM fluid	0.864	0.150 m
2)	Max GZ value	0.950	0.200 m
3)	Heel at Max. GZ	49°	25°

Area under curve:

4 a	Up to 30° heel	0.236	0.055 mr
4 b	Up to 36° heel	0.380	0.090 mr
4 c	30 to 36° heel	0.144	0.030 mr

Vessel meets all the requirements.

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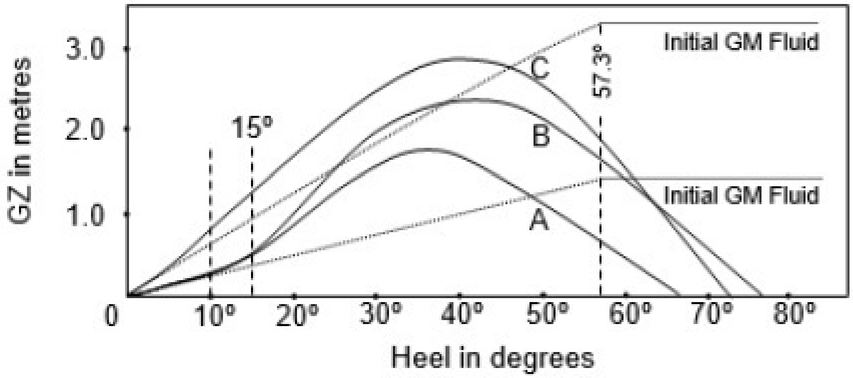
13. EFFECT OF BEAM AND FREEBOARD ON GZ CURVE

The beam and the freeboard of a ship influence GZ considerably as illustrated below. In the following diagram, curves A, B and C belong to three different box-shaped vessels whose draft, KG fluid and volume of displacement are the same.

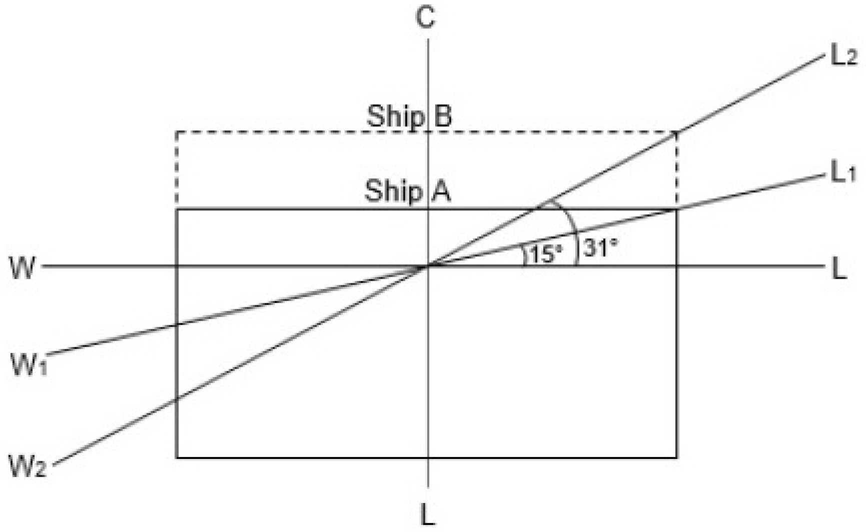


Effect of freeboard on GZ

Ship A’s deck edge immerses at 15° heel. Ship B has the same breadth as ship A but has a greater freeboard. As seen from the following figure, the GZ values of ship B are the same as that of ship A until 15° - the heel at which A’s deck edge immerses. On heeling further, the GZ of ship B is greater than that of ship A for the same angle of heel. This fact shows up clearly on inspecting curves A and B in the foregoing diagram. The range of stability of ship B is greater, than that of ship A, because of its greater freeboard.

To sum up: Greater freeboard means:

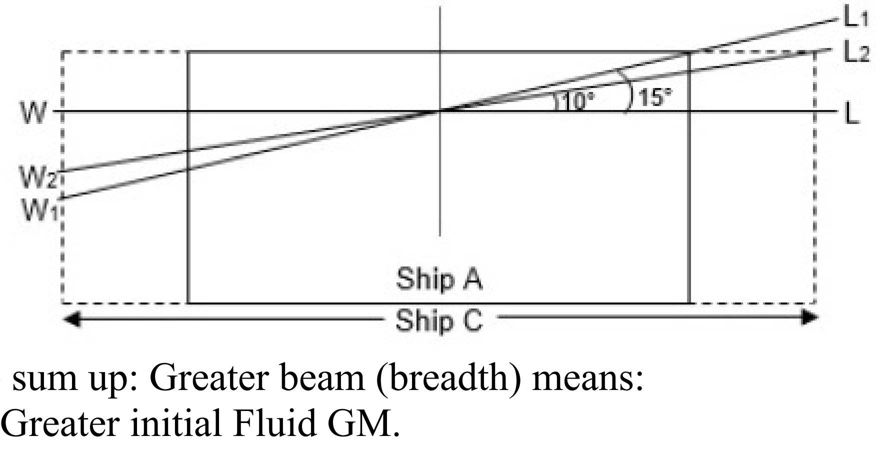
1. No change in initial Fluid GM.
2. Deck edge immerses at a greater angle of heel.
3. GZ values are unaffected until the deck edge immerses but thereafter, GZ values are greater.
4. Greater range of stability.



Effect of beam on GZ

Ship C, having the same freeboard as ship A, has greater beam (breadth). For ship-shapes, BM = I/V and for box-shapes, it is simplified as BM = $B^2/12d$, as explained in chapter 19 of 'Ship Stability at the Operational Level'. Since KM = KB + BM, initial KM of a ship with greater breadth is higher. Hence the GZ values of ship C are greater than those of ship A, at all angles of heel.

As apparent from the following figure, the deck edge of the broader ship immerses at a smaller angle of heel than the narrower ship. The range of stability also increases with increase in beam. All of the foregoing points are apparent when inspecting curves A and C in the first figure of this chapter.



To sum up: Greater beam (breadth) means:

1. Greater initial Fluid GM.
2. Deck edge immerses at a smaller angle of heel.

3. Greater values of GZ at all angles of heel
4. Greater range of stability.

The actual calculations in support of the foregoing statements are beyond the scope of this book.

Box-shaped vessels have been taken for illustration so that the variable parameters have been kept to a minimum for the sake of easy comparison.

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14. CHANGE OF TRIM DUE TO CHANGE OF DENSITY

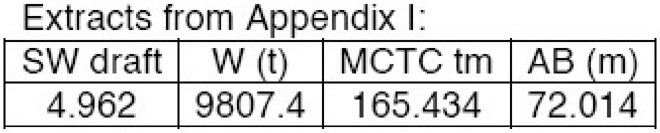
When a ship is in equilibrium, its COG & COB would be in the same vertical line. When it proceeds to water of another density, the volume of displacement and hence the draft, would change. If the AB of the ship at the new draft is different from the AB at the earlier draft, the COB would now be longitudinally separated from the COG by the distance referred to, in earlier chapters, as BG. The trimming moment, so formed, would be W.BG. The ship would then alter its trim until the COB comes directly under the COG. The trim, so caused, can be calculated by using the hydrostatic particulars of the ship for the new draft at the new density. This can be illustrated by the following example.

Example 1

M.V. VIJAY is in SW, drawing 3.60 m fwd & 6.40 m aft. Find the new drafts fwd and aft if it now proceeds to FW. (Extracts from Appendix I are given in the problem).

Fwd 3.6 m, aft 6.4 m, mean 5.0 m, trim 2.8 m (280 cm) by the stern. From appendix I, AF = 71.913 m.

Correction to aft draft = AF (trim) / L
= 71.913 (2.8) / 140 = 1.438 m
Initial hydraft = 6.40 – 1.438 = 4.962 m



Extracts from Appendix I:

SW draft	W (t)	MCTC tm	AB (m)
4.962	9807.4	165.434	72.014

Trim in cm = W.BG / MCTC or BG = trim (MCTC) / W

Initial BG = 280 (165.434) / 9807.4 = 4.723 m

Since trim was by stern, AG was < AB.

AG of vessel = 72.014 – 4.723 = 67.291 m

From appendix I,

	W (t)	draft	MCTC	AB m	AF m
SW	10052.6	5.073	166.212	72.013	71.887
FW	9807.4	5.073	162.158	72.013	71.887

BG = AB – AG = 72.013 – 67.291 = 4.722 m

Since AB > AG, final trim is by stern.

$$\text{Trim} = \frac{W.BG}{MCTC} = \frac{9807.4\ (4.722)}{162.158} = 285.6 \text{ cm.}$$

Ta = AF (trim) / L = 71.887 (2.856) / 140 = 1.466 m

Tf = Tc – Ta = 2.856 – 1.466 = 1.390 m

	Fwd (m)	Aft (m)
Final hydraft	5.073	5.073
Tf or Ta	-1.390	+1.466
Final drafts	3.683	6.539

The change of trim actually caused by this change in density of water displaced = 285.6 – 280 = 5.6 cm only.

This chapter is only meant to illustrate, in theory, that the trim of a ship is liable to slight change when the density of water displaced changes. It is not of much importance in practical operation of ships. Since the calculation is not only similar to, but simpler than, other problems on trim, no exercise has been set on this topic.

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15. CENTRE OF PRESSURE

Centre of pressure is that point through which the thrust, or total pressure, may be considered to act. Pressure and thrust were explained in chapter 2 of ‘Ship Stability at the Operational Level’. Calculation of pressure and thrust on curvilinear, immersed areas was done in chapter 20 in ‘Ship Stability at the Operational Level’. It is presumed that you would have gone through those chapters and, therefore, needless repetition is avoided here.

The depth ‘z’ of the centre of pressure (COP) below the water surface (WS) may be calculated by the formula:

z = I*ws / Ad

Where:

I*ws is the moment of inertia or second moment of the immersed area about the water surface expressed in m^4 (quadro-metres).

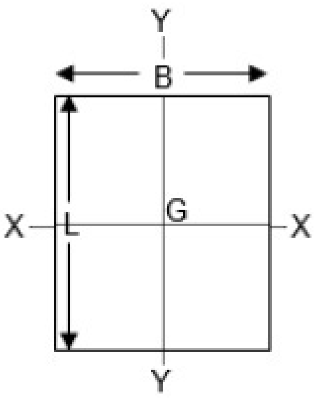
‘A’ is the area of the immersed portion in m^2 (square metres).

‘d’ is the depth, in metres, of the geometric centre of the immersed portion below the water surface.

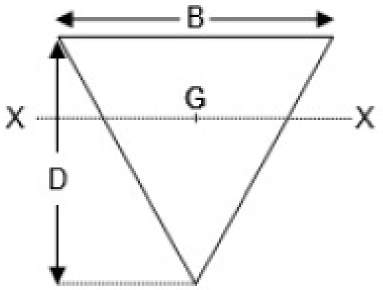
Standard formulae for the moment of inertia ‘I’ about an axis passing through the geometric centre of some regular shapes are given below. You should learn these by heart.

$$I^*YY = \frac{LB^3}{12}$$

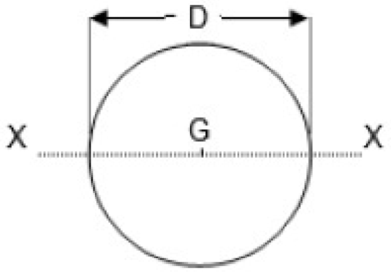
$$I^*XX = \frac{BL^3}{12}$$



$$I^*XX = \frac{BD^3}{36}$$



$$I^*XX = \frac{\pi D^4}{64}$$



Once ‘I’ of an area, about an axis passing through its geometric centre, is known, ‘I’ about any other parallel axis can be calculated by the theorem of parallel axes.

Theorem of parallel axes: If I*GG is the moment of inertia of an area about an axis passing through its geometric centre, and ZZ is an axis parallel to GG, then:

$$I^*ZZ = I^*GG + Ad^2$$

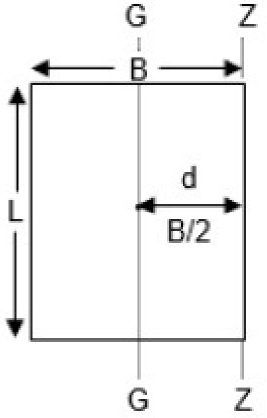
Where ‘d’ is the distance between axis GG & axis ZZ.

Example 1:

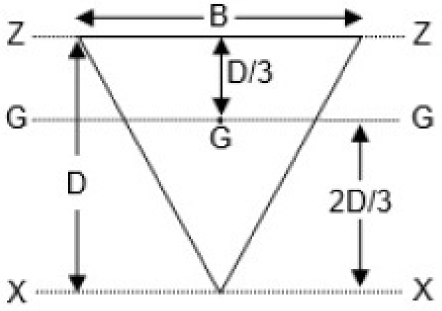
$$I^*ZZ = I^*GG + Ad^2$$

$$= \frac{LB^3}{12} + LB\,(B/2)^2$$

$$= \frac{LB^3}{3}$$



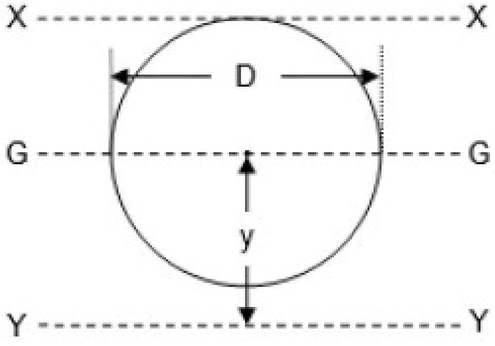
Example 2:



$$I^*ZZ = I^*GG + Ad^2 = \frac{BD^3}{36} + \frac{BD}{2}\,(D/3)^2 = \frac{BD^3}{12}$$

$$I^*XX = I^*GG + Ad^2 = \frac{BD^3}{36} + \frac{BD}{2}\,(2D/3)^2 = \frac{BD^3}{4}$$

Example 3:



$$I^*XX = I^*GG + Ad^2 = \frac{\pi D^4}{64} + \frac{\pi D^2}{4}(D/2)^2$$

$$I^*XX = = \frac{\pi D^4}{64} + \frac{\pi D^4}{16} = \frac{5\ \pi D^4}{64}$$

$$I^*YY = I^*GG + Ad^2 = \frac{\pi D^4}{64} + \frac{\pi D^2}{4}(y)^2$$

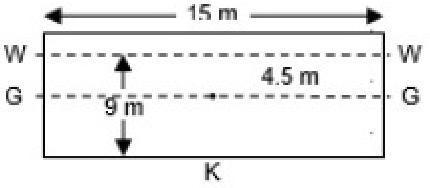
CALCULATION OF POSITION OF COP OF REGULAR SHAPES

Worked example 1

One side of a tank is a vertical, rectangular bulkhead 15 m long and 10 m high. Find KP (the height of the COP above the bottom of the tank) when the tank has SW in it to a sounding of 9 metres.

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15\,(9^3)}{12} + 15\,(9)\,(4.5^2)}{15\,(9)\,(4.5)}$$



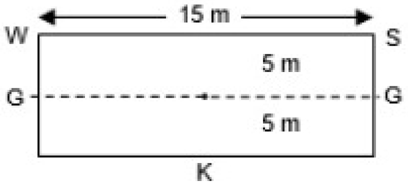
z = Depth of COP below ws	= 6.000 m
Sounding	= 9.000 m
KP (height of COP above bottom)	= 3.000 m

Worked example 2

Calculate KP (height of the COP above the bottom of the tank) in worked example 1, when the sounding is 10 m.

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15\,(10^3)}{12} + 15\,(10)\,5^2}{15\,(10)\,(5)}$$



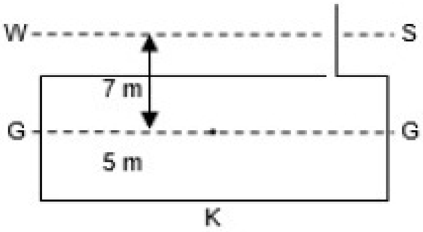
z = Depth of COP below ws	= 6.667 m
Sounding	= 10.000 m
KP (height of COP above bottom)	= 3.333 m

Worked example 3

Calculate KP (height of the COP above the bottom of the tank) in worked example 1, when the sounding is 12 m.

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15\,(10^3)}{12} + 15\,(10)\,7^2}{15\,(10)\,(7)}$$



z = Depth of COP below ws	= 8.190 m
Sounding	= 12.000 m
KP (height of COP above bottom)	= 3.810 m

Worked example 4

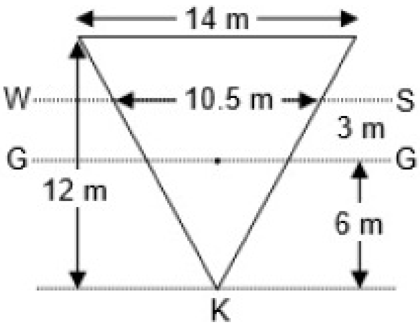
One bulkhead of a tank consists of a triangle, apex downwards, which is 14 m broad and 12 m high. Calculate KP (height of the COP above the bottom of the tank) when the sounding is 9 metres.

By similar triangles, breadth of water surface = 10.5 m

$$A = \frac{10.5\,(9)}{2} = 47.25\ m^2$$

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

$$= \frac{\frac{10.5(9^3)}{36} + 47.25(3^2)}{47.25(3)}$$



z = Depth of COP below ws	= 4.500 m
Sounding	= 9.000 m
KP (height of COP above bottom)	= 4.500 m

Worked example 5

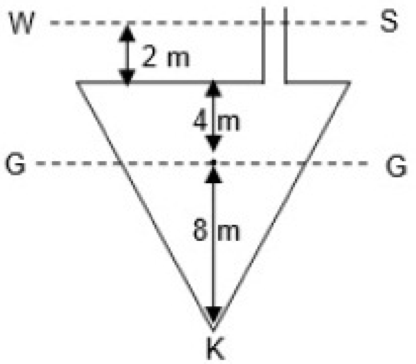
Calculate KP (height of the COP above the bottom of the tank) when the sounding of the tank in worked example 4 is 14 m.

$$A = 14\,(12)/2 = 84\ \text{m}^2$$

$$I^*GG = \frac{14(12^3)}{36} = 672\ \text{m}^4$$

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

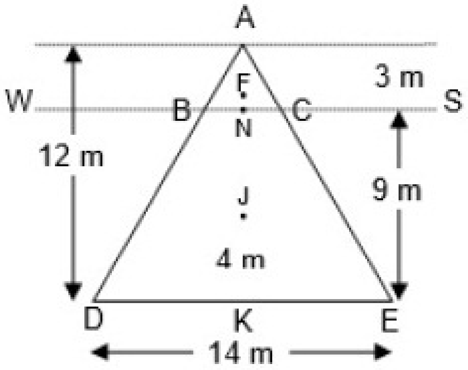
$$= \frac{672 + 84(6^2)}{84(6)} = 7.333$$



z = Depth of COP below ws	=	7.333 m
Sounding	=	14.000 m
KP (height of COP above bottom)	=	6.667 m

Worked example 6

A tank's bulkhead is triangular, apex upwards, 14 m broad and 12 m high. Calculate KP (height of the COP above the bottom) when the sounding is 9 m.



By similar triangles, BC = 3.5 m. Let F and J be the geometric centres of triangles ABC & ADE. To calculate the position of G, the geometric centre of trapezoid BCED (immersed area):

Taking moments about A,
Area ADE (AJ) – Area ABC (AF) = Area BCED (AG)

84 (8) – 5.25 (2) = 78.75 (AG); hence AG = 8.4 m.

NG = d = depth of geometric centre below ws = 5.4 m.

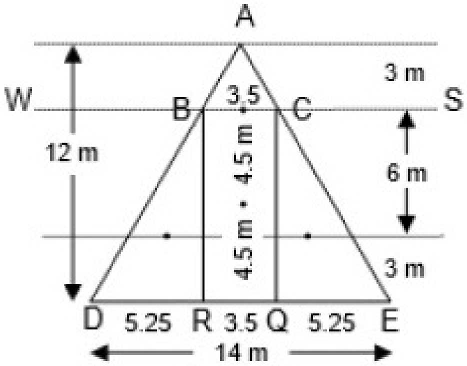
To find I*ws of immersed area:

I*ws of ADE = I*JJ + Area (JN) ^{2} = 14(12^3) / 36 + 84(5^2)
= 672 + 2100 = 2772 m^4.

I*ws of ABC = I*FF + Area (FN) ^{2}
= 3.5 (3^3) / 36 + 5.25 (1^2) = 2.625 + 5.25 = 7.875 m^4.

I*ws BCED = I*ws ADE – I*ws ABC
= 2772 – 7.875 = 2764.125 m^4.

Alternate method:



I*ws BCQR	=	3.5 (9^3)/3	=	850.5000 m^4
I*ws CQE	=	5.25(9^3)/4	=	956.8125 m^4
I*ws BRD	=	5.25(9^3)/4	=	956.8125 m^4
I*Ws BCED			=	2764.1250 m^4

Note: In case you are not able to readily follow the above steps, you are requested to refer to examples 1 and 2 on calculation of moments of inertia in the beginning of this chapter.

To find d (depth of geometric centre of immersed area BCED):

Taking moments about ws:

Area BCED (d) = Area BCQR (4.5) + Area CQE (6) + Area BRD (6)

78.75 (d) = 31.5 (4.5) + 23.625 (6) + 23.625 (6)

d = 5.4 metres.

Completion of calculation:

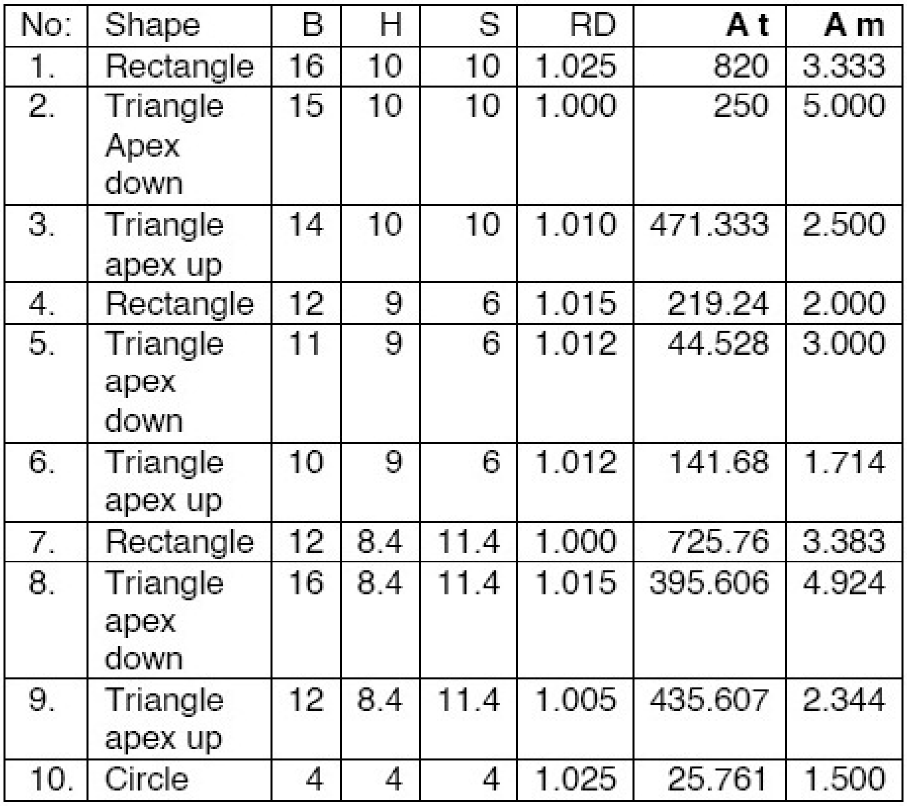
$$z = \frac{I^{*}ws}{Ad} = \frac{2764.125}{78.75\ (5.4)} = 6.500 \text{ m.}$$

KP = 9.000 – 6.500 = 2.500 m.

Compare the KP here with that of worked example 4 wherein the same tank had the same sounding but was apex downwards.

Exercise 14
(COP – regular shapes)

Find the thrust and KP (height of the COP above the bottom) of a vertical bulkhead in the following ten cases where B = breadth, H = height, S = sounding, all in metres. A t = answer in tonnes and A m = answer in metres.



No:	Shape	B	H	S	RD	**A t**	**A m**
1.	Rectangle	16	10	10	1.025	820	3.333
2.	Triangle Apex down	15	10	10	1.000	250	5.000
3.	Triangle apex up	14	10	10	1.010	471.333	2.500
4.	Rectangle	12	9	6	1.015	219.24	2.000
5.	Triangle apex down	11	9	6	1.012	44.528	3.000
6.	Triangle apex up	10	9	6	1.012	141.68	1.714
7.	Rectangle	12	8.4	11.4	1.000	725.76	3.383
8.	Triangle apex down	16	8.4	11.4	1.015	395.606	4.924
9.	Triangle apex up	12	8.4	11.4	1.005	435.607	2.344
10.	Circle	4	4	4	1.025	25.761	1.500

11. One bulkhead of a ship’s deep tank is a vertical rectangle 10 m broad and 6 m high. At what sounding would the COP be 2.5 metres above the bottom? **Answer**: 9 m.

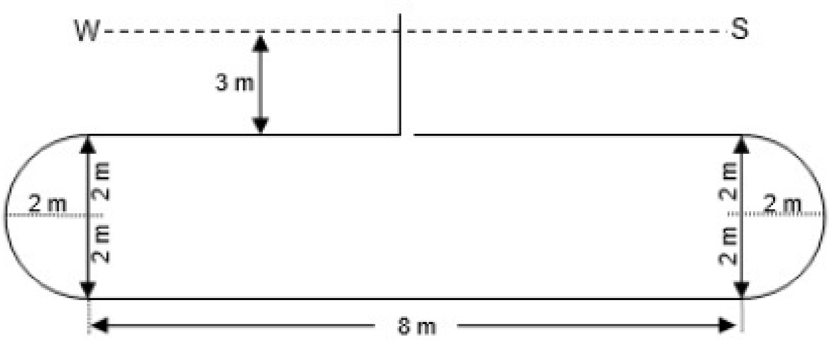
12. One side of a tank is a vertical bulkhead consisting of an isosceles triangle, 12 m broad & 6 m high, over a rectangle 12 m broad & 8 m high. Calculate the thrust and the KP (height of the COP above the bottom) When the tank has salt water in it to a sounding of 15 metres.

Answer: 1266.99 t, 4.401 m.

13. Calculate the thrust & KP of the tank in question 12, when the tank has FW in it to a sounding of 11 metres.

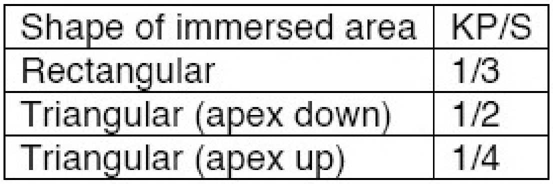
Answer: 717.000 t; 3.593 m.

14. Calculate the thrust & KP (height of the COP above the bottom) of a vertical bulkhead, whose shape is given below, when run up with SW to a head of 3 metres (i.e. to a sounding of 7 m).



Answer: 228.401 t, 1.752 m.

15. Divide KP by the sounding in each of the problems 1 to 9. It will be noticed that when the tank is just full or partly full:



Shape of immersed area	KP/S
Rectangular	1/3
Triangular (apex down)	1/2
Triangular (apex up)	1/4

Note 1: Problem 6 does not fall into any of the above categories because the immersed area is neither rectangular nor triangular.

Note 2: Where the tank is **more than full** (where ws is above the top of the tank), the COP is higher than when the tank is just full.

Note 3: COP is always below the geometric centre of the immersed area, regardless of the sounding.

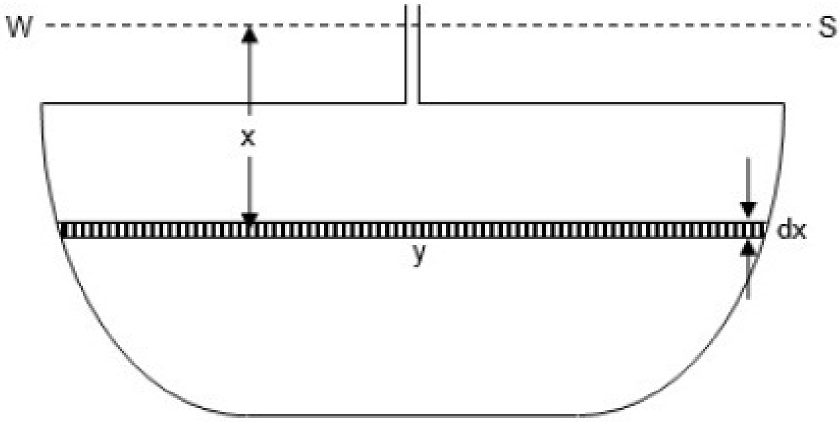
COP OF CURVILINEAR SHAPES

The position of the COP of a curvilinear shape may be found by using Simpson's Rules. Since it is expected that you would have already studied the use of Simpson's Rules to find areas, volumes, first moment and geometric centres, explained in chapter 20 of 'Ship Stability at the Operational Level', needless repetition has been avoided here.

The calculation of the position of the COP by Simpson's Rules may be done using either horizontal ordinates or vertical ordinates.

Using horizontal ordinates

Considering the elemental strip:



Area of elemental strip = y.dx
1^{st} moment about ws = y.dx.x = yx.dx
By parallel axes, I*ws = $(y.dx^3) / 12 + y.dx.x^2$

Since dx is very small dx^3 is negligible.

Therefore, I*ws element strip = $yx^2.dx$

Considering the whole immersed portion:

Area	=	$\int y.dx$
1^{st} moment about ws	=	$\int yx.dx$
I*ws	=	$\int yx^2.dx$

So, if y, yx & yx^2 are put through Simpson's Rules, the immersed area, the first moment of area about ws (water surface) and the moment of inertia of the immersed area about ws can be obtained. The calculation could then be completed as illustrated in the following example.

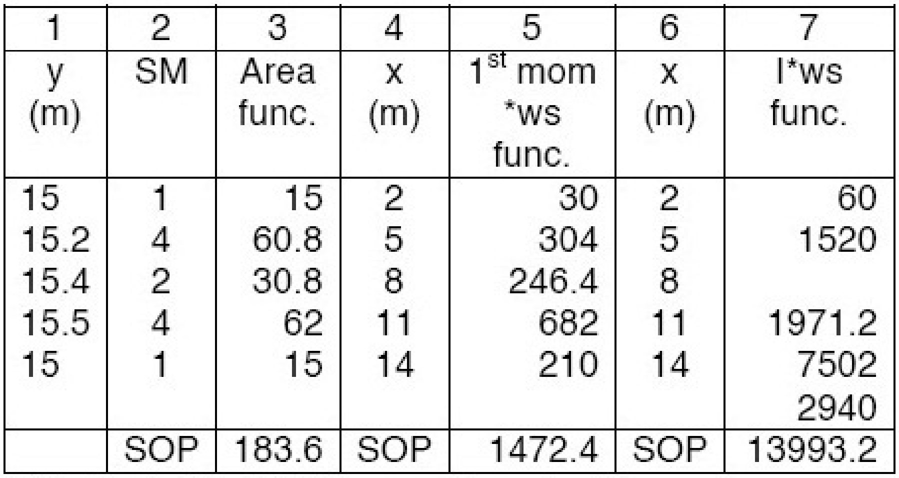
Worked example 7 – Horizontal Ordinates.

A lower hold bulkhead is 12 m high. The transverse widths in metres, commencing from the upper edge, at 3 metre vertical intervals, are:

15, 15.2, 15.4, 15.5 & 15 respectively.

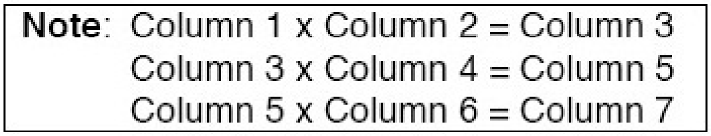
Find KP (the height of the COP above the bottom) and the thrust when the hold is filled with SW to sounding of 14 metres.

(Abbreviation SOP = sum of products).

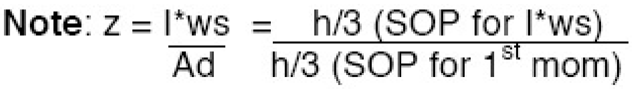


1	2	3	4	5	6	7
y (m)	SM	Area func.	x (m)	1^{st} mom *ws func.	x (m)	I*ws func.
15	1	15	2	30	2	60
15.2	4	60.8	5	304	5	1520
15.4	2	30.8	8	246.4	8	
15.5	4	62	11	682	11	1971.2
15	1	15	14	210	14	7502
						2940
	SOP	183.6	SOP	1472.4	SOP	13993.2

(Abbreviation SOP = sum of products).



Note: Column 1 x Column 2 = Column 3
Column 3 x Column 4 = Column 5
Column 5 x Column 6 = Column 7



Note: $z = \frac{I^*ws}{Ad} = \frac{h/3\ (\text{SOP for } I^*ws)}{h/3\ (\text{SOP for } 1^{st}\text{ mom})}$

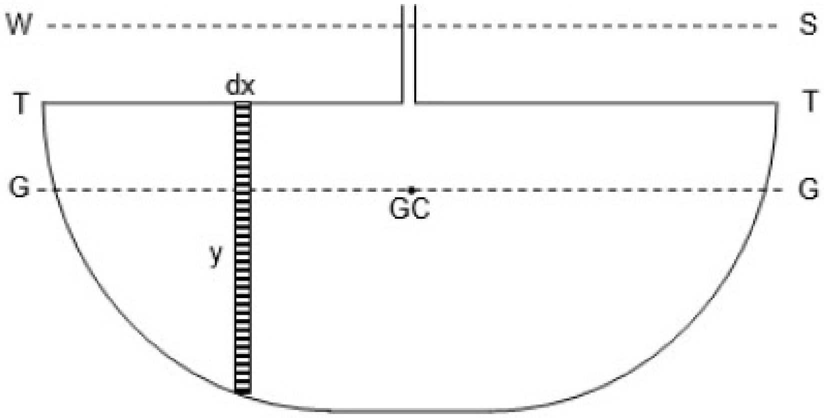
So, z = SOP column 7 / SOP column 5

Depth of COP = z = 13993.2 / 1472.4 = 9.504 m

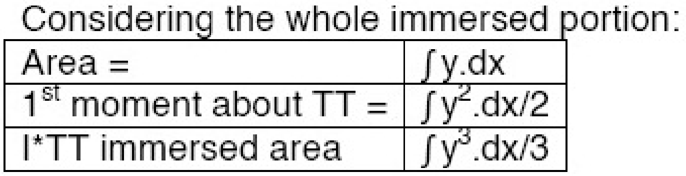
KP = sounding - z = 14 - 9.504 = 4.496 m

Thrust = Pressure at GC x immersed area
= depth of GC x density x area
= 1st moment of area x density
= 3 x 1472.4 x 1.025 / 3 = 1509.21 t.

Using vertical ordinates



Considering the elemental strip:
Area = y.dx
1st moment about TT = y.dx.y / 2 = (y^2.dx) / 2
I*TT immersed area = (y^3.dx) / 3 (standard formula)



Considering the whole immersed portion:

Area =	$\int y.dx$
1st moment about TT =	$\int y^2.dx/2$
I*TT immersed area	$\int y^3.dx/3$

So, if y, y^2 / 2 and y^3 / 3 are put through Simpson's Rules, the immersed area, the first moment of area about TT and the moment of inertia of the immersed area about TT may be obtained.

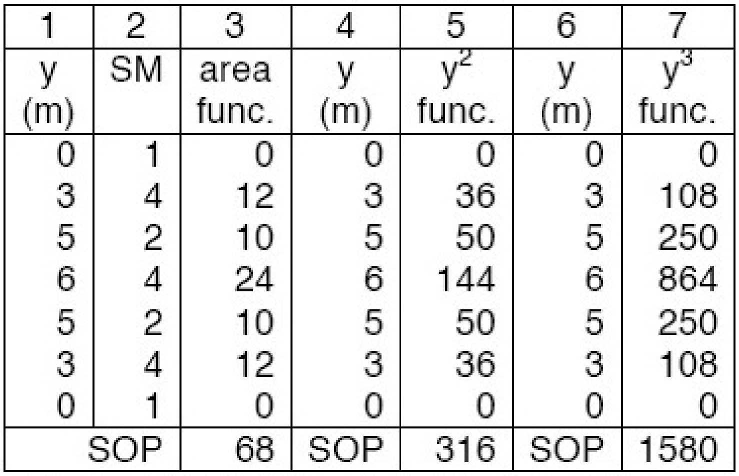
Note: for the sake of convenience in calculation, y^2 and y^3 may be put through Simpson's Multipliers and the SOP of the respective columns divided by 2 and 3, as shown in the following worked example.

Worked example 8 – Vertical ordinates.

A deep tank bulkhead is 12 m broad at the top. The vertical ordinates, at equidistant transverse intervals, are: 0, 3, 5, 6, 5, 3 and 0 m respectively.

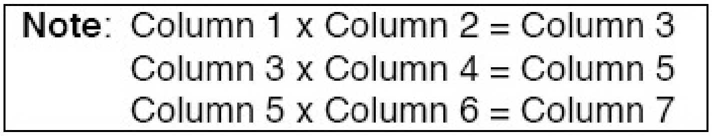
Find KP (the height of the COP above the bottom) and the thrust when the hold is filled with SW to a head of 2 metres (i.e., sounding is 8m).

The common interval in this case is 2m.



1	2	3	4	5	6	7
y (m)	SM	area func.	y (m)	y^2 func.	y (m)	y^3 func.
0	1	0	0	0	0	0
3	4	12	3	36	3	108
5	2	10	5	50	5	250
6	4	24	6	144	6	864
5	2	10	5	50	5	250
3	4	12	3	36	3	108
0	1	0	0	0	0	0
SOP		68	SOP	316	SOP	1580

(Abbreviation SOP = sum of products).



Note: Column 1 x Column 2 = Column 3
Column 3 x Column 4 = Column 5
Column 5 x Column 6 = Column 7

Area = (h / 3) (SOP column 3) = (2 / 3) (68) = 45.333 m^2

1^{st} moment about TT = (h / 3) (SOP column 5 / 2)
= 2 (316) / (3 x 2) = 105.333 m^3

I*TT immersed area = h / 3 (SOP column 7 / 3)
= 2 (1580) / (3 x 3) = 351.111 m^4.

Depth of GC below TT = 105.333 / 45.333 = 2.324 m

By theorem of parallel axes,

I*GG = I*TT – area (2.324^2)
= 351.111 – 45.333 (2.324^2) = 106.269 m^4.

I*ws = I*GG + area (4.324^2)

= 106.269 + 45.333 (4.324^2) = 953.859 m^4.

$$Z = \frac{I^*ws}{Ad} = \frac{953.859}{45.333\ (4.324)} = 4.866 \text{ metres.}$$

KP = 8.000 – 4.866 = 3.134 metres.

Thrust = pressure at GC x Immersed Area

= depth of GC below WL x density x immersed area

= (2.324 + 2) x 1.025 x 45.333 = 200.9 tonnes.

Worked example 9

The half-breadths of a transverse water-tight bulkhead 10 m high, at equal vertical intervals, are 10, 9.3, 8.3, 7.1, 5.7 & 3.8 m. Find the KP and the thrust when the hold is filled with SW to a sounding of 13 m.

Note 1: The number of ordinates being six, neither Simpson's Rule 1 nor Rule 2 is directly applicable.

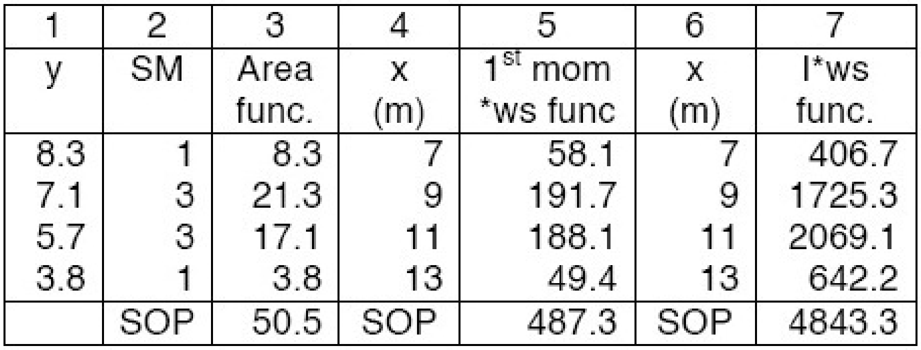
Note 2: Half-breadths are given here.

1	2	3	4	5	6	7
y	SM	area func.	x (m)	1st mom *ws func	x (m)	I*ws func.
10	1	10	3	30	3	90
9.3	4	37.2	5	186	5	930
8.3	1	8.3	7	58.1	7	406.7
	SOP	55.5	SOP	274.1	SOP	1426.7

Half the top area = 2 (55.5) /3 = 37.0 m^2

½ 1st moment *ws = 2 (274.1) / 3 = 182.733 m^3.

½ 2nd moment *ws = 2 (1426.7) / 3 = 951.133 m^4.

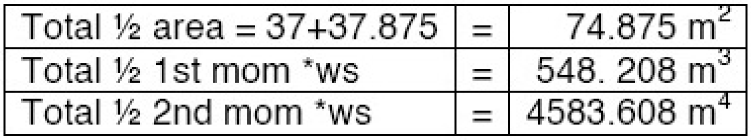


1	2	3	4	5	6	7
y	SM	Area func.	x (m)	1st mom *ws func	x (m)	I*ws func.
8.3	1	8.3	7	58.1	7	406.7
7.1	3	21.3	9	191.7	9	1725.3
5.7	3	17.1	11	188.1	11	2069.1
3.8	1	3.8	13	49.4	13	642.2
	SOP	50.5	SOP	487.3	SOP	4843.3

½ bottom area = 3 (2) 50.5 / 8 = 37.875 m^2.

½ 1st moment *ws = 3 (2) 487.3 / 8 = 365.475 m^3.

½ 2nd moment *ws = 3 (2) 4843.3 / 8 = 3632.475 m^4.



Total ½ area = 37+37.875	=	74.875 m^2
Total ½ 1st mom *ws	=	548. 208 m^3
Total ½ 2nd mom *ws	=	4583.608 m^4

$$z = \frac{I{*}ws}{Ad} = \frac{2\,(4583.608)}{2\,(548.208)} = 8.361 \text{ m}$$

KP = sounding – z = 13.000 – 8.361 = 4.639 m

Thrust = Ad (density) = 2 (548.208) 1.025
Thrust = 1123.826 tonnes.

Exercise 15
(COP of curvilinear shapes)

1. The collision bulkhead of a tanker is 12 metres high. The breadths at equal intervals from top are: 14, 9.6, 5.9, 4, 3.3, 2.6 & 0 m respectively.

Find the thrust and the KP (height of the COP above the bottom) when the forepeak tank is filled with FW to a head of 5 m (sounding 17 m).

Answer: 575.200 t, 7.057 m.

2. Find the KP (height of the COP above the bottom) and the thrust when the forepeak tank in question 1 is filled with SW to a sounding of

12 metres.

Answer: 257.480 t, 5.682 m.

3. Find the KP and the thrust when the tank in question 1 is run up with DW (RD 1.015) to a sounding of 8 metres.

Answer: 81.741 t, 3.497 m.

4. The half-breadths of a watertight bulkhead, at 2.5 metre vertical intervals from the bottom, are:

1, 2.9, 4.2, 5.1 & 5.7 m.

Find the KP and the thrust when the hold is flooded with SW to a sounding of 11.5 metres.

Answer: 445.277 t, 4.725 m.

5. The vertical ordinates of the after bulkhead of the port slop tank of a tanker, measured from the horizontal deckhead downwards, spaced at equal athwartship intervals of one metre from the side, are: 0, 3.25, 4.4, 5.15, 5.65, 5.9 and 6 m

Find KP (height of the COP above the bottom) and the thrust when the tank is full of slop (RD 0.98).

Answer: 69.604 t, 2.477 m.

6. The after bulkhead of a tank on the starboard side is 3 m high. It is bounded on the top by a horizontal deck, towards amidships by a vertical fore & aft bulkhead and on the starboard side by the shell plating. The vertical ordinates of this bulkhead, at equal athwartships intervals of 1.8 m, are:

3, 2.85, 2.6, 2.1, 1.1, & 0 metres.

Find the KP (height of the COP above the bottom) and the thrust when the tank has DW (RD 1.016) to a head of 12 m (sounding = 15 m).

Answer: 247.566 t, 1.776 m.

7. The half breadths of a transverse watertight bulkhead 14.2 m high, at 2.2 m intervals from the top, are:

10.6, 10, 9.3, 8.3, 7.1, 5.7 & 3.8 m.

Below the lowest semi-ordinate is a rectangular appendage 7.6 m broad and 1 m high. Find the KP (height of the COP above the bottom) and the thrust on the bulkhead when the hold is filled with SW.

Answer: 1331.759 t, 5.741 m.

8. The half-breadths of a transverse watertight bulkhead on a tanker, measured at regular vertical intervals, are:

10, 9.3, 8.3, 7.1, 5.7, 4.4 & 2.9 m.

The common interval between the first five semi-ordinates is 2.2 m, while that between the last three is 1.1 m. Calculate the KP (height of the COP above the bottom) and the thrust when the tank is full of SW to a sounding of 12.5 m.

Answer: 1032.985 t, 4.859 m.

9. The half-breadths of a collision bulkhead, at equal vertical intervals of 2 m from the top, are:

7, 4.8, 2.95, 2, 1.65 and 1.3 m.

Below the bottom semi-ordinate, there is a triangular appendage 2.6 metres broad and 1.2 metres high. Find the KP (height of the COP above the bottom) and the thrust when the forepeak tank is run up with salt water to a sounding of 14 metres.

(Suggestion: Use Simpson's First Rule for the first three semi-ordinates and Simpson's Second Rule for the last four.)

Answer: 421.062 t, 6.201 m.

16. THE INCLINING EXPERIMENT

The inclining experiment is performed by the shipyard in order to obtain the KG of the ship in the light condition. Once this is known, the KG can, thereafter, be calculated for any desired condition of loading, as illustrated in chapter 7 in the earlier book, ‘Ship Stability at the Operation Level’.

The inclining experiment should be done when the building of the ship is complete or nearly so. Any changes can, thereafter, be allowed for by calculation. This experiment may have to be performed again, during the life of the ship, if any large structural alterations are made. The result of the inclining experiment performed on one ship may be acceptable for identical sister ships.

Two pendulum bobs, attached to lines about ten metres or more in length, are suspended, in the open hatchway, at the centre line of the ship – one forward and the other, aft. Some shipyards use a third plumb bob amidships. The results obtained by the different bobs are averaged. For simplicity’s sake, only one plumb bob is considered here. The bob itself, though suspended freely, may be immersed in a trough of oil or water in order to damp out oscillations.

A horizontal batten, graduated in centimetres, is fitted a short distance above the plumb bob. The batten is adjusted to be horizontal, by use of a spirit level, when the ship is perfectly upright.

The fact that the ship is upright can be verified by measuring the height of the top of the sheer strake from the waterline on each side of the ship. By simple geometry:

Tan list = 2(freeboard difference) / Breadth of ship

Four equal weights are placed on deck, two on each side, at equal distances off the centre line. The weights are chosen to total about 1/500 of the light displacement. Most shipyards use concrete blocks of known weight.

One weight is shifted from starboard to port and, after allowing sufficient time for the ship to settle in the listed condition, the deflection of the pendulum is noted. The second weight is shifted from starboard to port and the deflection of the pendulum is noted. Both the weights are then shifted back to their original places – the deflection should again be zero. The procedure is then repeated by shifting the weights from port to starboard, one at a time.

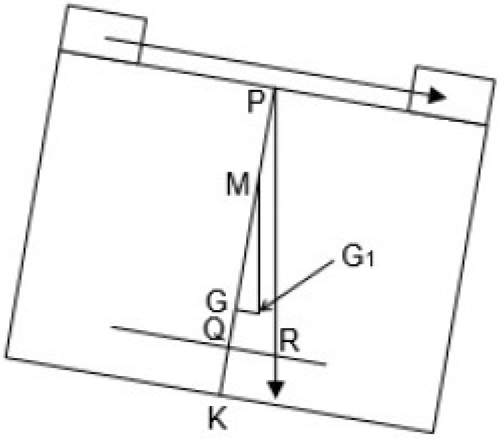
$$\text{Tan list} = GG_1 / GM = dw / (W.GM)$$

Referring to the figure on the next page:

$$\text{Tan list} = \frac{\text{deflection of pendulum}}{\text{length of plumb line}} = \frac{QR}{PQ}$$

$$\text{So, } \frac{\text{deflection}}{\text{plumb length}} = \frac{dw}{W.GM}$$

$$GM = \frac{dw\ (\text{plumb length})}{W\ (\text{deflection})}$$



The GM for each shift of weight is calculated and the average initial fluid GM, in that condition, is obtained. The actual method of averaging varies between shipyards. Some average the deflections to port and starboard for the same weight shift. Some shipyards prefer to use weights of different values.

The KM for that displacement, and the FSC applicable, would have already been calculated by the shipyard. The KG solid for that condition is thus obtained:

KG solid = KM – GM fluid – FSC

By taking moments about the keel, due allowance is made for any weights that should go on or go off the ship so that the KG for the light condition is finally obtained.

Conditions necessary for accuracy:

1. Before the commencement of the experiment, the ship should be perfectly upright.
2. A large trim should be avoided.
3. The ship's initial GM should not be too small.
4. There should be no wind. If this is not possible, the ship should be heading into the wind.
5. All mooring lines to be slack.
6. Gangway to be well clear of jetty.
7. No other craft to be alongside.
8. The depth of water should be enough to ensure that the ship is freely afloat throughout this experiment.
9. All portable beams, derricks, boats, etc to be in proper sea-going condition.
10. Any loose weights to be secured.
11. All persons not directly connected with the experiment should be ashore. Those on board should stay on the centre line when deflections are being noted.
12. Boilers to be completely full or empty.
13. As far as possible, all tanks should be full or empty. If not possible, the value of FSM should be noted.
14. All bilges to be dry.
15. A record of each weight (and its KG) to go on or off the ship should be kept.
16. Drafts forward, aft and amidships and the density of water to be noted.
17. Due allowance must be made, in all calculations, for the weights placed on board for the conduct of the experiment.
18. The weight and the distance moved should be adjusted such that the list caused is reasonably small. If the list is insufficient, the

deflection would be too small resulting in an inaccurate answer. If the list is more than a few degrees, the consequent increase of KM would render the result inaccurate.

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17. STABILITY INFORMATION SUPPLIED TO SHIPS

Regulation 10 of the International Load Line Convention 1966, & Regulation 5 of amended chapter II-1 of SOLAS 74 state in general terms that the master of a ship shall be supplied with sufficient information, approved by the government of the flag state, to enable him by rapid and simple processes to obtain guidance as to the stability of the ship under varying conditions of service.

The Merchant Shipping (Load Line) Rules 1968 of the United Kingdom, and the Merchant Shipping (Load Line) Rules 1979 of India, specify the requirements of stability data in detail.

The following is a summary of the stability information required to be provided on board ships under the above Rules:

1. The ship's name, official number, port of registry, gross & register tonnages, principal dimensions, draft, displacement & deadweight at the summer load line shall be stated in the beginning of the stability booklet.

2. A profile view of the ship, and plan views as necessary, drawn to scale, showing the names and locations of all main compartments, tanks, storerooms and accommodation for passengers and crew.

3. The capacity and the position of the COG (vertical and longitudinal) of every compartment available for cargo, fuel, stores and spaces for domestic water, feed water and water ballast. In the case of a vehicle ferry, the KG of a compartment shall be that estimated for the carriage of vehicles and not the volumetric centre of the compartment.

4. The estimated weight and position of the COG (vertical and longitudinal) of: (a) passengers and their effects and (b) crew and their effects, allowing for their distribution in the spaces they would normally occupy, including the highest decks to which they have access.

5. The estimated weight and position of the COG (vertical & longitudinal) of the maximum quantity of deck cargo that may reasonably be expected to be carried on exposed decks. If such deck cargo is likely to absorb water during passage, the arrival condition shall allow for such increase in weight. In the case of timber deck cargo, the absorption shall be assumed to be 15% by weight.

6. Information to enable calculation of the FSC of each tank in which liquids may be carried. A sample calculation to show how the information is to be used.

7. A diagram showing the load line mark and load lines with their corresponding freeboards.

8. A diagram or table giving the hydrostatic particulars – displacement, TPC, MCTC, AB, AF, KB, KMT, KML, water-plane areas and transverse cross-sectional areas for a range of drafts from the light waterline to the deepest permissible waterline. In the case of tables, the tabular interval shall be small enough for accurate interpolation. In case the ship has a raked keel, the base line for vertical distances shall be constant for all the particulars given/ used in calculations, including KG.

9. Diagram or tables to enable the construction of the GZ curve, mentioning clearly the KG assumed in the given information. The allowance made for the stability and buoyancy provided by enclosed superstructures must be clearly stated. A sample calculation to show how the GZ curve is to be drawn.

10. Supplementary information to allow for the volume of timber deck cargo while drawing the GZ curve.

11. Calculation of GM and construction of the GZ curve shall include FSC.

12. Complete separate calculations, each with a profile diagram to scale, showing the disposition of the main components of deadweight, under the following conditions:

(a) Light condition – with and without permanent ballast, if any.
(b) Ballast condition – departure port.
(c) Ballast condition – arrival port.
(d) Loaded condition – departure port.
(e) Loaded condition – arrival port.
(f) Service condition – departure port.
(g) Service condition – arrival port.

In the departure condition, fuel, FW and consumable stores are to be assumed full and in the arrival condition, they are to be 10% of their capacity.

In the loaded condition, each cargo space is to be assumed full of homogeneous cargo except where inappropriate as in the case of ships solely intended for the carriage of containers or vehicles. Sample calculations for loaded conditions shall be repeated for different stowage factors as appropriate.

Service conditions are conditions, other than those mentioned earlier, for which the ship is designed or which are desired by the shipowner.

13. Where the ship, in any of the sample conditions, does not satisfy the stability requirements under the Load Line Rules, such a warning shall be clearly marked on the sample calculation.

14. Where the shipyard feels that any particular loaded condition should be avoided, from the stress point of view, such a warning would be clearly given in the stability information supplied.

15. A copy of the report on the inclining test and the calculation therefrom, shall be included in the stability booklet. The inclining test on one ship may be acceptable for sister ships also.

16. The stability information booklet must have the approval of the flag state.

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18. STABILITY OF SHIPS CARRYING GRAIN IN BULK

The word ‘Grain’ includes wheat, maize (corn), barley, oats, rice, rye, pulses, seeds & the processed forms thereof, whose behaviour is similar to that of grain in its natural state. ‘In bulk’ means loaded directly into the hold of a ship without any packaging.

Hazards

While carrying grain in bulk, the hazards involved are two-fold:

1. Grain settles down at sea creating free space or **void on top**.
2. Grain shifts easily during rolling as it has a **low angle of repose.**

1. The void on top

Even though a compartment is filled completely with bulk grain at the port of loading, vibration and movement of the ship at sea causes the grain to settle down (by about 2% of its volume) resulting in the formation of void spaces at the top of the compartment.

This is further aggravated by the hatch coaming, girders and other structural members that extend downwards from the deck head and obstruct free horizontal movement of grain during the final stages of loading. Void spaces, therefore, exist beyond such obstructions even though the compartment appears to be full at the time of loading. These voids add to the voids created by the settling down of bulk grain at sea. Filled compartments tend to become partly filled later on at sea, thereby giving grain the freedom of movement during rolling.

2. Low angle of repose

Bulk grain has a low angle of repose (about 20°). If the ship rolls greater than that, the surface of loose grain would shift causing the ship to acquire a list. Such progressive shift could result in very large list.

In the Grain Rules the grain surface below the voids formed in filled compartments are assumed to shift at / to 15° and in partly filled compartments which are not appropriately secured, 25°.

In view of the above hazards, ships have to take special precautions when loading grain in bulk, regardless of whether the grain is loaded in only one hold or in more than one hold.

IMO's 'International Code for the Safe Carriage of Grain in Bulk', abbreviated here to IGC, based on Part C of Chapter VI of SOLAS 1974, deals with ships carrying grain in bulk. IGC is divided into parts A and B. Part A contains specific requirements and part B refers to calculation of assumed heeling moments and general assumptions. Here are some significant extracts:

Document of authorisation (DOA)

Every ship loading bulk grain shall have a document of authorisation issued by, or on behalf of, the Administration stating that the ship is capable of complying with the IGC.

The DOA shall accompany, or be incorporated in, the grain loading stability booklet to enable the Master to meet the IGC's 'Intact Stability Requirement'.

The DOA, grain loading stability data and associated plans may be in the language of the issuing country but a translation in English or in French shall be on board for the Master to produce them for inspection, if required, by the government of the country of the port of loading.

A ship without such a document of authorisation shall not load grain until the Master demonstrates to the satisfaction of the Administration, or the contracting Government of the port of loading on behalf of the Administration, that the ship, in its proposed loaded condition, will comply with the safety requirements of IGC.

Grain loading information

Information, in printed form, shall be available to the Master to ensure that the ship complies with this Code when carrying grain in bulk on an international voyage. Such information shall have the approval of the Administration and shall include:

1. Ship's particulars.
2. Light displacement and KG.
3. Table of free surface corrections.

4. Capacities and COG (vertical and longitudinal) of tanks and compartments.

5. Curve or table of angle of flooding, where less than 40°, at all permissible displacements.

6. Curves or tables of hydrostatic particulars for all operating drafts.

7. Cross curves of stability, including curves for 12° and 40°.

8. Curves or tables of grain heeling moments for every compartment, filled or partly filled, or combination thereof, including effects of temporary fittings.

9. Tables or curves of maximum permissible heeling moments sufficient to allow the Master to demonstrate that the angle of list due to assumed shift of grain will not exceed 12° or the angle at which the deck edge immerses, whichever is lesser.

10. Loading instructions in the form of notes summarising the requirements of this Code.

11. A worked example for the guidance of the Master.

12. Typical service conditions – loaded departure and arrival and, if necessary, intermediate worst service conditions – for three values of Stowage Factors such as 1.25, 1.5 and 1.75 cubic metres per tonne.

Before loading bulk grain

The Master shall, if so required by the government of the country of the port of loading, demonstrate the ability of the ship, at all stages of any voyage, to comply with the stability criteria required this Code.

After loading bulk grain

The Master shall ensure that the ship is upright before proceeding to sea.

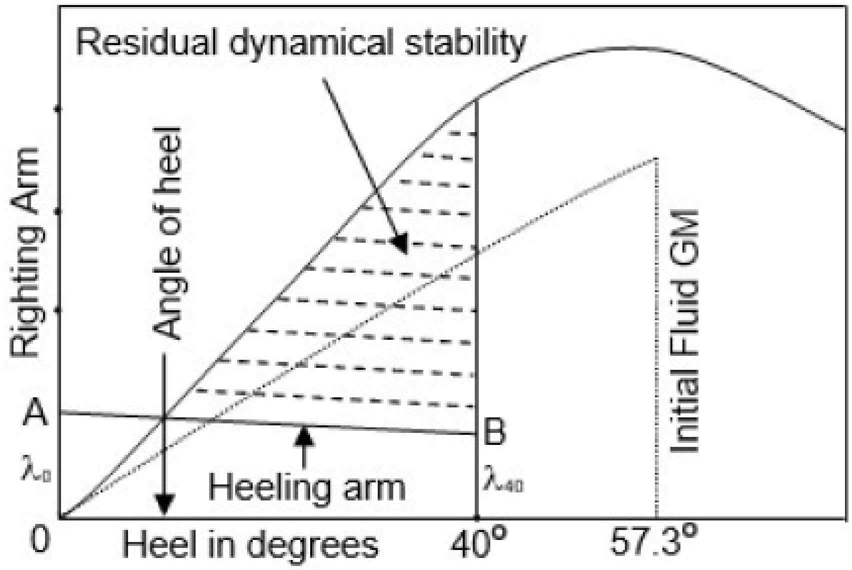
Intact stability requirements

1. The angle of heel due to the assumed shift of grain shall be not greater than 12° or the angle at which the deck edge immerses, whichever is lesser.

2. In the statical stability diagram, the net or residual area between the heeling arm curve and the righting arm curve up to the angle of heel of maximum difference between the ordinates of the two curves, or 40°

or the angle of flooding (θf), whichever is the least, shall in all conditions of loading be not less than 0.075 metre radians.

3. The initial fluid GM shall be not less than 0.30 metre.



Notes on the foregoing diagram

Calculation of list by use of the GZ curve has been explained in chapter 9 of this book. Hence the method followed here should be easy to follow.

Note 1: $\lambda_0 = \dfrac{\text{Volumetric heeling moment}}{\text{SF x Displacement}}$

Note 2: SF is volume per tonne of grain.

Note 3: $\lambda_{40} = 0.8 \times \lambda_0$.

Note 4: The heeling arm curve may be represented by the straight line AB.

Note 5: The righting arm curve shall be derived from cross curves which are sufficient in number to accurately define the curve and shall include cross curves at 12° and 40°.

Note 6: The KG of a filled compartment shall be taken as that when it is filled to capacity, disregarding the assumed void on top.

Note 7: In a partly filled compartment, the vertical rise of the COG, as a result of the assumed transverse shift of grain, shall be compensated for by multiplying the transverse volumetric heeling moment by 1.12.

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The volumetric heeling moment, in quadro metres, divided by the stowage factor of the grain loaded, in cubic metres per tonne, would give the heeling moment in tonne metres. This method has been adopted because the voids, and their assumed shift, are only dependant on the ship's geometry whereas the weight of cargo depends on the SF also.

$$GG_1 = \frac{\text{heeling moment in tonne metres}}{\text{Displacement}}$$

$$GG_1 = \frac{\text{Volumetric heeling moment}}{\text{SF x displacement}}$$

Appendix V of this book, repeated here at worked example 1, is an extract from the grain stability information of the general cargo vessel M.V. VIJAY. The volumetric heeling moments are given for each compartment when it is a 'filled compartment' and without any centre line division to restrict transverse shift of grain. The columns where the lower hold and the tween deck have been shown together are meant for use when the two compartments are loaded in common – the assumed voids in the lower hold would be filled up by flow of grain from the tween deck space, for which due allowance has been made in the assumed void at the top of the tween deck space.. The grain loading stability information would state the conditions necessary when resorting to common loading – such as keeping the tween deck hatchway and trimming hatches open, etc.

The KG shown, and to be used in calculations, is that for the full compartment disregarding the assumed void on top.

Appendix VI of this book, repeated here at worked example 1, is another extract from the grain loading stability information of the same cargo ship – M.V. VIJAY – showing the grain loading diagram of number 3 hold and tween deck. Similar diagrams would be given for all the other grain spaces also. This diagram gives the stability data – the volumetric heeling moment, volume of grain and its KG – for all possible levels of grain in this hold alone or in this lower hold and tween deck loaded in common. The only information needed to enter this diagram is the ullage of grain (vertical distance from the top of the hatch coaming of the upper deck to the surface of the grain) after level trimming of the grain surface. One curve gives the volume of grain while another curve gives its KG. For volumetric heeling moment, two curves are given here – one curve for loading in the lower hold alone and the other for loading in the lower hold and tween deck in common. When the hold is partly filled, if any centre line division is expected to be fitted to restrict shift of grain, the volumetric heeling moment would be considerably less and hence another pair of curves would be given – one for the lower hold alone and the other for the lower hold and tween deck loaded in common.

The volumetric heeling moment of a partly filled compartment must be multiplied by 1.12 to compensate for the vertical rise of the COG resulting from the transverse shift of grain. Hence the value of the volumetric heeling moment obtained from the grain loading diagram, in appendix VI of this book, must be multiplied by 1.12 whenever the compartment is partly filled.

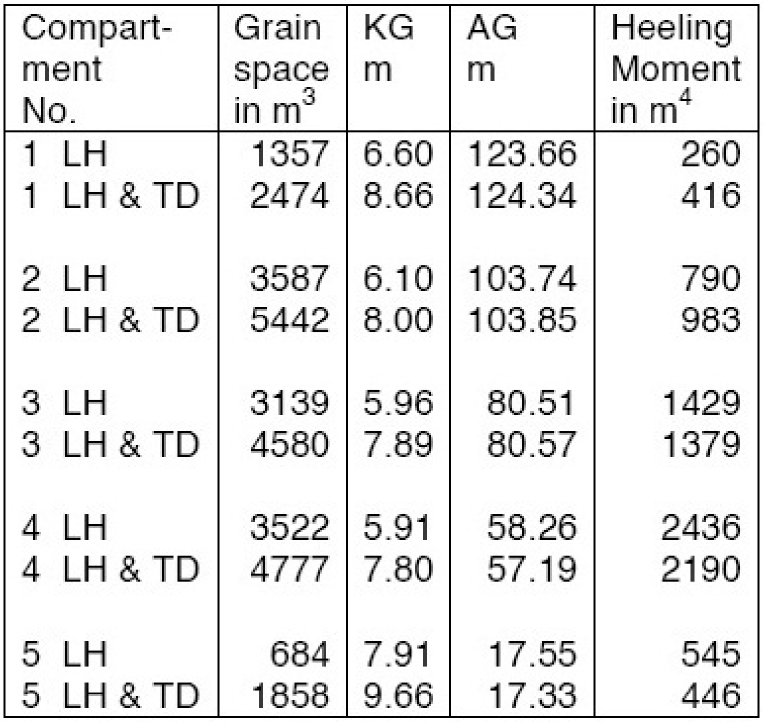
While calculating the volumetric heeling moments, in accordance with this Code, the shipyard would have assumed a shift of grain surface to be: 15° in filled compartments and; in partly filled compartments where the grain surfaces are not appropriately secured, 25°.

Appendix VII of this book, repeated here at worked example 1, is the KN table of m.v. VIJAY to be used when loading grain. This is similar to appendix II but, in accordance with this Code, it gives the KN values at 12° and at 40° also.

The stability calculation, using the information provided, is illustrated by the following worked examples.

Appendix V - m. v. VIJAY

Transverse volumetric heeling moments by assumed shift of grain as per chapter VI of SOLAS 1974.



Compartment No.	Grain space in m^3	KG m	AG m	Heeling Moment in m^4
1 LH	1357	6.60	123.66	260
1 LH & TD	2474	8.66	124.34	416
2 LH	3587	6.10	103.74	790
2 LH & TD	5442	8.00	103.85	983
3 LH	3139	5.96	80.51	1429
3 LH & TD	4580	7.89	80.57	1379
4 LH	3522	5.91	58.26	2436
4 LH & TD	4777	7.80	57.19	2190
5 LH	684	7.91	17.55	545
5 LH & TD	1858	9.66	17.33	446

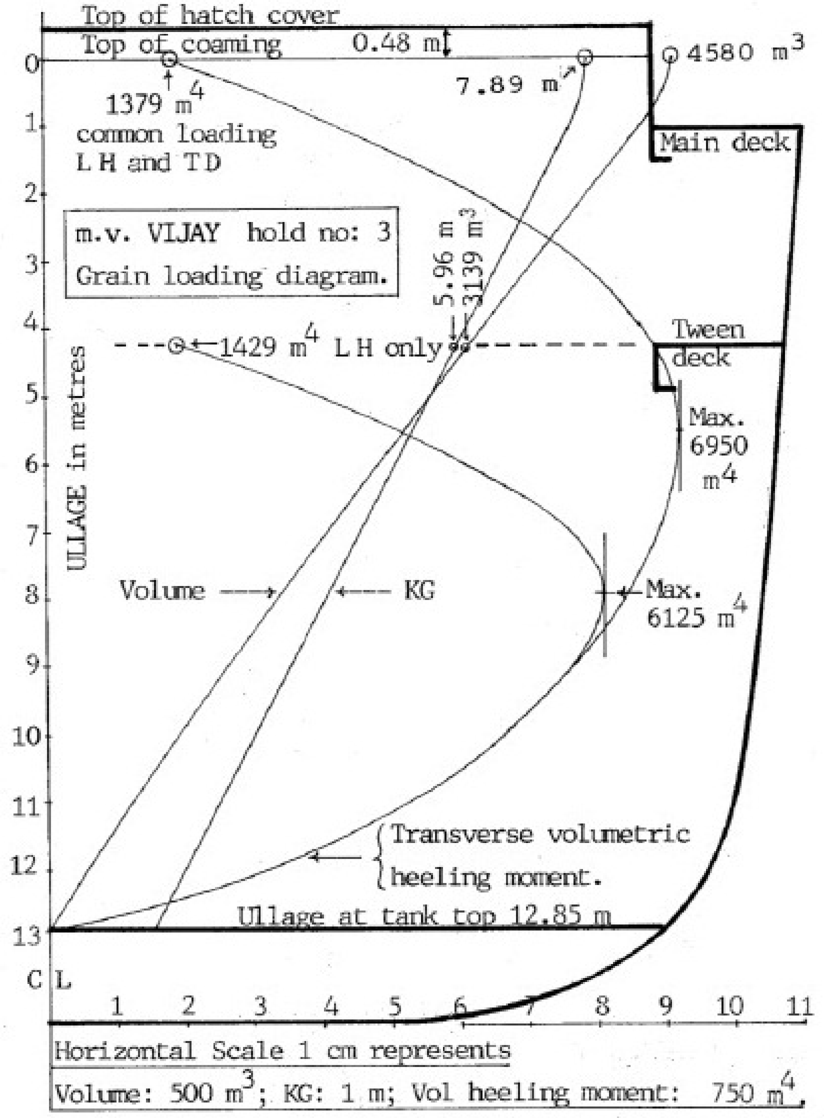
Note 1: This is for ‘Filled compartments’ as per Chapter VI of SOLAS 1974.

Note 2: The grain space divided by the SF would give the weight of grain.

Note 3: The volumetric heeling moment divided by the SF of grain loaded would give the heeling moment in tonne metres.

Note 4: If a compartment is ‘Partly filled’, refer to the grain loading diagram of that compartment.

Appendix VI



Appendix VII: m.v. VIJAY - KN Table for bulk grain

W	5°	12°	20°	30°	40°	60°	75°
6000	1.029	2.417	3.935	5.401	6.610	8.132	8.183
7000	0.953	2.255	3.717	5.247	6.512	8.185	8.322
8000	0.908	2.143	3.544	5.119	6.418	8.174	8.292
9000	0.875	2.062	3.415	5.012	6.304	8.106	8.254
10000	0.847	2.005	3.315	4.916	6.284	8.032	8.213
11000	0.827	1.962	3.241	4.843	6.197	7.957	8.166
12000	0.811	1.929	3.185	4.782	6.129	7.873	8.113
13000	0.798	1.907	3.153	4.733	6.072	7.788	8.057
14000	0.793	1.891	3.136	4.694	6.007	7.718	7.998
15000	0.794	1.882	3.110	4.657	5.939	7.645	7.941
16000	0.798	1.883	3.116	4.618	5.869	7.571	7.896
17000	0.793	1.887	3.127	4.580	5.799	7.495	7.854
18000	0.795	1.895	3.140	4.547	5.730	7.419	7.810
19000	0.802	1.908	3.134	4.510	5.721	7.341	7.766
20000	0.812	1.926	3.119	4.473	5.601	7.264	7.725

Example 1

M.V. VIJAY is in SW, loaded down to her marks with grain of SF 1.5. The KM, for the load displacement of 19943 tonnes, is 8.704 m. KG = 7.679 m, FSM = 1284 tm. All lower holds and tween decks are full and loaded in common. Using appendices V and VII of this book, verify whether the ship satisfies the requirements of the grain code, given that the angle of flooding at the load displacement is over 40°.

FSC	FSM/W = 1284/19943	=	0.064 m
KG solid		=	7.679 m
KG fluid		=	7.743 m
KM	for load displacement	=	8.704 m
GM fluid		=	0.961 m

The initial GM fluid = 0.961 m which is > 0.3 m.

From appendix V, total volumetric heeling moment (common loading of all LH & TD spaces) = 5414 m^4.

$$GG_1 = \frac{\text{volumetric heeling moment}}{\text{SF of grain loaded x W}} = \frac{5415}{1.5\ (19943)}$$

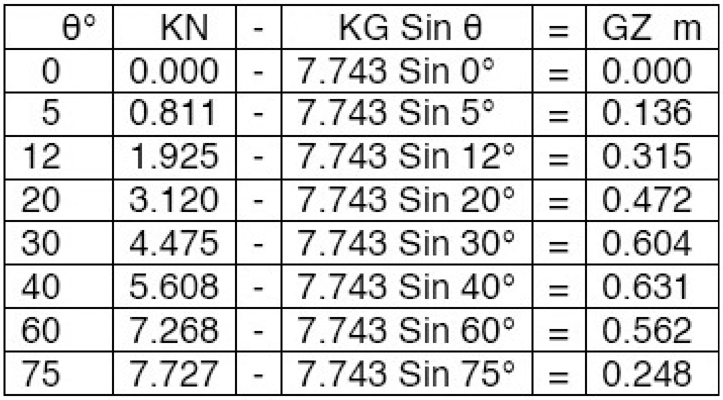
GG_1 = 0.181 m.

Approximate calculation:

$$\text{Tan } \theta = \frac{GG_1}{GM} = \frac{0.181}{0.961} = 0.188345$$

Approximate list = 10.67°

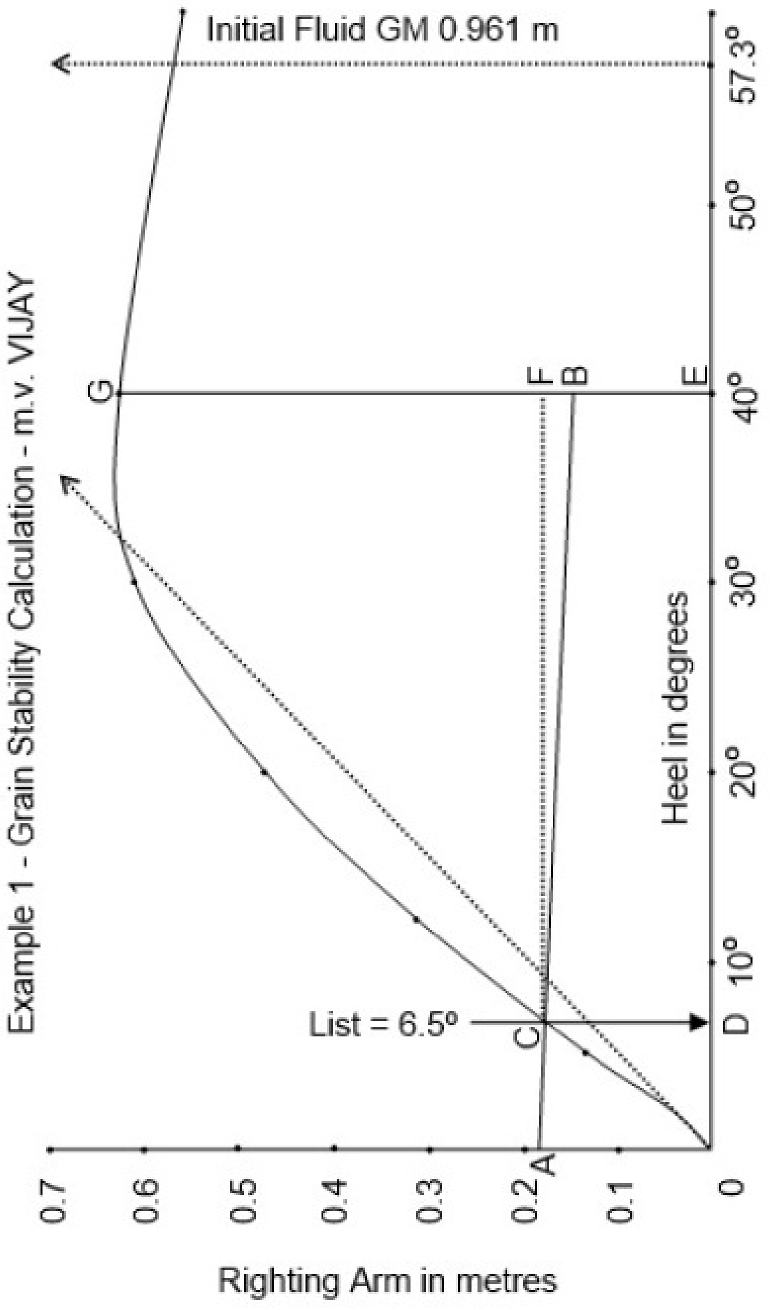
From appendix VII, righting lever:



θ°	KN	-	KG Sin θ	=	GZ m
0	0.000	-	7.743 Sin 0°	=	0.000
5	0.811	-	7.743 Sin 5°	=	0.136
12	1.925	-	7.743 Sin 12°	=	0.315
20	3.120	-	7.743 Sin 20°	=	0.472
30	4.475	-	7.743 Sin 30°	=	0.604
40	5.608	-	7.743 Sin 40°	=	0.631
60	7.268	-	7.743 Sin 60°	=	0.562
75	7.727	-	7.743 Sin 75°	=	0.248

Upsetting lever at 0° = $\lambda_0 = GG_1 = 0.181$ m

$\lambda_{40} = 0.8\ \lambda_0 = 0.8\ (0.181) = 0.145$ m.



The values of the righting arm and the upsetting arm obtained above, as shown in the foregoing figure, indicate that the list caused by the assumed shift of grain would be 6.5° which is well below the maximum allowed value of 12°.

From the foregoing curves plotted, it will be seen that:

Maximum difference between the righting arm and the upsetting arm occurs at about 45°. The angle of flooding is given to be over 40°. Hence the residual area is to be calculated between the angle of list (i.e., 6.5°) and 40°.

The residual area may be calculated with a fair amount of accuracy as follows:

Measure off distance DC, the upsetting lever at the computed list, and lay it off as EF at 40°. In this case, DC = EF = 0.180 m. BE is the upsetting lever at 40° and so BF = 0.180 – 0.145 = 0.035 m. CF = DE = 40 – 6.5 = 33.5°.

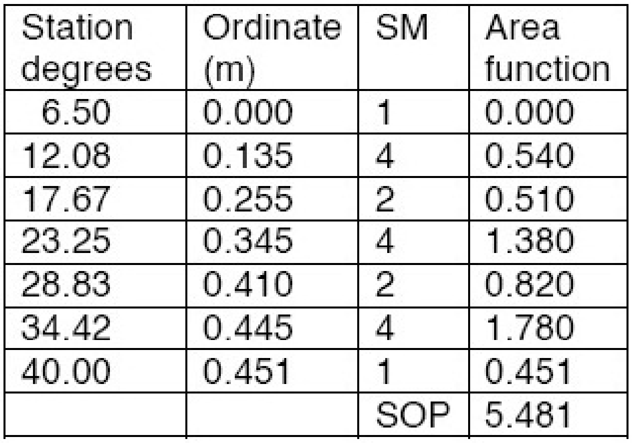
Area of triangle CFB = (33.5 x 0.035)/2
= 0.58625 metre degrees.

The area under the curve between CF & FG may be calculated using Simpson's Rules.

The residual area required is the sum of the two areas calculated as above.

CF may be divided into six equal parts and the seven ordinates measured off.

In this case, the interval would be 33.5/6 = 5.583°, starting from 6.5°, and the ordinates would thus be measured off at 6.5, 12.08, 17.67, 23.25, 28.83, 34.42 & 40°.



Station degrees	Ordinate (m)	SM	Area function
6.50	0.000	1	0.000
12.08	0.135	4	0.540
17.67	0.255	2	0.510
23.25	0.345	4	1.380
28.83	0.410	2	0.820
34.42	0.445	4	1.780
40.00	0.451	1	0.451
		SOP	5.481

Area = 5.583 (5.481) / 3 = 10.20014 metre degrees

Sum of areas = 10.20014 + 0.58625 = 10.78639 md
Sum of areas = 0.18824 metre radians

This is > 0.075 metre radians.

The ship in this condition, therefore, meets all the requirements of the Grain Code.

Example 2

M.V. VIJAY is displacing 11943 t in SW, KG = 7.18 m, FSM = 700 tm. A consignment of 2000 t of bulk grain, SF 1.25, is offered for shipment. No: 3 is the only empty hold available. Verify whether the ship would meet all the requirements of the Grain Code without fitting any shifting boards on the centre line. Use the relevant appendices of this book, repeated before example 1, where necessary.

Volume of grain = 2000 x 1.25 = 2500 m^3.

Entering the grain loading diagram of No: 3 (appendix VI) with the volume of grain as 2500 m^3, the ullage is found to be 5.75 m. Entering the same diagram with ullage as 5.75 m, the KG of grain and the volumetric heeling moment are found to be 5.15 m and 4275 m^4.

Note: Since the LH will only be partly full, the tween deck hatchway must be properly closed and either battened down or over stowed with suitable cargo so that the bulk grain in the lower hold cannot shift into the tween deck space during rolling. If this is not done, the volumetric heeling moment must be taken from the other curve which is meant for common loading. This would give 6950 m^4!

Taking moments by keel for the new KG:

11943 (7.18) + 2000 (5.15) = 13943 (new KG)

New KG		=	6.889 m
FSC =	FSM / W = 700 / 13943	=	0.050 m
Final KG	fluid	=	6.939 m
Final KM	At W = 13943 t	=	8.076 m
Final GM	fluid	=	1.137 m

The Final fluid GM > 0.3 metre.

Note: The rise of COG, due to transverse shift of grain in a partly filled compartment, is to be compensated for by multiplying the transverse heeling moment by 1.12 in accordance with the Grain Code

Transverse volumetric heeling moment, from appendix VI, = $4275 m^4$.

Volumetric Heeling Moment = 4275 x 1.12 = $4788 m^4$

$$GG_1 = \frac{VHM}{SF \times W} = \frac{4788}{1.25 \times 13943} = 0.275 \text{ m}$$

Approximate calculation of list:

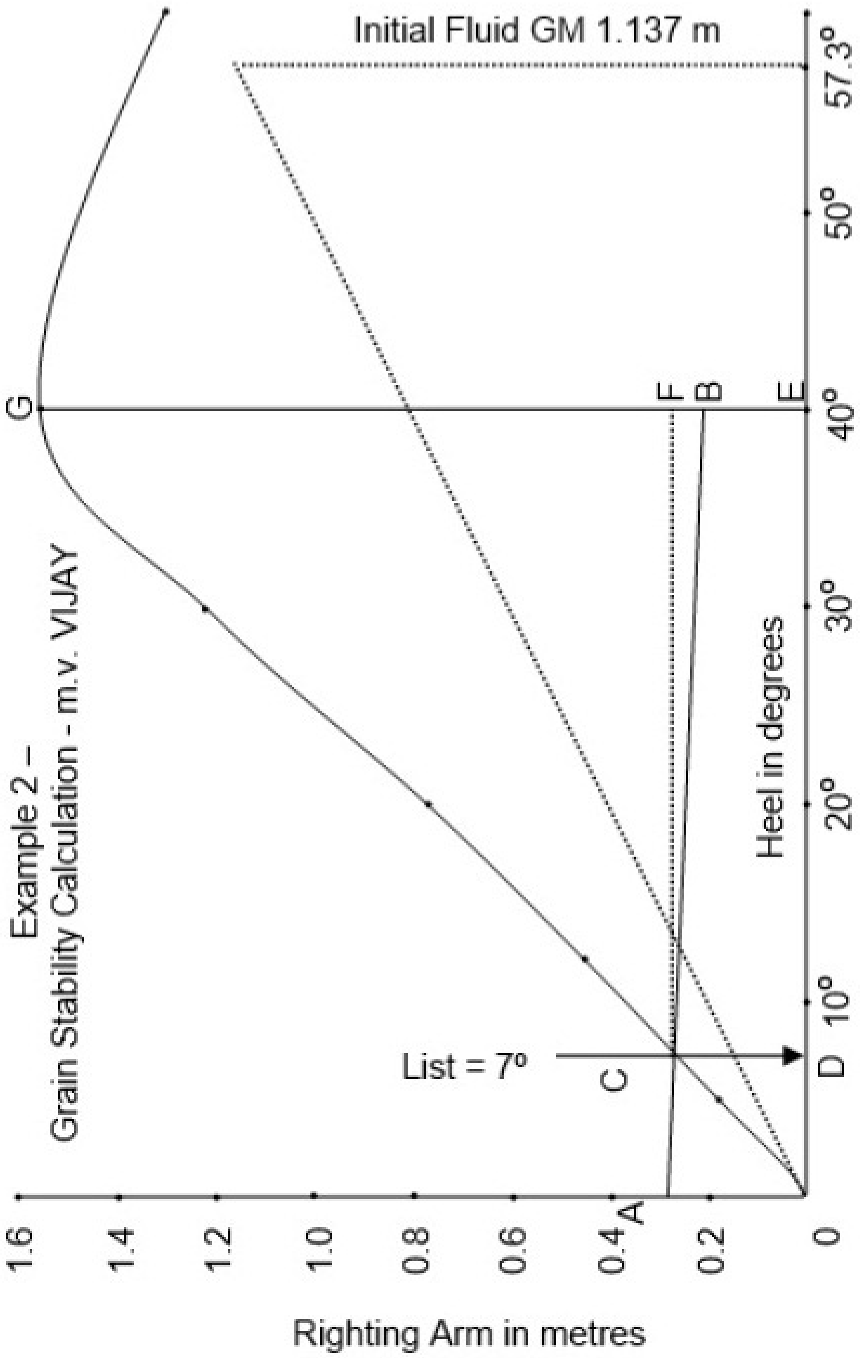
$\tan \theta = GG_1/GM = 0.275 / 1.137 = 0.24186$

Approximate list = 13.6°

Calculation of GZ from appendix VII:

θ°	KN	-	KG Sin θ	=	GZ m
0	0.000	-	6.939 Sin 0°	=	0.000
5	0.793	-	6.939 Sin 5°	=	0.188
12	1.892	-	6.939 Sin 12°	=	0.449
20	3.137	-	6.939 Sin 20°	=	0.764
30	4.696	-	6.939 Sin 30°	=	1.227
40	6.011	-	6.939 Sin 40°	=	1.551
60	7.722	-	6.939 Sin 60°	=	1.713
75	8.001	-	6.939 Sin 75°	=	1.298

$\lambda_0 = GG_1 = 0.275$ m and $\lambda_{40} = 0.8\, \lambda_0 = 0.220$ m



The values of the righting arm and the upsetting arm plotted on the previous page indicate that the list caused by the assumed shift of grain would be 7° which is well below the allowed maximum of 12°.

From the curves plotted on the previous page it will be seen that:

Maximum difference between the righting arm and the upsetting arm occurs at about 45°. The angle of flooding is known to be over 40°. Hence the residual area is to be calculated between the angle of list (i.e., 7°) and 40°.

As done in example 1, points A, B, C, D, E, F and G may be inserted on the graph on the previous page and the residual area calculated in two parts and added together.

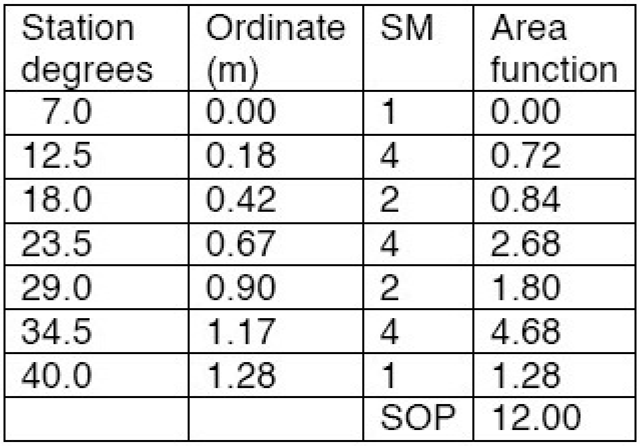
BF = EF – BE = 0.268 – 0.220 = 0.048 m.

Area of triangle CBF = (33 x 0.048)/2 = 0.792 md.

As done in Worked Example 1, seven ordinates may be chosen on CF & measured off upwards from CF to the curve at six equal intervals from 7° to 40°. The interval would be thus be 5.5°. Hence the ordinates would be at:

7°, 12.5°, 18°, 23.5°, 29°, 34.5° & 40° respectively.

These may be put through Simpson's first Rule as shown herewith:



Station degrees	Ordinate (m)	SM	Area function
7.0	0.00	1	0.00
12.5	0.18	4	0.72
18.0	0.42	2	0.84
23.5	0.67	4	2.68
29.0	0.90	2	1.80
34.5	1.17	4	4.68
40.0	1.28	1	1.28
		SOP	12.00

Area = 5.5 (12) / 3 = 22.000 metre degrees

Sum of the two areas = 22 + 0.792 = 22.792 md
Sum of the two areas = 0.3978 metre radian.

This is > than 0.075 metre radian.

The ship in this condition, therefore, meets all the requirements of the Grain Code.

-o0o-

19. SHEAR FORCE AND BENDING MOMENT IN BEAMS

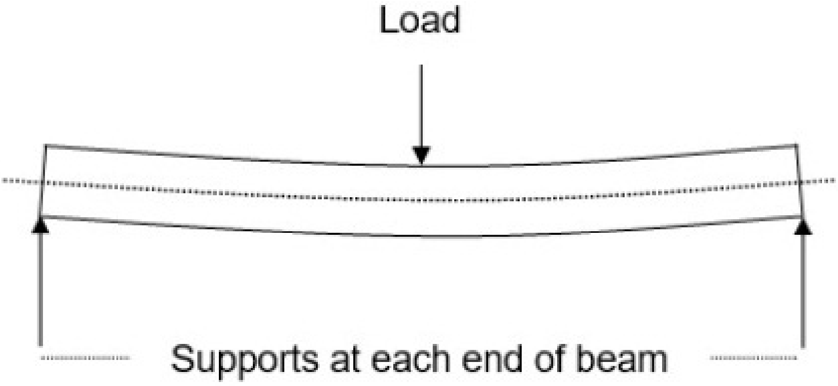
A ‘beam’ is a structural member that offers resistance to bending caused by applied loads. Unless stated otherwise, a beam should be considered to be straight and homogenous – of uniform construction & constant cross-sectional area throughout its length.

The term ‘light beam’ means that the weight of the beam may be neglected in that problem.

The term ‘concentrated load’ means that the given force acts at a single point.

The term ‘uniform load’ denotes that the force is spread evenly over a given distance on the beam.

In this chapter, all forces are considered to be in the same plane - act either upwards or downwards only.



When a load is applied to a beam, it gets deflected (bent). In the above case the upper part suffers compression and gets shorter. The lower part suffers tension and gets longer. The middle part remains at its original length, as it does not experience any tension or compression, and is called the ‘neural axis’. That is why the top and bottom of a beam must have more material in them to provide greater strength to the beam. The beam need not be very strong at its neutral axis. It is for this reason that ‘I’ beams are most popular.

Normally, the beam would regain its original shape when the load is removed. But, if the beam is stressed beyond its elastic limit, the deflection would be permanent.

Shear force is a force which tends to break or shear a beam across (perpendicular to) its major axis. Shear Force (SF) tends to cause one layer of the material to slide over an adjacent layer and thereby tends to cause the material to separate into two parts.

When a beam is in static equilibrium, the net resultant of all the forces acting on it must be zero. If the resultant force to one side of a point on the beam has a value 'x' in the upward direction, then the resultant forces on the other side of that point must also be 'x' but in the downward direction. Therefore, at any point on a beam, SF is the algebraic sum of the forces acting on any one side of that point. In this book, the left side has been considered to calculate SF at any point.

Sign convention for SF: In this chapter, all upward forces are considered positive and all downward forces, negative.

Bending moment at any point on a beam is the total moment tending to alter the shape of the beam. Since the beam is in static equilibrium, the sum of the clockwise moments about any point on the beam is equal to the sum of the anticlockwise moments about the same point. Bending Moment (BM) is, therefore, the algebraic sum of all the moments acting on any one side of the point under consideration.

Sign convention for BM: All clockwise moments to the left, and anti-clockwise to the right, of the chosen point are termed positive. In other words, bending moments that tend to cause the beam to sag are considered positive.

Clockwise moments to the right, and anti-clockwise to the left, of the chosen point are termed negative. In other words, bending moments that tend to cause the beam to hog are considered negative.

S.I. Units:

Force = mass x acceleration

where acceleration is in metres sec^{-2}, mass is in kilogrammes and force is in Newtons. Acceleration due to gravity being 9.81 m sec^{-2}, the gravitational force acting on a mass of 1 Kg = 9.81 N.

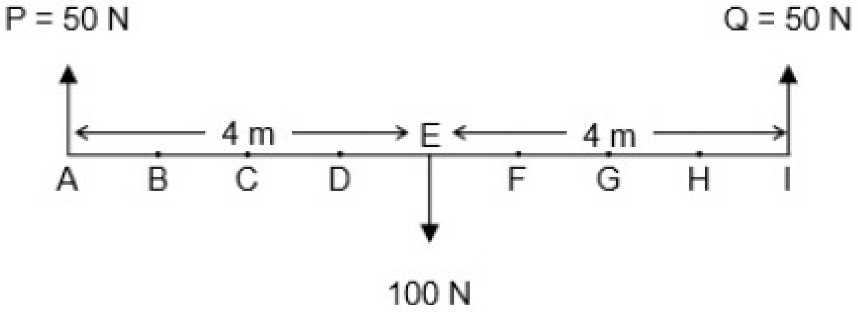
In stability, the kilogramme is found to be too small a unit and hence mass is expressed in tonnes and the units of force would then be kilonewtons or kN.

SI units of BM would be ‘N m’ or ‘kN m’.

Example 1

A light beam 8 m long is supported at its ends. If a mass of 10.1937 kg is placed at its centre, draw the SF and BM diagrams to scale.

Gravitational force = mass x g = 10.1937(9.81) = 100 N



Since the load is at the centre of the beam, the reactions (upward) at the ends (forces P & Q in the foregoing figure) would be 50 N each.

Calculation of SF:

Consider point A. To its left, there are no forces. So, the SF at A should be zero. However, at a point just one mm away from A, the force to its left would be +50 N. So, the SF at A may be said to be changing from zero to +50 N.

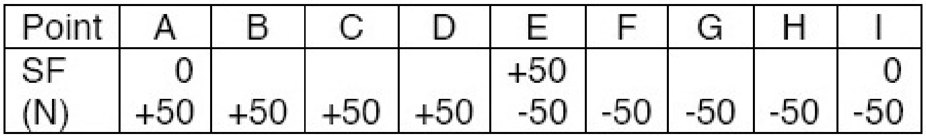
Consider point B. To its left, the sum of all the forces is +50 N. So, SF at B = +50 N. At points C and D also, the value of SF is found to be +50 N.

Consider point E. One mm to the left of E, the SF is still +50 N. At a point one mm to the right of E, the sum of all the forces to the left is -50 N. So, the SF at E may be said to be changing from +50 N to -50 N.

Consider point F. The sum of all the forces to its left = SF = -50 N. At points G and H also, the SF is found to be -50N.

Consider point I. One mm to the left of I, the SF = -50 N, as was in points F, G and H. At I, the SF changes from -50 N to zero.

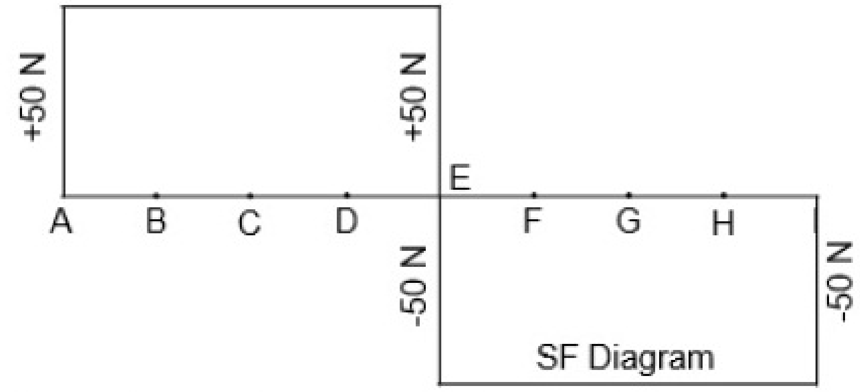
The values of shear force at each of the chosen points may be expressed, in the form of a table, as shown below. From the left end, at one metre intervals:



Point	A	B	C	D	E	F	G	H	I
SF	0				+50				0
(N)	+50	+50	+50	+50	-50	-50	-50	-50	-50

The SF diagram:

The values of SF, calculated for each of the chosen points, may be graphically depicted and is called the SF diagram:



Scale: Linear 1 cm: 1 m, SF 1 cm: 25 N

As mentioned earlier in this chapter, the algebraic sum of the SF acting on the beam must be zero because the beam is in static equilibrium. This means that the area enclosed by the SF curve, above and below the base line, must be equal. Since SF above the base line is termed positive and below termed negative, the algebraic sum must = zero.

Calculation of BM: Method 1:

Referring to the earlier SF diagram, consider point A. There are no forces to the left of A. So, the sum of moments to the left of A = BM at A = zero.

At point B. The moment of the only force to the left, about point B, is + (50 x 1) = 50 N m = BM at B.

At point C. The sum of moments of all the forces to the left, about point C, is (50 x 2) = 100 N m = BM at C.

At point D. The sum of moments of all the forces to the left, about point D, is (50 x 3) = 150 N m = BM at D.

At point E. The sum of moments of all the forces to the left, about point E, is (50 x 4) = 200 N m = BM at E.

At point F. The sum of moments of all the forces to the left, about F, is (50 x 5) – (100 x 1) = 150 N m = BM at F.

At point G. The sum of moments of all the forces to the left, about G, is (50 x 6) – (100 x 2) = 100 N m = BM at G.

At point H. The sum of moments of all the forces to the left, about H, is (50 x 7) – (100 x 3) = 50 N m = BM at H.

At point I. The sum of moments of all the forces to the left, about I, is (50 x 8) – (100 x 4) = 0 N m = BM at I.

Calculation of BM: Method 2:

The BM at any point on the beam is the area under the SF curve up to that point. Cover up the SF diagram with a paper. Keeping its left edge vertical, move it slowly to the right, thereby uncovering the SF diagram from the left.

At point A, the area uncovered so far = BM at A = 0.

At point B, the area uncovered so far = (50 x 1) = 50 N m = BM at B.

At point C, the area uncovered so far = (50 x 2) = 100 N m = BM at C.

At point D, the area uncovered so far = (50 x 3) = 150 N m = BM at D.

At point E, the area uncovered so far = (50 x 4) = 200 N m = BM at E.

At point F, the area uncovered so far = (50 x 4) – (50 x 1) = 150 N m = BM at F.

At point G, the area uncovered so far = (50 x 4) – (50 x 2) = 100 N m = BM at G.

At point H, the area uncovered so far = (50 x 4) – (50 x 3) = 50 N m = BM at H.

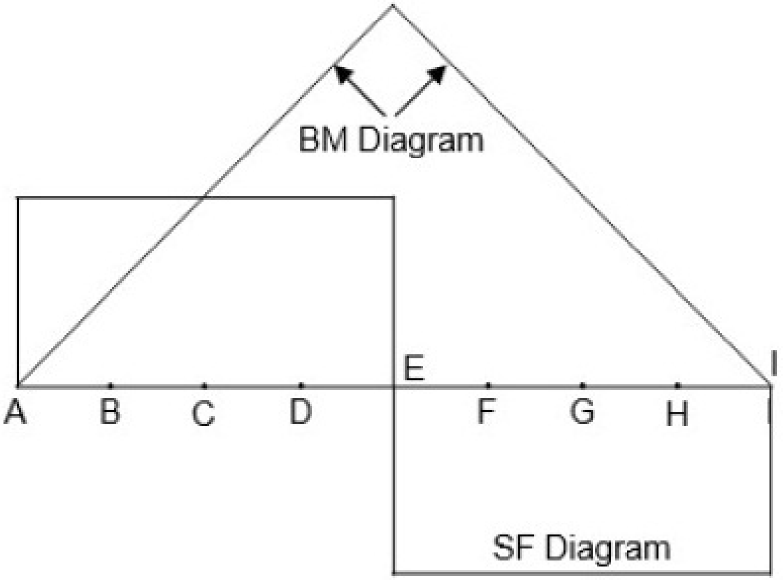
At point I, the area uncovered so far = (50 x 4) – (50 x 4) = 0 N m = BM at I.

The values of BM at each of the chosen points may be expressed, in the form of a table, as shown below. Commencing from the left end of the beam, at one metre intervals, BM in N m is:

Point	A	B	C	D	E	F	G	H	I
BM	0	50	100	150	200	150	100	50	0

The values of BM, calculated for each of the chosen points, may be graphically depicted as illustrated in the following figure:

The BM diagram:



Scales: Linear 1 cm: 1 m
SF 1 cm: 25N; BM 1 cm: 50 N m

Important notes

The BM curve is drawn on the same base line as the SF curve. This is done for the sake of convenience in plotting and for easy reference.

The scales used herein are small owing to the small size of the pages in this book but, in order to obtain accurate results in problems of this type, the student is advised to use as large a linear scale as would comfortably fit on the paper used by him.

The scales used for SF and BM should be reasonably large. A common mistake made by students is to make the SF and BM scales too large, being tempted to do so by the shape of the fools-cap size of paper used! This makes the diagrams look lop-sided and also makes it difficult to draw the curves. In example 1, the SF and BM diagrams were made up of straight lines but, as may happen frequently in later examples, they may be curved. The importance of this point would then become obvious. It is recommended here that the scales for SF and BM should be so adjusted that the vertical size of the entire diagram does not exceed the horizontal size.

Where the SF curve is a horizontal straight line, the BM curve would be a sloping straight line.

Where the SF curve is a sloping straight line, the BM curve would <u>not</u> be a straight line.

At the point where the SF curve crosses the base line, the BM curve would reach a peak or a trough – change direction in such a manner that if it was going away from the base line, it would thereafter bend towards the base line and vice versa. In example 1, there is only one peak and hence that is also the point of maximum BM. In subsequent problems, it will be seen that there may be more than one peak and/or trough of differing values of BM but, at each peak or trough of the BM curve, the value of SF at that point on the beam would be zero.

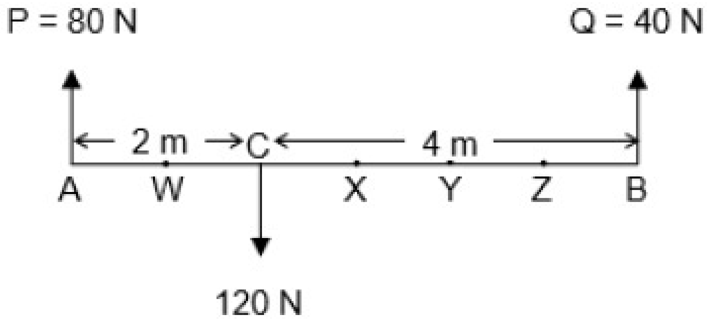
When looking for the maximum value of BM, it must be remembered that the numerical value is of primary importance. The sign + or – before the value of BM only indicates whether the beam tends to sag or hog at that point.

Wherever there is a uniform load or force, SF and BM curves will experience a gradual change there.

Example 2

A light beam 6 m long is supported at ends A and B. A mass of 12.232 kg is hung at point C, 2 m from end A. Draw the SF and BM diagrams to scale.

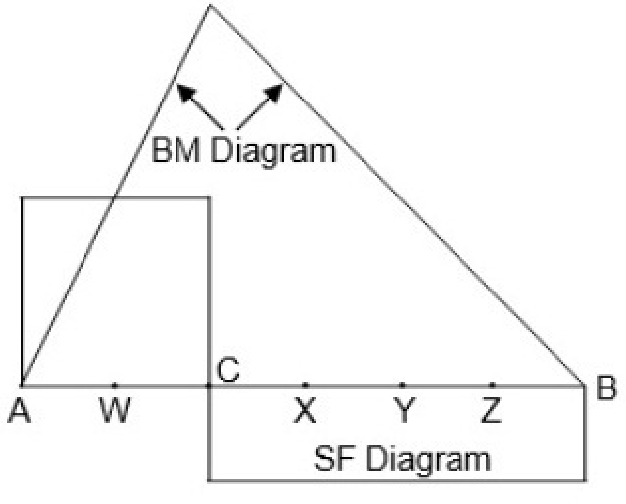
Force of gravity = mass x g = 12.232 (9.81) = 120 N.
To find the reactions at each end, moments about A:
(120 x 2) = (Q x 6), so Q = 40 N.
Total force up = total force down.
(P + Q) = 120, so P = (120 – 40) = 80 N.



Following the procedure explained in example 1, the values of SF and BM, at each point, are as given below in the form of a table:

Point	A	W	C	X	Y	Z	B
SF (N)	00		+80				00
	+80	+80	-40	-40	-40	-40	-40
BM (N m)	00	80	160	120	80	40	00

The SF & BM diagrams:



Note: The SF curve consists of two horizontal straight lines. So, the BM curve consists of two sloping straight lines, as mentioned earlier in this chapter.

The scale used should be clearly mentioned on the diagrams. In this book, the scale has sometimes been omitted intentionally as the diagrams are only to illustrate the nature of the curves so that the student understands their construction.

Example 3

A uniform bar of length 10 m and mass 407.747 kg is supported at its ends.

Draw the SF and BM curves to scale.

Gravitational force = load = mass x g = 407.747 (9.81) = 4000 N = 4 kN.

Since the bar is uniform and supported at its ends, the reactions (P and Q) at the ends are each 2 kN.

Load per m run = load / length = 0.4 kN.

Calculation of SF

At A, SF is changing from 0 to +2 kN.

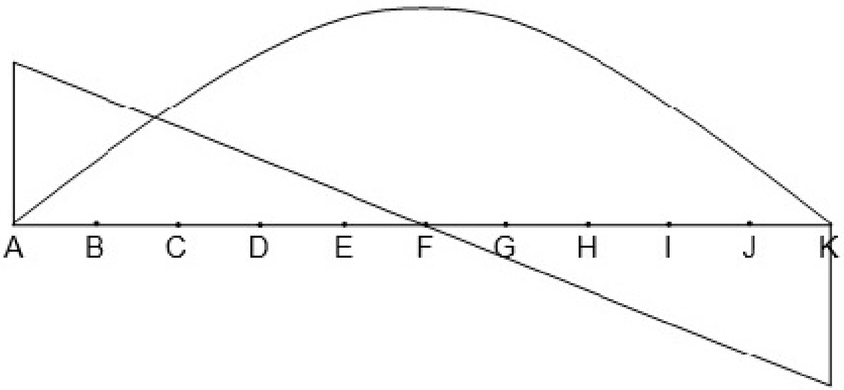
At B, SF = (+2 – 0.4) = +1.6 kN. The -0.4 kN is the weight of the one-metre section AB, which acts at the mid-point of AB, which is to the left of point B.

At C, SF = (+2 – 0.8) = +1.2 kN. The -0.8 kN is the weight of the two-metre section AC which acts at B.

It is now obvious that for every 1 metre of length, the SF changes by -0.4 kN.

The SF, in kN, at each point would be:

Pt	A	B	C	D	E	F	G	H	I	J	K
SF	0 2	+ 1.6	+ 1.2	+ 0.8	+ 0.4	0	-0.4	-0.8	-1.2	-1.6	-2 0



After drawing the SF curve, the values of BM may be computed, as described earlier in this chapter, and the results obtained in kN m would be:

Pt	A	B	C	D	E	F	G	H	I	J	K
BM	0	1.8	3.2	4.2	4.8	5	4.8	4.2	3.2	1.8	0

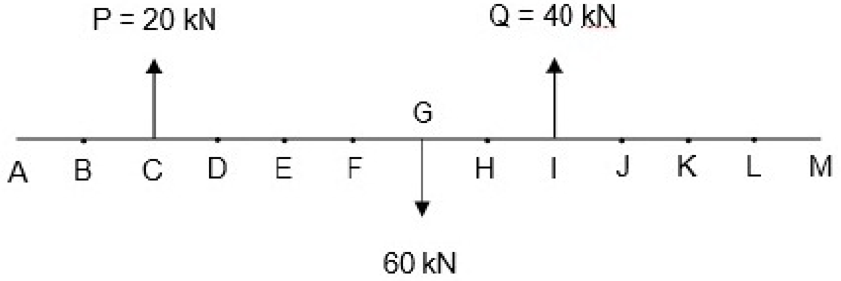
The values of BM may now be plotted to scale, and joined together, as shown in the foregoing diagram.

Example 4

A beam of mass 6.116 t & length 12 m is suspended horizontally by two wires. The first wire is attached 2 m from the left end and the second wire, 4 m from the right end. Draw the SF and BM diagrams to scale.

Force of gravity = 6.116 (9.81) = 60 kN.

Load per m run = 60 / 12 = 5 kN.



To find P & Q, the reactions at C & I, moments about point C:

Note: For this purpose, the entire gravitational force is considered to act at point G, the COG of the beam. In the rest of the problem, the load will be considered separately per metre run.

(Q x 6) = (60 x 4) so Q = 40 kN.

(P + Q) = 60 so P = 60 – 40 = 20 kN.

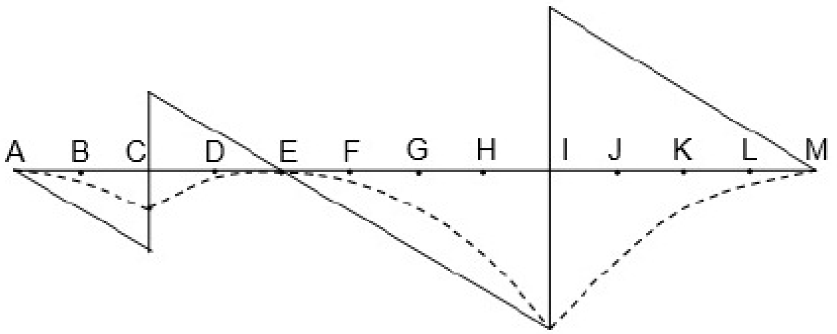
The values of P and Q are inserted in the foregoing figure for easy reference.

Following the procedure explained in the earlier examples, the values of SF and BM may be calculated for a number of points and the diagrams drawn as illustrated in the next page.

Point	A	B	C	D	E	F	G
SF (kN)	0	-5	+10 -10	+5	0	-5	-10
BM (kN m)	0	-2.5	-10	-2.5	0	-2.5	-10

Point	H	I	J	K	L	M
SF (kN)	-15	-20 +20	+15	+10	+5	0
BM (kN m)	-22.5	-40	-22.5	-10	-2.5	0

In this case, the values of SF could have been calculated conveniently at two metre intervals and plotted without loss of accuracy in the SF diagram because it consists of three straight lines only. However, while calculating the values of BM at various points and plotting them, the shape of the curve would not be properly obtained, in this case, if the points considered were two metres apart instead of one metre.



If necessary, the important notes contained at the end of example 1 of this chapter may be re-read and verified by inspecting the SF and BM diagrams of this example.

An interesting feature, noticeable in this example, is that SF and BM may both be zero at the same point on the beam.

Example 5

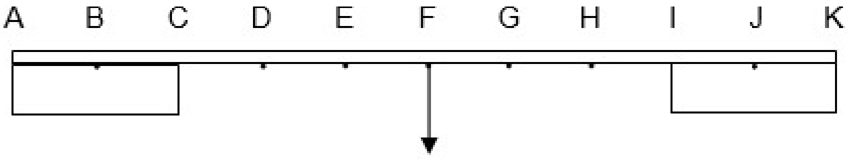
A beam of mass 61.162 kg and length 10 m rests on two flat supports. Each support extends 2 m inwards from the end of the beam. A concentrated mass of 30.581 kg is placed on the centre of the beam. Draw the SF and BM diagrams to scale.

Gravitational force on beam = m x g = 600 N.

Gravitational force on concentrated mass = 300 N.

Total force downwards = 900 N. So, the total force upwards also = 900 N. Hence the reaction at each support = 450 N, spread over 2m.

Reaction per metre, at each end = 450 / 2 = 225 N.



Weight of beam alone per metre = 60 N.

SF at A = 0. SF at B = +225 – 60 = 165 N

SF at C = (SF at B + 225 -60) = 330 N

SF at D, E and one mm before F are 270, 210 and 150 N respectively. At F, SF changes by 300 N, from +150 to -150 N.

SF at G, H and I are -210, -270 & -330 N respectively.

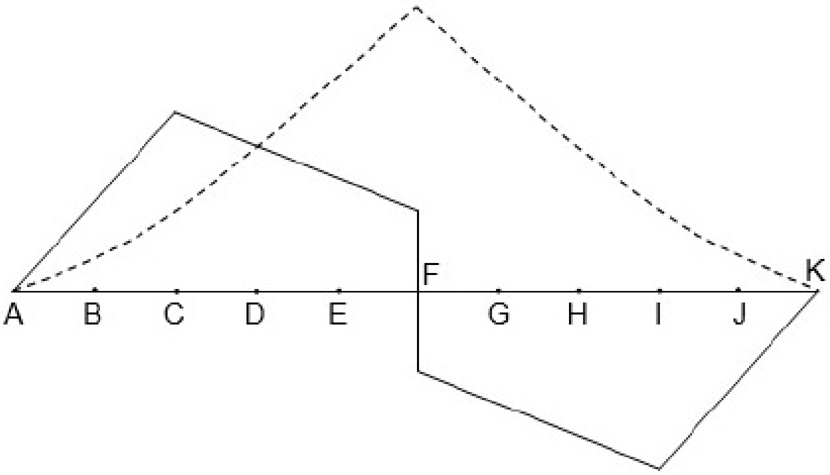
SF at J = (SF at I + 225 – 60) = -165 N.

SF at K = (SF at J + 225 – 60) = zero N.

The values of SF at various points may be tabulated as follows:

Point	A	B	C	D	E	F
SF (N)	0	165	330	270	210	150 -150

Point	G	H	I	J	K
SF (N)	-210	-270	-330	-165	0



The SF diagram may now be drawn to scale and then the BM values calculated as in earlier examples.

The values of BM, in N m, may be tabulated:

Pt	A	B	C	D	E	F
BM	0	82.5	330	630	870	1050

Pt	G	H	I	J	K
BM	870	630	330	82.5	0

The values of BM may now be plotted to scale as shown in the foregoing diagram.

Exercise 16
(SF and BM – Beams)

1. A light beam 12 m long is supported at its ends. A concentrated load of 40 N is applied at its centre. Draw the SF and BM curves to scale.

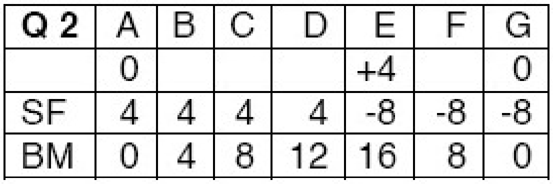
Answer:

Q 1	A	B	C	D	E	F	G
	0			+ 20			0
SF	20	20	20	- 20	- 20	- 20	- 20
BM	0	40	80	120	80	40	0

All points connected by straight lines.

2. A light beam AG, 6 m long, is supported at its ends. A load of 12 N is placed at E, such that GE = 2 m. Draw the SF and BM curves to scale.

Answer:

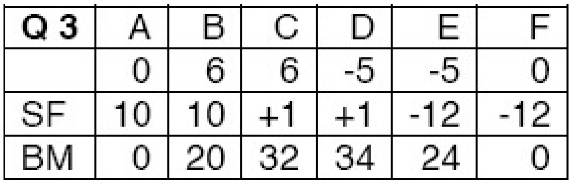


Q 2	A	B	C	D	E	F	G
	0				+4		0
SF	4	4	4	4	-8	-8	-8
BM	0	4	8	12	16	8	0

All points connected by straight lines

3. A light beam AF, 10 m long, rests on its ends. B, C, D & E are points at 2 m intervals on this beam. Concentrated loads of 4, 5, 6 & 7 N are placed at B, C, D & E respectively. Draw the SF and BM curves to scale.

Answer:

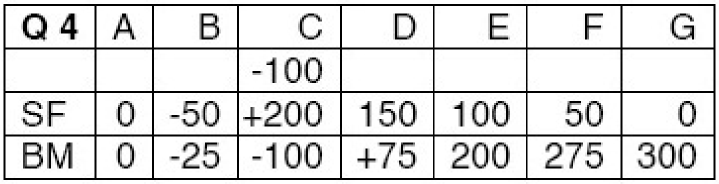


Q 3	A	B	C	D	E	F
	0	6	6	-5	-5	0
SF	10	10	+1	+1	-12	-12
BM	0	20	32	34	24	0

All points connected by straight lines

4. A beam AM, 12 m long & of mass 61.163 kg, is suspended horizontally by two wires attached at points C & K such that AC = KM = 2 m. Draw the SF and BM diagrams to scale.

Answer:

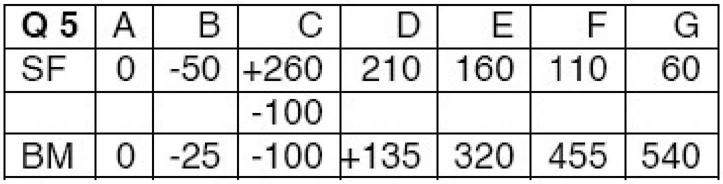


Q 4	A	B	C	D	E	F	G
			-100				
SF	0	-50	+200	150	100	50	0
BM	0	-25	-100	+75	200	275	300

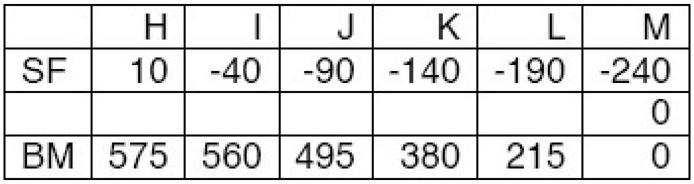
BM is zero also at 2.536 m from each end.
SF – all straight lines. BM is curved.

5. In question 4, if the support wire from point K is shifted to end M, draw the SF and BM diagrams to scale.

Answer:



Q 5	A	B	C	D	E	F	G
SF	0	-50	+260	210	160	110	60
			-100				
BM	0	-25	-100	+135	320	455	540

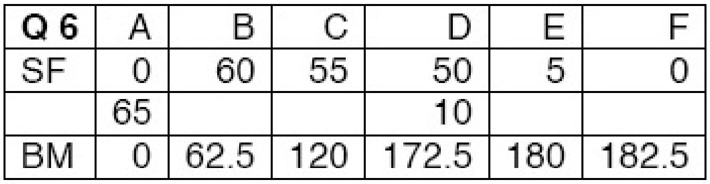


	H	I	J	K	L	M
SF	10	-40	-90	-140	-190	-240
						0
BM	575	560	495	380	215	0

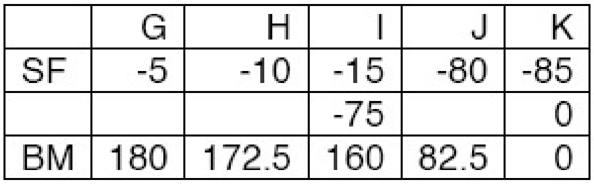
Maximum BM 576 Nm 0.2 m to right of H.
BM = zero also at 0.4 m to right of C.

6. A beam, of mass 5096.84 kg and length 10 m, is supported at its ends. Two concentrated masses are placed on it: 4077.482 kg 3 m from the left end and 6116.248 kg 2 m from the right end. Draw the SF and BM diagrams to scale.

Answer:



Q 6	A	B	C	D	E	F
SF	0	60	55	50	5	0
	65			10		
BM	0	62.5	120	172.5	180	182.5

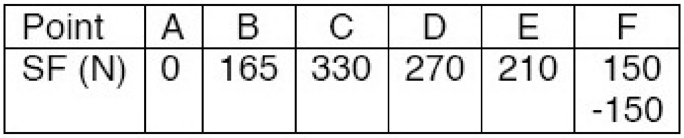


	G	H	I	J	K
SF	-5	-10	-15	-80	-85
			-75		0
BM	180	172.5	160	82.5	0

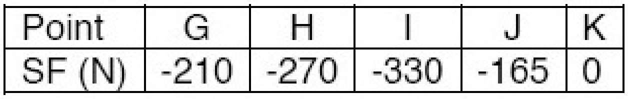
SF – all straight lines. BM is curved.

7. A beam AK, of 10193.68 kg mass and 10 m length, is marked A, B … K at one metre intervals. It is supported at point C and H. A concentrated mass of 2038.736 kg is placed at end K. A uniform mass of 3058.104 kg is spread evenly between points B and E. Draw the SF and BM diagrams to scale.

Answer:



Point	A	B	C	D	E	F
SF (N)	0	165	330	270	210	150 -150

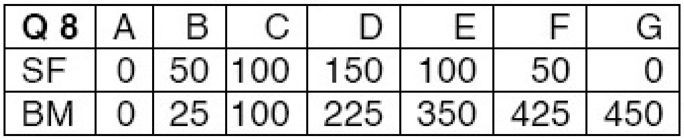


Point	G	H	I	J	K
SF (N)	-210	-270	-330	-165	0

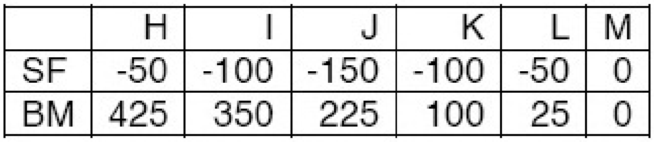
3.25 m from A, SF = 0, BM = -9.375 Nm.
SF – all straight lines. BM is curved.

8. A beam, of mass 61.162 kg and length 12 m, rests on two flat supports which extend 3 m inwards from each end. Draw the SF and BM diagrams to scale.

Answer:



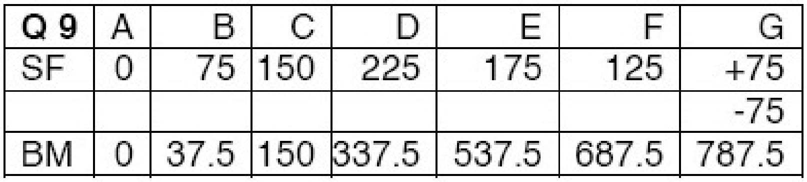
Q 8	A	B	C	D	E	F	G
SF	0	50	100	150	100	50	0
BM	0	25	100	225	350	425	450



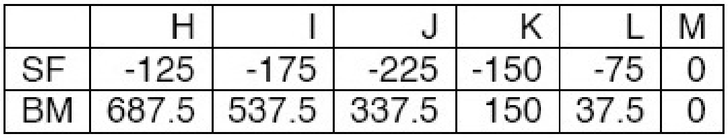
	H	I	J	K	L	M
SF	-50	-100	-150	-100	-50	0
BM	425	350	225	100	25	0

SF – all straight lines. BM is curved.

9. If in question 8, a concentrated load of 150 N is placed on the centre of the beam, draw the SF and BM diagrams to scale. Answer:



Q 9	A	B	C	D	E	F	G
SF	0	75	150	225	175	125	+75
							-75
BM	0	37.5	150	337.5	537.5	687.5	787.5



	H	I	J	K	L	M
SF	-125	-175	-225	-150	-75	0
BM	687.5	537.5	337.5	150	37.5	0

SF – all straight lines. BM is curved.

10. A beam AK, of mass 2038.736 kg and length 20 m, rests fully on a level surface. Points A, B, C …K are marked on it at two metre intervals.

Three masses are placed on it as follows:

5096.84 kg spread evenly between points B & D;

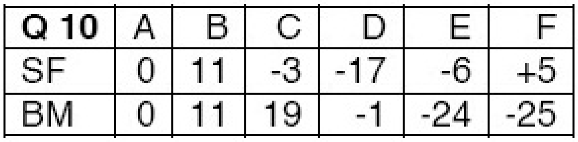
3058.104 kg spread evenly between F & G;

3058.104 kg spread evenly between J & K.

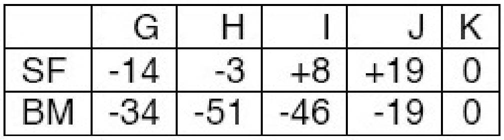
Draw the SF and BM diagrams to scale.

State the maximum values of SF and BM and the points where they act.

Answer:



Q 10	A	B	C	D	E	F
SF	0	11	-3	-17	-6	+5
BM	0	11	19	-1	-24	-25



	G	H	I	J	K
SF	-14	-3	+8	+19	0
BM	-34	-51	-46	-19	0

SF is zero at 3.571 m, 9.091 m, 10.526 m and 14.545 m from A, at which BM is 19.64, -27.28,

-23.69 and -51.85 kN m respectively.

Maximum SF is 19 kN and occurs at J.

Maximum BM is 51.83 kNm, 14.545 m from A.

SF – all straight lines. BM is curved.

-o0o-

20. SHEAR FORCE AND BENDING MOMENT IN BOX-SHAPED VESSELS

For calculations involving SF and BM, a ship may be considered to be a beam whose length equals the length of the ship. When floating freely, the forces of gravity and buoyancy, acting on the ship, are equal.

The force of gravity, acting on the ship, would have different values at various places along the ship's length depending on the longitudinal distribution of the weights on board, including the weight of the hull itself.

The force of buoyancy also would have different values at various points along the length of the ship as it depends on the shape of the underwater part of the hull in the vicinity of the point under consideration.

If the vessel is box-shaped and on an even keel, the force of buoyancy would act evenly all along the length of the ship. If the box-shaped vessel is trimmed by the stern, buoyancy would be more at the stern and less at the bow, and vice versa, but the total buoyancy must always be equal to the total gravity experienced.

To facilitate calculation, the forces of buoyancy and gravity are split up on a 'per metre' basis. This is because the mass of each item considered is so great - in tonnes and not in kilogrammes - that a load has to act over a definite distance along the length of the ship and cannot be considered to act at a single point.

Using the ship's length as the base line, the values of 'weight per metre' and 'buoyancy per metre' are plotted to scale and the 'weights curve' and the 'buoyancy curve' are constructed. The area between the weights curve and the base line would give the total weight of the ship, while the area between the buoyancy curve and the base line would give the total buoyancy.

At any point along the length of the ship, the difference between the values of 'weight per metre' and buoyancy per metre' is called 'load per metre'. At certain parts of the ship, buoyancy would be greater than gravity – the load is then considered to be positive. Over other parts of the ship, gravity would be more than buoyancy – the load is then considered to be negative. The resultant load, or the sum total of the load, experienced by the ship must be zero - the area enclosed by the loads curve above the base line must equal the area enclosed by it below the base line.

Integration of the loads curve, up to any chosen point, would give the SF at that point. In other words, the algebraic sum of the area enclosed by the loads curve, to one side of the chosen point, is the SF at that point. The values of SF may thus be calculated at various points along the length of the ship and the SF curve may be drawn.

The method of obtaining the BM curve, from the SF curve, is the same as that explained in the previous chapter.

Since the words 'displacement' and 'buoyancy' are used extensively in the subject of stability and are expressed therein in tonnes (denoting the mass of water displaced), the unit used in this chapter also, for weight, buoyancy, load, etc is tonnes. It is considered essential to use this unit here, in preference to kilonewtons, in order to co-relate the subjects of ship stability and ship construction. Those desirous of using kilonewtons may multiply tonnes by 'g' i.e., 9.81 $msec^{-2}$.

Example 1

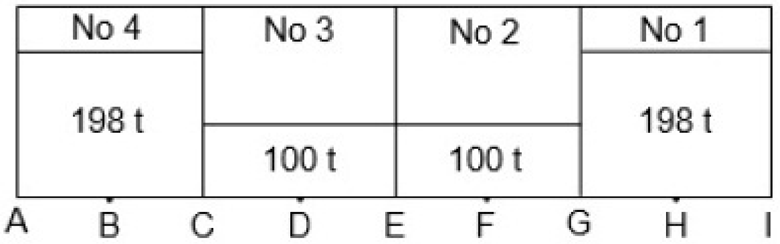
A box-shaped barge 40 m x 5 m has light draft of 0.8 m fwd and aft in SW. It has four identical holds, each 10 m long. Cargo is loaded level as follows:

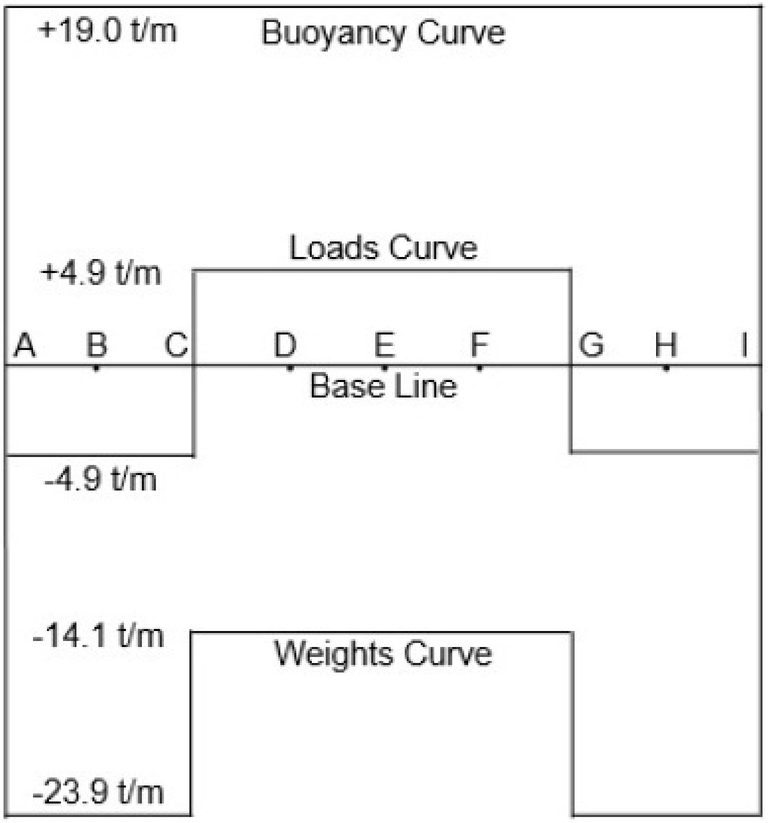
No 1 hold: 198 t
No 2 hold: 100 t
No 3 hold: 100 t
No 4 hold: 198 t.

Draw the SF and BM curves to scale.

Light W = 40 x 5 x 0.8 x 1.025 =	164 t
Cargo loaded =	596 t
Loaded W = Buoyancy =	760 t

Hold numbers	1 & 4	2 & 3
Cargo loaded per m run =	19.8	10.0
Barge alone per m run = 164/40 =	4.1	4.1
Total weight per m run = (-)	23.9	14.1
Buoyancy per m run = (+)760/40 =	+19.0	+19.0
Load per m run	-04.9	+04.9





Note: In the case of an actual ship, the weights curve would be very complex and the load per metre can be deduced at each location only after drawing the weights curve and the buoyancy curve.

At any point, SF is the area enclosed by the loads curve, up to that point.

SF at A = 0. SF at B = -4.9 x 5 = -24.5 tonnes
(or -24.5 x 9.81 = -240.345 kN).

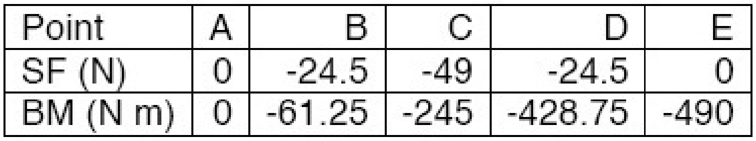
SF at C = -4.9 (10) = -49 t or -480.69 kN.

SF at D = -49 + (4.9 x 5) = -24.5 t (or -240.345 kN).

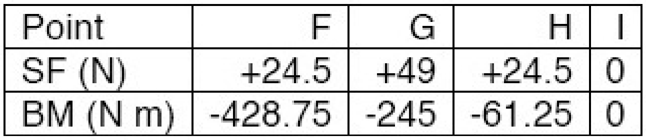
SF at E = -49 + (4.9 x 10) = zero t and so on.

Once the value of SF at various points has been calculated, the SF curve may be drawn, BM at each point calculated and the BM curve drawn to scale, as explained in the previous chapter.

The results may be tabulated as under:

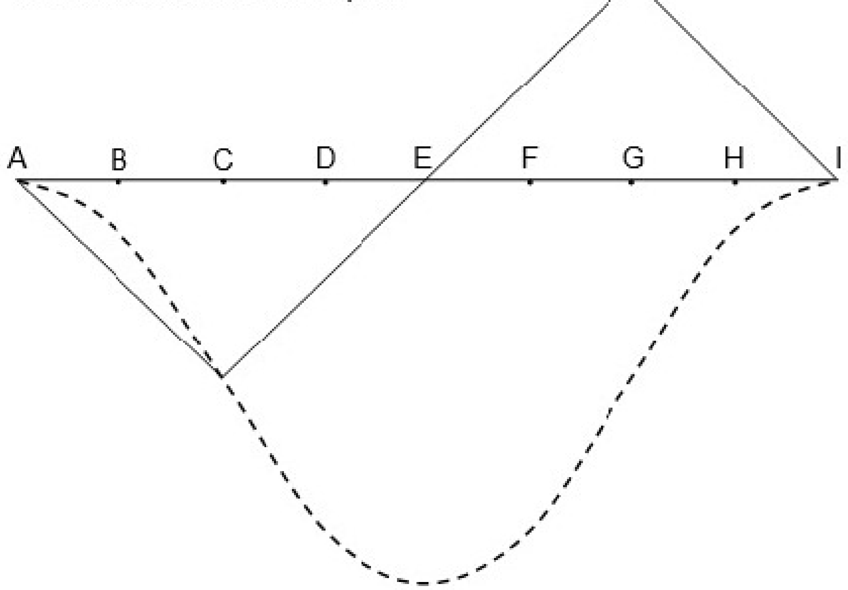


Point	A	B	C	D	E
SF (N)	0	-24.5	-49	-24.5	0
BM (N m)	0	-61.25	-245	-428.75	-490



Point	F	G	H	I
SF (N)	+24.5	+49	+24.5	0
BM (N m)	-428.75	-245	-61.25	0

The SF & BM curves are illustrated on the next page.


SF & BM Curves for Example 1

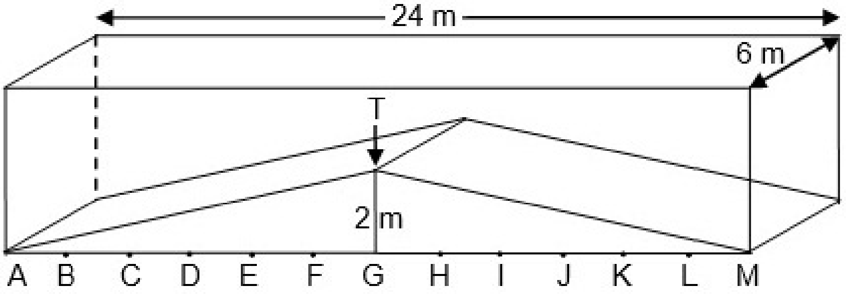
Since BM is (-), the barge tends to hog.

Example 2

A box-shaped barge 24 x 6 m has a light draft of 0.778 m in FW. Ore of SF 0.5 is loaded 2 m high at the centre, sloping steadily downwards to 0 m at the forward and after ends. Draw the SF & BM diagrams to scale.

Light W = 24 x 6 x 0.778 x 1 =	112 t
Cargo loaded = volume / SF =	288 t
Load W = buoyancy =	400 t
Buoyancy/m run = 400 / 24 =	16.667 t/m
Empty barge/m run= 112 / 24 =	4.667 t/m

Calculation of weight of cargo:



Note 1: AT and MT are straight lines.

Note 2: The height of ore, at any point, may be calculated by the principle of similar triangles.

Note 3: The weight per metre of cargo, calculated at each point, is valid only for that particular point. It is not valid over a length of one full metre. This may be illustrated by some simple examples:

(i) If a runner in a race crosses the finish line at a speed of 36 km/hour, that rate is valid only for the instant of crossing the line. He may not have run for a full hour!

(ii) The air pressure at a nozzle may be 100 kNm^{-2} though the cross sectional area of the nozzle may be only a few square centimetres!

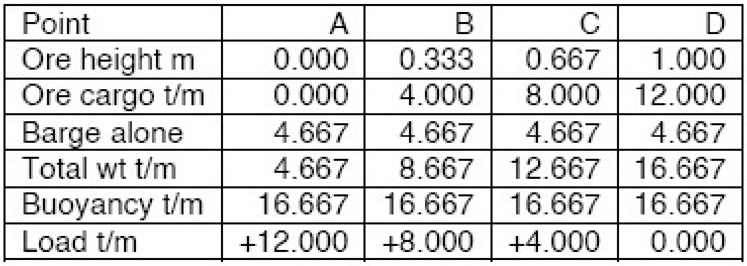
At any point,

Cargo weight/m run = volume of 1 m length of ore / SF

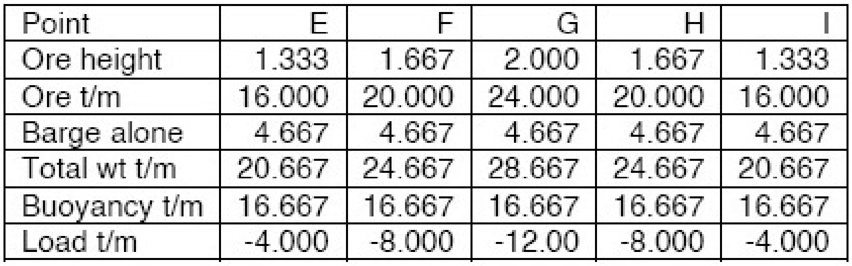
= 1 x 6 x height of ore cargo / 0.5

= 12 x height of ore.

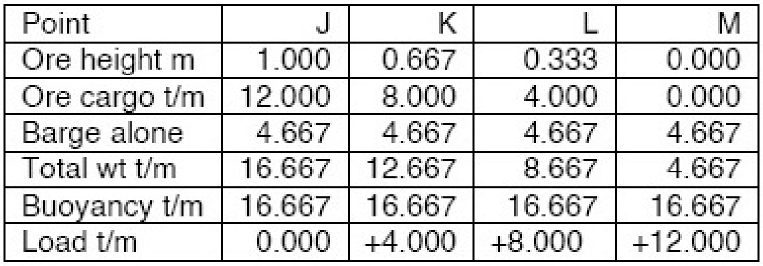
The following is a summary of the calculations at each point:



Point	A	B	C	D
Ore height m	0.000	0.333	0.667	1.000
Ore cargo t/m	0.000	4.000	8.000	12.000
Barge alone	4.667	4.667	4.667	4.667
Total wt t/m	4.667	8.667	12.667	16.667
Buoyancy t/m	16.667	16.667	16.667	16.667
Load t/m	+12.000	+8.000	+4.000	0.000



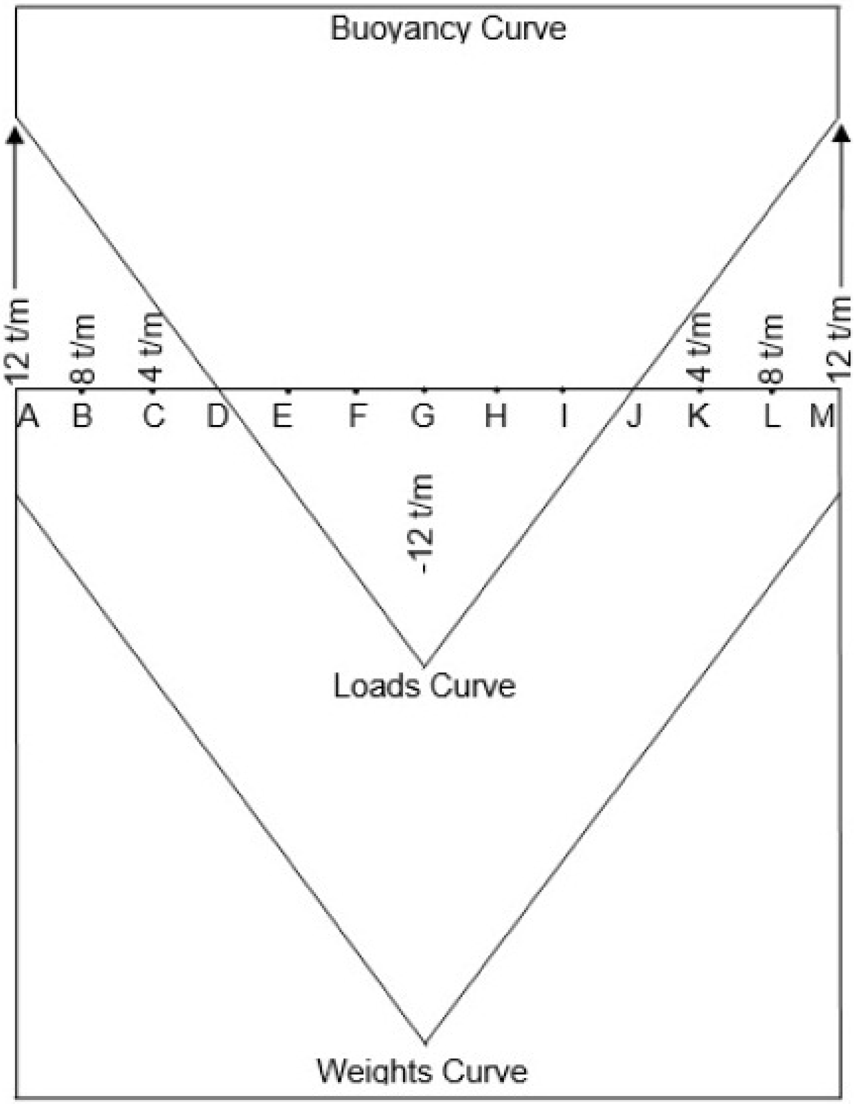
Point	E	F	G	H	I
Ore height	1.333	1.667	2.000	1.667	1.333
Ore t/m	16.000	20.000	24.000	20.000	16.000
Barge alone	4.667	4.667	4.667	4.667	4.667
Total wt t/m	20.667	24.667	28.667	24.667	20.667
Buoyancy t/m	16.667	16.667	16.667	16.667	16.667
Load t/m	-4.000	-8.000	-12.00	-8.000	-4.000



Point	J	K	L	M
Ore height m	1.000	0.667	0.333	0.000
Ore cargo t/m	12.000	8.000	4.000	0.000
Barge alone	4.667	4.667	4.667	4.667
Total wt t/m	16.667	12.667	8.667	4.667
Buoyancy t/m	16.667	16.667	16.667	16.667
Load t/m	0.000	+4.000	+8.000	+12.000

The diagram on the next page illustrates the above results graphically.

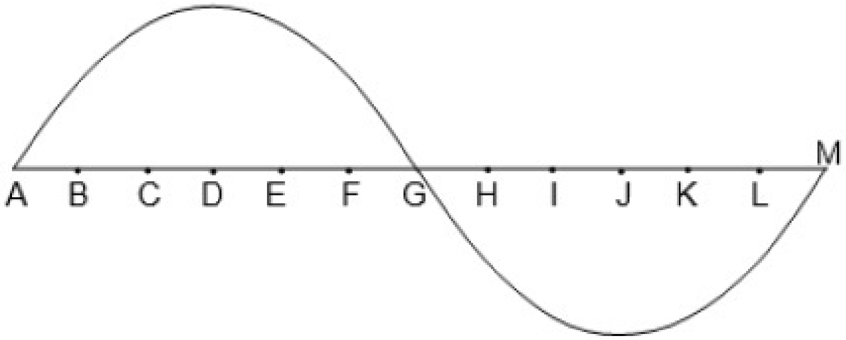
Loads curve of example 2:



Calculating the area under the loads curve, the SF at each point is as under:

A: 00, B: 20, C: 32, D: 36, E: 32, F: 20, G: 00, H: -20, I: -32, J: -36, K: -32, L: -20, M: 00.

The SF curve of example 2:



Using Simpson's Rules for area under the SF curve at each point:

Area up to point B

	Ord	SM	prod
A	0	5	0
B	20	8	160
C	32	-1	-32
SOP for area			128
Area = $\frac{2(128)}{12}$ =			21.333 tm

Area up to point C

	Ord	SM	prod
A	0	1	0
B	20	4	80
C	32	1	32
SOP for area			112
Area = $\frac{2(112)}{3}$ =			74.667 tm

Area up to point D

	Ord	SM	prod
C	32	5	160
D	36	8	288
E	32	-1	-32
SOP for area			416
Area CD = $\frac{2(416)}{12}$ =			69.333
Area up to C			74.667
Area up to D			144.000 tm

Area up to point E

	Ord	SM	Prod
A	0	1	0
B	20	4	80
C	32	2	64
D	36	4	144
E	32	1	32
SOP for area			320
Area = $\frac{2(320)}{3}$			213.333 tm

Area up to point F

	Ord	SM	prod
E	32	5	160
F	20	8	160
G	0	-1	0
SOP for area			320
Area EF = $\frac{2(320)}{12}$			53.333
Area up to E			213.333
Area up to F			266.666 tm

Area up to point G

	Ord	SM	Prod
A	0	1	0
B	20	4	80
C	32	2	64
D	36	4	144
E	32	2	64
F	20	4	80
G	0	1	0
SOP for area			432
Area = $\frac{2(432)}{3}$			288.000 tm

Since the SF curve, in this case, is symmetrical about amidships, the values of BM at M, L, K, J, I, and H are the same as those at A, B, C, D, E and F respectively.

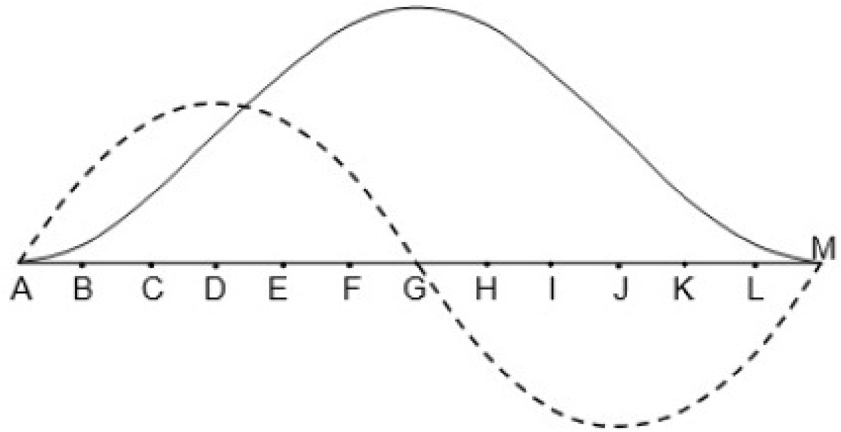
The values of BM are:

Point	A	B	C	D	E
BM	0	21.333	74.667	144	213.333

Point	F	G	H	I
BM	266.666	288	266.666	213.333

Point	J	K	L	M
BM	144.000	74.667	21.333	0.000

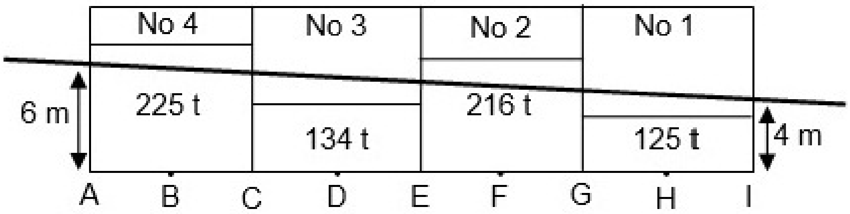
The BM curve may now be inserted on the same base line as the SF curve:



Since BM is (+), the barge tends to sag.

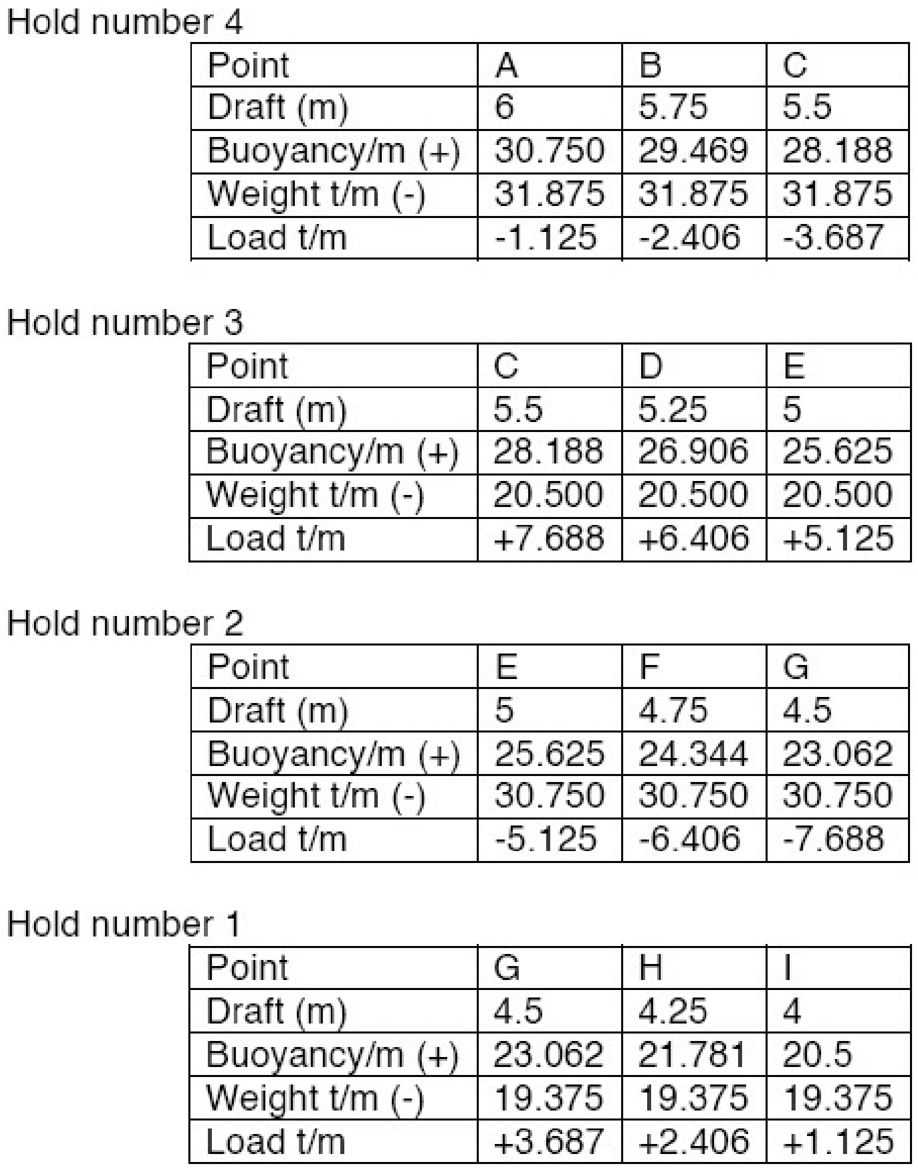
Example 3

A box-shaped barge, 32 m long and 5 m broad, is empty and afloat on an even keel. It has four identical holds and its light displacement is 120 t. Bulk cargo is then loaded and trimmed level as follows: No 1: 125 t, No 2: 216 t, No 3: 134 t and No 4: 225 t. The final drafts are 4 m fwd and 6 m aft. Draw the SF and BM curves to scale.



At any point, Buoyancy / m = 1 x 5 x draft x 1.025 t
= 5.125 x draft at that point

The following is a summary of calculations for each point. It is left as an exercise for the student to arrive at the same values by himself.



Hold number 4

Point	A	B	C
Draft (m)	6	5.75	5.5
Buoyancy/m (+)	30.750	29.469	28.188
Weight t/m (-)	31.875	31.875	31.875
Load t/m	-1.125	-2.406	-3.687

Hold number 3

Point	C	D	E
Draft (m)	5.5	5.25	5
Buoyancy/m (+)	28.188	26.906	25.625
Weight t/m (-)	20.500	20.500	20.500
Load t/m	+7.688	+6.406	+5.125

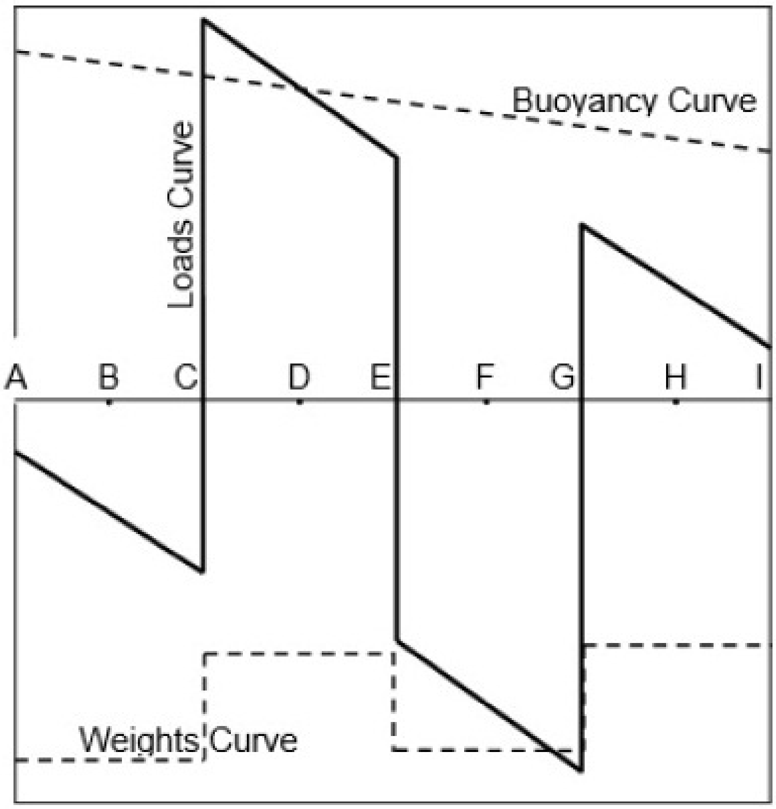
Hold number 2

Point	E	F	G
Draft (m)	5	4.75	4.5
Buoyancy/m (+)	25.625	24.344	23.062
Weight t/m (-)	30.750	30.750	30.750
Load t/m	-5.125	-6.406	-7.688

Hold number 1

Point	G	H	I
Draft (m)	4.5	4.25	4
Buoyancy/m (+)	23.062	21.781	20.5
Weight t/m (-)	19.375	19.375	19.375
Load t/m	+3.687	+2.406	+1.125

The Weights, Buoyancy & Loads Curves of example 3



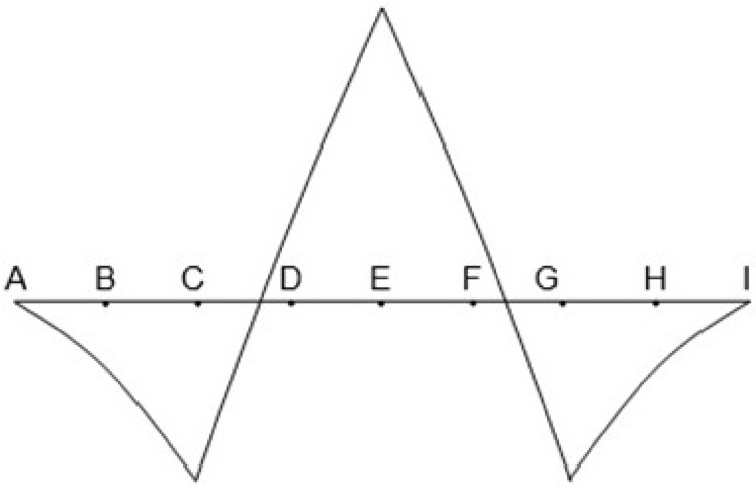
In the above diagram, a larger scale has been used for the loads curve than for the curves of buoyancy and weight.

The values of SF at each point:

Point	A	B	C	D
SF t	0.000	-7.063	-19.250	+8.938

Point	E	F	G	H	I
SF t	+32	+8.938	-19.25	-7.063	0

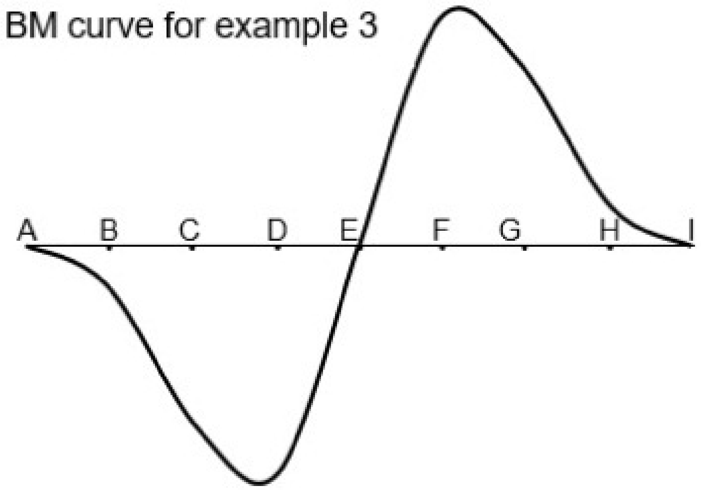
SF diagram for example 3



By using Simpson's 1st & 3rd Rules & plane geometry:

Point	A	B	C	D
BM tm	0.000	-12.418	-63.336	-81.876

Point	E	F	G	H	I
BM tm	0	+81.876	+63.336	+12.418	0

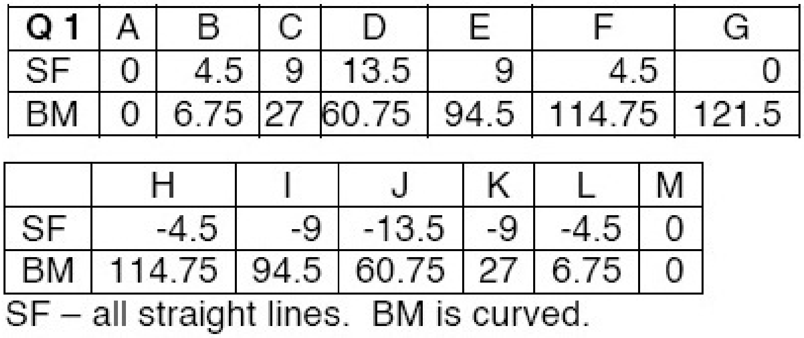


Maximum values of BM, taken from the curve are:
-88.207 tm, 10.584 m from point A &
+88.207 tm, 10.584 m from point I.

Exercise 17
SF & BM in box-shaped vessels

1. A box-shaped barge is 36 m long and has light displacement = 198 t. It has four identical holds into which cargo is loaded and trimmed level as follows: 135 t in No: 1, 162 t in No: 2, 162 t in No: 3 and 135 t in No: 4. Draw the SF & BM curves to scale.

Answer:



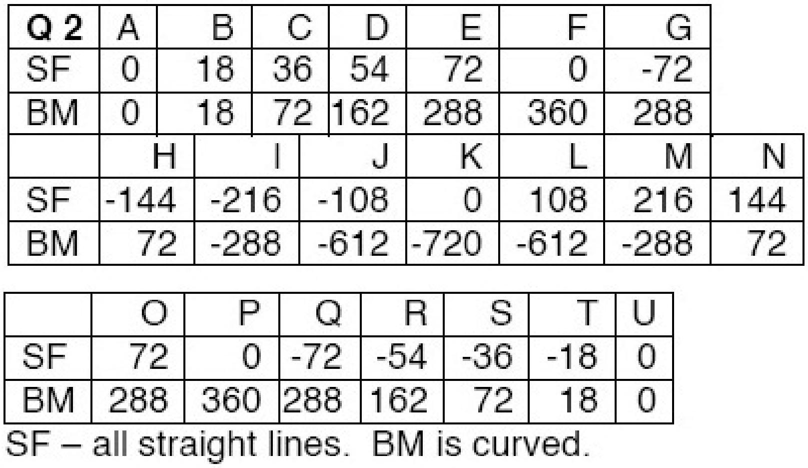
Q 1	A	B	C	D	E	F	G
SF	0	4.5	9	13.5	9	4.5	0
BM	0	6.75	27	60.75	94.5	114.75	121.5

	H	I	J	K	L	M
SF	-4.5	-9	-13.5	-9	-4.5	0
BM	114.75	94.5	60.75	27	6.75	0

SF – all straight lines. BM is curved.

2. A rectangular barge of length 40 m and light displacement 200 t has five identical holds into which bulk cargo is loaded and trimmed level as follows: 360 t in No: 1, 720 t in No: 2, 720 t in No: 4 and 360 t in No: 5. No: 3 hold is left empty. Draw the SF & BM diagrams to scale.

Answer:



Q 2	A	B	C	D	E	F	G
SF	0	18	36	54	72	0	-72
BM	0	18	72	162	288	360	288

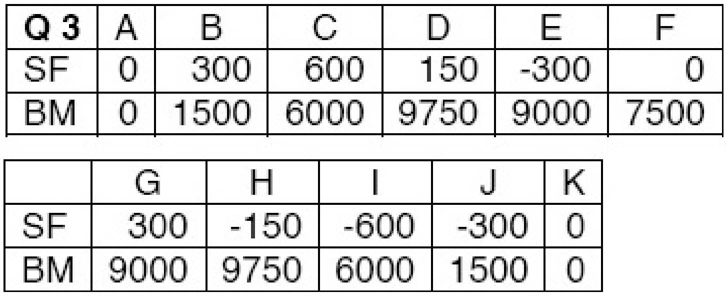
	H	I	J	K	L	M	N
SF	-144	-216	-108	0	108	216	144
BM	72	-288	-612	-720	-612	-288	72

	O	P	Q	R	S	T	U
SF	72	0	-72	-54	-36	-18	0
BM	288	360	288	162	72	18	0

SF – all straight lines. BM is curved.

3. A box-shaped vessel 100 m long, 15 m wide, light displacement 1200 t, has five identical holds. 3000 t of bulk cargo is loaded and trimmed level: 1500 t in No: 2 and 1500 t in No: 4. Draw the SF and BM diagrams to scale.

Answer:



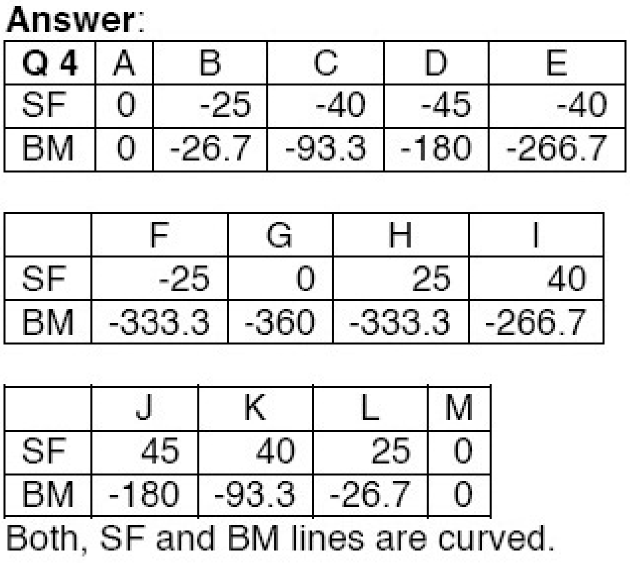
Q 3	A	B	C	D	E	F
SF	0	300	600	150	-300	0
BM	0	1500	6000	9750	9000	7500

	G	H	I	J	K
SF	300	-150	-600	-300	0
BM	9000	9750	6000	1500	0

Maximum BM 10,000 tm occurs at 16.667 m forward and aft of amidships.

SF – all straight lines. BM is curved.

4. A box-shaped barge 24 m long and 6 m wide has light displacement = 120 t. Iron ore (SF 0.6) is loaded, 3 m high at the forward & after ends, sloping steadily to zero at the centre. The ore has no slope in the athwartship direction. Draw the SF and BM diagrams to scale.



Answer:

Q 4	A	B	C	D	E
SF	0	-25	-40	-45	-40
BM	0	-26.7	-93.3	-180	-266.7

	F	G	H	I
SF	-25	0	25	40
BM	-333.3	-360	-333.3	-266.7

	J	K	L	M
SF	45	40	25	0
BM	-180	-93.3	-26.7	0

Both, SF and BM lines are curved.

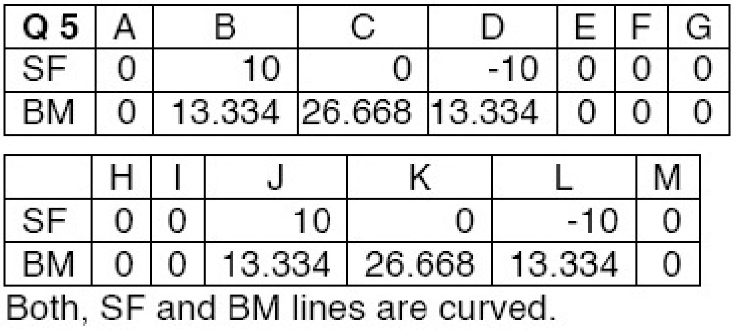
5. A box-shaped barge 24 m long, 5 m wide, light displacement 96 t, has three identical holds. Ore of SF 0.5 is loaded as follows:

Nos 1 and 3 holds: 2 m high at the centre of the hold and sloping steadily down to zero at the forward and after ends of the hold. There is no slope in the transverse direction.

No 2 hold: 1 m high and trimmed level.

Draw the SF and BM diagrams to scale.

Answer:



Q 5	A	B	C	D	E	F	G
SF	0	10	0	-10	0	0	0
BM	0	13.334	26.668	13.334	0	0	0

	H	I	J	K	L	M
SF	0	0	10	0	-10	0
BM	0	0	13.334	26.668	13.334	0

Both, SF and BM lines are curved.

21. SF & BM IN SHIPS

The principles involved in the calculation of SF and BM of ship shapes is the same as that illustrated in chapters 19 and 20 of this book. However, the methods of arriving at the values of weight, buoyancy and load per metre, at each point, are complex and very tedious. In the case of ships, calculations must be made for 'still water' and for 'wave conditions' as explained later in this chapter.

The weights curve

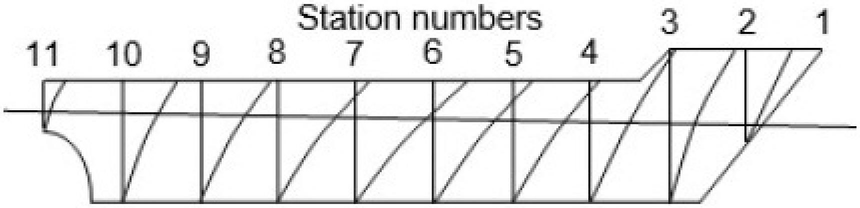
The weight of all the permanent features like the hull, superstructure, fittings, equipment, etc, are estimated and split up on a 'per metre basis' along the ship's length. This was a very tedious and time-consuming process until the advent of computers. The weight of all variable factors such as cargo, fuel, stores, etc are then similarly dealt with but separately so that future changes in their values can be allowed for simply. The weights curve is then drawn, to scale, using the LOA (length overall) as the base line.

The buoyancy curve

The use of Bonjean (pronounced as Bonjohn) Curves (explained later in this chapter) simplifies considerably the procedure of calculating the values of 'buoyancy per metre'. The ship is divided into several stations spaced at equal longitudinal intervals of ten to fifteen metres. The first and last stations coincide with the forward and after tips of the hull. The exact value of the common interval is arrived at by dividing the length overall by the number of spaces chosen. For example, if the LOA is 149.16 m, and eleven stations have been chosen, the common interval would be 14.916 m.

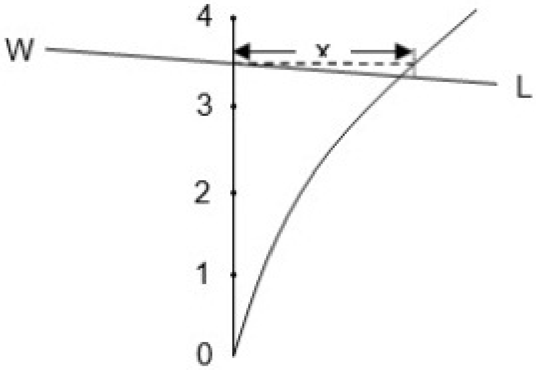
Bonjean Curves

A Bonjean Curve is a curve drawn with the draft of the ship along the vertical axis and the transverse cross-sectional area, of the immersed part of the hull, along the horizontal axis. One such curve is drawn for each station chosen, as illustrated below.



Still water buoyancy curve

The waterline at the proposed drafts fwd and aft is drawn as a straight line on the ships profile containing the Bonjean Curves and the transverse cross sectional area, of the immersed part of the hull at each station, is obtained.



One Bonjean Curve, on a larger scale, is shown above. The desired waterline cuts the station at a draft of 3.5 m. Horizontal distance ‘x’, read off the scale of the drawing, is the transverse cross sectional area of the immersed part of the hull at that station.

At each station, such area, multiplied by a length of one metre and by 1.025 would give the buoyancy in tonnes per metre in SW. The buoyancy curve can then be drawn to scale with the LOA as the base.

Adjustments

Suitable adjustments are made to the values of buoyancy per metre and weight per metre, if necessary, to ensure that the total calculated weight equals the total calculated buoyancy.

The loads curve

The load at various locations is deduced from the values of buoyancy and weight, obtained from the respective curves, and the curve of loads is then drawn. As explained in chapters 19 and 20 of this book, the resultant load on the ship should be zero – the area enclosed by the loads curve above and below the base line should be equal.

The SF & BM curves

The values of SF and BM are computed for various locations, as done in chapters 19 and 20 of this book, and the SF and BM curves are drawn to scale.

Wave conditions

Whilst at sea, waves would cause the buoyancy curve to change drastically. The ship would suffer maximum longitudinal stress when the wave length equals the length of the ship. This is because:

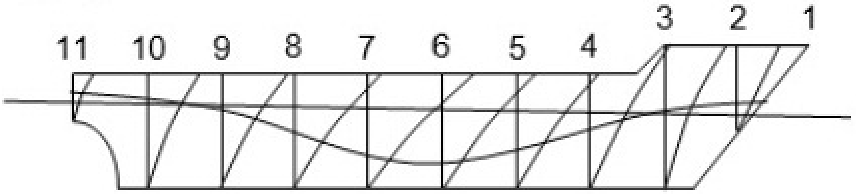
(i) It is then possible that the ends of the ship are supported by consecutive crests leaving the centre with little or no support – maximum sagging stress.

(ii) It is also possible that the centre of the ship is supported by a crest leaving the ends with little or no support – maximum hogging stress.

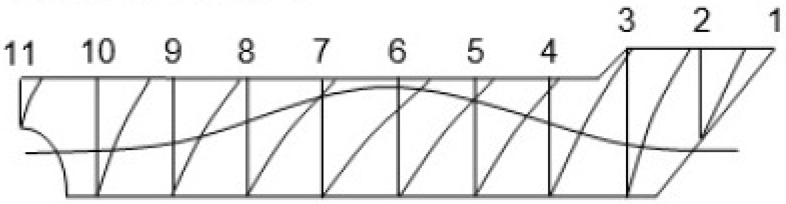
Shipyards make longitudinal stress calculations assuming that the wave length 'L' equals the length of the ship. A standard wave height of L/20 is used.

The assumed wave pattern is drawn, on a transparent plastic sheet, on the same scale as the ships profile. This is then placed over the ships profile such that, despite the sagging or hogging condition being considered, the total under-water volume of the ship (volume of buoyancy) is constant as shown below:

Sagging condition:



Hogging condition:



The transverse cross sectional area of the immersed part of the hull, at each station, is read off using the Bonjean Curves and the value of buoyancy per metre in SW obtained by multiplying by 1.025 as mentioned earlier in this chapter. The buoyancy curve can thus be drawn for the wave condition, separately for sagging and for hogging. Since the weights curve is not affected by wave action, the rest of the calculations may completed in the same manner as done for still water.

Sample SF & BM calculations are made by the shipyard, and supplied to the ship, for the various departure and arrival conditions similar to those found in the stability particulars book of the ship. Clearly mentioned therein would be any special stress related precautions or restrictions – for example: in a partly loaded sea going condition, whether a particular hold should not be left empty; under full load, whether jump loading is permitted and, if so, which alternate holds may be left empty, etc.

In conclusion

It is thus obvious that the calculation of SF and BM of a ship is a complex and tedious process. Manual calculation of the same is not possible, by the ship's staff, for each voyage. However, all modern ships have computerized loadicators by which not only stability, but also stress calculations, can be made. These loadicators have the ship's data already programmed into them. Only the variable factors of the voyage, such as fuel oil, water, stores, cargo, etc are to be entered by the ship's staff. Print outs of the calculations should, each time, be carefully filed away as evidence, in case any kind of reference becomes necessary later on.

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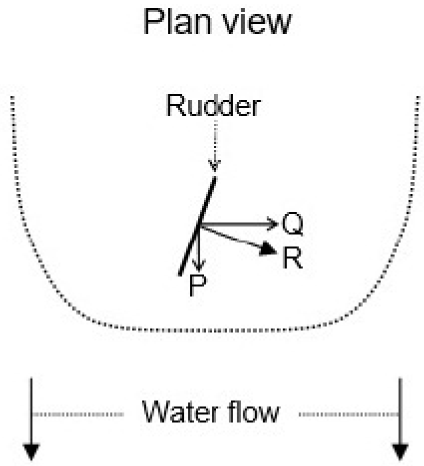
22. HEEL DUE TO TURNING

This chapter considers only the heeling effect caused by the rudder while turning the ship with adequate headway. Other forces such as tide, wave action, wind pressure, etc. are not considered here.

When the helm is put over to turn the ship, two forces come into play – water pressure on the rudder and centrifugal force.

Water pressure on the rudder

When the helm is put over to one side, say to port, the after part of the rudder moves to port obstructing the flow of water past it.



In the foregoing diagram:

R is the resultant force acting normal to the rudder surface by the water flow.

P is the fore and aft component of R.

Q is the transverse component of R.

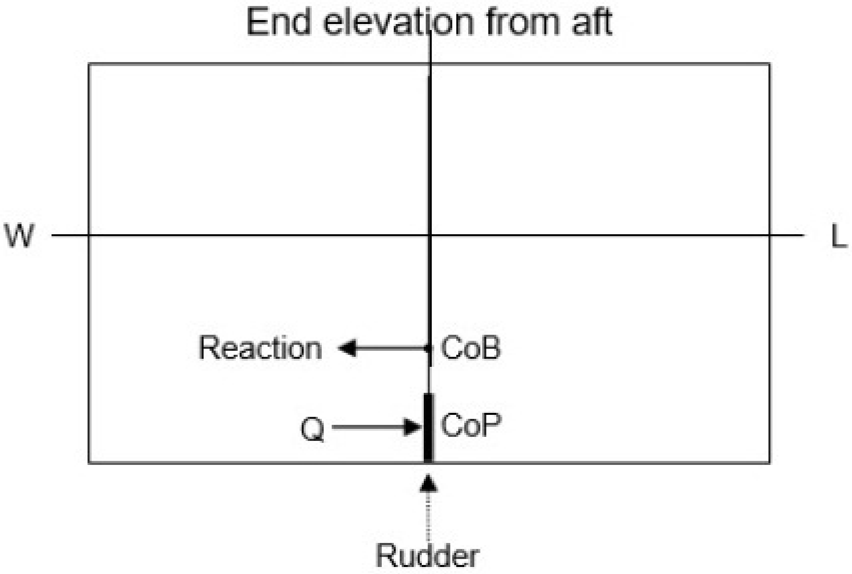
P causes retardation to movement ahead resulting in a slight drop in the speed of the ship.

Q causes the stern of the ship to move to starboard altering the course of the ship to port.

The value of Q is maximum when the rudder is put hard over (i.e. about 35 to 40° off the centre line, depending on the design of the ship).

The greater the speed of the ship, the greater the value of R and the greater the value of Q.

Heel caused by water pressure on the rudder



In the foregoing diagram:

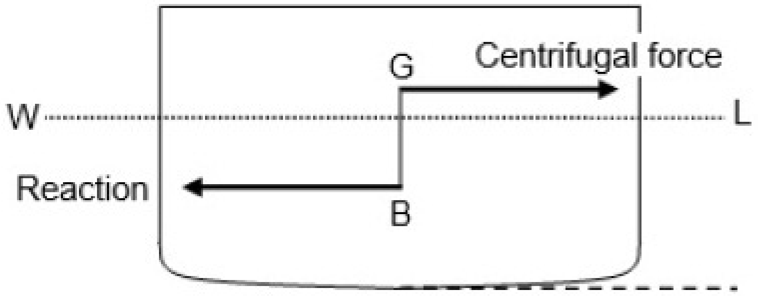
The helm has been put to port, as mentioned earlier. The force Q acting through the Centre of Pressure (CoP) on the rudder pushes the stern to starboard. The reaction or resistance to this force acts towards port through the CoB of the ship. Since the rudder is very near the level of the keel, CoP is lower than CoB. Thus, a heeling moment is caused to port. Had the helm been put to starboard, the heel caused by pressure on the rudder would be to starboard.

In general terms, the heel caused by water pressure on the rudder would cause the ship to heel over towards the centre of turn. The greater the speed of the ship, the greater the heel caused.

Since the area of the rudder is very small compared to the underwater part of the ship, this heel is very small and is overcome by the heel caused by centrifugal force explained below.

Heel caused by centrifugal force

When turning, centrifugal force (Cf), acting at the CoG and away from centre of turn, forms a couple with the righting force which acts inwards through CoB. They are separated by BG, as shown in the following figure.



$$\text{Centrifugal force } (C_f) = \frac{M.v^2}{R} = \frac{W.v^2}{g.R}$$

Where M = Mass, g = acceleration due to gravity
M/g = Weight of ship (i.e. displacement) in tonnes
v = velocity in m sec^{-1}, R = turning radius in metres.

$$\text{Heeling Moment due to } C_f = C_f\ (BG) = \frac{W.v^2\ .\ BG}{g.R}\ \ \text{tm}$$

Assuming that the value of θ is small,
Righting moment = W.GZ = W.GM.Sin θ tonne metres

Equating the Righting & Heeling Moments:

$$W.GM.\sin\theta = \frac{W.v^2\ .\ BG}{g.R} \quad \text{or} \quad \sin\theta = \frac{v^2\ .\ BG}{g.R.GM}$$

where v is in m sec^{-1}.

Substituting [v in m sec^{-1}] by [S in knots (1852/3600)]

and inserting g = 9.81 m sec^{-2}, the formula becomes:

$$\sin\theta = \frac{0.027\ S^2\ .\ BG}{R.GM}$$

where S in knots.

Restriction in the formulae above:

Since it has been assumed that GZ = GM Sin θ, the value of θ should be small, say NOT exceeding 5°.

Summing up:

When the helm is put over to one side, water pressure on the rudder would cause a small heel (say 1 or 2°) towards the centre of the turn, whereas centrifugal force would cause heel away from the centre of turn. The latter tends to have a greater value than the former.

Worked example

While proceeding at 13 knots, the helm is put over to starboard. If GM = 0.36 m, BG = 1.4 m and the turning radius is 120 m, estimate the heel due to turning.

$$\text{Sin } \theta = \frac{0.027\ S^2 .\ BG}{R.GM} = \frac{0.027\ (13^2)\ 1.4}{120\ (0.36)} = 0.147875$$

$\theta = 8.504° = 8° 30'$ to port.

The actual value would be slightly lower owing to contra heel caused by water pressure on the rudder.

Exercise 18
(Heel due to turning)

Find the heel due to turning if g = 9.81, 1 NM = 1852 m

No:	S (kn)	BG (m)	Radius (m)	GM (m)	Helm	**Answer**	
						Heel	**Side**
1.	15	2.2	300	0.32	Port	8.00	S
2.	12	4.1	460	0.50	Stbd	3.97	P
3.	26	5.8	660	1.40	Port	6.58	S
4.	14	4.6	360	0.40	Stbd	9.73	P
5.	13	3.9	320	0.38	Stbd	8.42	P

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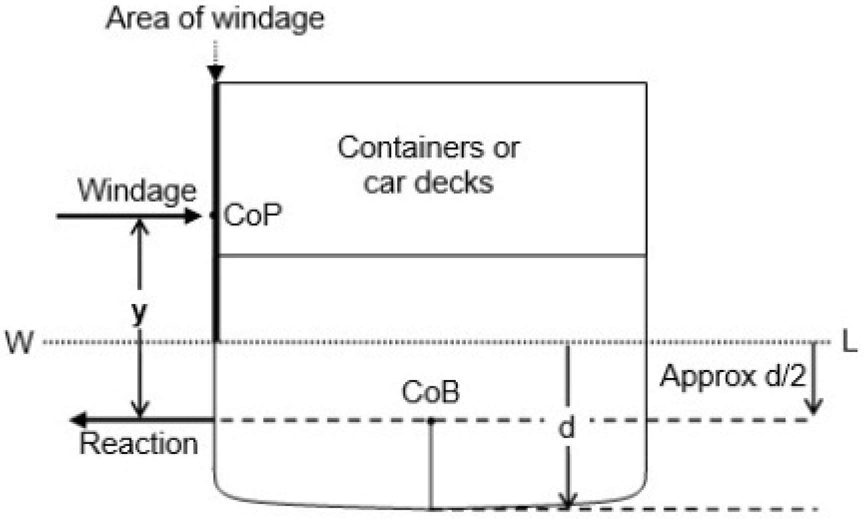
23. HEEL DUE TO BEAM WIND

This chapter considers the heeling effect caused by beam winds to ships. Other forces such as tide, wave action, centrifugal force while turning, etc are not considered here.

Beam winds cause a thrust, called windage, on above-water obstructions. The term ‘wind force’ is not used here as it can be confused with ‘Beaufort Wind Force’ as used in Meteorology. The term ‘Area of windage’ may be used to denote the area that results in windage.



Windage is experienced by all ships, especially when in ballast when the freeboard is high. Container ships (with full stacks of boxes above deck), car carriers, cruise line ships, etc have a large windage area whether loaded or in ballast.

$$P = 2\,(10^{-b})\,A_w\,(W_s)^2$$

Where
P = windage in tonnes
A_w = Windage area in m^2
W_s = Wind speed in knots

Wind Heeling Moment = P (y) tonne metres

Wind Heeling Lever = P (y) / W metres
(Also called Upsetting lever)

Righting Lever to counter this = GZ metres

Equating above, GZ = P (y) / W metres

For small angles only, GZ = GM Sin θ

So P (y) = W.GM.Sin θ OR Sin θ = P (y) / (W.GM)

The heel can be calculated thus for small values of θ.

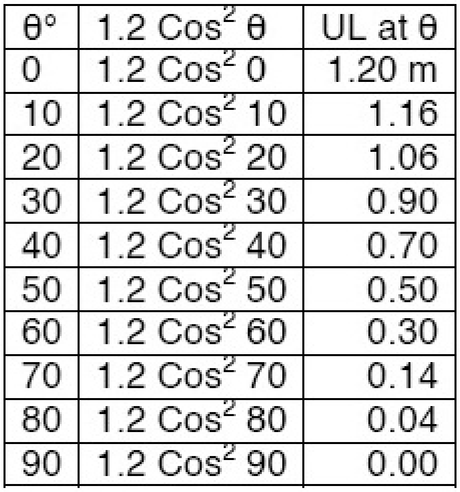
For larger angles of heel, A_w would decrease as the windage area would no longer be vertical. It would thus become A_w Cos θ. So, P would become P Cos θ. Also, the vertical distance 'y' would likewise become y Cos θ.

Heeling lever of P (y) / W becomes P (y) Cos^2 θ / W

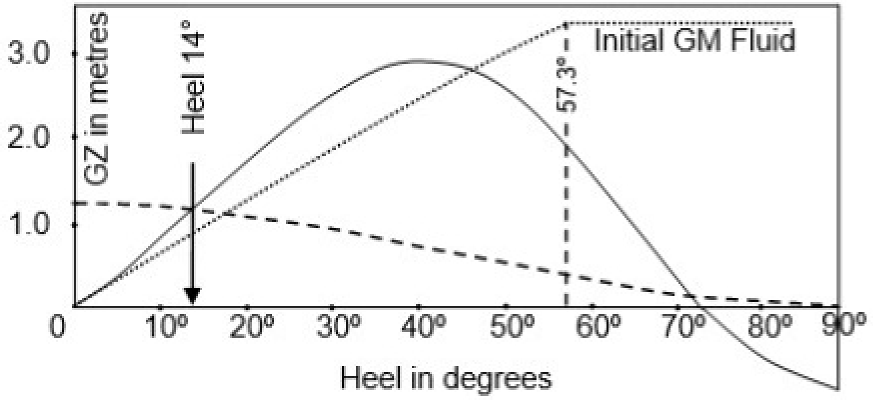
The Upsetting Lever can be calculated for various values of θ and inserted on the Curve of Statical Stability. The value of heel due to wind can then be obtained, as shown in the following example.

Example 1

If the Wind Heeling Lever is found to be 1.2 m, the calculation would be as follows:



θ°	1.2 Cos² θ	UL at θ
0	1.2 Cos² 0	1.20 m
10	1.2 Cos² 10	1.16
20	1.2 Cos² 20	1.06
30	1.2 Cos² 30	0.90
40	1.2 Cos² 40	0.70
50	1.2 Cos² 50	0.50
60	1.2 Cos² 60	0.30
70	1.2 Cos² 70	0.14
80	1.2 Cos² 80	0.04
90	1.2 Cos² 90	0.00



So far it has been assumed that the wind has a steady speed. The resultant heel would then be constant. In actual situations, gusts would be experienced whereby the heel would increase momentarily.

Exercise 19
Heel due to beam wind

1. A container ship is expected to experience winds of 30 knots from the beam. If the windage area is estimated to be 8750 m^2 with its geometric centre 12.5 m above the waterline, W is 60,000 t & GM is 0.8 m, estimate the heel that would be caused.
Answer: 2.35°.

2. A car carrier of W 55,000 t, GM 0.6 m has windage area of 6600 m2 whose geometric centre is 11 m above the waterline. Estimate the heel that would be caused by a 40 knot beam wind.

Answer: 4.04°.

3. A container ship has windage area of 12000 m2 with its centre 15 m above the waterline. If W is 75000 t & GM 0.9 m, calculate the heel if it experiences a beam wind of 50 knots.
Answer: 7.66°

4. A container ship of 100,000 t W and 0.5 m GM has windage area of 8640 m2 whose centroid is 12 m above the waterline. Estimate the heel that would be caused by a 60 knot beam wind.
Answer: 8.59°

5. A car carrier has windage area of 3360 m2 whose geometric centre is 6 m above the waterline. If W is 50,000 t and GM is 0.3 m, estimate the heel caused by a 40 knot beam wind.
Answer: 2.46°

24. INVOLUNTARY MOVEMENTS OF THE SHIP DUE TO WAVE ACTION

Wave action causes the ship to move involuntarily in three planes – longitudinal (or fore and aft) plane, transverse (or athwartship) plane and the vertical plane. These movements can be classed as rotary and non-rotary.

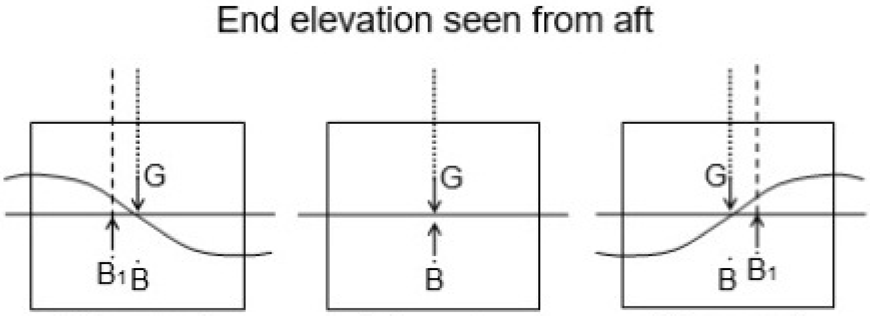
Involuntary rotary movements:

1. Rolling

When the ship is afloat in calm water, the CoG and the CoB are in a vertical line. If the crest of a wave was to strike the ship on the starboard side, the underwater volume on the starboard side would increase. The CoB, being the geometric centre of the underwater volume, would shift to the starboard side. Since no weight has been added or removed, the position of the CoG remains unaffected. The force of buoyancy, acting upwards from the new position of the CoB to starboard, would cause the ship to incline to port. The opposite happens when the crest of the wave passes over to the port side – the ship would incline to starboard. This oscillatory rotary movement from starboard to port is called rolling.

A simple way to understand rolling is as follows:

Suppose we take a wax model of a ship and poke a pencil through it in the fore and aft direction, passing through its CoG. Imagine that the wax is tight fitting on to the pencil. If the pencil was slowly rotated along its axis by a few degrees to either side alternately, the ship model would simulate rolling.



Wave crest on port side, ship rolls to stbd side

Calm water

Wave crest on stbd side, ship rolls to port side

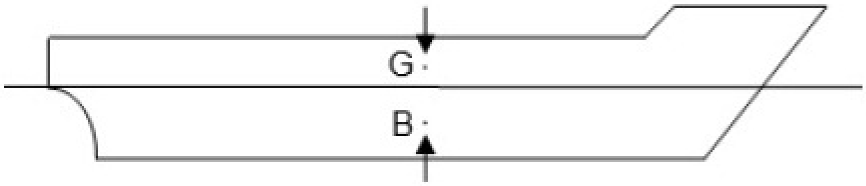
2. Pitching

When the ship is afloat in calm water, the CoG and the CoB are in a vertical line. If the crest of a wave was to pass under the bow, the underwater volume at the bow would increase. The CoB, being the geometric centre of the underwater volume, would shift to the forward side. Since no weight has been added or removed, the position of the CoG remains unaffected. The force of buoyancy, acting upwards from the new position of the CoB ahead, would cause the bow to rise up and the stern to dip down. The opposite happens when the crest of the wave passes under the stern – the stern would rise up and the bow would dip down. This oscillatory rotary movement up and down by the bow and stern of the ship is called pitching.

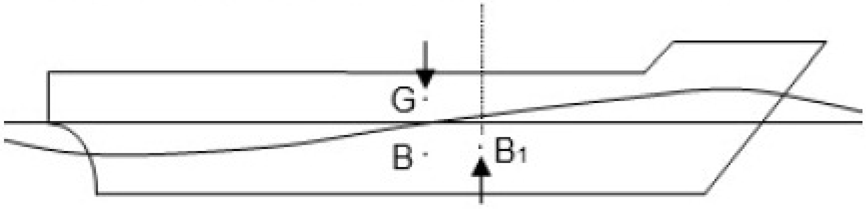
A simple way to understand pitching is as follows:

Suppose we take a wax model of a ship and poke a pencil through it in the athwartships direction, passing through its CoG. Imagine that the wax is tight fitting on to the pencil. If the pencil was slowly rotated along its axis by a few degrees to either side alternately, the ship model would simulate pitching.

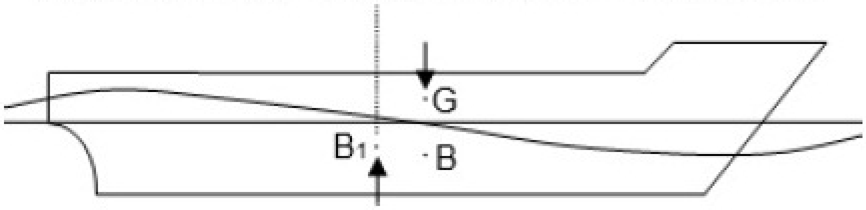
Calm water – G & B in a vertical line



Crest at bow – B shifts ahead – Bow rises



Crest at stern – B shifts astern – stern rises



3. Yawing

When a wave strikes the ship on one bow (say starboard), the bow gets pushed to the other (port) side. When the next trough is against the same bow (starboard), the bow gets pulled towards that side (starboard). Since the crest and trough would come alternately, the ship would tend to oscillate about the original direction in which it was heading. This is called yawing.

A simple way to understand yawing is as follows:

Suppose we take a wax model of a ship and poke a pencil through it in the vertical direction, passing through its centre. Imagine that the wax is tight fitting on to the pencil. If the pencil was slowly rotated along its axis by a few degrees to either side alternately, the ship model would simulate yawing.

Involuntary non-rotary movements:

1. Swaying

When the crest of a large wave strikes against the side of the ship (say starboard), the ship may get pushed bodily in the direction of the wave (to port). When the trough of the wave comes against the same side, the ship may get bodily pulled in the direction of the trough (to starboard). The position of the ship thus tends to oscillate from one side to the other due to wave action. This is called swaying.

A simple way to understand swaying is as follows:

Consider the wax ship model and pencil used to illustrate rolling. If the pencil was bodily moved slowly in the athwartships direction by a few centimetres from one side to the other alternately (without rotating the pencil on its axis), the ship model would simulate swaying.

2. Surging

When the crest of a large wave strikes against one end of the ship (say the stern), the ship may get pushed bodily in the direction of the wave (ahead). When the trough of the wave comes against the same end (stern), the ship may get bodily pulled in the direction of the trough (astern). The position of the ship thus tends to oscillate from ahead to astern due to wave action. This is called surging. If the ship was enroute, the speed of the ship would tend to increase and decrease momentarily due to wave action from astern or ahead.

A simple way to understand swaying is as follows:

Consider the wax ship model and pencil used to illustrate pitching. If the pencil was bodily moved slowly in the fore and aft direction by a few centimetres alternately (without rotating the pencil on its axis), the ship model would simulate surging.

3. Heaving

When the crest of a large wave comes under the bottom of the ship, the whole the ship may get lifted bodily upwards. When the trough of the wave comes under the bottom of the ship, the whole ship would get lowered in space, bodily downwards. The position of the ship thus tends to oscillate up and down due to wave action. This is called heaving. Heaving occurs in very bad weather, especially when the wave direction is perpendicular to the ship's course.

A simple way to understand heaving is as follows:

Consider the wax ship model and pencil used to illustrate yawing. If the pencil was bodily moved slowly in the vertical direction by a few centimetres up and down alternately (without rotating the pencil about its axis), the ship model would simulate heaving.

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25. PERIOD OF ROLL AND PITCH, SYNCHRONOUS ROLLING

Some more explanation of roll and pitch is given in this chapter namely, period of roll, period of pitch and synchronous rolling of ships.

1. Period of roll

The period of roll is the time taken for the ship to roll once completely – say from full starboard heel to full starboard heel again.

A ship normally will <u>not</u> roll in still (calm) water as the CoB will remain on the centre line. However, rolling can be induced, theoretically for study purposes, by say lifting a heavy weight slightly off a wharf by the ship's derrick or crane, thereby creating a slight list, and suddenly lowering it fully. The ship would then roll in simple harmonic motion with reducing amplitude until it is steadily upright. The period of roll (P_R) so experienced is the natural rolling period of the ship in that condition – for that GM_F and for that athwartship distribution of weights on board. If the athwartship distribution of weights on board was increased, the period of roll of the ship would increase and vice versa. The natural period of roll of a ship may be calculated by the following formula given in the **Intact Stability Code of IMO:**

$$P_R = 2CB / \sqrt{GM_F}$$

Where: $\mathbf{P_R}$ = Natural period of roll of the ship in seconds

C = 0.373+0.023(B/d)-0.043(L/100), or by equivalent determination of coefficient C.

L = Length of the ship at waterline in metres

B = Moulded breadth of the ship in metres

D = Mean moulded draught of the ship hull in metres

$\mathbf{GM_F}$ = Transverse Fluid Metacentric height in metres.

Naval architects have simplified the above formula to an approximate one:

$\mathbf{P_R = 0.8B / \sqrt{GM_T}}$

Where $\mathbf{P_R}$ = Period of roll in seconds,
$\mathbf{GM_T}$ = Transverse GM Fluid & B = Moulded breadth.

In bad weather, a stiff ship may experience a period of roll of about 8 to 10 seconds whereas a tender one, about 25 to 35. A period of roll of 20 seconds and up to ± 5 is considered comfortable for those on board.

2. Period of pitch

Since ships are long and narrow, the angle of pitch is small compared to the angle of roll under the same wave conditions – end on for pitching and beam on for rolling. The longitudinal GM or GM_L may be approximated to 1.1 x L with reasonable accuracy for the sake of convenience in calculation. The approximate value of the natural period of pitch may be calculated by the following formula:

$\mathbf{P_P = \frac{1}{2} \sqrt{L}}$

Where $\mathbf{P_P}$ = Period of pitch in seconds and **L** is the ship's LBP in metres.

A ship normally will not pitch in still (calm) water as the CoB will remain on the centre line. However, assuming that pitching can be induced for study purposes the period of pitch may be calculated by the foregoing formula.

By the above formula,
If L = 100 m, P_P would be 5 seconds
If L = 200 m, P_P would be 7 seconds
If L = 300 m, P_P would be 8.7 seconds

3. Synchronous rolling

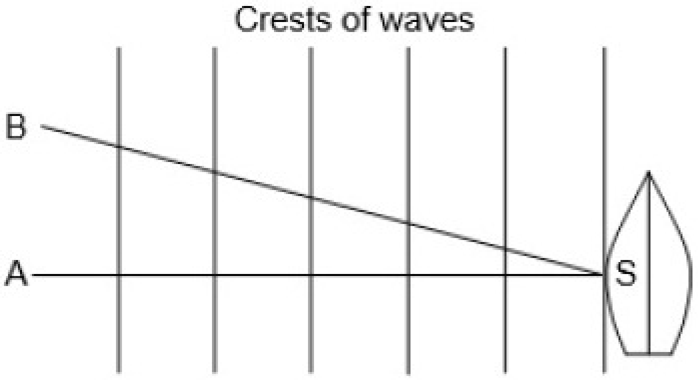
As stated earlier, rolling of ships is caused by wave action. The wave period and wave height affect the amplitude of the roll of the ship. When the waves are from abeam, the amplitude of roll is greatest while pitch is absent. If the ship's course is gradually altered, the amplitude of roll would progressively decrease and the angle of pitch would steadily increase. When the waves are from ahead or from astern, the pitch would be greatest while there would be no roll. In actual practice, however, wave action and the course of the ship in bad weather are not strictly steady, so some roll will be present even the waves are from ahead or astern.

When the waves are from abeam, if the period of the waves and the natural period of roll of the ship coincide, synchronous rolling would occur. The amplitude of roll would gradually increase to very high values and the ship may tend to capsize.

Synchronous rolling can be illustrated by a simple example - a large man sitting on a swing and being pushed by a small boy. If the boy gives a slight push at the right time every time – just when the swing is moving away from him – the angle of swing would increase gradually to high values even though the boy is very small compared to the man sitting on the swing. The boy is giving a synchronised push to the swing!

When the ship is at its maximum roll to port, the crest of a wave appears at the starboard side and gives a synchronised push to port. The converse happens when the ship rolls to starboard. In a very short while, the angle of roll would increase considerably.

Immediate action when synchronism seems to be occurring is to alter course.



In the above diagram the vertical lines indicate the crests of waves. The distance between them indicates the wavelength. The wave encounter length is greater in the direction SB than SA. So, if the ship alters course, the encounter wavelength and hence the encounter wave period would increase. If synchronism was occurring on the original course, it would not occur at the new course. The ship could then do a zigzag course, without too much increase in distance, until the situation changes.

Two formulae are of significance here:

$P_W = 0.8\sqrt{W_L}$

Where P_W = Wave Period in seconds
and W_L = Wave Length in metres and

$$P_E = \frac{3(P_W)^2}{3\,P_W + S \cos \alpha}$$

Where
$\mathbf{P_E}$ = Encounter Wave Period in seconds,
$\mathbf{P_W}$ = Wave Period in seconds,
S = speed of ship in knots and
$\boldsymbol{\alpha}$ = angle in degrees between the direction of the keel (ship's head) and the direction of the waves.

If the waves are from abeam, $\alpha = 90°$, then $\cos \alpha = 0$, and then $P_E = P_W$. If this = P_R, synchronous rolling would occur. It would be alarming only when it results in large angles of roll. In that case, a large alteration of course would make P_E greater than P_R and synchronism would be broken.

To sum up, synchronous rolling is the result of resonance between the natural period of roll of the ship and the encounter period when the waves are from abeam. Such a situation is highly likely also when the natural rolling period of a ship coincides with the encounter wave period when following or quartering seas are experienced in a ship with small GM_T. A significant alteration of course would remedy the situation.

26. PARAMETRIC ROLLING OF SHIPS

What is parametric rolling?

Parametric rolling is a phenomenon whereby a ship which is pitching moderately in bad weather suddenly experiences very heavy rolling, without any warning. The roll angle can increase from 2 or 3° to over 30° in just two or three cycles.

Financial consequences

On container ships, the violent motions resulting from parametric rolling could introduce extreme stresses on containers and their securing systems, resulting in failures and loss of containers overboard. Some of the largest cargo casualties in history with hundreds of containers damaged or lost overboard have been attributed to parametric rolling. The worst case so far exceeded US$ 100 million in 1998.

A real life incident

The ship: A Post Panamax container ship (just under 5000 TEUs).

The situation: It was night time. The ship was on reduced speed due to bad weather. The wind was about 1 point on the starboard bow. The ship was pitching moderately without any slamming. The angle of roll was negligible. The Master was in his office one deck below.

The occurrence: The ship began rolling about 10°. The Master was not alarmed. However, he decided to go up and have a look around. While he was on his way up to the bridge, the ship took a sudden violent roll of around 30°. The OOW was caught off guard and went flying from one end of the wheelhouse to the other, accompanied by the Pilot's chair. The door of a storage cupboard, containing SCBA bottles, line throwing apparatus and other odds and ends, broke open and all these and more went flying on to the OOW.

On opening the bridge door, the Master put on the lights and saw everything on the floor including the OOW going from side to side. He tried to catch hold of the 90-kilo OOW but was unsuccessful. He managed to deflect some of the 'flying' equipment away from the

OOW who then managed to get up. The ship continued to roll about 30-35°. The Master then instructed the OOW to change over to hand steering and go hard a port and alter course to bring the wind nearly abeam. As soon as the alteration was effected, the ship settled down to moderate pitching and slight rolling.

Injuries to crew: Luckily, there were no severe injuries to any of the crew. The OOW escaped with some bruises and pain on both his thighs for a few days.

The damage: Several containers on the port side had broken loose and gone overboard. Several containers on deck were damaged. This ship was lucky – the damage/loss could have been much more.

What kind of ships experience parametric roll?

Ships with a wide beam, streamlined underwater hulls at the bow and large bow flares are prone to parametric rolling. Post-Panamax container ships fit this description. They have wide beams, small water plane areas below the waterline at the forward end so as to minimise water resistance and a large flare in order to carry more containers on deck. Summing up the foregoing, the area of the water plane forward increases drastically and suddenly as draft forward increases. Other ship-types such as tankers, bulkers, etc that have bluff underwater hull forms and small flares do not experience parametric rolling.

Causes of parametric roll

When the bow is down during moderate pitching, and the ship has rolled slightly to one side (say to starboard), the sudden immersion of the large flare causes the restoring buoyancy force to push the bow upwards and to the other side of roll (portside). The opposite happens during the next pitch of the bow downwards. Within a few cycles, the angle of roll would suddenly and become very large without any warning. The maximum angle of roll would occur at the maximum dip of the bow during pitching. To sum up, parametric rolling is the result of synchronism between the pitch, roll and wave periods.

Circumstances when parametric roll may occur

1. It occurs only when the pitching is heavy enough for the flared bow to submerge when the ship pitches down by head.

2. It occurs when the waves are from nearly ahead or astern – when the pitch angle is greatest for that wave condition.

3. It requires a group of waves above a critical height for it to be initiated and sustained. The critical height depends on size and shape of the hull. For Post Panamax container ships, 6 m may suffice.

4. It occurs when the natural roll period is equal to, or twice, the period of pitch. Mathematically, when

$$\mathbf{P_R = P_E \quad or \quad P_R = 2P_E}$$

where P_R is the natural period of roll and P_E is the period of encounter, both expressed in seconds.

(P_R and P_E were explained in previous chapter).

5. Low GM: For ships with low GM, the natural roll period (PR) would be high, say over 20 seconds. Waves that could cause the pitching period around 10 seconds are moderately high and therefore highly likely to initiate parametric rolling in head/stern seas. However, when the waves are from the beam, parametric roll is unlikely.

Action to take when it occurs

Do not panic. Change heading to bring the wind broad on the bow to break the synchronism that has caused parametric rolling. Come back to the original heading gradually, if necessary. Otherwise, if time and space permit, steer a zigzag course spread over few hours, until the weather abates.

Anticipatable but unpredictable

Parametric rolling can be anticipated but not predicted. It is like a tropical revolving storm in that we know what it is, we know under what circumstances it occurs, we know what action to take when we experience it but we do not know exactly when and where it will occur! It can be anticipated but not predicted. The real danger of parametric rolling is the suddenness of its occurrence.

Precautions to take

1. Ensure that all personnel on board the vulnerable ship-types are aware of the phenomenon of parametric rolling.

2. Take all heavy weather precautions stated in the company's SMS (Safety Management Systems) Procedures Manual on board the ship.

3. Modern Container ships have strengthened/ additional lashings to allow for the extra stresses likely to be experienced during parametric rolling.

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27. SQUAT

What is squat?

Squat is the decrease in the under keel clearance (UKC) of a ship when it is proceeding in shallow water. In the case of large, fast ships, squat can be as much as two metres. Squat does not occur when the ship has no movement through the water. When anchored or alongside, in shallow water, strong tide can cause squat as there is movement of the ship through the water, though there is no movement over the ground.

Why does a ship squat?

Consider a ship afloat in a paste like butter. When it is pushed ahead by one length, it leaves behind it a visible hollow whose shape & volume are equal to the underwater part of the hull of the ship. The same tends to happen when the ship moves ahead in water. Since water finds its own level, the hollow is filled up by water from the sides & from below, mainly from below. Since in shallow waters this causes a low-pressure area below the hull, both, the water level & the ship, are pulled downwards, decreasing the UKC. This called the Bernoulli Effect in Physics.

What is shallow water?

A grown man may feel that one metre of depth in a swimming pool is shallow but for a small boy, it would be too deep! Similarly, the depth that may be shallow for a large ship may be deep water for a small one. Hence, we arrive at a figure that would be a function of the draft. Water is considered shallow if the depth to draft ratio is equal to or less than 2 (i.e. if $D/d \leq 2$ or when UKC ≤ draft). If $D / d = 1$, the ship is already touching the seabed in still water!

In other words, shallow water means when the UKC is equal to, or less than, draft.

Factors governing squat

The main factors governing squat are:

1. The ship’s speed
2. The block coefficient

3. The hull form
4. The ratio of draft to depth of water (D/d)
5. The narrowness of the channel or canal.

1. The ship's speed: Squat varies directly as square of the speed. If the speed is doubled, the squat quadruples. If the speed is halved, the squat would become ¼ of its original value. Among all factors that cause squat, speed is the biggest contributor.

The word speed here means speed through the water. Consider a ship that is doing 12 knots in calm water with no current. If it then experienced a head current of 2 knots, its speed over ground would be 10 knots while the speed of water flow past the hull would be 12 knots i.e., speed through the water would be 12 knots. If the 2 knot current was from astern, the speed over ground will be 14 knots but the water flow past the hull would be only 12 knots i.e., the speed through the water.

A ship in shallow water may squat even whilst at anchor or made fast alongside, if it experiences a current. The strength of the current would be the flow of water past the hull i.e., the speed through the water.

2. The block coefficient: Squat varies directly as the block coefficient of the ship. The closer a ship's underwater portion is to a box, the greater the squat.

3. The hull form:

- *When on an even keel draft*, full form ships like large tankers & bulkers would squat by the head whereas streamlined ships like container ships & passenger ships would squat by the stern.

- *Where a ship already has a trim*, the ship would squat by the deeper end regardless of the shape of the hull – full form or streamlined.

4. The draft to depth ratio: Squat varies inversely as the D/d ratio - the smaller the ratio, the greater the squat. If D/d = 1, the ship is already touching the seabed! If the ratio is above 2, there would be negligible squat.

5. The narrowness of the channel or canal: Squat can be considered separately in two situations:

- In shallow 'open waters', such as in coastal areas, wide rivers, lakes, etc, there is no hindrance to water from the sides in filling up the void created by the moving ship and the only restriction is from below.
- In shallow 'narrow channels or canals', the narrowness also restricts the water from the sides in filling up the void created by the moving ship. The ship would then squat much more than in 'open waters'. In such cases, the squat is assumed to be TWICE that in open waters.

What is a narrow channel or canal?

For the purposes of squat, naval architects have opined that a channel or canal may be considered narrow if its width is:

a. 8.25 x B or less for large tankers & bulkers
b. 9.5 x B or less for general purpose ships
c. 11.75 x B or less for container ships,
where B is the extreme breadth of the ship.

To err on the safer side, it may be better for all ship-types to assume that channel or canal widths less than 12B are narrow.

Empirical formulae:

Empirical formulae are those that have no scientific derivation but give reasonably accurate results based on practical observations in the past. The following two simple formulae give values of squat that are slightly higher than the squat that may be actually experienced.

In shallow 'open waters'

$$\text{Squat in metres} = \frac{C_b \times V^2}{100}$$

where V = speed in knots

In shallow narrow channels or canals

$$\text{Squat in metres} = \frac{\mathbf{2}[C_b \times V^2]}{100}$$

where V = speed in knots

Ready-made calculations of squat

Navigators will be happy to know that modern ships have a ready-made table, prepared by naval architects, on the bridge showing the maximum squat for various drafts & speeds for that particular ship. In such cases, calculation by empirical formulae is not necessary.

Control over squat

From the foregoing formulae, it is evident that, though the navigator has no control over the C_b of the ship, but he has full control over the speed of his ship.

Bearing in mind that:

- Grounding is hazardous,
- Grounding is a very costly incident,
- Grounding raises questions about competency,
- All calculations regarding squat are approximate,
- It is better to err on the safer side,

REDUCE SPEED

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28. UNDER KEEL CLEARANCE (UKC)

What is UKC?

Under Keel Clearance (UKC) is the vertical distance between the lowest part of the ship and the seabed. In other words, UKC is difference between the depth of water and the draft of the ship. Where the ship a trim, the deeper draft is to be considered:

UKC = (D – d) in metres

Where D is the Depth of water and d is the draft at the deeper end of the ship.

If D = d (i.e., if the depth to draft ratio or D / d = 1), then UKC = zero meaning that the ship is touching the seabed. If depth to draft ratio or D / d is 2 or less, the ship would experience shallow water effects like squat.

What is the importance of UKC?

When the ship passes over shallow ground, adequate UKC should be maintained so that the ship would not run aground. As stated in the previous chapter:

- Grounding is hazardous to the ship and the environment,
- Grounding is very costly,
- Grounding raises questions about competency.

Which depth do we use?

The depth of water considered is the charted depth plus the height of tide during the passage. Reduction to the water level has to be made for any known factors that such as seasonal fall in the water level due to strong, prolonged, off-shore winds (if given in the 'Sailing Directions' or publications of the port), height of waves (sea and swell) at that time, etc.

Gross UKC:

This is the UKC considering the depth of water at that time and the salt water draft at the deeper end of the ship. This would be the UKC when the ship is at anchor or alongside a salt water berth with no current / tide.

Net UKC:

This is the reduced UKC obtained after subtracting from the Gross UKC:

- The increase of draft due to change of density of water and
- Increase of draft due to list or roll (this is explained in Chapter 2 of this book.
- The squat of the ship (this is explained in the previous chapter of this book).

The diagram on the next page illustrates Gross UKC and Net UKC and their various constituents.

UKC policy

Management companies, and owners who operate ships, clearly state their UKC policy in their Safety Management System (SMS) manuals. This is to prevent ships from running aground while also maximising the cargo carried. The Master must not breach the UKC prescribed for each situation. If under compulsion to do so, he must seek the advice of his company's managers ashore.

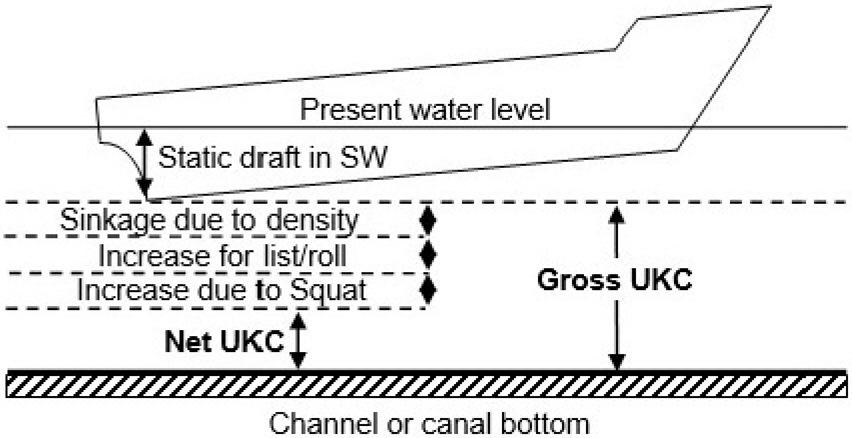

Illustration of UKC policy

An example of the requirements of a company policy for minimum UKC for different situations:

1. Ocean passages - 20% of the deepest draught.
2. Fairways (port approaches) - 15% of the deepest draught.
3. Inside ports - 10% of the deepest draught.
4. Canals - as per local navigation rules.

Err on the safer side

Accuracy of the calculated Net UKC depends on variables such as squat, correctness of charted depth, unevenness of the seabed, silting up since last dredging, seasonal factors, meteorological factors, etc that affect the actual depth of water available under the keel. Hence, it is better to err on the safer side. The main control is on the squat, which depends on the speed of the ship in the shallow water area.

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29. DRAFT SURVEY

What does a Draft Survey do?

A Draft Survey calculates the displacement of the ship at that time. The quantity of cargo on board is then computed by making allowance for all the known weights on board at that time.

Why is accurate cargo quantity important?

Accurate computation of the quantity of cargo on board a ship is of vital importance because of the great financial implications involved. The quantity of cargo affects each interested party in a different way – cost of cargo for traders and insurers, quantum of freight for shippers and ship operators, quantum of duties to be levied by Customs, cost of logistics to and from each end port, cost of transhipment, statistical data for ports, etc.

Cargo accuracy on container ships

In the case of container ships, the total quantity of cargo on board can be easily computed as each and every container is accurately weighed ashore before loading. Each container is considered as a separate unit for freight, insurance, etc. Hence, the ship is not responsible for the nature, quality, quantity and stowage or lashings of cargo inside any container. The packing list of each container and the cargo manifest is all that the ship gets from ashore. The ship is interested in the total weight of blocks of containers for calculation of stresses, draft, trim, etc before hand. Each container has a maximum gross weight which is clearly marked on it. Many containers are less than the maximum permitted gross weight so a container ship, in fully loaded condition, is usually not down to its marks. Deadweight capacity is available for ballast water to adjust the trim and list of the ship and increase the GM as necessary.

Cargo accuracy on tankers

In the case of tankers, the quantity of cargo is computed accurately by ullage observations in properly calibrated shore tanks and verified by ullage observations of ship's tanks making due allowance for relative density of the cargo, its temperature, ship's trim, list, etc.

Cargo accuracy on bulkers

In the case of bulk carriers, some ports have accurate weighing systems for loading bulk cargo but many do not. Even if accurate weighing systems exist at the loading port, the other parties concerned would like an independent assessment to protect their interests. At the arrival port, the consignee, the Customs department, etc would want to verify the correct quantity of cargo received. Sometimes, part cargo is discharged in one port and the balance cargo in another. At each place, the quantity of cargo on board has to be established as accurately as practicable. In all these cases, only a Draft Survey can verify the quantity of cargo loaded, discharged, remaining on board, etc.

Accuracy of a Draft Survey depends on what?

The reliability of a draft survey depends heavily on the accuracy of the drafts observed at the six locations – forward, aft and amidships, port and starboard sides in each case. Inaccuracies due to swell, sea, etc will reflect on the accuracy of the result.

Explanation of calculations used for draft survey

A sample draft survey is shown on the next page. Explanations where necessary are given below:

Explanation:

Lines numbered from 1 to 4 need no explanation.

Lines 5 to 8: The draft marks of a ship are usually NOT at the fwd and aft perpendiculars, for obvious reasons. The shipyard provides tables to convert the draft at the marks to the draft at the perpendiculars.

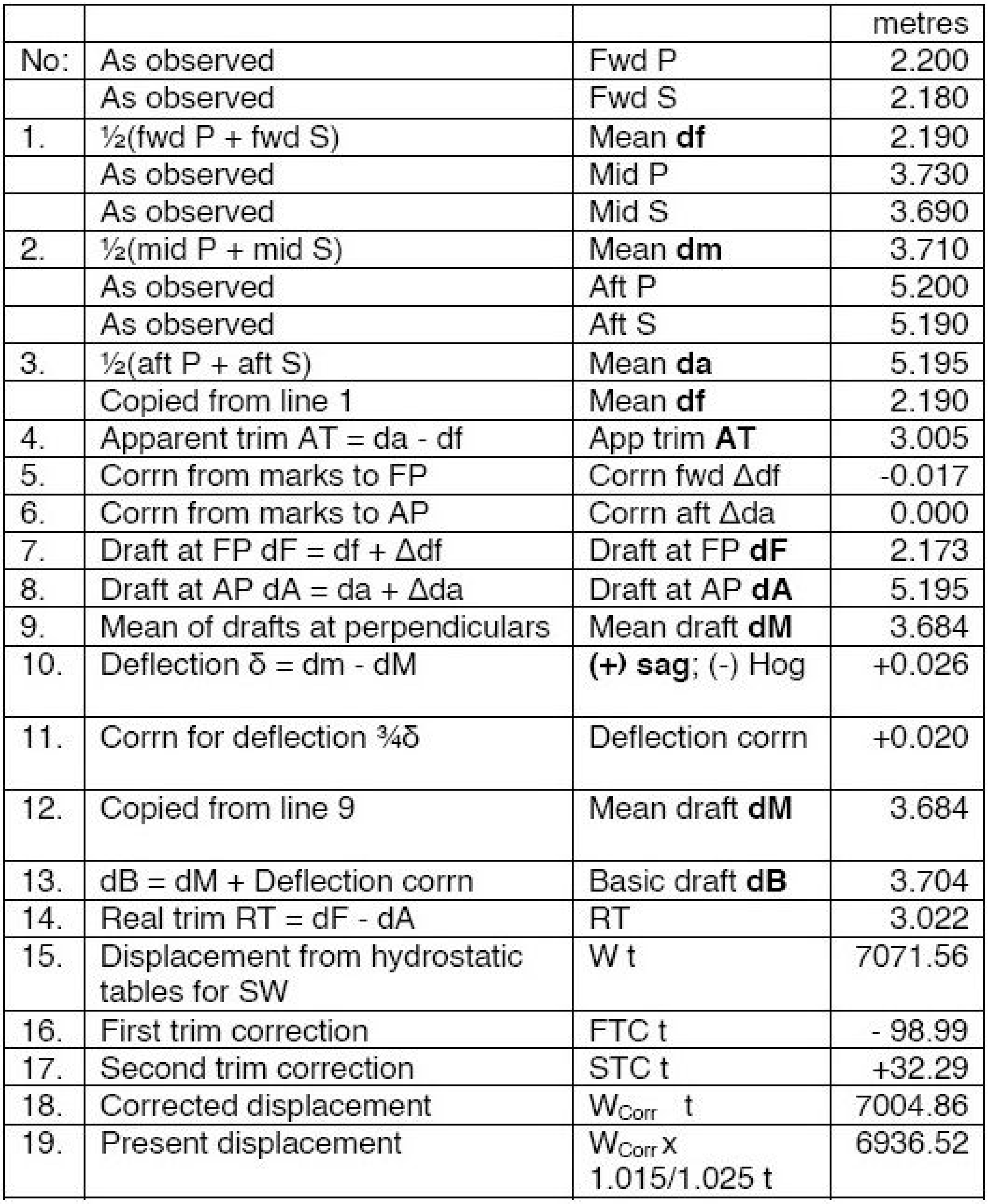
After applying the corrections, the drafts are referred to here as dF and dA.

Line 9: This is the mean of the drafts at the perpendiculars, referred to here as dM.

dM = (dF + dA) / 2.

Line 10: The value of sag or hog is obtained by the formula: **Deflection δ = (dm – dM),** wherein (+) indicates sag and (-) indicates hog. The explanation for this is straightforward. In this case, dM = 3.684 m and dm = 3.710 m. If the ship did not have any hog or sag, the draft amidships, dm, would be equal to dM, the mean of the drafts at the perpendiculars.

M.V. Vijay at Mumbai, 13th Sep 2009. In ballast. DW RD 1.015.



			metres
No:	As observed	Fwd P	2.200
	As observed	Fwd S	2.180
1.	½(fwd P + fwd S)	Mean **df**	2.190
	As observed	Mid P	3.730
	As observed	Mid S	3.690
2.	½(mid P + mid S)	Mean **dm**	3.710
	As observed	Aft P	5.200
	As observed	Aft S	5.190
3.	½(aft P + aft S)	Mean **da**	5.195
	Copied from line 1	Mean **df**	2.190
4.	Apparent trim AT = da - df	App trim **AT**	3.005
5.	Corrn from marks to FP	Corrn fwd Δdf	-0.017
6.	Corrn from marks to AP	Corrn aft Δda	0.000
7.	Draft at FP dF = df + Δdf	Draft at FP **dF**	2.173
8.	Draft at AP dA = da + Δda	Draft at AP **dA**	5.195
9.	Mean of drafts at perpendiculars	Mean draft **dM**	3.684
10.	Deflection δ = dm - dM	**(+) sag**; (-) Hog	+0.026
11.	Corrn for deflection $\frac{3}{4}\delta$	Deflection corrn	+0.020
12.	Copied from line 9	Mean draft **dM**	3.684
13.	dB = dM + Deflection corrn	Basic draft **dB**	3.704
14.	Real trim RT = dF - dA	RT	3.022
15.	Displacement from hydrostatic tables for SW	W t	7071.56
16.	First trim correction	FTC t	- 98.99
17.	Second trim correction	STC t	+32.29
18.	Corrected displacement	W_{Corr} t	7004.86
19.	Present displacement	W_{Corr} x 1.015/1.025 t	6936.52

Instead of being 3.684 m, if the dm, or actual draft amidships, is less than the dM of 3.684 m, it indicates that the ship's central part has bent upwards indicating hog.

If dm, or actual draft amidships, is more than the dM of 3.684 m, the ship's central part has bent downwards, indicating sag.

The use of the formula stated above is quick and simple. Here, deflection δ = dm – dM = +0.026 m.

Lines 11 to 13: The correction for deflection (sag or hog) is 0.75 of the deflection. It is applied as per sign to dM to get the basic working draft referred to as dB here.

In the calculation shown, dB = dM + 0.75(deflection) = 3.684 + 0.020 = 3.704 m.

Another way to get the same result is as follows:

dB = (dF+dA+6dm) / 8 = [2.173+5.195+6(3.710)] / 8

dB = 3.704 m, which is the same as that by the earlier method.

Line 14: This is the real trim (RT) which is the difference between the draft at the fwd and aft perpendiculars i.e., (dA - dF). Here RT = 5.195 – 2.173 = 3.022 m.

Line 15: This is the displacement of the ship, as if it was in SW, taken from the hydrostatic particulars of the ship (see Appendix 1).

Line 16: The first trim correction (FTC) is obtained by the formula:

FTC in tonnes = RT x HF x TPC x 100/LBP

FTC is the same as the formula derived and fully explained in Chapter 18 'Hydrostatic Draft' of 'Ship Stability at the Operational Level', except that the result has been multiplied by 100TPC to make the answer come in tonnes instead of metres. The rules for obtaining the sign of the correction are also the same:

Note: F is the Centre of Flotation and H is amidships.

If F is aft of H, and RT is by stern, then FTC is plus.

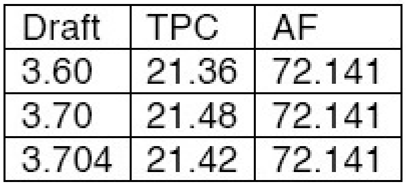
If F is aft of H, and RT is by head, then FTC is minus.

If F is fwd of H, and RT is by stern, then FTC is minus.

If F is fwd of H, and RT is by head, then FTC is plus.

Calculation of FTC is as follows:

From the hydrostatic particulars of m.v. Vijay:



Draft	TPC	AF
3.60	21.36	72.141
3.70	21.48	72.141
3.704	21.42	72.141

AH = LBP/2 = (140)/2 = 70 m. AF is 72.141 m.

Hence F = 2.141 m fwd of H.

F is fwd of H, and RT is by stern, hence FTC is minus.

FTC in tonnes = **-** (RT x HF x TPC x 100/LBP)

= **-** (3.022 x 2.141 x 21.42 x 100/140) = **-**98.99 tonnes.

Line 17: The Second Trim Correction (STC) is ALWAYS POSITIVE and is obtained by the formula:

STC in tonnes = RT x RT(MCTC2 - MCTC1) x 50/LBP

MCTC 2 = MCTC at draft + 0.5 metre

MCTC 1 = MCTC at draft - 0.5 metre

Basic draft dB = 3.704 m

Draft	MCTC
4.204	159.9
3.204	150.0
Difference	9.9

STC = 3.022 x 3.022 x 9.9 x 50/140 = 32.29 t

Line 18: This is the sum of lines 15, 16 and 17.

Line 19: W_{sw} (DW density/SW density) = Present W

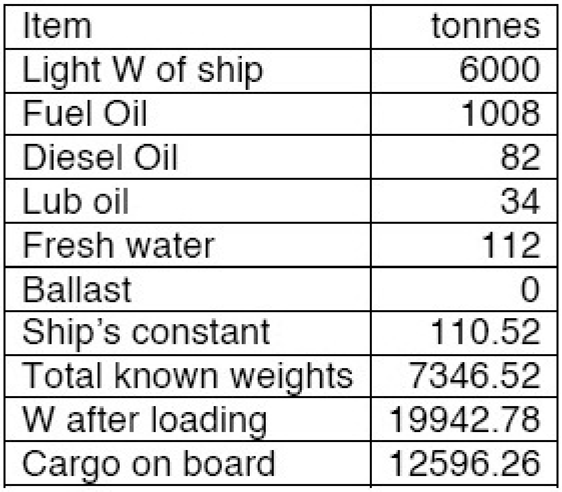
Continuation of the draft survey

After calculating the present displacement in the ballast condition, known weights of items on board are allowed for as follows and the ship's constant is obtained.

Item	tonnes
Light W of ship	6000
Fuel Oil	108
Diesel Oil	22
Lub oil	6
Fresh water	50
Ballast	640
Total known weights	6826.00
Present W	6936.52
Ship's constant	110.52

The constant of the ship consists of unknown weights on board. It includes stores, spares, lashing gear, condemned items on board (empty paint drums, old wires and ropes, broken parts, etc), and also accumulated rust on various parts of the ship, etc.

After loading, another draft survey is carried out and the constant is allowed for as follows:



Item	tonnes
Light W of ship	6000
Fuel Oil	1008
Diesel Oil	82
Lub oil	34
Fresh water	112
Ballast	0
Ship's constant	110.52
Total known weights	7346.52
W after loading	19942.78
Cargo on board	12596.26

Cautionary note: Draft surveyors are trained in their job to carry out draft surveys in a particular manner. They follow practices accepted the world over.

They may not be Master Mariners or, for that matter, not mariners at all. Hence their knowledge of naval architecture, especially ship stability, may not be as high as that of Masters and Mates. As ship's officers, we must adapt our ways to their system and not try to convince them to change. Any dispute in the methodology would only delay the ship.

In view of the above, here are a few differences between pure stability and draft survey practice.

Pure stability versus draft survey practice

1. In purely theoretical stability calculations, the ship is assumed to be a straight, rigid beam from end to end. In actual practice, the ship is rarely so. Bulk carriers generally sag. On a Capesize Bulker, 6 cm is common and up to 10 cm is not unusual.
2. In purely theoretical stability calculations, since the ship is considered rigid with no sag or hog, the mean of the drafts forward and

aft is accepted as the draft amidships. During draft survey, the draft amidships is measured separately.

3. In purely theoretical stability calculations, the draft marks are assumed to be at the respective perpendiculars. In modern ships, only the amidships drafts are at their correct locations. Since the after perpendicular is the axis of the rudderstock, and the aft draft marks cannot be painted on this axis, the marks are located a few metres forward of the after perpendicular. Most ships have a raked bow whereby the draft marks forward cannot be painted at the forward perpendicular and are hence situated a few metres abaft the forward perpendicular. The values of such offset from the forward and after perpendiculars are given in the ship's particulars. The correction to be applied to the draft at the marks to convert it to the draft at the perpendicular is usually given in the form of a table wherein the observed draft and the trim are the variables.

4. In purely theoretical stability calculations, allowance for the density of the water in which the ship is floating (abbreviated to DW as derived from 'Dock Water' to distinguish it from SW for Salt Water) is made to the mean of the drafts forward and aft. In a Draft Survey, this is done at the end and in tonnes.

5. In purely theoretical stability calculations, where the COF is not amidships, a correction is made in centimetres to the mean of the drafts forward and aft to obtain Hydrostatic draft (the draft at the COF or the draft at zero trim). In a Draft Survey, this is done at the end and in tonnes.

6. In a Draft Survey, a correction is made, at the end, to the displacement obtained in tonnes for change of water plane area, and hence the TPC, due to list, if any. This is generally insignificant as the ship is usually upright, or very nearly so, during a Draft Survey. However, where the list is significant, the correction may be a few tonnes, often in single digits.

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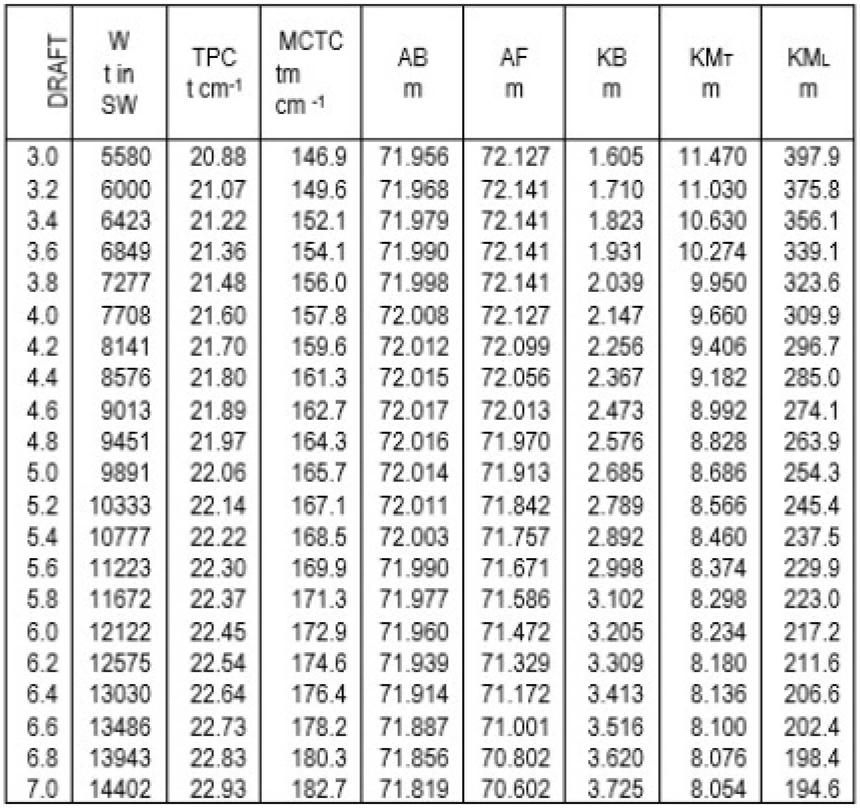
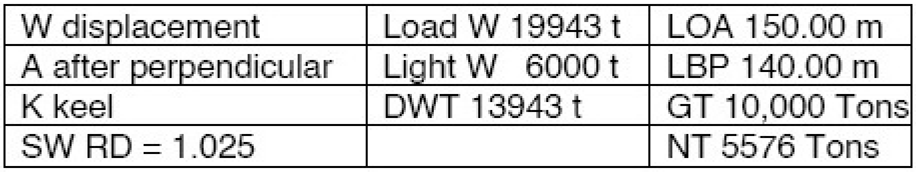
Appendix I

HYDROSTATIC TABLE OF M.V. 'VIJAY'



DRAFT	W t in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM$_T$ m	KM$_L$ m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

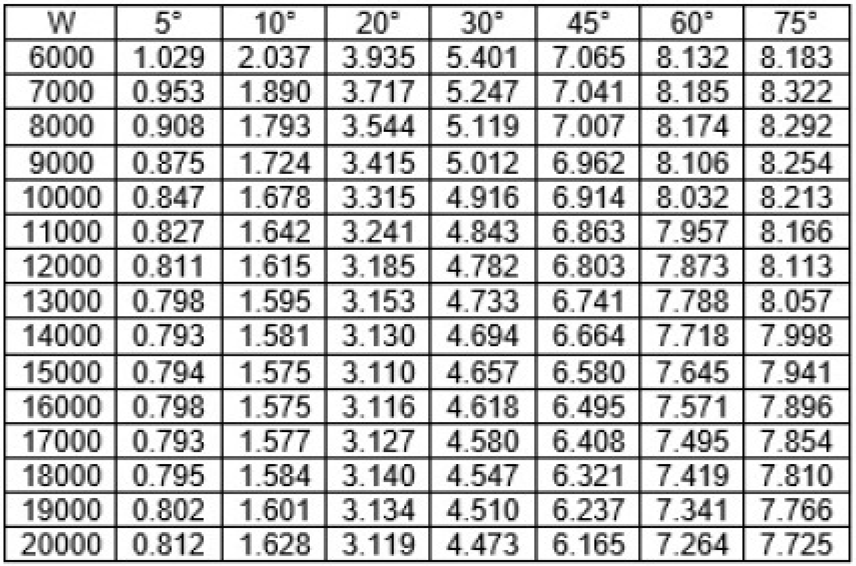


W displacement	Load W 19943 t	LOA 150.00 m
A after perpendicular	Light W 6000 t	LBP 140.00 m
K keel	DWT 13943 t	GT 10,000 Tons
SW RD = 1.025		NT 5576 Tons

Appendix II

M.V. VIJAY

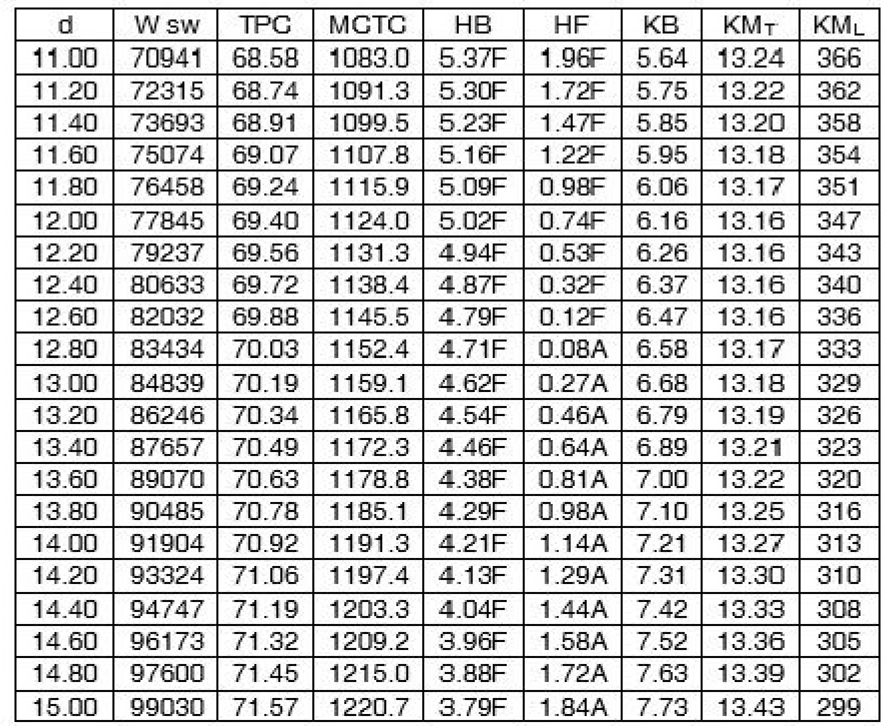
KN – Table



W	5°	10°	20°	30°	45°	60°	75°
6000	1.029	2.037	3.935	5.401	7.065	8.132	8.183
7000	0.953	1.890	3.717	5.247	7.041	8.185	8.322
8000	0.908	1.793	3.544	5.119	7.007	8.174	8.292
9000	0.875	1.724	3.415	5.012	6.962	8.106	8.254
10000	0.847	1.678	3.315	4.916	6.914	8.032	8.213
11000	0.827	1.642	3.241	4.843	6.863	7.957	8.166
12000	0.811	1.615	3.185	4.782	6.803	7.873	8.113
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896
17000	0.793	1.577	3.127	4.580	6.408	7.495	7.854
18000	0.795	1.584	3.140	4.547	6.321	7.419	7.810
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

Appendix III

Hydrostatic particulars of m.v. VICTORY



d	W_{sw}	TPC	MCTC	HB	HF	KB	KM_T	KM_L
11.00	70941	68.58	1083.0	5.37F	1.96F	5.64	13.24	366
11.20	72315	68.74	1091.3	5.30F	1.72F	5.75	13.22	362
11.40	73693	68.91	1099.5	5.23F	1.47F	5.85	13.20	358
11.60	75074	69.07	1107.8	5.16F	1.22F	5.95	13.18	354
11.80	76458	69.24	1115.9	5.09F	0.98F	6.06	13.17	351
12.00	77845	69.40	1124.0	5.02F	0.74F	6.16	13.16	347
12.20	79237	69.56	1131.3	4.94F	0.53F	6.26	13.16	343
12.40	80633	69.72	1138.4	4.87F	0.32F	6.37	13.16	340
12.60	82032	69.88	1145.5	4.79F	0.12F	6.47	13.16	336
12.80	83434	70.03	1152.4	4.71F	0.08A	6.58	13.17	333
13.00	84839	70.19	1159.1	4.62F	0.27A	6.68	13.18	329
13.20	86246	70.34	1165.8	4.54F	0.46A	6.79	13.19	326
13.40	87657	70.49	1172.3	4.46F	0.64A	6.89	13.21	323
13.60	89070	70.63	1178.8	4.38F	0.81A	7.00	13.22	320
13.80	90485	70.78	1185.1	4.29F	0.98A	7.10	13.25	316
14.00	91904	70.92	1191.3	4.21F	1.14A	7.21	13.27	313
14.20	93324	71.06	1197.4	4.13F	1.29A	7.31	13.30	310
14.40	94747	71.19	1203.3	4.04F	1.44A	7.42	13.33	308
14.60	96173	71.32	1209.2	3.96F	1.58A	7.52	13.36	305
14.80	97600	71.45	1215.0	3.88F	1.72A	7.63	13.39	302
15.00	99030	71.57	1220.7	3.79F	1.84A	7.73	13.43	299

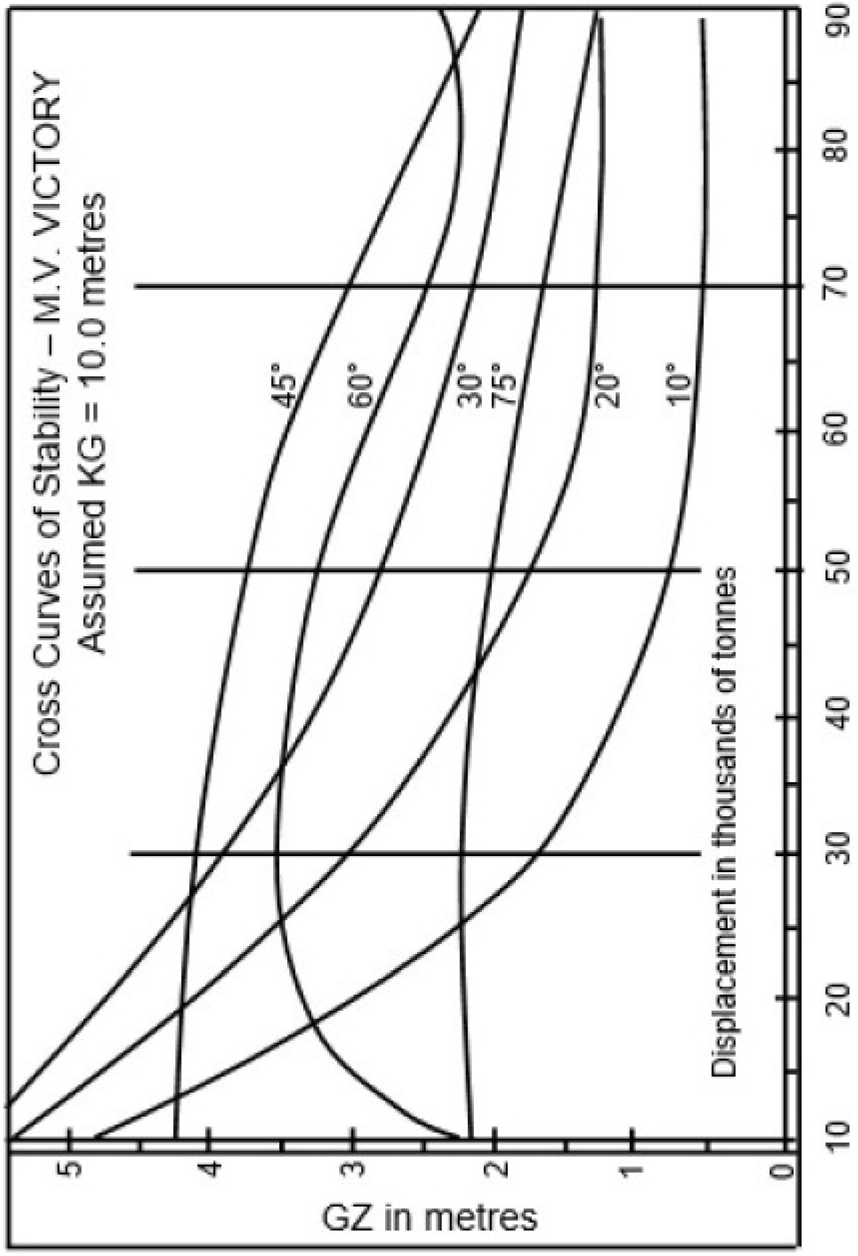
d = draft in metres, K = keel, H = amidships,

LOA 245 m, LBP 236 m, GT 42000 Tons,

NT 28000 Tons, Light W 14000 t, Load W 98000 t, Deadweight 84000 t.

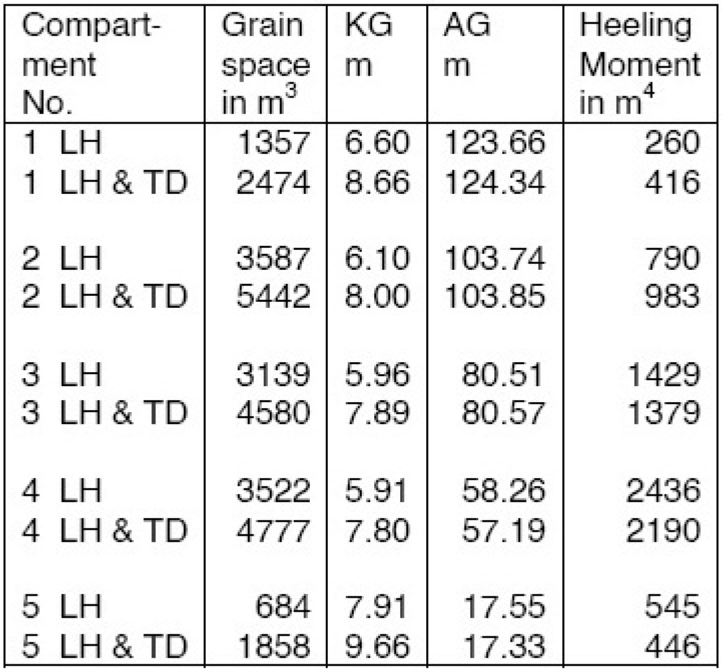
Appendix IV

Cross Curves of m.v. Victory



Appendix V
m. v. VIJAY

Table of transverse volumetric heeling moments due to assumed shift of grain as per chapter VI of SOLAS 1974.



Compartment No.	Grain space in m^3	KG m	AG m	Heeling Moment in m^4
1 LH	1357	6.60	123.66	260
1 LH & TD	2474	8.66	124.34	416
2 LH	3587	6.10	103.74	790
2 LH & TD	5442	8.00	103.85	983
3 LH	3139	5.96	80.51	1429
3 LH & TD	4580	7.89	80.57	1379
4 LH	3522	5.91	58.26	2436
4 LH & TD	4777	7.80	57.19	2190
5 LH	684	7.91	17.55	545
5 LH & TD	1858	9.66	17.33	446

Note 1: This is for 'Filled compartments' as per Chapter VI of SOLAS 1974.

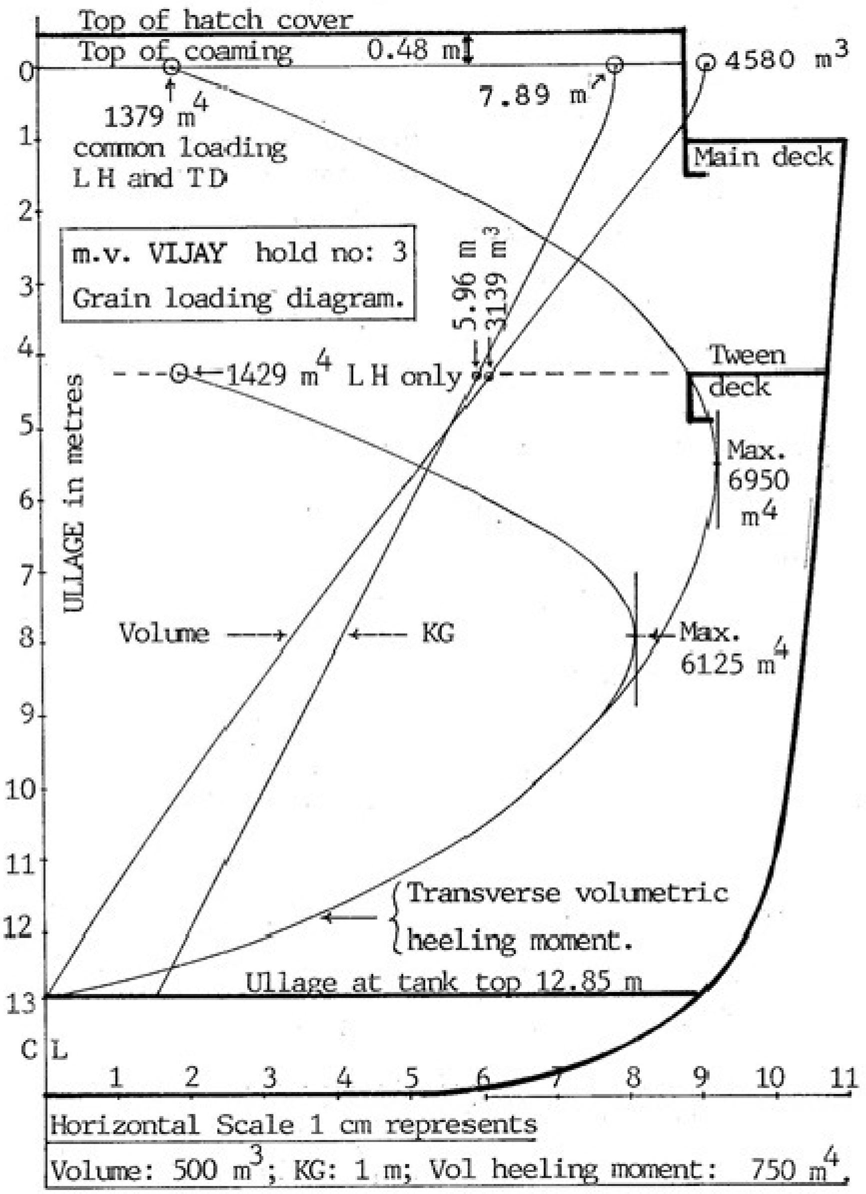
Note 2: The grain space divided by the SF would give the weight of grain.

Note 3: The volumetric heeling moment divided by the SF of grain loaded would give the heeling moment in tonne metres.

Note 4: If a compartment is 'Partly filled', refer to the grain loading diagram of that compartment.

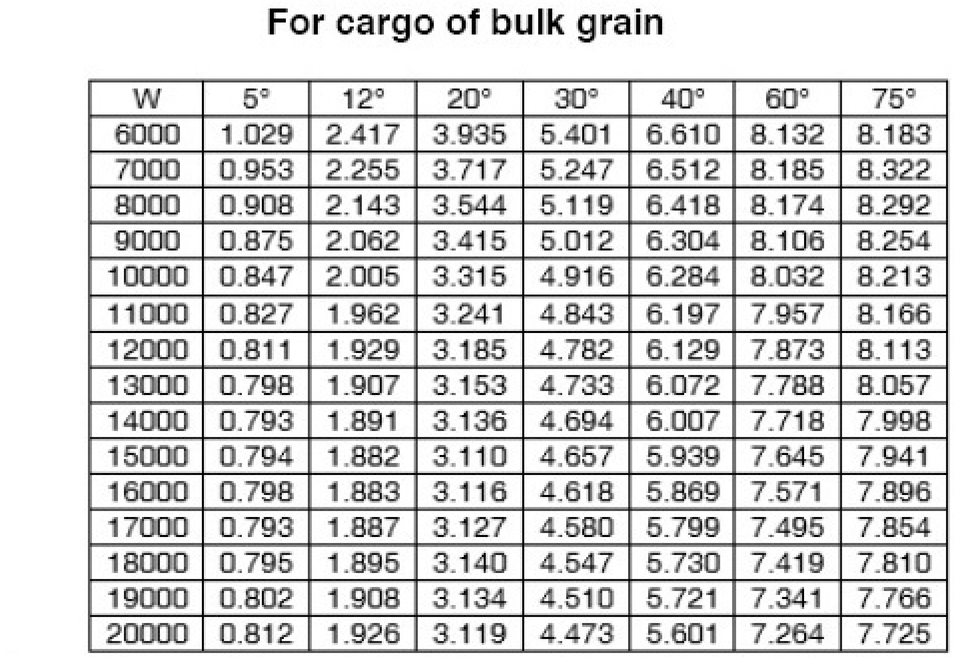
Appendix VI

Appendix VI



Appendix VII

m.v. VIJAY – KN Table



For cargo of bulk grain

W	5°	12°	20°	30°	40°	60°	75°
6000	1.029	2.417	3.935	5.401	6.610	8.132	8.183
7000	0.953	2.255	3.717	5.247	6.512	8.185	8.322
8000	0.908	2.143	3.544	5.119	6.418	8.174	8.292
9000	0.875	2.062	3.415	5.012	6.304	8.106	8.254
10000	0.847	2.005	3.315	4.916	6.284	8.032	8.213
11000	0.827	1.962	3.241	4.843	6.197	7.957	8.166
12000	0.811	1.929	3.185	4.782	6.129	7.873	8.113
13000	0.798	1.907	3.153	4.733	6.072	7.788	8.057
14000	0.793	1.891	3.136	4.694	6.007	7.718	7.998
15000	0.794	1.882	3.110	4.657	5.939	7.645	7.941
16000	0.798	1.883	3.116	4.618	5.869	7.571	7.896
17000	0.793	1.887	3.127	4.580	5.799	7.495	7.854
18000	0.795	1.895	3.140	4.547	5.730	7.419	7.810
19000	0.802	1.908	3.134	4.510	5.721	7.341	7.766
20000	0.812	1.926	3.119	4.473	5.601	7.264	7.725

Note: KN values are necessarily shown at 12° and 40° heel for grain calculations.

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