Chapter 43
Bending and shear stresses

The shear forces and bending moments which act upon a ship's structure cause shear and bending stresses to be generated in the structure. We have seen earlier that the shearing forces and bending moments experienced by a ship are similar to those occurring in a simply supported beam. We shall therefore consider the shear and bending stresses created when an ordinary beam of rectangular section is simply supported.

Bending stresses

The beam in Figure 43.1(a) is rectangular in cross-section, is simply supported at each end and has a weight W suspended from its mid-point.

This distribution will tend to cause the beam to bend and sag as shown in Figure 43.1(b).

Consider first the bending stresses created in the beam. Let ab and cd in Figure 43.1(a) be two parallel sections whose planes are perpendicular to the plane AB. Let their distance apart be dx. When the beam bends the

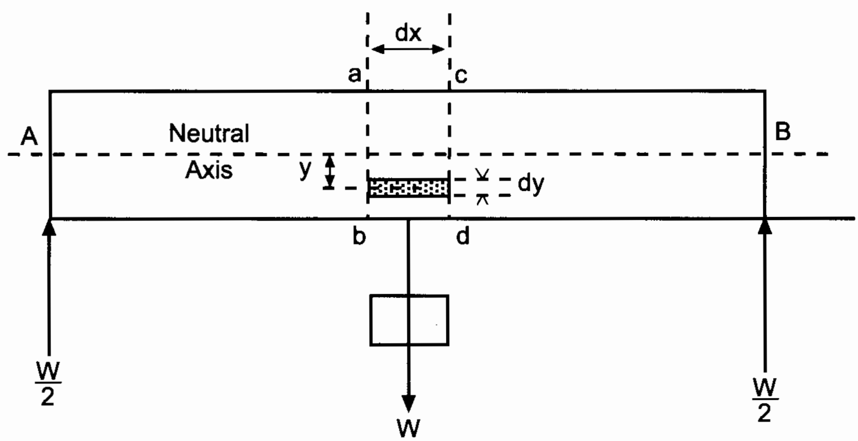


Fig. 43.1 (a)

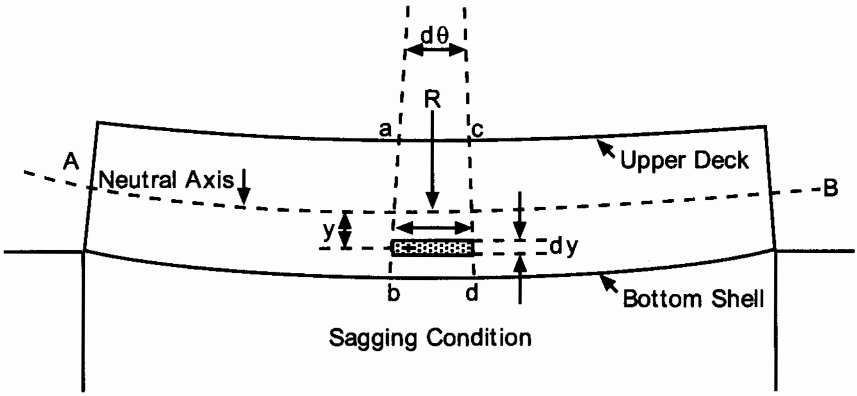


Fig. 43.1 (b)

planes of these two sections will remain perpendicular to the plane AB but will now be inclined at an angle dθ to each other. The parts of the beam above the layer AB are in compression and those below the layer AB are in tension. Thus the layer AB is neither in compression or tension and this layer is called the Neutral Axis.

Let the radius of curvature of the neutral axis layer be R.

Consider a layer of thickness dy which is situated at distance y from the plane of the Neutral Axis.

$$\text{Original length of layer} = dx$$

$$\text{After bending, this length} = R \cdot d\theta \text{ no stress or strain here}$$

$$\text{Length of layer after bending} = (R + y)\,d\theta \text{ at a distance y below } A - B$$

But

$$\text{Strain} = \frac{\text{Elongation}}{\text{Orig. length}}$$

$$= \frac{(R + y)\,d\theta - Rd \cdot \theta}{Rd \cdot \theta}$$

$$\text{Strain} = y/R$$

This equation indicates that strain varies directly as the distance from the neutral axis. Also, if the modules of elasticity is constant throughout the beam, then:

$$E = \frac{\text{Stress}}{\text{Strain}}$$

or

$$\text{Stress} = E \times \text{Strain}$$

and

$$\text{Stress} = E \times \frac{y}{R}$$

So

$$f = E \times \frac{y}{R}$$

This equation indicates that stress is also directly proportional to distance from the neutral axis, stress being zero at the neutral axis and attaining its maximum value at top and bottom of the beam. The fibres at the top of the beam will be at maximum compressive stress whilst those at the bottom will be at maximum tensile stress. Since the beam does not move laterally, the sum of the tensile stresses must equal the sum of the compressive stresses. This is illustrated in Figure 43.2.

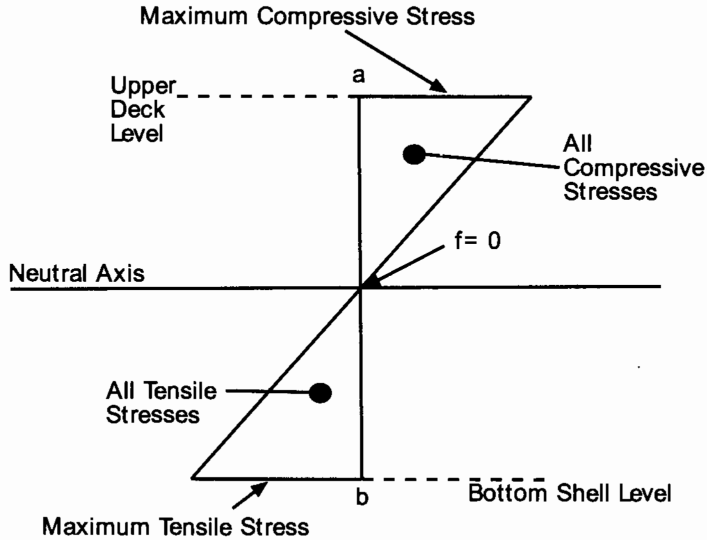


Fig. 43.2. Bending Stress diagram for a Beam in a sagging condition of loading.

Figure 43.3 shows the cross-section of the beam at ab. NA is a section of the neutral surface at ab and is called the neutral axis at ab. At NA there is no compressive or tensile stress, so $f = 0$.

In Figure 43.3 bdy is an element of area at distance y from the Neutral Axis. Let bdy be equal to dA. The force on dA is equal to the product of the stress and the area. i.e.

$$\text{Force on dA} = \frac{Ey}{R} \times dA.$$

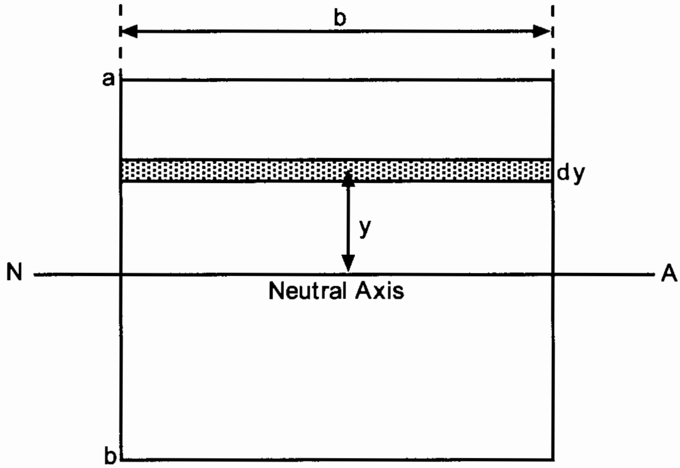


Fig. 43.3

The total or resultant force on the section is equal to the sum of the forces on the section. i.e.

$$\text{Total or Resultant force on the section} = \Sigma \frac{Ey}{R} dA$$

But the total or resultant force on the section is zero.

$$\therefore \Sigma \frac{Ey}{R} dA = 0$$

Since E and R are constant, then

$$\Sigma\, ydA = 0$$

But ΣydA is the first moment of the area about the neutral axis and if this is to be equal to zero then the neutral axis must pass through the centre of gravity of the section. In the case being considered, the neutral axis is at half-depth of the beam.

The sum of the moments of the internal stresses on the section is equal to M, the external bending moment at the section.

At a distance y from the neutral axis, the moment (m) of the stress acting on dA is given by the formula:

$$m = \frac{Ey}{R} \times y \times dA$$

Also,

$$M = \Sigma \frac{Ey}{R} \times y \times dA$$

$$= \Sigma \frac{E}{R} y^2 dA$$

Since E and R are constant, then:

$$M = \frac{E}{R} \Sigma y^2 dA$$

But $\Sigma y^2 dA$ is the second moment of the area of the section about the neutral axis. Let $\Sigma y^2 dA$ be equal to I.

$$\therefore M = \frac{E}{R} \times I$$

Now if f is the stress at a distance of y from the neutral axis, then:

$$f = \frac{Ey}{R}$$

or

$$\frac{E}{R} = \frac{f}{y}$$

But

$$\frac{M}{I} = \frac{E}{R}$$

$$\therefore \frac{f}{y} = \frac{M}{I}$$

and

$$f = \frac{M}{I/y}$$

The expression I/y is called the section modulus, designated Z, and attains its minimum value when y has its maximum value. The section modulus is the strength criterion for the beam so far as bending is concerned.

Example

A steel beam is 40 cm deep and 5 cm wide. The bending moment at the middle of its length is 15 tonnes metre. Find the maximum stress on the steel.

$$I = \frac{lb^3}{12} \qquad f = \frac{M}{I} \times y$$

$$= \frac{5 \times 40^3}{12} \qquad y = \frac{d}{2} = \frac{40}{2} = 20 \text{ cm}$$

$$I = \frac{80\,000}{3} \text{ cm}^4$$

So

$$f = \frac{1500 \times 3 \times 20}{80\,000} \text{ tonnes per sq cm}$$

$$f = 1.125 \text{ tonnes per sq cm}$$

Ans. Maximum Stress = 1.125 tonnes per sq cm or 1125 kg per sq cm

Example
A deck beam is in the form of an H-girder as shown in the accompanying Figure 43.4.

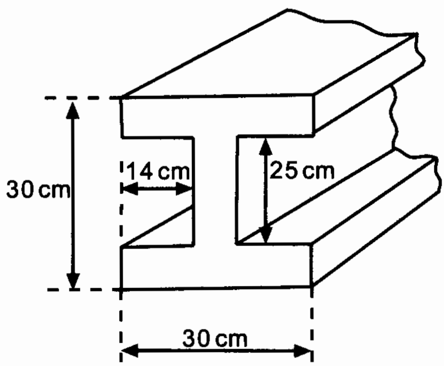


Fig. 43.4

If the bending moment at the middle of its length is 15 tonnes metres, find the maximum stress in the steel.

$$I = \frac{BH^3 - 2bh^3}{12} \qquad f = \frac{M}{I}\cdot y$$

$$I = \frac{30 \times 30^3 - 2.14.25^3}{12} \qquad y = \frac{H}{2} = \frac{30}{2} = 15\text{ cm}$$

$$I = \frac{810\,000 - 437\,500}{12} \qquad f = \frac{1500 \times 12}{372\,500} \times 15$$

$$I = \frac{372\,500}{12}\text{ cm}^4 \qquad f = 0.725\text{ tonnes per sq cm}$$

Ans. Max. Stress = 0.725 tonnes per sq cm or 725 kg per sq cm

The above theory can now be used to find the section modulus of the ship. The external bending moment can be calculated, as can the stress at the transverse sections under the conditions of maximum bending moment. The neutral axis passes through the centre of gravity of the section and, because of this, its position can be found. The moments of inertia of all of the continuous longitudinal material about this axis can be found. Then the section modulus is equal to I/y.

Shearing Stresses

It has already been shown that a shearing stress across one plane within a material produces another shearing stress of equal intensity on a plane at right angles. (See **Complementary Stresses** in Chapter 40.)

The mean shearing stress in any section of a structure can be obtained by dividing the shearing force at that section by the cross-sectional area of the section. i.e.

$$\text{Mean shearing stress} = \frac{F}{A}$$

where

$$F = \text{Vertical shearing force and}$$

$$A = \text{Area of cross-section}$$

A more accurate estimation of shear stress distribution can be obtained from a consideration of the bending of beams.

Consider the short length of beam dx in Figure 43.5(a) which lies between the vertical planes ab and cd. Let dy be a layer on this short length of beam which is situated at distance y from the neutral plane.

From the formula for bending moments deduced earlier, the longitudinal stress 'f' on a small area b·dy of section ab can be found from the formula:

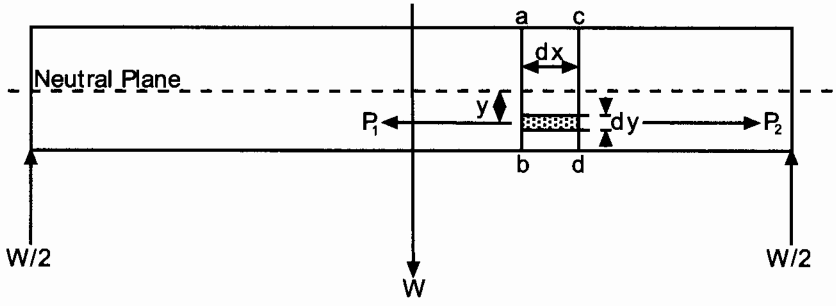
$$f = \frac{M_1}{I_1} \cdot y$$

where

M_1 = the bending moment at this section,

I_1 = second moment of the section abut the neutral axis, and

y = the distance of the area from the neutral axis.



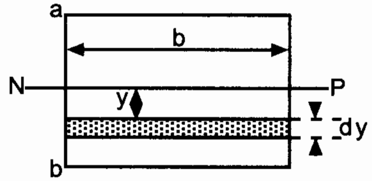


Fig. 43.5

Let

$$b \cdot dy = dA$$

$$\text{The force acting on } dA = f \cdot dA$$

$$= \frac{M_1}{I_1} y \cdot dA$$

Let A_1 be the cross-sectional area at ab, then the total force (P_1) acting on the area A_1 is given by:

$$P_1 = \frac{M_1}{I_1} \times \Sigma y \cdot dA$$

$$= \frac{M_1}{I_1} \times y \times A_1$$

Let P_2 be the force acting on the same area (A_2) at section cd.

Then

$$P_2 = \frac{M_2}{I_2} \times y \times A_2$$

where

$$M_2 = \text{Bending moment at this section,}$$

and

$$I_2 = \text{Second moment of the section about the neutral axis.}$$

Since dx is small then $A_1 = A_2$ and $I_1 = I_2$. Therefore let $A =$ area and $I =$ second moment of the section about the neutral axis.

$$\text{Shearing force at } A = P_1 - P_2$$

$$= \frac{M_1 - M_2}{I} \times y \times A$$

$$= \frac{M_1 - M_2}{dx} \times \frac{dx \times y \times A}{I}$$

But $\frac{M_1 - M_2}{dx}$ is equal to the vertical shearing force at this section of the beam.

$$\therefore P_1 - P_2 = F \times \frac{y \times A \times dx}{I}$$

Now let 'q' be the shearing stress per unit area at A and let 't' be the thickness of the beam, then the shearing force is equal to $q \cdot t \cdot dx$.

$$\therefore q \cdot t \cdot dx = \frac{F \times y \times A \times dx}{I}$$

or

$$q = \frac{F \cdot A \cdot y}{I \cdot t}$$

Example

A solid beam of rectangular section has depth 'd' and thickness 't' and at a given section in its length is under a vertical force 'F'. Find where the maximum shearing stress occurs and also determine its magnitude in terms of 'd', 't' and 'F'.

Since the section is rectangular, the I and y about the neutral axis are given by:

$$I = \frac{td^3}{12}$$

and

$$y = \frac{d}{2} \times \frac{1}{2} = \frac{d}{4}$$

and

$$\text{Area } A = \frac{t \times d}{2}$$

In the case being considered, Ay attains its maximum value at the neutral axis and this is therefore where the maximum shearing stress (q) occurs.

$$q = \frac{F \cdot A \cdot y}{I \cdot t}$$

$$\therefore q_{max} = \frac{F \cdot \frac{td}{2} \cdot \frac{d}{4}}{\frac{td^3}{12} \times t}$$

Ans. $q_{max} = \dfrac{3F}{2td}$

Consider the worked example for the H-girder shown in Fig. 43.6.

When the shear stress distribution for an H-girder is calculated and plotted on a graph it appears similar to that shown in Figure 43.8. It can be seen from this figure that the vertical web of the beam takes the greatest amount of shear.

Example 1. A worked example showing distribution of shear Stress 'q' (with flanges). (See Figs. 43.6 and 43.7.)

Let

$$F = 30 \text{ tonnes.}$$

$$I_{NA} = \tfrac{1}{12}(6 \times 12^3 - 5.5 \times 11^3)$$

$$\therefore \underline{I_{NA} = 254 \text{ cm}^4}$$

At upper edge of top flange and lower edge of lower flange the stress 'q' = zero.

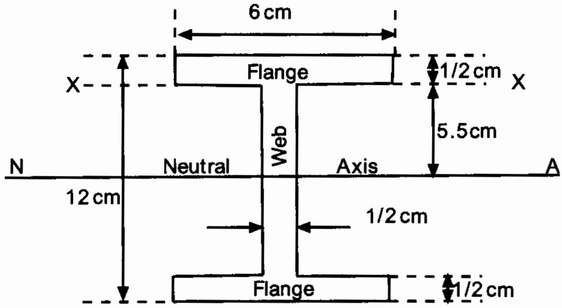


Fig. 43.6

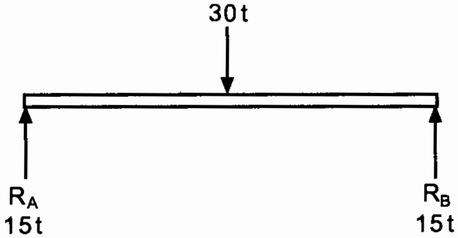


Fig. 43.7

(a) 'q'_a' value:

$$Ay = m = 6 \times \tfrac{1}{2} \times 5.75 = 17.25\ \text{cm}^3$$

$$b = 6\ \text{cm}$$

$$q = \frac{F \times A \times y}{I_{NA} \times b}$$

$$\therefore\ 'q'_a = \frac{30 \times 17.25}{254 \times 6} = \underline{0.34\ \text{t/cm}^2}$$

(b) Just below '$x - x$':

$$Ay = 17.25\ \text{cm}^2$$

$$b = \tfrac{1}{2}\ \text{cm}$$

$$q_b = \frac{30 \times 17.25}{254 \times 0.5} = \underline{4.07\ \text{t/cm}^2}$$

(c) At 3 cm from Neutral Axis

$$m = 17.25 + (2.5 \times 0.5) \times 4.25$$

$$= 22.56\ \text{cm}^3 = Ay$$

$$b = \tfrac{1}{2}\ \text{cm}$$

$$q_c = \frac{30 \times 22.56}{254 \times 0.5} = \underline{5.33\ \text{t/cm}^2}$$

(d) At Neutral Axis

$$m = 17.25 + (5.5 \times \tfrac{1}{2} \times 2.75)$$
$$= 24.81\,\text{cm}^3 = Ay$$

$$b = \tfrac{1}{2}\,\text{cm}$$

$$q_d = \frac{30 \times 24.81}{254 \times 0.5} = \underline{5.86\,\text{t/cm}^2}$$

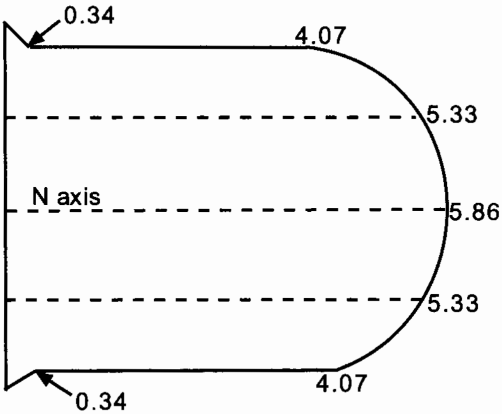


Fig. 43.8

q_{max} occurs at Neutral Axis.

Load carried by the Web is 28.9 t when Force F = 30 t. Web gives resistance to shearing stress. Flanges give resistance to Bending stress.

Example 2. Second worked example showing distribution of shear stress 'q' (with no flanges). (See Figs 43.9 and 43.10.)

Let

$$F = 30 \text{ tonnes}$$

$$q = \frac{F \times A \times y}{I_{NA} \times b}$$

$$I_{NA} = \frac{td^3}{12} = \frac{0.5 \times 12^3}{12} = 72\,\text{cm}^4$$

$$\therefore\ q = \frac{30 \times Ay}{72 \times 0.5} = \underline{0.833 \times A \times y}$$

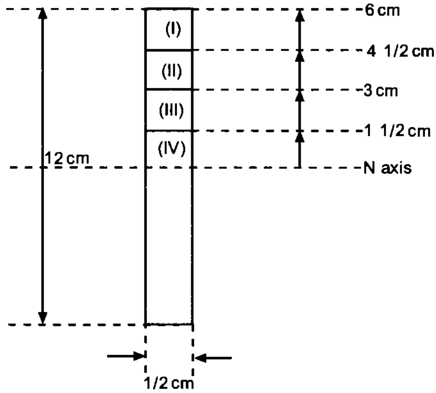


Fig. 43.9

$$q_{(I)} = 0.833 \times 1.5 \times 0.5 \times 5.25 = \underline{3.281\ t/cm^2}$$

$$q_{(I+II)} = 0.833 \times 3.0 \times 0.5 \times 4.5 = \underline{5.625\ t/cm^2}$$

$$q_{(I+II+III)} = 0.833 \times 4.5 \times 0.5 \times 3.75 = \underline{7.031\ t/cm^2}$$

$$q_{(I\ to\ IV)} = 0.833 \times 6.0 \times 0.5 \times 3 = \underline{7.500\ t/cm^2}$$

Check:

$$q_{max} = \frac{3 \times F}{2td} = \frac{3 \times 30}{2 \times 0.5 \times 12} = \underline{7.500\ t/cm^2}$$

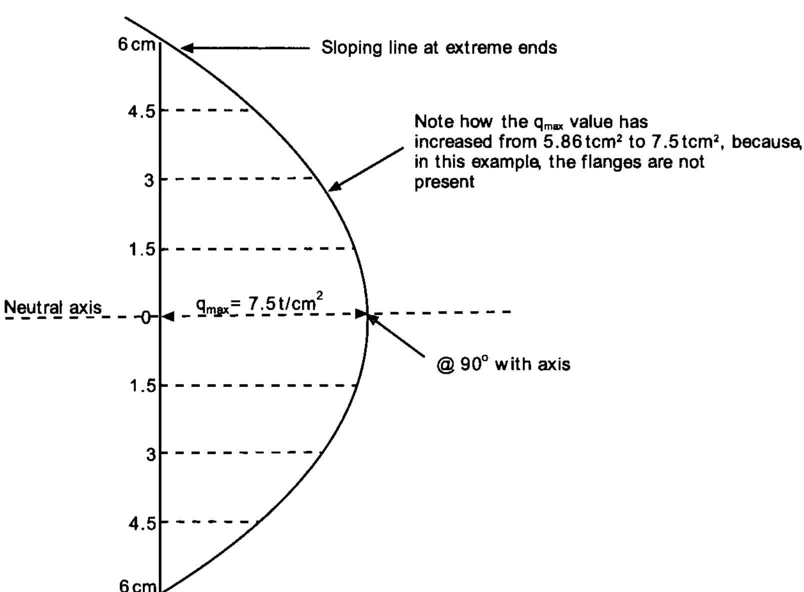


Fig. 43.10

Summary sketches for the two worked examples relating to shear stress

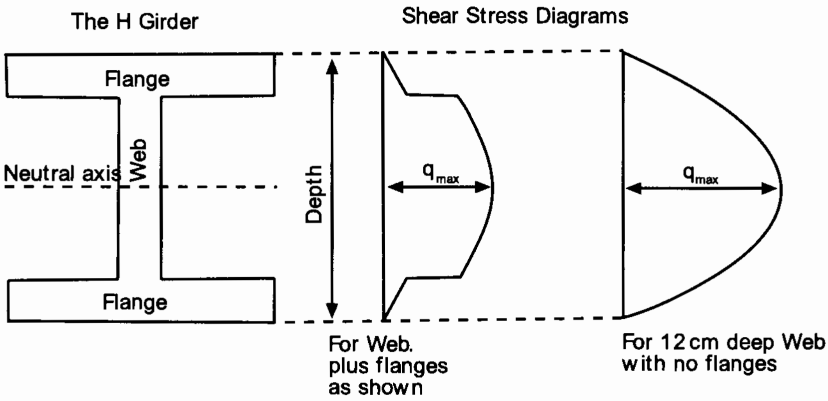


Fig. 43.11

In a loaded ship with a wave crest or trough amidships, the shearing force attains its maximum value in the vicinity of the neutral axis at about a quarter of the ship's length from each end. The minimum shearing force is exerted at the keel and the top deck.

Bending stresses in the hull girder

Example

The effective part of a transverse section of a ship amidships is represented by the steel material shown in Fig. 43.12 (also see note at the end of this chapter).

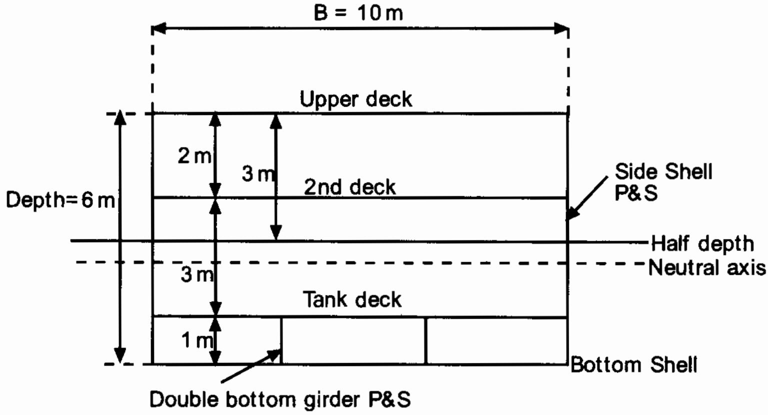


Fig. 43.12

The beam of the ship is 10 m and the depth is 6 m. All plating is 1.5 cm thick. Find the maximum tensile and compressive stresses when the ship is subjected to a sagging moment of 6000 tonnes metres.

Assume initially that Neutral Axis is at $\frac{1}{2}$ depth, i.e. 3 m above base.

Item	*Area (sq m)*	*Lever*	*Moment*	*Lever*	*I*
Upper Deck	$10 \times 0.015 = 0.15$	3	0.45	3	1.35
2nd Deck	$10 \times 0.015 = 0.15$	1	0.15	1	0.15
Tank Top	$10 \times 0.015 = 0.15$	− 2	− 0.30	− 2	0.60
Bottom Shell	$10 \times 0.015 = 0.15$	− 3	− 0.45	− 3	1.35
Sideshell P&S	$2 \times 6 \times 0.015 = 0.18$	0	0	0	0
Double Bottom Girders	$2 \times 1 \times 0.015 = 0.03$	− 2.5	− 0.075	− 2.5	0.1875
	0.81		− 0.225		3.6375

Item	*Own inertia* $= \frac{1}{12} Ah^2$
Upper Deck	$\frac{1}{12} \times 0.15 \times 0.015^2 = 2.8 \times 10^{-6}$ *
2nd Deck	$\frac{1}{12} \times 0.15 \times 0.015^2 = 2.8 \times 10^{-6}$ *
Tank Top	$\frac{1}{12} \times 0.15 \times 0.015^2 = 2.8 \times 10^{-6}$ *
Bottom Shell	$\frac{1}{12} \times 0.15 \times 0.015^2 = 2.8 \times 10^{-6}$ *
Sideshell P&S	$\frac{1}{12} \times 0.18 \times 36 = 0.54$
Double Bottom Girders	$\frac{1}{12} \times 0.03 \times 1 = 2500 \times 10^{-6}$
	0.5425

*It can be seen from this table that the second moment of area of *horizontal* members in the structure such as decks, tank tops and outer bottom, about their own neutral axes are small and in practice these values are ignored in the calculation.

$$\text{Depth of Neutral Axis below half depth} = \frac{-0.225}{0.81}$$

$$= -0.28\,\text{m}$$

$$\text{Total second moment about half depth} = 3.6375 + 0.5425$$

$$= 4.18\,\text{m}^4$$

$$\text{Total second moment about neutral axis} = 4.18 - 0.81 \times 0.28^2$$

$$I_{NA} = 4.18 - 0.06$$

$$= 4.12\,\text{m}^4$$

The maximum compressive bending stress is at the Upper deck level.

$$\frac{f}{y} = \frac{M}{I}$$

$$\therefore f = \frac{6000}{4.12} \times 3.28$$

$$= 4777 \text{ tonnes per sq m}$$

The maximum tensile bending stress is at the bottom shell.

$$f = \frac{6000}{4.12} \times 2.72$$

$$= 3961 \text{ tonnes per sq m}$$

Ans. Maximum tensile bending stress = 3961 tonnes per sq m.
Maximum compressive bending stress = 4777 tonnes per sq m

Summary

The steel material shown in Fig. 43.12 is steel that is *continuous* in a longitudinal direction. Intercostal structures are not considered because they contribute very little resistance to longitudinal bending of the ship.

The calculation and table on page 369 is known as the 'Equivalent Girder Calculation'. It is the I_{NA} that helps resist hogging and sagging motions of a ship. In doing so, I_{NA} helps reduce the tensile and compressive bending stresses.

Lloyds suggest maximum value for these bending stresses in conjunction with a factor of safety of 4. If mild steel structure, f_{max} is about 110 MN/m^2 or about 11 000 tonnes/sq. m for medium-sized ships. If high tensile steel is used, f_{max} is about 150 MN/m^2 or about 15 000 tonnes/sq. m for medium-sized ships.

Take medium-sized ships as being 100 m to 150 m LBP. If there is any danger of these bending stresses being too high in value for a ship in service, a change in the loading arrangement could help make this loaded condition safer.

EXERCISE 43

1 The hull of a box-shaped vessel is 50 m long and has a mass of 600 tonnes. The mass of the hull is uniformly distributed over its length. Machinery of 200 tonnes mass extends uniformly over the quarter length amidships. Two holds extending over the fore and aft quarter length each have 140 tonnes of cargo stowed uniformly over their lengths. Draw the curves of shearing force and bending moments for this condition and state their maximum values.

2 A uniform box-shaped barge, 40 m × 12 m beam, is divided into four cargo compartments each 10 m long. The barge is loaded with 600 tonnes of iron ore, level stowed, as follows:

No. 1 hold – 135 tonnes, No. 2 hold – 165 tonnes,
No. 3 hold – 165 tonnes, No. 4 hold – 135 tonnes

The loaded barge floats in fresh water on an even keel at a draft of 1.75 m. Construct the curves of shearing force and bending moment for this condition and also find the position and value of the maximum bending moment for the still water condition.

3 A box-shaped vessel, 100 m long, floats on an even keel displacing 2000 tonnes. The mass of the vessel alone is 1000 tonnes evenly distributed and she is loaded at each end for a length of 25 m with 500 tonnes of cargo, also evenly distributed. Sketch the curve of loads, shearing force and bending moments. Also state the maximum shearing force and bending moment and state where these occur.

4 Describe in detail Murray's Method for ascertaining the longitudinal bending moments in a ship when she is supported on a standard wave with: (a) the crest amidships, and (b) the trough amidships. Include in your answer details of what is meant by a 'Standard Wave'.

5 A supertanker is 300 m LOA. Second moment of area (I_{NA}) is 752 m^4. Neutral axis above the keel is 9.30 m and 9.70 m below the upper deck. Using the information in the table below, proceed to draw the Shear Force and Bending Moment curves for this ship. From these two Strength curves determine:

(a) Maximum Shear Force in MN.
(b) Maximum Bending Moment in MNm.
(c) Position along the ship's length at which this maximum BM occurs.
(d) Bending stress f_{max} in MN/m^2 at the upper deck and at the keel.

Station	Stern	1	2	3	4	5
SF(MN)	0	26.25	73.77	115.14	114.84	21.12
BM(MNm)	0	390	1887	4717	8164	10199
		6	7	8	9	Bow
SF(MN)	−78.00	−128.74	−97.44	−45.78	0	
BM(MNm)	9342	6238	2842	690	0	

Chapter 44
Simplified stability information

DEPARTMENT OF TRADE MERCHANT SHIPPING NOTICE NO. 1122

SIMPLIFIED STABILITY INFORMATION
Notice to Shipowners, Masters and Shipbuilders

1 It has become evident that the masters' task of ensuring that his ship complies with the minimum statutory standards of stability is in many instances not being adequately carried out. A feature of this is that undue traditional reliance is being placed on the value of GM alone, while other important criteria which govern the righting lever GZ curve are not being assessed as they should be. For this reason the Department, appreciating that the process of deriving and evaluating GZ curves is often difficult and time-consuming, strongly recommends that in future simplified stability information be incorporated into ships' stability booklets. In this way masters can more readily assure themselves that safe standards of stability are met.

2. Following the loss of the *Lairdsfield*, referred to in Notice M.627, the Court of Inquiry recommended that simplified stability information be provided. This simplified presentation of stability information has been adopted in a large number of small ships and is considered suitable for wider application in order to overcome the difficulties referred to in paragraph 1.

3. Simplified stability information eliminates the need to use cross curves of stability and develop righting lever GZ curves for varying loading conditions by enabling a ship's stability to be quickly assessed, to show whether or not all statutory criteria are complied with, by means of a single diagram or table. Considerable experience has now been gained and three methods of presentation are in common use. These are:

(a) The Maximum Deadweight Moment Diagram or Table,
(b) The Minimum Permissible GM Diagram or Table,
(c) The Maximum Permissible KG Diagram or Table.

In all three methods the limiting values are related to salt water displacement or draft. Free surface allowances for slack tanks are however applied slightly differently.

4 Consultation with the industry has revealed a general preference for the Maximum Permissible KG approach, and graphical presentation also appears to be preferred rather than a tabular format. The Department's view is that any of the methods may be adopted subject to:

(a) clear guidance notes for their use being provided and
(b) submission for approval being made in association with all other basic data and sample loading conditions.

In company fleets it is however recommended that a single method be utilized throughout.

5 It is further recommended that the use of a *Simplified Stability Diagram* as an adjunct to the *Deadweight Scale* be adopted to provide a direct means of comparing stability relative to other loading characteristics. Standard work forms for calculating loading conditions should also be provided.

6 It is essential for masters to be aware that the standards of stability obtainable in a vessel are wholly dependent on exposed openings such as hatches, doorways, air pipes and ventilators being securely closed weathertight; or in the case of automatic closing appliances such as airpipe ball valves that these are properly maintained in order to function as designed.

7 Shipowners bear the responsiblity to ensure that adequate, accurate and up-to-date stability information for the master's use is provided. It follows that it should be in a form which should enable it to be readily used in the trade in which the vessel is engaged.

Maximum Permissible Deadweight Moment Diagram

This is one form of simplified stability data diagram in which a curve of Maximum Permissible Deadweight Moments is plotted against Displacement in tonnes on the vertical axis and Deadweight Moment in Tonnes metres on the horizontal axis, the Deadweight Moment being the moment of the Deadweight about the keel.

The total Deadweight Moment at any Displacement must not, under any circumstances, exceed the Maximum Permissible Deadweight Moment at that Displacement.

Diagram 3 (Figure 44.1) illustrates this type of diagram. The ship's Displacement in tonnes is plotted on the vertical axis from 1500 to 4000 tonnes while the Deadweight Moments in tonnes metres are plotted on the horizontal axis. From this diagram it can be seen that, for example, the Maximum Deadweight Moment for this ship at a displacement of 3000 tonnes is 10 260 tonnes metres (Point 1). If the light displacement for this ship is 1000 tonnes then the Deadweight at this displacement is 2000 tonnes. The maximum kg for the Deadweight tonnage is given by:

$$\text{Maximum kg} = \frac{\text{Deadweight Moment}}{\text{Deadweight}}$$

$$= \frac{10\,260}{2000}$$

$$= 5.13\text{ m}$$

Example 1

Using the Simplified Stability Data shown in Diagram 3 (Figure 44.1), estimate the amount of cargo (kg 3 m) which can be loaded so that after completion of loading the ship does not have deficient stability. Prior to loading the cargo the following weights were already on board:

250 t fuel oil	kg 0.5 m	Free Surface Moment	1400 t m
50 t fresh water	kg 5.0 m	Free Surface Moment	500 t m
2000 t cargo	kg 4.0 m		

The light displacement is 1000 t, and the loaded Summer displacement is 3500 t

Item	*Weight*	*Kg*	*Deadweight Moment*
Light disp.	1000 t	–	–
Fuel oil	250 t	0.5 m	125 t m
Free surface	–	–	1400 t m
Fresh water	50 t	5.0 m	250 t m
Free surface	–	–	500 t m
Cargo	2000 t	4.0 m	8000 t m
Present cond.	3300 t		10 275 t m – Point 2 (Satisfactory)
Maximum balance	200 t	3.0 m	600 t m
Summer displ.	3500		10 875 t m – Point 3 (Satisfactory)

Since 10 875 tonnes metres is less than the maximum permissible deadweight moment at a displacement of 3500 tonnes, the ship will not have deficient stability and may load 200 tonnes of cargo.

Ans. Load 200 tonnes.

Example 2

Using the Maximum Permissible Deadweight Moment diagram 3 (Figure 44.1) and the information given below, find the quantity of timber deck cargo (Kg 8.0 m) which can be loaded, allowing 15 per cent for water absorption during the voyage.

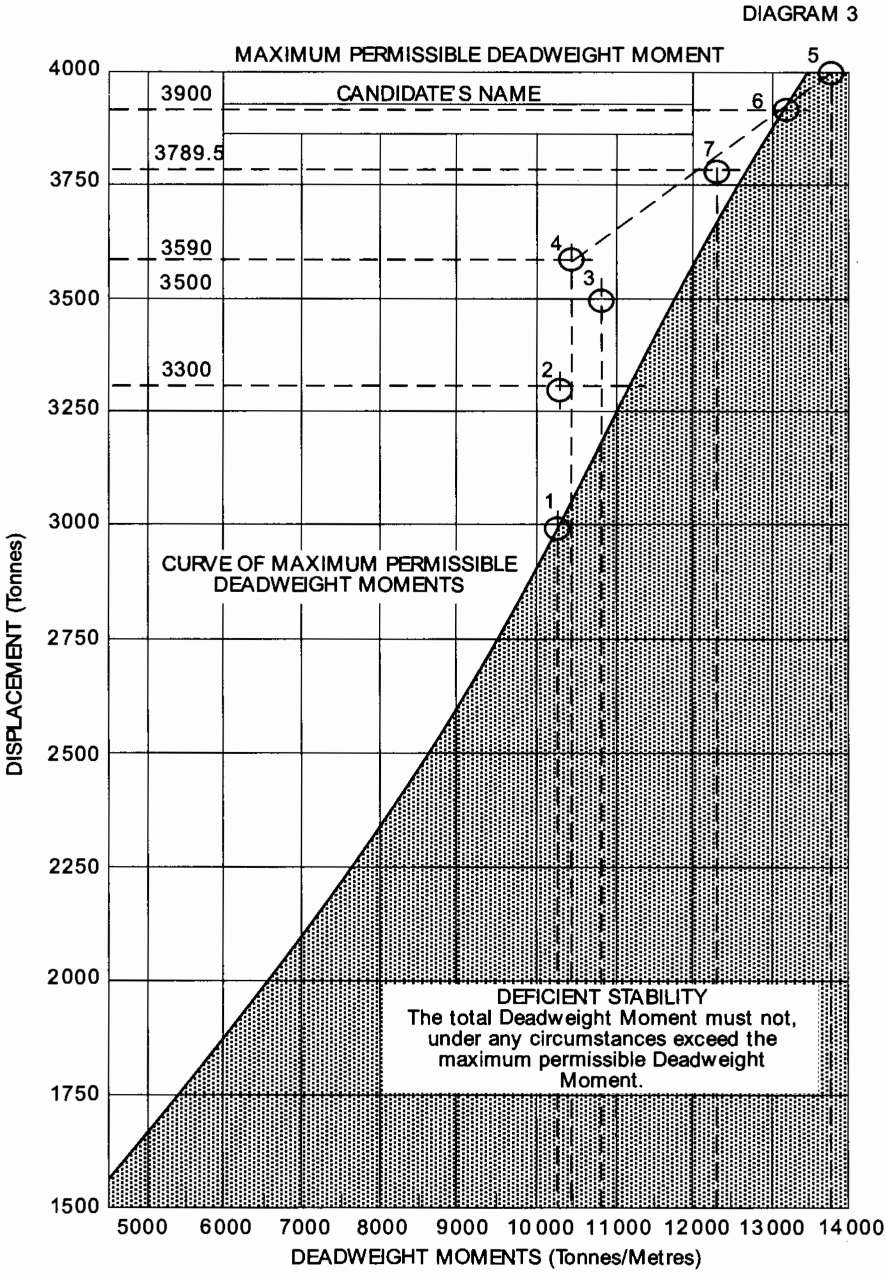


DIAGRAM 3
MAXIMUM PERMISSIBLE DEADWEIGHT MOMENT
CANDIDATE'S NAME
4000
3900
3789.5
3750
3590
3500
3300
3250
3000
2750
2500
2250
2000
1750
1500
1
2
3
4
5
6
7
CURVE OF MAXIMUM PERMISSIBLE
DEADWEIGHT MOMENTS
DEFICIENT STABILITY
The total Deadweight Moment must not,
under any circumstances exceed the
maximum permissible Deadweight
Moment.
DISPLACEMENT (Tonnes)
5000
6000
7000
8000
9000
10 000
11 000
12 000
13 000
14 000
DEADWEIGHT MOMENTS (Tonnes/Metres)

Fig. 44.1

Summer displacement 4000 tonnes, Light Displacement 1000 tonnes.
Weights already on board:

Fuel oil	200 tonnes,	Kg 0.5 m, free surface moment 1400 t m
Fresh water	40 tonnes,	Kg 5.0 m, free surface moment 600 t m
Cargo	2000 tonnes,	Kg 4.0 m
Ballast	350 tonnes,	Kg 0.5 m

The following weights will be consumed during the voyage:

Fuel oil	150 tonnes, Kg 0.5 m. Free surface moment will be reduced by 800 t m
Fresh water	30 tonnes, Kg 5.0 m. Free surface moment will be by 200 t m

Departure Condition

Item	*Weight*	*Kg*	*Deadweight Moment*
Light ship	1000	–	–
Fuel oil	200	0.5	100
Free surface			1400
Fresh water	40	5.0	200
Free surface			600
Cargo	2000	4.0	8000
Ballast	350	0.5	175
Departure Disp. (without deck cargo)	3590		10 475 – Point 4 (Satisfactory)
Maximum deck cargo	410	8.0	3280
Summer disp.	4000		13 755 – Point 5 (Deficient Stability)

From diagram 3, where the line joining points 4 and 5 cuts the curve of Maximum Permissible Deadweight Moments (point 6), the displacement is 3920 tonnes.

Total departure displacement	3920 tonnes
Departure displacement without deck cargo	3590 tonnes
∴ Max deck cargo to load	330 tonnes

$$\text{Absorption during voyage} = \frac{15}{100} \times 330 = 49.5 \text{ tonnes}$$

Arrival Condition

Item	*Weight*	*Kg*	*Deadweight Moment*
Departure disp. without deck cargo	3590		10 475
Fuel oil	− 150	0.5	−75
Free Surface			−800
Fresh water	−30	5.0	−150
Free surface			−200
Arrival disp. without deck cargo	3410		9250
Deck cargo	330	8.0	2640
Absorption	49.5	8.0	396
Total arrival disp.	3789.5		12 286 – Point 7 (Satisfactory Stability)

Ans. Load 330 tonnes of deck cargo.

Exercise 44

1 Using the Maximum Permissible Deadweight Moment diagram 3, find the amount of deck cargo (kg 8.0 m) which can be loaded allowing 15 per cent for water absoption during the voyage given the following data:

Light displacement 1000 tonnes, Loaded displacement 4000 tonnes. Weights already on board:

Item	*Weight*	*Kg*	*Free Surface Moment*
Cargo	1800	4.0	–
Fuel oil	350	0.5	1200
Fresh water	50	5.0	600
Ballast	250	0.5	–

During the voyage the following will be consumed (tonnes and kg):

Fuel oil	250	0.5	Reduction in free surface moment 850 t m.
Fresh water	40	5.0	Reduction in free surface moment 400 t m.

Appendix I
Standard abbreviations and symbols

K	The keel.
B	The centre of buoyancy when the ship is upright.
B_1	The centre of buoyancy when the ship is inclined.
BM	The height of the transverse metacentre above the centre of buoyancy.
BM_L	The height of the longitudinal metacentre above the centre of buoyancy.
CB	Centre of buoyancy.
G	The original position of the centre of gravity.
G_1	The new position of the centre of gravity.
M	The original position of the transverse metacentre.
M_1	The new position of the transverse metacentre.
M_L	The longitudinal metacentre.
KB	The height of the centre of buoyancy above the keel.
KG	The height of the centre of gravity above the keel.
Kg	The height of the centre of gravity of an item above keel.
KM	The height of the transverse metacentre above the keel.
GM	Initial transverse metacentric height.
CF	Centre of Flotation.
GZ	The length of the righting lever about centre of gravity.
KN	The length of the righting lever about keel.
V or ∇	The ship's volume of displacement.
W or Δ	The ship's weight of displacement.
w	A weight to be loaded, discharged, or shifted.
)(	Amidships. (The symbol)(is shown on trim diagrams).
L	The ship's length.
D	The ship's depth.

B	The ship's maximum beam.
d	The ship's draft.
F	Forward, or centre of flotation.
A	Aft.
M or m	Metres.
C_w	The water-plane coefficient.
C_b	Block coefficient.
C_m	Coefficient of midships area.
C_p	Prismatic coefficient.
I or i	Second moment of an area.
l	The distance of the centre of flotation from aft.
P	The upthrust on the keel blocks when drydocking.
μ	The permeability of a compartment.
WL	The original waterline.
W_1L_1	The new waterline.
G_v	The virtual centre of gravity.
t	The trim.
MCTC or MCT 1 cm	The moment to change the trim by 1 cm.
TPC	The tonnes per centimetre immersion.
GM_L	The longitudinal metacentric height.
SG	Specific gravity.
θ	An angle of list or heel.
WPA	Area of a water-plane.
FWA	Fresh water allowance.
FW	Fresh water.
SW	Salt water.
CDB	Cellular double-bottom tank.
CI or h	The common interval used in Simpson's Rules.
E	Young's Modulus.
y	Depth from the neutral layer.
f	Stress.
q	Shearing stress.
ρ	Density in tonnes/m^3.
ρ_{FW}	Fresh water density @ 1.000 t/m^3.
ρ_{SW}	Salt water density @ 1.025 t/m^3.
ρ_{DW}	Dock water density as given in t/m^3.
δ_{max}	Maximum squat.
S	Blockage factor.
y	Static underkeel clearance.
y_2	Dynamical underkeel clearance.
H	Water depth relating to squat.
T	Ship's mean draft relating to squat.
V_k	Speed of ship relative to the water.