CHAPTER 29

BASIC SHIP STABILITY

CONTENTS

Para

CHAPTER 29

BASIC SHIP STABILITY

2901. Stability Knowledge Requirements

a. All members of a ships company should have some knowledge of the elementary principles of ship stability. This chapter provides, in easily understood terms, a basic explanation of those principles and the associated terminology. The subject is dealt with in greater detail in subsequent chapters, so there is intentionally some duplication of information.

b. This chapter and the succeeding chapters provide guidance to tackle many problems encountered with ship stability. Information and data provided by the CBRNDC Class Book and issued with the Stability Statement, together with the principles provided in these chapters will allow sensible conclusions to be drawn and appropriate actions to be taken. Submarine stability is covered separately in BR 2170(4). There is no substitute for experience and previous training; whenever possible advice should be sought after any incident or prior to any unusual loading situation that may jeopardise the stability of the ship. Advice can in the first instance be sought from the MEO or DMEO, further specialist advice maybe obtained from any ME 106 trained officer (the HEO of larger ships QEC/LPD/LPH)) or direct from the Naval Support Command. In all circumstances, if the ship is to be operated outside the Design Intent as stated in the Certificate of Safety - Stability, both the Operating and Design Authorities must be informed and a concession sought at the earliest opportunity as required by JSP 430 - MOD Ship Safety Management.

c. The stability of a ship in the transverse or athwartships direction is much more easily prejudiced than that in a fore-and-aft direction; this chapter is therefore almost wholly concerned with transverse stability.

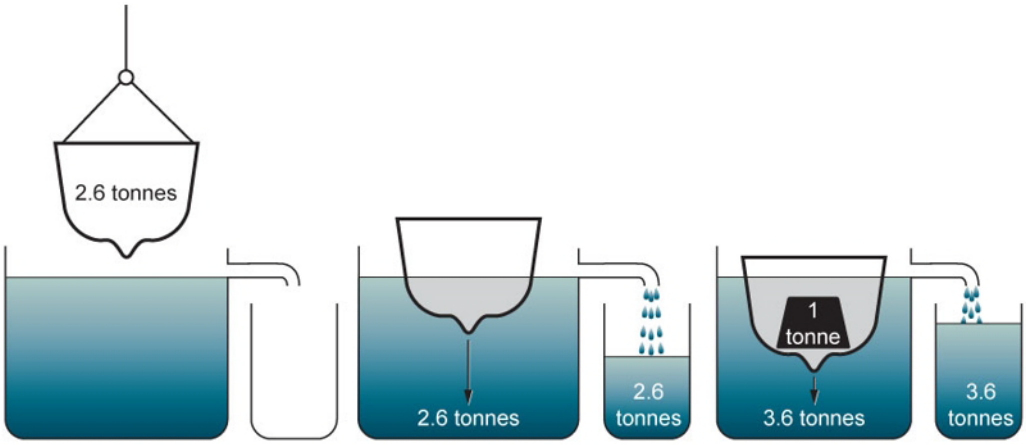
2902. Flotation

A flat sheet of metal placed in a tank of water will sink to the bottom, and the volume of water displaced by it will be equal to the volume of the sheet of metal. If the sheet of metal is moulded into the form of a watertight box it will float on the surface of the water; the volume of water then displaced will be equal to the volume of the immersed part of the box, and its weight will be equal to the weight of the box.

2903. Displacement

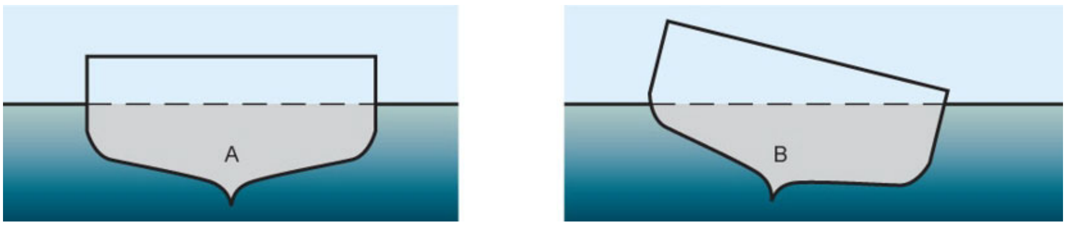
a. The facts are illustrated in Fig 29-1, which represents a boat weighing 2.6 tonnes lowered into a tank of water. When the boat is waterborne, 2.6 tonnes of water are displaced, the volume of which is equal to the immersed volume (shown shaded) of the boat. If a weight of one tonne is placed in the boat she will sink down into the water until 3.6 tonnes of water are displaced, and the volume of water displaced will again be equal to the volume (shown shaded) of the immersed part of the boat. The weight of water displaced always equals the weight of the floating object and is referred to as her displacement.

Fig 29-1. Flotation and Displacement



b. If the boat heels to one side the shape of the immersed part of her hull will alter, but the volume will remain the same. In Fig 29-2 the volume of the shaded portion A equals that of the shaded portion B, and the weight of water displaced is the same in each instance.

Fig 29-2. Heel and Immersed Section Contour

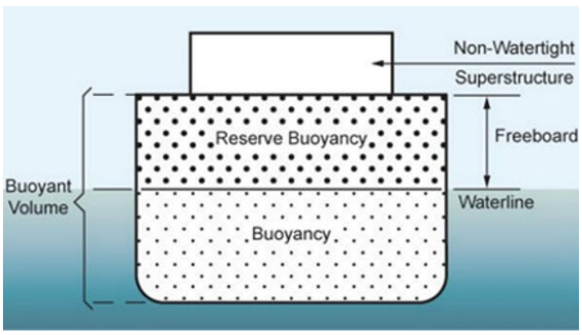


Volume of the shaded Portion A equals that of the shaded Portion B

2904. Buoyant Volume

a. The buoyant volume of a ship is the volume of the entire watertight part of the hull. That part of the buoyant volume below the waterline is called her buoyancy, and that part above the waterline is called her reserve of buoyancy (Fig 29-3).

Fig 29-3. Buoyant Volume



b. Additional loading or flooding after damage will sink a ship lower into the water. Part of the reserve buoyancy then becomes the buoyancy. It is the reserve of buoyancy that largely determines the ships ability to float after flooding damage.

c. The freeboard is the height above the waterline, at the ships side, of the highest continuous watertight deck. As most ships are nearly wall sided ie perpendicular above the waterline the freeboard gives an approximate measure of the reserve of buoyancy.

2905. Centre of Gravity and Buoyancy

A ships ability to float depends upon two factors - her total weight (or displacement) and her buoyancy.

Fig 29-4. Centre of Gravity

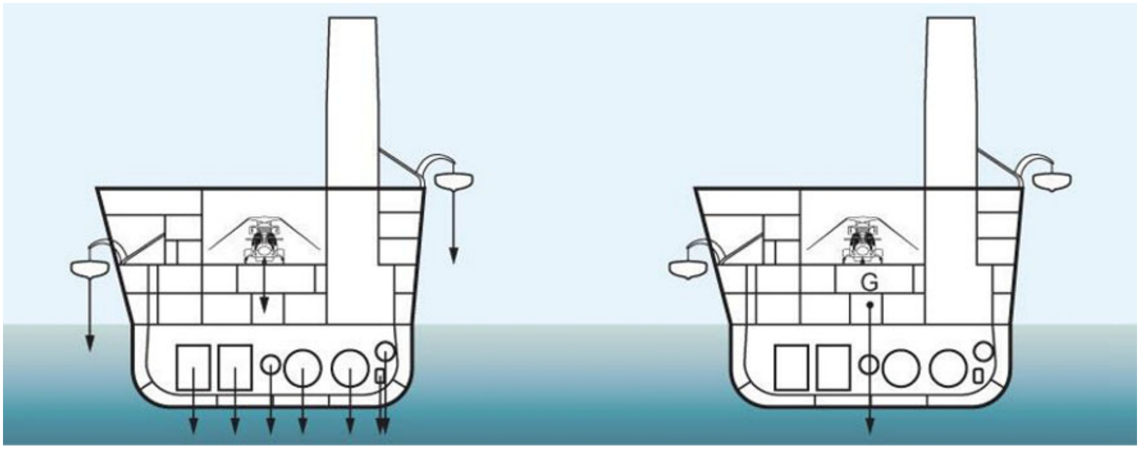
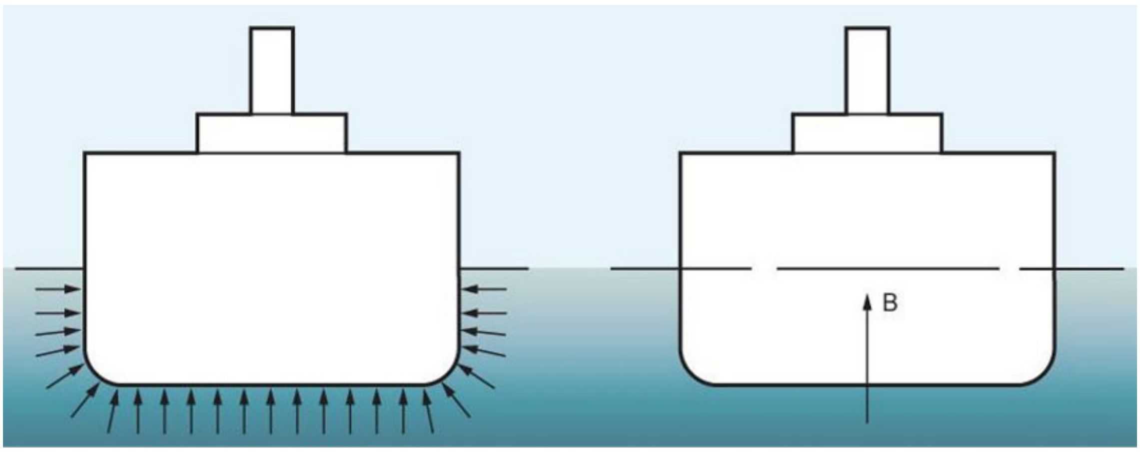


Fig 29-5. Centre of Buoyancy



a. The total weight is the sum of the weights of everything in the ship, including that of all the structure, machinery, armament, fittings, stores, fuel and ships company, and it can be visualised as the effect of exerting a single force through a central point which is called the centre of gravity (usually indicated by the letter G, see Fig 29-4).

b. Buoyancy is the upward force exerted on the ships hull by the water when she is floating, and it is equal to the weight of water she displaces. Although this force is distributed over all the underwater surface of the ships hull it also can be resolved into a single force exerted through a central point which is called the centre of buoyancy (usually indicated by the letter B, see Fig 29-5).

c. A ships hull is symmetrical about a fore-and-aft vertical plane, so B is on the middle line when the ship is floating upright; as the weight in this condition must be distributed symmetrically about this plane, G is also on the middle line.

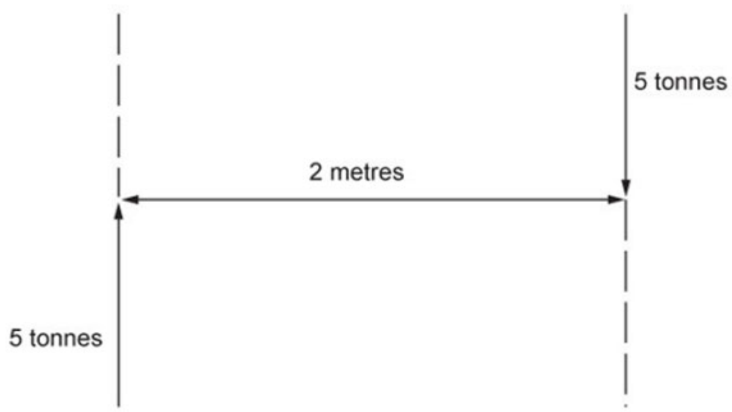
2906. Conditions for Equilibrium

a. For a ship to float in equilibrium the buoyancy force pushing upward on the underwater part of the hull must be equal to the total weight of the ship, and as these two forces balance one another they must be acting in the same straight line (Fig 29-7(a)).

b. When two equal and opposite forces acting on the same object are not in line these are known as a 'couple' and produce a moment tending to rotate the object; this moment is found by multiplying the perpendicular distance between the lines of action of the forces by the force of one of them. This is illustrated by the example at Fig 29-6.

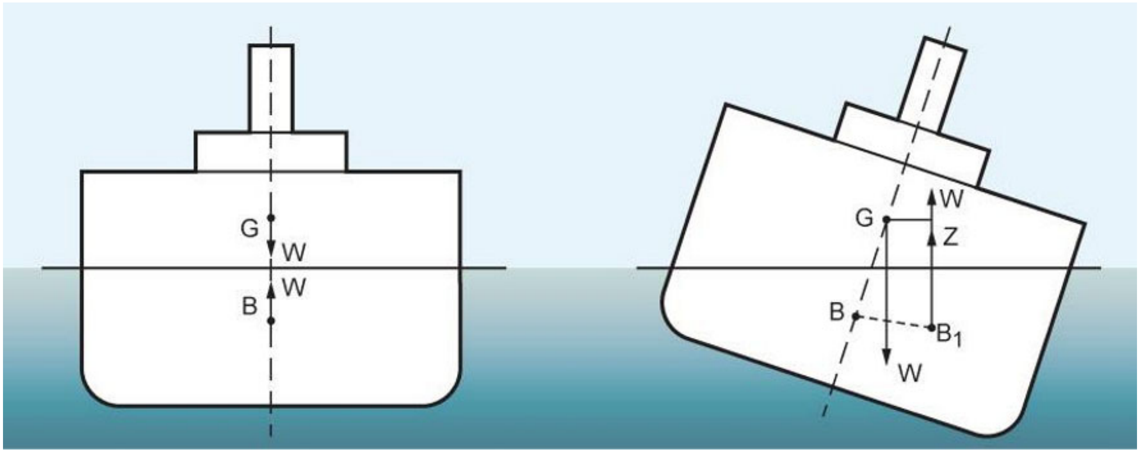
Moment = 5 tonnes x 2 m = 10 tonnes-m

Fig 29-6. Couple and Moment



c. If a ship is heeled over by some external force such as wind or wave, the weight, and hence the position of the centre of gravity, will, for all practical purposes, remain unaltered; but as the shape of the submerged part of the hull will be changed, the centre of buoyancy, B, will move from the middle line towards the lower side of the ship to B_1, as shown in Fig 29-7(b). Hence the forces of weight and buoyancy are out of line and therefore produce a moment tending to return the vessel to an upright position and she is said to be in stable equilibrium.

Fig 29-7. Stable Equilibrium



(a) (b)

2907. Righting Moment and Righting Lever

a. In Fig 29-7(b) the righting moment acting on the ship is calculated by multiplying the displacement, W, by the horizontal distance between the resolved forces of weight and buoyancy, GZ. This horizontal distance GZ, which separates the forces of weight and buoyancy as the ship heels, is called the righting lever.

b. The stability of a ship (ie her resistance to heeling forces) at any angle of heel is given by her righting moment, which depends on the size and shape of the submerged part of the hull (which determines the position of B) and also on the distribution of the weights of stores, fuel, weapons, machinery, etc (which determines the position of G). As the weight and the centre of gravity of a ship remain unaltered (apart from small differences due to free liquids) when she is heeled by an external force, her stability can be judged by the length of the righting lever GZ at the particular displacement.

c. Thus it will be seen that the stability of a ship depends on three factors:

(1) The shape of her hull (both of the part normally underwater and the part liable to be submerged as the ship rolls) which determines the position and movement of the centre of buoyancy.

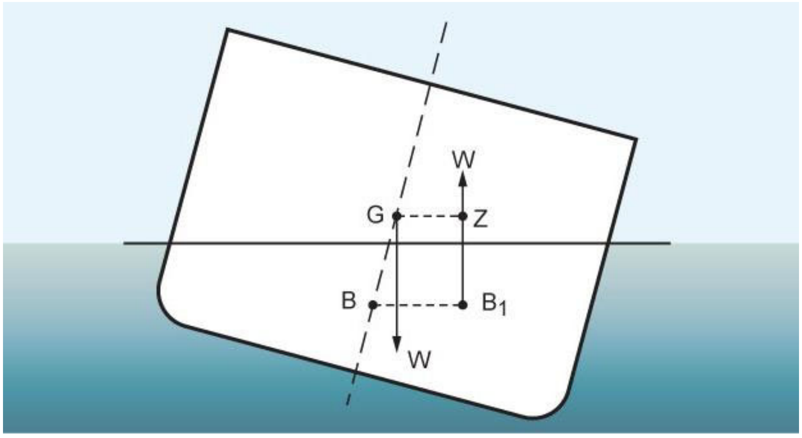
(2) The arrangement of all weights such as the hull, machinery, stores, weapons and fuel, etc, which determines the position of the centre of gravity.

(3) The positions of the centres of gravity and buoyancy in relation to each other and to the ship.

d. In designing a ships hull, a compromise must be reached between the requirements of speed, capacity and stability. Too much weight above the centre of gravity, due to superstructures, weapons, radar equipment, etc, may raise the centre of gravity enough to make her top heavy and endanger her stability.

Again, a ship whose beam is unduly narrow may not have a sufficiently large righting lever (and thus righting moment) to enable her to recover from a heavy roll. A warship, also, must be designed with enough margin of stability to keep her stable when damaged and partly flooded.

Fig 29-8. Period of Roll



2908. Period of Roll

a. When a ship is rolling, the righting moment produced depends upon the severity of the roll, ie how far the ship rolls from the upright. This righting moment (W x GZ in Fig 29-8) will oppose the roll away from the upright position and hasten the roll back to it.

b. A ship with a large righting moment (ie good stability) will usually roll rapidly. Conversely, a ship with a small righting moment (ie poor stability) will usually roll sluggishly. The period of a ships rolling can thus give an indication of her stability.

c. A ship that is too lively will be uncomfortable; her violent movements may even carry away fittings and, if a warship, will make it difficult to use the weapons effectively or operate aircraft. If too sluggish, however, she will be unsafe in heavy weather, so a compromise in these respects has to be achieved by the designer.

2909. Heel and Trim

a. **Heel**. This is the athwartships inclination of a ship to either side from the vertical however caused; a sailing vessel, for example, may be heeled by the wind to her leeward side.

b. **List**. This is a heel caused by off-centre loading, ie G is not on the middle line.

c. **Trim**. This is the inclination of the ships designed horizontal fore and aft plane with the surface of the water in which she floats. It is the difference between the draughts forward and aft. Warships are generally trimmed (down) by the stern.

2910. Effects of Loading

a. The effects on her stability of adding a weight to a ship will depend on the size and position of the weight, but it will always result in the mean draught of the ship being increased and in her centre of gravity being moved towards the added weight. The latter effect can be illustrated by the simple example given in Fig 29-9 and Fig 29-10.

b. If two equal weights are hung equidistantly from the middle point of a metal bar it will balance about that point because that is the centre of gravity of the whole (Fig 29-9).

Fig 29-9. Centre of Gravity

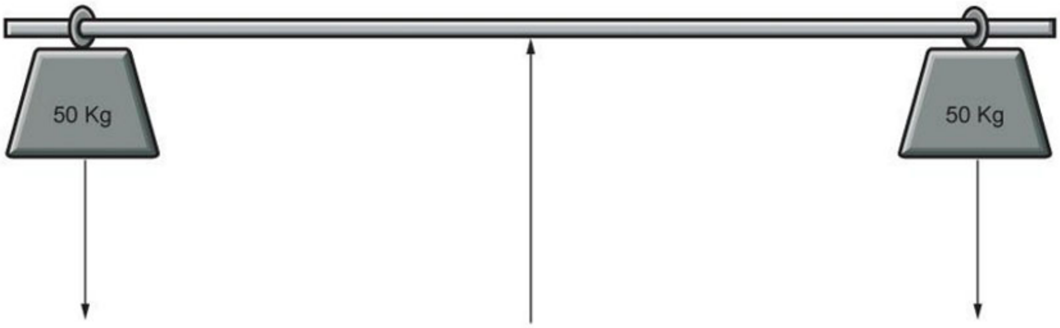
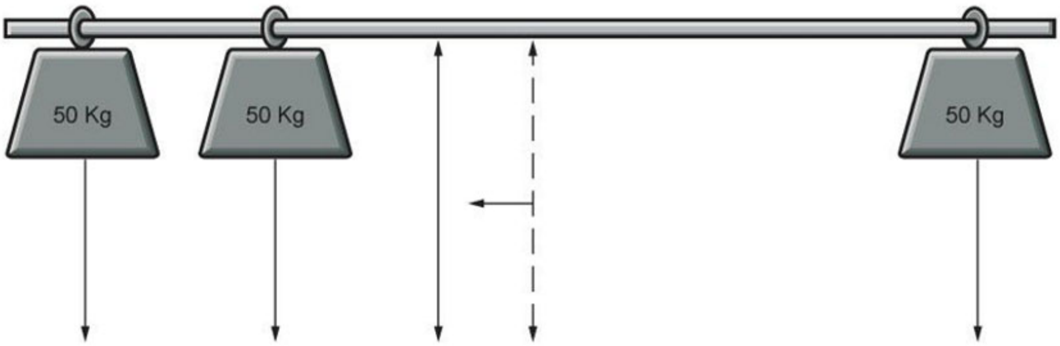


Fig 29-10. Movement of Centre of Gravity

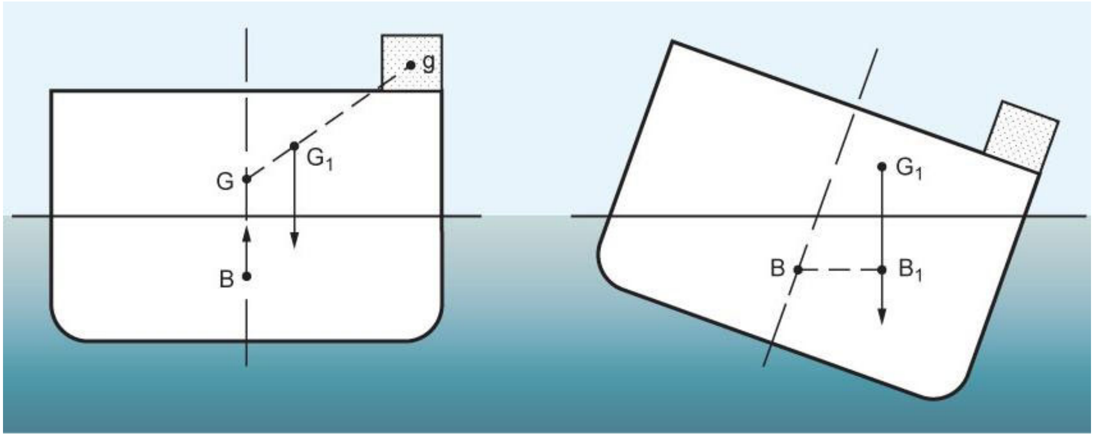


c. If another weight is added on one side of the support (as shown in Fig 29-10, the support will have to be moved from the middle towards the heavier end in order to preserve the balance of the whole. In other words, the centre of gravity of the whole has moved towards the added weight.

2911. Off Centre Loading

When a heavy weight is added on either side of a ship, her centre of gravity moves towards that of the added weight, ie from G to G_1 in Fig 29-11(a). The weight and buoyancy forces are no longer in the same vertical line and so they produce a moment that will list the ship towards the side on which the weight was added. As the ship lists, so B moves towards the low side until it reaches position B_1 vertically below G_1 as shown in Fig 29-11(b).

Fig 29-11. Effect of Off-Centre Loading



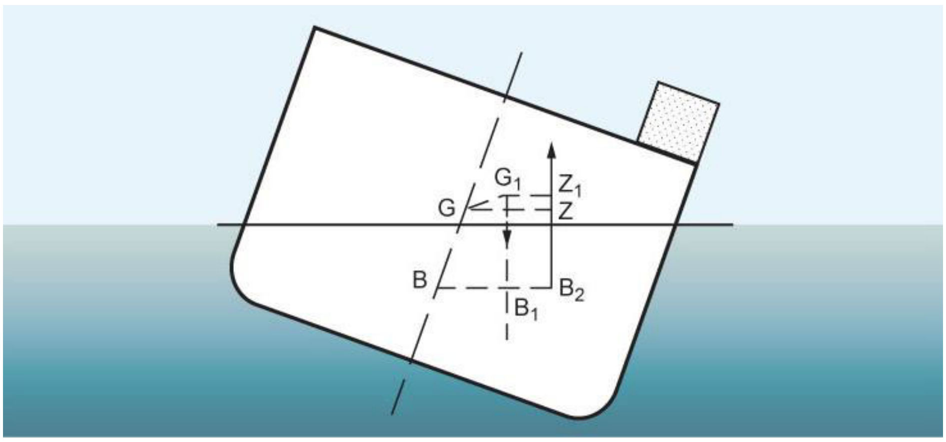
(a) (b)

Then, with the centres of buoyancy and gravity once more in the same vertical line, the ship will float in equilibrium in the inclined or listed position. Removing a weight causes the opposite effect, ie the centre of gravity moves away from the centre of gravity of the removed weight and the ship will list away.

2912. Effect of List on Stability

It may be said that the stability of a ship is reduced by a list because G has moved off the middle line (in Fig 29-12, G has moved to G_1 and B has moved to B_1). Any further heel by an external force in the same direction as the list will produce a smaller righting lever at the particular angle of heel than it would if G were still on the middle line; in Fig 29-12, for example, G_1Z_1 is less than GZ.

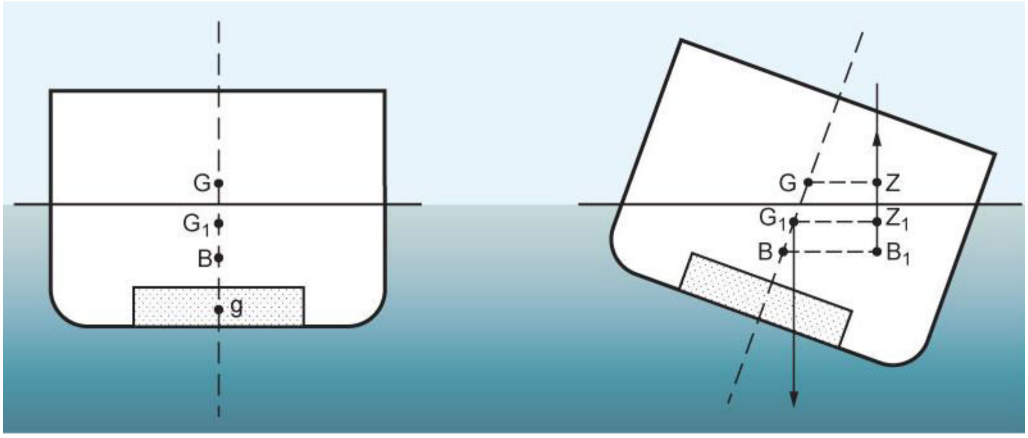
Fig 29-12. Effect of List on Stability



2913. Effect of Ballast

If ballast is added low down in a ship, the position of the centre of gravity will be lowered and stability will be increased. In Fig 29-13, G has moved to G_1 making G_1Z_1 greater than GZ.

Fig 29-13. Effect of Ballast

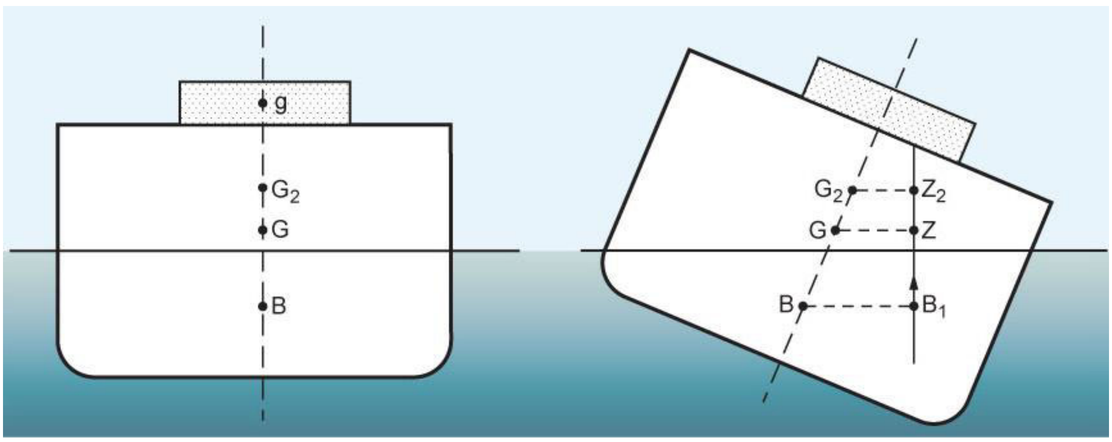


(a) (b)

2914. Topweight

If a weight is added high in the ship the centre of gravity will be raised, eg from G to G_2 in Fig 29-14(a), and the stability will then be reduced. In Fig 29-14(b), for example, G_2Z_2 is less than GZ. Top weight is therefore dangerous and must be kept to the essential minimum. A similar effect results from raising weight vertically in a ship. Removal of top-weight, however, lowers G and improves stability. Increase in top weight can arise from such diverse causes as unauthorised additions (to structure or fittings), unnecessary accumulations of paint coatings, equipment and obsolete fittings, and severe icing of topsides. Ships operating in or near the Arctic or Antarctic may experience heavy icing of superstructure, weather decks and exposed equipment. Apart from the loss of stability caused by topweight, the ice may be asymmetrical (lopsided) and will then cause list. Other evils are overloading of decks, masts and aerials; slippery decks, interference with the handling and operation of topside weapons and equipment. Information on ice prevention and removal is given in Chapter 17.

Fig 29-14. Effect of Topweight



(a) (b)

2915. Effects of Flooding

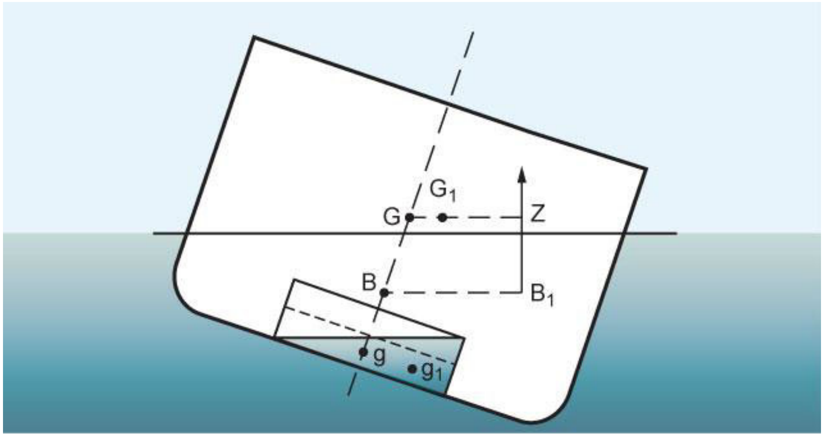
Completely flooding a compartment will have exactly the same effect on the stability of a ship as adding a solid substance of equal weight at the centre of gravity of the floodwater (Fig 29-13). For example, completely filling a centre line fuel tank would ballast the ship and so improve her stability.

2916. Free Surface Liquids

a. If a fuel or other tank is only partly filled, however, the liquid in it has what is called a ***free surface***, being free to run across to the low side as the ship heels or rolls. This will have the effect of moving the centre of gravity of the ship towards the low side, thus reducing the righting lever, so that in the example in Fig 29-15, G_1Z is less than GZ.

b. Free surface liquid therefore reduces stability. The ***free surface effect*** (ie reduction of stability) depends on the area (mainly width) of the free surface liquid but not on the quantity. If liquid with a free surface is added to compartments high up in the ship, during firefighting for example, it will have a more adverse effect on the ships stability than if it were added low down, because it will combine the bad effects of free surface and topweight.

Fig 29-15. Effect of Free Surface Liquid

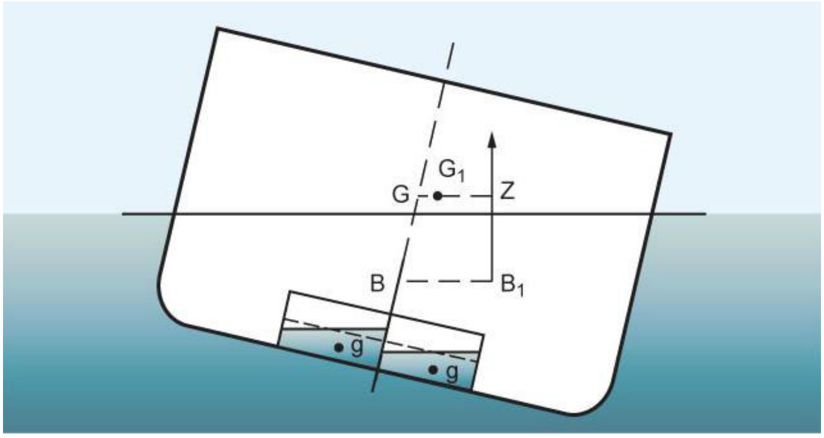


2917. Subdivision of Free Surface Liquids

a. If the tank in the example above were fitted with a middle line bulkhead (Fig 29-16) the centre of gravity of the liquid in it will not move so far from the middle line when the ship heels or rolls, because the two smaller volumes of liquid will move through shorter distances; the loss of righting lever and stability will therefore not then be so great.

b. For this reason longitudinal bulkheads may be fitted in fuel and water tanks to break up the free surface and so reduce its effect on the ships stability. For the same reason, and excepting hangars, large areas of unbroken deck space are avoided in warship design as far as possible.

Fig 29-16. Subdivision of Free Surface Liquid



2918. Correction of List

a. Unless caused by damage, list is usually easy to correct. All that is required is to balance the ship and so bring the centre of gravity back to the middle line. There are three ways of doing this:

(1) By removing the off-centre loading, or an equivalent weight on the low side.

(2) By adding an equivalent weight on the high side.

(3) By shifting weights from the low side to the high side.

b. For a damaged ship with off-centre flooding causing a list (that is, generally, a large ship) the first method is usually impracticable because flood water cannot be removed from compartments which are open to the sea, and the weight of this water is so great that there is nothing that can be removed from the low side heavy enough to compensate it.

c. The second method usually affords the quickest way to correct list because, in big ships, the equivalent weight can be added by admitting sea water to wing compartments on the high side as counterflooding. In such ships, valves are usually fitted low down in wing watertight compartments so that they can be flooded direct from the sea.

d. The last method is theoretically the best because it avoids the increase of the ships displacement produced by method b. In practice, however, it usually means transferring fuel or other liquids across the ship, which is a slow process and not suited to the rapid correction of list. However, when the list has been reduced to a safe angle by counterflooding, pumping across of liquids is undertaken and, concurrently, pumping out counterflood water.

e. List caused by flooding is unusual in DD/FF and smaller ships because there is little or no longitudinal subdivision.

2919. Loll

a. The term loll is applied to the state of a ship that is unstable when in an upright position and therefore floats at an angle or heel to one side or the other indifferently. If disturbed by some external force, such as wind or waves, the ship will lurch to the same angle of loll on the opposite side. Loll is quite different from list, being caused by different circumstances and requiring different countermeasures to correct it, and it is therefore most important that sea going personnel should be able to distinguish between the two.

b. Loll may be caused either by a large area (especially breadth) of free-surface liquid inside the hull or by a large addition of topweight; the following example shows how it may be caused by free surface liquid.

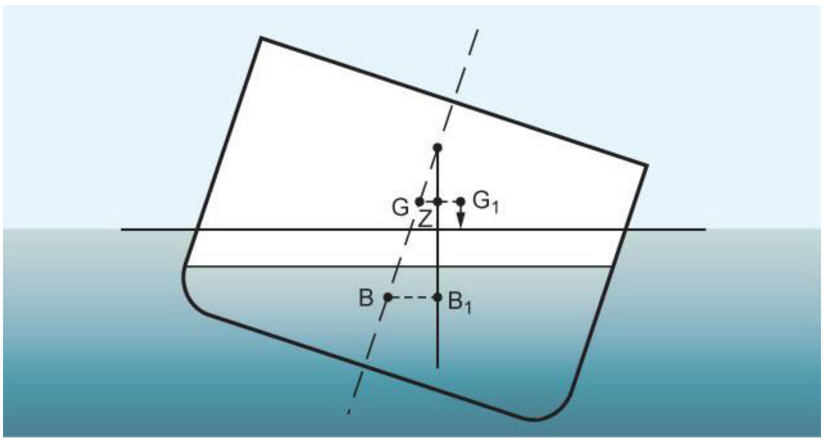
c. In the description of free surface it was shown that the effect of free-surface liquid was to reduce the righting lever by shifting G towards Z. The greater the extent of flooding by free-surface water the further will G move away from the middle line when the ship heels.

d. Consider a frigate with free flooded main-compartments extending right across the ship. If the ship heels to starboard, for example, as shown in an exaggerated form in Fig 29-17, the water in the flooded compartments will run across to starboard and shift G so far that it may well pass beyond B_1 to the position G_1.

e. The centre of gravity G_1 of the flooded ship is now beyond the centre of buoyancy B_1 and these two forces are tending to heel the ship still more instead of returning her to the upright position.

f. As the ship heels over further, however, the centre of buoyancy will also move further to starboard and the ship will come to rest at an angle of heel at which the centres of gravity and buoyancy, G_1 and B_1, are again in line as shown in Fig 29-18. The cross-sectional shape of the hull determines the extent to which the centre of buoyancy can move, and if G_1 is still beyond B_1 when the latter has reached the limit of its travel, the ship will capsize.

Fig 29-17. Free Surface Liquid Effect on G



g. If, due to a change of course or to action by wind or waves, the ship heels over to port, the water in the flooded compartments will flow across the ship from starboard to port, and she will come to rest heeled to port at an angle equal to that of her previous heel to starboard (Fig 29-19).

Fig 29-18. Loll to Starboard

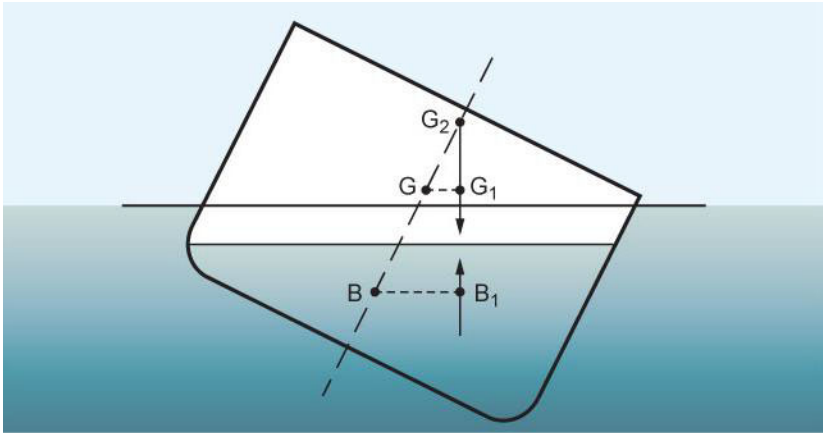
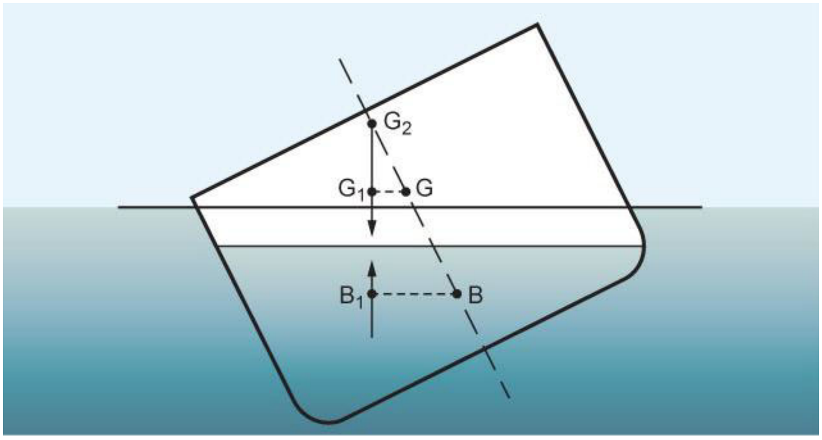


Fig 29-19. Loll to Port



h. An exactly similar effect would be caused by an excessive amount of top weight being placed in the ship, thereby raising the centre of gravity to a dangerous extent. This is illustrated in Fig 29-18 and Fig 29-19, in which G_2 represents the raised centre of gravity caused by top weight. It will be seen that the vertical line of action of the force exerted by the weight of the ship passes through both G_2 and G_1. In this case the centre of gravity is fixed and does not move from one side to the other with the heel of the ship, but the effect is the same as that caused by free-surface liquid.

i. In each case the ship is unstable when upright and also when heeled to port or starboard up to the angle where B and G are in the same vertical plane.

2920. Reduction of Loll

a. There are 4 ways to reduce loll:

(1) Remove weights from high up in the ship.

(2) Reduce the area, especially the breadth, of free-surface liquid.

(3) Add weight low down in the ship.

(4) Shift weights from high in the ship to lower levels.

b. The choice of method or methods to be used depends on the causes of the loll and the means available in the ship for correcting it.

c. The first method is probably the most practicable, especially in small ships, and produces a double improvement because it lightens the ship, increasing her reserve of buoyancy, and also lowers her centre of gravity. It is affected by jettisoning movable gear from the upper decks, but care must be taken to do this evenly each side of the middle line, and not to jettison damage control, firefighting or lifesaving equipment, or ready-use ammunition if further attack seems probable. Lists of suitable equipment should be prepared in the order in which they may be jettisoned so that this method can be used quickly and correctly should the need ever arise. Such items as boats (which should be tied up aft), torpedoes, helicopters and anchors may be included. Some guidance on preparing a Jettison Bill for the ship is given in Chapter 10.

d. The second method is to plug leaks and pump out water; drain to lower and, if possible, narrower compartments; use longitudinal dwarf bulkheads - which may be quite temporary arrangements - to break up the free-surface area; or completely empty (or fill) tanks which contain liquid, according to whether they are high or low in the ship.

e. The third method is to flood compartments or tanks low down in the ship to their full capacity and thus ballast the ship. It is effective in lowering the centre of gravity, but has the disadvantage of loading the ship still further and thereby reducing her reserve of buoyancy. If this method is employed it is important that the flooding should be carried out evenly each side of the middle line of the ship to avoid introducing a list in addition to the existing loll.

f. Apart from draining down of floodwater, the fourth method is usually impracticable because movable objects small enough to be lowered through hatches are not usually of sufficient weight to appreciably affect the centre of gravity. If they were heavy enough, they would then be difficult to shift, particularly if the ship was lolling to a large angle.

2921. Use of Fin Stabilisers After Damage

a. Fin type stabilisers are fitted to warships to minimise roll and assist in weapon operation. They should not be used for heel correction after damage for 2 reasons:

(1) Ships with fin stabilisers are designed so that list after damage is slight, if any. If the ship has a large angle of heel after damage, she is almost certainly lolling. Any attempt to correct loll by applying heeling moments, using the stabilisers, could result in the ship lolling to a greater and possibly dangerous angle on the side remote from the original loll.

(2) Conventional methods of heel correction after damage (Para 2918) restore to the ship a capacity to withstand further damage, which does not depend on maintenance of ship speed. Should initial heel correction be obtained by the use of stabilisers, and further damage cause serious loss of mobility, the resulting heeling moments and/or loss of stability from both incidents would be cumulative, possibly with serious consequences.

b. If enough speed can be maintained after damage to make the stabilisers effective, they may be used to minimise roll, thus effectively augmenting the inherent ship stability remaining after heel correction and damage control action have been taken.

2922. Effect of Heel and Trim on Fighting Efficiency

a. Excessive heel from any cause will reduce the fighting efficiency of the ship in a number of ways, of which the following are examples.

(1) It is difficult for personnel to get about the ship and carry out their duties properly when the ship is heeled.

(2) Heel may restrict the effectiveness of weapons. It also entails increased effort to move any manually trained equipment. 6° is about the largest angle of heel at which a ships armament can be effectively fought.

(3) Speed and manoeuvrability are reduced by heel.

(4) The efficiency of some machinery, such as fixed pumps, which depend for their operation on the maintenance of a steady liquid level, is reduced if the ship is much heeled.

b. For information on the effects of heel on the operation of aircraft and helicopters refer to BRd 766 - Aircraft Operating Handbook.

c. Trim does not have any appreciable effect on fighting efficiency or stability unless it is so large that the freeboard at the low end is reduced to the point where the seaworthiness of the ship is endangered, or the forecastle or quarterdeck is under water.

2923. Stability Information

a. All ships are supplied with the following stability information:

(1) Stability statement.

(2) Curves of statical stability (GZ curves).

(3) Hydrostatic particulars.

b. All RN surface ships and RFAs have a CBRNDC Class Book (CB 4538 Series), which contains much useful information, including stability characteristics and also various examples of flooding with the resulting stability conditions. Some ships are issued with a Ship Stability and Survivability Book in the CB 9500 Series.

2924. Stability Statement

This gives draught, metacentric height, angle of maximum stability and range, usually in the light, average action and deep conditions (or deep, light seagoing and light harbour conditions), which are defined in the statement. Details of any fixed ballast and instructions on working of fuel may also be given.

2925. Curves of Statical Stability

These, generally called ‘GZ curves’, are usually given for the same conditions of loading as the stability statement. They show the length of the righting lever at all angles of heel, up to the angle at which the ship loses all transverse stability in the particular condition, and indicate the angle at which the deck edge will be immersed and the angle at which the righting lever is greatest.

2926. Hydrostatic Particulars

These are tables which give, for different draughts over a wide range, the designed stability characteristics of the ship, including displacement, tonnes per centimetre immersion, moment to change trim one centimetre, height of transverse and longitudinal metacentres, and fore-and-aft position of the centre of flotation.