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MONOGRAPH

ANCHORING LARGE VESSELS
A new approach

By
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Summary

ANCHORING SYSTEMS ON LARGE VESSELS are designed within the following general parameters. The anchor and cable are capable of holding a loaded vessel in a current of three knots and a wind of 28 knots, maximum. They are not designed to stop a vessel with way on, as this momentum exceeds the limit of the system.

There are generally 13 shackles on the starboard anchor and 12 shackles on the port anchor. The windlass motor is designed to lift three shackles vertically plus the weight of the anchor, with a 50% allowance on test when new. The cable stopper should be able to carry approximately twice the proof load of the cable and the windlass brake holding power is approximately half the breaking strength of the cable.

The usual way of anchoring a VLCC is to stem the wind and tide, stop the ship and put the engines astern. The anchor is walked out to just above the bottom, after which it is let go or walked out until the required length of cable is on the bottom. This approach to anchoring gives heavy wear to the anchor system and can take a long time. A better and more effective approach is to attempt to keep the cable leading at right angles to the bow so controlling the change in axial inertia rather than controlling ship momentum.

To achieve this the bow should be about 20° off the weather and moving sideways when the anchor is let go. This must occur at the end of a tightly executed turn of about 135°. To achieve this the anchorage is approached down weather at slow speed. On reaching the position abeam of where the bow is desired to be, the engine is put on dead slow ahead and the helm put hard over towards the anchoring position. As soon as the turn is initiated the engine is stopped. Let go the anchor (it may need walking out to free the cable) but control the speed of descent with the brake. Control the direction of the anchor cable at right angles to the bow until sideways motion has stopped and allow the vessel to rotate about the anchor until brought up.

This monograph describes the principles behind this manoeuvre and discusses limitations in anchoring systems about which the prudent mariner should be aware.

Introduction

Anchoring by walking the anchor and cable back the whole way is permissible, providing the cable is kept up and down the whole time and providing the design speed of the windlass is not exceeded. Because putting 10 shackles out in this manner takes in excess of half an hour, it is exceedingly difficult to do in practice without damaging the windlass motor. However, the problem of speed control of the cable does not arise with this method as it does with the brake, which is why many people do it.

Alternatively, the brake designed for the purpose can and should be used with care, as described below. The brake has a rated static applicable force typically 10 to 12 times that sustainable by the motor. Dynamic force is reduced by a factor of about six, so the brake is about twice the available force of the motor. The problem with the brake method is that speed control and the force of brake application rest with the skill of the fo'c'sle crew. Maintenance of the brake in an as-new condition is also necessary.

Anchoring with the brake is a team skill on the part of the crew and the master. Despite the stories of accidents, these are mainly caused by human error of one kind or another – water too deep, only one man operating the brake, cable speed excessive, ship speed excessive, windlass brake not maintained, cable not kept abeam and failure of associated equipment also due to lack of maintenance. Occasionally equipment may fail unexpectedly, but this is really blaming the gear design rather than causal lack of maintenance. Using the brake rather than the motor has two main advantages:

1. In an emergency, having the skill to drop will save the day.
2. Using the motor rather than the brake and having an accident as a result could lead to problems of insurance, because the equipment is not being used for its designed purpose. The motor can only be used with the ship stopped over the ground and with power available, so walking back is not an emergency option. Habitually walking back, it has been found, only leads to an inability to drop the anchor at all due to the progressive seizure of parts.

Recommendation

The brake should be used with due care. Practice should be a minimum of monthly for each windlass. This will involve dropping both anchors at each voyage end, Arabian Gulf to Europe via the Cape. Less frequent practice is considered inadequate.

Anchoring a VLCC

This skill is not taught in college and it is not taught at sea. People arrive on the bridge on their first command, having learned the habits of the people with whom they happen to have served. Due to lack of maintenance of anchor equipment and the increasing size of ships over the last forty years, more and more masters walk the anchor back all the way. This is not generally a good idea, for a number of reasons, as will be shown, though on occasions it may be unavoidable.

Masters act according to their perception

The general belief amongst ship's masters, particularly those who have little or no experience of anchoring a very large ship (VLCC) is that the anchor equipment has not in any way kept up with increases over the years of the mass of the loaded vessel. This is indeed so (reference OCIMF 'Anchoring procedures for large tankers'). Yet the actual tongue mooring stoppers provided on the fo'c'sle of tankers are all the same (78mm), because they limit the horizontal force that can be applied to the equipment of the oil terminal, the single buoy mooring (SBM), which force is sustained at the sea bed level. This safe working load (SWL) is a world standard of 400 tonnes (200 times two). This has been found to be quite satisfactory in winds up to 30 knots.

In some ports, the stoppers are used singly, not in pairs, to limit the force on the equipment at the sea bed to 200 tonnes instead of 400 tonnes. General experience has shown that this available strength is adequate, providing a tug is in attendance and/or the engines are on 10 minutes' notice at all times. From the following data, it is clear that the anchoring equipment is well in excess of the strength of the SBM mooring stoppers.

A typical actual 150,000 tonne deadweight ship, a tanker, say, has anchor equipment rated approximately as follows, as calculated from the classification society rules:

Windlass brake holding force:	395 tonnes force
Cable stopper safe working load:	650 tonnes force
Ultimate tensile strength of cable:	600 tonnes force
Weight of one shackle of cable:	2·5 tonnes force
Weight of anchor:	10 tonnes force
Lifting power of anchor windlass*:	32 tonnes force

(This is based on the rule of 47·5 x diameter squared, newtons*. Divide by 10,000 to get tonnes.) Length of cable: starboard 13 shackles, port 12 shackles. Two bow stoppers for SBMs, SWL: each 200 tonnes (78mm stud chain). It is immediately apparent that the cable stopper has twice the holding power of the brake, even when the brake is in the as-rated condition, without fade and the brake is twelve times stronger than the motor.

The International Association of Classification Societies (IACS) recommendation is that the maximum static pull on the brake should be 45% of the ultimate tensile strength (UTS) of the chain cable, the force at which the cable is designed and tested to fail. Proof strength of the cable is in the order of 86% of UTS, so it is apparent that the above brake is 70 tonnes over minimum recommended strength (see Appendix 6.8 for the IACS recommendations). The tendency, on this showing, is for brakes to be made stronger rather than weaker than the recommendation.

The reason for the deemed adequacy of strength of the anchoring equipment lies in the fact that the windlass motor is designed to lift three shackles (82 metres) of cable plus the anchor. There is an allowance of 50% over this for safety purposes on test, but not for in-service use. The brake, which is 12 times more powerful than the motor, is designed to control the mass of the cable in motion; not, absolutely not, the mass of the ship. Therefore persons who attempt to control the mass of the ship by means of the windlass brake or worse, the motor, are not using the equipment as it was designed to be used. They are liable to have an accident. Any weight coming on the cable is induced by the ship mass.

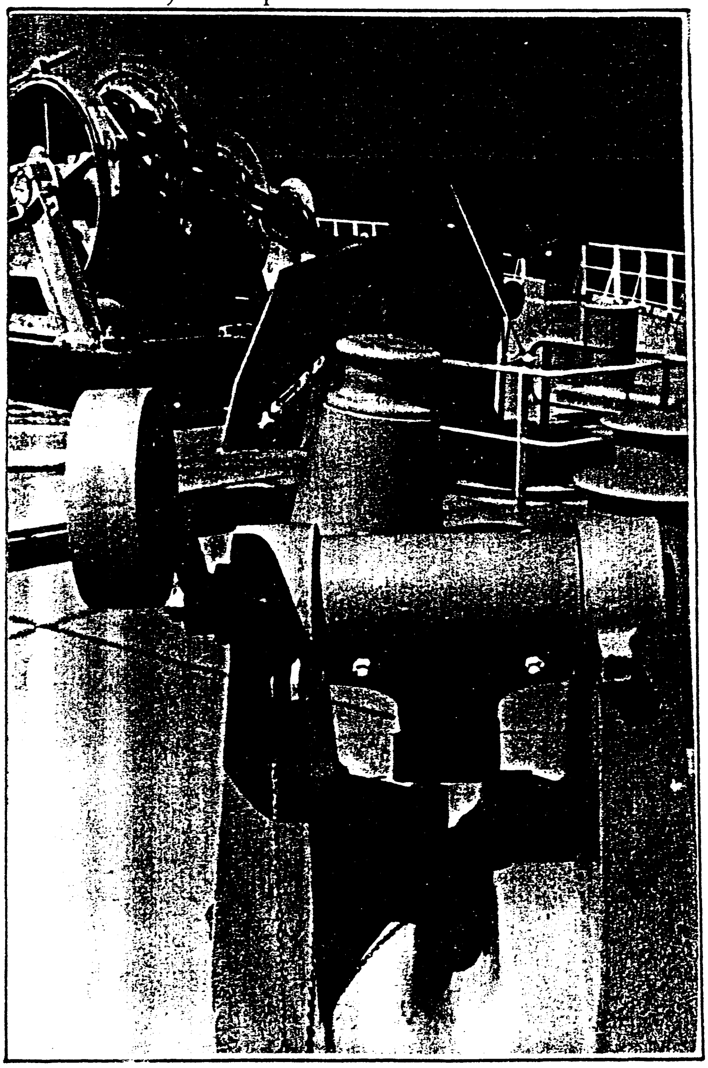

Figure 1 A modern windlass installation (150,000 dwt S.B.T. tanker) 200t S.B.M stopper in foreground. Pawl (guillotine stopped) 650t in background. Windlass behind

The situation as viewed by the classification societies

At present the standard, as stated, is three shackles/82 metres of water, cable up and down, whether hoisting or using the brake. In the case of the windlass motor, there is a proposal by the International Association of Classification Societies (IACS) that the windlass should be capable of lifting the anchor and cable in 100 metres of water, in a wind speed of 14 m/sec (28 knots), and a three knot current, at a speed of 0·15 m/sec (9 m/min). This proposal has not as yet been adopted (Appendix IACS recommendation). This would lift 10 shackles of cable in 30 minutes, which is approximately one and a half to twice the speed encountered in practice. Almost all ships are designed to the 82 metre rule.

There is no classification society rule for the testing of the brake. The brake is tested by the shipyard on trials. Some yards evade the full depth. However, test or no test, the designed strength remains the same, and provided the calculations are correct the brake should operate as designed. The inference is that if the cable must be recovered in 82 metres of water, then presumably the brake must be capable of arresting the cable in that depth. This is the depth specified by the manufacturers.

The situation as viewed by the deck machinery manufacturers

The manufacturers state that the anchor should be dropped on the brake at some point from the hawse pipe to the sea bed, but that the cable must be kept vertical whilst the operation is by the brake, because of the risk of overload. Contrary to popular belief, it makes no difference to the speed of dropping whether the drop is made from the pipe or from sea bed level. This is because terminal velocity is $\sqrt{2gh}$, regardless of weight or density, water friction ignored. Dropping is made at sea bed level to protect the anchor (where g is 9·81 m/sec/sec, the acceleration due to gravity and h is the depth in metres). The manufacturers do not recommend walking back all the way, because of the difficulty of avoiding over-speed and/or overload of the windlass motor, which leads to internal damage. This practice was initiated without consulting them.

The pawl (guillotine or bar stopper) must be engaged and the motor declutched when the drop is finished, with the cable up and down. Windlasses are not designed to pull all the ship. They are designed to control the weight of the cable only at a reasonable speed (as slow as possible) in up to 82 metres of water maximum, with the cable up and down throughout the operation – not leading even short stay and certainly not long stay.

The usual method of anchoring can cause an accident, so is mistaken

This statement does not mean that we are all unwise. However, the solution to the perceived problem of using the believed-to-be inadequate brake of VLCC windlasses by using the motor to walk back the anchor all the way instead is itself also a problem, but a less obvious one. The usual method of anchoring a VLCC is to approach the position stemming the tide and wind, then to stop the ship, put the engine astern, possibly full astern. This is itself potentially damaging in the engine room due to the vibration induced, particularly on a steam turbine ship. The ship goes astern very slowly, at approximately 0·1–0·2 knots. This is 0·05–0·1 m/sec, 10 to 20 feet per minute – no more, over the sea bed and is exceedingly difficult to judge accurately without sophisticated navigation aids such as Doppler log, ground stabilised or GPS in an open anchorage.

The anchor is then walked out until just above the bottom or until it just touches the bottom, in which case the direction the cable starts to lead indicates the direction of drift of the bow. Then:

A The anchor is then taken out of gear and let go, controlled by the brake.

B Alternatively, the anchor is walked out all the way, not being taken out of gear at all, by means of the windlass motor. This not recommended by the manufacturers of windlasses.

Failure to ensure that the ship is, in fact, going astern may cause a fouled anchor, because the cable is laid over the anchor, which itself lies on the bottom shank forward instead of aft. Therefore when the weight comes on the cable, the cable is liable to be pulled back over the anchor, with consequent possibility of fouling. Then the anchor has to be pulled round by 180°, either capsized or, worse, horizontally. This last has, on occasions, broken the shank of the anchor.

If the depth of water is in the order of 50 metres, two shackles being equal to 55 metres) and the final length of cable is 10 shackles, then the difference in horizontal movement of the ship from the moment that the cable is up and down to the moment that the cable is bar taut is, by Pythagoras, 49·3 metres. This is very nearly the width of the ship, which is between 50 and 60 metres, usually (see figure 2).

If the depth is one shackle, say 27 metres, and the cable out five shackles, then there is only 25 metres before the cable becomes bar taut. The actual allowed distance is nil, because the cable is supposed to be maintained up and down and to do this when anchoring with the brake is quite easy (method A). However, to maintain the cable up and down whilst walking back is almost impossible (method B). The distance moved whilst maintaining the cable vertical depends on the speed of veering the cable with respect to the speed of drift of the ship. This is not difficult with the windlass brake, but is extremely difficult using the windlass motor.

It is absolutely necessary, therefore, to halt the ship's astern movement over the bottom before the cable becomes out of the vertical; and ships are very slippery in the fore and aft line: they are difficult to hold stationary, particularly where there is no reference point. Otherwise, the windlass brake or motor, designed to control the mass of the cable and anchor vertically only, will be being used to try to effect the deceleration of the mass of the hull. This is a so much a greater force than that for which the brake was designed that it is difficult to describe adequately. The motor is not designed to lower the cable in this manner at all.

Failure to achieve this halt to the ship's astern movement will result in a bar taut cable with no elasticity left by virtue of all the catenary having been used up – the astern movement being attempted to be arrested by the fo'c'sle crew with the brake. Long before this situation, the designed maximum forces, therefore stresses, in the brake or motor have been exceeded. Because the ship is proceeding astern, the full mass of the ship comes on to the brake, so the force being exerted is approximately one thousand times the maximum allowed force in practice.

Had the designer been asked to design a brake capable of arresting the mass of the ship, the scantlings would be of the order of the propeller shaft. The new stern towing brackets designed by Pusnes, for example, are massive. No mention of acceleration; solely steady state towing forces of 200 tonnes. If the reader is still not convinced, consider now that other operation that regularly takes place on the fo'c'sle, the securing of the 78mm chain in the tongue stopper for the SBM.

Securing the chain stopper of the nylon cable connecting the VLCC to a SBM

The brake that is used here is the mooring brake, which has a rated holding power as tested of 47 tonnes, regardless of the size of the ship. The stopper is always put on with the nylon cable slack. Only when the chain tail is secure in the stopper, and the securing pin home, is the weight allowed to come on the nylon cable, very gently.

Yet people talk about swinging the ship about on the anchor brake or the motor, without the point of ground/sea bed reference that the SBM provides. There is only one component in the anchor handling equipment capable of sustaining the inertia of the ship, the pawl (guillotine stopper).

If the design forces are exceeded the cable will run out

In this case, before the cable can be halted, it has run out to the bitter end. Detachment of the bitter end from the cable locker then occurs and the cable is lost. If such brake failure takes place in a big way, centrifugal reaction causes the whole cable to rise up off the gypsy in a great arc about 10 metres high. When the bitter end is reached there is no discernible pause. The end comes out of the locker and flails forward on to the deck, where it may cause a split in the 20 mm deck plate, doing severe damage as it disappears from view. All this happens in about 12 seconds, with deafening noise and flames.

The practice of walking back the scope all the way on the windlass is largely caused by fear of the above scenario

The practice of walking back all the way has other unpleasant surprises, too. The lifting power of the windlass motor is, typically, less than $^1/_{12}$th that of the brake holding force, as already seen. The motor, as already stated, is designed to lift the anchor and cable in a maximum of 82 metres of water, vertically.

Imagine for a moment that one was using an overhead gantry crane, but one where the wire and the gantry were greatly over-strength. Suppose that a load to be hoisted consisted of a large container. Imagine that this container was then progressively loaded until the weight in the container was ten times the original, safe, load. Now imagine what would happen to the motor and gear box if this overload was then lowered to the deck. Clearly, the components of the motor and gearbox would be grossly overloaded and damage would result. This is exactly what happens when the anchor and cable are walked back under load by the windlass motor, if the cable is not vertical.

The braking effect of the motor occurs because the mechanical advantage of an hydraulic motor plus gearing is more than 50:1. A gear ratio of 50:1 or more is not capable of running back on itself. In fact, a Sumitomo hydraulic motor alone has a reduction ratio in the order of 180:1, so there is no way it can be overrun. Instead, if the rated lifting power of the windlass motor is exceeded – which is very easy to do by allowing the cable to get out of the vertical so that part of the mass of the ship comes on to the motor – then what happens is that the casing of the hydraulic motor may become progressively over-pressurised, and so the allowable designed internal forces on the motor components also become excessive.

This always gives rise to metal particles in the hydraulic oil which, because filters on the pump are quite coarse, go through the pump, causing further similar damage. If you are a master who habitually walks his anchor back, it is suggested that you now ask your chief engineer to examine the filters in the anchor windlass hydraulic system. You will probably find metal fragments as described, for the reason given.

Two other adverse effects exist of walking back the cable all the way

The first is that the casing of the hydraulic motor may crack and, on occasion, does. This has the result that the anchor cannot be raised again. The cable has to be buoyed, disconnected and slipped, to be recovered later, if possible, at very considerable expense. The only reason that the casing does not crack more often is because of the huge extra strength that the designers have put into it, knowing that users will abuse it if they are able to do so, quite unintentionally. If your windlass is steam, then the stress that walking back puts on the valve gear, which is operated by an 'eccentric' disc, is colossal. Such an eccentric cannot be driven backwards. Failure of the eccentric is very common due to trying to rotate it by the valve gear and leads to difficult and time-consuming rectification by the ship's engineers, with the likelihood of reduced windlass power because of errors in resetting.

The second, more common and more dangerous happening is that the windlass clutch jumps out of engagement. This happens for a number of reasons, regrettably most often because the clutch lever securing pin has not been inserted or not secured. Added to this is the fact that the windlass clutch 'dogs' are manufactured straight crosscut, instead of slightly rebated, as would be most desirable. Because the clutch dogs are straight, most force comes on to the ends, with the result that they always wear slightly tapered. This in turn causes lifting torque on the shaft to result in a secondary parting force on the clutch, which is sometimes sufficiently strong to overcome the restraint of the operating lever securing pin, especially if the clutch dogs are well greased.

In addition to the above, the dog-clutch operating fork, which runs in an annular groove cut in the clutch sliding part, is a weak spot and has been known to deform and spring out of engagement owing to this parting force, caused by tapered wear of the dogs, as described. This accident has the same effect as releasing the clutch lever, as above. In both the above cases, the effect is to release the anchor suddenly with the brake off. It is very difficult to get the brake back on in time, because the crew are quite unprepared for this eventuality. To arrest the cable before the speed has built up too fast to stop takes very quick physical reactions – partly because the available length of cable in the locker is no longer there. This is a frequent mistake.

Walking back the anchor and cable to full scope, all the way, itself can lead to accidents

Whilst the anchor is walking back, which may be very slow and on big VLCCs as slow as 7·5 cm/sec (15 ft/min) or even slower, the brake is normally off. This speed is slower than the speed at which the ship can normally be controlled. Walking back 10 shackles at this speed takes a long, long time – half an hour minimum, usually 45 minutes – so the tendency is for masters to use less cable than they should. This leads to dragging and consequent grounding – the writer is thinking of a particular recent case in Delaware Bay due to this.

Walking back, with stress coming on the anchor before there is sufficient cable to protect it, can also lead to over-stressing of the anchor itself with consequent fracture. This has happened on two occasions at Itaqui, on one occasion leading to the total loss of a very large bulk carrier on her maiden voyage. Her wreck is still there, a warning to others. The second occasion led to the fracture of the anchor at the join of the shank with the flukes. Who can possibly keep the bow of his ship under control for half an hour with the cable up and down, let alone one hour or more?

So care in keeping the cable fore and aft and walking back all the way can lead to the accident this procedure is designed to avoid

People have the kinds of mishap described above because they are being very, very careful, but operating the whole system in quite the wrong way, for wrong reasons.

There is another, safer method of getting the anchor and cable laid out on the sea bed

When our grandfathers in the navy anchored, they wanted to be secure in the knowledge that they could maybe have a pink gin, or possibly a huge party and know absolutely that the ship was not going to move. So what they did was to steam with the tide and or wind, whichever was stronger, put the helm hard over and just as the ship started to swing, let go the cable on the run on the inside of the turn. They then ran it out to the required length, set the stopper and allowed the anchor and cable to snub the ship round into the weather. This set the anchor and the whole operation was over in about four minutes. By today's standards this sounds deeply shocking.

The navy still anchor in a very similar way, except that they use the brake a bit, which is not the purpose for which it was designed, as already exhaustively described. This added 'caution' they caught from their merchant service colleagues, no doubt. This practice of 'running out' had its roots in the days of sail, where Admiralty pattern (Fisherman) anchors with stocks were used and the danger of fouling the flukes was a serious risk. The anchor absolutely had to set correctly first time – no engine to get you out of trouble, so no second chance.

Such an anchor must lie on the sea-bed in the correct direction, without any possibility of fouling. Therefore the hull movement had to be sufficiently brisk to ensure that the rope cable did not get entangled in the flukes or the stock. This happened naturally, because a sailing vessel's tendency when stopped with the sails aback is for the bow to fall off the wind, which gives the necessary sideways movement which is the secret of safe anchoring. The same thing applies today – it is fatal to get the cable fouling the anchor.

'One could not possibly do that in today's ships', you say. Certainly not deliberately, but one 250,000 tonne VLCC did just that by accident in the early 1970s. She was steaming towards Kharg Island, in

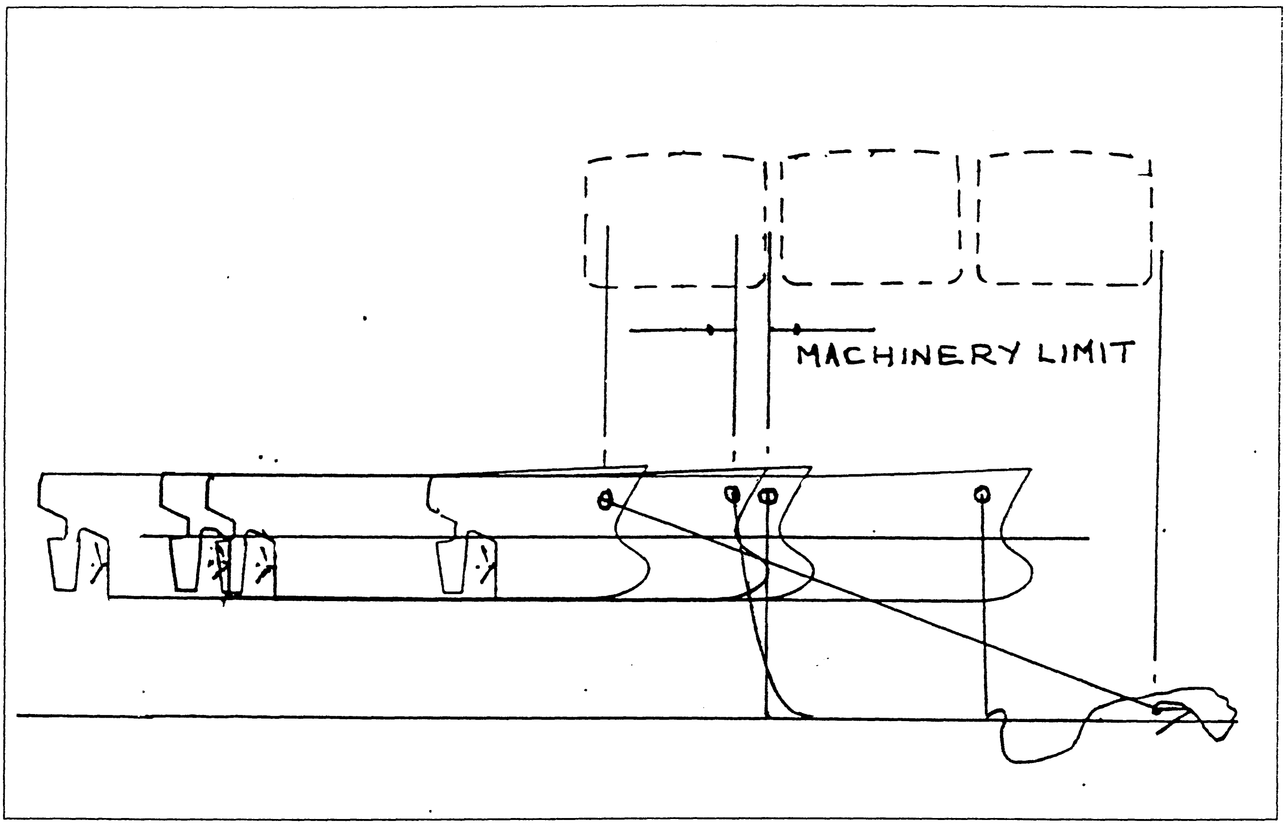

Figure 2 From up and down to bar taut is only one ship's width in 50 metres water depth

ballast, at 19 knots when the starboard anchor was accidentally let go. Due to the great beam and the bluff hull form forward, the cable was deflected to the ship's side and the ship was turned by the cable 180° without the bitter end parting. How can this possibly happen? Is there a clue here in a safer way to anchor?

The secret lies in separating the momentum of the ship's hull from the forces necessary to control the movement of the cable

The reason is the difference between momentum of translation and momentum of rotation. This principle is seen in the operation of salvage tugs. When the load is taken up, it is observed that the tugmaster always aligns his tug at right angles to the fore and aft line of the ship towed. The ship is easily canted and the tug is then gradually aligned in the fore and aft line. This effect is well known. It avoids snatch of the tow wire.

To demonstrate this, you can take a walk into a marina and choose a small yacht. Push hard on the stern with your foot in the fore and aft line and the yacht will not move – you are trying to shove about five tonnes in a straight line. Now move round to the side and push at the end on the stern (or the bow) at right angles to the fore and aft line. The hull is easily deflected because the inertia, instead of being five tonnes, is now one tonne, with no friction and this can be moved quite easily. One can also make a small desktop model to demonstrate this (see model.) How does this work?

Axial inertia allows only the cable slack for deceleration of the whole mass of the ship

Taking the case of the coaxial push in the fore and aft line first, force = mass x acceleration (F = MA). Let the available distance for the ship to come to rest = S. Then, by the standard equation of motion:

$V^2 = U^2 + 2AS$, where U = final velocity = zero and V = Initial velocity = coaxial speed astern when the anchor is let go/commenced walk out, A = deceleration of bow and S = distance required in which to stop the ship. Therefore the available distance to stop ship's translation is:

$$S = \frac{V^2}{2A} \quad \text{and } A = \frac{V^2}{2S} \quad \text{so } F = \frac{WV^2}{2gS} \text{ (newtons)}$$

between V = V, V = 0, where W = weight (that is displacement) and g = acceleration due to gravity.

Although it is correct to express force in newtons, a more realistic unit for calculations of this sort is tonnes (force). One newton is the force required to accelerate one kilogram-mass by one metre per second per second (kilogram-mass = kilogram-weight/acceleration due to gravity)

= 1 kg/9·81 m/sec

So one newton is approximately 1/9·81 kilograms, or 2·2/9·81 pounds force = 0·22426 lbs force, depending where on the earth's surface. (A quarter of a pound is the size of an apple, hence the name).

So $F = \frac{MV^2}{2S}$

or, momentum equals half mass multiplied by the square of the velocity and the force required is inversely proportional to available distance.

That this must be so is made clear in the following analogy. If you are driving a heavy lorry and the traffic lights turn red, you may or may not get the vehicle stopped in time -- it depends how fast you are going, how much stopping distance is available, how heavy the lorry is and the steepness of the slope down to the lights. So, whether you get the cable stopped in time depends how fast it is running out, how much remains in the locker and how deep the water is, because depth governs weight of cable. The comparison between linear deceleration and angular deceleration is as follows :

Axial case (see Appendix for total derivation)

$F = \frac{MV^2}{2S} \quad F = \frac{M(L/m)^2}{2L/n}$

where m is a number such that $L/m = V$,
M, mass $= \frac{W}{g}$
where n is a number such that $L/n = S$ and L is the ship's length, whence

$F = \frac{MLn}{2m^2}$

the force to decelerate the rectangular block in a straight line (block coefficient of 1).

The foregoing leaves out the mass of the ship, because when considering prismatic sections in plan, mass terms are equal in both equations, so for purposes of comparison the mass may be ignored. This is the usual steel designers' method. This is why steel tables give second moment of area of section, not moment of inertia of section, which varies depending on the specific gravity of the material being used. (Dorman Long steel tables.) Actually, to quantify these forces directly, the mass would have to be included to get the correct answer, but we just want to compare the effects of motion.

Rotational inertia is less than axial inertia

Now consider the same rectangular section body being accelerated not axially but rotationally. The variables are expressed as fractions of length (L) in the same way as in the axial case, so that the result is directly comparable, independent of integer values.

Let T = torque = force x radius (FR)
I = angular moment of inertia
@ = angular acceleration, in radians per second (alpha)
There is a relationship that T = I@, so $F = \frac{I@}{R}$
where T = FR

I, angular moment of inertia, is mass x radius of gyration^2. This rotational moment of inertia is also expressed as Ipp = Ixx + Iyy (also true when comparing the second moments of area).

That is to say, the inertia around the vertical axis of rotation equals the sum of the moments of inertia around the fore and aft axis plus the moment of inertia around the athwartships axis. The moment about the fore and aft axis is very small for a body such as a ship, in the region of 3%. It can, therefore, be ignored. Direct comparisons between plan moment of inertia about the athwartships axis can thus be made with very little appreciable error.

The radius of gyration^2 of a rectangle about its axis through the centroid is:-

$\frac{L^2}{12}$

and the second moment of area is

$\frac{BL^3}{12}$

whence

$F = \frac{ML^2V^2}{12R\ 2S} = \frac{ML^2\ (L/m//2/L)^2}{(12L/2).2.(L/n//2/L)}$

where L/2 = R and n, m are factors as before. Therefore:

$F = \frac{ML}{6}\left|\frac{\frac{2}{m}}{2 \times \frac{2}{n}}\right|^2 \quad \text{so } F = \frac{ML4n}{6 \times 4m^2}$

whence

$F = \frac{MLn}{6m^2}$

the force required to decelerate the rectangular block through the same distance angularly as to decelerate the block in a straight line. This is one third of the force to decelerate the block in a straight line. Just for a moment, consider what this means.

If the fo'c'sle officer is decelerated axially in the fore and aft line in the first case with the bow on which he is standing, he will have moved through a distance fore and aft equal to the beam of the ship and the force will be, say, F newtons; because we have chosen the beam as the distance constant to make the comparison. In the second case, he will have been moved through exactly the same distance in the same time, but at right angles to the fore and aft line and the force will have been exactly one third of the force in the axial mode, F/3 newtons. But we have considered a rectangular block, block coefficient 1.

Ships are not rectangular in plan view or in mass distribution

In fact, ships are not rectangular. Their shape is pointed at the bow and stern. Suppose the block were cut down the centre line, so that it consisted of two blocks, each of width B/2. Clearly, the rotational inertia of the two together remains the same, so the inertia of the half block is exactly half of the whole block.

It can be seen that, in an extreme case, a hypothetical ship might have a plan mass distribution not rectangular, but diamond shaped, being approximately two triangles base to base. This is a block coefficient of 0·5. The removed mass is greater with an increase of radius and therefore the radius of gyration is less, not greater, than half the radius of gyration of the half rectangle.

This is found to be the case, so that the second moment of area of two triangles base to base, the axis coincident with the common bases, is:

$$\frac{BL^3}{48}$$

This is one quarter of the second moment of area of that of the rectangular block, whose breadth is equal to the base length of the triangles (see figure 3). However, this actual planar area of the diamond is only half that of the rectangle.

Clearly, $^1/_4$ of $^1/_3$ is $^1/_{12}$ and if the ship had a triangular plan view from amidships both fore and aft, the rotational factor would be 12/2 = 6 – because the mass would be half of the similar rectangular block. So the maximum possible reduction factor of rotational inertia compared with axial inertia is six, the minimum three.

Cable management at right angles to the fore and aft line reduces cable force owing to increased distance to decelerate the bow

There are, however, two further reductions in anchoring forces when the cable is made to lead out on the beam instead of fore and aft. One is because the cable and the ship make two sides of a right-angled triangle. The mass of the ship can therefore move a further distance, which is approximately her own length if the length of cable equals the length of ship (10 shackles being 274 metres). Furthermore, the cable is dragged in an arc over the sea bed, which has a retarding effect. Obviously, this is not a good idea if the ground is a coral reef, but one hopes such a site will not have been chosen.

The available length to retard the ship is therefore increased by 274 metres, to which is added 49 metres, the original distance available if the length out is 10 shackles (274 metres), in 50 metres of water, making 323 metres. The retardation force necessary is inversely proportional to the distance available, we have already seen, because

$$F = \frac{WV^2}{2gS}$$

We have increased S, the distance available, by a factor of 323 / 49 = 6·59 = 6·6. This is a factor times the saving due to managing the inertia rotationally instead of axially, which factor lies between three and six. A factor of 3.·5 is reasonable and conservative. Any attempt to be more exact is not necessary for this exercise. 3·5 x 6·6 = 23 times less force on the cable. In other words the cable, when used at right-angles to the vessel, is about 23 times more effective than when used axially, which is why people who anchor in this manner so seldom have accidents – these are very sound reasons indeed for so doing.

There is a further reason for keeping the cable at right angles to the hull

If the cable is at right angles to the hull, the fore and aft movement is not transferred to the cable. Consequently, if the master has got his speed wrong and is going too fast, the mass of the ship will not alter the tension on the cable, or only minimally. This is because

$F_a = F_c \cos \emptyset$, Axial force = Cable force x Cos Ø

For fore and aft movement and the cable fore and aft also, Ø is 90 and Cos Ø is therefore 1. For fore and aft movement and the cable leading out at 90°, Ø is 90, and Cos 90 is zero. The hull mass has been kept separate from the weight of anchor and cable and the allowed forces are not exceeded (see figure 4).

There is an analogy here with horses – breaking a wild horse on a long rein called a lunge, the beast is kept at right angles to the trainer with the aid of a long whip. Allowing the animal to get end-on, either back or front, puts the whole weight against the trainer and control is lost. The principle is very similar. There are other advantages as well. The bow bottom surface may have delicate equipment installed.

The bow of a modern warship has a lot of expensive and delicate items installed on the bottom surface, right forward, in a dome. Also, a large tanker has at least three very sensitive, delicate items under the bulb – an echo sounder transducer plus two, sometimes three, Doppler transducers. These are glass. There is also the paintwork. It is essential not to allow the cable to lead under the bow.

Engine failure is a powerful reason for having the skill to anchor a ship which is moving

Modern merchant ships are powered by diesel engines, which are two-stroke. They can and sometimes do fail to start when needed. This means they fail to go astern. More rarely, they cease to operate when running, which can be much worse. The writer has experienced two occasions when a diesel engine has failed whilst running; three occasions when it has failed to start again when stopped in a critical place (more occasions in uncritical places) – on each occasion the anchor saved the day, four times when a steam engine stopped and two occurrences when it

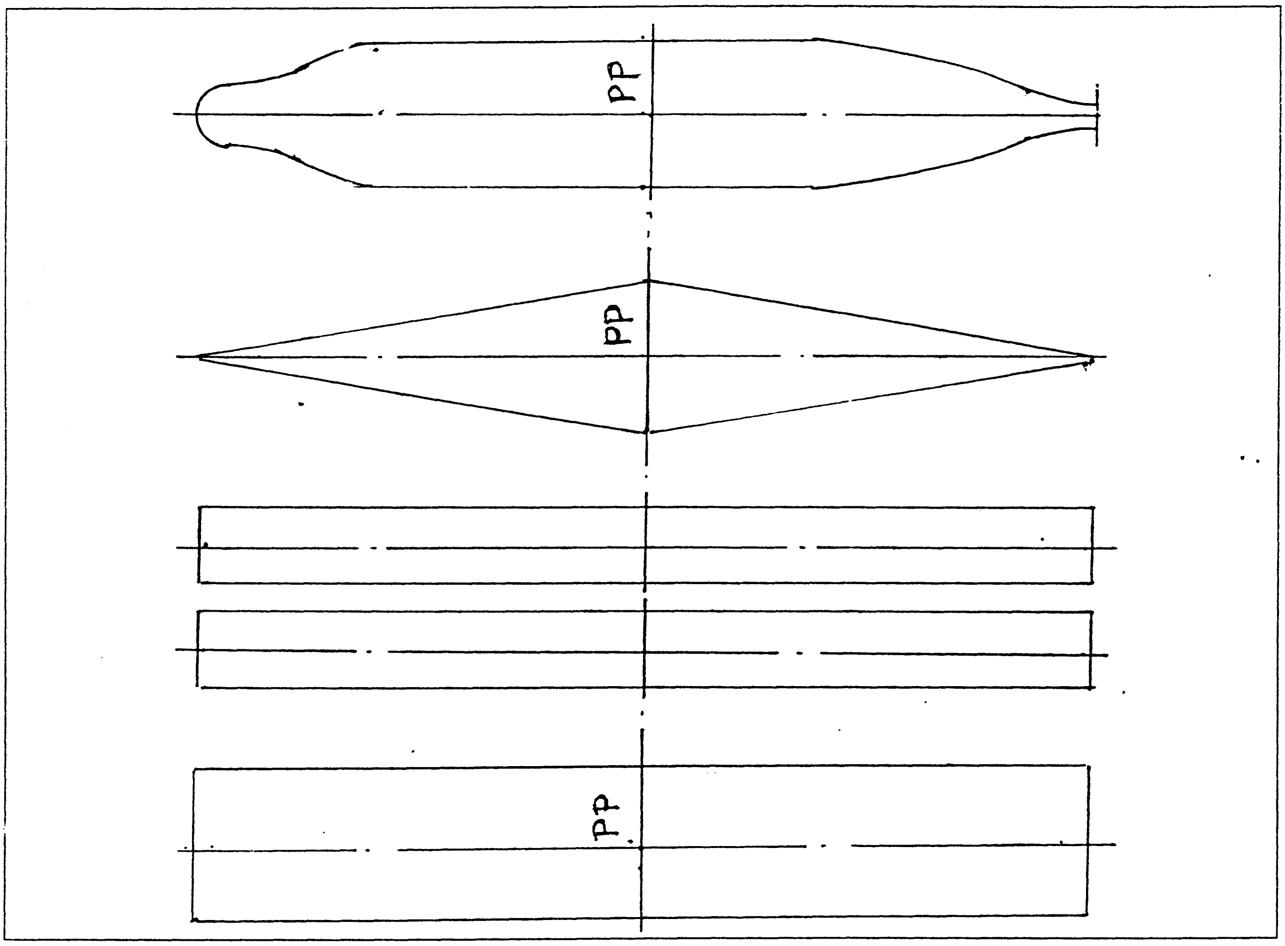

Figure 3 The ship's hull plan section area is less than a rectangle, but more than a diamond of half the area

took a very long time to get a steam engine going after it had stopped due to blackout; once fourteen hours and once no less than four days and nights. On many occasions, both the motor or steam engine has blacked out for short periods.

One also needs to be able to anchor on the run when doing a Mediterranean moor, such as at Jebel Dhana, or very similar facilities in North-West Australia. Had the tanker *Braer* been able to use her anchors, the ship would have been less likely to go ashore on the Shetland Islands. The bottom was only 60 metres down, well within the capability of a ship's brake, properly maintained. With the confidence imbued by lots of practice, the master could have used his anchors, despite the weather. He could at least have tried.

Having the anchor ready, knowing how to drop it from the pipe, is a very large plus in one's safety equipment skills arsenal. Dropping the anchor from the pipe is a skill that can save the ship – possibly your life and your job. If the anchor is dropped, it should never hit the bulb, provided the brake is held open, because the hawse pipe leads outwards. In an emergency, if it does hit the bulb, it does not matter. The writer has personally never served in a ship where this has been a problem.

The correct procedure for anchoring using the cable at right angles deployment method (orthogonal anchoring)

The objective is to let the anchor go with the bow moving sideways over the sea bed, at about 0·5 knots. The actual speed of the bow may be much greater by this method. The writer has done it successfully with no problems at all at speeds in excess of 4 knots, in an emergency. But four knots sideways, not ahead or astern.

The cable must lead out on the beam – it is not possible to overemphasise this – and be maintained on the beam until the speed of the ship is zero. The ship will not maintain her way sideways, owing to the great projected area and un-hydrodynamic form.

Preparation

The equipment was tested when the ship was new. Every new ship undergoes anchoring trials and the anchors are dropped and recovered several times to ensure that they operate as designed, with very rare exceptions. Good seamanship is ninety nine per cent preparation. It is therefore necessary to make careful pre-operational checks, including these:

1. The brake drum should be in good condition – not coated with rust and resin.

2. The brake lining should also be in good condition, adequately thick. It does not matter too much if the bolt heads are flush with the brake lining, but better still if they are recessed, countersunk.
3. The brake band joints should not be seized.
4. The brake band bottom support stud-bolts must be correctly adjusted, otherwise all the wear will come on the top half of the band.
5. The brake actuating lead screw should be clean, free from rust and well greased. The form is Acme, which is a square cut. If the thread is at all rounded, it is badly corroded and worn.
6. The brake clutch dogs should be clean, the surfaces dry, the sliding part only greased.
7. All bearings greased and free of grit.
8. The clutch actuating fork should be in good condition, without slack and not corroded away.
9. **Warning** – the adjustment marks should be within the makers' limits. This is particularly important with regard to 'hydraulically operated brakes'. (This term is a misnomer.) In order to be fail-safe, the brake of such a windlass is put on by a powerful coil spring and released hydraulically. Because the mechanical advantage is very large, any wear of the brake band causes large movements of the adjustments. It is necessary to check this at each and every operation. Also, and this is most important, when doing any change-over from manual to hydraulic or vice-versa, always ensure that the pawl is fully engaged down with the safety securing pin fully home. This is because there have been losses because the brake can become released inadvertently during change-over from manual to hydraulic or back.

Another point that must be checked is that the brake, when operated by hand, is actuated by a lead-screw through a nut which is connected to the brake operating arm by a pin. The nut in the manual mode is at the bottom of the arc of a radial

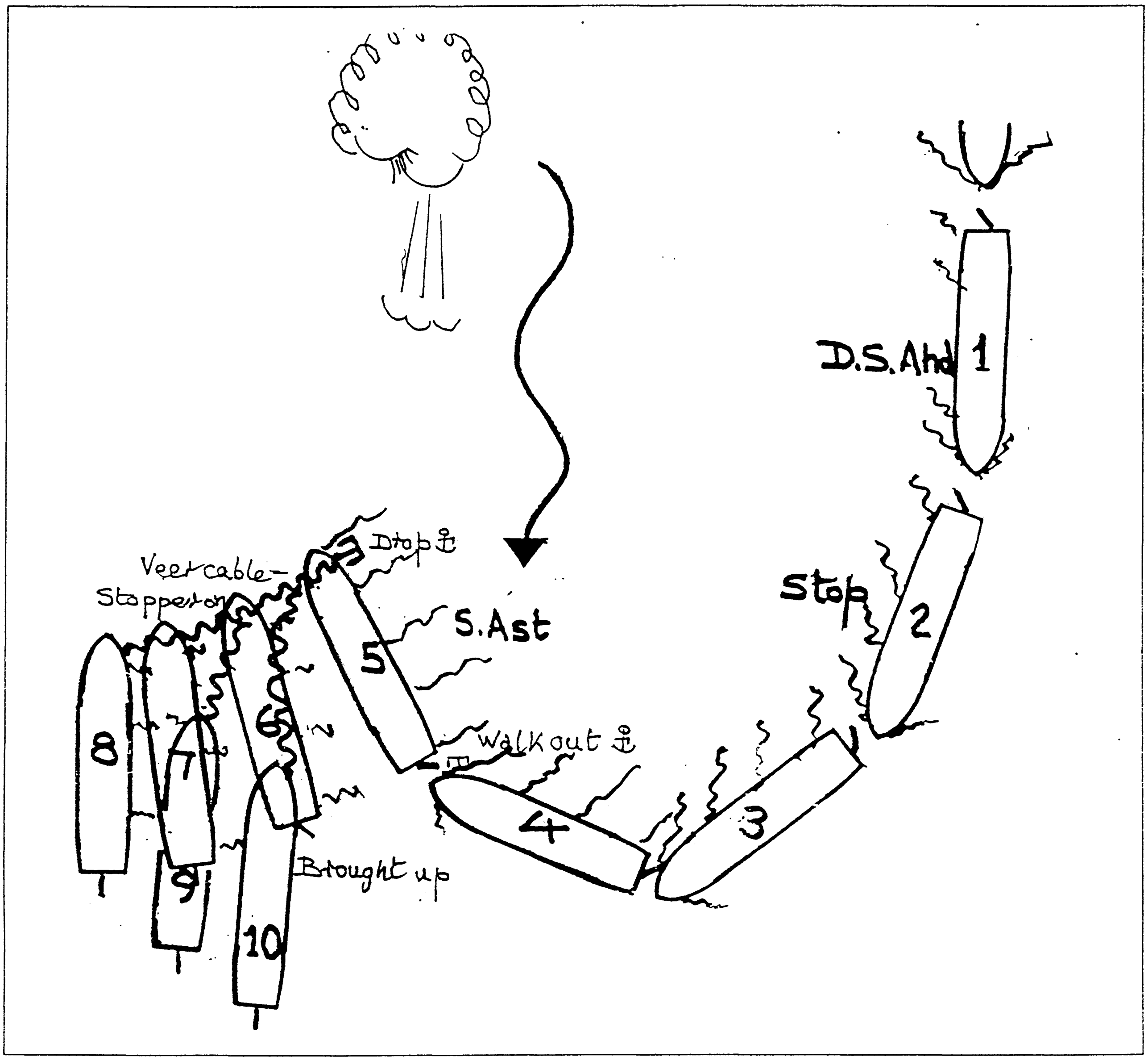

Figure 4 Turn in a strong tide and wind

slot in the end of the brake actuating lever arm. Putting the brake on moves the whole arm by means of the nut travelling up the lead screw, this movement being transferred by the pin to the brake actuating lever arm.

For hydraulic operation, keep the nut in the centre of the slot

When changed over from manual to hydraulic release, the nut must be moved towards the centre of the slot to allow the arc free movement about the now stationary nut. Failure to ensure this will lead to an accident, because any contact during operation of the nut by either end of the slot will act as a stop and so arrest further movement of the brake actuating lever. It is a good practice to paint this safe arc green and the arc on either side red, to make it obvious.

Second adjustment

There is a second adjustment down in the mechanism at the first joint. This adjustment tolerance is about 50mm long, usually marked by an engraved brass or stainless steel plate – one must take care that this is in adjustment also, because it represents spring compression. Provided the spring is correctly compressed, force exerted by the spring is greater than force exertable by hand, so hydraulic release is to be preferred.

Some ships have a disc brake in addition to the band brake and this is applied hydraulically. Direct hydraulic application is not fail-safe in the same way that spring application is. Furthermore, still other windlasses have a hydraulic speed-limiting device which operates on the same principle as a motor car fluid flywheel. This may be used with a brake of various designs, but usually with a band brake, spring operated.

Yet others have a hydraulic speed limiter which operates by the windlass shaft driving a hydraulic pump through a heat exchanger and a needle control valve. This will actually arrest the cable as a brake, although it is possible to over-stress this equipment for the same reasons that motors get over-stressed. The standard equipment is a band brake, dependent on the training and care of the fo'c'sle crew.

You have now completed the necessary checks that the equipment is truly in correct working order, by inspecting it personally. If things go wrong, the master will most certainly be held responsible. So, as master, it is prudent to look at it oneself, in addition to any work given to others. The checks are very simple, but the consequences of wrong equipment or wrong operation are so serious that much extra care must be taken.

Pre-anchoring operational briefing

Before the anchor is to be let go, there need to be two pre-operational briefings. The first briefing is a training session to ensure that the personnel concerned know absolutely how the equipment works. Very often, masters assume that because the crew use equipment frequently, they understand how it operates. This is not necessarily so. Therefore, one must make sure they understand what each item is, so that when instructions are given from the bridge, the correct action is carried out.

The second briefing is just before anchoring, to ensure that they understand that:

1. There are to be two men on the brake – the rated force can not be applied by one man alone.
2. That the anchor will be lowered to an ordered number of shackles on deck, say two, prior to taking out of gear and letting go on the brake.
3. That when the cable is released, the cable will be let out in a controlled manner so that each link can be followed with the eye. If each link cannot be followed with the eye, then the crew do not have control and therefore the cable is being allowed out too fast.
4. That the cable is kept running out until the desired length is all out. This is contrary to what the majority of masters learn from others. However, when the brake is first let go, the cable is not under control until the brake can be tightened up again because, to release the cable, more slack needs to be put on the brake than the amount of slack necessary just to keep it running at the desired speed. If you stop the cable at say, eight shackles and wish to put out nine, and the total length available is twelve, then when the brake is reopened for the last shackle, there are only four shackles left in the locker, not twelve – the margin for error is greatly reduced. This stopping and starting has been found to cause accidents, so should be avoided. Nevertheless, some windlass manufacturers stipulate stopping and starting to avoid brake fade. It is the experience of the writer that one gets more brake fade stopping and starting than doing it all in one go. The reason for this is that a VLCC cable link weighs around a third of a ton. Considerable force is required to change the chain from straight line to curve over the gypsy and back to a straight line again, and this itself has a braking effect.
5. That when the cable is out to this desired length, the cable is stopped moving by the brake, and the pawl (guillotine stopper) put on and the safe pin fully engaged to keep it down whilst the cable is stopped and still vertically up and down. This is the crucial point of safe anchoring. The brake is designed for controlling the movement of the cable. The pawl (guillotine stopper) is designed for holding the mass of the ship. Therefore the pawl must be engaged whilst the cable is still up and down. The brake is emphatically not designed to control the mass inertia of a VLCC. Consider this; If the force generated were sufficient to carry away the cable, with a proof load of 600 tonnes,

generated were sufficient to carry away the cable, with a proof load of 600 tonnes, how much more would it carry away a brake with a best proof load of 395 tonnes? Or a motor, with a rated load of only 32 tonnes?

6. When the pawl is on, the bridge is to be kept informed of the direction of the lead of the cable, which, as already exhaustively explained, must be kept on the beam until all movement has ceased. Then and only then may the cable be allowed slowly to draw ahead.

Method of approach to anchorage, the anchorage manoeuvre and letting go

In order for the bow to be at about twenty degrees off the weather and moving sideways when the anchor is let go, this must occur at the end of a tightly executed turn of about 135°. The hull will not maintain sideways movement easily, owing to its great underwater projected side area. The ship is steamed slowly towards the anchorage downwind, at about six knots. The speed of approach depends on whether the anchorage is crowded or empty. If the anchorage is empty, 10 knots is quite slow enough. If very full, between two and three knots is prudent. The turning manoeuvre will take off all the speed, no matter what the speed of approach is, 10 knots or two knots.

On reaching a position abeam of where the bow is desired to be, the engine is put on dead slow ahead, and the helm put hard over towards the anchoring position. As soon as the turn is initiated, the engine is stopped. The wind will catch the accommodation, and swing the ship round. Be very careful at this juncture not to allow the wind to catch the wrong side of the accommodation tower, or the ship will swing the wrong way. This wind-aided swing takes all the speed off the ship by hull turbulence. The faster the approach speed, the greater the sideways transfer, which cancels out any tendency to make way the other way. By the time the ship has turned 90°, the speed will be approximately three to four knots.

If the wind is blowing strongly, and the speed of approach at the initiation of the turn is five to six knots and the engine is put full astern on the initiation of the turn, after 90° of turn the ship will be stopped in the water. This is a useful thing to know and worth trying sometime. It is possible to drop the anchor from the pipe in shallow water with a soft bottom now, if necessary, because the whole ship will be moving slightly downwind, broadside. If the ship has fine lines and a small rudder, then putting the engine astern during the turn will tighten the turn and cause the ship to slow up to match her bluffer sister. Usually, by the time the ship is 45° off the wind/tide, she will be stopped fore and aft in the water and drifting sideways. A very small amount of slow astern will ensure that all forward movement has, in fact, ceased.

When the speed by log is two knots, no more, to prevent the anchor banging on the hull, walk the upwind or up-tide anchor out to just above the sea-bed. This is the anchor on the inside of the turn, so if turning to port, the port anchor; if turning to starboard, the starboard anchor. If the water is shallow and the bottom is soft, practice dropping the anchor from the pipe. On occasions, it will be found that the anchor will not drop from the pipe. In such a case, some maintenance must be done later to ensure that it will drop – emergency response is only possible when the equipment operates as you require. It must be possible to let go from the hawse pipe. One day you will need to and if it will not drop then you will have that accident.

However, for normal purposes, to ensure that the anchor is not dropped onto a rock and cracked, being a steel casting, it is walked back until just above the sea bed. Put the engine slow astern and when the propeller wash has reached one quarter of the length from aft, the ship is stopped in the water. Allow for the tide – one wants the ship stopped over the ground. The GPS ground speed indicator is a useful tool to tell you when the ship is stopped over the ground; alternatively the Doppler log (ground stabilised), if one is fitted.

Let go the anchor, allow the cable to pay out to the required length, say 10 shackles on deck, put on the brake, set the stopper with safe pin engaged and wait. The ship will drift slowly sideways. Make the fo'c'sle keep you informed that the cable is either at nine o'clock or three o'clock, as appropriate, keeping it there by small movements ahead or astern on the engine as required. With some practice, no engine movements will be needed at all. What happens next is that the cable pulls out straight along the sea bed, abeam of the ship. When it is straight, the weight comes on gradually, but at right angles to the ship, which causes the ship to turn gently towards the cable.

Control the rate of swing with the engine and the rudder if necessary – usually not. The tension of the cable determines this. Whilst the cable is tight, maintain it at 90° to the hull, until tension becomes moderate to short stay. The cable will now begin to form an arc on the sea bed, as the ship turns and begins to move astern. Monitor the astern movement. Make the cable return to nearly up and down before this swing is allowed to commence. By the time the cable is fore and aft, there is still an arc on the sea bed, which forms a further shock absorber were it necessary, which it very seldom is, unless the weather is quite severe.

This method takes approximately 12–15 minutes from initiation of turn to stopper on, if done without hesitation, smoothly, even on the largest ship. It has been practised many times over many years, and proved to be a safe, reliable method of anchoring by a number of experienced pilots and masters. It also has an irrelevant advantage – it looks really neat and tidy, as indeed it is.

Some factors which need to be taken into account when planning to anchor

1. If the anchorage is crowded, it is a good plan to avoid the centre of the anchorage. Whilst at anchor, the ship is unable to avoid others and is without the capability of manoeuvring. Certain anchorages are notoriously dangerous and should be avoided if possible. The entrance to the Scheldt is one – there is a safe anchorage at Dunkirk close to the south. Ulsan is another dangerous anchorage, due to crowding. Khor Fakkan is dangerously deep except very close inshore, as is Tenerife. A crowded anchorage is best utilised on the edge – it is usually possible to get the bunker tanker to come to you, rather than go to him. Likewise, it is best to anchor away from a fairway.
2. If the pilot wants to anchor, many pilots use the right-angled method anyway. Otherwise, it is sufficient to say something like, 'I prefer the cable to lead out on the beam to protect our new paint job' – if asked nicely, most pilots readily cooperate.
3. The method above should be included in the syllabus for seamanship training, so that good habits are acquired from the beginning. This is a matter for training organisations and the shipping companies themselves. This method really needs demonstration and travelling trainers are a possibility. Doubters only have to be shown once to be totally converted.
4. Knowing how much cable is out is obviously necessary. Modern ships have a cable indicator, but having the cable properly marked and those marks maintained is essential.
5. Both anchors are used in the so called Mediterranean moor. This is used on tankers at berths such as Jebel Dhana in the Arabian Gulf and the island facilities in northwest Australia, fitted with a submarine pipeline, to which is attached a long marker buoy, sometimes called a quill. The stern of the ship is kept in place by a system of, usually, six buoys, which are connected by the ships wires, sometimes with the ship's nylon tails attached, usually without. The ship approaches at right angles to the final berthed line. If the ship is going to end up berthed at 000°, then she approaches at 270°, say, drops the starboard anchor on the run, pays out to nine to 10 shackles, drops the port anchor, then starts to turn to port. At the same time, the starboard anchor is heaved in until there are about $5^1/_2$–6 shackles out and the port anchor paid out the same amount. By the time the ship is turned 90°, she should be on the leading marks for the quill to be alongside about 3 metres off the port side, usually. Sometimes the starboard side. By means of a tug holding the stern in place; but some berths dispense with such a convenience, and use the propeller thrust against the anchor chain to keep the stern in place; the stern wires are run out to the buoys - the abeam windward buoys first. The final position is adjusted by heaving / slacking the wires and the cable. Done right, the ship should be in the correct position first go.
6. Large ship anchors do not lend themselves to dredging. This is because the flukes are thinner for their length than those of a small ship and are more liable to get bent. Dropping the anchor off a berth to use in departing as a means of pulling off the berth is a useful manoeuvre seldom seen nowadays, partly because the windlass motor force is not really adequate in very large ships.
7. When taking into account under-keel clearance, do not consider dropping the anchor to prevent the ship grounding. Under keel clearance is 10% only in estuaries and inland waterways. To allow more is uncommercial. A famous recent case concerned a passenger ship, again in Delaware Bay, which dropped her anchors when the steering gear failed, so ran aground right over them which ripped the bottom open, and necessitated a very costly salvage operation. It is true that the US Coastguard will fine the master who still has his anchor in the hawse pipe, but drop it early, or not until afterwards, to avoid tearing the bottom.
8. Anchor buoys are difficult to manage in practice. If you are going to slip the cable, then of course use an anchor buoy. However, the buoy rope gets tangled in the propellers of third parties and they get under the bow on heaving up, or wrapped round the cable, so that they are almost impossible or very time consuming to release. Rigging an anchor buoy and unrigging it involves passing a wire attached to the cable down the hawse pipe and then catching it with a boathook over the side and pulling it up to the bulwark level, a distance of some four metres above the hawse pipe bellmouth. Then the rope has to be attached. Then the buoy and sufficient rope needs to be put overside and the anchor dropped. On recovery, the procedure is reversed.

Difficulties recovering anchors

There are three main difficulties here.

1. The anchor fluke gets caught under a rock, or a crevice, or in a wreck. This happens rarely but, if it does, will result in a bent fluke. So avoid anchoring on a rocky sea bed, because in addition to being very poor holding ground, there is a risk of damage on recovery.
2. The clutch may jump out of engagement. This frequently leads to anchor loss, because the crew are quite unprepared for it, do not get the brake on in time, the cable runs out too fast to arrest. So, the anchor is lost. This problem has already been described.
3. The depth of water anchored turns out to be too deep for the windlass to recover the anchor and cable.

The maximum depth should not be more than 82 metres. However, not everyone knows this, and there are anchorages of 90–100 metres, such as Khor Fakkan bunkering station. If you have a special anchor windlass, such as some Shell tankers have, this is not a problem, but if there is no special reference in the instruction book, then the limit is 82 metres. The writer does not anchor in more than 60 metres of water if it can be avoided. In more than 60 metres, it is prudent to walk the anchor back against the brake, which is a skilful and dangerous job in deep water, very difficult to keep within the windlass motor strength – better to avoid anchoring at all in such a case.

Some owners stipulate 30 metres as a limit of dropping before the anchor is walked back, or even 20 metres, but walking back in deep water causes more damage than walking back in shallow. Some owners/ managers stipulate walking back because they economise by not supplying brake linings. The logic is that if the brake is dangerous anyway, money can be saved on maintenance by not using it at all. This viewpoint is frequently voiced, but seldom in writing.

Should the ship be anchored in water which is too deep for the windlass motor to lift the anchor and cable, there is a recovery trick as follows. Say the anchor that will not lift is the starboard one, for example. From the port windlass coaxial mooring wire reel, remove the nylon tails, lead the wire out through the fairlead, forward along one fairlead; back inboard, across the deck; out through the opposite fairlead, aft one fairlead, and back inboard in line with the wire on the starboard anchor windlass coaxial reel. On VLCCs these fairleads are of the 'old man' roller type. Then, shackle the two wire eye ends together. Now, slack all the wire from the starboard anchor side reel and take it up on the opposite, port side, reel. You will have needed to remove both nylon tails to do this, to get enough space on the reel. All the wire is now on the port windlass coaxial reel.

Next, re-reel back again, but over the starboard reel in the opposite way that it was before; so that where the wire on the starboard windlass reel originally led under the bottom of the reel to lead forward, it now leads over the top. This is because on heaving, the cable leads over the gypsy, but the wires on reels lead under (see figure 5). Now, if this wire is pulled, the torque so applied to the reel is in the same direction as the torque applied to lift the anchor and therefore power from the spare, port windlass can be transferred to the starboard windlass, via the connecting mooring wires.

All the turns are on the starboard windlass reel and there are, say, five turns left on the port windlass reel. Therefore there is a mechanical advantage exerted which gradually reduces as the wire transfers from the starboard reel to the port reel (figure 5). Again try to hoist the anchor and, at the same time, heave in on the port windlass with anchor disengaged and mooring reel clutched in. This nearly doubles the torque on the windlass and it has been found in practice that an anchor which would not come up in 95 metres, when treated in this way lifted easily. This has saved getting a salvage tug at the time from Singapore to Khor Fakkan.

Statistics for anchoring accidents collected by Captain A.O. Ojo and Professor J. King MSc FNI of Cardiff University, put causes as follows:

Engineering design	38·1 %
Operational practice	33·3 %
Combination of design and operational practice	14·3 %
Inadequate maintenance	9·5 %
Other causes	4·8 %

The statement that design is responsible for accidents is because band brakes are very efficient when static, but less good dynamically. To get a certificate of classification, hull, the anchor equipment must operate on trials correctly. Provided, therefore, that the equipment is properly maintained, there should be no problem. The writer has personally experienced anchoring accidents, or knows of others, not by third parties, but they have all been failures due to lack of maintenance or human error of judgment, or mal-operation by the fo'c'sle crew. As stated at the beginning of this paper, the problem with band brakes is that they depend on the skill of the operator – they are by no means foolproof. The reality of the situation is that if the brake is properly maintained, the cable is led abeam, the water is of moderate depth and the crew well trained and practised, there should be no problem. Always resorting to walking back is not considered to be a good idea, by the writer or the makers, for the reasons given in the text, mainly because it leads to inability to drop from the hawse pipe in an emergency.

The way forward

In the last 20 years there have been 1,086 recorded accidents to do with anchoring. Ship owners and managers are clearly unhappy about this, which is why so many instructions exist for walking back all the way, in spite of the problems this stores up. Rusting of the brake drum is a problem in ships which use the windlass infrequently – welding stainless steel into the surface in deep grooves cut with a nose tool solves this problem – it is not expensive at the manufacture stage. (The writer has served in a very old tanker so equipped and there was never any problem.) This treatment can be done in situ; there is sufficient power to drive the drum for the nose tool to cut. Welding without the cut could be done, but it would not be so good. Both the nose tool and the welding rod need to be fed in the manner of a thread cutter. The rod needs to follow in the groove cut by the nose tool, obviously. This is the way naval ships' propeller shafts have been sheathed in the past and there are various plants in the world that can do this.

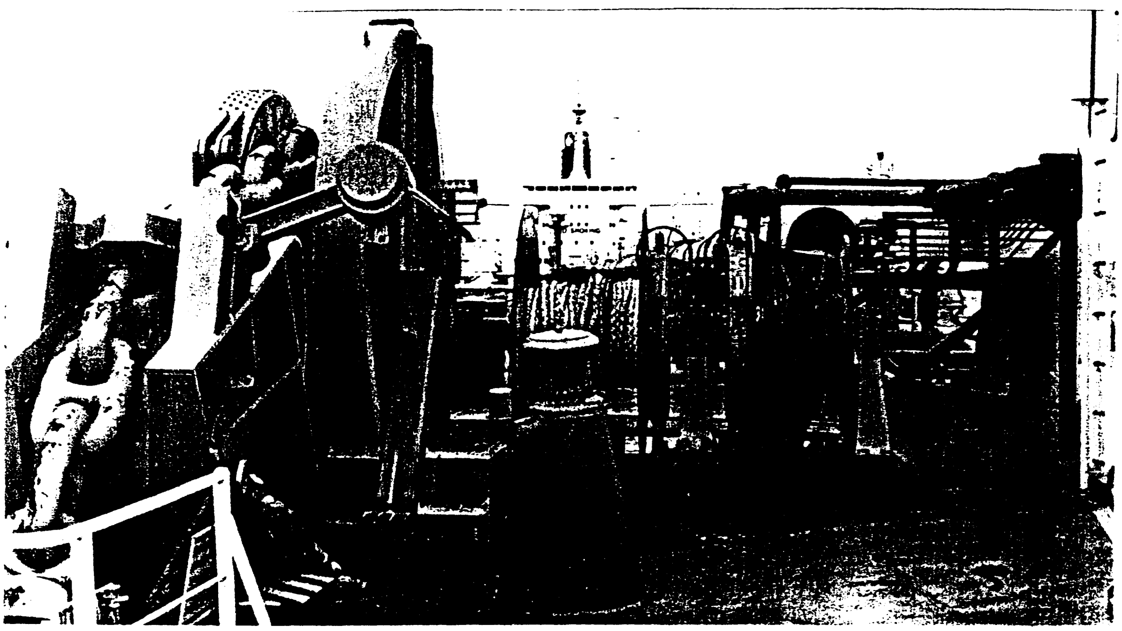

Figure 5 All the wire on the starboard reel. If this wire is pulled, the torque is applied to lift the anchor (A 267,000 dwt S.B.T. ship windlass)

It is clearly necessary to separate the mass of the ship, the mass of the anchor and cable and the kinetic energy stored by allowing the cable speed to build up. The solution to separating the mass of the ship has been exhaustively described here, namely by keeping the cable at right angles to the hull. Control of the mass of the anchor and cable could be managed by radically rethinking the cable locker arrangement. At present, the cable locker is just a box close under the deck, wherein the cable is stored – it has no engineering significance in the calculations.

With a depth of hull of 30 metres, use could be made of this height to utilise the mass of the cable differently. If the cable locker is in a tube which reaches right down to the bottom of the ship and the cable fills the tube right up, then the more depth of water and the more cable out, the more counterbalancing weight of cable would remain in the locker. Although the windlass scales up linearly for the mass of anchor and cable, the strength of the man on the brake remains the same. Increase in the force of brake application is necessary, because friction is independent of area. This increase in force is easily applied by a very powerful spring. Release of the brake is by means of compression of the spring by hydraulic cylinder. Adjustment of the spring tension is not necessary, providing compression is adequate.

It is not practical to put a brake further back in the gear train, because the gears are sized for the motor, and that is $^{1}/_{12}$ the force exerted by the brake. For the same reason, adding an hydraulic speed limiter is best done from the coaxial shaft of the gypsy and main spur. The alternative is a massive increase in gear size, if the stresses are to be correctly managed. Providing the speed is not allowed to build up in the first place, heat generation is limited. However, it is necessary to be able to render the cable at a minimum of four knots, otherwise no benefit exists in emergencies – they tend to happen rather quickly. Adding a spring actuator to windlasses not so equipped would appear to be the conceptual way ahead.

Adding a speed limiter to the main spur gear is simple apart from the tooth loading limitation. This can be solved conceptually in three ways:

1. By fitting a slipping clutch to limit tooth load – which will not help when it is most needed.
2. By multiple offtake around the perimeter of the spur gear. Tooth load is a limiting factor.
3. By a coaxial addition to the main shaft.

This is simple in concept but actually difficult and costly to engineer on existing windlasses, because it involves removal of the cable from the gypsy and then removal ashore of the main spur and gypsy complete to have a lengthened shaft and coaxial pump fitted. If the speed limiter is a direct pump, then more than one would be necessary – four for a VLCC have been suggested. Yet there are several VLCCs that have been fitted with only one pump, which fed a hydraulic cylinder concentric with the spring actuator. The faster the cable runs, the greater the pressure available on this secondary actuator, to back up the spring. The advantage of this configuration is that the pump can be quite small and can be taken off the gear train anywhere, because all it is doing is supplying the pressure for a high pressure cylinder. Indeed, the writer once sailed on a VLCC that had no spring, only this device. Without the spring, such an arrangement is not fail-safe.

There are, indeed, many possible configurations. The aim should be for simplicity, because reliability and economy result. The vast majority of ships will remain as they are for years to come. Therefore, real at-sea training would appear to be the best way forward, carefully planned in stages.

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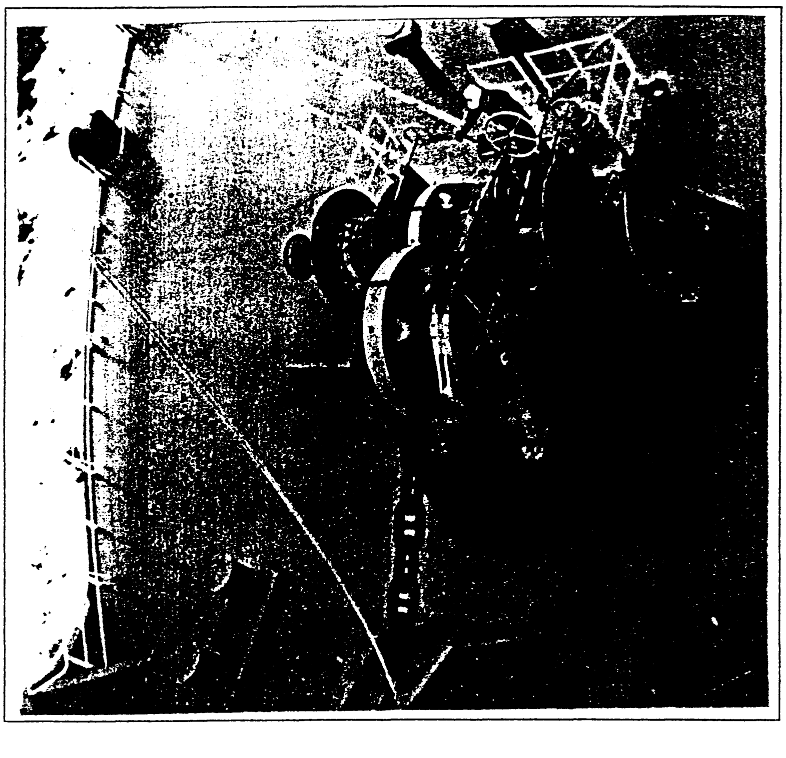


Figure 6 Bird's eye view of a 150,000 dwt S.B.T. windlass and stopper

Anchoring checklist

	Yes	No
A. PRE-OP MAINTENANCE		
1. Has the windlass been tested within the last 30 days? *If NO, then extra care needs to be taken.*	❑	❑
2. Has maintenance been done as per the makers instruction book? *If there are NO instructions, do the following:*	❑	❑
a) Ensure the brake lining is 7mm or more.	❑	❑
b) Ensure the brake drum is smooth, with no build up of rust or resin. (Use frequently, or use needle gun plus pneumatic wire brush)	❑	❑
c) Ensure ALL bearings and joints are FULL of grease, with no grit or rust in.	❑	❑
d) Ensure that hydraulic oil is at the correct level (if applicable).	❑	❑
e) Ensure hydraulic filters are clean, with no metal particles in. (Metal particles are an indication of past overload)	❑	❑
f) Ensure the brake lead screw and nut are clean and greased.	❑	❑
3. Have the owners' managers' instructions been read?	❑	❑
4. These instructions should be in accordance with the maker's instructions. Are they?	❑	❑
5. Are the brake adjustments in the middle of the range? *If NO, then operation is near the edge of permissible limits.*	❑	❑
B. PRE-OP PLAN - ENVIRONMENT		
1. Is the depth less than 82 metres absolute maximum? *Unless your ship is specially equipped, this is the class limit.*	❑	❑
2. Is the depth less than the owners stipulated depth for using the brake? If more than owners stipulated depth then walk back, using the brake also. *Never walk back without using the brake also* *If no instructions, regard 60 metres as the limit for brake only*	❑	❑
3. Is the nearest grounding line more than 1 mile away? *Allowing for the tide to go down*	❑	❑
4. Is the weather/tide NOT onshore? or drag will result in grounding. *If the weather is onshore and anchorage close, do not anchor.*	❑	❑
5. Is the sea bed suitable? *Not rock or coral, e.g. Tokyo Bay.*	❑	❑
6. Is there enough room to turn 180°/360°?	❑	❑
7. Is the wind less than 28 knots?	❑	❑
Is the current less than 3 knots? *These are Classification Society limits. You may trade wind for current: i.e. 1 knot current = 9 knots wind.*	❑	❑
8. Is the sea sufficiently calm? *Excess motion of the hull.*		
C. PRE-OP PLAN – TRAINING		
1. Have the foc'stle crew had training and are they certificated through the company's training scheme? *Windlass = primary lifting gear.*	❑	❑
2. Has a pre-op briefing been held so that they understand that:		
a) There should be 2 men on the controls, particularly the brake.	❑	❑
b) One man to apply grease to gears when heaving.	❑	❑
c) The orders that will come from the bridge.	❑	❑

Anchoring checklist (continued)

d) The cable will be walked back when at 2 knots to just above the bottom = the DIRECT method by 'U'-turn,	❑	❑
OR When stopped to just touch the bottom = the TENTATIVE method.	❑	❑
e) The cable will be veered in one go. *On the beam, 90° to the fore and aft line, because forces on the windlass are 20 times less this way, approximately 3.5 times for inertia and 6 times for added scope.*	❑	❑
f) The stopper will be put on and securing pin engaged whilst the cable is still up and down *Because this is the windlass makers and class requirement.*	❑	❑
D. THE APPROACH TO THE ANCHORAGE		
1. Are there any.other ships at anchor to indicate tide/wind?	❑	❑
2. Is there a suitable anchoring space, not in the fairway?	❑	❑
3. Is there a clear, safe passage to the space?	❑	❑
4. Is the space clear of the fairway? *(e.g. Scheldt, Ulsan are not good)*	❑	❑
5. If the anchorage is empty with a strong current, do you know the direction of the current? *(e.g. Withnell Bay, West Australia)*	❑	❑
6. Is the chosen space accessible for bunker barges/launches/etc?	❑	❑
E. THE ANCHORING OPERATION – AIDE MEMOIRE		
1. Choose a suitable speed of approach for the traffic/searoom.	❑	❑
2. If 'U' turn, approach at 180° to the final heading.	❑	❑
If 'tentative', approach at 20–90° to the final heading. In both cases, the aim is to lead the cable at 90° to the ship.	❑	❑
The 'U' turn method		
3(u) 'U' turn – start the turn when the bow is abreast of the planned bow final position, full rudder. Speed is not important.	❑	❑
4(u) Once the turn is started, stop engine.	❑	❑
5(u) When speed is 2 knots, start to walk the anchor out to above the sea bed. Use the anchor on the inside of the turn.	❑	❑
6(u) When the ship has canted 135° she will be virtually stopped. Adjust the angle to the weather to suit the strength of the tide and wind.	❑	❑
7(u) With the bow moving slowly sideways, let go/walk back with the brake to 3.5 to 4 times the depth, 5 times if possible.	❑	❑
8(u) Put the stopper on and engage securing pin with the cable up and down. Do not attempt to bring the ship up on the brake or the motor – doing so is against the maker's and class limits.	❑	❑
9(u) Ensure the ship is brought up with the cable abeam before allowing the cable to draw ahead.	❑	❑
The 'tentative' method		
3(t) Approach the anchorage slowly, angling to the weather 20–90°.	❑	❑
4(t) Start walk back at 2 knots, to avoid the anchor banging on the hull. Use the anchor on the weather side, not the lee side.	❑	❑

Anchoring checklist (continued)

5(t)	When the ship is stopped, walk back the anchor to just touch the sea bed. The fo'c'stle crew observe the lead, informing the bridge when leading out on the beam and clear of the hull.	❑	❑
6(t)	When the cable is leading in the desired direction, let go/walk back to the required scope – 3.5 to 4 times the depth, 5 times if possible.	❑	❑
7(t)	Put the stopper on and engage the securing pin with the cable up and down. Do not attempt to bring the ship up on the brake or the motor – doing so is against the maker's and class limits.	❑	❑
8(t)	Ensure the ship is brought up with the cable abeam before allowing the cable to draw ahead, for inertia and scope reasons, the same as for the 'U' turn.	❑	❑
	In both cases, when the depth is shallow and the bottom is soft, practice letting go the anchor from the hawse pipe. In an emergency you will have to. It is surprising how few ships can do this. If you cannot, the necessary maintenance needs to be done.	❑	❑

Appendices

Appendix 1

Difference in horizontal movement

If the depth of water is in the order of 50 metres (two shackles being equal to 55 metres) and the final length of cable is 10 shackles, then the difference in horizontal movement of the ship from the moment that the cable is up and down to the moment that the cable is bar taut is, by Pythagoras (maximum stress would be exceeded):

$$\begin{aligned} &= ((\ /\ (10 - 2)) - 8\ ) \times 27{\cdot}432\text{m} \\ &= ((\ /\ 96) - 8 \times 27{\cdot}432\text{m} \\ &= (9{\cdot}797958971 - 8) \times 27{\cdot}432\text{m} \\ &= (1{\cdot}797958971) \times 27{\cdot}432\text{m} \\ &= 49{\cdot}32 \text{ metres} \end{aligned}$$

Appendix 2

Rotational inertia is less than axial inertia

Considering the same rectangular section body being accelerated not axially, but rotationally, the variables are expressed as fractions of length (L) in the same way as the axial case, so that the result is directly comparable, independent of integer values. Let:

T = torque, = force x radius, FR
I = angular moment of inertia
@ = angular acceleration, in radians per second (alpha)

There is a relationship that T = I@,
so $F = \frac{I@}{R}$ where T = FR

The radius of gyration^2 of a rectangle about its axis through the centroid is:

$\frac{L^2}{12}$ therefore,

$$F = \frac{ML^2.V^2}{12R\ \ 2S} = \frac{ML^2(L/m//2/L)^2}{(12L/2).2.(L/n//2/L)}$$

where L/2 = R and n, m are factors as before. Therefore:

$$F = \frac{ML}{6}\left|\frac{\frac{2}{m}}{2 \times \frac{2}{n}}\right|^2 \qquad \text{so } F = \frac{ML4n}{6 \times 4m^2}$$

whence $F = \frac{MLn}{6m^2}$

the force required to decelerate the rectangular block through the same distance angularly as to decelerate the block in a straight line. This is one third of the force to decelerate the block in a straight line.

Appendix 3

Derivation of coaxial force

Taking the case of the coaxial push in the fore and aft line first, force = mass x acceleration (F = MA).

Let the available distance for the ship to come to rest = S, then:

$V^2 = U^2 + 2AS$

where U = final velocity = zero, V = initial velocity = coaxial speed astern when anchor is let go/ commenced walk out, A = deceleration of bow and S = distance required in which to stop ship. Therefore the available distance to stop ship's translation is:

$$S = \frac{V^2}{2A} \text{ and } A = \frac{V^2}{2S} \quad \text{so } F = \frac{WV^2}{2gS} \text{ (newtons)}$$

between V=V, V=0, where W = weight, that is displacement and g = acceleration due to gravity.

Although it is correct to express force in newtons, a more realistic unit for calculations of this sort is tonnes (force). One newton is the force required to accelerate one kilogram-mass by one metre per second per second.

(kilogram-mass = kilogram-weight/acceleration due to gravity) = 1 kg/9·81 m/sec^2

So one newton is approximately 1/9·81 kilograms or 2·2/9·81 pounds force = 0·224 pounds, the weight of an apple.

So, $F = \frac{MV^2}{2S}$

or, momentum equals half the mass divided by the square of the velocity and the force to exert is inversely proportional to the available distance. The comparison between linear deceleration and angular deceleration is as follows:

Axial case:

$$F = \frac{MV^2}{2S} \qquad F = \frac{M(L/m)^2}{2L/n}$$

where m is a number such that L/m = V, M = S/g mass, where n is a number such that L/n=S, and where L is the ship's length, whence:

$$F = \frac{MLn}{2m^2}$$

The force to decelerate the rectangular block in a straight line (block coefficient of 1).

Appendices (continued)

Appendix 4

Derivation of second moment of area of a) a rectangle and b) a diamond shape around a central axis

a) Second moment of area of a rectangle about one side is:

$$\int_0^d bd^2 dd = \frac{bd^3}{3}$$

For two such rectangles the common length is D/2, then:

$$\int_0^D b\frac{(D^2)}{2}dD = \frac{2b(dD)^3}{2 \times 3}\Bigg|_0^D = \frac{2bD^3}{24} = \frac{bD^3}{12}$$

b) Second moment of area of a diamond is obtained by finding second moment of area of a triangle about one side first:

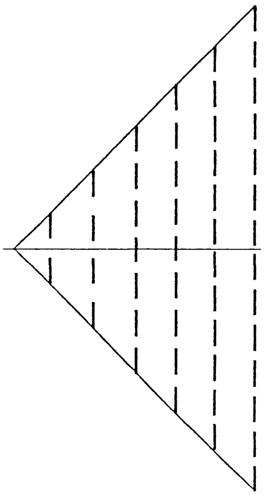
$$\int_0^d b\frac{(d^2)}{2}dd = \frac{b(d)^3}{3 \times 4}\Bigg|_0^d = \frac{bd^3}{12}$$

For a diamond, find as in a) then second moment of area:

$$\frac{2b}{12}\frac{(D)^3}{(2)} = \frac{2b}{12}\frac{D^3}{8} = \frac{bD^3}{48}$$

$$\text{Area} = \frac{bD}{2} \text{ whence } k^2 = \frac{D^2}{24}$$

This can also be shown by the mid-ordinate rule, a process similar to Simpson's rules. Mid-ordinate is the mean height of each ordinate.



If the height of each ordinate is: 2,4,6,8,10,12, then the height of each mid-ordinate is as follows: 1st = 0 to 2, 2nd = 2 to 4, 3rd = 4 to 6, 4th = 6 to 8, 5th = 8 to 10, 6th = 10 to 12.

So, for mid-ordinates 1st, 2nd, 3rd, 4th, 5th and 6th, lengths are 1, 3, 5, 7, 9 and 11. The second moment of each ordinate is:

$$\frac{bd^3}{12}$$

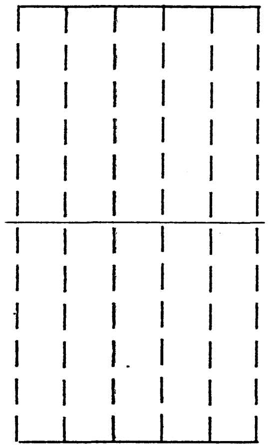
If the width of each ordinate is 1, then:

$$I_t = \frac{bd^3}{12} + \frac{bd^3}{12} + \frac{bd^3}{12} + \frac{bd^3}{12} + \frac{bd^3}{12} + \frac{bd^3}{12}$$

$$= \frac{1\cdot1^3}{12} + \frac{1\cdot3^3}{12} + \frac{1\cdot5^3}{12} + \frac{1\cdot7^3}{12} + \frac{1\cdot9^3}{12} + \frac{1\cdot11^3}{12}$$

$$I_t = \frac{1}{12}(1 + 27 + 125 + 343 + 729 + 1331) = \frac{2556}{12} = 213$$

Compare with the second moment value of the enclosing rectangle, which is:



$$\frac{bD^3}{12} = \frac{6\cdot12^3}{12} = 6.12^2 = 864$$

This is four times greater than the value (213) obtained for the two triangles back to back. Therefore, second moment of area of two equal triangles about a common base is:

$\frac{1}{4}$ x 2nd moment of rectangle about centroid

$$\frac{bD^3}{12} \times \frac{1}{4} = \frac{bD^3}{48}$$

the same result obtained by basic integral calculus.

Appendix 5

Demonstration that second moment of area of rectangle is changed approximately 3% by the inclusion of secondary term for second axis at right angles

Let B = breadth, L = length, and Ixx + Iyy = Ipp, where Ixx is moment of inertia/second moment of area about athwartships line centroid, Iyy is moment of inertia/second moment of area about fore and aft line centroid and Ipp is the moment of inertia/second moment of area about the vertical turning axis through the centroid. Then:

$$\frac{BL^3}{12} + \frac{LB^3}{12} = I_{xx} + I_{yy}$$

Let length to breadth ratio be 6:

$$\frac{1 \times 6^3}{12} + \frac{6 \times 1^3}{12} = \frac{36}{2} + \frac{1}{2} = 18 + 0{\cdot}5$$

0·5 is 2·8% of 18. This is less than 5%, so less than the limits of experimental error and can be ignored.