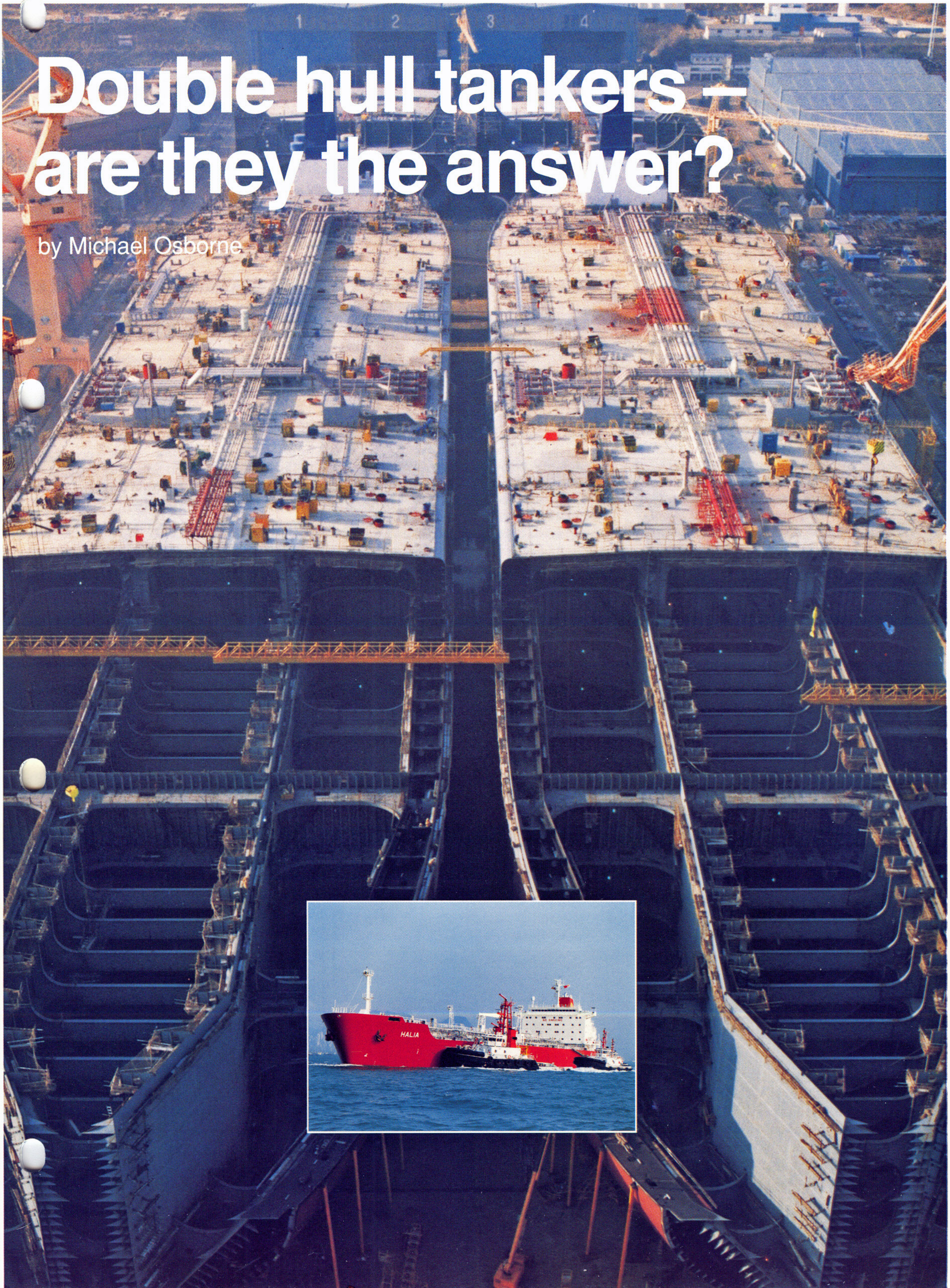
Double hull tankers – are they the answer?

by Michael Osborne



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DOUBLE HULL TANKERS – ARE THEY THE ANSWER?

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Michael Osborne

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He joined the Technical Department of Shell International Marine in 1980, becoming chief naval architect in 1986. He is presently manager of the Technical Services Department of Shell International Shipping, which took over the business of Shell International Marine at the beginning of 1994.

Much of his work is concerned with new regulations for tanker design, from both the International Maritime Organisation (IMO) and the classification societies. He is a member of the Technical Committee of the American Bureau of Shipping and has represented the UK and the Oil Companies International Marine Forum (OCIMF) at IMO meetings on new tanker legislation.

Introduction

Legislation now requires all new marine tankers above 5000 tonnes deadweight* (dwt) to be constructed with a double hull or equivalent. Apart from some chemical, liquefied natural gas (LNG) and small product tankers, the marine industry has little experience in the design, construction and operation of double hull tankers. Therefore, traditional tanker owners and builders are working in something of a vacuum when it comes to both satisfying the new design requirements and operating the tankers safely and economically.

It is important to recognise that double hull tankers have different characteristics to those of single hull tankers, some of which are beneficial and others of which are not. This paper sets out the principal areas in which the design, construction, operation and maintenance of tankers needs to be carefully considered to cater for these differences.

Shell International Shipping (SIS) has considerable experience of LNG ships, going back over 30 years to *Methane Progress* and *Methane Princess*. All LNG ships are built with double hulls and much of this experience is relevant to double hull tankers. More recently, SIS has been operating double hull product carriers of 40 000 and 80 000 tonnes dwt and has contracted for five new double hull VLCCs (very large crude carriers which are typically greater than 200 000 tonnes dwt).

*deadweight (dwt) – difference in a ship's displacement loaded and light

Design issues

Structural design

The history of ship structural design is one of evolution rather than revolution. Designers learn from past experience and each new ship tends to be a development of a previous successful design. Whenever this course has been abandoned – as in the rapid growth in size of tankers in the 1960s and the large open hold container ship designs of the 1970s – structural problems have materialised sooner or later. Despite the advent of ever more powerful computers and increasingly sophisticated structural analysis programs, structural design remains a largely empirical process. The stresses in a tanker's structure depend on such variables as:

- structural design – plate thicknesses, local stress concentrations, stiffness and proper transmission of loads;
- construction quality – for instance alignment, local imperfections, the quality of steel and welding;
- distribution of the cargo weight in the ship;
- static and dynamic forces of the sea and waves resulting from heaving, pitching, rolling and possibly slamming;
- vibration from machinery;
- random corrosion; and
- the complex internal distribution of stresses between primary, secondary and tertiary structures.

Clearly, the 'design' or calculated stress levels in any element of the structure should have a safety factor based on previous successful experience. It is impossible to calculate accurately the true stress levels in service throughout the tanker's structure entirely from first principles. However, safety factors for large double hull structures are not yet available for the simple reason that there is no service experience. Although there is already some successful service experience from LNG ships and smaller double hulled product carriers, it will be several years before the structural design of double hulled VLCCs can be proved. In the meantime, generous safety factors need to be incorporated into the design.

The difficulty of accurate stress prediction is compounded by the higher hull girder bending moments of double hull tankers (Table 1). These arise because of the uniform distribution of cargo and ballast over the length of the ship, whereas in a single hull tanker the ballast tanks can be positioned to minimise longitudinal bending and shear stresses, resulting in values well below the classification society maxima (Figure 1). Double hull tankers will operate with global stress levels some 30% higher than those with single hulls – close to the maxima acceptable to classification societies – unless an owner spends a substantial amount on extra steel thicknesses and suffers the attendant increase in design draught, or builds in extra ballast tanks to reduce bending moments. These higher stresses will increase the risk of buckling failure – especially after several years in service and the consequent reduction in plate thickness from corrosion. They will also increase the likelihood of the development of small fatigue cracks.

Successful experience of the design of double hull tankers obviously exists but it is concentrated in relatively few hands at the smaller end of the tanker size spectrum. Thus, there will be many shipyards worldwide designing double hull tankers for the first time, based on their own direct calculations and guided by the experience of the classification society, which, in the case of some of the smaller societies, may also be limited. This could put the design of double hull VLCCs, for example, closer to 'revolution' than 'evolution' in the absence of service and operational

Table 1

Stresses in double hull tankers (ballast condition)

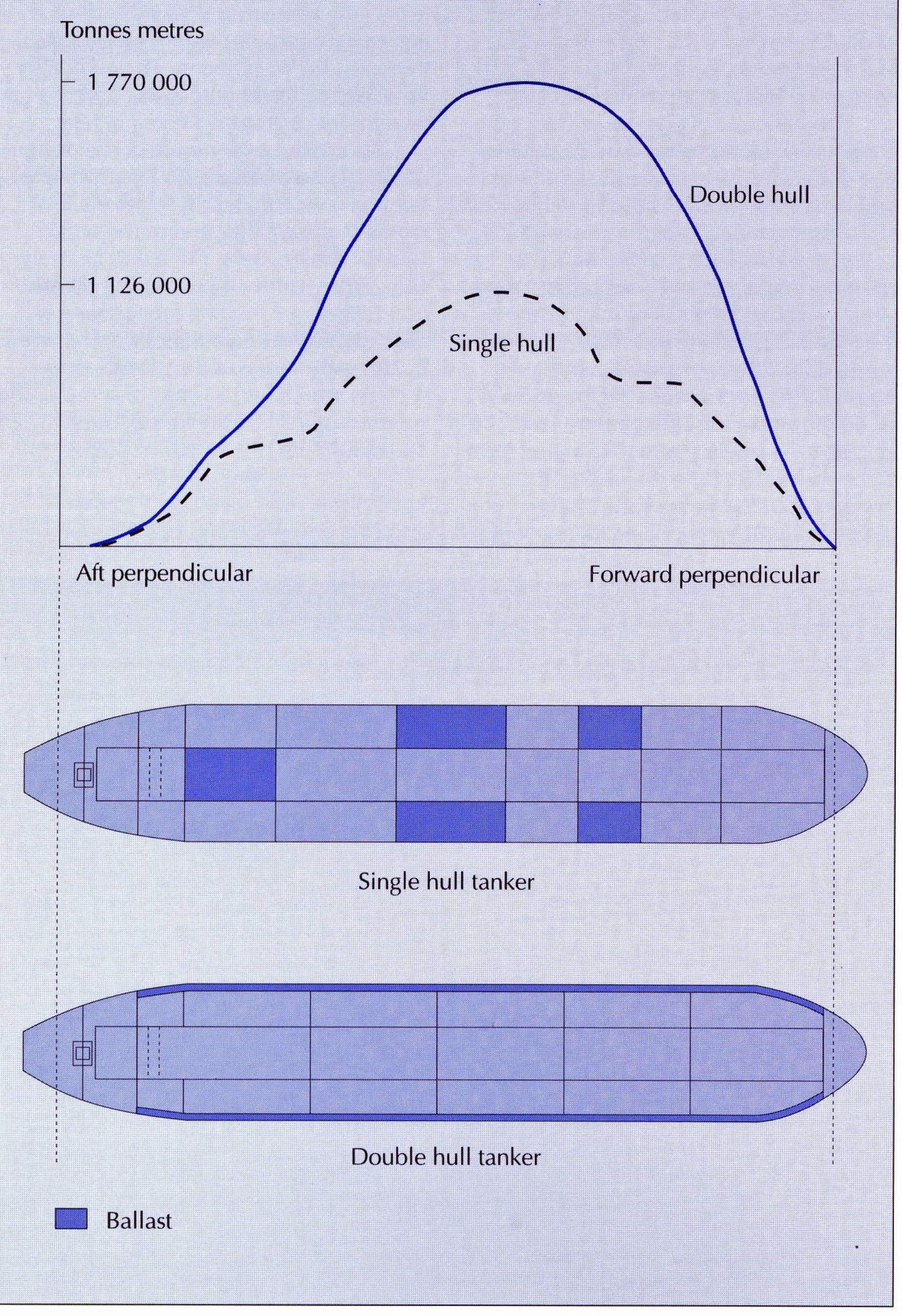
VLCCs – same dimensions and hull shape	Double hull tanker	Single hull tanker
Still water bending moment (TM)	695 200	183 400
Wave bending moment (TM)	1 074 500	1 074 500
Total bending moment (TM)	1 769 700	1 257 900
Minimum midship I/y (m^3)	95.770	95.770
Required I/y (m^3)	101.125	95.770
Seagoing Stress (N/mm^2)	**171.7**	**128.8**

Seagoing stress of double hull VLCCs will be 33% greater than seagoing stress of single hull VLCCs

TM = Tonnes metres
I/y = Inertia/distance from neutral axis
N/mm^2 = Newtons per square millimetre, a measure of stress

Figure 1

Bending moments in sea going tankers in ballast



experience and safety factors. The consequences will most likely be small fatigue fractures in the early years of service, especially in larger double hull tankers, unless great care is exercised in the design detail and workmanship during construction. Some of the major classification societies have put much effort into studying these problems and are confident that they can achieve a successful structural design first time.

The first generation of double hull tankers may also suffer from defects in poor design details, either due to local stress concentration or to inadequate access to allow proper weld connection. There will be a learning process as these problems are detected and solved. In the meantime all operators of these ships will have to be on their guard to detect fatigue cracks as quickly as possible to prevent crude oil leaking into ballast tanks or the contamination of valuable product cargoes with ballast water. Perhaps the greatest fear is that of an accumulation of hydrocarbon gas inside an empty ballast tank.

Intact stability

The transverse stability – the ability of a ship to remain upright and a measure of its resistance either to take on a list or to capsize completely – of single hull tankers has never really been a problem. Meeting damage stability criteria in the event of an incident can sometimes be difficult for smaller tankers with a relatively narrow beam, but there are generally no constraints on loading and deballasting operations imposed by lack of stability. This situation has changed with the introduction of double hull tankers.

Single hull tankers need longitudinal bulkheads which run throughout the length of the cargo tanks to provide longitudinal strength. The transverse spacing of these bulkheads can be chosen to give tank sizes of approximately equal capacity and bottom support structure of manageable proportions. The inner hull of double hull tankers already provides sufficient longitudinal strength and no further longitudinal bulkheads are necessary for structural purposes. Shipyards have therefore started to build double hull tankers with no longitudinal subdivision inside the cargo tank section, so that a single tank extends across the ship from double side to double side (Figure 2). It is possible to produce designs of this nature for tankers up to about 150 000 tonnes dwt. Inclusion of a further longitudinal bulkhead obviously increases the weight of steel, making the design more expensive, less marketable and less attractive to a prospective owner.

The result of having these very wide cargo tanks is a substantially increased free surface effect. The free surface effect is the degradation in transverse stability which occurs when there are slack surfaces – the liquid surface in any tank which is not filled so full that surface movement is effectively restricted by the deck structure. Combined with the double bottom, which raises the centre of gravity of the cargo, there is a consequent large reduction in intact stability reminiscent of the situation which has arisen on some combination carriers.

The stability problem is further compounded during loading and discharging operations by free surface effects inside the double bottom ballast tanks. If a tanker is loading cargo and discharging ballast simultaneously (or vice versa), there can be slack surfaces in both cargo tanks and ballast tanks. The new raking damage criterion (where raking is assumed to have caused a long narrow slit along the bottom), which only double hull tankers must satisfy, dictates that several of the double bottom tanks must be designed without watertight subdivision at the centreline (a 'U' tank, Figure 3). If the double bottom tanks were divided (an 'L' tank), then any raking damage on one side of the bottom would cause flooding on one side only, leading to capsize. VLCC sized double hull tankers usually only need a maximum of one 'U' tank, but smaller tankers need two or three in order to survive raking damage. Whilst deballasting these 'U'

Figure 2

Double hull design with no longitudinal bulkheads

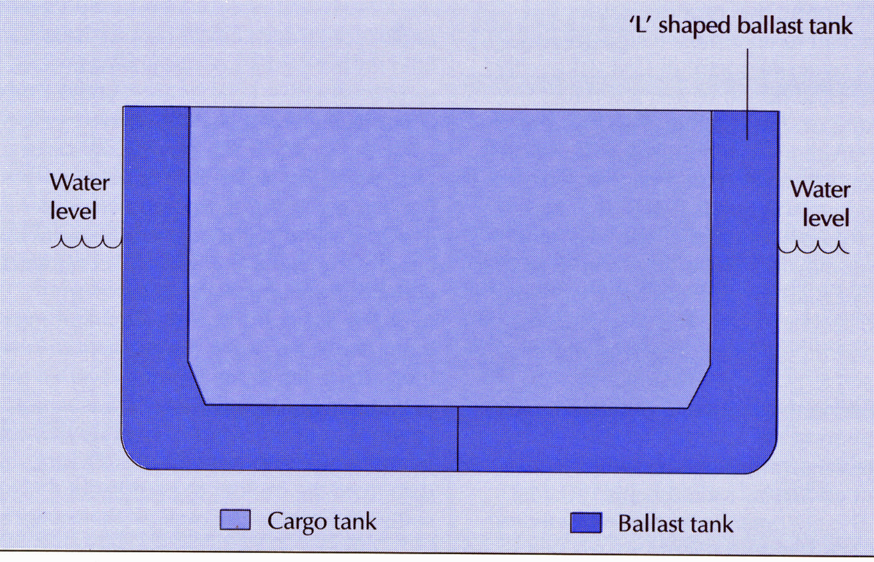
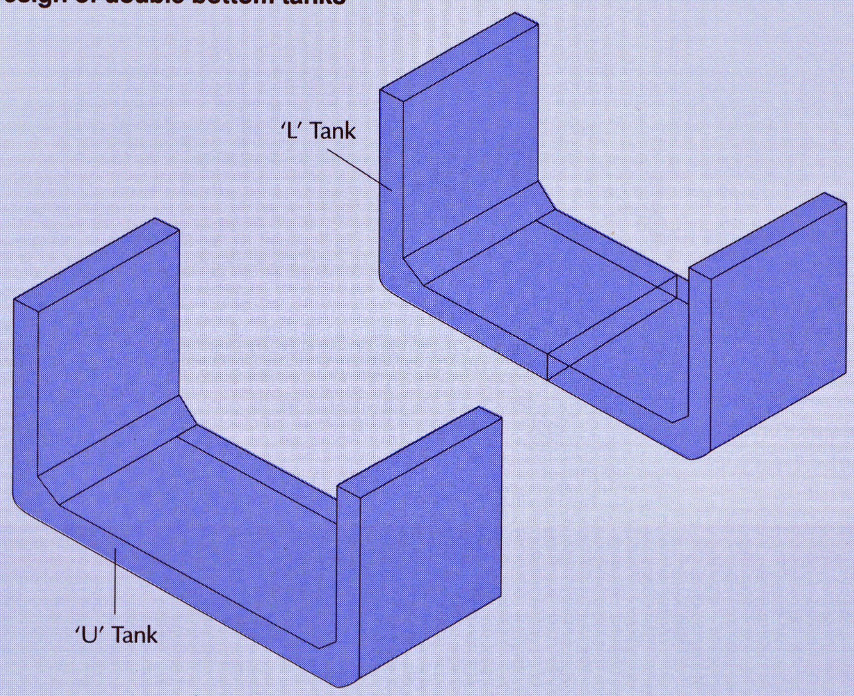


Figure 3

Design of double bottom tanks



tanks, the free surface inside the side tanks is relatively small. But when the level drops below the inner bottom, it increases suddenly. In the case of a 40 000 tonne dwt product carrier it is equivalent to an almost instantaneous loss of over one metre in GM value – the metacentric height which is a direct measure of ship stability. This has already led to instances of these ships taking on a sudden list during cargo handling. The immediate solution is better training of the cargo officers and the provision of high quality information on board, so that positive stability is retained throughout cargo and ballast handling operations. On-board computer programs which can be used to plan the discharge by simulating the sequence of operations and alerting the operator to any dangerous condition which could arise are an additional valuable aid.

The acceptance by the International Maritime Organisation (IMO) of a submission from the Oil Companies International Marine Forum (OCIMF), which requires that stability criteria are satisfied without undue reliance on operational constraints, puts the onus on the designer to ensure that the design remains stable at any stage in the cargo and ballast handling operation. This should mean that either:

- cargo tanks are subdivided longitudinally;
- stability is improved by increasing the beam; or
- other means are adopted to reduce the free surface effect.

However, the effectiveness of this requirement is dependent on the rigour with which Flag States – the countries in which ships are registered – apply it.

Damaged stability

The second aspect of stability concerns the need to load tankers so that they will survive specified types of damage (The International Convention for the Protection of Pollution from Ships, MARPOL, Regulation 25). The smaller the ship the more difficult a task this becomes. Checking a proposed seagoing condition against all the possible damage scenarios can be a laborious process and one which all Chief Officers cannot easily undertake. Ship builders usually have little understanding of the pressures surrounding this activity and can be persuaded only rarely to provide sufficiently comprehensive guidance in a form which is easily understood. Fortunately the use of computers is of assistance here. Most loading instruments are already based on personal computers and additional programs are now available for checking intended loading patterns. These programs can be integrated with the trim and stress calculator, giving a quick and easy solution to the problem. The only difficult part can be the extraction of sufficient data from the builder to enable the software supplier to cover all the owner's requirements.

Owing to the intact stability problems referred to above, compliance with damaged stability criteria is now not so easy and considerable care needs to be taken in distribution of the cargo. For example, there are instances where a cargo of warm product can be loaded in compliance with the regulations; but on cooling, the cargo surface is slightly lower down the tank and, because of the deck camber, the free surface effect has increased to a point where the stability is unsatisfactory. A conscientious officer will check for these small details but others might not. This raises the question of the policing by Flag or Port States of this particular regulation. It is notoriously difficult to apply Regulation 25 effectively in practice. A Flag State may approve certain specific cargo loading conditions in a trim and stability manual, or it may even approve some form of stability envelope. But there is nothing in practice to prevent a ship from distributing cargo either in contravention of the approved conditions or in a manner which has not been specifically approved. This has led to situations where a cargo has been declined by one ship but a sister ship, operated by a different company, has accepted it. This is undoubtedly an area in which the conscientious operator is penalised and where tighter vigilance by Flag and Port States is required.

Ventilation and access

Full scale trials carried out in a shipyard on completion of a double hull tanker of about one million barrel capacity have shown that it is not possible mechanically to ventilate from the deck of one side of a 'U' shaped ballast tank and exhaust naturally from the other, despite the fact that an apparently ample number of openings are provided. This is due to the cellular nature of the wing and double bottom tanks. Personnel entry into these spaces – which is necessary to check for corrosion, leakage and mud build-up – will be hazardous unless proper consideration is given at the design stage to the provision of sufficient openings to permit good ventilation. This is a feature which is usually not fully appreciated by shipyard designers who have no operational experience.

The importance of good access has been endorsed by the Report of the Donaldson Enquiry following the 'Braer' incident in 1993. Current surveys on VLCCs demonstrate how difficult it is to obtain close-up access to inspect the structure inside large tanks. Rafts, remotely controlled vehicles (both underwater and above), 'mountaineering' and staging platforms have all been tried with varying degrees of success. These problems can be solved at the design stage by the provision of permanent walkways for access to those parts which need to be closely inspected. Structure inside double bottom tanks will be relatively easy to inspect, but other tanks will have little or no structure inside from which to permit a close inspection. The double side tanks, for instance, can easily be made more 'inspection friendly' by the addition of some fore and aft stringers – horizontal structural members running the length of the ballast tank – at convenient heights which can serve as inspection platforms. Cargo tanks, which will be relatively free of internal structure, will also need some provision for inspection of deckhead structure, especially when heated cargoes are carried and corrosion can be expected to be more rapid.

Construction issues

Modern shipyards adopt 'factory' techniques to improve productivity and thus reduce ship construction times. Whereas a VLCC might have taken two years to build in the early 1970s, double hull VLCCs are now being built, from first steel cutting to delivery, in about eight or nine months. This puts a great deal of emphasis on doing the job correctly first time – corrective work causes delay and disrupts the shipyard's programme. This in turn puts pressure on quality and an owner's supervision team needs to be alert to several critical aspects of the construction of double hull tankers.

Probably the most significant of these is the protection of the ballast tanks. This aspect attains far greater significance in a double hull tanker because of the increased surface area of the structure inside the ballast tanks. Because these tanks are much longer and narrower than those in single hull tankers, their surface area is two to three times that of the ballast tanks in a single hull ship. Although protective coatings are an obligatory requirement of the major classification societies, it is up to the owner to choose the type and number of coats, ensure that they are properly applied and decide whether to fit anodes as well. The standard coating specification from the builder will usually be inadequate for the expected lifetime of the ship, again to keep the build cost down and also because it is increasingly difficult to find people willing to undertake the extremely unpleasant job of applying the coating. The confined spaces of the double hull ballast tanks, whether sides or bottom, are far more unpleasant to work in than the comparatively spacious ballast tanks of the single hull tanker. Here again, good ventilation through the design of openings is very important.

Some features of the double hull design make life easier for the builder. The double sides and double bottom form natural three-dimensional rigid building blocks, less susceptible to deformation than the predominantly two-dimensional components of the single hull ship.

Operational issues

Operational safety on double hull tankers was recognised at IMO as requiring special consideration and industry representatives were asked to draw up a set of guidelines. These are now included as chapter eight in the fourth edition of the International Safety Guide for Oil Tankers and Terminals (ISGOTT). In addition to highlighting the potential problems of stability and ventilation referred to above, the guide gives useful advice on:

- routine monitoring of empty ballast tanks for hydrocarbon gases;

Figure 4

Undetected corrosion caused a major structural failure in this non-Shell tanker

- action to be taken in the event of cargo leakage;
- procedures to be followed if a ballast tank must be inerted as a result of cargo leakage into the tank; and
- advice on gas freeing, cleaning and entry after inerting.

There is no doubt that significant advantages in cargo operations will accrue from the change to double hulls. This will especially benefit product carriers, which carry high value cargo, and where even better outturns can be expected. The smoother internal tank surfaces and pump suctions recessed into wells in the double bottom will make cargo discharge and tank washing much easier and lead to reduced cargo residue in the tanks. Less well known is the fact that an unobstructed tank bottom, such as is found in OBO (oil/bulk/ore) carriers, tends to suffer less corrosion than a conventional tanker, which often suffers pitting corrosion in this area. This should be another major operational advantage of double hull tankers.

The obvious hazard, which all operators of double hull tankers will need to guard against, is that of cargo leakage into the ballast spaces. The ISGOTT document is a useful guide to handling this situation. Leakage arises from small fractures in bulkhead plating between cargo and ballast tanks which may be caused by unpredicted local stress concentration, fatigue, construction defect or, eventually, corrosion through failure of the protective coating system. The unproved structural design of double hull tankers renders them more susceptible to minor failures of this type than the relatively well proven single hull designs. Apart from taking even more care at the design and construction phases, regular inspection of the structure to detect incipient failures will be a necessary operational routine.

Mud build up in the ballast spaces should be expected to be even more of a problem with double hull tankers than with single hull tankers. Experience with LNG ships and double bottom coasters indicates that when ballast is taken on in estuarial waters, the cellular nature of the tanks causes a much higher retention of mud than is the case in the wider ballast tanks of a single hull ship. Some owners have fitted ballast tank washing systems to combat this effect.

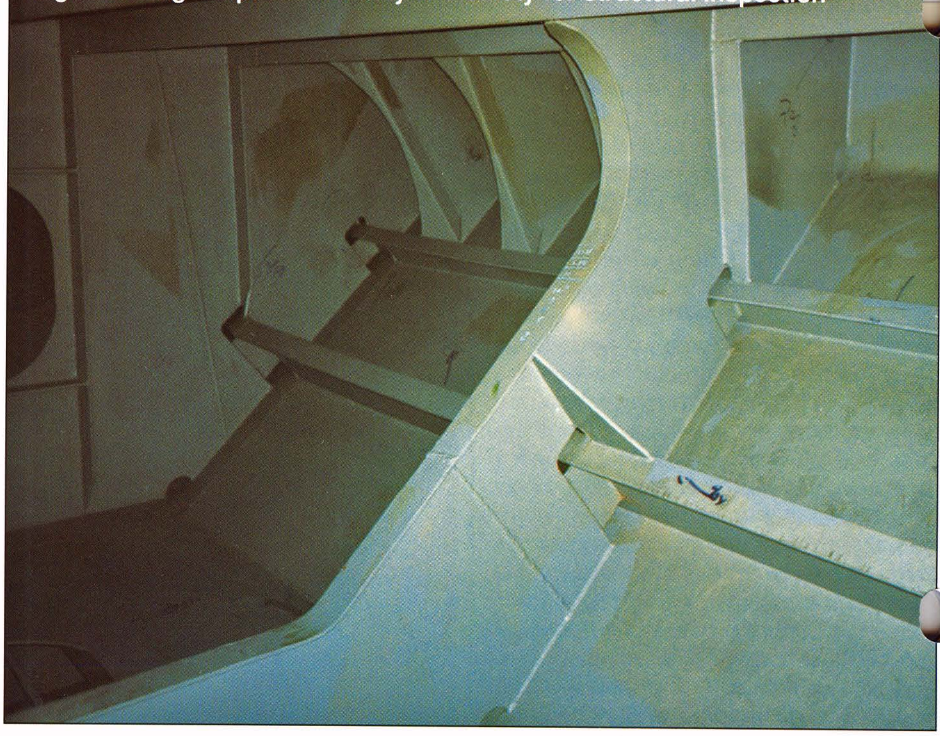
Piping systems in double hull tankers will be fully segregated, with cargo pipes running almost exclusively through cargo tanks and ballast pipes through ballast tanks. This overcomes the problem which exists today of ballast pipes running through cargo tanks and becoming a potential source of pollution by cargo leaking into the pipes and through into the clean ballast. It does mean, however, that replacement of ballast pipes will be more difficult since they will be threaded through access holes in the floors of the double bottom tanks, as they are in bulk carriers and other dry cargo ships with double bottoms. Removal of old pipes and fitting of new pipes will require the cutting of large openings in the bottom shell plating or inner bottom.

Maintenance

Proper maintenance is the responsibility of the ship owner and manager. It is not the responsibility of the classification society, the Flag State, the underwriter or the charterer. These latter bodies can exert some influence on the maintenance of the ship but they will never be in a position to see or learn as much about the condition of the ship as the manager. Nevertheless, the influence which these organisations wield has a heavy

Figure 5

Light coatings improve visibility and safety for structural inspection



commercial impact – detention, withdrawal of certificates, loss of business – and it is essential that their monitoring activity is not diminished in any way as it represents the best deterrent to lack of maintenance.

Undetected corrosion is a major cause of some of the spectacular structural failures we have seen in the last few years (Figure 4). In particular, failure to maintain the integrity of protective coatings and cathodic protection in ballast tanks has led to leakage, pollution and sometimes fire. Maintenance of the ballast tanks of double hull tankers will be just as essential, perhaps even more so since there is two to three times the surface area of structure compared with a single hull tanker. However, the structure in the double hull spaces will be far more accessible than are the ballast tanks of a single hull ship. Usually they will be between 2 and 3.5 m wide (or high), allowing easy close up inspection provided the side tanks are fitted with side stringers to serve as inspection platforms at reasonable intervals. There should therefore be no excuse for neglecting the inspection and maintenance of this structure and its coatings. ISGOTT guidelines do, however, recommend that ballast tanks are not entered while the ship is loaded with cargo, but that weekly sampling of the atmosphere is undertaken during loaded voyages. Inspection inside ballast tanks is greatly facilitated by the use of light coloured coatings. Not only does this make the detection of any cargo leakage much easier, it also makes the operation much safer (Figure 5).

The easier maintenance of ballast tanks is likely to be the main difference between double and single hull tankers. Maintenance of other areas, such as machinery and deck equipment are unlikely to be affected.

Further guidance on the inspection and maintenance of double hull tankers is given in a book published jointly by the Tanker Structures Co-operative Forum, the International Association of Classification Societies (IACS) and OCIMF.

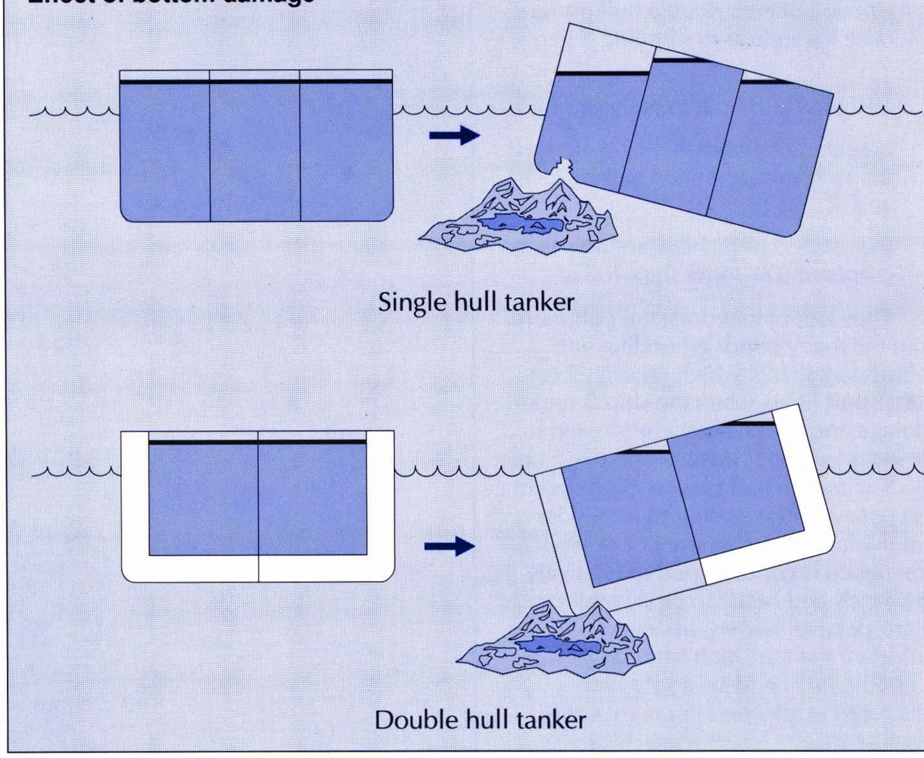
Salvage of a double hulled tanker

If a double hull ship should run aground and rupture the outside shell, the available damage statistics suggest that the inner hull will, in most cases, not be breached and no oil will be spilt. However, on smaller tankers the damaged space might easily be a 'U' shaped tank, allowing free flooding right across the double bottom and up to the outside water level each side of the cargo tank. Thus a considerable weight of flood water would be admitted, making the ship sit more firmly on the bottom and more difficult to refloat. A single hull tanker, by contrast, would spill cargo which would lighten the ship and make it easier to re-float (Figure 6). Damage to an 'L' shaped double bottom tank on the other hand, would cause asymmetric flooding resulting in considerable heel should the ship not come to rest on the rock but remain free-floating. This would need to be corrected by the filling of an opposite tank. If the ship remained aground with damage to an 'L' shaped tank, then the consequent heel when the ship floated free would need to be considered in the salvage plan.

The relative merits of single and double hull designs would depend on weather conditions at the time and on the availability of salvors. It might in some circumstances be advantageous to have

Figure 6

Effect of bottom damage



the ship sitting more firmly aground until salvage equipment arrives.

Salvors have indicated that they would prefer to salvage a ship with a double bottom as it gives them the option of using air pressure to expel the flood water. This is certainly true of dry cargo ships, which do not have to meet the raking damage criterion and have greater subdivision in their double bottom tanks. Nor do they have interconnected side and bottom tanks. The use of air pressure then becomes a feasible salvage technique. Almost certainly it will take longer to re-float a damaged double hull tanker than a damaged single hull tanker, during which time the weather conditions could be critical.

Conclusion

Are double hulls the answer? The gradual introduction of new double hull designs will raise the industry's standing if they are:

- designed and built to high standards;
- operated by personnel who are well trained and committed to their jobs; and
- maintained to higher standards than is apparent in some ships today.

They can help reduce the pollution from the many minor grounding and collision incidents which usually occur within port limits when the ship is under pilotage and which have contributed to the industry's poor image.

But double hull tankers are different and pose different problems to builder and owner. The small amount of service experience is concentrated in relatively few hands and needs to be disseminated to prospective owners, operators and builders if the transition from single hulls to double hulls is to be a smooth one. This paper is intended to contribute to this process.

However, it should be recognised that the public's current perception of the industry has not been acquired simply because double hull tankers have not been used extensively. Furthermore, the new regulations by themselves will not necessarily change that. The standards of design, construction, maintenance and operation of this new breed of ships will be every bit as important as those of their single hull predecessors and the tanker industry cannot afford to relax its vigilance in these areas. All those who have a responsibility for monitoring these standards – in particular the management of the owning company – must be aware of the different problems posed by double hulls and implement appropriate inspection and check procedures to counter them.