THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Suite 400, Jersey City, New Jersey 07306 USA
Paper presented at the Marine Structural Inspection, Maintenance, and Monitoring Symposium
Sheraton National Hotel, Arlington, Virginia, March 18-19, 1991

Some Considerations Regarding Tank Inspection Priorities for Oil Tankers

J.M. Ferguson, Lloyd's Register, London, United Kingdom

INTRODUCTION

Philosophy

A ship's hull is made up from thousands of structural elements of various sizes and complexity welded together with the best intentions in a production orientated environment. The role these structural elements play is dependent on their location and position in the load transmission chain. Shipbuilding has never been an exact science and involves the manufacture of large fabricated building blocks and the erection of these blocks on site in the shipbuilding berth or dock. With the best intentions in the world the deformations created during construction and handling together with the sheer weight and size of these building blocks, and the effect of accumulative building tolerances, will create variances in as built tolerances and therefore arguably in structural performance. These variances in structural performance in similar elements of tank ship structures do, it can be argued, have their advantages, and careful monitoring will reveal design inadequacies at an early stage before the situation becomes more critical in extent.

Cracking in ship's hulls, once detected, necessitates positive action with a view to arresting propagation or carrying out repair. There are of course lower areas of risk in terms of fatigue cracking and this should be borne in mind in making decisions and plans for repair.

The monitoring process with regard to ship's hulls should , therefore, be a consistent process so that any warning signs can be detected. Access to the various structural elements is therefore an important consideration. Ship structures will inevitably age with time necessitating contingency plans for maintenance, education and staff availability. Regrettably time waits for no man, particularly in a competitive and environmentally sensitive operational environment, and an appreciation of today's trends is perhaps the necessary spur for action.

Structural Development

The most appropriate historical starting point would be the birth of the very large crude carriers in the mid nineteen sixties. These ships, in terms of structural arrangements, employed an extrapolation of those previously used. These arrangements had a design emphasis on longitudinal strength. The evolution of these larger ships also brought about a high degree of structural optimisation and, in addition to the overall dimensions of the ships being larger, aspects such as transverse spacing and cargo tank lengths increased dramatically. In the absence of computer availability and an awareness of the potential problems this was a step into the unknown. The future consequences became, as is now known, an expensive learning process. This learning process was as a result of extensive fatigue cracking at areas of detail design, such as longitudinal connections to web frames, and, on a grander scale, the extensive shear buckling of web frames and wash bulkheads which supported the longitudinal girder systems these ships had inherited from the smaller experience based unoptimised tankers. The increased availability of computer facilities and the lessons learned soon resulted in designs which had simpler load flow paths with the deletion of multi-longitudinal girder systems in favour of a simpler primary centreline girder, or even no longitudinal girders, in the late sixties and early seventies. In the early seventies the lessons learned from the previous extensive fatigue cracking which had occurred made this the consolidation period for detail design.

In the mid seventies, another noteworthy development was the progressive increase of construction oriented structural arrangements, particular by European shipyards. This entailed the use of arrangements which employed uni-directional welding as far as practicable. Such arrangements employed separate primary brackets, as opposed to the continuous face plate arrangements being employed by the Japanese, and asymmetrical face plates. The results of this were

not always beneficial towards fatigue performance, particularly at bracket toe regions.
At this time, European shipyards were also carefully assessing the use of higher tensile steels for members other than the deck and bottom. Verolme shipyard in Holland was one of the shipyards who did extensive work in this area and concluded that it had benefits for selective use. Other shipyards, such as Kockums and Gotaverken in Sweden, used these materials with a yield stress up to 36 kg/mm^2 extensively for the hull girder members, and in particular for longitudinal stiffening.

The subject matter for this presentation looks at the situation "as is" and then addresses the situation with tomorrow's ships and the situation as hopefully it "will be". The general subject matter being as follows:-

* Structural Aspects of Concern with pre-MARPOL ships
* Aspects which influence the location of structural problems
* Access facilities and arrangements
* Structural aspects of concern with post-MARPOL ships
* US and Pending IMO Legislation
* Computed Aided Monitoring Systems

STRUCTURAL ASPECTS OF CONCERN WITH PRE-MARPOL SHIPS

With the scale, methods and welding practices employed in the construction of large tankers it requires to be recognised that there will always be residual cracking in tank ship structures. The structural development in the late sixties and early seventies, as previously stated, resulted in a wide range of defects being experienced, however, this situation stabilised. In the early seventies, the legacy from the events of the preceding years could be seen in the form of fatigue cracking in areas of detail design or where marked discontinuities existed. Again, as previously indicated, there are certain details which are repeated thousands of times in a typical tanker and the enormity of the consequence resulting from a local design deficiency was a major factor in the scrapping of many tankers in the late seventies when the cost of repair outweighed the value of the ship. Experience has clearly shown that the connection of side longitudinals to web frames or transverse bulkheads are the predominant locations for fatigue cracking on tank ships built in the early seventies. Cracking of bottom longitudinal connections to web frames and transverse bulkheads has, however, never been a significant problem after some incidents in the early seventies. Bracket toes at the extremities of transverse webs and transverse bulkhead horizontal girders were also a focal point for fatigue cracking on these earlier ships.

Potential consequences from fatigue cracking depend greatly on the local structural arrangements employed. As an example of this it was found that, with side longitudinals fabricated with completely asymmetrical face bars, the fracture propagation from the longitudinal connection to the web frame was perpendicular though the web of the longitudinal and into and through the side shell. An interesting point to note was that, while it was obvious that the side shell was cracked, the stiffness of the side longitudinals closed the cracks in the longitudinals so that under normal close up tank inspection conditions they became undetectable. Dye penetrant methods were also inconclusive in detecting their presence and it was only by using magnetic particle methods that the crack sites were identified. The great majority of longitudinals are fabricated with a small upstand and their connections will normally fracture through the connecting pillar stiffeners. These fractures are usually easy to detect and consequences from this are not as immediate.

To understand the potential secondary consequences of failures to longitudinal connections it is useful to understand the basic mechanics of the joints.In simpler terms, the load from the platings is mainly transmitted by the longitudinal stiffeners to the web frames, with only a local triangular area of load being transmitted directly to the web frames via the plating. This load from the longitudinal is then conveyed into the web frame by the pillar stiffener and lugs, or clips as they are sometimes called. By virtue that the stiffener extension or contraction, and therefore its load, is determined by its effective area and the Young's modulus of the material, and the load taken by the lug or lugs is influenced by their area and the material shear modulus, it is apparent that a degree of conflict exists in the joint. The fact that the pillar stiffener is also out of plane with the web frame also creates a couple and a non-uniform distribution of load across its breadth. Upon the commencement of cracking in the pillar stiffener, therefore, a progressive redistribution of loading takes place and normally results in yielding at the transverse notches for the longitudinals and subsequent cracking of the transverses. This has been known to develop, where adjacent longitudinals are also effected, to situations bordering on the loss of the ship's side shell. This of course is not the whole story and the more knowledgeable will realise that the general shear loading in the transverse web frames also influences the load distribution in these connections by virtue of the shear deformation created in the vicinity of the longitudinal notches. Cracking at bracket toes is a little more predictable but propagation into bounding bulkheads cannot be discounted.

As a measure of the unpredictability of hull cracking (some may say predictability), the case of the "Kurdistan", a 40,000 tdwt oil tanker, must be among the foremost. The case was extreme and resulted in the ship breaking in two due to brittle fracture which propagated from a small crack in a bilge keel butt weld.

Another aspect of major concern is the occurrence of corrosion on tank ships which can be very generally categorised as being general corrosion and localised corrosion . It is not intended to go into any depth on these aspects but suffice it to say that in a ship which has been reasonably maintained the levels of general corrosion in the cargo area should be very much smaller than in their pre-IGS/Crude Oil Washed forebears.

Focal areas for general corrosion are the water ballast spaces, particularly the longitudinal bulkhead structures and the deck structure in way, i.e. areas which experience a high degree of condensation. Other areas susceptible to accelerated corrosion in water ballast spaces being the upper structure of the transverse bulkheads and horizontal structures such as side longitudinals.

Whether or not the bottom of the cargo tanks are protected by coatings or even anodes will influence the levels and extent of pitting on the ship's bottom. Where devoid of any coatings, the pitting will tend to be more general in nature. Whereas, where it has occurred at locations of paint breakdown, then it is of a very localised and significant nature.

ASPECTS WHICH INFLUENCE THE LOCATION OF STRUCTURAL PROBLEMS

In its seagoing environment a tanker experiences cyclic loading from a variety of sources. Examples of these sources are:-

- i) the passage of waves along the length of the ship.
- ii) loads due to a ship's response in a seaway.
  e.g. pitching, rolling, heaving, etc.
- iii) internal loads from cargo and structural inertial loads.
- iv) engine and/or wave induced vibratory loads.

Considering only the external environmental loads, it becomes apparent that the almost continual cyclic loadings created by the passage of waves along the ship's sides, and the associated local structural response this produces, will create the highest risk for fatigue damage and cracking. Other aspects of load, such as those due to ship response and wave impacts, will of course exacerbate this situation but are considered as lesser components.

With regard to the loadings on the ship's bottom, the loading spectrum (both in terms of hull girder responses and local pressure variation) is heavily influenced by the length of the waves and their direction in relation to the ship's length and draught. In a general sense, however, the structural components on the bottom of the ship are not exposed to the same frequency of loads as the side shell. In a similar manner the ship's deck structure is exposed to structural loads from the hull girder in response to relatively longer waves and also local loads from cargo as induced by ship responses. In a simplistic way, if a twenty year wave load spectrum is considered,the side shell at about the ship's mid-depth will experience the maximum accumulative fatigue damage due to the higher number of load cycles experienced. In the case of the bottom shell the higher frequency low load waves will not be experienced but, it is considered, waves with longer lengths will induce pressure variations on the bottom structure and, with even longer waves primary structural response of the hull. With regard to the deck, only the longer waves, which create hull girder response are significant in effect. Of course the other non direct loads, i.e. those created by ship responses, will complement the stresses experienced.

In order to support this simplification, experience has clearly shown that the side structure of oil tankers is the most fatigue prone area, followed by the bottom and then the deck, in descending order of risk. See figure 1.

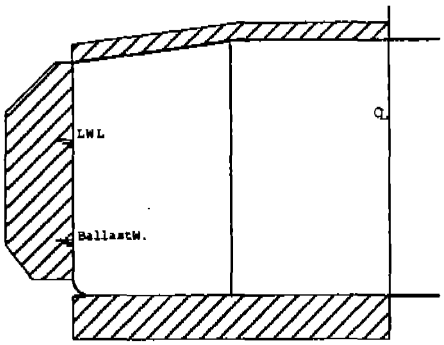

Figure 1
Diagram Indicating Relative Magnitudes of Risk for Fatigue Failures at Locations of Detail Design

Occasionally, however, there are cases which initially seem to confound this rational. A perfect example of this was when a series of ships were found to be experiencing fatigue cracks in longitudinal connections and bracket toes when all previous knowledge and calculations indicated that there should be no problem. All these ships in question were modern Segregated Ballast tankers (SBT) of deadweights ranging from 40,000 to 90,000 tonnes. All of the ships were powered by five cylinder medium speed diesel main engines. Full scale measurements revealed that the added hull stiffness, created by the SBT structural configuration, was transmitting axial thrust variations through the thrust block into the hull and inducing vibratory effects, and thereby high frequency loadings, over the entire length of the cargo area. Modifications to eliminate the source forces and to repair the 'fatigue aged' structural details were subsequently carried out.

Inadequate design aspects are of course not the only causes for structural failure. Construction methods and workmanship are also prime candidates in many cases. In this respect, in the earlier VLCC's, some of the problems could be traced back to both the fabrication and erection stages of construction whereas, in the ships constructed in the mid-seventies, the problems mainly have been found to originate from the procedures and tolerances employed in the erection of the blocks. Location of defects from these latter aspects, while generally consistent in nature on a ship, are normally individual to that ship.

ACCESS FACILITIES AND ARRANGEMENTS

Standing on the bottom of a tanker and looking up brings an immediate realisation that the arrangements employed are not sympathetic to any inspection. This is not a new realisation and committee's were set up in the early seventies, and presumably before this, to investigate and evaluate various schemes available to enable access. Aspects considered as being sensible are listed from reference 1 as follows:

(i) The fitting of permanent staging at strategic locations within the tank, i.e. below deckhead.

(ii) The attachment of permanent lugs, clips and so on to the internal structure for retaining portable staging supports.

(iii) The provision of permanent longitudinal and transverse walkways across the shell bottom primary members having suitable hand rails with foot rungs or ladders attached to bottom members for access to the walkway.

(iv) The fitting of guard rails to shell and bulkhead stringers with access ladders to the stringers.

(v) Examination of the deckhead by cage or hoist suspended through the tank access opening

(vi) The provision of holes in the deck necessary for the use of completely portable and independent staging systems such as 'Skyclimber', 'Safe Walk', etc.

(vii) Examination of the deckhead from an inflatable raft floating in a partially filled tank.

(viii) Examination of the deckhead by use of a diver and television camera in a fully filled tank.

Aspects such as the utilisation of existing structure, by increasing their dimensions, at erection butts, were features used with some success in many ships, although many a surveyor used them with some trepidation. As with most things in life the most convenient, and seemingly safe means, became the most popular and in this case this resulted in the use of rafting as being a predominant means for each inspection.

A brief synopsis of the points discussed so far is as follows:-

On the negative side:-

- i) A variety in levels of workmanship standards exist on a ship's hull even for similar structural details.
- ii) The structural performance of similar joints will vary because of location and variations in workmanship standards.
- iii) Planned structural maintenance can provide an early warning system with regard to any structural inadequacies.
- iv) In service inspection methods commonly use rafting.
- v) Cracks in some locations and in certain configurations of structure are difficult to detect until the next, and more critical, phase of the failure occurs.
- vi) Cracks in seemingly insignificant locations can result in critical hull failure.

On the positive side:-

- i) There is a more open awareness of the problems being experienced.
- ii) Ships which suffered the majority of structural failures were scrapped during the late seventies.
- iii) The maintenance of water ballast spaces will greatly enhance hull performance.

STRUCTURAL ASPECT OF CONCERN WITH POST-MARPOL OIL TANKERS

The development of hull structural arrangements to incorporate the requirements of the MARPOL convention are well documented. Also well known is the development of competitive structural arrangements and the more extensive use of higher tensile steels in the ships of this period.

Reference 2 relates to many of the structural trends for oil tankers of this era. There are, however, three fundamental questions which, it is considered, are important with regard to "post-MARPOL" ships. These are:

Has MARPOL increased the risk of accidental pollution?

Has MARPOL influenced the potential life of ships?

Will US legislation influence these aspects?

A reiteration of the probable similar influences of both the MARPOL Convention and US Legislation on ship life and accidental pollution is necessary at this point in order that the differences between pre-and post-MARPOL ships can be appreciated and to set the scene for discussion on maintenance.

It is emphasised at this time that this comparison is not meant to question the value of the MARPOL requirements and indeed it is believed that this Convention has been largely successful, particularly with regard to the operational discharge of oils.

With regard to the question of increasing the risk of accidental pollution, experience has shown, that water ballast spaces are the focal point for maintenance and, if this is inadequate, the possible site of major structural failure. Ships which comply with SBT and Protective Location requirements will inherently have about three times the number of dedicated salt water ballast spaces in relation to their predecessors. In the event that maintenance levels are consistent on these ships with those on earlier ships the probability for major structural failures and therefore pollution must be more than proportional, i.e. if ship operators could not maintain two ballast spaces the greatly added cost of maintaining up to sixteen ballast spaces or more must be an even a bigger deterrent.

Defining ship life is of course a difficult task and for the purpose of this presentation it will be taken as the potential life of the main hull girder platings (i.e. deck, side and bottom platings) against corrosion attack. Studies on the average corrosion rate of the platings show that for the majority of the hull girder platings bounding cargo tanks the diminution rate is about 0.1 mm per year for ships with inert gas and crude oil washing. With ships built up to the time when compliance with MARPOL requirements became mandatory, deck and bottom thicknesses for a VLCC were in the region of 25 mm hts. With the change in length to depth proportions, which came about as a result of builders trying to reach optimum arrangements for ballast and cargo in order to comply with the

MARPOL Convention requirements, the scantlings for these members dropped dramatically, due to the increased ship depths involved, to about 20 mm hts. The margins in a comparative sense against their predecessors were, therefore, very much reduced. With these lower thicknesses a ship life of 15 to 20 years as traditionally expected, based on the predicted corrosion rate, is still attainable. However, this attainment is conditional on a system of planned maintenance being carried out.

Turning to the aspects discussed with regard to pre- MARPOL ships the following is a brief summary with regard to post-MARPOL ships:-

Structural Development

Structural concepts are generally similar to pre-MARPOL arrangements although breadths of centre tanks are consistently wider. Competition has dictated greater levels of scantling optimisation, particularly for primary supporting structures. This has resulted in greater defections of primary structures and greater concentrations of load on secondary supporting structure. In addition to this, higher tensile steels have been used more extensively for both secondary and primary structure. Without extensive computer analyses this is a step into the unknown. With the use of computer analyses techniques there is still an element of risk and for this reason the level of optimisation requires to be controlled so that the factors for ignorance, or uncertainty, are not depreciated to unjustifiable levels.

Structural Aspects of Concern

While the lessons learned from the ships built during the early seventies are documented, parameters such as the use of higher tensile steel for detail areas of design have made the original experience based data base not directly applicable. Scantling reductions for the deck and bottom platings have changed the mode of failure for these structural elements and a reduced reserve from that which existed for pre-MARPOL ships exists for these members against collapse.

Areas Considered to be of a Higher Risk

The use of higher tensile steel and computer based structural optimisation must increase the risk for the occurrence of fatigue cracking at areas of detail design. Locations such as bracket toes, connections of longitudinals and stiffeners to primary members being the primary areas of concern. With this in mind Lloyd's Register modified its criteria for dealing with these locations by requiring permissible stress criteria similar in magnitudes as for normal yield steel, i.e. as higher tensile steel (HTS) does not display improved properties for fatigue resistance over normal yield steel, normal yield criteria were largely retained. In certain cases, however, such as longitudinal connections, the permissible stress criteria were reduced, where HTS was employed, to levels below that for normal yield steel to make allowance for the various component HTS stresses in the joint. The occurrence of fatigue fractures on VLCC's built in Japan in the early eighties is a well documented happening. It is not considered that the blame for their occurrence can be attributed to a single reason but rather a amalgamation of causes symptomatic of the shipping community attitudes at the time e.g. competition forcing reduction of steelweight by virtue of structural optimisation, the use of higher tensile steels and the acceptance by the owner of the lower costs.

Maintenance of water ballast spaces, as mentioned earlier, is a matter of great concern because of the greater number of water ballast spaces involved. It was for this reason that the classification societies now require the maintenance of protective coatings in these spaces from May 1991.

Access Facilities and Arrangements

There has been no great change in access arrangements for the new generation VLCC's from those employed in the pre- MARPOL ships.

US AND PENDING IMO LEGISLATION

The purpose of this presentation is not to judge whether or not double hulls are desirable or not. They are, by virtue of US legislation, a reality and require to be addressed accordingly. Remembering the problems experienced in the past, when the scale of certain structural configurations changed, it should be realised that this is not the time for complacency. Regretfully the lessons learned from the experience with previous single hull VLCC's cannot be taken as applicable on tomorrow's double hull ships without serious consideration.

An important realisation is that the wing water ballast tanks cannot easily employ the same inspection procedures of rafting as traditionally employed on existing pre-MARPOL and post-MARPOL ships. The ships must therefore be designed from the outset with maintenance in mind. To recognise the ultimate consequence in not doing so one has only to turn to the many recent losses of side shell on current pre-MARPOL ships. In the event that a similar failure occurred to a double hull tanker the lack of structural isolation between the side shell and the longitudinal bulkhead structure would, in all probability, lead to extensive pollution and possibly the loss of the ship.

Returning to the previous question raised "Will US Legislation influence accidental pollution and potential ship life?" the answer is "YES" if we do not plan accordingly. Fundamental questions are, "Is it so difficult to plan structural arrangements so as to facilitate maintenance?" and "What are the deterrents for shipbuilders/shipowners in doing so?" The answers to these two questions are "NO" and "Short Term Cost".

For information purposes a diagram illustrating a possible arrangement of structure which would enable easier access and maintenance is shown as figure 2. In this theoretical design the wing tank

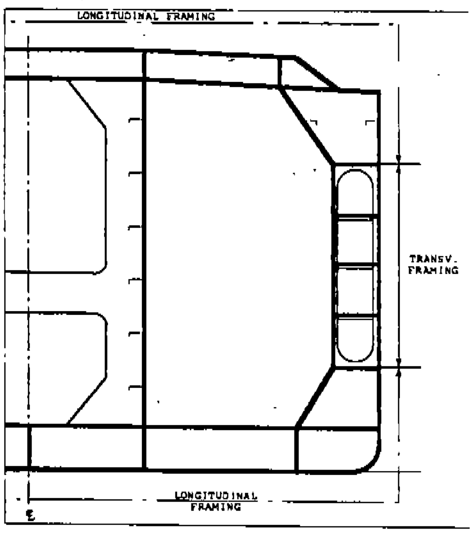

Figure 2
Possible Double Hull Configuration which would Permit Improved Access

structure is arranged so that fore and aft access can be attained at various levels by virtue of the horizontal stringer arrangements. To obviate the need for rafting in the port and starboard cargo tanks the deck longitudinals and supporting transverses have been located on top of the deck. In the centre cargo tanks a system of horizontal walkways could be fitted at various levels to permit inspections, measurements and maintenance of any coatings or steelwork. There is nothing new in these proposals which have been used, albeit in a limited sense, on smaller vessels.

There are, of course, limitations to the use of these arrangements and arguments will abound forever on the practicality of overdeck structure but possibilities, do exist for intermediate solutions.

Realisation that maintenance of the hull and particularly water ballast spaces is fundamental if a ship is to operate successfully without causing pollution during its envisaged life. With this in mind attention to detail design and adequate coating of ballast spaces are considered prerequisites for safe operation.

COMPUTER AIDED MONITORING SYSTEMS

If you purchase a family car or other vehicle the purchaser is normally presented with a service booklet outlining or specifying the extent and time intervals between the services to be carried out. Why can this not be the case with a ship? With a major consequence of the potential legislation being the enormous increase in spaces which require a higher degree of maintenance and vigilance it would seem that this is the logical time to implement hull planned maintenance schemes at the newbuilding stage.

Such schemes will however dictate a commitment from the shipbuilder, in terms of making available the necessary CAD files, from the classification society who will require to develop with other parties location and periodicy of measurements and, importantly from the shipowners who will have to implement the scheme and carry out much of the necessary inspections and measurements. An example of such a scheme is the CATSIR system developed by Chevron.

SUMMARY

Over 70% of oil tankers in today's fleet are pre-MARPOL ships and possess a degree of structural robustness which is more accommodating to lapses or variances in maintenance levels. It is recognised by many that the lower levels of reserve strength possessed by post-MARPOL ships will necessitate more extensive maintenance and inspection. With double hull configurations the need for even greater inspection/maintenance planning and commitment becomes imperative.

It is Lloyd's Registers experience that within the shipping community there appears to be a tendency to reinvent the wheel. In the last decade, however, realisation of lack of accumulation of experience led organisations such as the Tanker Structural Cooperative Forum to try and encapsulate the available experience in an understandable and usable form. The result was their guidance manual which is widely used today within the oil tanker community. More recently the need for planned monitoring and maintenance /repair systems for ship hulls was recognised by the US tanker operating community and as a result of this a subsidised study is presently being undertaken by Berkeley University in California. What is obtained from this study will be a measure of what is put in by the community in terms, not only of funding, but also of experience and knowledge. At this time this study is progressing towards a crossroads between experience based and untried computer systems. To obtain the necessary confidence level these latter day developments must prevail and succeed. Bye products from such systems are of course improved data access/storage and trend assessment together with the use of semi-intelligent systems in the form of a relevant structural data base as well as a capability for assessing damage severity and repair need and extent. Not as evident is the gain by the industry as a whole by enabling access to experience in terms of structural performance it is noted with interest that shipbuilders/repairers from Japan and Korea are now involved in this study.

To realise the ability to attain the necessary levels of inspection, maintenance and monitoring, means to accomplish adequate access to the structures should be inherent in the structural design. Alternatively supplementary fixed access facilities could be provided. If such provisions are not made, planning for maintenance will never result in the reality of maintenance only the reality of compounding the risk for major structure failure and pollution. Arquably therefore adequate access arrangements should be a requirement by the authorities concerned.

References

Ref:1 "Hull Survey of VLCC's" by F.N. Boylan and F.H. Atkinson, LR Technical Reprint No. 69

Ref:2 "Oil Tankers in the 1990's by J M Ferguson."

Walter Maclean

How much do you think a more complicated structure would cost in terms of construction costs?

J.M. Ferguson

I would guess a few percent, nothing more than that. You are not increasing the weight by any great extent - it is a question that you are putting additional pieces on the ship. You're isolating the overhead deck with transverses. You're creating additional work by building a topside tank, which would be necessary. There are complications. I said it was not a practical design as it was, but it could be. The problems are that the side structure, the horizontal girders, would be the strength members, and of course the span, which would be the length of the cargo tanks ,would be a fundamental design consideration. Nevertheless, I think that it is important that even though a builder build a ship with longitudinal frames inside and incorporates structural webs inside, that it should have horizontal girders for access. That was the main point I was making. The other aspect is that these ships will be very difficult to raft because of the smooth wall tanks, where I think it would be a nightmare to go into with a raft; in other tanks there is at least something to grab on to. So I think that the idea of the overdeck structure is very sensible. Shipbuilding and ship owning is a very traditional business; the possibilities are probably very low. There are positive means that can be taken to improve access on these ships.