THE UNITED STATES OIL POLLUTION ACT OF 1990
HISTORY, TECHNICAL REVIEW AND OBSERVATIONS

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1. INTRODUCTION

On 16 August 1990, the President of the United States signed into law a much debated and controversial bill known as the Oil Pollution Act of 1990. This law has far-reaching implications for tanker owners operating or intending to operate in United States waters. For them perhaps the most significant aspects of this legislation pertain to tanker structures and liability.

1.1 HISTORY

Tracing the history of this legislation helps one to see how it came into being. Concern in the United States about the perceived relationship of tanker design to oil spills has existed for quite some time. In fact, the first attempt to mandate design requirements in the United States occurred in 1976 when President Carter instructed the United States Coast Guard, through the Secretary of Transportation, to develop requirements for double bottoms on all new tankers over 20,000 deadweight tons. He also recommended that a special international conference be held to consider these proposed requirements.

As a result, the conference on Tanker Safety and Pollution Prevention [TSPP] was held by IMO in 1978, but the United States proposal for double bottoms was rejected. However, requirements were adopted for Protectively Located (PL) Segregated Ballast Tanks (SBT) covering a percentage of affected cargo area ranging from 45% for vessels up to 20,000 DWT and thereafter an interpolation percentage of up to 30% for vessels greater than 200,000 DWT. Additionally, requirements were developed for Crude Oil Washing (COW) and Inert Gas Systems (IGS). Crude Oil Washing was developed for all new tankers carrying crude oil above 20,000 deadweight tons and was made one of the options for existing crude oil carriers to facilitate the implementation of MARPOL 73/78. Inert Gas Systems, already required for vessels 70,000 deadweight tons and above, were modified to apply to oil carriers of 20,000 deadweight tons and above. The results of the TSPP Conference were embodied in MARPOL 73/78 and the 1978 Protocol to SOLAS 74. The United States compromised and accepted these requirements. The United States Port and Tanker Safety Act of 1974 mandated the IMO Standards as minimum requirements which became U.S. Law in 1979. However, as a result of several catastrophic oil spills of the multimillion gallon category in International waters in the late seventies and in the eighties, the drumbeat for some type of additional legislation affecting tanker structures grew ever louder. Requirements for double bottoms and other structural arrangements were introduced into legislation on a number of occasions in the past decade but were defeated. This was to change in 1989.

It was in that year that the 211,000 deadweight ton tanker EXXON VALDEZ ground to a halt on Bligh Reef shortly after departing the Port of Valdez, resulting in the largest spill ever to occur in United States waters. This set into motion the development of legislation by the United States Congress which heard the cries of public indignation and sensed a need for action. The United States Senate passed a Bill in August of 1989, followed by the United States House of Representatives in November. These two bills differed on a number of points and were the subject of much debate.

The pressure to act on a national scale increased when a rash of other spills polluted United States waters in the late winter and early spring. The

Environmental effects of these spills were minor, but they served to defeat any meaningful opposition to the Bills. Consequently, a joint House/Senate Conference Committee met in the late spring to resolve their differences. Agreement was reached in the early summer, leading to proposed legislation passed by both houses that was signed into law by President Bush on 16 August 1990 as the Oil Pollution Act of 1990.

These activities in the U.S. have prompted similar efforts around the world, most notably the centralized discussions ongoing at the International Maritime Organization (IMO). In the following sections a summary of the U.S. and international efforts is offered along with a discussion of the most pertinent related considerations.

2. U.S. OIL POLLUTION ACT

The United States' Oil Pollution Act of 1990 (OPA 90) (Public Law 101- 380) embodies the first requirements ever mandating the use of double hulls for tank vessels. While this is the most significant technical aspect of OPA 90, the law contains comprehensive language on a far-reaching scope of related topics. One topic which may very well represent a more significant impact than the double hull requirement is that covering the liability limits with which owners will have to concern themselves.

While the OPA 90 is of particular concern to those involved in operating tank vessels in U.S. waters, this legislation and the events triggering it have provided the catalyst for similar efforts worldwide. For the purpose of examining the implications of the U.S. law as well as its impact on international efforts, a brief summary of OPA 90 is presented in the following sections.

2.1 Double Hulls

The Act addresses both oil pollution prevention and removal. The focal point of the prevention topic is the requirement of double hulls for tank vessels. Specifically, double hulls are required for all tank vessels for which a building contract, or a contract for a major conversion, was placed after 30 June 1990 or for vessels delivered after 1 January 1994. Existing tonnage is also subject to requirements of OPA 90. Existing tonnage is defined as any new construction or major conversion for which contracts were signed before 30 June 1990 and delivered under those contracts prior to 1 January 1994. These vessels must be fitted with double hulls. However, these vessels are subject to many qualifications and temporary exemptions summarized as follows:

Less Than 5,000 GT

Tank vessels less than 5,000 gross tons are exempt from having double hulls until 1 January 2015. These vessels can also satisfy the terms of OPA 90 by employing an effective double containment system approved by the Secretary of Transportation. A point worth noting with respect to "an effective double containment system" is that no such system has been identified or approved for use.

Ofshore Unloading

All vessels delivering oil to a lightering operation more than 60 miles offshore and/or unloading at a licensed deepwater port (Louisiana Offshore Oil

Table 1
Phase Out Schedule - Vessels at least 5,000 but less than 15,000 GT

Vessel Delivered During Period Shown				Phase-Out Date
With a Single Hull		With a Double Bottom or Double Sides		Retired or Retrofitted
After	But not later than	After	But no later than	After 1 January of
-	1 Jan 1955	-	1 Jan 1950	1995
1 Jan 55	1 Jan 1957	1 Jan 50	1 Jan 1952	1996
1957	1959	1952	1954	1997
1959	1961	1954	1956	1998
1961	1963	1956	1958	1999
1963	1965	1958	1960	2000
1965	1980	1960	1975	2005
1980	1994*			2010
		1975	1994*	2015

* Contract placed before 30 June 1990

Port, LOOP) are exempt from the double hull requirement until 1 January 2015.

Phase-Out / Retrofit Schedule

In general, OPA 90 requires all single skin tankers to be retrofitted with double hulls or phased-out of the trade by the year 2010. However, to avoid the potential impact of a large number of tankers reaching a legislated obsolescence on 1 January 2010, a phase-out schedule based on vessel size and age is included in OPA 90.

In addition to the under-5,000 GT vessels mentioned above, three vessel size ranges are prescribed:

- 5,000 or greater, but less than 15,000 gross tons,
- 15,000 or greater but less than 30,000 gross tons, and
- 30,000 gross tons and over.

For the purposes of OPA 90 the definition of vessel age is based on the latter date of:

1) delivery date after original construction,
2) delivery date after a major conversion, or
3) qualification for documentation under the "Wrecked Vessel Act".

Item 2 deserves a special note since what constitutes a major conversion may not be clear. If a vessel undergoes a major conversion, as opposed to a more limited modification, for the purposes of OPA 90 the age of the vessel will be based on the delivery date following the conversion. Under U.S. law, a major conversion means a conversion of a vessel that:

(A) substantially changes the dimensions or carrying capacity of the vessel;
(B) changes the type of the vessel;
(C) otherwise so changes the vessel that it is essentially a new vessel, as decided by the Secretary of Transportation.

Since the decision as to whether a vessel has undergone a major conversion is made on a case-by-case basis, if an owner feels that a vessel has undergone such a conversion he should contact the USCG for a determination of the vessel's age for the purposes of OPA 90.

The phase-out schedules based on the above and defined in OPA 90 are summarized in Tables 1,2 and 3.

Table 2

Phase Out Schedule - Vessels at least 15,000 but less than 30,000 GT

Vessel Delivered During Period Shown				Phase-Out Date
With a Single Hulll		With a Double Bottm or Double Sides		Retired or Retrofitted
After	But not later than	After	But no later than	After 1 January of
-	1 Jan 1955	-	1 Jan 1950	1995
1 Jan 55	1 Jan 1958	1 Jan 50	1 Jan 1953	1996
1958	1961	1953	1956	1997
1961	1964	1956	1959	1998
1964	1967	1959	1962	1999
1967	1970	1962	1965	2000
1970	1972	1965	1967	2001
1972	1974	1967	1969	2002
1974	1976	1969	1971	2003
1976	1978	1971	1973	2004
1978	1980	1973	1975	2005
1980	1994*			2010
		1975	1994*	2015

* Contract placed before 30 June 1990

Table 3

Phase Out Schedule - Vessels at least 30,000 GT

Vessel Delivered During Period Shown				Phase-Out Date
With a Single Hull		With a Double Bottom or Double Sides		Retired or Retrofitted
After	But not later than	After	But no later than	After 1 January of
-	1 Jan 1967	-	1 Jan 1962	1995
1 Jan 67	1 Jan 1969	1 Jan 62	1 Jan 1964	1996
1969	1971	1964	1966	1997
1971	1973	1966	1968	1998
1973	1975	1968	1970	1999
1975	1977	1970	1972	2000
1977	1994*			2010
		1972	1994*	2015

* Contract placed before 30 June 1990

Technical Requirements

The Act calls for the Secretary of Transportation to establish the specific requirements for double hulls. The Secretary has authorized the U.S. Coast Guard (USCG) to perform the rulemaking for these requirements. The specifics of the USCG rulemaking are presented in Section 4.1, below.

Alternatives

Here again OPA 90 authorizes the Secretary of Transportation to study alternative methods which provide the same protection afforded by double hulls. Should such alternatives be identified, the Secretary can recommend these to Congress for legislative action to adopt them for use in U.S. waters. This aspect of alternatives is discussed below in Section 6. The conclusions of the study performed for OPA 90 are summarized in Section 7.

2.2 LIABILITY

The Act also establishes new federal maximum limits on shipowner liability. Each responsible party for oil spills from vessels will be strictly liable for removal costs and damages, including natural resource damages, resulting from the spill.

For a vessel over 3,000 GT, the new limit has been increased from $ 150 to $ 1,200 per gross ton of the vessel or $ 10 million, whichever is greater. For vessels 3,000 GT or less, the maximum liability is $1,200 per GT or $2 million, whichever is greater.

In instances where costs exceed those covered by the liability limits, money will be drawn from a fund supported through a 5 cent/barrel federal excise tax on the industry.

Five important points are to be noted which qualify the above requirements:

1) For vessel owners there are NO limits on liability in cases of gross negligence, willful misconduct, failure to report a spill or violation of federal safety regulations.

2) The Act does not preempt states' rights. In other words, individual states retain their authority to impose higher or unlimited liability on spillers. The states can also implement their own compensation plans.

3) Documentation is required showing the financial ability of vessels/owners to fulfill their required responsibilities. Sanctions are to be imposed for failure to have evidence of this on board the vessel.

4) A third party can also be suject to liability when it can be established that damages or removal costs were caused by an act or omission of that third party.

5) Under OPA 90 third party responsibility for spills is a recognized defense along with an act of war and act of God.

Congress did consider the International Protocol of 1984 to amend the International Convention on Civil Liability for Oil Pollution Damage, 1969, and the Protocol of 1984 to amend the International Convention for the Establishment of a Fund for Compensation for Oil Pollution Damage, 1971. However, it was felt these two treaties would preempt states' rights as outlined in item 2 above, and therefore were not included in OPA 90.

2.3 Other Provisions

In addition to the two major topics discussed above, there are other significant provisions in OPA 90. The provisions include:

- review of international oil pollution agreements,
- alcohol and drug abuse matters,
- manning standards,
- Vessel Traffic Service (VTS),
- oil spill response plans, and
- oil pollution research studies.

3. INTERNATIONAL EFFORTS

Catalyzed by the events in the United States, similar efforts on the development of double hull standards have become the new focal point for the international maritime community. Numerous national and regional activities are in progress. For instance, Canada is currently exploring a rationalized approach towards achieving full double hull tanker trade in its waters in seven years. The Conference of North Sea States is also considering proposals to require some form of double containment system; double bottoms, double hulls, etc.; on tankers entering the waters of member states. Finland has taken the approach of encouraging the employment of double hull tankers by imposing a 30 cents (U.S.) per barrel tax on single hull tankers entering its ports. Double hull tankers are taxed at a much lower rate.

However, the most significant international effort considering more stringent anti-pollution tank vessel requirements is the centralized work underway in the International Maritime Organization (IMO).

3.1 MEPC - 30th Session

In November 1990 IMO's Marine Environmental Protection Committee (MEPC) began considering a proposal submitted by the United States which is intended to amend current Regulations 13E and 14 of Annex I of MARPOL 73/78 to require double hulls on all new oil tankers. This has taken the form of draft Regulation 13F. This proposal effectively parallels the U.S. legislation. The ensuing discussions among the participants demonstrated a broad base of international support for efforts, led by the U.S., related to amending MARPOL 73/78. However, there also was an underlying concern in enacting further unilateral regulations, this time on an international level, without due technical review and consideration of the impact on tankers safety and the industry, as well as on the environment.

In general, the concept of requiring double hulls as prevention against oil spills was accepted. Several delegations explicitly supported the requirement of double hulls but qualified this position with concerns that the U.S. proposal is too stringent for certain tanker sizes. In particular, the concerns raised were in regard to requirements for tankers under 20,000 DWT. For these vessels it was felt by many that the proposed minimum tanker widths/depths are disproportionately large for the risk associated with these vessels and that they represent an excessive economic burden.

Some delegations did address the need for new requirements for tankers in more general terms with the view that particularly specifying a double hull requirement may be premature. Instead, technical investigations examining the "whole scope of means, measures and methods" need to be performed in preventing oil spills from ships. In addition to examining the appropriateness of double hull designs the subject of alternative concepts was identified as an important topic requiring attention. Alternative designs were seen as representing promise to the extent that they should be included in any proposed amendments to MARPOL. The major issue raised with respect to alternatives was concerned with how to judge the effectiveness of the concept. An appropriate reference level must be established in order to rationally assess these designs. Further discusion on alternative concepts being addressed internationally is presented in Section 6 of this presentation.

Hand-in-hand with all of the above discussions is consideration of the impact of this activity on existing tankers. There were opinions expressed during the discussions that any proposals affecting new construction must also address requirements for the existing world fleet, so as to not unfairly burden new vessels with the associated economic and environmental responsibilities.

To address the issues raised during the MEPC discussions, a working group was established. The primary result of the meeting of the MEPC working group was the prpeparation of Draft Regulation 13F to Annex I of MARPOL 73/78. The draft requires double hulls for new vessels but allows the use of equally effective alternative designs. The working group determined that at the present time the double hull concept represents an appropriate reference level for assessing alternative designs. The specifics of the draft regulation are discussed in Section 4.2. Regarding existing vessels, a preliminary proposal was put forth that categorizes existing tankers into four groups as described in Table 4. Two phase-out dates have been proposed for each group as described in the following.

1) The first phase-out date assumes that a vessel is operated "as-is" with no modifications.
2) The second would be set for a later date based on compliance with new requirements. These new requirements would be unique for each existing tanker group and would specify a percentage of side shell area for protectively located segregated or clean ballast tanks (SBT,

CBT). Additionally, the vessel must operate with either hydrostatically balanced loading or a vacuum system.

The actual dates for these phase-outs has not yet been discussed.

Aside from the above, the working group also considered the need to focus on management principles, operational practices, human factors and possible consideration of means for the transfer of oil in damaged tankers.

The MEPC, after discussing the Working Group's report, referred the following items to IMO's Maritime Safety Committee (MSC) for further referral to MSC's appropriate subcommittees for detailed technical evaluations:

- Oil outflow due to contact casualties,
- Non contact casualties,
- Damage stability, and
- Maintenance and repair.

Regarding the discussions on the human element by the working group, the MSC was also invited to consider requirements for management with respect to pollution prevention under the scheduled discussion on maritime casualties during MSC's upcoming session.

3.2 Pending IMO Action

With the referral of actions to MSC and its subcommittees, activity at IMO on this subject is expanding. A summary of recent and upcoming activity at IMO is offered in the following.

SLF 35 During its recent thirty-fifth session in February, the Stability, Load Line and Fishing Vessel Subcommittee discussed double hull tanker design as it pertains to stability as well as to allowable extent of damage for both vessel sides and bottoms.

DE 34 The Design and Equipment Subcommittee met for its thirty-fourth session in March and discussed recommendations on access and inspectability of double hull tankers and application and maintenance of tank coatings.

MSC 59 The fifty-ninth session of the Marine Safety Committee met 13-24 May. During this period a joint working group was convened consisting of MSC and MEPC members. The decisions of the DE and SLF subcommittees were the central topics for the joint working

Table 4

Vessel Groupings for IMO Existing Vessel Proposal

Group 1	
No tank size limitation and tank arrangement	Tanker not complying with Reg. 24 of MARPOL Annex I, (from definition of tanker coming within the scope of Reg. 24 in Reg. 24 (1)) (building contract on or before 1 January 1974)
Group 2	
Comply with tank size limitation but no SBT	Tanker complying with Reg. 24 but existing ship according to Reg. 1 (7) of Annex I (building contract after 1 January 1974 but before 31 December 1975)
Group 3	
Comply with tank size limitation for all sizes, but SBT only above 70,000 DWT	Tanker being a new ship according to Reg. 1(6) but existing oil tanker according to Reg. 1(27), (building contract after 31 December 1975, but before 1 June 1979)
Group 4	
Comply with tank size limitation, and SBT + PL, if above 20,000 DWT	Tanker being a new oil tanker according to Reg. 1(26) (building contract after 1 June 1979, but before entering into force of new amendments)

group. Although lengthy discussions were held on this topic, no firm decision on the required sizes of double hull spaces was reached.

FP 36 The Subcommittee on Fire Protection held its thirty-sixth meeting in June at which time discussions on the risk of fire and explosions in double hull ballast tanks took place.

MEPC 31 The Thirty-first session of MEPC is currently the focal point of upcoming IMO activity. Final decisions on the amendments to MARPOL can be expected. These will include requirements for minimum double hull dimensions, damage stability requirements, recommendations on fire and explosion risks, tank sizing and associated allowable outflows, and recommendations on tank coatings. Methods for assessing the equivalency of alternative designs will also be discussed along with further attention to the issue of existing vessels. No definitive action on existing vessel upagrading or phase-outs is expected. It may be anticipated that MEPC could accept Draft Resolution 13F in November 1991 and have it come into force in May 1993 at the earliest by tacit acceptance.

4. DOUBLE HULL REQUIREMENTS

In the preceding sections summaries of OPA 90 and the related activities underway within IMO have been presented. The discussion has so far addressed the political concerns surrounding the double hull issue. While somewhat political in content themselves, this section turns to the technical requirements which are now in force, or under consideration, and how they define double hull tankers as they are to be built. Two separate sets of requirements are presented below: the guidelines issued by the United States Coast Guard (USCG) under OPA 90, and the Draft Regulation proposed at IMO by the MEPC. In addition to the specific double hull requirements, a brief comparison of the two sets of requirements is offered along with a summary of the alternative criteria included in the IMO proposal.

4.1 NVIC 2-90

In September 1990, following the enactment of OPA 90, the USCG, at the direction of the Congress and the Secretary of Transportation, issued the Navigation and Vessel Inspection Circular Number 2-90 (NVIC 2-90) which provides recommended standards for double hulls. The standards in the NVIC are interim guidance that are in force until a formal rulemaking process can be completed and final regulations issued. Oil tankers that are built in accordance with this NVIC will satisfy the requirements of OPA 90. The guidelines use current MARPOL minimums. The final rulemaking process is now underway and, while further definition and refinement have been added, no significant changes to the standards found in the NVIC have been proposed.

To reiterate the preceding discussion on OPA 90, these requirements for the fitting of double hulls in way of cargo tanks apply to oil tankers. However, to fully state the scope of the requirements, they apply to self-propeller vessels and barges of any kind whatsoever including cargo vessels, passenger vessels, etc., intended to carry any quantity of oil as a cargo in bulk, that are constructed (or that undergo major conversions) under contracts awarded after 30 June 1990 or are delivered after 1 January 1994 if they are:

- U.S. flag,
- U.S. or foreign flag operating on the navigable waters of the United States including the Exclusive Economic Zone, or
- U.S. or foreign flag which transfer oil in a port or placesubject to the jurisdiction of the United States.

Wing Tanks or Spaces

The minimum width, 'w', of each wing ballast tank or void space, extending for the full depth of the vessel's side or from the deck to the top of a double bottom, is not to be less than:

$$w = \begin{cases} 2,0\text{m where DWT} \geq 20,000 \text{ tonnes} \\ \text{DWT} \times 10^{-4}\text{m where } 20,000 > \text{DWT} > 10,000 \text{ tonnes} \\ 1.0 \text{ where DWT} \leq 10,000 \text{ tonnes} \end{cases}$$

MKS Units

$$w = \begin{cases} 6,56\text{ft where DWT} \geq 19,684 \text{ tonnes} \\ (\text{DWT}/3000)\text{ft where } 19,684 > \text{DWT} > 9,842 \text{ tonnes} \\ 3.28\text{ft where DWT} \leq 9,842 \text{ tonnes} \end{cases}$$

US Customary Units

The above minimum width, 'w', is to be measured inboard from the vessel's side at right angles to the centerline, at a height of 0.2D above the baseline (see Figure 1) and is to be maintained throughout the entire length and depth of the tank.

The stern is not to be closer to any part of a cargo tank than 'w' as determined for the vessel's side at amidships.

Double Bottom Tanks or Spaces

The minimum vertical height, 'h', of each double bottom ballast tank or void space is not to be less than 2.0m (6.56ft) or B/15, whichever is lesser, but in no case is the height to be less than 1.0m (3.28ft).

The above minimum vertical height, 'h', is to be measured at a vertical plane 0.2D inboard of the intersection of the shell with a horizontal line 0.2D above the baseline (see Figure 2) and it to be maintained throughout the entire length and breadth of the tank.

Suction wells may protrude into the double bottom provided they are as small as practicable and that the protrusion below the inner bottom does not exceed 0.5h.

River and Harbor Service

Vessels intended solely for river and harbor service are also subject to the foregoing except that where the vessel's DWT is less than 10,000 tonnes (9,842 tons) the value of 'w' and 'h' may be taken as 0.61m (2.0 ft) provided this distance will provide sufficient clearance for inspection and maintenance. An example of minimum clearance for inspection is shown in Figure 3.

In river and harbor barges, cargo tanks are not to be located forward of the following locations:

- Lead Barges:
  0.05L or 7.62m (25ft) whichever is the lesser, from the head log at the bow.
- Box and Trail Barges:
  0.61m (2ft) from the head log at the bow.

No oil may be carried in spaces forward of the cargo tanks.

Definitions

DWT The deadweight of the vessel in tonnes (tons).

D The molded depth of the vessel at side in m (ft) as defined in the appropriate ABS Rules.

B The greatest molded breadth of the vessel in m (ft).

Oil Petroleum in any form including crude oil, fuel oil, sludge, oil refuse, refined products, etc.

General

None of the foregoing is to be construed as alleviating a vessel from compliance with the requirements of MARPOL.

4.2 Draft Regulation 13F

Draft Regulation 13F - "Prevention of oil pollution in the event of collisions or strandings" proposed by the MEPC of IMO is in its very preliminary stages. The technical requirements for double hulls as currently drafted are offered in the following.

Wing Tanks or Spaces

The minimum width, 'w', of each wing ballast tank or void space, extending for the full depth of the vessel's side or from the deck to the top of a double bottom, is not to be less than:

l2.0m where DWT ≥ 100,000 tonnes

w=l(DWT/50,000)ft where 100,000 > DWT > 38,000 tonnes

l0.76m where DWT ≤ 38,000 tonnes

Double Bottom Tanks or Spaces

The minimum vertical height, 'h', of each double bottom tank or space measured from the baseline is not to be less than 3.0m or B/15, whichever is the lesser, but in no case is the height to be less than 0.76m.

An additional provisional qualification is that on oil tankers less than 500 gross tons, the height of the double bottom is to be determined by the Administration.

Compliance with Regulation 13

It is also required that the total ballast capacity in wing, double bottom, and fore and aft peak tanks must be at least that required for segregated ballast tanks under existing Regulation 13.

Double Hull Alternative

Unlike the U.S. legislation, the IMO draft regulation explicitly includes equivalent alternatives to double bottom tanks or spaces. Two methods are presented - hydrostatically balanced loading and the mid-deck concept. Both of these concepts are discussed in more detail in a later section.

For the draft regulation, the hydrostatically balanced loading specifically requires that the static cargo pressure exerted on the bottom shell plating does not exceed the external hydrostatic water pressure. This is expressed as:

$$h_c \rho_c \leq d_n \rho_s - (\text{DELTA})_p$$

where:

h_c = height of cargo above the bottom shell plating in meters,

ρ_c = maximum cargo density in t/m³

d_n = minimum operating draft in meters,

ρ_s = density of seawater in t/m³

DELTA_p = maximum set pressure of pressure/vacuum valve provided for the cargo tank in t/m²

For the mid-deck concept the above hydrostatic balance properties are applied with the addition that the 'tween deck is not less than B/6 or 6m, whichever is less, above the baseline.

An additional qualification on these alternatives is that the design must be approved by the Administration. Other alternatives can also be employed under Draft Regulation 13F provided that it offers the same protection of a double hull and that it is approved by the MEPC.

4.3 NVIC 2-90 versus Draft Regulation 13F

Aside from the proposal of double hull alternatives in Draft Regulation 13F, which is beyond the scope of NVIC 2-90, the two sets of regulations are very similar and show the common approach of both efforts. In looking at the specific parameters for wing and double bottom tanks and spaces, the source of debate at IMO is obvious. For wing tanks and spaces the two criteria agree for vessels of 100,000 DWT and above (Figure 4). The argument that the U.S. requirements are too stringent stems from the effect on tankers below 100,000 DWT, particularly as seen in the 10,000 - 50,000 DWT range. The IMO criteria linearly reduces wing tank width from the 2 meter minimum at 100,000 DWT to the 0.76 meter minimum at 38,000 DWT. The U.S. guideline maintains the 2 meter minimum down to 20,000 DWT before dropping the width linearly to its 1.0 meter minimum.

Better agreement is seen in Figure 5 for the double bottom height requirements. The disagreement between the 1.0 meter and 0.76 meter minimums is seen for beams below 15 meters. The linear increase in eight for both criteria is identical for beams of 15 to 30 meters. For beams greater than 30 meters the IMO proposal is more stringent in requiring up to a 3 meter height in the double bottom. The 3 meter minimum for large tankers is proposed mainly from an operational perspective to enhance access. This is in consideration of the increased size of structural stiffeners and the associated problems for personnel in terms of physical access, air circulation, etc. Three meters is thought to be an adequate compromise for these purposes without further impairing the vessel stability.

It is hoped that in ensuing discussions on this subject at IMO agreements will be reached in which unified requirements will be adopted for double hull proportions and requirements for small tankers. Regarding possible discrepancies between the final IMO requirements and those imposed in U.S., there is no indication at this time as to whether changes may be made to the U.S. requirements to bring them into compliance with those of IMO.

5. DESIGN CONSIDERATIONS

Now that double hulls have been mandated in the United States, and major strides are being taken in this direction internationally, the debate on the appropriateness of this approach must shift to a thorough examination of the technical and operational characteristics to assure that new double hull tankers do indeed contribute to a lowering of pollution risks.

Despite the more popular employment of single hull tankers over the years, it is comforting to realize that the double hull concept is by no means exotic or novel from the technical perspective. In fact, the industry has long experience in the use of double bottom and double hull construction for tank vessels of various types. The marine industry has typically employed double hull construction for vessels which have been traditionally engaged in the transportation of cargoes considered "hazardous" such as gas and chemicals. Because of earlier concerns with potential pollution from crude oil, a number of vessels employed to transport these cargoes have had double bottom or complete double hull construction.

This ongoing experience can help us identify what is really important, what will work satisfactorily, and what practices should be avoided as the industry makes greater and greater use of double hulls. At the same time we must realize that the elements of design are not static. New features of design and the extensive use of novel design approaches and methods in lieu of proven empirical criteria are constantly being introduced. All of these new elements must be critically assessed individually and in concert to establish what is appropriate to assure the safety of human life, the ship and the environment.

The following is a brief overview of the most often cited design considerations that need to be addressed for double hull vessels. Some issues associated with the general arrangement of the vessels are offered followed by the more detailed technical considerations associated with the structural design. In addition to what may be considered strictly technical issues, there are also other matters relating to survey and operational topics which will be briefly mentioned since they will have a bearing on what needs to be done in the ongoing technical criteria development area.

5.1 General Arrangement

The basic controlling proportions of double hull tankers as currently required or pending were previously presented in the section on double hull requirements. The following touches upon some of the related aspects of designs pertaining to the current MARPOL regulations.

Double Bottom and Wing Tank Sizes

Despite the current concerns and discrepancies in the minimum double bottom and wing tank widths and heights being discussed for new regulations, the designs of recent double hull crude carriers that ABS has examined typically exceed current MARPOL minimums, usually by a wide margin. This happens because of three primary reasons. The first is the need to provide sufficient space to fit the supporting structural members inside the ballast tanks and still leave enough room for inspection, construction access, and so on. The second is the need to provide a sufficient volume to carry required ballast water. The third arises from the competing needs to taper the outer hull of a vessel at its ends versus the desire to have the cargo block boundary as prismatic as possible.

Cargo Tank Sizes

Beyond the ballast tank sizes, the other major question of a general arrangement nature concerns the maximum size of a cargo tank. The question arises if we compare the typical arrangement of a single hull tanker to one with a double hull. In the single hull tanker the longitudinal bulkheads separating the center cargo tank from the side tank (either SBT or cargo) is usually located no closer than 20% of the ship's breath (or B/5) from the side shell. In the double hull vessel the internal longitudinal bulkheads may be located less than several meters from the side shell (Figure 6). This could potentially represent a very large volumetric increase of the cargo tank if no other watertight subdivisions are provided in the transverse or longitudinal directions.

The present MARPOL convention stipulates the maximum volumes of a cargo tank. The objective of this requirement is to limit the amount of potential oil outflow in the event of damage to the cargo tank.

Sloshing Loads

From the technical point of view, if we concern ourselves with the question of everyday loads and stresses in the ship's structure rather than limiting pollution potential, there are other reasons to be concerned with an increase of the cargo tank size. Clearly the loadings and resulting stresses on the boundary bulkheads of the cargo tanks will be greater for the larger tanks. Larger tanks also increase the potential for operational tank filling levels which may be other than full or empty. This gives rise to the potential of sloshing of the cargo in the tank when the vessel is rolling or pitching.

Analytical methods to assess the potential of resonant sloshing of liquids in partially filled tanks and to assess the sloshing load effects are quite complex. At ABS we have treated this problem using non-linear domain numerical simulation techniques which have been calibrated with model test data. An example of the numerical simulation results are shown in Figure 7. Design and design verification relying on these techniques have been successful, but can also be relatively costly. ABS is developing a simplified procedure which obviates the need for complex analyses in some commonly occurring situations. However, there will always be some special situation which will require in-depth analysis.

5.2 Structural Design

In addressing the more detailed technical aspects associated with the structural design of double hull tankers, the following discussion is offered.

Shear Lag

As mentioned in the previous section, some double hull designs utilized wide (or undivided) cargo tanks. The use of this configuration has other implications on structural behavior when compared to a conventional single hull tanker. These relate to the shear stress distribution in the hull and the effects of a phenomenon called "shear lag".

The phenomenon of "shear lag" has to do with the (possibly non-uniform) variation of stress across a plate which is assumed to have uniform stress distribution to resist bending. Ordinarily, simplified design procedures consider the longitudinal stresses in the hull girder deck or bottom plating to be uniformly distributed using the commonly assumed principle that the stress is simply the hull girder bending moment divided by the section modulus. Because of the relatively wide width of the center tank with respect to its length, it is possible that the longitudinal stress in the ship's plating due to hull girder bending may be under-predicted because of the shear lag effect. This non-uniform distribution can be seen graphically in Figure 8 for a design with a wide center tank compared to a design with a centerline bulkhead and more uniform stress distribution. Figure 9. Again the tools to accommodate this effect are well known and readily available. But, we feel it is important to remind designers that they may need to brush up on these concepts.

Transverse Flexibility

Another major change in overall structural behavior can arise from the relative flexibility in the transverse or athwartship direction of the double hull vessel compared to that of a vessel with a single hull. When comparing a typical transverse section from double hull and single hull vessels (Figure 10) it can be seen that the transverse structure in the wing or side tank region can be quite different. For example, in the double hull vessel the side transverse frame connecting the side and longitudinal bulkheads can be narrow in depth. Also the horizontal struts which tie these frames together may be reduced or omitted entirely. Further, the deep brackets tying the deck and bottom transverse frames in the center tank to the side tank structure may also be considerably reduced or eliminated in the double hull design.

Such changes have the tendency to make the structure more flexible indicating that other modes of behavior need to be explicitly considered in the design. Some of these are associated with what have been called "secondary effects" or ones which could be treated in a less than rigorous manner in design, indeed if at all. With the reduced design margins and more "efficient" designs these effects may now represent the controlling influence in the design, in terms of its overall and local strength and serviceability. An example of a secondary effect is the design of structural details. Figure 11 shows the structural detail of a side shell longitudinal in a tripping mode where it intersects a transverse bulkhead.

Scantling Comparison of Generic Tankers

On an even more detailed level ABS has performed a simple comparative study showing the relative difference of vessel steel weights (which directly affect construction costs) and local plate thicknesses for a conventional single hull vessel, a double bottom vessel and a double hull vessel. The base (single hull) design is shown on the left of Figure 12, the double bottom in the middle and the double hull on the right. The vertical axis shows values from 0 to 160, which is a comparison index with 100 being the value for the base design. The horizontal axis shows, starting from the left, comparisons of the longitudinal steel weight over the middle 0.4 length of the vessel, the section modulus at deck, section modulus at bottom, hull girder moment of inertia, section area of deck plating and deck longitudinals, sectional area of bottom shell plating and stiffeners, and at the far right, the sectional area of the side shell longitudinals and plating.

In this example, the vessel's length and breadth are constant and the depth is allowed to increase to maintain the 250,000 DWT capacity for the double bottom and double hull designs. The design bending moment is the same for all three designs. One interesting observation shown is the reduction of scantlings of the deck and bottom structures for the double bottom and double hull designs. The reduction in scantlings can be attributed to the greater depth of these designs which requires less material in the deck and bottom flanges of the hull girder to equivalent single hull design. This gives rise to concerns of structural damage for double bottoms because of reduced margins for corrosion, fatigue life and reduced resistance to impact.

Higher Strength Steels

The topics above point out some of the most significant structural related issues surrounding the use of the double hull designs of which the designer needs to be aware. However, before leaving the structural topic the point must be made that a key consideration in the design of any ship today is the ever increasing use of higher strength steels. It is not the intention to get involved in a lengthy discussion of this subject here because it is not the exclusive domain of the double hull ship. However, it must be stated that the increased use of higher strength steels must be accompanied by increased care in design to preclude failure modes such as buckling and fatigue induced cracking which, using the terminology stated previously, may have been treated by some designers and other classification societies as "secondary effects".

5.3 Survey and Operational Issues

Periodic surveys of vessels to assess their condition throughout their service life is required for classification. At ABS we do not envision the need to alter the frequency or extent of periodic inspections presently applied to double hull tankers. However, the double hull vessel presents both advantages and disadvantages for inspection which need to be addressed in the initial design of the vessel.

Both for new construction and surveys of existing vessels, much more time and effort will be needed to survey a double hull tanker in comparison to one with a single hull due to the significant increase in material, welding, structure, and overall surface area. Also, generally speaking, surveys of a double hull tanker will be more demanding on the surveyor due to the presence of a double bottom and double sides which require more climbing, crawling and exposure to harsh atmospheres.

Access to Side and Bottom Space

Access into the side and bottom space must be considered at the design stage as it is essential that there is ample room for a surveyor to enter and move freely in order to properly inspect all areas. These spaces by their nature are very difficult to access, negotiate and navigate. It is also necessary that the bottom and particularly the side space be of sufficient dimension to allow for the entrance and maneuverability of rescue equipment.

Hazardous Atmosphere

In service, one of the greatest potential hazards to the surveyor or crew is the presence of gases causing toxic or flammable conditions resulting from cargo leakage into the ballast space. Another potentially lethal condition is the depletion of oxygen resulting from accelerated corrosion which can occur when side and bottom spaces are used for ballast or the vessel is operating in a tropical environment. It is vital that not only the side and bottom space be properly gas-free and oxygen-safe before any entry, but also that proper chemical tests are made to assure this is so. Finally, upon entry it is important that inspection personnel are continuously monitored.

Cleanliness

Because it is common practice to locate the plating stiffeners, and major structural and support framing within the ballast tanks, one of the biggest advantages to double hulls is that there are completely unobstructed surfaces forming the boundaries of the cargo tanks adjacent to the side ballast and double bottom tanks. This will greatly facilitate inspection as well as cleaning of the inside of the cargo tank plating.

However, a drawback to double hulls on the cleanliness issue is the increased number of ballast spaces. The surfaces in these tanks must be free of mud, slime and rust in order for surveys to be effectively carried out. Because of the limited access and dimensions, the cleaning and removal of these undesirable substances from the bottom and side spaces of double hull tankers can be a difficult and time consuming undertaking.

Explosion Risks

The possibility of a cargo leak into a ballast tank raises one of the most serious concerns about double hull vessels — the risk of explosion. A cargo leak into an empty ballast tank could cause an explosive condition. The industry has made positive strides in reducing the probability of explosions as a result of the use of inert gas systems. However, there is concern that double hulls could result in a reversal of these trends in explosion casualties. This is especially true as ships age and their cargo tanks are more prone to fractures which will leak as a result of material wastage from fatigue and corrosion. However, in the history of modern tankers designed exclusively for the carriage of product or crude oil we are not aware of any reported incidents of explosions having taken place in double bottom tanks.

A related concern regards the structural survivability of a vessel following an explosion. Explosions in wing and center tanks are known to rupture decks and hatches but to cause limited damage beneath the waterline. On the other hand, an explosion in the double bottom has the potential for creating a significant breach of the vessel's bottom.

Corrosion

Lastly, the potential for danger from corrosion is a matter requiring continuous scrutiny during the operational life of any steel structure exposed to the marine environment. Corrosion is the primary factor in the deterioration of a vessel and in no location is this more true than in the ballast tanks. As with the ballast tanks of any type of vessel, proper corrosion protection for double hull spaces used for ballast is critical and should be of high quality both in its reliability and application. Success with corrosion protection systems has varied widely, but it is recognized that systems, especially coatings, which remain completely intact and effective for times approaching the 20 year anticipated life of a tanker are a rarity. This fact compounded with the relative difficulty of maintaining coatings in the more confined spaces of the ballast tanks and the relatively much larger surface area to be protected in the ballast tanks of a double hull tanker combine to require that much greater attention needs to be given this subject.

6. ALTERNATIVES

The double hull concept has received the majority of the attention in the development of new standards for reducing the risk of pollution from oil tankers. However, there are a myriad of alternative methods for reducing pollution risks which have been presented to the industry.

In the United States OPA 90 does currently mandate the use of double hulls for tankers over 5,000 Gross Tons (tankers under 5,000 GT may utilize an alternative double containment system under the current terms of OPA 90). But there is a provision in OPA 90 which calls for the Secretary of Transportation to determine if there are structural and operational alternatives that provide protection at least equivalent to double hulls. The primary source of this information is the study conducted by the Committee on Tank Vessel Design under the Marine Board of the National Academy of Sciences. This study is now available and it contains one of the most comprehensive reviews of alternative methods compiled to date (a summary of the conclusions of the study is presented in Section 7, below). It does not, however, provide a full endorsement of any of the various methods. Even if equivalent alternatives are recommended by the Secretary of Transportation, this does not represent approval for use in U.S. waters. The Congress must approve the recommended alternatives through legislative action. From this it is obvious that double hulls will be the preferred method in the U.S. for some time to come.

On the international level the employment of double hull alternatives appears to be much more viable in the proposed regulations under consideration. As previously discussed, Draft Regulation 13F pending at IMO provides for the use of alternatives equivalent to double hulls and goes so far as to specifically outline the use of hydrostatically balanced based systems. In discussions on the treatment of existing vessels one of the proposed requirements is for vessels to utilize either hydrostatic balance or underpressure.

The following sections are offered as descriptions of the various alternatives currently being addressed. No assessment is made as to their effectiveness in reducing the risk of pollution relative to double hulls. Much more study and practical full-scale testing must be completed to arrive at comparable evaluations.

6.1 Hydrostatically Balanced Loading

Hydrostatically balanced loading represents one of the simplest yet effective means for reducing the outflow of oil in instances of grounding. It is also a method, by its simplicity, which represents the most viable alternative concept for implementation on board existing tankers with little or no modification.

It is also essentially self-tending after loading which allows it to do its job without relying on action by the crew during the critical first few minutes following an accident.

With a typical tanker, when a cargo tank is breached, the main cause of oil pollution is due to a hydrostatic pressure imbalance, which is, the pressure inside the cargo tank is greater than the outside sea pressure. A continuous outflow of oil will occur until a hydrostatic balance is reached between the ruptured tank and the outside sea.

The basic concept of hydrostatic loading proposes that tankers be loaded and leave port with their tanks in hydrostatic balance (Figure 14) such that:

$$\text{Maximum Cargo Depth in Tanks} = \frac{\text{Draft of Vessel} \times 1.025\ \text{ton/m}^3}{\text{Specific Gravity of Cargo}}$$

This is a simplified formula assuming deep sea service. Adjustment would have to be made for fresh water service, ullage pressure compensation, etc.

It is also proposed that the vessel be loaded to its maximum allowable draft. This would occur by loading ballast in the segregated ballast tanks. By employing this concept, if a cargo tank is ruptured in a grounding, the equilibrium between the inside and outside pressure will prevent any significant outflow.

In order to achieve the pressure balance, tanks would generally be operated in a more significant slack mode than typical tankers. Because of this, sloshing loads could create dynamic pressures that may cause damage to the vessel's tank boundaries. Case studies have shown that for most vessels sloshing loads would not represent a significant problem.

Intact stability is also a concern with the operation of slack tanks. Even though a substantial increase in free surface effects can be expected, no intact stability problems are anticipated because of the excessive stability inherent to crude oil carriers.

Hydrostatic loading would reduce the carrying capacity of existing tank vessels. A study by Maritime Overseas Corporation shows that the reduced capacity for existing SBT vessels handling crude would be about 19% of the original carrying capacity. Converting an existing non-SBT vessel to SBT and hydrostatic loading, the loss would be 23%. The cargo carrying capacity changes with changes in cargo specific gravity.

A close variation on the basic hydrostatic balance theme, and along the lines of traditional load-on-top operation, is the imaginary double bottom where a several meter thick layer of chemically treated water is carried below the cargo. It would be designed such that only the treated water would escape in the event of a bottom shell rupture.

6.2 Mid-Deck Design

One of the most recent and promising design alternatives is the mid-deck tanker developed by Mitsubishi Heavy Industries (MHI). The design offered by MHI provides spill protection in both collision and grounding situations. The grounding protection is effectively a hybrid utilization of hydrostatically balanced loading. By splitting the cargo tanks into upper and lower spaces with a horizontal 'tween deck, the pressure head at the bottom shell in the lower tank is substantially reduced below the outside pressure head. This increased hydrostatic pressure differential will greatly reduce the amount of oil that may leak from the vessel through ruptured bottom plating (Figure 15). To enhance the effectiveness of the hydrostatic balance the lower tanks will be operated at a 98% loaded condition to allow seawater to form a layer below the cargo in a grounding. Collision protection is provided through the use of a typical double side configuration.

Some of the concerns with the concept surround requirements for access to the lower tanks (air pipes, trunks), increased structural support and cargo piping; all of which contribute to a reduction in cargo capacity. The question of structural adequacy in the event of full upper cargo tanks and partially drained/damaged lower tanks must be answered. Also, there are questions surrounding the need for increased tank cleaning hardware as well as any problems in inerting the bottom tank ullage space.

The number of cargo tanks required by MARPOL would be 26 compared to 17 for a comparably sized double hull vessel. However, the total coating surface would be about 60% of that for a comparable double hull. These points considered, MHI estimates the cost for the mid-deck design would be approximately 117 million U.S.D. compared to

120 million U.S.D. for the comparable double hull.

6.3 Underpressure

Another alternative which has been discussed for several years now is the concept of underpressure, or creation of a vacuum in the ullage of cargo tanks to literally hold the cargo in the tank in the event of a bottom plate rupture. Two approaches have been proposed depending on whether the vacuum is to be developed actively or passively. The active method would depend on pumps to evacuate the ullage space and establish the vacuum. The passive method would depend on the dropping of the cargo level in a ruptured tank to establish the vacuum in the ullage space.

One of the major prerequisites of this concept is the sealing of the tank connections to permit a vacuum to develop. The two principal connections concerned are the inert gas line and the vent PV valves. The concept involves isolating the inert gas connections and either blanking of resetting the PV valves to a higher vacuum assuming that all other openings or fittings are tight.

Theoretically, the concept works and in some situations a significant quantity of cargo could be retained in a punctured cargo tank by allowing a vacuum to develop in the ullage space. This, of course, is predicated on the assumption that the puncture is in the bottom of the tank or low down on the tank side, since all cargo at and below the puncture will flow to the sea regardless of the vacuum.

The concept does lend itself to retrofitting on existing vessels; however, there are significant risks. Application of the vacuum method to new and existing ships introduces the risk of structural damage due to excessively high vacuums (e.g., collapsing deck structures, etc.). This possibility increases with the age of the ship due to age related defects such as minor cracks or thinning of the structure. With the inert gas connections sealed, any case involving blanking of the PV valves in anticipation of a casualty is a hazardous action; particularly in partially laden vessels with high freeboard (with some slack and empty tanks). Outflow from the fully loaded tanks could create vacuums as high as 6 or 7 meters water gauge. This vacuum could seriously damage the tank structure and could lead to a substantial increase in the loss of oil.

In the case of resetting the PV valves, new larger valves may be required. The reason for this is that with a higher vacuum setting the structural safety margin is reduced. For a large hole, oil outflows could exceed the air inflow through the PV valve and allow the vacuum to rise above the critical value for structural safety. This bottom-falls-out scenario is seen as a governing case for any proposed changes to present ship design and operating conditions.

While this scenario is also possible for existing ships, the present low vacuum setting provides more margin for overshoot against the tank structural limit. This risk can be further reduced by keeping all tanks connected via the IGS main which normally can pass on the order to four times the volume of the PV valve.

An additional area of concern is the possibility of having an electrical charge build up on the surface of the cargo. No provision is made for safely discharging this. The concept relies on either an adequate concentration of inert gas or a sufficiently conductive cargo to prevent the build up of a static charge.

The system relies on near perfect maintenance of the PV valves, tank hatches and tank cleaning covers. It also relies on full compliance by the crew with operational practice to isolate the damaged tanks.

As the method relies upon rapid reaction to isolate a cargo tank it is essential that a leak in the tank be

Table 5
Outflow - metric tons
Bottom Damage - Tanks Individually Isolated

	Tank Contents	Outflow without Vacuum	% of Tank	Outflow with 2.5m Vacuum	% of Tank
VLCC					
Full Draft	31,400	2180	7	110	<1
75 % Draft	31,400	9520	30	6310	20
90 kDWT					
Full Draft	10,655	2010	19	100	1
75% Draft	10,655	4180	39	2670	25

quickly discovered. This puts emphasis on the accuracy of ullage measurements.

The retention efficiency of the method is quite sensitive to the degree of tank filling, and with a 2% ullage the retention may be very favorable. If a double bottom is breached, and the air in this escapes to the cargo tank, this will act as an increased ullage. The air in a 2 meter deep double bottom would increase the ullage considerably. The smaller the ship the greater the increase.

If the assumption is made that adequate size PV valves are installed, a considerable quantity of cargo can still be lost if the ship is in a light load condition even with a ullage space vacuum of 2.5 meters. Table 5 shows estimated outflows for two single hull vessels for a cargo with a specific gravity of 0.85.

In order to provide the vacuum in the tanks it is necessary to secure the inert gas system when the vessel is coming into port. This is the very time that the inert gas system is most critically needed to prevent a possible explosion. With a non-inerted cargo tank under vacuum an explosion could occur as a result of air drawing heat and sparks into the tank should the tank be breached in a collision.

Any procedure that involves the isolation of the inert gas connection to each tank should include the individual remote reading pressure gauges for each tank to guard against the accidental failure to reopen the tank to the inert gas system. Structural failure could occur if discharge rates are high enough.

The normal overpressure due to inert gas must be reduced for the system to be effective.

6.4 Cargo Transfer Systems

There are several concepts which incorporate the idea of transferring cargo from a damaged tank to an empty cargo or ballast tank. The simplest of these is the fitting of high capacity pumps located above any anticipated cargo/seawater interface in the damaged tank.

The more complex variation of the concept is the use of pumps in conjunction with an underpressure system. The difficulty is in pumping out the cargo without breaking the vacuum. This is accomplished by means of a vacuum bell designed to fit over a tank cleaning opening and containing a submersible pump. Cargo is pumped from the ruptured tank down to a level where the tank can be opened to the atmosphere without any further outflow.

The third variation is the sluice valve approach. This system utilizes valves mounted in bulkheads to sluice cargo by gravity from damaged cargo tanks to segregated ballast tanks thus reducing the amount of oil available for loss overboard from damaged tanks.

The system aims at performing two functions:

a) transfer oil out of any damaged tank to a ballast space, and

b) minimize the reduction of draft at the damaged area.

Each connection between a cargo and ballast tank would be fitted with two automatically actuated valves, as required by regulations, to prevent contamination of ballast due to minor valve leakage in normal operations. The connections would be about B/15 above the bottom and would be welded into the hull structure at the bulkhead intersections.

The advantage of the system is its ability to be economically retrofitted (as compared to a double bottom) to existing tankers which comply with IMO requirements for segregated ballast. The potential drawback of the system is that it requires action by the crew at the time of an accident as it requires activation of the valves in the damaged tank or tanks.

In addition, vessels must comply with MARPOL requirements which is a two compartment standard of damage, thus oil transfer to a ballast space may not be possible if the ballast tank is damaged along with the cargo tank. Stability effects of the transfer must be found acceptable prior to transfer.

Inert gas connections would be required for ballast spaces. If these are permanent the forepeak will be a hazardous space, unless served by a separate ballast line not connected to the other ballast tanks. MARPOL prohibits connection of cargo and ballast spaces. Either special valves would be required or the regulations revised.

A drawback to the system is that determination of which spaces are damaged may be quite time consuming which can reduce the effectiveness of the system by not being able to immediately begin dumping cargo to the Segregated Ballast Tank.

6.5 Combinations

Probably the most viable alternatives to double hulls are actually combinations of several proposed approaches with complementing advantages. An example would be the combination of double sides and hydrostatically balanced loading. This would provide protection in grounding and collisions as well. The mid-deck tanker is effectively a hybrid variation of this combination. Another combination is the proposal made by Sweden with its Emergency Transfer System. This combines the underpressure approach and a vacuum bell cargo transfer system. The ullage vacuum provides initial protection after damage allowing time to draw off the cargo with the pumps prior to significant cargo loss.

Further investigation of the use of several alternatives is definitely warranted. While some individual concepts may be less than totally effective, used in conjunction with complementary systems they may represent truly viable alternatives to double hulls.

6.6 Other Concepts

As previously mentioned there are a multitude of concepts being discussed on this topic. Aside from those described above some of the other concepts include the following:

- Resilient Membrane - A pliable membrane fitted into the existing cargo tank that would deform and not breach in the event of a structural penetration of the tank.
- Smaller Tanks - A flashback to earlier times. Smaller tanks mean less cargo to spill for any given cargo tank breach.
- Internal Deflecting Hulls - Effectively an icebreaker type hull in terms of shape and strength fitted inside the typical bow which would assure that the hull is deflected away from any point of impact.
- Unidirectional Structure - Removal of structural hard spots, such as deep transverse frames, adjacent to the bottom shell. This would allow the bottom shell to deflect for a longer period of time before tearing.
- Honeycomb Hull - A cousin of the unidirectional structure. The honeycomb would utilize a high strength and high energy absorbent sandwich structure.
- Grinding Bow - This would employ high strength structure in the fore-foot of the tanker which would rasp away any obstruction to allow passage of the rest of the vessel.
- Advanced Materials - Employment of materials to increase the resistance of the hull to damage. These include high yield steel for bottom structures, concrete/steel composites, and ceramic coatings.

7. U.S. NATIONAL ACADEMY OF SCIENCE TANK VESSEL STUDY

At the end of February 1991 the National Academy of Sciences Committee on Tank Vessel Design released its final report entitled "Tanker Spills: Prevention By Design". The major importance of this report in the U.S. is its use by the Secretary of Transportation as technical support in possibly recommending the use of double hull alternatives for tank vessels. A summary of the conclusions and recommendations of this study are presented in the following:

- **Existing tank vessel design standards are no longer adequate.**

  Because of the reduction in design margins in recent years, modern tankers are less robust than earlier vessels. Existing standards must be strengthened for proper consideration of:

  1) corrosion protection,
  2) scantlings, and
  3) high tensile steel.

  Also, design practices should be modified for better resistance to grounding and collision damage.

- **Available information is inadequate for decision making.**

  Existing data are so limited that only very basic factual conclusions can be drawn on the environmental benefits of design improvements. Based on the information received, the Committee did feel the facts support the following conclusions:

  - Double hulls should not pollute in low energy accidents.
  - Single hulls will pollute whenever the hull is penetrated. Some alternatives may mitigate the amount of pollution from the single hull.
  - High energy accidents nearly always pollute.
  - The relative advantages of various containment systems are highly dependent on the assumptions made for different scenarios.
  - Research is required to provide a database allowing assessment based on facts rather than opinions.

Because of the previously mentioned data limitations, the Committee relied heavily on its own judgement for this study. Despite the gaps in factual information, the Committee did reach a "strong consensus" on the following issues.

- **Double hulls reduce pollution from groundings and collisions.**
  - On the basis of cost effectiveness, the double hull is the best value among the systems studied.
  - Double hulls are effective in low energy groundings and collisions.
  - No outflow from double hulls would be expected when the inner hull remains intact after an accident.
  - Adequate clearances must be maintained in spaces to provide protection and allow maintenance and inspection. A two meter minimum in vessels over 20,000 DWT should provide adequate access. <u>To provide pollution protection, inter-hull spacing should be the greater of B/15 or 2m but not greater than 3m in the double bottom.</u>
  - A minimum outer plate thickness requirement for double hulls must be established. In the meantime, the minimum allowed for present single hull vessels should be utilized.
  - Studies of tank spacing for small tank vessels

are needed.

- Current stability criteria for double hulls is not sufficient following high energy accidents. Criteria should be revised to assure vessels are not less stable than single hull vessels after damage.

Merits of other design alternatives.

The Committee studied the technical, outflow, performance and cost aspects of 17 design concepts. The concepts that received comprehensive study were:

- double bottom,
- double sides,
- double hull,
- hydrostatically balanced loading,
- smaller cargo tanks,
- mid-deck design,
- double sides with hydrostatically balanced loading, and
- double hull with hydrostatically balanced loading.

The conclusions of this evaluation are as follows:

- No design was identified as superior to the double hull in all scenarios.
- Double bottoms and smaller tanks are cost effective but not comparable in pollution prevention.
- Double sides are not cost effective.
- Combinations utilizing hydrostatically balanced loading are not as desirable as double hulls and are not favored by the Committee because effectiveness is too dependent on operations, and some outflow would be expected in groundings due to tide and wave action.
- The mid-deck tanker design concept was given a significant amount of attention. The Committee was split in its conclusions on this concept. Those in favor cited its practical and innovative approach. Those reserving judgement felt that it is an unproven concept needing more study before acceptance as a means to reduce pollution risks.
- Some other general recommendations for new designs included: fitting of towing fittings on bow and stern, onboard cargo transfer systems and prohibition of cargo piping in ballast tanks.

Double hulls need not increase incidence of fires or explosions, impair post-accident stability or complicate salvage.

- No reliable evidence was found of increased incidence of fires or explosions in double bottoms or double hulls. But risk must be managed through inspection and maintenance.
- Double hulls can be designed to meet requirements for damage stability and also survive more damage than is currently required.
- Salvage concerns about difficulties in handling damaged double hulls from grounding are only partly supported. In general, there are no salvage related concerns limiting the use of properly designed double hull tankers.

Personnel hazards differ with various designs, but are difficult to evaluate.

In general, the concerns with personnel safety do not represent unmanageable risks in any of the designs considered, but they do require continuing attention.

Existing vessels will comprise the majority of fleet for many years.

Even with the phase out plan of OPA 90, existing single hull tank vessels will be in operation for another 20 years. Therefore, pollution control on these existing vessels should be considered. Consideration should be given to prompt compliance with MARPOL — SBT, COW and PL/SBT — requirements, use of hydrostatically balanced loading, and retrofitting of double hulls.

These recommendations were qualified as follows. For the MARPOL compliance, a phase-in plan would be required to allow for shipyard capacity requirements, particularly for pre-MARPOL tankers. More research is required for hydrostatically balanced loading to determine appropriate parameters for each vessel, sloshing problems, leakage after grounding as well as the overall cost of having these vessels operate in U.S. waters. For retrofitting, the problem is basically whether it is cost effective.

A comprehensive research program should be mounted in the U.S.

This is aimed at increasing the factual database of information for use in assessing tank vessel design, particularly from the standpoint of accident data.

The following areas were identified as requiring attention:

1) the dynamics of ship structural failure,
2) failure theory,
3) mandatory engineering documentation of casualties, and
4) computational models for outflow predictions.

The U.S. Government, industry and academia need to conduct joint research to:

- develop basis for risk-based design goals,
- study the four areas noted above,

- test and evaluate design concepts,
- develop a better understanding of the environmental effects of spills, and
- optimize pollution control using design.

8. CONCLUSION

The Oil Pollution Act of 1990 although unilateral in nature has changed the course of tanker design and operation forever more. Significant technical study remains to be completed before the engineering community develops truly reliable means of reducing the possibility of marine oil pollution within reasonable economic parameters. OPA-90 has certainly been a catalyst in directing our efforts in this most important undertaking. For this reason alone, the historical significance of the OPA-90 is noted forever in the marine field.

Figure 1
Measurement of Minimum Width of Wing Ballast Tank

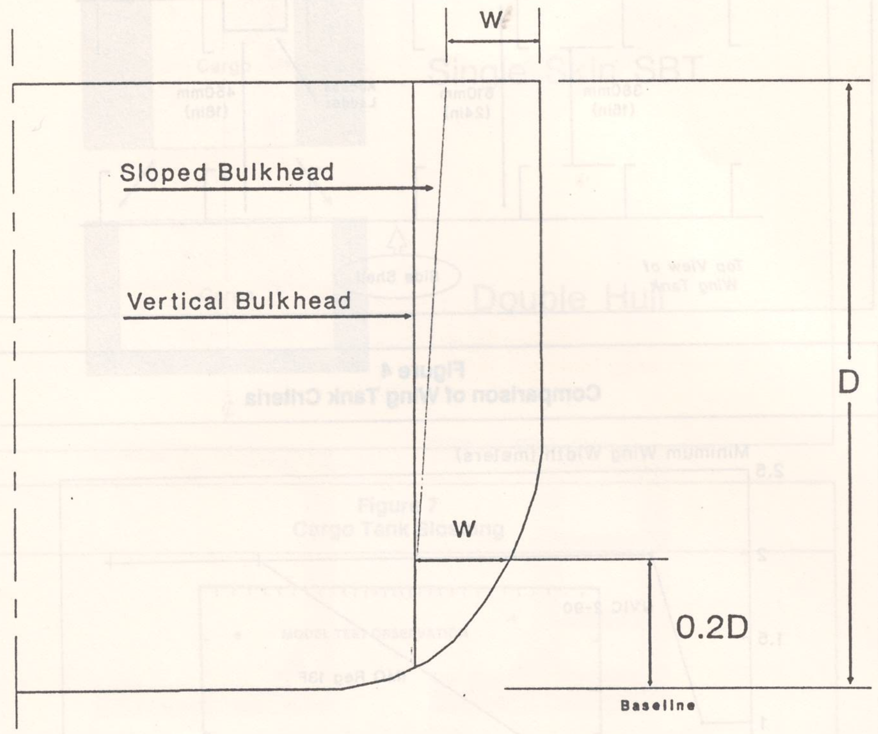

Figure 2
Measurement of Minimum Height of Double Bottom Tank

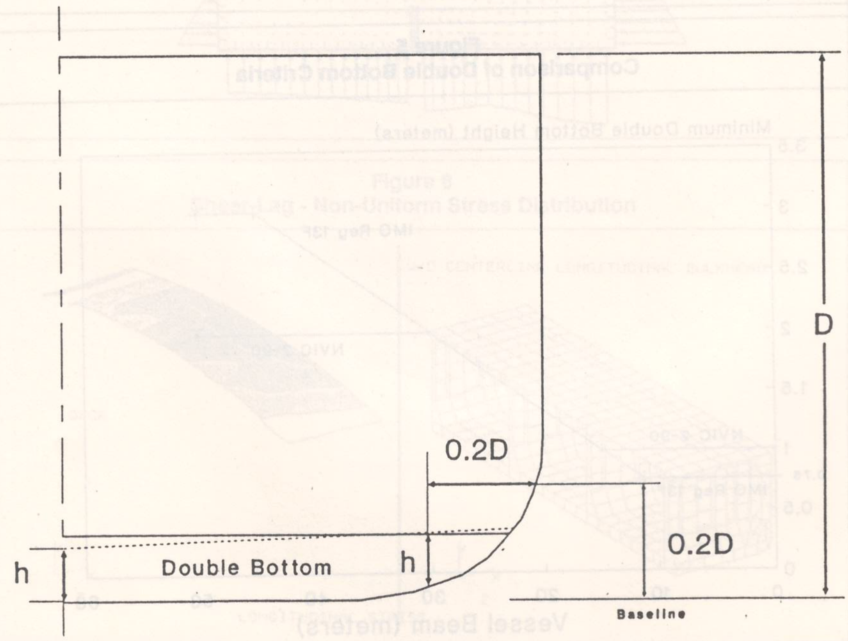

Figure 3
Minimum Clearances for Inspection

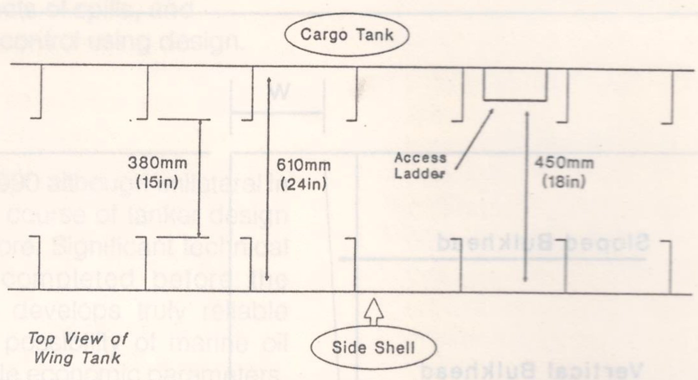

Figure 4
Comparison of Wing Tank Criteria

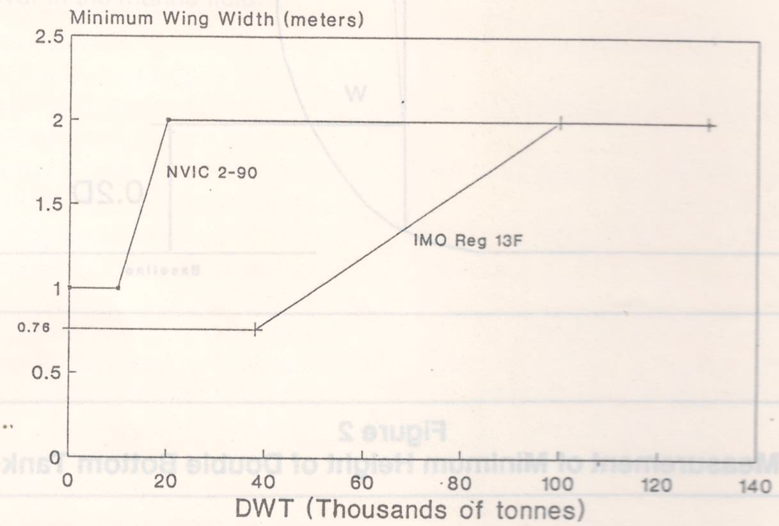

Figure 5
Comparison of Double Bottom Criteria

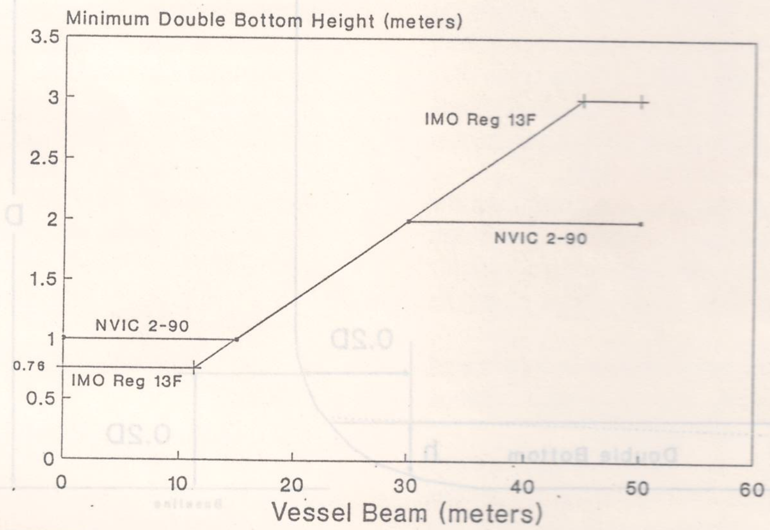

Figure 6
Maximum Cargo Tank Sizes

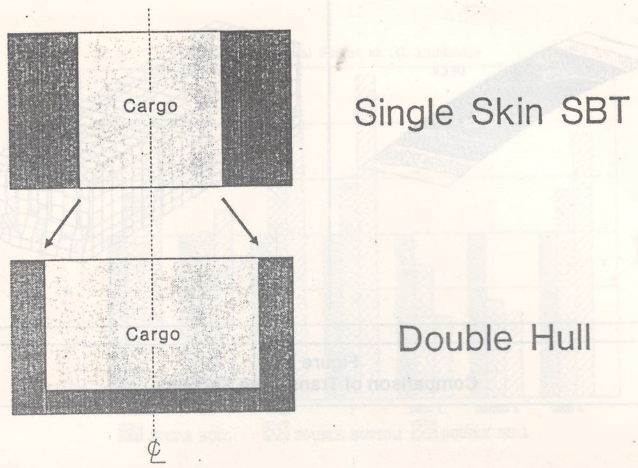

Figure 7
Cargo Tank Sloshing

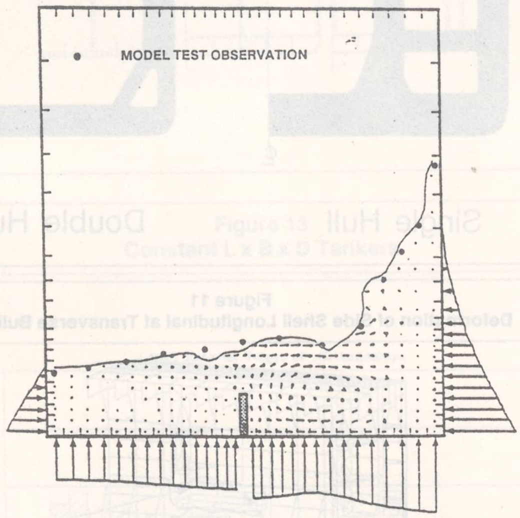

Figure 8
Shear-Lag - Non-Uniform Stress Distribution

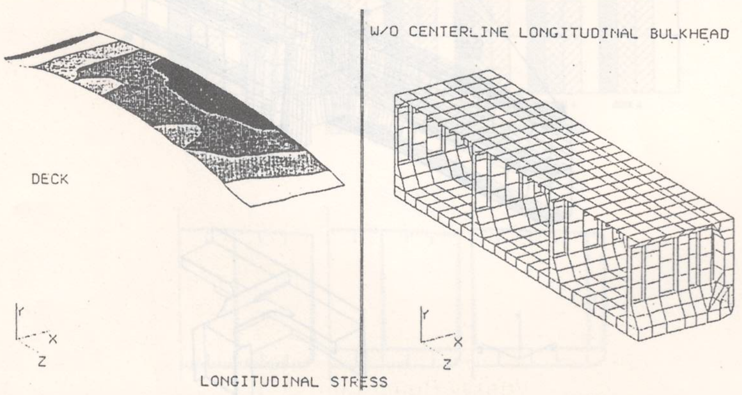

Figure 9
Uniform Stress Distribution

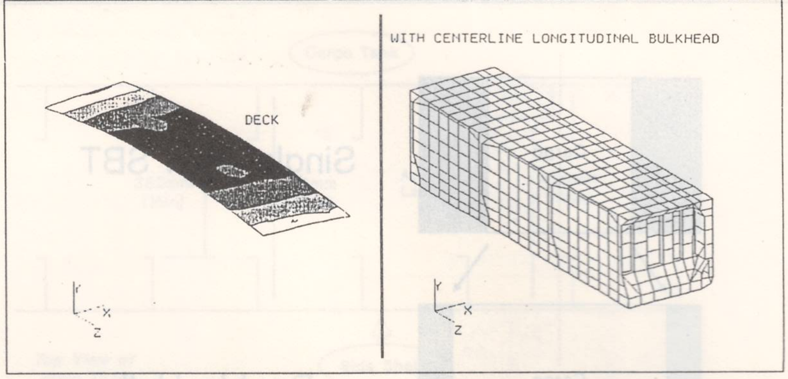

Figure 10
Comparison of Transverse Sections

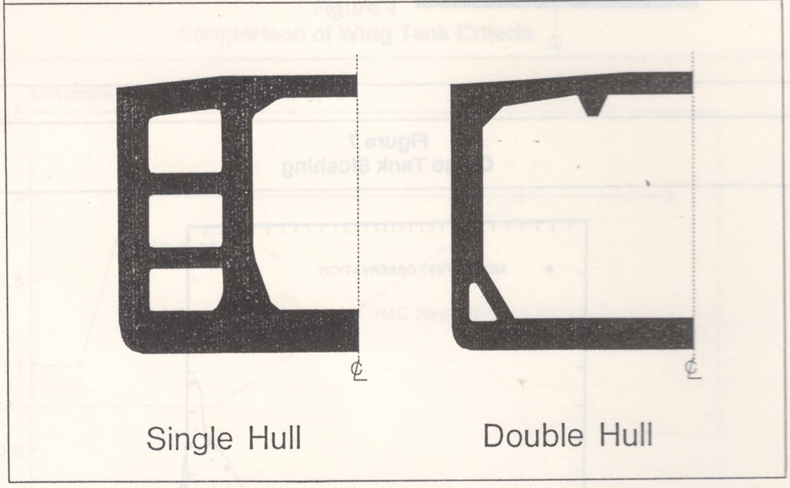

Figure 11
Deformation of Side Shell Longitudinal at Transverse Bulkhead

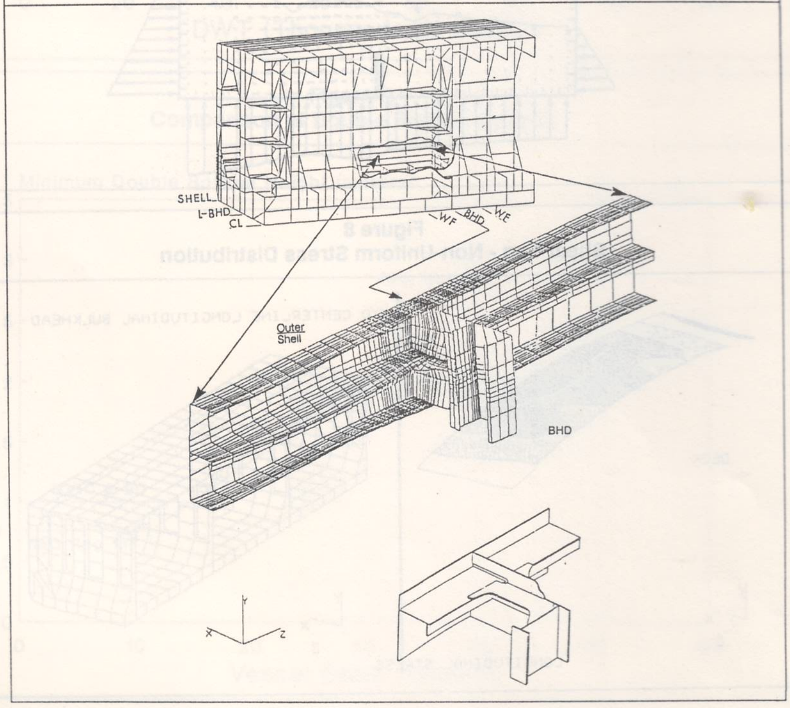

Figure 12
Structural Properties - Constant 250,000 DWT Tankers

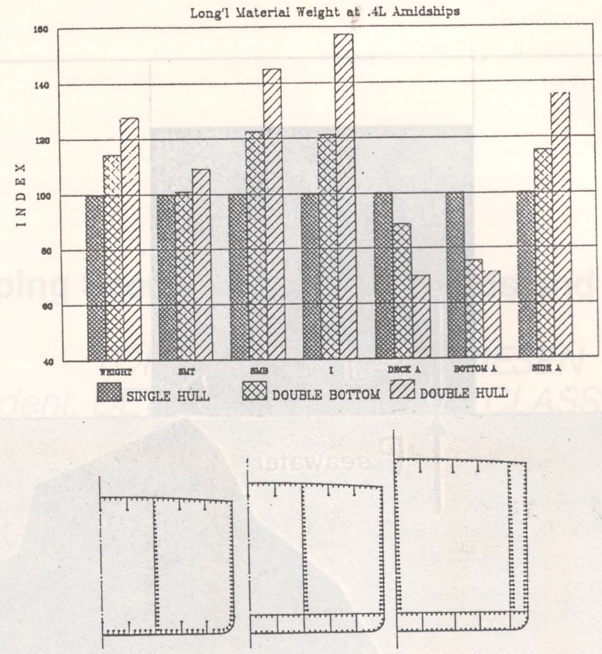

Figure 13
Constant L x B x D Tankers

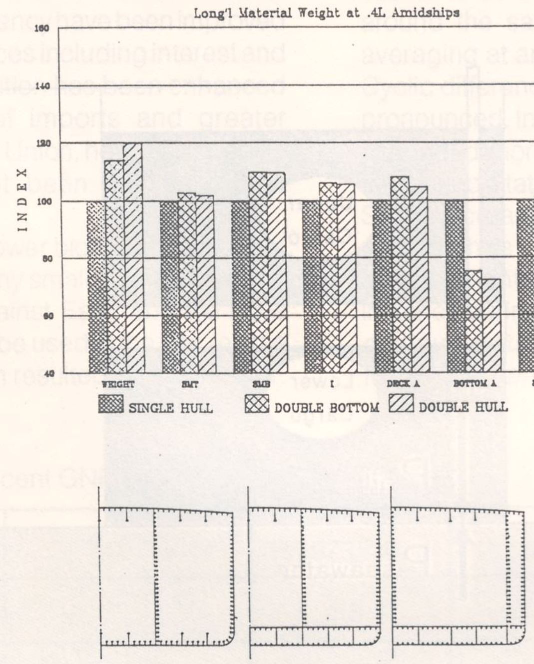

Figure 14
Hydrostatically Balanced Loading

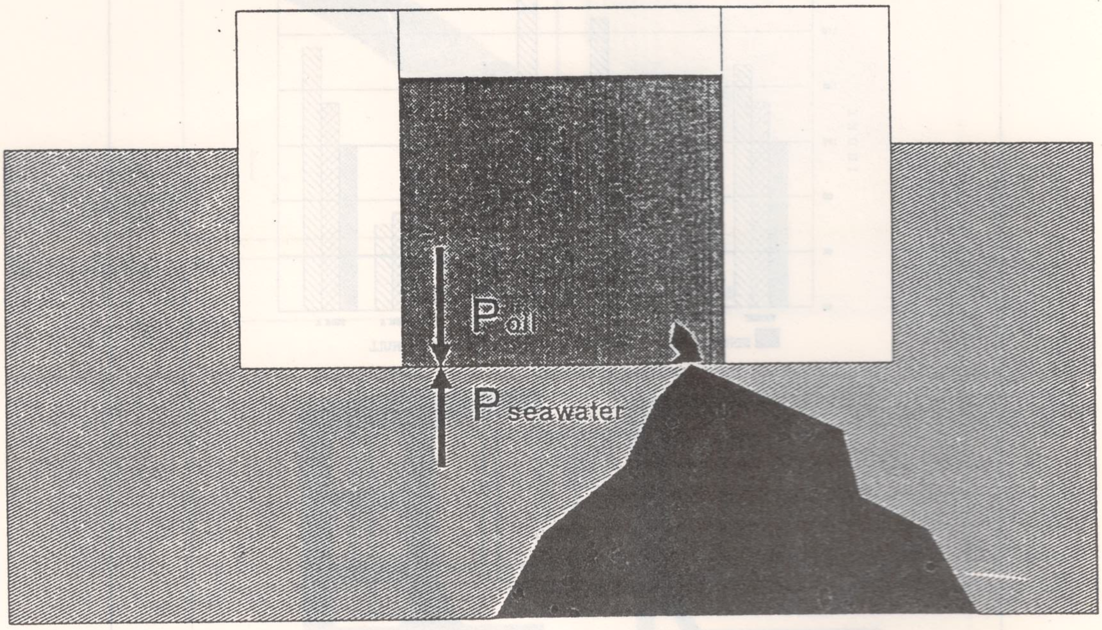

Figure 15
Mid-Deck Tanker Design