DESIGN CONSIDERATIONS

FOR

SEGREGATED BALLAST TANKERS

by

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B.S., UNIVERSITY OF VERMONT

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ABSTRACT

Sources of routine oil tanker pollution and accidental oil tanker pollution are examined and the effectiveness of proposed sollutions is discussed. The existence and status of regulations which affect the design, construction and operation of tankers and are aimed at reducing oil pollution, are examined on the International, Federal, and Classification Society levels. A design methodology is developed for dealing with IMCO'78 Regulations, principally the segregated ballast requirement. Included is a program for computing the final weight curve from the light weight curve plus a user specified tank loading arrangement. A 75,500 DWT tanker and an 125,200 DWT tanker are redesigned to meet IMCO'78 standards. The additional construction and operating costs involved are estimated.

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I. Introduction

Oil tankers make up over half of the world's merchant fleet and they are responsible for the transport of some eight million barrels of oil per day. Oil transport is a one way trade and with the exception of ore-bulk-oil carriers, tankers carry no cargo for half of their life at sea. In order to maintain maneuverability, propeller submergence, and satisfactory sea-keeping qualities on their return voyage, the tankers take on from 30 to 65 percent of their full load displacement in salt water ballast. When this ballast is loaded and unloaded from cargo tanks, up to 15 percent of the oil sludge which remained after cargo discharge will go with the ballast, back to the sea. As a pollution preventative measure, the InterGovernmental Maritime Consultative Organization has proposed that new tankers be built with enough dedicated ballast capacity that the cargo tanks need not be used for ballast storage. This thesis discusses the implications of this proposal along with the other anti-pollutitive measures currently being taken by existing regulatory bodies.

Oil pollution from tankers falls into the two categories of routine operations and accidental spills. Remedies for routine operational pollution include Load on Top, Crude Oil Washing, increased slop tank capacity, better reception facilities, and segregated ballast systems. Accidental spills are due to explosions, groundings, collisions, and structural failures. Inert gas systems, double bottoms, improoved steering and navigational gear, and strength standards which are abreast of design development, are the proposed means of abating the respective types of accidental spills. Chapters II and III discuss the effectiveness of these proposals.

Maritime traffic is regulated on the International and Federal level and many of the standards are set by the classification societies. Chapter IV brings the reader up to date on the regulating bodies of relevance to the design, construction and operation of non-polluting tankers.

The regulations requiring segregated ballast and protective location of that ballast call for some new and innovative approaches to tanker design. Chapter V introduces the beginnings of an optimization procedure for developing the internal layout of new tanker designs. Chapter VI uses this methodology for the redesign of a 75,500 DWT tanker and an 125,200 DWT tanker. The final chapter estimates the added construction and operational costs of the design changes which are necessitated by the new regulations.

II. Prevention of Pollution by Routine Tanker Operations

Annual oil pollution of the oceans has been estimated at 4,897,000 metric tons; 28.32 per cent of this is caused by oil tankers with 21.8 per cent due to routine tanker operations. Load on Top (LOT) and tank cleaning operations account for 265,000 tons; non-LOT tank cleaning 702,000 tons; and discharge due to bilge pumping, leaks, and bunkering spills 100,000 tons. (1)

The different efforts to reduce this routine operational pollution include LOT, crude oil washing, and segregated ballast tanks, all of which are, to some extent, now part of IMCO regulations.

Taking a typical round trip cycle of a tanker which utilizes LOT, here is a description of the loading, unloading, ballasting and deballasting procedures. (15)

The vessel arrives in port with full cargo and begins pumping the oil ashore. Depending on the oil viscosity, cargo discharge should take 16 to 20 hours on a VLCC.(13) The first tanks emptied should be those which will need to be ballasted before the vessel can leave port. The oil cargo is pumped from the tanks, the tanks are washed, the dirty wash water is transferred to the slop tanks, the lines are drained of oil, and the tanks are ballasted. Standard ballasting time is approximately 10 hours. (2) The slop tanks are spaces used solely for the containment of material unsuitable for discharge into the sea. This includes wash water, bilge water, engine room sludge, and pumping residues. Slop tank contents are discharged to reception facilities in port.

The order in which the tanks are unloaded, washed, and ballasted, must be such that the ship maintains proper trim and heel, does not develop excessive bending moments, and makes full use of available pumping capacity.

There is not always time to wash the tanks before the vessel is ready to leave port. In those instances the minimum ballast required for safe port departure will be placed in the dirty cargo tanks and as the voyage progresses, tank washing begins. Any additionally needed ballast then goes in the cleaned tanks. The 1978 IMCO Regulations state that all tank washing must be completed before the vessel leaves port.

While at sea the water and oil seperates and just before arrival in port the water is pumped out from the tank bottom. New cargo is then loaded on top of the remaining oil residue.

Load on Top: Load on Top is a method of removing the oil from tank cleaning and dirty ballast water. The oil and water are seperated by gravity at a rate roughly proportional to the square of the oil droplet's diameter. The residence time is from 12 to 24 hours (2) but the process is slowed by heavy ship motions as well as by high intensity washing operations. Shallow slop tanks will help to speed up the process. When all the oil is above the oil/water interface, the water is pumped out and new cargo is loaded on top.

LOT operations are estimated to be 80 to 95 per cent effective in eliminating pollution. (2) It cannot be used if tanks are to carry refined products since they cannot be mixed and also, refined products cannot tolerate salt content to the extent that crude oils can. Because of the residence time required, LOT is not practical on short voyages and in severe sea conditions it cannot be used since the seperation process will not be effective. Because some components of crude oil are water soluble, seperation will never be 100 per cent effective.

Crude Oil Washing: Crude oil washing (COW) is a relatively new process, developed in the last five years. The incentives behind COW's development stem from the fact that it recovers more of the oil cargo from the tanks, cargo which otherwise would be left behind as sludge. (3)

COW is a method of tank cleaning which uses crude oil as the washing medium. Crude oil used instead of water, eliminates the introduction of salt into the water; does not create dirty wash water and; does not have the corrosive qualities of salt water. (COW has not been in use long enough to determine what new corrosive problems might arise from the process. (3)

The residues remaining from a discharged oil cargo are on the order of 0.3 per cent to 0.5 per cent of the Bill of Lading quantity. Crude oil washing with strategically placed jets and well designed tanks will dislodge this sludge and leave the tanks nearly oil free. With a small additional amount of water and chemical washing, the tanks can be deemed fit for clean ballast.

One drawback is that because the oil and water are transferred through the same lines, oil is introduced into the clean ballast water. For economic reasons it would not be practical to install segregated piping and pumps although it would be desirable environmentally.

A study performed by BP (3) showed COW to be quite effective in cutting down on pollution. Their VLCC's, utilizing crude washing, were able to keep the ballast water's oil content to 20 ppm. This is well within the 100 ppm discharge maximum set by IMCO.

Air pollution could proove to be a significant problem with crude washing. Once the tank atmosphere reaches saturation, the gas released from the oil washing jets must be expelled, the atmosphere is where it goes.

Because of the flammable atmosphere created, especially in the vicinity of the tank's air inlet, new IMCO regulations (4,5) require vessels using COW to also have Inert Gas Systems.

Crude Oil Washing and Inert Gas Systems are sophisticated and therefore the operating personnel must be highly trained. This will probably cause vessels to be held up in port trying to get their systems operating at IMCO standards (Resolution 15, ref.4) and will proove a disadvantage to the less technologically advanced maritime nations.

Segregated Ballast: A sollution to the problem of dirty ballast water is to build a ship with seperate tankage and piping which handles ballast exclusively, i.e. build an 100 per cent segregated ballast tanker.

The 1978 IMCO Conference on Tanker Pollution Prevention (4) will, to some extent, make such tankers a reality. Regulation 13 of the conference reads as follows;

"Every new crude oil tanker of 20,000 tons deadweight and above and every product tanker of 30,000 tons deadweight and above shall be provisioned with segregated ballast tanks .... The capacity of the segregated ballast tanks shall be so determined that the ship may operate safely on ballast voyages without recourse to the use of cargo tanks for ballast except.... on those rare voyages when weather conditions are so severe that in the opinion of the master, it is necessary to carry additional ballast water in cargo tanks for the safety of the ship...... Every existing crude oil tanker of 40,000 tons seadweight and above shall be provided with segregated ballast tanks, ... or in lieu... be operated with a cargo tank cleaning procedure using crude oil washing...."

The new ships will be designed for a minimum draft of $T = 2.0 + 0.2L$ (m), propeller submergence and with trim by the stern not greater than $0.015L$ (m).

These regulations represent a large step towards pollution reduction however, they do not mean complete elimination of routine tanker operational pollution. Questionable are both the effectiveness of COW, and the ability of the IMCO draft restriction to necessitate sufficient segregated ballast capacity for most operating conditions.

The existing tanker fleet represents approximately 330 million tons deadweight with the mean deadweight at 82,000 tons and the mean for tankers over 70,000 tons, at 170,000 tons deadweight. (6) None of this tonnage will be required to operate as segregated ballast tankers but as a compromise, must implement crude washing systems. It will be some time before segregated ballast tankers make up the bulk of the fleet. Because of the current slump in the market, new tanker orders represent only about 8.4 per cent of the existing tonnage. (6)

Inescapeable still, is the necessity all tankers have to wash their cargo tanks. Washing eliminates sludge build-up which can become intolerable as often as every fourth voyage. Also for purposes of drydocking, repairs, and inspection, periodic cleaning of the cargo tanks must be done.

The question of how often a ship designed to IMCO minimum draft will require recourse to the ballasting of cargo tanks, is an interesting and controversial question. What are the sea conditions that require a deeper draft and how often do they occur on the typical tanker routes?

In the past ship masters have tended to ballast on the heavy side since insufficient ballast can cause numerous problems, the chief ones being:

1) The increased freeboard, (sail area), can make maneuvering in any kind of wind conditions very difficult. In fact, many port authorities have minimum drafts and trims which they require before harbor entry is allowed. (7)

2) Ship vibrations could become worse at a decreased draft. This problem is interrelated with that of proper propeller immersion. (18)

3) The metacentric height (GM), goes up as displacement is reduced. This will cause larger roll amplitudes at higher frequency waves and thus lower sea states. (8) Crew comfort is an important consideration here.

4) The dynamic stresses resulting from slamming may be a limiting factor of the ballast draft requirement. Slamming stresses increase with increased speed as well as with a decreased draft. (8)

5) Longitudinal strength is a key consideration, especially in the case of the segregated ballast tanker. Severe

bending moments will result if the ballast is not strategically located throughout the ship's length. For example, ballast at the bow and stern of a vessel may give sufficient draft, trim, and satisfactory motion, but the resulting hogging moment would be intolerable.

6) Springing may also be a light ballasting problem. Springing is a low cycle response of the hull girder to vave encounter frequencies at the hull's first node frequency. The location and amount of ballast could conceivably have a strong influence on the natural frequency of the hull girder. (11)

Lighter ballasting has its advantages. Reduced fuel consumption can realize significant savings. In a VLCC test program conducted by EXXON (10,11), fuel savings of 5 to 15 percent resulted when full speed ballast operation was brought from 53.5 percent to 42 percent of full load displacement.

Port time is reduced in the case of a segregated ballast tanker. Ballasting and cargo discharge can be done simultaneously. Using less ballast can also mean a considerable time saving; at a pump rate of 1500 tons/hour and a 5000 ton ballast reduction, 3.3 hours would be saved.

IMCO draft proponants argue that ship masters ballast in an overly conservative manner. For safety reasons this would be true however, from an economic standpoint, it is to the vessel master's advantage to ballast as light as possible. Standard practice has been to ballast the min mum necessary to leave port and then, as more severe weather is encountered, take on additional ballast. In the absence of severe weather, no more ballast would be loaded and therefore current ballasting practice should represent minimal safe operation.

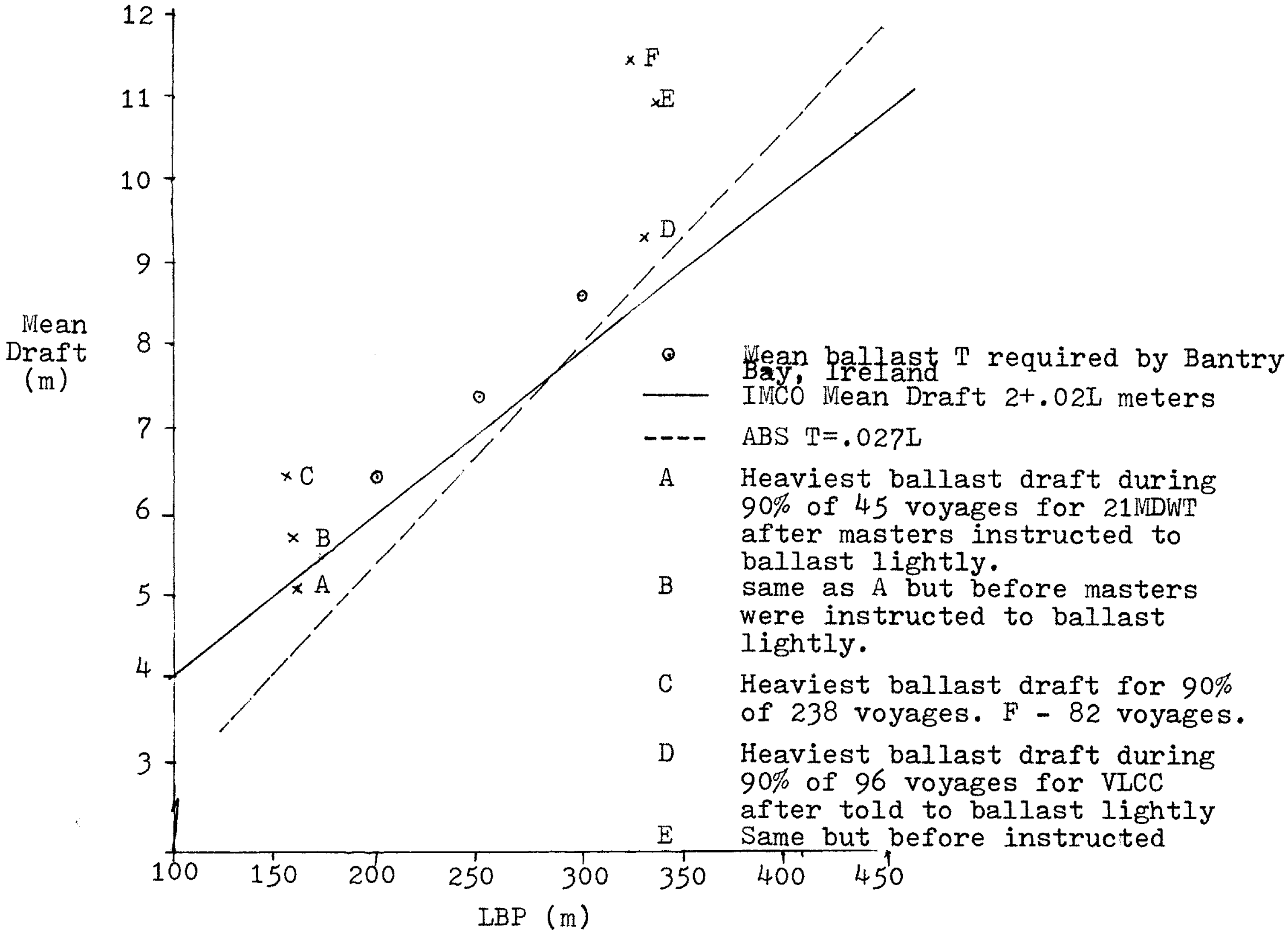
A rough rule of thumb given in reference 2 suggests 18-24,000 tons of ballast for a 50,000 ton DW tanker operating in all but the heaviest weather conditions. From limited data taken by VLCC operators (12), lightest ballast displacement used was in the range of 40-45 percent with the heaviest weather ballasting sometimes exceeding 60 percent. Data taken by the Ship Research Institute of Norway shows an even wider range with the lightest at 35 percent and the heaviest at 65 percent of full load displacement. Current practice shows that as ship length increases, the percent of full load displacement ballasted decreases.

Figure 2.1 plots draft versus vessel length for the minimum draft restriction of IMCO, actual ballasting practice data, a port authorities draft restrictions, and the bow drafts required for the allowance of bow scantling modification according to ABS.

The actual practice data shows, for a 22,000 DWT and a 215-250,000 DWT group of tankers, the heaviest ballast draft during 90 percent of 320 voyages between Northern Europe and the Persian Gulf via the Cape of Good Hope. (21) Also shown is the cummulative ballast experiences of a group of 250,000 DWT

Figure 2.1

MEAN BALLAST DRAFT VS LBP



tankers, first their normal practice, and second; after they were carefully instructed to ballast as light as possible.(11)

In the second case, the reasons given by the masters for not ballasting still lighter, were as follows:

Reason for Not Ballasting Lighter	Percent of Time	
	250MDWT	21MDWT
Springing	35%	2%
Rolling	26	32
Slamming	22	45
Pitching	9	--
Vibration	8	8
Propeller Emergence	--	8
Docking	--	5
	100%	100%

It is noteworthy that in all cases, IMCO is the minimum draft and also that the rise in draft does not increase linearly as the IMCO draft rule does. For model test and seakeeping computer predicted results of lighter ballasting, the reader is referred to references 7 and 11 respectively.

From the preceding discussion one might condlude that severe weather will almost always cause a master to ballast deeper than the IMCO minimum. Since this is the segregated ballast capacity new vessels will be designed for, the added ballast will go in cargo tanks.

The Persian Gulf to North Europe via the Cape of Good Hope and back, is a well used tanker route. In sailing it, a vessel must pass through three severe storm areas; the Mozambique Channel, the Cape of Good Hope, and the Bay of Biscay. While severe sea states may not be encountered during very much of the voyage, a severe sea state necessitating additional ballast will be encountered on most such voyages. Not only should the IMCO draft restriction be tailored to tanker size, perhaps it should be tailored to the main tanker routes as well.

III. Environmental Analysis

As discussed in Chapter II, routine tanker operations account for approximately 70 percent of oil tanker pollution. The segregated ballast, COW, and operational discharge limit requirements of MARPOL'78 are designed to reduce this pollution.

Poricelli (1) estimates that 0.4 percent of a tanker's total cargo capacity remains as sludge after cargo discharge. 15 percent of this clingage is removed when the dirty ballast water is discharged. This accounts for 967,000 metric tons per year of oil pollution to the oceans. These estimates are based on 1970 oil transport figures. In 1970 approximately 280 million tons/ year were transported. The 1977 figure is 365 million tons/year and 547 mtons/year is projected for 1985.

Correctly operated COW systems should reduce the .4 percent clingage to .2 percent of the vessel's cargo carrying capacity(3), this would half the routine oil discharge. The segregated ballast system would eliminate dirty ballast water discharge so that oily water discharge would be reduced to cargo tank washing and bilge water, leaks and bunkering spills. If a vessel with segregated ballast washed 1/8 of its cargo tanks each voyage and used COW, than the 1970 figure 967,000 metric tons pollution per year, would be reduced to 325,000 metric tons/year.

Regulation 12 of MARPOL'78 requires party governments to make reception facilities available to vessels using their ports. Such facilities are not yet readily available but thir worldwide implementation would eliminate operational oil discharge. Oily water would be stored in the slop tanks required by Regulation 15 and then discharged to port reception facilities.

Accidental Oil Discharge: Poricelli estimates that 18 percent of tanker pollution is due to vessel casualties. For a period from 1969 to 1973, the oil tankship losses for 47 vessels over 10,000 DWT amounted to 774,095 long tons. 42 percent of the oil outflow resulted from structural failure and the next largest percentage of outflow (18 %) was due to collisions. Oil outflow due to grounding was 17 percent of the total. Table 3.1 shows the breakdown. (20)

Table 3.1

Accident	Number	Oil Outflow long tons	% of Oil Outflow	% of Incident
Breakdown - Structural Failure - Sink	1	16,350	4	4
Breakdown Grounding - Sink	1	13,000		
Collision - Sink	2	4,138	18	13
Collision - Explosion/ Fire - Sink	4	136,163		
Grounding Explosion/ Fire - Sink	13	92,530	12	26
Grounding - Sink	9	134,726	17	21
Flooding - Sink	2	54,669	7	4
Structural Failure - Grounding - Sink	1	40,000	42	32
Structural Failure - Sink	14	282,519		
Total	47	774,095	100	100

The Inert Gas System requirement is expected to eliminate spills due to tanker explosions. From 1969 to 1970, 16 percent of the polluting incidents due to casualties were caused by explosions. During that time, 36 percent of the large tanker fleet had IGS, none of the IGS equipped vessels were part of the list of tankers with cargo tank explosions. (1)

The protective location clause of Regulation 13E is intended to reduce outflow in the event of collision or grounding. Regulation 13E encourages the use of wing tanks for ballast and double bottom design.

Double bottoms can increase the survivability of a vessel and will also contain the oil longer in the event of grounding thus buying time for the disaster crew. On the other hand, the double bottom design decreases the longitudinal strength of the vessel and it will tend to increase the hogging moment.

In the still water condition, the buoyancy force exceeds the weight force amidships. The resulting hogging moment has been reduced in the past by concentrating the ballast amidships. Double bottoms will be used for ballast storage so that the ballast will be distributed throughout the vessel's length.

Double bottom construction will increase the section modulus of the tanker. I_{bot}/y for a double bottom tanker is approximately 20 percent greater than a non-double bottom tanker of the same design. This, however, is misleading because double bottom construction rules according to ABS allow for smaller scantlings. (12) The required center-girder thickness amidships for a single bottom tanker is t = 0.00075L + 0.2 in. For a double bottom tanker t = 0.00067L + 0.22 in. For a 1000 foot vessel this works out to 0.95 inches and 0.89 inches respectively, a 6.3 percent difference.

Rules and Regulations for the Construction and Operation of Tankers

There are three classes of rules and regulations which effect the construction and operation of tankers. They are International, Federal, and those of the classification societies.

International: The principal international regulating body is the Intergovernmental Maritime Consultative Organization, IMCO. IMCO was set up at a United Nations Conference in 1948 and officially came into being in 1958. IMCO was the first international body concerned solely with maritime affairs. The organization is one of 12 specialized agencies operating under the auspices of the United Nations. The body's principal purpose is to establish international standards for thesafe and effective operation of sea going vessels. The organization functions in an advisory and consultative capacity with the responsibility of enforcing the ratified IMCO conventions, resting in the hands of the flag nations or when applicable, the coastal nations which are party to the conventions.

IMCO administers the International Conventions on the Safety of Life at Sea, 1948, 1960, 1974, and 1978: the International Regulations for Preventing Collisions at Sea, 1961,1971; the International Convention for the Prevention of Pollution of the Seas by Oil (MARPOL), 1954, as amended in 1962, and 1973, as amended in 1978;

The International Code of Signals; the International Convention on Load Lines, 1966; the International Convention of Tonnage measurement of Ships, 1969; the Convention on Facilitation of International Maritime Traffic, 1965; the International Convention Relating to Intervention of the High Seas in Cases of Oil Pollution Casualties, 1969, 1971 (Public Law Convention); and the International Convention on Civil Liability for Oil Pollution Damage, 1969 (Private Law Convention).

Regulatory History of IMCO Pollution Prevention Conventions: The issue of tanker oil pollution of the sea was first officially addressed on a multilateral basis, in 1954 with the convening of the International Convention for the Prevention of Pollution of the Sea by Oil. This convention came into force in July 1958, was amended in 1962 and the amenddments came into force in 1967. Forty two governments were party to these coventions.

The 1954 Convention would have been superseded by the 1973 Convention, MARPOL 73, except that the 73 Convention never came into force.

MARPOL 73: MARPOL 73 addressed the problem of routine operati nal tanker pollution. The convention proposed that all existing and new tankers of 70,000 tons deadweight plus, have segregated ballast capacity as specified by the regulations and according to their timetable.

MARPOL 73 was to enter into force one year after at least 15 states whose combined merchant fleets made up at least 50 per cent of the world's combined merchant fleet, had become party to it. Then it would be the individual party state's responsibility to see that the convention was enforced.

The convention was rewritten at the February 1978 Internatinal Conference on Tanker Safety and Pollution Prevention, MARPOL 78.

MARPOL '78: The 1978 MARPOL regulations require segregated ballast in new tankers and crude oil washing and inert gas systems in all existing and new tankers. The regulations also make requirements for the protected location of segregated ballast which in effect, means that the smaller tankers will have double bottoms. The regulation requires a 45 per cent hull coverance for 20,000 tons deadweight plus tankers and this decreases linearly to 30 per cent for tankers over 200,000 tons deadweight.

A summary of the regulations pertaining to the segregated ballast, COW, and IGS requirements appear in Appendix A.

The time table for their implementation is as follows:

New Tankers: ships ordered from June 1979 or ships commenced from January 1980 or ships delivered from June 1982.

Crude oil tankers over 20,000 tons deadweight must have segregated ballast, COW, and IGS. Product carriers over 30,000 tons deadweight must have segregated ballast.
Existing Tankers: Crude oil tankers from enforcement date, all ships over 70,000 tons deadweight must have either segregated ballast or COW. Two years after enforcement date, all ships over 40,000 tons deadweight must have IGS; 4 years after enforcement date, all ships over 20,000 tons deadweight must have IGS.
Product Tankers: from enforcement date all ships over 40,000 tons deadweight shall have segregated ballast. For IGS, same as for existing tankers.

Enforcement date will be six months after 15 states representing at least 50 per cent of the gross tonnage of the world's merchant fleet, become party to the convention.

Issues Resolved by MARPOL'78: The '78 Convention represents the compromise of a number of vested interests they being principally those of ; the United States; Norway; Great Britian; the 'underdeveloped nations' and; the oil companies.

The compromise centered around two key issues. First was the segregated ballast requirement and COW alternatives. Second was the questin of how far to go in requiring double bottoms.

President Carter sent a message to Congress on March

17, 1977 in which he called for regulations requiring the following of tankers over 20,000 tons deadweight;

1) segregated ballast capacity in new and existing tankers.
2) double bottoms in all new tankers
3) inert gas plants in all new tankers
4) extra radar systems
5) improoved emergency steering

These regulations were never passed in the House and it now looks as if the United States Coast Guard will adopt the regulations set forth in MARPOL '78 and SOLAS '78.

Norway has wanted the segregated ballast requirement for all existing and new tankers. Presently there are approximately 31 million tons of idle tonnage. This represents 12 per cent of the existing fleet. Nearly 20 per cent of the idle tonnage is Norwegian. A retrofit of the segregated ballast requirement could have reduced existing oil carrying capacity by 10 to 15 per cent. Such a reduction would bring Norway out of the hole as well as supply floundering Noerwegian shipyards with work. Norwegian estimates put the cost of conversion at an average of 1.4 million dollars per tanker. (9)

Estimates put forth by Great Britian are much higher. This represents the British predjudice towards the crude oil washing alternative. They see segregated ballast tankers as a wasteful expense.

The less developed nations have not been in favour of the COW and IGS requirements. Not only is a great deal of technical innovation required for the installation of the systems, in order to operate and maintain them, the crew must have a high level of training sophistication.

The oil companies have been in favour of COW for all tankers and no segregated ballast requirement. A study performed by EXXON (9) indicated that $100,000 per ship could be saved each year if the ship used Crude Oil Washing.

There is no guarentee that the present convention will enter into force, however, new tanker designs do show a marked trend toward increasing segregated ballast capacity to IMCO standards. Also more and more tankers are installing COW and IGS.

Federal Law and Jurisdiction - U.S.: The Department of Transportation is responsible for the regulation of waterborne traffic, the U.S. Coast Guard is the principal regulating and enforcement body. Federal regulations apply to all vessels entering U.S. waters, vessels which do not satisfy the rules can be denied access to U.S. ports.

Individual states can regulate maritime matters which do not require uniform Federal regulation and which are consistent with Federal legislation. A landmark case regarding this issue of state and federal power, was resolved by the U. S. Supreme

Court in March, 1978. Atlantic Richfield was fighting Washington for the right to bring supertankers into Pugent Sound. It was decided that the state of Washington cannot supersede Federal Regulations which permit supertankers into the Sound.

For the most part, the U.S. Coast Guard has adopted into the Code of Federal Regulations, requirements established by IMCO and the American Bureau of Shipping. It is Title 33 and Title 46 of the U.S. Code of Federal Regulations which apply to maritime matters. Revisions of these regulations appear in the Federal Register which comes out daily.

Title 33 is entitled "Navigation and Navigable Waters", of relevance is Subchapter O on "Pollution". Hypothetical Oil Outflow limitations consistent with MARPOL'78, and Oil Discharge and Transfer Operations and Arrangements, are specified.

Title 46 is entitled "Shipping", chapters D through F are of relevance, they deal with the ; Rules and Regulations for Tank Vessels; Load Lines; and Marine Engineering, respectively. The regulations refer to ABS for standards and as matters now stand, satisfaction of IMCO and ABS, also means satisfaction of the Federal Regulations.

There are two important acts which the Department of Transportation is responsible for: the Ports and Waterways Sfety Act of 1972 and the Oil Pollution Control Act of 1961.

Title I of the former, gives the Coast Guard broad authority for; controlling vessels in nation's ports, coastal waters, and waterways; for operating vessel traffic control systems and otherwise improoving the safety of the transportation system as a way of preventing pollution. Title II directs the Coast Guard to develop new regulatory standards for vessels carrying polluting substances.

The oil Pollution Control Act of 1961 prohibited oil discharge from ships within 50 miles of land; set tank arrangement and size standards,; established discharge limits; and established penalties and enforcement requirements. This act was updated by President Carter's March, 1978 message to Congress.
The adoption of MARPOL '78 is expected to supersede both of these actions.

Classification Societies: The classification societies are semi-official regulating bodies. For example, on hull standards the U.S.C.G. will refer to ABS for the final specifications.

A vessel cannot be insured if it has not been classed by a classification society. The societies also set standards for routine inspections. A summary of ABS rules for tankers is given in Appendix B.

The seven major classification societies in the world today are as follows:

1. American Bureau of Shipping (ABS) 7. Registo Italiano
2. Bureau Veritas
3. det Norske Veritas
4. Germanische Lloyd
5. Lloyd's

V. Design Considerations

The coming into force of the 1978 MARPOL will cause a change in approach to tanker design. The designer's principal interest is to maximize cargo carrying capacity and average vessel speed, within the constraints of the owner's requirements. In the past, since empty cargo tanks held the ballast water, ballasting configuration has not been a principal design consideration, it did not become important until the outfit design stage was reached.

With the new regulations, maximizing cargo carrying capacity is integral with optimizing the ballast configuration. Any space which is allotted to ballast can never be used for cargo. The placement of bulkheads is not a straightforward procedure. Ballast capacity and protective location of the ballast must be maximized and lost cargo carrying capacity minimized.

Design innovations motivated by Regulation 13 (4) will include new approaches to hull shape, bulkhead and piping arrangements, and better utilization of spaces whose productive potential have previously been ignored.

One example of proposed hull modifications is a cutaway  -shape which is currently being studied at M.I.T. Such a hull would reduce the amount of ballast required and thus reduce the space dedicated for ballasting.

New tanker hulls will tend to have more depth in order to increase the cargo carrying capacity. Because existing cargo space will be lost to ballast space, an increase in depth and thus cargo capacity, will not cause the vessel to exceed the designed full load displacement or the owner's draft restriction. Increasing vessel depth has the advantages of: increasing the section mosulus; decreasing the probability of shipping green water; and reducing the metacentric height and thus improove the period of rolling motions.

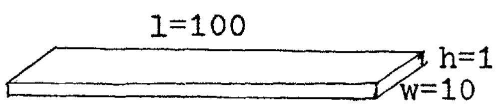
Internal Structure: The internal structure must be designed to meet the requirements for ballast capacity and protective location as outlined in Regulation 13, Appendix A.

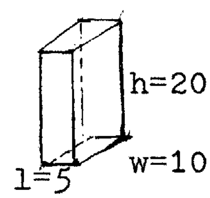
The first major consideration will be determining the necessity of a double bottom. Due to the way Regulation 13E is written, this will be a function of vessel size. The regulation requires $\Sigma PA_c + \Sigma PA_s \geq J(L_t(B+2D))$ (Eq5.1) where PA_c and PA_s are the side and bottom shell areas respectively, of all non oil tank areas with the cargo tank length, L_t. J depends on vessel deadweight, it is equal to 0.45 for 20,000 DWT, 0.30 for 200,000 DWT, and reduced as a function of hypothetical outflow as DWT continues to increase.

In nearly all cases, the only possible way for a vessel under 200,000 DWT to satisfy (5.1) is with a double bottom running the length of the cargo tanks.

Double bottom tankers are more expensive to construct and they weigh more (reducing cargo carrying capability), then their non-double bottom sisters. If it is possible to satisfy the protective location requirement with a partial double bottom, this would be a favorable alternative.

The reason the double bottom is the most effective means of stisfying (5.1) can be shown quite simply:





Volume = 1000	Volume = 1000
PA_c = 100	PA_c = 100
PA_s = 1000	PA_s = 50
$PA_c + PA_s$ = 1100	$PA_c + PA_s$ = 150

To further maximize side shell area, the wing tanks are used for ballast. Wing tank ballasting has the added advantage of increasing the transverse radius of gyration which reduces the natural roll period.

If additional ballast capacity is needed, and the fore peak, aft peak, and other available space outside of the cargo area, have been utilized, than the bulkhead arrangements must be adjusted such that the ballast tank volume is increased.

The location along the length of the cargo area, of the ballast wing tanks, is determined from the limits placed on hyposthetical oil outflow and still water bending momment coniderations. Regulations 22 through 24, dealing with damage assumptions and hypothetical outflow calculations, encourage the staggered placement of ballast tanks.

For the purposes of checking the bending moment, a program which adds the litht weight curve to a user specified loading condition, is included in Appendix C.

Design Methodology: After the internal layout of the vessel has been settled upon, it is useful to develop a methodology for checking that all regulatory and operational requirements have been met. Figure 5.1 shows such a methodology. The philosophy is that the simplest and least time consuming calculations should be made first.

Following the flowchart through, the initial volume of allotted segregated ballast space is determined by the IMCO draft requirement of T = 2.0 + 0.2L (m). The displacement which will bring the vessel to that draft is calculated, the lightweight subtracted, and the difference is equal to the tonnage of salt water ballast required. This is converted into volume and the requisite space is allocated. The protective location is checked and at this point the designer must decide how much of a double bottom will be necessary. From the weight and buoyancy curves the draft and trim are checked and propeller submergence is verified. Hypothetical outflow and the damaged stability requirements are then checked but it is unlikely that once there is suf-

Flowchart for Design of Ballast Configuration

Start

Allocate Segregated
Ballast Spaces

Weight Curves...
Bending Moment

Protective Location
of Ballast Spaces

Draft and Trim

Hypothetical Oil
Outflow

Damaged Stability

Section Modulus...
Bending Moment (ABS)

Figure Cost, if there
is a clear alternative
begin cycle again and
compare costs

Move on to Outfit Design

FIGURE 5.1

ficient protective location of ballast, that there will be insufficient damaged stability or too much hypothetical oil outflow.

The vessel's section modulus is calculated in order to determine whether or not the bending moments are permissable. The criterion for these calculations come from section 6 of the ABS "Rules for the Building and Classing of Steel Vessels", see Appendix B.

All of the above calculations and design work can be done by hand or with the aid of simple computer programs.

VI. Design Example

A tanker designed to the IMCO '78 Regulations will not have the same oil carrying capacity as it would have, had it not been designed with segregated ballast capacity and protective location of that ballast capacity. In order to estimate how much cargo carrying capacity is lost, a 75,515 DWT tanker, the Machias, and a 125,200 DWT tanker, the Voyager, had their internal structures redesigned such that they would satisfy MARPOL '78. First the base case, as designed, was ballasted, next the longitudinal bulkheads were moved so as to optimize tank sizes, and finally double bottoms were added the length of the cargo tank area. The depth was increased to make up for lost cargo carrying capacity. Cargo specific gravities of 0.83, 0.85, and 0.88 were used so that with the two vessels 18 versions were examined.

A list of typical crude oils and their specific gravities is as follows:

Crude Oil	Specific Gravity
Lybyan Zelten	0.829
Venezuela Tia Juana Medium	0.836
Iraq Kirkuk	0.845
Iraq Light	0.854
Iraq Heavy	0.869
Kuwait	0.869

Table 6.1

Tables 6.2 and 6.6 summarize the results for the Machias and Voyager respectively. Figures 6.1 a and b through 6.6 a and b show the layout of the vessels and figures 6.1 c and

6.5 c show the weight, shear force, and bending moment curves.

In the case of the Machias, moving the longitudinal bulkheads out, decreased the amount of lost cargo capacity. The Voyager was redesigned with an additional set of tanks as well as having the longitudinal bulkheads moved out, this also helped to decrease the lost cargo carrying capacity. Both vessels needed the double bottom in order to satisfy Regulation 13E requiring protective location, unfortunately adding a double bottom decreased the cargo carrying capacity. No significant variations in bending moment resulted from the different ballasting schemes.

What follows is an explanation of how the vessels were redesigned including the basis for the calculations.

1) Cargo tank capacity of the vessel is calculated by summing the volumes of all available cargo tanks. Because the tanks will never be more than 98 percent full, the volume is multiplied by 0.98.

2) The amount of cargo by weight which the vessel can carry is calculated, this is equal to the full load displacement minus the lightweight and consumables. This is converted into volume: $V = \frac{\text{(Cargo wt) (water density)}}{\text{specific gravity of cargo}}$

3) The available cargo tank volume minus the vessel cargo capacity is equal to the volume which could not be utilized for cargo and is regarded as extra space.

4) The amount of ballast required to sink the vessel to a draft of 2 + 0.2L m is calculated. This was done by using the hydrostatic curves to get the required displacement and subtracting the lightweight, one half of the slop tank capacity, fore and aft peaks.

5) The double bottom is designed:(this step is skipped for the non-double bottom case.)

a. The depth of the double bottom is the ABS minimum allowable: $D_{db} = 0.384\ B + 4.13\ T$ in.

b. $V_{db} = L_t B\ C_x$ the length of the double bottom is the length of the cargo tank area.

c. Tank capacities are redefined: $V_t = V_t - V_{dbt}$

d. the weight of the double bottom is calculated as follows: The thickness is as required by ABS: t = .00067L + .22 in.

$W_{db} = \rho steel L_t C_x B\ t$ $\qquad \rho steel = .219\ ton/ft^3$

e. The weight of the double bottom is added to the lost capacity, which is calculated in (6).

6) The ballast spaces are asigned so that (4) is satisfied, and excessive bending moments do not exist. The lost capacity is then the vessels cargo carrying ability minus the space which is left for cargo stowage.

8) Depth is increased to make up for lost cargo capacity.

a. The cargo area per unit depth is approximated by:

$V_{cargo}/C_{x} D = A/D$

b. The additional depth required is calculated:

Lost cargo capacity/(A/D) = Dadded

c. The old and new vessel weights are calculated according to reference 13:

$$\text{Steel Weight} = y\ c\ f^{.65} z^{.65} L\ 1008\ \frac{(1.108 - .016L/B)(1.12 - .0163L/D)}{(35.8 - L/D)(14 + L/D)}$$

$$y = 3.8 - 1.1(L/B) + .1(L/B)^2$$

$$c = 1 + 1.32/L$$

$$f = 3.8 + 2.1\ L\ 10^{-3}$$

$$z = 5.95\ L^2 B\ (C_B + 0.7)\ 10^{-3}$$

The steel weight for the original depth is subtracted from that of the new depth. This number is then the lost cargo capacity by weight.

9) The protective location requirement is checked, Regulation 13E, appendix A.

10) Damage assumptions are made according to Regulation 22 and hypothetical oil outflow is checked according to Regulations 23 and 24, appendix A.

MACHIAS

Principal Characteristics:

LOA	821 ft
LBP	775
B	105.5
D	62.5
T	47
C_B	0.831
LWT	15,685 tons
DWT_{FL}	75,515
DISPL	91,200
SHP	19,250
AVE. SPEED	16 knots

Total Cargo Capacity = $\sum_{i=1}^{7}$ Centers + $\sum_{i=1}^{3}$ Wings = 3,434,845 ft^3

Capacity at Full Load Draft = 72,020 tons

IMCO Draft Requirement $T \geq 22.08$ ft

Ballast Requirement 25,515 tons

Trim by Stern ≤ 11.6 ft

ABS Bending Moment Maximum: M_{SW} = 645,680 ton-ft

Wave Height = 25.2 ft

M_W = 957,523 ton-ft

SUMMARY OF LOST CAPACITY CALCULATIONS (tons)
Table 6.2

	Case 1			Case 2			Case 3		
Specific Gravity	0.88	0.85	0.82	0.88	0.85	0.82	0.88	0.5	0.82
Lost Capacity before Depth Added	8,160	10,676	12,514	none	1,053	3,558	none	7,436	9472
Weight of Added Depth	133	196	262	---	16	37	--	133	196

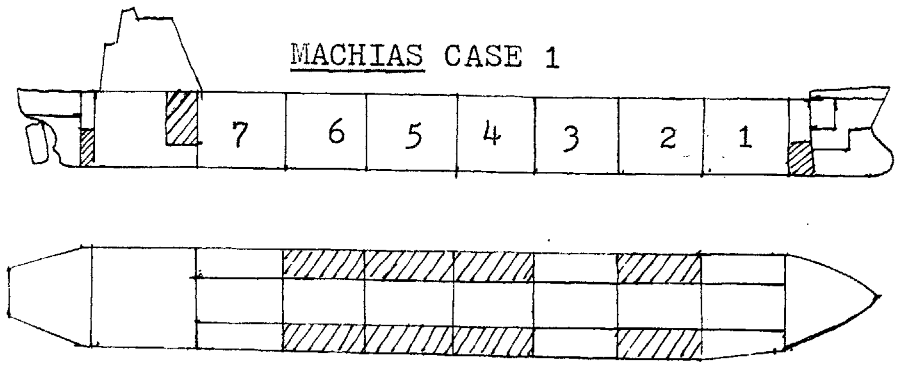
MACHIAS CASE 1: As designed with IMCO draft for ballast departure

Ballast in Wings # 2, 4, 5, 6

Cargo in centers # 1-7
in wings # 1, 3, 7 Cargo Capacity = 2,539,892 ft^3

Table 6.3

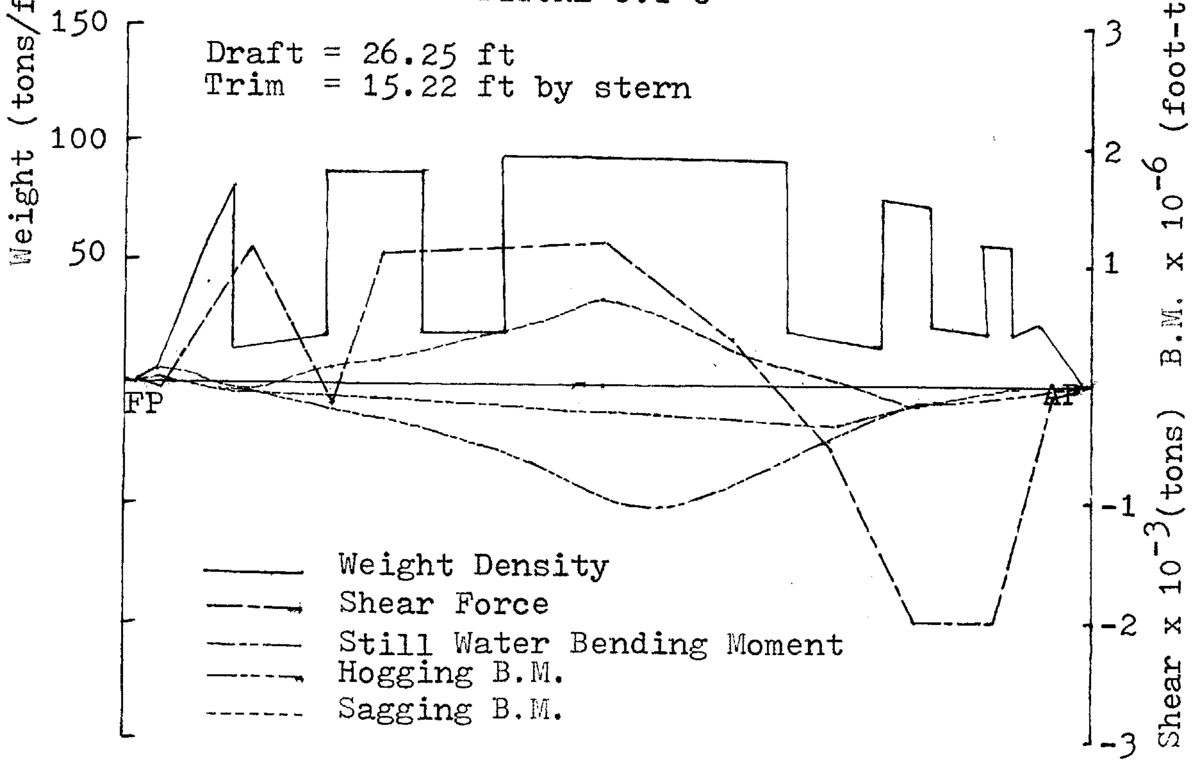
Specific Gravity	0.88	0.85	0.82
Cargo Carrying Ability (ft^3)	2,864,431	2,965,529	3,074,024
Lost Cargo Carrying Capacity $_{ft^3}$:	324,539	439,637	534,132
tons:	8,160	10,676	12,514
Increase Depth:			
D_{added} (ft)	5.7	7.5	9.4
L/D_{new}	11.4	11.1	10.8
Steel Weight of Original Vessel (tons)	12,661	12,661	12,661
Steel Weight of Vessel with Added Depth	12,794	12,875	12,923
Weight of Added Steel	133	196	262



cargo tank length = 563 ft
wing tank width = 25.84 ft
center tank width = 25.84 ft

FIGURES 6.1 a&b

FIGURE 6.1 c



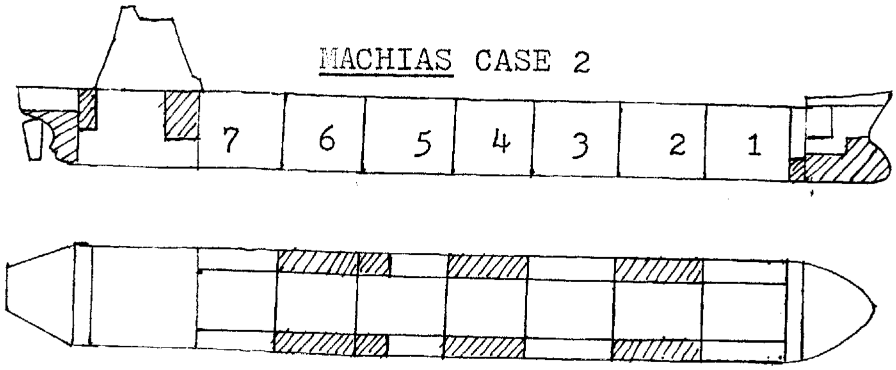
MACHIAS CASE 2: Longitudinal Bulkheads moved out 4.74 ft and slop tanks placed in Wkngs # 5.

Ballast in Wings # 2, 4, 6
Slop # 5
Aft Peak
Fore Peak

Cargo in Centers # 1-7
in Wings # 1, 3, 5, 7   Cargo Capacity = 2,922,139 ft^3

Table 6.4

Specific Gravity	0.88	0.85	0.82
Cargo Carrying Ability (ft^3)	2,864,431	2,965,529	3,074,024
Lost Cargo Carrying Capacity ft^3:	none	43,390	151,885
tons:	--	1,053	3,558
Increase Depth:			
D_{added}(ft)	--	0.8	2.7
L/D_{new}	--	12.2	11.9
Weight of Added Steel (tons)	--	16	37

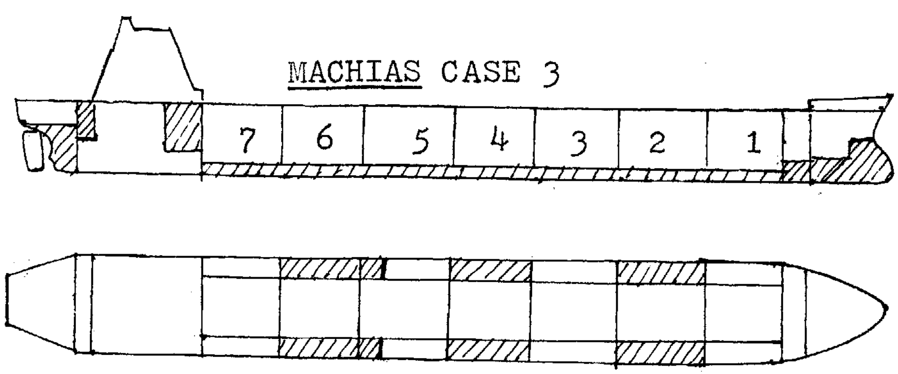


cargo tank length = 563 ft
wing tank width =21.1 ft
center tank width =63.3 ft

FIGURES 6.2 a&b

FIGURES 6.3 a&b

cargo tank length = 563 ft
center tank width = 21.1 ft
wing tank width = 21.1 ft
center tank width = 63.3 ft
double bottom depth = 5.78 ft



MACHIAS CASE 3: Double Bottom of depth 5.78 ft added to case 2 and the slop tank size is decreased.

Ballast in Wings # 2, 4, 6
Slop # 5
Fore Peak
Aft Peak

Cargo in Centers # 1-7
in Wings # 1, 3, 5, 7 Cargo Capacity = 2,690,216 ft^3

Table 6.5

Specific Gravity	0.88	0.85	0.82
Cargo Carrying Ability (ft^3)	2,864,431	2,965,529	3,074,024
Lost Cargo Carrying Capacity ft^3:	none	306,188	415,817
tons:	--	7,436	9,742
Increase Depth:			
D_{added}(ft)	--	5.4	7.3
L/D_{new}		11.4	11.1
Weight of Added Steel (tons)		133	196

VOYAGER

Principal Characteristics:

LOA	950	ft
LBP	900	
B	147.5	
D	63.5	
T	48.5	
C_B	0.8	
LWT	22,200	tons
DWT	125,200	
DISPL	147,400	
SHP	24,200	
AVE. SPEED	15.5	knots

Total Cargo Capacity = $\sum_{i=1}^{6}$Centers + $\sum_{i=1}^{6}$Wings = 5,543,325 ft^3

Capacity at Full Load Draft = 120,200 tons

IMCO Draft Requirement: T $\geq$ 24.58 ft

Ballast Requirement: 44,833 tons

Trim by Stern $\leq$ 13.5 ft

ABS Bending Moment Maximum: M_{SW} = 1,609,431 ton-ft

Wave Height = 26.3 ft

M_W = 1,787,279 ton-ft

Table 6.6

SUMMARY OF LOST CAPACITY CALCULATIONS (tons)

	CASE 1			CASE 2			CASE 3	
Specific Gravity	0.88	0.85	0.82	0.88	0.85	0.82	0.88	0.85 0.82
Lost Capacity Before D Added	13,279	16,924	20,569	12,412	16,086	19,761	26,103	29,347 32,597
Weight of Added Depth (D)	218	299	389	196	278	366	462	567 651

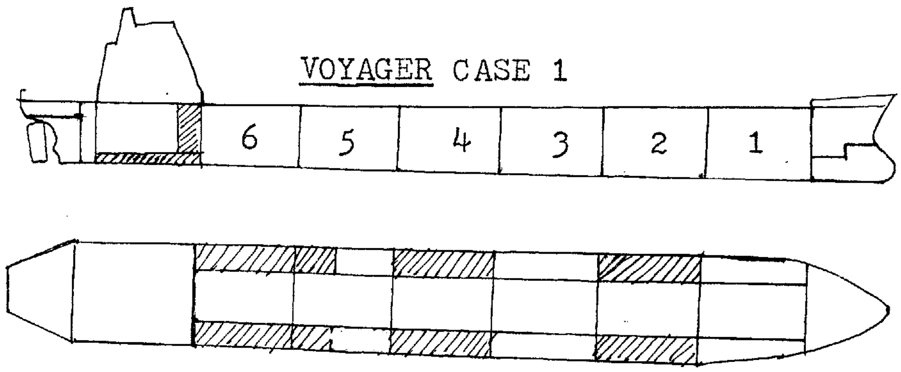
VOYAGER CASE 1: As designed with IMCO draft for ballast departure

Ballast in Wings # 2, 4, 6
Slop Tank

Cargo in Centers # 1-6
Wings # 1, 3, 5   Cargo Capacity = 4, 252, 535

Table 6.7

Specific Gravity	0.88	0.85	0.82
Cargo Carrying Ability (ft^3)	4,780,682	4,949,411	5,130,488
Lost Caro Carrying Capacity:			
(ft)	528,147	696,876	876,953
(tons)	13,279	16,924	20,569
Increase Depth:			
D_{added}(ft)	7.0	9.2	11.6
L/D_{new}	12.8	12.4	12.0
Steel Weight of Original Vessel (tons)	16,308	16,308	16,308
Steel Weight of Vessel with Added Depth	16,526	16,607	16,697
Weight of Added Steel	218	299	389

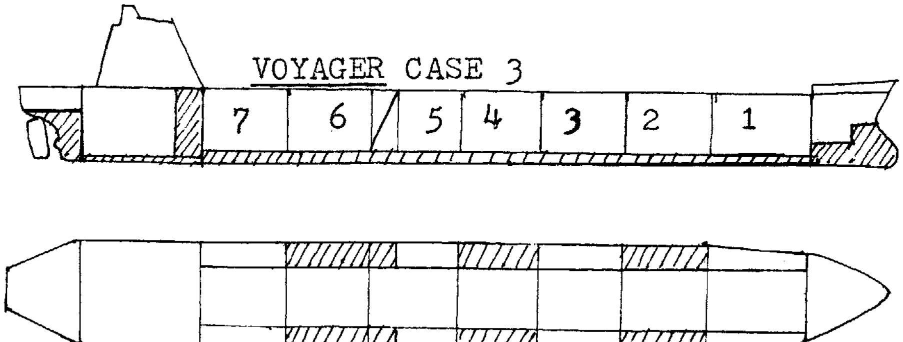


cargo tank length = 630 ft
wing tank width = 33.42 ft
center tank width = 80.6 ft

FIGURES 6.4 a&b

FIGURES 6.6 a&b

cargo tank length = 630 ft
wing tank width =29 ft
center tank width = 89.5 ft
double bottom depth = 7.12 ft



VOYAGER CASE 2: Longitudinal Bulkheads moved out.

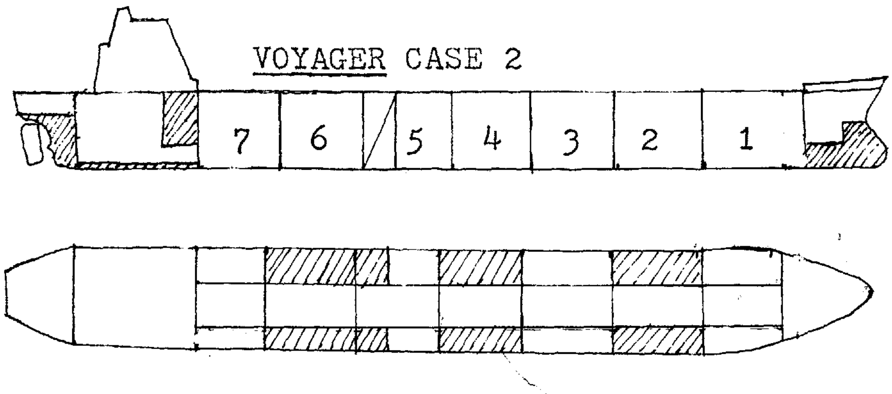
Ballast in Wings # 2, 4, 6
Slop tank
Aft and Fore Peaks

Cargo in Centers # 1-7
Wings # 1, 3, 5, 7   Cargo Capacity = 4,287,040

Table 6.8

Specific Gravity	0.88	0.85	0.82
Lost Cargo Carrying Capacity: (ft^3)	493,642	662,371	843,448
(tons)	12,412	16,086	19,761
Increase Depth:			
L/D_{new}	12.9	12.5	12.1
Weight of Added Steel (tons)	196	278	366

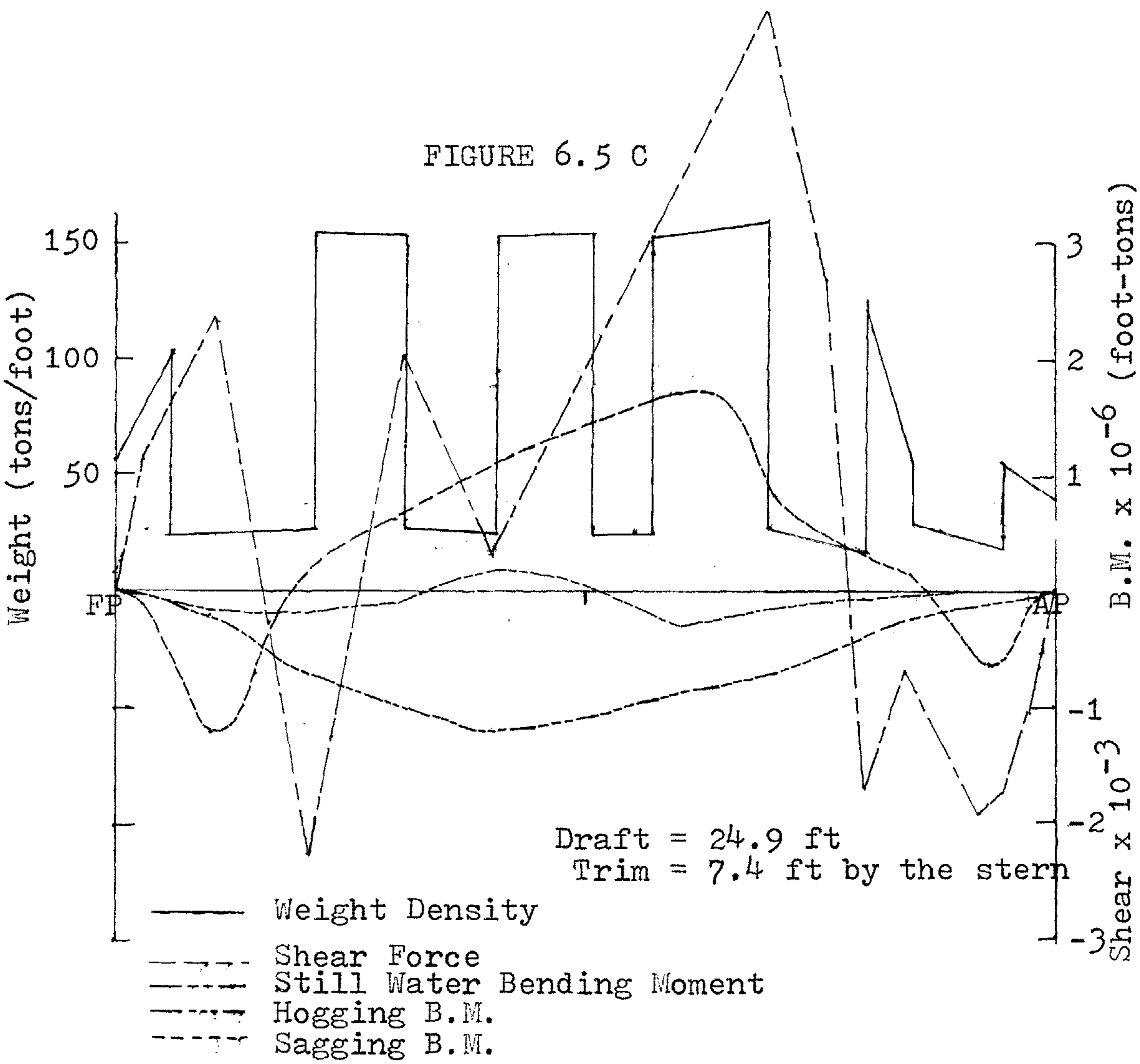
VOYAGER CASE 2



cargo tank length = 630 ft
wing tank width = 29 ft
center tank width = 89.5 ft

FIGURES 6.5 a&b

FIGURE 6.5 C



VOYAGER CASE 3:Double Bottom added to case 2.

Ballast in Wings # 2, 4, 6
Slop tank
Double Bottom
Fore and Aft Peaks

Cargo in Centers # 1-7
Wings # 1, 3, 5, 7   Cargo Capacity = 3,791,538 ft^3

Table 6.9

Specific Gravity	0.88	0.85	0.82
Cargo Carrying Ability (ft^3)	4,780,682	4,949,411	5,130,488
Lost Cargo Carrying Capacity:			
(ft^3)	1,038,186	1,208,405	1,391,335
(tons)	26,103	29,347	32,591
L/D_{new}	11.7	11.3	11.0
Weight of Added Steel (tons)	462	567	651

VII. Cost Analysis

The costs of designing to meet the 1978 IMCO Regulations can be broken down into three categories; construction costs due to added steel of depth and double bottom; the cost of outfit where, segregated ballast piping and pumps as well as crude oil washing and inert gas systems, are included; and the cost of lost cargo capacity. Also, coatings and paint would mean a couple of hundred thousand dollars extra, depending on the design.

The Maritime Administration has estimated that the average unit material prices for tankers to be built in the period starting from 1977 and spanning 36 months are:

steel.........$530 - $540/Long Ton
outfit........$4900 - $5600/LT (13)

The steel manhour erection rates are given as an average of 48 man-hours/ LT and outfit as 225 MH/LT. In the U.S. the shipyard personnel earn approximately $7.00 per man hour. This means that the cost of steel construction is roughly 535 + 7(48) = $871/LT. The cost of outfit is approximately 5250 + 7(225) =$6825/LT.

Looking at the two examples discussed in chapter VI, table 7.1 shows the additional steel costs for the 6 cases. United States shipyard estimates for the cost of installing a double bottom in a 40,000 DWT tanker are $1,000,000, and $2,000,000 for an 120,000 DWT tanker.

Table 7.1

<u>STEEL COSTS</u> (thousands of $)

Specific Gravity	MACHIAS 0.88	MACHIAS 0.85	MACHIAS 0.82	VOYAGER 0.88	VOYAGER 0.85	VOYAGER 0.82
Case 1 Added Depth	116	171	228	190	260	539
Case 2 Added Depth	--	14	32	171	242	319
Case 3 Double Bottom	644	644	644	1069	1069	1069
Added Depth	--	116	171	402	494	567

Additional outfit which will be made necessary by MARPOL'78 is as follows:

	Estimated Cost (thousands of $) MACHIAS	VOYAGER
Segregated Ballast Pumps	85	95
Piping Systems	700	900
Crude Oil Washing System	500	650
Inert Gas System	900	1,200
Total	2185	2845

The cost calculations are made on a weight basis using the equations given by the Maritime Administration.

The oil monitoring device and oil/water interface detectors are not included in the above list because it is not clear that such equipment has yet been comercially developed to IMCO standards. This will probably proove a stumbling block in the ratification of MARPOL, the less technically advanced countries are unwilling to become party to a convention which has standards they are not capable of meetin a proposed oil monitoring device developed in the U.S. which does meet IMCO standards.

The cost of installing COW and IGS has been aproximated by Norwegian experts (9) to be between .6 and .8 million for each system. The U.S. Maritime Administration estimated .9 to 1.2 million.

All vessels over 70,000 DWT must have both of these systems installed 2 years after enforcement date, vessels over 20,000 DWT must have IGS after 4 years. Comprehensive scrappings of these vessels at these points in time can be expected. Also, since the bulk of the fleet in the 12-20 year age range is under 100,000 DWT, this is where most of the scrapping will occur. Because of the slump in the market, owners are reluctant to reorder and a shortage can be expected in this size range of tanker. In general, the coming into force of MARPOL'78 will tend to accelerate the scrap - reorder cycle for tankers.

VIII. Summary and Recommendations

The first MARPOL was written nine years before it was signed into force, MARPOL'73 never came into force but instead was amended by MARPOL'78. There is no assurance that MARPOL'78 will enter into force, politics may stand in the way and better technological alternatives may be developed.

Like most comprehensive packages, MARPOL'78 contains good and bad parts and opinions differ as which are the good and which are the bad. Few will disagree that requiring IGS will greatly reduce tanker explosions.

Crude oil washing is more effective than water washing and the additional cargo recovery resulting from the technique will, over the lifetime of the vessel, pay for the cost of installation.

The cost of segregated ballast is not so excessive that it does not merit the pollution it will prevent. The designer must realize that the vessel becomes volume limited as opposed to weight limited, and proceed accordingly.

The protective location requirement would be better if it did not encourage double bottoms. Double bottoms can, instead of increase, decrease a vessel's survivability in the event of grounding. They also make the vessel more expensive.

The author recommends that regulations requiring COW, IGS, and segregated ballast, be adopted. A means of transferring COW and IGS technology to less developed countries, should be formalized. Oil/Water monitoring devices and interface detectors need to be further developed. The draft requirement for segregated ballast tankers in the ballast condition, should be tailored more to vessel size and what is current practice. There is a need for further study of how to optimize the design of a segregated ballast tanker so that the lost cargo capacity is minimized. The protective location requirement should be rewritten so that double bottoms are not encouraged. An in depth study of the relative merits of double bottoms would be useful.

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Appendix A

IMCO Regulations

The International Conference on Tanker Safety and Pollution Prevention, 1978, modifies and supplements Safety of Life at Sea (SOLAS) 1974, and the International Convention for the Prevention of Pollution by Ships 1973 (MARPOL '73)

Annex I of Attachment 2 of the Conference contains 25 regulations which deal with the prevention of pollution by oil. These regulations make up MARPOL '78 and are outlined as follows; (4,5)

1) Definitions: Thirty definitions are given, those which are not obvious, are defined as follows; (4,5)

"Major conversion" means a conversion of an existing ship:

i) "which substantially alters the dimensions or carrying capacity of the ship; or

ii) which changes the type of the ship; or

iii) the intent of which in the opinion of the Administration is substantially to prolong its life; or

iv) which otherwise so alters the ship that if it were a a new ship, it would become subject to relevant provisions of the present Protocol not applicable to it as an existing ship."

"Nearest land" begins at the baseline from which the territorial sea of the territory in question is established in accordance with international law, except for some special provisions which were made for the north eastern coast of Australia.

"Instantaneous rate of discharge of oil content" is the oil discharge in litres per hour at any instant divided by the speed of the ship in knots at the same instant.

"Segregated ballast" is ballast water in a tank which is completely seperated from the cargo oil and oil fuel system and which is permanently allocated to the carriage of ballast or cargoes other than oil or noxious substances.

"New oil tanker" means a ship:

6) a. for which the building contract is placed after 12/31/75
   b. if no contract, the keel is laid after 6/30/76
   c. delivery is after 12/31/79
   d. has undergone a major conversion;
      i.for which the contract is placed after 12/31/75
      ii. or construction work begun after 6/30/76
      iii or is completed after 12/31/79

26) For the purposes of Regulations 13, 13A-E and 18(5), a new oil tanker means:
   a. for 70,000 DWT and above and for the purposes of Regulations 13(6), 13E and 18(5):
      i. building contract placed after 6/1/79
      ii. or keel laid or in similar stage of construction after 1/1/80.
      iii. delivered after 6/1/82
      iv. undergone a major conversion:
         1.for which contract placed after 6/1/79
         2. or construction work begun after 1/1/80
         3. completed after 6/1/82

The date of the contract takes presedence over the date on which the construction work was begun.

"Existing oil tanker" means an oil tanker which is not a new oil tanker as defined by paragraph (26) above.

"Crude oil" means any liquid hydrocarbon mixture occurring naturally in the earth whether or not treated to render it suitable for transportation.

" Product carrier" means an oil tanker engaged in the trade of carrying oil, other than crude oil.

2) Application: States what vessels the convention applies to.

3) Equivalents: Prescribed requirements may be satisfied by alternative means provided the Administration finds them acceptable.

4) Surveys: Outlines a timetable and enforcement procedures for surveys.

5) Issue of Certificate: (International Oil Pollution Prevention Certificate)

6) Issue of a Certificate by Another Government

7) Form of Certificate

8) Duration and Validity of Certificates

9) Control of Discharge of Oil: Oil or oily mixtures cannot be discharged from oil tankers; within fifty miles of land; within a special area; if the instantaneous rate is greater than 60 litres per nautical mile; or if the oil discharged is greater than 1/15,000 of the oil cargo for existing tankers and 1/30,000 of the oil cargo for new tankers.

10) Methods for the Prevention of Oil Pollution from Ships While Operating in Special Areas: The special areas are the Mediterranean Sea area, the Baltic Sea area, the Black Sea area, the Red Sea area and the Gulfs area. The Gulfs area means the sea area located north west

of the rhumb line between Ras al Hadd and Ras Al Fasteh.

11) Exceptions: Emergencies which can in part be remedied by oil discharge are the exceptions.

12) Reception Facilities: It is the Government of each Member Party's responsibility to provide facilities for the reception of oily mixtures and residues at oil tanker ports and terminals.

13) Segregated Ballast Oil Tankers: Every new oil tanker of 20,000 tons DW and above and every new product carrier of 30,000 tons DW and above shall have segregated ballast tanks of sufficient capacity such that the ship may"operate safely on ballast voyages without recours to the use of cargo tanks for water ballast...".
In any ballast condition of the voyage, the capacity of the ballast tanks must be such that thevessel's draft and trim can meet the following requirements;
1) T = 2.0 + 0.2L (meters)
2) trim by the stern is not greater than 0.015L (meters)
3) the propeller is fully immersed

Every new crude oil tanker of 20,000 tons DW and above must have a crude oil washing system. Existing tankers may, in lieu of the segregated ballast requirement, install crude oil washing or else operate with dedicated clean ballast tanks as described in Resolution 14. All tankers with crude oil washing shall also be provided with an inert gas system in every cargo and slop tank.

13E) Protective Location of Segregated Ballast Spaces: Spaces other than oil tanks within the cargo tank length (L_t) must be arranged such that:

$$\Sigma PA_c + \Sigma PA_s - J(L_t(B + 2D))$$

where: PA_c is the side shell area in m^2 for each non-oil tank within L_t

PA_s is the bottom shell area in m^2 for each non-oil tank within L_t

J = 0.45 for 20,000 tons DW and is linearly interpolated to:

J = 0.30 for 200,000 tons DW and above or reduced as follows:

$J = (J - (a - \frac{O_c + O_s}{4O_a}))$ or 0.2 whichever is greater.

a increases with vessel deadweight, O_s, O_c, and O_a are defined in Regulations 23 and 24.

The minimum vertical depth of any double bottom tank or space is B/15 or 2 m, whichever is the lesser.

14) Segregation of Oil and Water Ballast: Except under abnormal conditions, no new vessel of 4000 tons gross tonnage and above other than oil tankers and in new oil tankers of 150 tons gross tonnage and above, no ballast water is to be carried in any oil fuel tank.

15) Retention of Oil on Board: Without segregated ballast capacity, slop tanks of at least 3 per cent of the vessel's oil carrying capacity, must be provided. With segregated ballast, slop tanks must have a capacity of 2 per cent of the oil carrying capacity and new oil tankers of 70,000 tons DW and above must have at least 2 slop tanks.

Oil tankers must have an oil discharge and monitoring control system which is approoved by the Administration. Oil/ water interface detectors approoved by the Administration must be provided.

16) Oil Discharge Monitoring and Control System and Oily-Water Seperating Equipment: Specifies standards

17) Tanks for Oil Residues (Sludge): These t aks are for residues such as machinery leakages, which cannot otherwise be dealt with.

18) Pumping, Piping and Discharge Arrangements of Oil Tankers: A discharge manifold for connection to reception facilities must be located on the open deck on both sides of the vessel.

Pipelines for discharge to the sea of effluent allowed under Regulation 9, must be above the waterline in the deepest ballast condition.

A means to stop the discharge from a position on the upper deck or somewhere such that thedischarge can be visually observed. (applies to new oil tankers)

Segregated ballast and clean ballast may be discharged below the waterline.

New oil tankers must have the means to drain all cargo pumps and oil lines at the completion of cargo discharge. The drainings must be capable of being discharged ashore and to a cargo or slop tank.

19) Standard Discharge Connection: Standardized so that pipes of reception facilities can connect to the vessel's discharge pipeline.

20) Oil Record Book: Ballast, cargo, tank washing, and residue operations must be recorded.

21) Special Requirements for Drilling Rigs and Other Platforms

22) Damage Assumptions: These assumptions are used in the calculation of hypothetical oil outflow.

a) Side Damage

i. Longitudinal extent (l_c): $1/3L^{2/3}$ or 14.5 m, the smaller value.

ii. Transverse extent (t_s): B/5 or 11.5m, the smaller value.

iii. Vertical extent (v_c) from baseline upwards

b) Bottom Damage

	0.3L from forward perpendicular	any other part of the ship
i. Longitudinal extent (l_s):	L/10	L/10 or 5m, the smaller val.
ii. Transverse extent (t_s):	B/6 or 10m, the smaller value but 5m min.	5m

iii. Vertical extent from the base line (v_s): B/15 or 6m, the smaller value.

23) <u>Hypothetical Outflow of Oil</u>: All conceivable locations along the length of the ship are checked. Assumed damage is according to Regulation 22.

a) Side damages (O_c): $O_c + \ W_i + \ K_iC_i$

b) Bottom damages (O_s): $O_s = 1/3(\ Z_iW_i + \ Z_iC_i)$

where: W_i is the volume of wing tank in m^3 assumed damaged according to Regulation 22. For a segregated ballast tank; W_i=0

C_i= volume of a center tank in m^3. For segregated ballast tank; C_i=0

$K_i = 1 - \frac{b_i}{t_c}$ If $b_i - t_c$; K_i=0

$Z_i = 1 - \frac{h_i}{v_s}$ If $h_i - v_s$; Z_i=0

b_i is the width of a wing tank measured inboard from the ship's side at right angles to the centerline.

h_i is the minimum depth of a double bottom, for no double bottom; h_i=0

If an empty space or segregated ballast tank of length less than l_c is located between wing oil tanks, O_c may be calculated on the basis of W_i being the volume of the smaller of the two tanks if their capacity differs, multiplied by S_i.

$S_i = 1 - \frac{l_i}{l_c}$ l_i is the length of an empty space or the segregated ballast tank under consideration.

If bottom damage simultaneously involves four center tanks, O_s may be calculated as follows:

$O_s = 1/4(\Sigma Z_i W_i + \Sigma Z_i C_i)$

If a ship has emergency high suction in each cargo tank which is capable of transferring from a damaged tank or tanks to segregated ballast tanks or other available cargo tankage, then credit as reducing oil outflow in the case of bottom damage will be given.

24) <u>Limitation of Size and Arrangement of Cargo Tanks</u>: All tankers will eventually be required to comply with this Regulation. The cargo oil tanks must be such that the hypothetical oil outflow O_s or O_c anywhere in the length of the ship does not exceed 30,000 m^3 or 400 ^{3} DW, whichever is larger with a maximum of 40,000 m^3.

The volume of any one wing cargo oil tank must not exceed 75 per cent of the limits of O_s or O_c stated above. The maximum volume for a center cargo oil tank is 50,000 m^3. In the case of segregated ballast tankers, the volume of a wing cargo tank placed between two ballast tanks, each longer than l_c, may be increased to the maximum limit of hypothetical outflow given that the width of the wing tank is greater than t_c.

The length of each cargo tank shall not exceed 10 m or one of the following values, whichever is greater:

a) no longitudinal bulkhead: 0.1L
b) centerline longitudinal only: 0.15L

c) with two or more longitudinals:
   i. for wing tanks: 0.2L
   for center tanks:
      if $\frac{b_i}{B} \geq 1/5$ 0.2L
      $\frac{b_i}{B} < 1/5$
      no centerline longitudinal: $(0.5\frac{b_i}{B} + 0.1)L$
      centerline longitudinal: $(0.25\frac{b_i}{B} + 0.15)L$

Valves must be provided for seperating tanks from each other when they are interconnected. If pipes run through cargo tanks in a position less than t_c from the ship's side or v_c from the ship's bottom, then valves must be fitted at the point where they open into any cargo tank.

25) Subdivision and Stability: Tankers more than 250 m long shall have the subdivision and damage criteria applied anywhere in the ship's length. The extent of damage is as specified in Regulation 22 except that the longitudinal extent of bottom damage within 0.3L from the forward perpendicular shall be the same for side damage as specified in Regulation 22.

The damage stability criteria for oil tankers is as follows: The final waterline must be below the lower edge of any opening through which progressive flooding could occur. Openings include air pipes and weathertight doors or hatch covers. Watertight covers, flush skuttles and side skuttles of the non-opening type are not considered openings.

In the final stage of flooding, the angle of heel must not exceed 25 degrees, and this angle may be increased to 30 degrees if no deck immersion occurs.

Stability is sufficient if in the final stage of flooding, the righting lever curve has at least a range of 20 degreew beyond the position of equilibrium in association with a maximum residual reghting lever of at least 0.1m. The Administration must be satisfied that stability is sufficient during intermediate stages of flooding.

<u>Resolutions</u>: Attachment 3 of the Conference contains 18 Resolutions, they are outlined as follows:

1) The target date for entry into force of MARPOL'78 is set at not later than June 1981. It is recommended that all states contemplating becoming Party to the MARPOL protocol, do so no later than June 1980.
2) Target date for entry into force of Attachment 1 (SOLAS)
3) Future developments aimed at eliminating Pollution
4) Control procedures for existing crude tankers of less than 40,000 tons DW. It is recommended that Governments pay special attention to loading and unloading procedures of such tankers.
5) Further development of international standards for inert gas systems.

6) Procedures for the effective enforcement of conventions relating to SOLAS and MARPOL

7) Development of guidlines for the performance of in port inspections of the result of tank cleaning by means of crude oil washing.

8) Improovement of the standard of crews on tankers

9) Amendments to the draft resolution on protection of particularly sensitive sea areas

10) Development of guidlines for the performance of statutory surveys and inspections including unscheduled inspections and mandatory annual surveys of ships

11) Marine Safety Corps: an effort to make relevant expertise available through technical assistance programs.

12) Improoved steering gear standards

13) Carriage of collision avoidance aids

14) Specifications for oil tankers with dedicated clean-ballast. (for existing tankers)

15) Specifications for the design, operation and control of Crude Oil Washing Systems: Design criteria are set for the piping, tank washing machines, pumps, stripping system, and ballast lines. Tank washing machines must be permanently installed.

Training of the personnel involved in the crude oil washing operations must be to the satisfaction of the Administratiion.

Operation requirements cover; th tankage which must be crude washed; drainage and discharge ashore of cargo lines; filling of departure ballast tanks; crude oil washing at sea, discharge of oily water effluents on ballast voyages; use and control of inert gas; precautions against electrostatic generation; and vapour emission.

Approximately 1/4 of thecargo tanks must be crude oil washed for sludge control purposes, before departure on a ballast voyage. Ballast water is not to be put in a tank which hs not been crude oil washed. Crude oil washing cannot be conducted during the ballast voyage.

There must be an operation and equipment manual which is to the satisfaction of the Administration. The information and operational instructions which it must contain are specified.

Training for persons which will assume overall charge of crude oil wahing must be according to the Administration approoved syllabus.

16) Existing tankers engaged in specific trades: Regulation 13 includes special provisions for tankers engaged in specific trades. It is recommended that the specific trades should be further studied.

17) Protective location of ballast tanks in segregated ballast tankers: It is recommended that a more rational

probabilistic formula or criteria then that put forth in Regulation 13E, be developed.

18) Possible replacement of "deadweight" by another parameter in the 78 and 73 Protocols: In order to insure uniformity in the application of various requirements for oil tankers, study into other possible parameters is recommended.

Appendix B

AMERICAN BUREAU OF SHIPPING REGULATIONS

Summarized below are the ABS rules and regulations which effect the design, construction, and operation of oil tankers according to MARPOL '78.(12)

Longitudinal Strength, Section 6:

The required hull-girder section modulus amidships is the greater of equations (1) and (2).

(1) $SM = M_t/f_p$ where: M_t is the total bending moment
f_p is the nominal permissable bending stress, it is a function of vessel length

(2) $SM = 0.01C_1L^2B(C_B + 0.70)$ where C_1 is a function of vessel length

$M_t = M_{SW} + M_W$ where: M_{SW} is the still-water bending moment
M_W is the maximum wave-induced bending moment

Still-water bending moment and shear force calculations for the anticipated loaded and ballasted conditions must be submitted.

A standard M_{SW} may be used within 0.4L amidships;

$M_{SW} = C_{ST}L^{2.5}B(C_B + 0.5)$ where C_{ST} is a function of vessel length

The wave-induced bending moment amidships may be calculated according to; $M_W = C_2L^2BH_eK_b$ where K_b and C_2 are functions of the block coefficient and H_e is a func-

The envelope curve of M_W may be obtained by multiplying the midship value by a distruvbution factor given in Table 6.1 (12). Statistical analysis may also be used.

Permissable Shear Stress: The nominal total shear stress must be not greater than 1.065 metric tons/cm^2. For longitudinal bulkhead plating, the total shear stresses can be increased to 1.225 m. tons/cm^2 or to the critical shear buckling stress of the bulkhead plate pane between stiffeners, whichever is less.

$F_t = F_{SW} + F_w$

If a cargo is carried in alternate holds and the vessel has a double bottom, F_{SW} may be modified to account for the shearing loads transmitted through the double bottom structure to the transverse bulkhead.

Methods for calculation of shear stress are given in Section 6.3.3 of reference 12.

Bottom Structure, Section 7:

Double bottomed vessels must have inner bottoms fitted all fore and aft between the peaks. If other arrangements are desired they will be specially considered for approoval.

The depth of the double bottom is;

$d_{db} = 32B + 190\sqrt{d}$ mm   L   427m

where: L is in m   d is draft in m   B is in m

The thickness of the center girder plates must be:

$t = 0.056L + 5.5$ mm and 85% of that at amidships, at the ends. Special consideration is given if the vessel is intended to carry cargo in alternate holds.

Special Rules for Vessels Intended to Carry Oil in Bulk, Section 22: Of relevance are the requirements for cofferdams; gastight bulkheads for any area with a source of ignition present; location of cargo oil tank openings, shell plating; bulkhead plating and; webs, girders, and transverses.

The vessel must be capable of withstanding the following local loading conditions:

1) Center tank loaded	wings empty	1/3 summer Load Line
2) center tank empty	wings loaded	1/3 summer Load Line
3) center tank loaded	wings loaded	1/3 summer Load Line

For segregated ballast tankers:

4) Center tank loaded	wings empty	Summer Load Line
5) Center tank empty	wings loaded	Summer Load Line

Appendix C <u>Weight Curve Program Listing</u>:

```
00010 C FROM A USER SPECIFIED LWT CURVE AND LOADING ARRANGEMENT,
00020 C A FINAL WEIGHT CURVE IS COMPUTED.
00030 C THE FINAL WEIGHT CURVE VARIABLES ARE THE SAME AS THOSE USED BY VEIGA
00040 C TO SEND INPUT TO A DATA FILE, CHANGE KO IN LINE 140
00050       DIMENSION XW(20),WR(20),WL(20),XFF(20),WRT(20),WLFT(20),WWA(20)
00060       DIMENSION XF(40),WF(20),WA(20),GAMMA(20),PF(20),XXF(20)
00070       XW(1)=0.
00080       WR(1)=0.
00090       WL(1)=0.
00100       XF(1)=0.
00110       WF(1)=0.
00120       WA(1)=0.
00130       XF(2)=0
00140       WWA(1)=0
00150       L=1
00160       WRITE(KO,8)
00170 8     FORMAT('WHERE IS LWT CURVE INFO. COMING FROM?'/
00180      1'       IF USER INPUT; KI=5'/
00190      2'       IF DATA SET; SPECIFY KI'/
00200      3'       INPUT KI')
00210       READ(KI,*)KI
00220       IF(KI.NE.5) GOTO 45
00230       DATA KI/5/,KO/6/
00240       WRITE(KO,5)
00250 5     FORMAT('  1) ENTER DATA FOR LIGHT WT CURVE'/
00260      1'       XW = LONGITUDINAL POSITION'/
00270      2'       WR = WEIGHT COMING FROM RIGHT OF XW'/
00280      3'       WL =     "        "       LEFT    "   '/
00290      4'       TO END DATA INPUT ENTER XW=9999.')
00300 10    WRITE (KO,15)L
00310 15    FORMAT('      ENTER DATA FOR POSITION NO.',I2/
00320      1'       ENTER XW')
00330       L=L+1
00340       READ(KI,*)XW(L)
00350       IF(XW(L).EQ.9999.)GOTO 40
00360       WRITE(KO,20)
```

```
20    FORMAT('      ENTER WR')
      READ(KI,*) WR(L)
      WRITE(KO,30)
30    FORMAT('      ENTER WL')
      READ(KI,*) WL(L)
      GOTO 10
40    L=L-1
C     TANK DIMENSIONS
      WRITE(KO,60)
 60    FORMAT('WHERE ARE THE TANK DIMENSIONS COMING FROM?'/
     1'       IF USER INPUT; KI=5'/
     2'       IF DATA SET; SPECIFY KI'/
     3'        INPUT KI')
      READ(5,*)KI
      IF(KI.NE.5) GOTO 120
 45    B=1
      J=1
C THE LOAD CURVE IS DEFINED IN THE FOLLOWING WAY:
C     1) THE FORE AND AFT CROSS SECTIONAL AREAS OF EACH
C        TANK ARE SPECIFIED
C     2) THE DENSITY OF THE TANK CONTENTS IS SPECIFIED
C     3) THE PERCENT OF THE TANK WHICH IS FULL IS SPECIFIED
C     4) AREA*DENSITY*PERCENT = WEIGHT PER UNIT LENGTH
      WRITE (KO,105)
105   FORMAT('  2) ENTER INFORMATION ABOUT TANKS'/
     1'       THE VARIABLE "S" WILL DETERMINE THE FOLLOWING;'/
     2'       S=0; READY TO INPUT NEW TANK DIMENSIONS'/
     3'       S=1; TANKS SYMMETRICAL, NEW TANK SAME AS PRECEDING'/
     4'       S<0; NO MORE TANKS'/
     5//'  3) TANK CHARACTERISTICS:'/
     6'       XFWD = FORWARD POSITION OF TANK'/
     7'       XAFT = AFT       "       "    '/
     8'       WF = CROSS SECTIONAL AREA OF TANK AT XFWD'/
     9'       WA =   "                          "    XAFT')
 100    WRITE(KO,104) B
104   FORMAT(//'      ENTER S FOR TANK NO.',F2.0)
       B=B+1
```

```
      J=J+2
      READ (KI,*)S
      IF(S.LT.0.)GOTO 120
      IF(S.EQ.1.)GOTO 110
      WRITE (KO,106)
106   FORMAT('      ENTER XFWD')
C NOTE THAT IF THERE IS AN EMPTY SPACE BETWEEN TANKS A DUMMY
C TANK WILL BE CREATED OF CROSS SECT. AREA = ZERO.
      WRITE(6,115) B
      FORMAT(' ***NOTE*** TANK NO.',I2,' IS A DUMMY')
      READ(KI,*)XF(J)
      WRITE(KO,107)
107   FORMAT('      ENTER XAFT')
      READ(KI,*) XF(J+1)
      WRITE(KI,108)
108   FORMAT('      ENTER WF')
      READ(KI,*)WF(B)
      WRITE(KO,109)
109   FORMAT('      ENTER WA')
      READ(KI,*)WA(B)
      IF(XF(J).GE.XF(J-1)) GOTO 100
      XF(J+2)=XF(J)
      XF(J+3)=XF(J+1)
      XF(J)=XF(J-1)
      XF(J+1)=XF(J+2)
      WF(B+1)=WF(B)
      WA(B+1)=WA(B)
      WF(B)=0.
      WA(B)=0.
      B=B+1
      J=J+2
      GO TO 100
 110    XF(J)=XF(J-2)
      XF(J+1)=XF(J-1)
      WF(B)=WF(B-1)
      WA(B)=WA(B-1)
      GOTO100
```

```
 120    M=B-1
130    CONTINUE
C      SUBROUTINE BALLAST TANKER
       BI=M
 200    IF(B.EQ.BI)GOTO 230
        WRITE(6,201)
201    FORMAT('   4)ENTER INFORMATION ABOUT TANK CONTENTS'/
      1'       FLUID DENSITY = GAMMA(I)'/
      2'       PERCENT OF TANK FILLED (AS%) = PF(I)')
       B=2
210    DO 230 I=2,M
       I=I-1
       WRITE (KO,215)I
215    FORMAT('          ENTER GAMMA(',I2,')')
       I=I+1
       READ(KI,*) GAMMA(I)
       I=I-1
       WRITE(KO,220) I
220    FORMAT('          ENTER PF(',I2,')')
       I=I+1
       READ (KI,*)PF(I)
       WF(B)=WF(B)*0.01*PF(I)*GAMMA(I)
        WA(B)=WA(B)*0.01*PF(I)*GAMMA(I)
       B=B+1
230    CONTINUE
       N=1
       J=1
       B=1
       I=1
250    I=I+1
       N=N+2
       Z=0.0
       WA(I)=WA(B+1)
       WF(I)=WF(B+1)
 240     B=B+1
       J=J+2
       XF(N)=XF(J)
```

```
      XF(N+1)=XF(J+1)
          IF (B.EQ.M) GOTO 255
      IF (XF(N).NE.XF(J+2)) GOTO250
      IF (Z.EQ.0) GOTO 254
      WA(B)=WA(I)
      WF(B)=WF(I)
  254 WA(I)=WA(B)+WA(B+1)
      WF(I)=WF(B)+WF(B+1)
      Z=1
      GOTO 240
 255  M=I+1
      DO 280 I=2,M
      XXF(I+1)=XF((2*I))
      WWA(I)=WA(I)
      WA(I)=WWA(I-1)
 280  CONTINUE
      XXF(2)=XF(3)
      WF(I+1)=0
      WF(I)=0.
      WA(I+1)=0.
      WR(L+1)=0
C THE LWT IS ADDED TO THE LOAD CURVE
C THE FINAL WEIGHT CURVE IS COMPUTED AT EACH LWT AND TANK STATION
      I=2
      J=2
      K=1
      IF(XW(2)-XXF(2)) 330,320,310
 310  XFF(1)=XW(2)
      WLFT(1)=WL(2)
      I=I+1
      GOTO 340
 320   XFF(1)=XW(2)
      WLFT(1)=WL(2)+WF(2)
      I=I+1
      J=J+1
      GOTO340
 330  XFF(1)=XXF(2)
      WLFT(1)=WF(2)
```

```
      J=J+1
 340   K=K+1
      IF(J.EQ.0)GOTO 355
      IF (I.EQ.0)GOTO 365
      IF(XW(I)-XXF(J))370,360,350
C WEIGHT BEENG COMPUTED AT A LWT STATION
 350  XFF(K)=XW(I)
       B=J-1
      WRT(K)=(XFF(K)-XXF(B))*(WA(J)-WF(B))/(XXF(J)-XXF(B))+WF(B)
      WRT(K)=WRT(K)+WR(I)
      WLFT(K)=WRT(K)-WR(I)+WL(I)
      I=I+1
      GOTO380
 355  XFF(K)=XW(I)
      WRT(K)=WR(I)
      WLFT(K)=WL(I)
      I=I+1
C LWT STATION IS THE SAME AS THE TANK STATION
 360  XFF(K)=XW(I)
      WRT(K)=WR(I) +WA(J)
      WLFT(K)=WF((J))+WL(I)
      I=I+1
      J=J+1
      GOTO 380
 365  XFF(K)=XXF(J)
      WRT(K)=WA(J)
      WLFT(K)=WF(J)
      J=J+1
C WEIGHT BEING COMPUTED AT A TANK STATION
 370  XFF(K)=XXF(J)
      B=I-1
      WRT(K)=WA((J))+(XFF(K)-XW(B))*(WR(I)-WL(I-1))/(XW(I)-XW(I-1))
      WRT(K)=WRT(K)+WL(I-1)
      WLFT(K)=WRT(K)-WA((J))+WF((J))
      J=J+1
 380  IF(J.EQ.0)GOTO 500
      IF(J.EQ.(M+1))J=0.
 500  IF(I.EQ.0)GOTO 520
```

```
      IF(I.EQ.(L+1))GOTO 510
      GOTO 340
510    I=0.
520   IF (J.NE.0) GOTO 340
C PRINTOUT OF LWT, TANK, AND FINAL WEIGHT CURVES
      WRITE(KO,382)
382   FORMAT(////'    LIGHT WEIGHT CURVE'/
     1'      XW      WR       WL')
      DO 384 I=2,L
      WRITE(KO,383)XW(I),WR(I),WL(I)
383   FORMAT(3X,F6.1,1X,F6.1,1X,F6.1)
384   CONTINUE
      WRITE(KO,385)
385   FORMAT(//'    TANK WEIGHT CURVE'/
     1'     XXF      WA        WF')
      DO 387 I=2,M
      WRITE(KO,386) XXF(I),WA(I),WF(I)
386   FORMAT(3X,F6.1,1X,F6.1,1X,F6.1)
387   CONTINUE
      WRITE(KO,410)
410     FORMAT(///'    FINAL WEIGHT CURVE'/
     1'     XPOS   WTRT   WTLFT')
      WRT(1)=0.0
      DO 400 I=1,K,1
      WRITE(6,390) XFF(I),WRT(I),WLFT(I)
390   FORMAT(3X,F6.1,1X,F6.1,1X,F6.1)
400   CONTINUE
       STOP
      END
END OF DATA
```

SAMPLE OUTPUT: Weight curve for *Voyager* Case 2

```
WHERE IS LWT CURVE INFO. COMING FROM?
      IF USER INPUT; KI=5
      IF DATA SET; SPECIFY KI
      INPUT KI
 ?
 5
  1) ENTER DATA FOR LIGHT WT CURVE
      XW = LONGITUDINAL POSITION
      WR = WEIGHT COMING FROM RIGHT OF XW
      WL =    "       "       LEFT   "
      TO END DATA INPUT ENTER XW=9999.
      ENTER DATA FOR POSITION NO. 1
      ENTER XW
 ?
 450.
      ENTER WR
 ?
 0.
      ENTER WL
 ?
 22.1
      ENTER DATA FOR POSITION NO. 2
      ENTER XW
 ?
 249.
      ENTER WR
 ?
 23.9
      ENTER WL
 ?
 23.9
      ENTER DATA FOR POSITION NO. 3
      ENTER XW
 ?
 50.
```

```
     ENTER DATA FOR POSITION NO. 7
     ENTER XW
 ?
 9999.
WHERE ARE THE TANK DIMENSIONS COMING FROM?
     IF USER INPUT; KI=5
     IF DATA SET; SPECIFY KI
      INPUT KI
 ?
 5
  2) ENTER INFORMATION ABOUT TANKS
     THE VARIABLE "S" WILL DETERMINE THE FOLLOWING;
     S=0; READY TO INPUT NEW TANK DIMENSIONS
     S=1; TANKS SYMMETRICAL, NEW TANK SAME AS PRECEDING
     S<0; NO MORE TANKS


  3) TANK CHARACTERISTICS:
     XFWD = FORWARD POSITION OF TANK
     XAFT = AFT      "      "
     WF = CROSS SECTIONAL AREA OF TANK AT XFWD
     WA =   "                        "    XAFT


     ENTER S FOR TANK NO.1.
 ?
 0
     ENTER XFWD
 ?
 450.
     ENTER XAFT
 ?
 394.
      ENTER WF
 ?
 34.7
     ENTER WA
 ?
```

```
     ENTER S FOR TANK NO.8.
?
0
     ENTER XFWD
?
-410.
     ENTER XAFT
?
-450.
      ENTER WF
?
34.
     ENTER WA
?
21.5


     ENTER S FOR TANK NO.9.
?
-1
  4)ENTER INFORMATION ABOUT TANK CONTENTS
     FLUID DENSITY = GAMMA(I)
     PERCENT OF TANK FILLED (AS%) = PF(I)
     ENTER GAMMA( 1)
?
1
     ENTER PF( 1)
?
100
     ENTER GAMMA( 2)
?
1
     ENTER PF( 2)
?
100
     ENTER GAMMA( 3)
?
1
     ENTER PF( 3)
```

```
     ENTER GAMMA( 5)
?
1
     ENTER PF( 5)
?
100
     ENTER GAMMA( 6)
?
1
     ENTER PF( 6)
?
100
     ENTER GAMMA( 7)
?
1
     ENTER PF( 7)
?
100
     ENTER GAMMA( 8)
?
1
     ENTER PF( 8)
?
100
```

LIGHT WEIGHT CURVE

XW	WR	WL
450.0	0.0	22.1
249.0	23.9	23.9
50.0	23.9	27.1
-171.0	26.1	26.1
-280.0	17.1	31.1
-450.0	18.9	0.0

TANK WEIGHT CURVE

XXF	WA	WF
450.0	0.0	34.7
394.0	78.6	236.2
354.0	107.3	113.3
249.0	166.0	29.0
-223.5	28.8	41.6
-276.0	87.5	113.5
-319.5	59.7	13.1
-410.0	0.0	34.0
-450.0	21.5	0.0

FINAL WEIGHT CURVE

XPOS	WTRT	WTLFT
450.0	0.0	56.8
394.0	101.2	258.8
354.0	130.3	136.3
249.0	189.9	52.9
50.0	52.8	56.0
-171.0	54.9	54.9
-223.5	50.6	63.4
-276.0	104.9	130.9
-280.0	125.7	139.7
-319.5	88.0	41.4
-410.0	21.8	55.8
-450.0	40.4	0.0