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THE ISOLATION OF OIL AND OTHER FLUIDS IN TANKERS FROM SEA WATER BALLAST USING IMPERMEABLE MEMBRANES

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13. ABSTRACT

A preliminary engineering assessment has been made of a proposed method of isolating oil and other fluids from sea water ballast using impermeable membranes. The design constraint of smooth walled tanks has been assumed and feasible methods of achieving this feature have been established both for new and existing tankers. Preliminary designs for membranes in cargo-ballast tanks were established and costs of suitable rubber-nylon membranes for a 250,000 ton tanker were obtained. Future efforts will extend the analysis to 50,000 ton tankers and will include a detailed analysis into the adequacy of structural modifications, an evaluation of membrane attachment methods and model testing of operational features.

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THE ISOLATION OF OIL AND OTHER FLUIDS IN TANKERS FROM SEA WATER BALLAST USING IMPERMEABLE MEMBRANES, PHASE 1 REPORT

Report No. 72-2

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1. ABSTRACT

A preliminary engineering assessment has been made of a proposed method of isolating oil and other fluids from sea water ballast using impermeable membranes. The design constraint of smooth walled tanks has been assumed and feasible methods of achieving this feature have been established both for new and existing tankers. Preliminary designs of cargo-ballast tanks were established and costs of suitable rubber-nylon membranes for a 250,000 ton tanker were obtained. Many questions are unanswered with regard to the method of membrane attachment, the possible operational problems, action in a seaway and so forth. A proposed future program is presented.

2. INTRODUCTION

The problem of the discharge of oil and other fluids with sea water ballast has become of increasing concern. It is not proposed to discuss here the various adverse effects of oil pollution of the oceans since these are well described elsewhere. During the 10th session of the IMCO Sub-Committee on Marine Pollution several methods were discussed which would have the potential of completely eliminating intentional pollution of the sea by oil. One of these proposals is the isolation of the oil (or other fluid) in a tanker from sea water ballast by means of impermeable membranes. The preliminary engineering analysis of this proposal is the purpose of this report. This method of isolation would allow oil to be carried on one side of the membrane in the tanks of a tanker during the outward voyage from the oil loading port and to carry ballast water in the same tanks but on the other side of the membrane on the return journey. The ballast water eventually pumped out prior to reloading with cargo would obviously be uncontaminated provided the membranes remained intact during the outward and return journeys.

As an example of the possible configurations of membranes, one could imagine that the ballast water could be carried inside a bag which has the same geometry and dimensions as the tank. When the tanker is filled with cargo the bag would be collapsed at the bottom of the tank with the cargo on the outside of the bag.

However, it is felt that such a geometry is not the most practical method of providing an isolating membrane. Various membrane geometries are discussed later in this report.

It is obvious that the structural arrangement of most existing tankers would preclude the use of simple membranes for isolating purposes. The webs, stiffeners, supports, and ladders which appear in profusion in most tanks would have to be modified and, if possible, deleted to provide relatively clean tank walls required for membrane applications. In new designs of tankers many of the structural features could be placed externally for those tanks which are designed to carry both cargo and ballast. In existing tankers the removal of the internal tank structure is somewhat more difficult and probably costly.

The problem of the best material for the membrane is difficult to decide at this stage although the general requirements can be defined. The membranes would be fabricated in a suitable elastomer compatible with oil and water, and probably reinforced with nylon or other suitable fabric to prevent tearing. The steel structure of tank would take most of the loads so that strength requirement of the rubber would probably be minimal. However, the membrane is likely to be subject to abrasion by contact with tank walls during ship motions in seaways.

In this preliminary report of the study, the isolation of oil from ballast sea water and the various problems mentioned in the previous paragraphs are discussed in more detail. This initial phase of the study described here has considered only the 250,000 ton VLCC (very large crude carrier), the extension of the investigation to examine the problems of using impermeable membranes in 50,000 ton coastal tankers will be presented in later reports.

3. THE APPLICATION OF IMPERMEABLE MEMBRANES TO NEW TANKER DESIGNS

In new tankers the possibility obviously exists for providing tank designs which are compatible with the requirements of impermeable membranes. One important feature is the provision of smooth tank walls free of the usual structural stiffening members. A representative 250,000 ton VLCC will be established in order to determine whether such a design is indeed feasible and, in addition, to optimize the design for minimum increase in cost compared with current tanker designs.

3.1 STRUCTURAL DESIGN OF TANKS

The basic problem of providing smooth inside walls for tanks which are to have the membranes can only be solved by placing all the stiffening members outside the tank.

All the side bulkheads would have their stiffening members in the wing tanks. This obviously implies that the cargo-ballast tanks can only be center tanks.

For the transverse bulkheads, a possible solution is to adopt cargo-only tanks between the cargo-ballast tanks and to place the stiffening members in these cargo tanks as shown on figure 3.1. The size of these cargo tanks will depend on the available space and on the strength requirements.

In order to stiffen the tank bottom it would be necessary to provide a double bottom construction either across the whole breadth of the ship, as on figure 3.2, or beneath the center tanks. Large tankers are weight limited ships, that is ample volume is always provided by the minimum freeboard or depth requirements of the regulatory bodies. With suitable design it should therefore be possible to utilize the double bottom construction without any loss of carrying capacity. Furthermore, the double bottom provides a measure of protection in the event of grounding (ref. 3.1). Some tankers have already been built with double bottoms (ref. 3.2).

The strength members at the deck should be placed above the top of the tank. One possibility is to place these strength members above the deck. This suggestion has also been proposed by Bannerman (ref. 3.3) to reduce corrosion in tankers. A further possible solution is to provide double decks across the center tanks as shown on figure 3.3. To avoid loss of cargo carrying capacity the space between the decks would carry cargo.

The decisions with regard to the various structural alternatives would be made after a more detailed design analysis.

3.2 BALLAST REQUIREMENTS

The ballast requirements for a representative 250,000 ton tanker have been established for a VLCC having the same characteristics as a tanker described in ref. 3.1. The general characteristics of this ship are as follows:

L_{BP},	Length	1085 ft.
B,	Breadth	170 ft.
D,	Depth	84 ft.
T,	Draft	65.4 ft.
DWT,	Dead weight tons	250,500 L.T. (Cargo DWT 240,550 LT Misc. DWT 9,950 LT)

Δ,	Displacement	286,600 L.T.
SHP,	Shaft horse power	32,000 H.P.
V,	Speed	15.3 knots

The design requirement for the ballast tanks was determined using the following three guide lines:

a. The requirements of the classification societies

b. The recommendations from design manuals

c. Current practice in large tankers

The classification societies generally require a minimum forward draft for good seakeeping performance (refs. 3.5 and 3.6) About 42% of full load displacement is required to satisfy the forward draft limitations and provide complete propeller immersion for the tanker being considered.

The calculation methods of ballast requirements given in the design manuals (refs. 3.7 and 3.8) call for a forward draft somewhat larger than the classification societies together with a propeller immersion. The calculated ballast requirements by these methods corresponded to about 57.6% of the full load displacement.

The current practice in large tankers indicates between 55% and 65% of the full load displacement.

A figure of 57.6% was therefore selected.

The estimated ballast conditions are approximately as follows:

Light ship	36,500 L.T.
Misc. DWT	10,000 L.T.
Ballast in ballast tanks	38,000 L.T.
Ballast in cargo tanks	80,500 L.T.
Total ballast	165,000 L.T.

% Full load displacement	57.6%
Mean draft in ballast	39.2 ft.
Propeller tip immersion	7.5 ft.

3.3 BALLAST TANK DIMENSIONS

The maximum length of the ballast tank without a wash bulkhead is given by the classification societies (refs. 3.5 and 3.6) as 10% of the length between perpendiculars (i.e. 108 ft.). The height of the tanks is about 74 ft. assuming the double bottom height is about 10 ft. The width of the center tanks has not been firmly established but should be about 70 ft. The anticipated maximum tank size is therefore about 100 ft. by 70 ft. by 74 ft. Five center tanks would be needed to satisfy the cargo-ballast tank requirements.

The final arrangement for the disposition and size of the cargo-ballast tanks will be made from consideration of the bending moments and shear forces on the ships structure, the stability characteristics of the ship, and the possible limiting tank sizes from considerations of probable damage in the event of collision (ref. 3.9).

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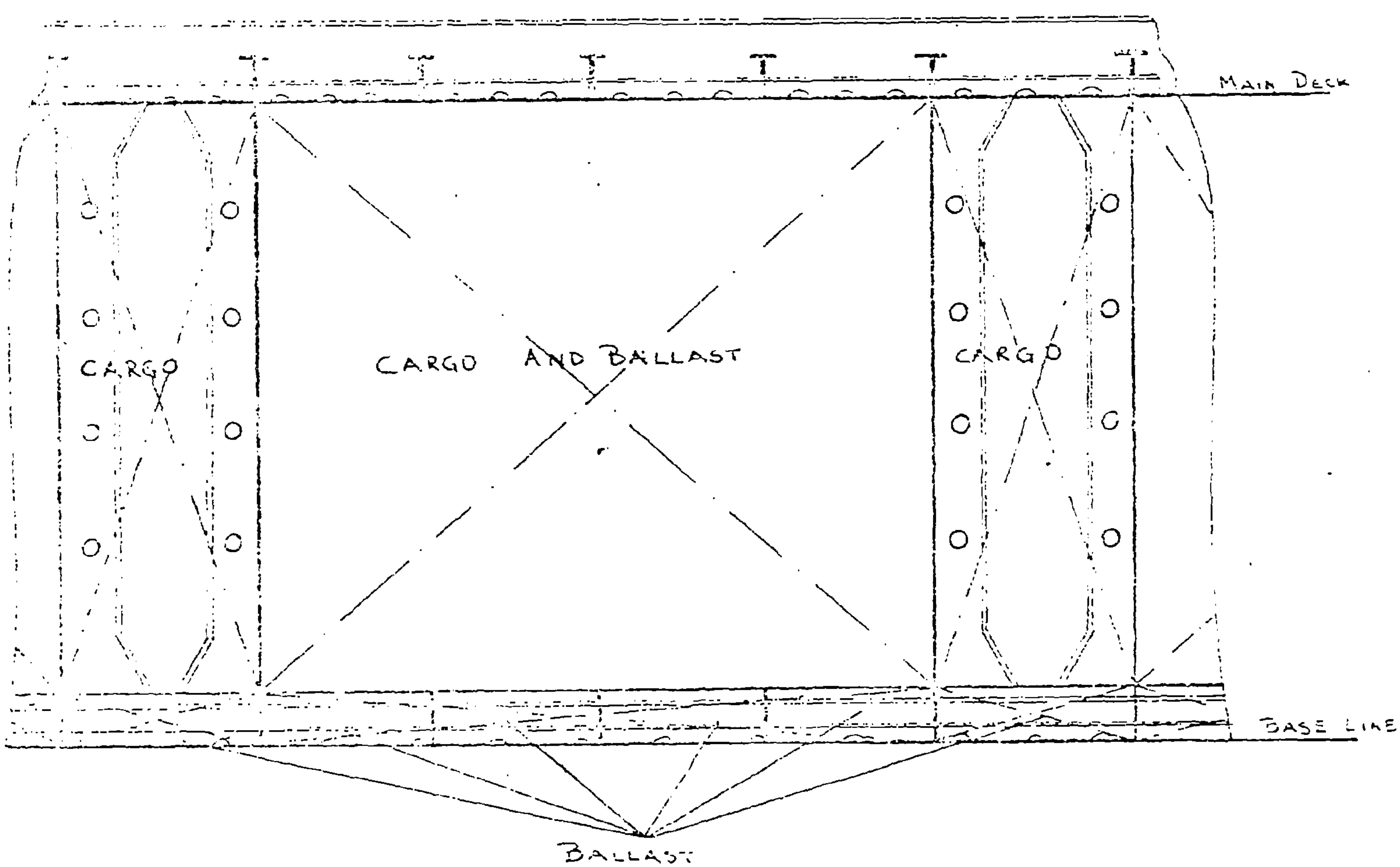


Figure 3.1 Section Along ℄ In Way of Cargo Tanks

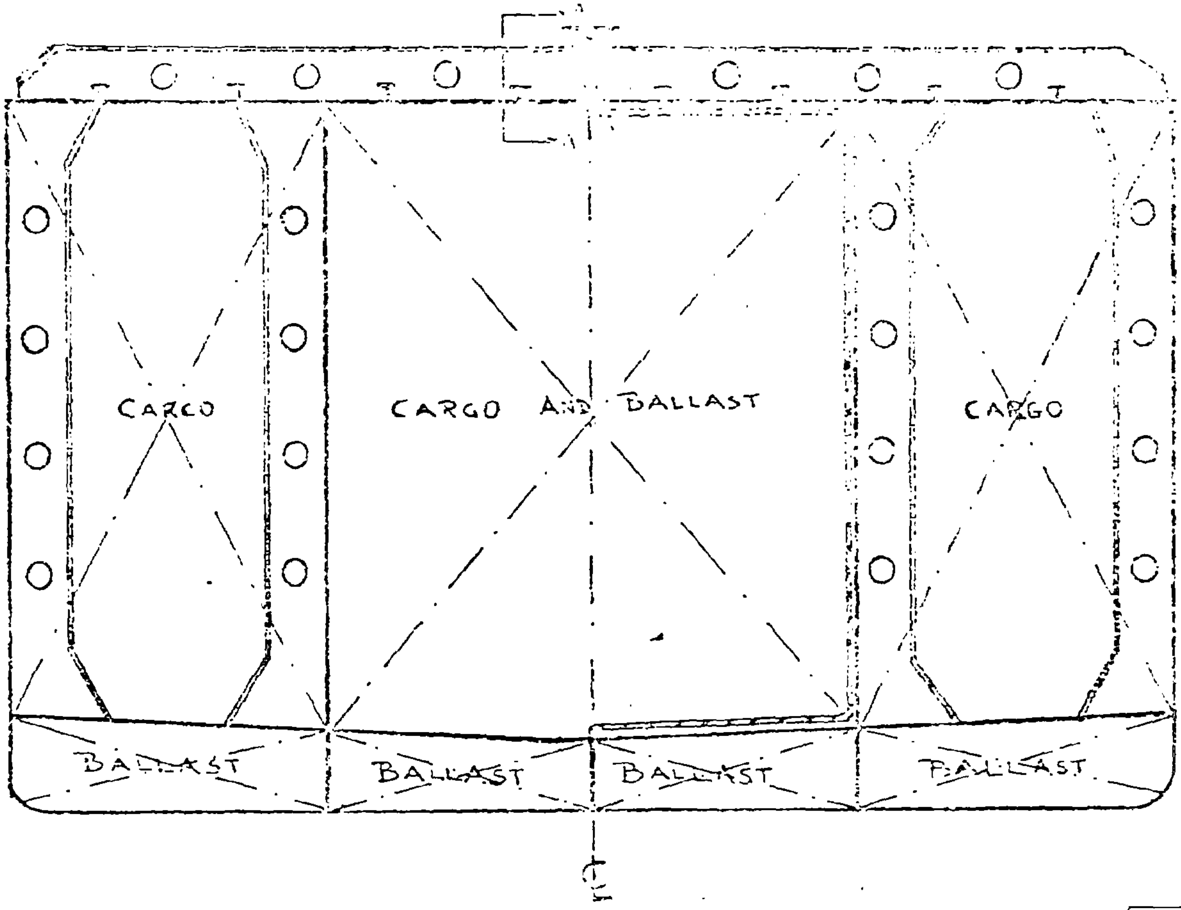
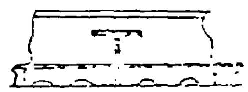


Figure 3.2 Midship Section (Sketch Without Structural Details)



Section A-A

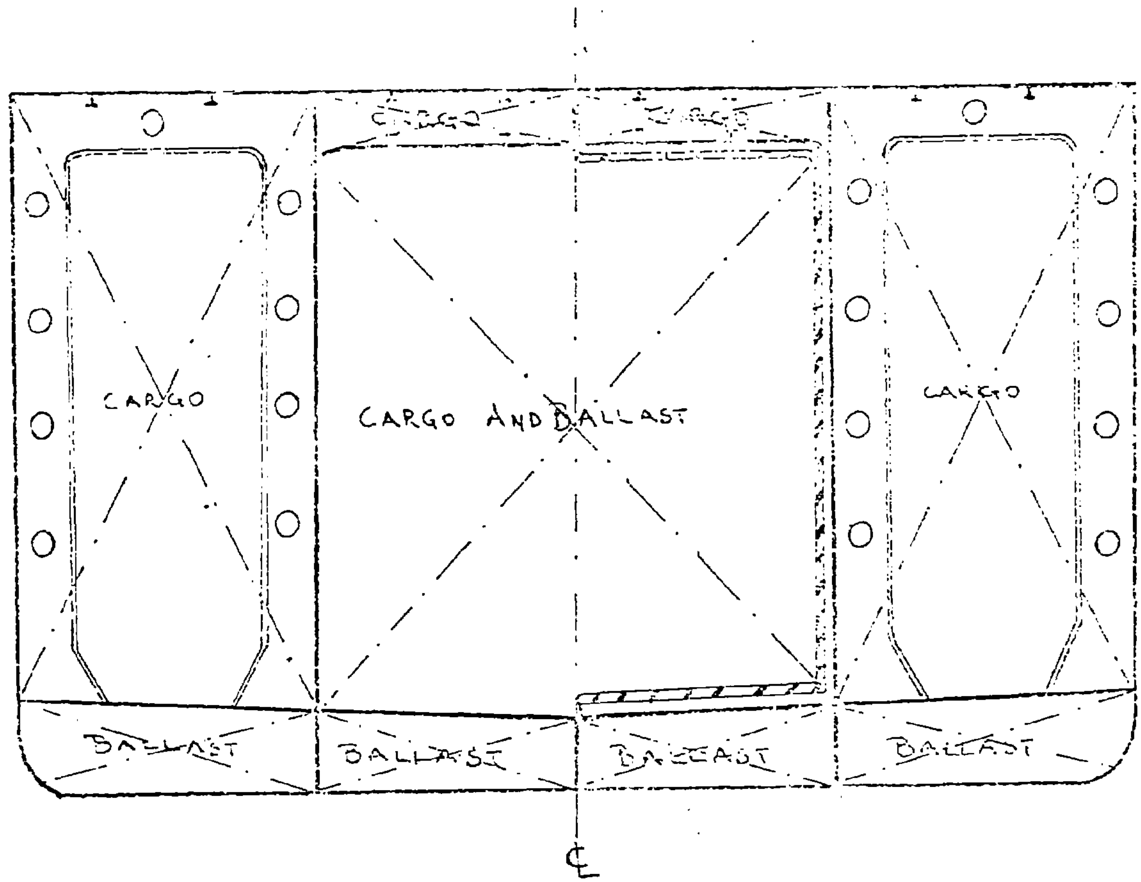


Figure 3.3 Double Deck Across C Tanks

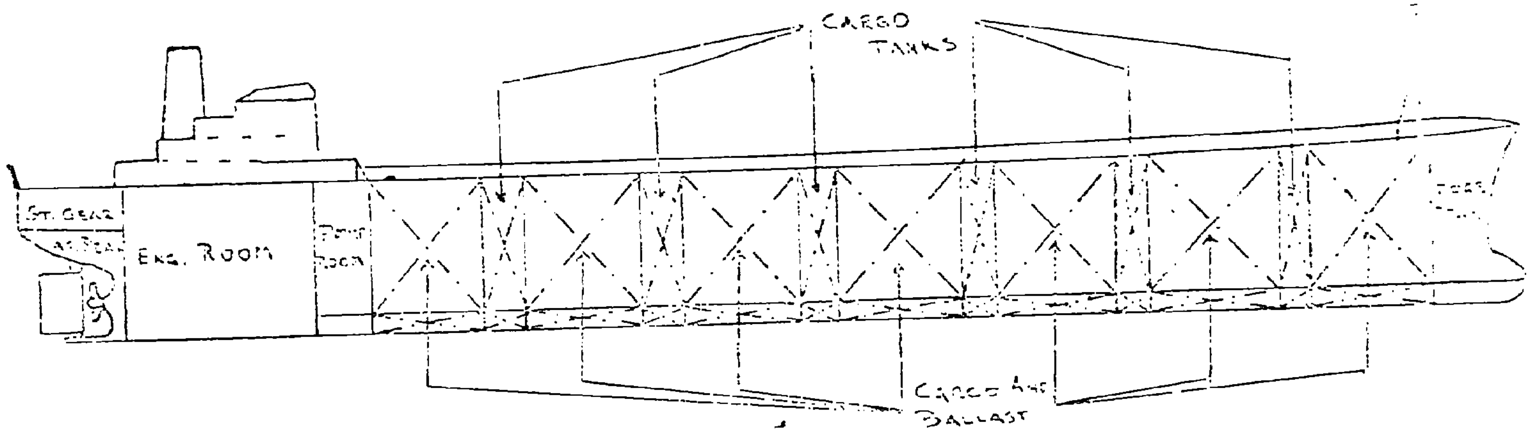


Figure 3.4 Ship's Profile

4. MEMBRANE GEOMETRIES

4.1 INTRODUCTION

Several geometrical arrangements of membranes in tanks have been proposed. Preliminary examination of these various geometries was conducted from a physical and operational point of view. Later in this program model tests will be conducted to obtain representative operational data. Only the advantages and disadvantages singular to each geometry will be discussed here to avoid repetition. For example, all geometries physically separate oil and ballast, so this would not be mentioned.

4.2 MEMBRANE GEOMETRIES

4.2.1 Geometry Number 1

The membrane is attached to the four tank walls at the horizontal center line (figure 4.1). In the loaded condition oil is on top of the membrane, and in the ballast condition water is under the membrane. It was concluded that oil discharge would not be accomplished by the normal method because the cargo suction cannot be placed at the tank bottom. Ballast water probably would be pumped into the tank under the membrane thus "pushing" the oil out of the tank. Due to the high head encountered in discharging, it was concluded that the oil from the tank would be discharged first to another tank containing no membrane and then ashore. Discharging ballast could be accomplished conventionally.

This geometry provides the added protection from pollution in the event of grounding or stranding, since the membrane would contain the oil should the tank bottom be ruptured.

A certain degree of versatility in cargo operations is lost due to the method of discharge. This method would limit the number of cargo grades that could be carried and would necessitate a more complex discharge plan to avoid contaminating a higher grade cargo in a membrane tank with a lower grade cargo in the conventional tank used to facilitate discharge. It would be necessary to pump ballast into all membrane tanks which had contained cargo regardless of ballast requirements in order to discharge every loaded tank. The result of these operations could be increased port time. Failure of the membrane during the discharge operation would contaminate the cargo with ballast water.

Venting in the ballast condition would be difficult. Possible abrasive action in the loaded condition may occur.

4.2.2 Geometry Number 2

The membrane is fabricated as a large balloon attached to the tank bottom (figure 4.2). Oil is loaded on top of the slack membrane and ballast is loaded through the discharge thus expanding the membrane.

Existing means of oil loading and discharging may be used since the positioning of the membrane opening is optional. The membrane is relatively easy to attach to the tank, and tank walls can be cleaned easily.

This geometry requires nearly twice the minimum amount of rubber membrane thus introducing an increased cost factor. The fabrication of the membrane would be complicated. Both oil and ballast suctions could become fouled by the membrane. Cleaning the tank bottom and the membrane outside, as well as inside, if needed, would be difficult. Venting in the ballast condition would probably be difficult, and abrasive action may occur in the loaded condition. The position and movement of the membrane in the loaded condition is unpredictable.

4.2.3 <u>Geometry Number 3</u>

The membrane is attached to the tank bottom and to a floating barrier (figure 4.3). Oil is loaded on top of the barrier and membrane. In the ballast condition water is pumped through the ballast discharge under the barrier causing it to rise to the top of the tank, unfolding the membrane walls as it floats up.

This geometry facilitates cleaning tank walls, and the membrane is relatively easily attached to the tank. This geometry also reduces the risk of pollution due to grounding or stranding.

This geometry requires more area of membrane than geometries 1, 5, and 6 if the length of the tank is greater than the depth of the tank. The membrane density should be greater than water to prevent fouling while the barrier rises and falls. The membrane would undergo excessive folding which could limit its life. The barrier should be strong, since it acts as a partial tank bottom, yet it must float. The barrier in the ballasted condition can slam into the sides of the tank in a seaway. The barrier may not rise and fall as desired and could completely block the oil discharge. Installing this device in the tank and venting in the ballast condition would be difficult. Cleaning the tank bottom and the membrane would also be difficult, and the oil suction is restricted in positioning.

4.2.4 Geometry Number 4

A container with perforated sides to allow free communication of the oil is fixed in the tank from the tank top to the tank bottom. A flexible membrane is fitted inside this container (figure 4.4). In the loaded condition the oil is on top of the membrane which is collapsed at the bottom of the container. The membrane in this position has been neatly folded by the extra apparatus which includes the metal guide rings and rubber band like contracting rings. After discharging the oil, ballast is pumped into the membrane which rises to the desired level or until all folds are out of it. The membrane bottom is sealed to the sides of the container; the membrane top is sealed to a metal disc along its edges or by extending the membrane to cover the disc.

This geometry provides uniform folding of the membrane. The oil suction can not be fouled, and there would be relatively small structural changes in existing tankers. The added protection from pollution due to grounding or stranding would exist if the rupture occurs inside the area of the tank bottom covered by the container.

The extra apparatus necessary for uniform folding is rather complicated thereby introducing more possible parts to fail, such as the contracting rings. The membrane may bulge out of the side perforations and increase abrasive action. The overall size of the membrane system would probably be as close to the size of the tank as possible. Thus the membrane could possibly become wedged or frozen in the container. The rubber membrane may be difficult to manufacture, and abrasion would be great against the sides of the container.

Installation of this unit would tend to be difficult. Accurate means of telling when the membrane is full would need to be employed to avoid any problems due to over-pressurizing the ballast.

4.2.5 Geometry Number 5

The membrane is attached to the center line of the top and bottom of the tank and to the forward and after tank walls at their vertical center line (figure 4.5). In the loaded condition, oil is to port of the membrane as viewed from aft the tank. In a ballast condition, ballast is to starboard of the membrane.

This geometry provides some protection in the event of a collision, but only if the membrane is between the point of impact and the oil in the tank. It provides some flexibility in positioning of the suctions for oil and ballast, and venting is no problem. However, the membrane may interfere with the suctions.

Installation of the membrane may be difficult. The necessary ullage when loaded may cause abrasion between the membrane and the tank top as the vessel moves in a seaway.

4.2.6 Geometry Number 6

An analysis of this particular variation shows that due to the unsymmetrical shape the membrane would not function satisfactorily in both the loaded and ballasted conditions. This is due to the three dimensional configuration of the membrane, and indicates that no unsymmetrical variation can work except in the restrictive case of a cubical tank.

4.3 CONCLUSIONS

It has been shown that several possible geometries exist and should be analyzed. Each geometry has its advantages and disadvantages which must be weighed as to feasibility and economy. Other possible geometric configurations will continue to be sought. None of the presented geometries will be rejected from analysis although more emphasis may be placed on a more advantageous geometry. Currently geometry 5 is favored.

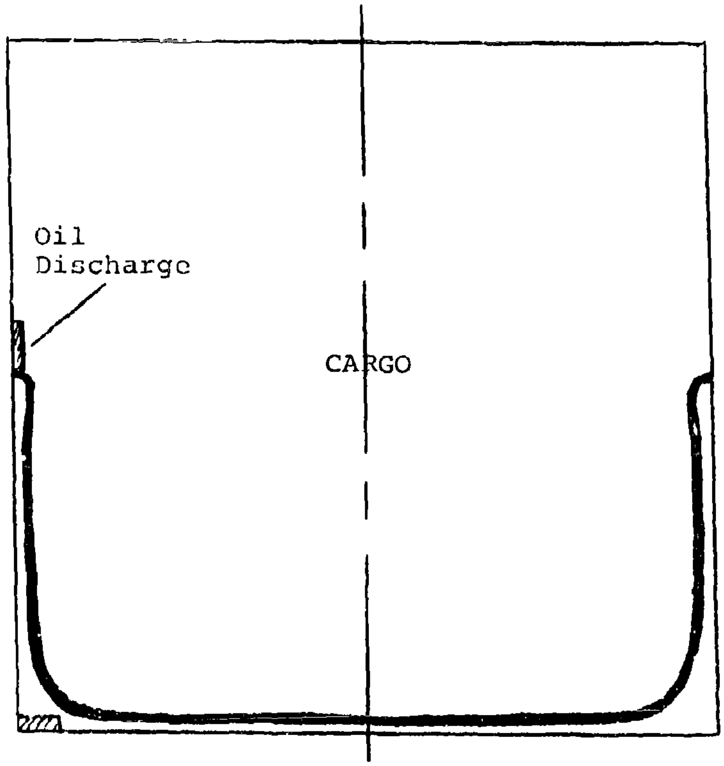
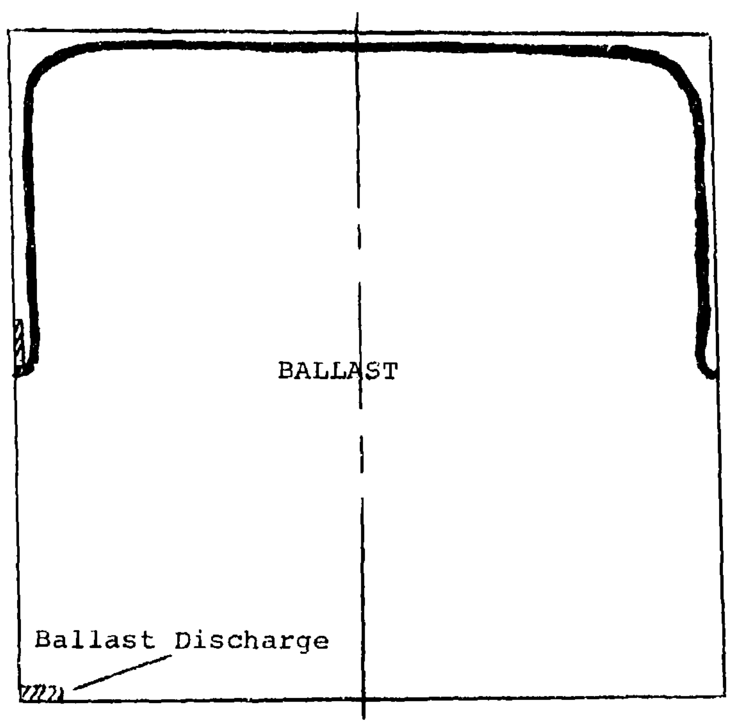


Figure 4.1 Membrane Geometry 1



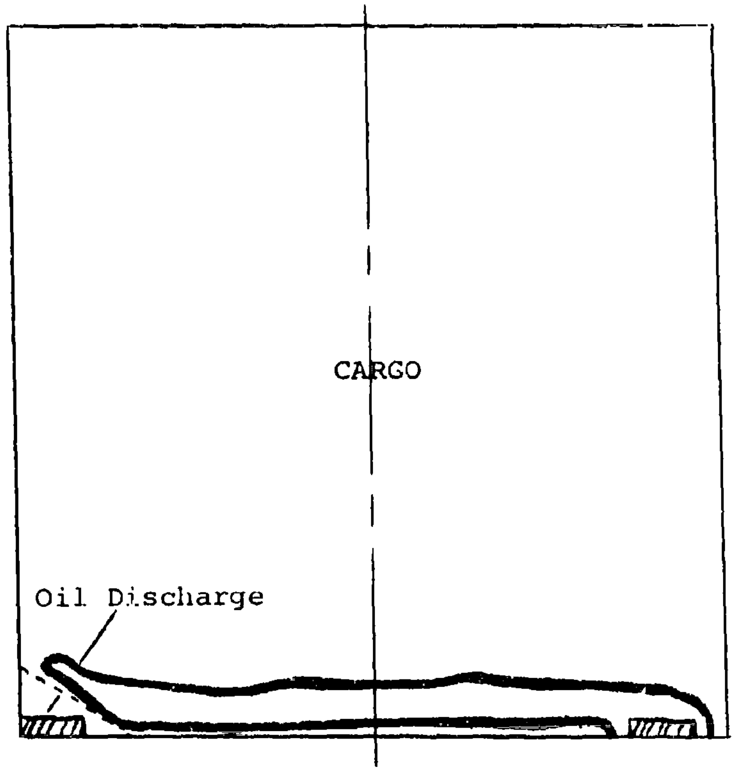
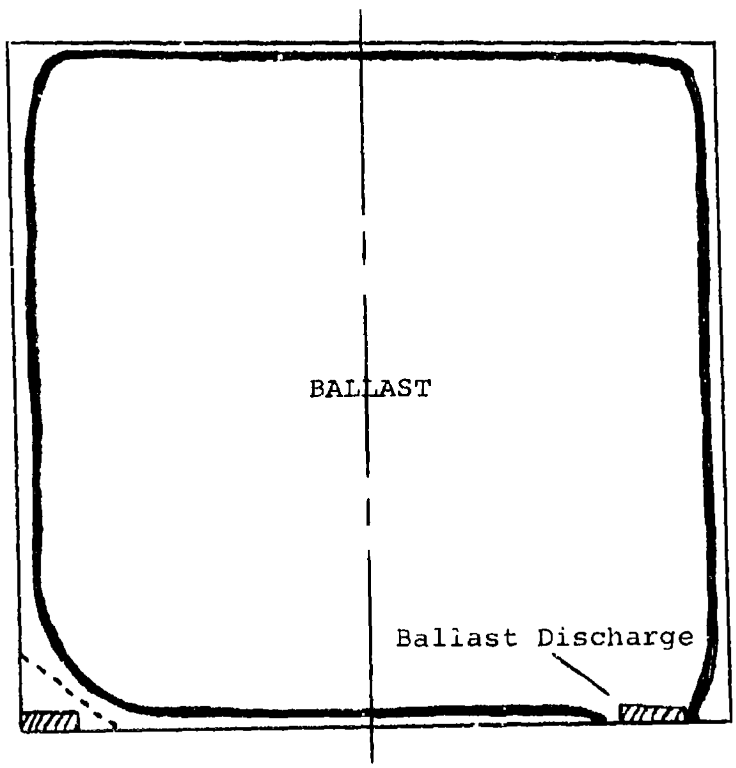


Figure 4.2 Membrane Geometry 2



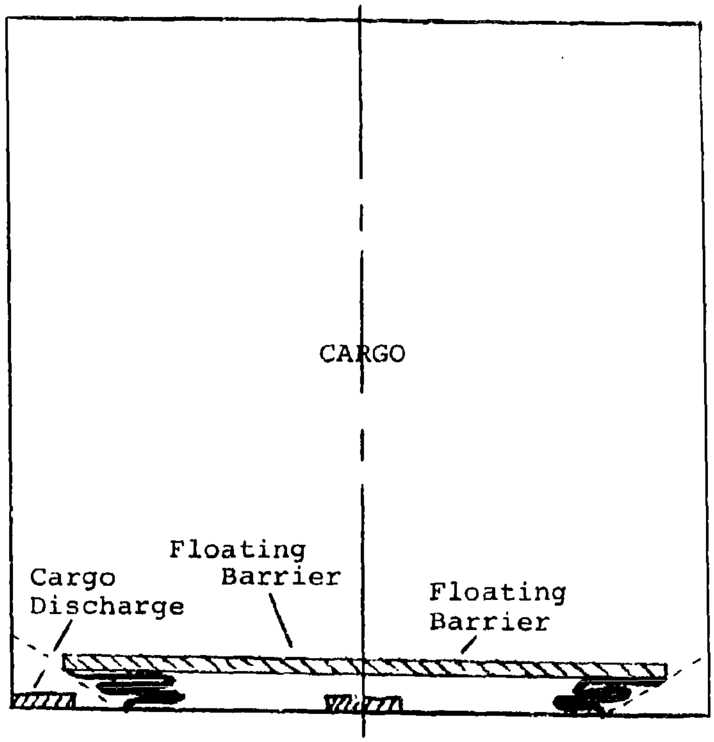
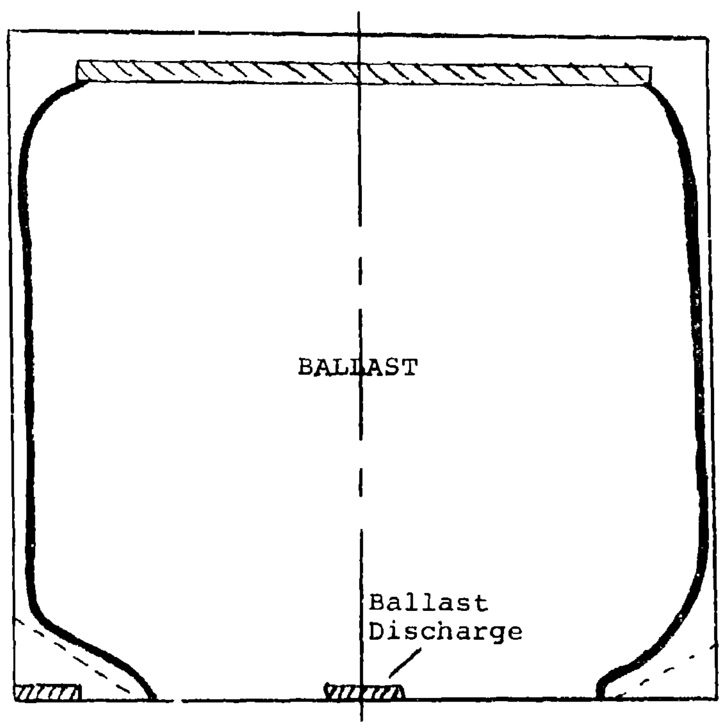


Figure 4.3 Membrane Geometry 3



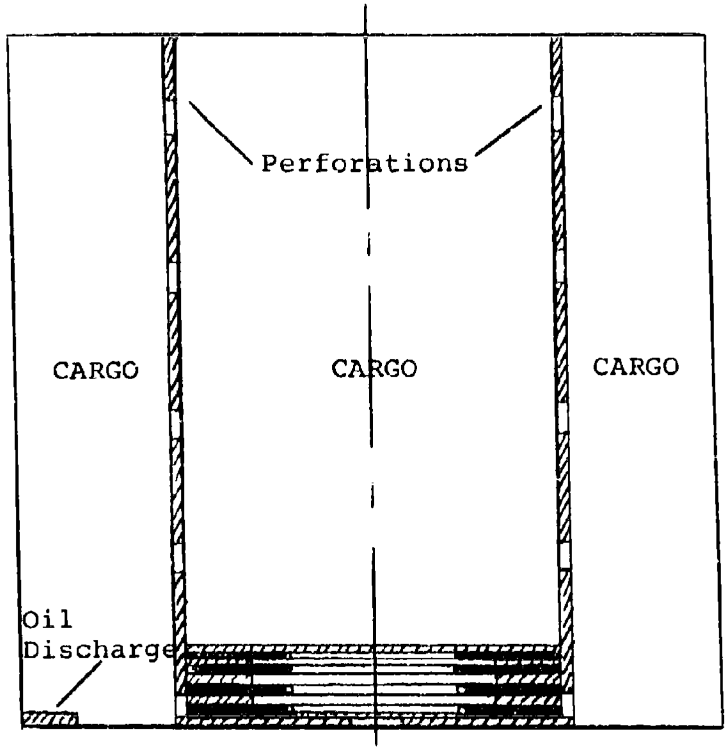
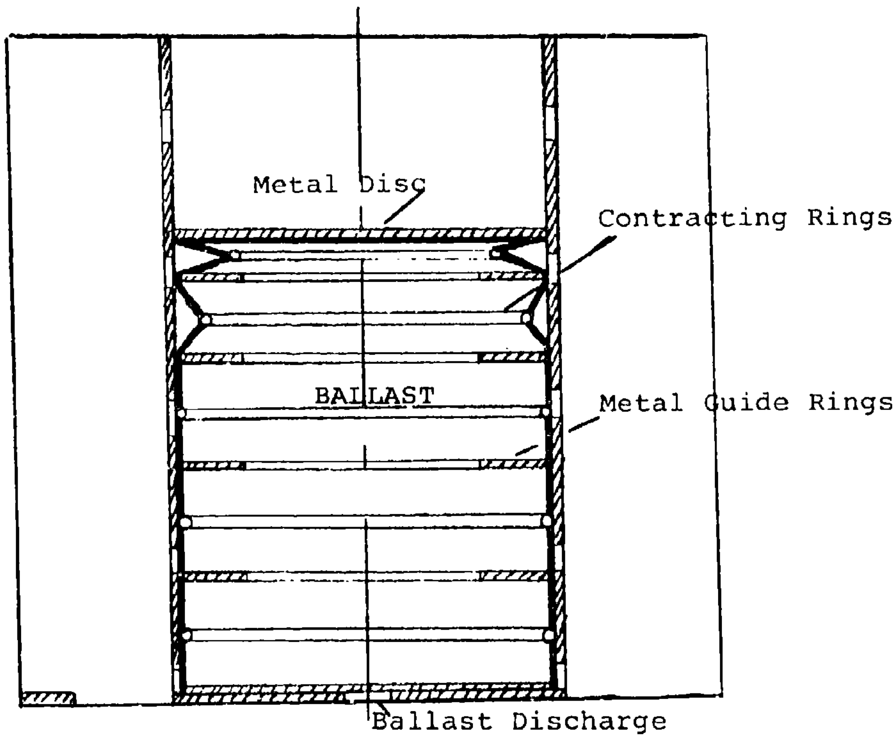


Figure 4.4 Membrane Geometry 4



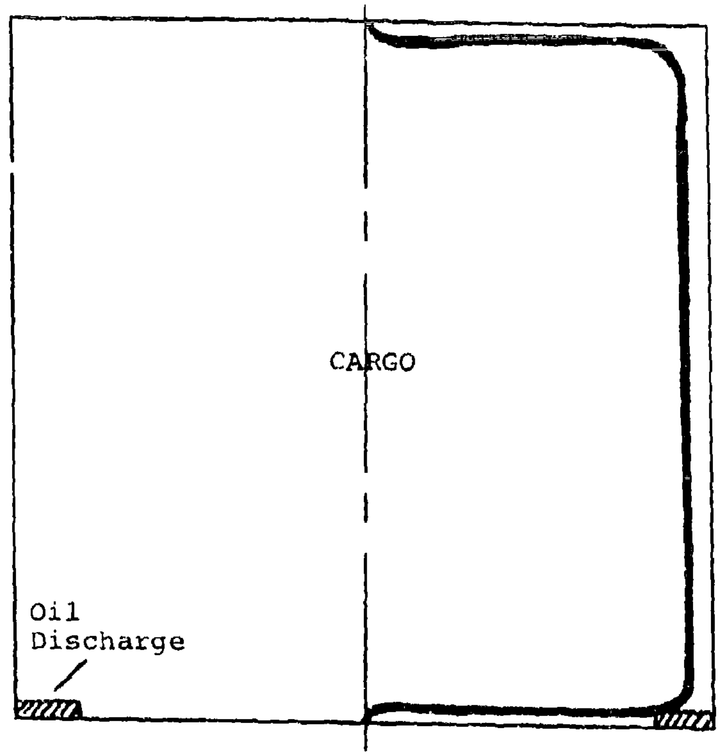
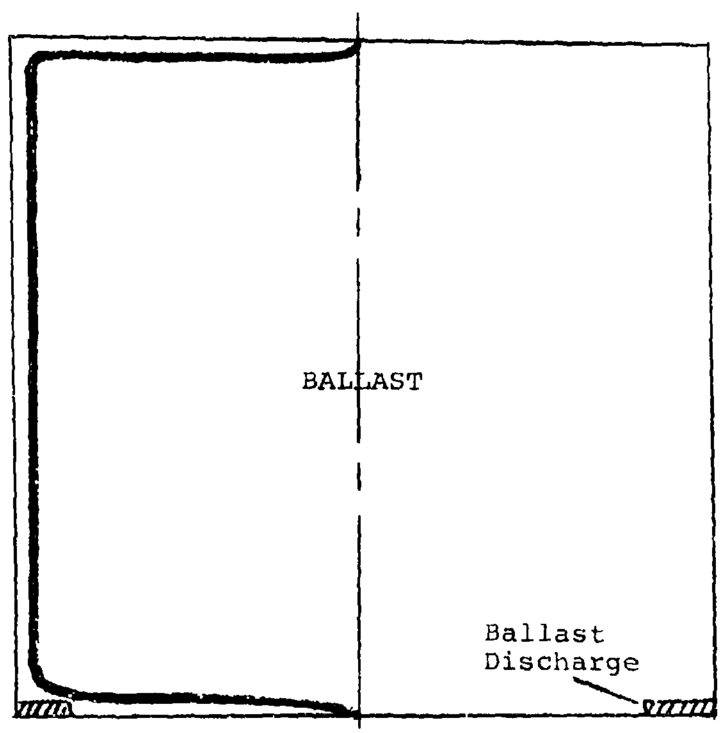


Figure 4.5 Membrane Geometry 5



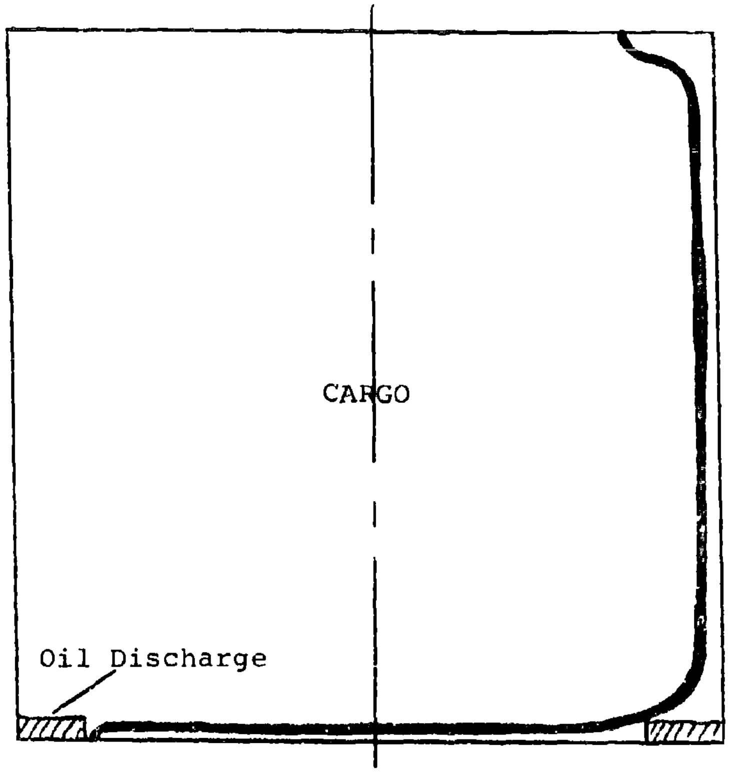
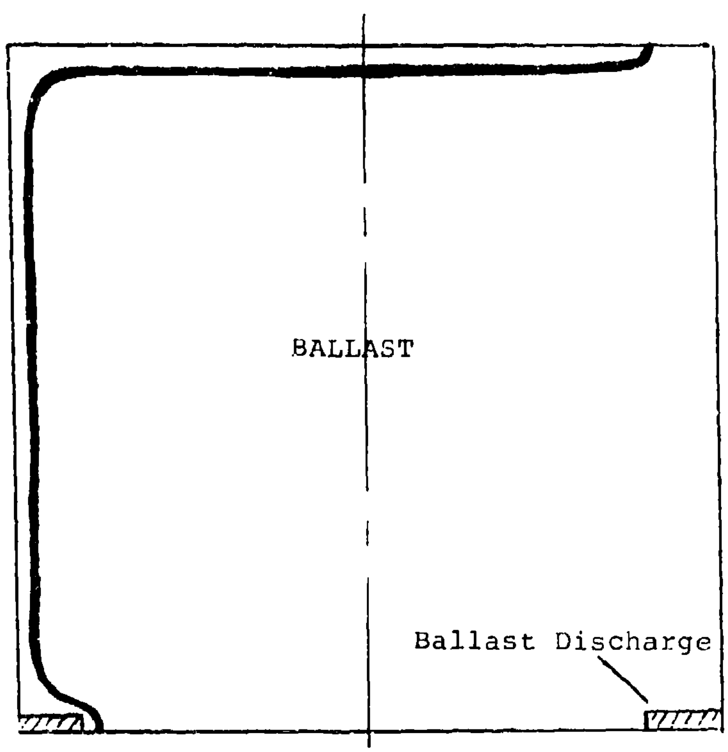


Figure 4.6 Membrane Geometry 6



5. THE MODIFICATION OF EXISTING TANKERS

5.1 INTRODUCTION

Existing tankers exhibit a variety of structural designs with structural complexity of the cargo spaces being a common factor. Introducing an elastomer membrane into this environment will require modification to the structural layout of the tanks since smooth inner surfaces are desirable for satisfactory membrane performance. A preliminary study has been carried out on a representative 250,000 ton VLCC to determine the extent of such modifications and to define the main problems than can be anticipated with membrane tanks. Proposed solutions to these design problems are presented which will be investigated in more detail later in this study.

5.2 GENERAL ARRANGEMENT OF CARGO AND BALLAST TANKS

The classification societies require the length of a tank not to exceed 0.2L and if the length exceeds 0.1L, a transverse wash bulkhead is to be fitted at about mid-length of the tank (ref. 5.1). An example of the arrangement of the cargo space for a VLCC is given on figure 5.1. The ship has six transverse O.T. (oil tight) bulkheads with wash bulkheads at mid-length of tanks 1, 2, 4, and 5. Two continuous longitudinal bulkheads divide the cargo space into wing and center tanks. Since the VLCC has excess volume, no. 3 port and starboard wing tanks and the fore-peak tank are used for water ballast only.

The amount of ballast carried on a ballast trip varies. The minimum amount is determined by requirements for minimum draught forward to avoid slamming, and a sufficient immersion of the propeller.

Figure 5.2 shows an example of ballast distributions at departure (ref. 5.2) for the VLCC. The two ballast conditions shown are based upon normal operating practice, resulting in a displacement of about 45% and 65% of that in full load condition. The distribution of ballast is determined by bending moments and shear forces along the hull girder and also by company policy with regard to tank cleaning. The clean water ballast tanks are always employed when the tanker is in the ballast condition.

5.3 STRUCTURAL FEATURES OF CARGO TANKS

For the purposes of this discussion, only the structural members restricting the operation of the membranes have been considered. Furthermore, it has been assumed that membranes would only be utilized in the center tanks. The reason, of course, is the complexity of the structure in the wing tanks.

5.3.1 Longitudinal Members

The VLCC is longitudinally framed as indicated in figure 5.4. The continuous longitudinal strength members, a deep center keel, a deep centerline deck girder, and longitudinal bulkheads are shown.

The depth of the keel and deck girder is determined from requirements by the classification societies (ref. 5.1). If deep girders are fitted only on the centerline, the depth of these is considerable, as shown on figure 5.3.

The longitudinal bulkheads are stiffened from the wing tank side, giving a reasonably clean wall on the center tank side.

5.3.2 Transverse Members

The ships cargo space is, in the example, divided into five compartments by transverse O.T. bulkheads. In addition, wash bulkheads are fitted at mid-length of tanks 1, 2, 4, and 5. For our purpose there is little structural difference between O.T. and wash bulkheads. The bulkheads are stiffened on one side only, leaving the other side reasonably clean.

Transverse frames are fitted throughout the length of the ship with deep web frames on an even spacing as shown on figures 5.3 and 5.5.

5.3.3 Other Structural Obstacles

Beam knees, brackets, struts, and other stiffening and supporting members are extensively used. Of major concern are the brackets on the transverse web frames to the longitudinal bulkheads as shown on figures 5.3 and 5.4. In the longitudinal direction, large brackets are welded to the center girders, to the bulkheads and to the bulkhead webs as indicated on figure 5.5.

Access ladders for cleaning, inspection, maintenance, etc., reach-rods for valve operation, anodes for corrosion protection and piping, all with supporting structure, represent problems when introducing the membranes.

5.4 STRUCTURAL MODIFICATION

The tank space into which the membrane is to be fitted, should be "cleaned up" to give smooth surfaces with no internal structure to obstruct the operation of the membrane.

5.4.1 Removal of Structural Members

The large brackets on transverse web frames and longitudinal center girders should preferably be removed. Since these represent important local strength and their removal will create "hard" stress concentrations, a study will be carried out on the feasability of structural compensation for the removal of these brackets.

Fixed access ladders should be replaced by a portable access device. Reach-rods within the membrane area should be removed. Pipes or any other structure within the membrane area should be moved elsewhere.

5.4.2 Inner Skin

Having removed the structural members as discussed above, the deep center keel, the deck center girder and the web frames now form a boundary for the available membrane space.

For proper operation of the membrane tank, a horizontal, flat bottom surface is desirable. This could be achieved by constructing an inner bottom level with the center keel as shown on figure 5.4. This inner bottom skin should be supported by longitudinals and transverses as indicated.

The longitudinal bulkheads may be "cleaned up" and no plating should be required.

Under deck plating could be constructed using the web frames for transverse support as shown on figure 5.4. Only minor longitudinal stiffening would be required.

In one end of the tank plating could be constructed to envelop the bulkhead stiffeners, making use of the webs for support as under deck (see figure 5.3 and 5.5). At the other end of the tank the bulkhead could be "cleaned up" and no skin should be required. In case of a wash bulkhead, perforated by large holes, experiments should be carried out to analyse the effect of such holes on the membrane. From operational considerations the wash bulkheads may have to be made O.T.

5.4.3 Features of Operation

The no. 3 wing tanks and fore peak would still be used for clean water ballast after modification. The number of center tanks would be almost double, since the wash bulkheads in effect act as O.T. bulkheads. The number of center tanks to be provided with membranes should be carefully evaluated and brought to a minimum.

As indicated on figure 5.4 the spaces originating between the deck and the inner skin, and in the double bottom could be used for cargo, either as separate tanks, or as part of the wing tanks, depending upon possible perforations of the longitudinal bulkheads and operational considerations. Likewise the inner skin will create a space on one side of the transverse bulkhead, which could be used for carrying cargo as shown on figure 5.5.

5.5 REFERENCES

5.1 Rules for the Construction and Classification of Steel Ships, Det Norske Veritas, 1971.

5.2 Brayard, J., Guide pour la Conduite des Projets de Navires Petroliers, Ecole Nationale Superieure de Techniques Avancees, 1970.

5.3 Det Norske Veritas, Annual Report, 1969.

5.4 209000 DTW Tubrine tanker "Texaco Hamburg",
Schiff und Hafen, p. 957, November, 1969.

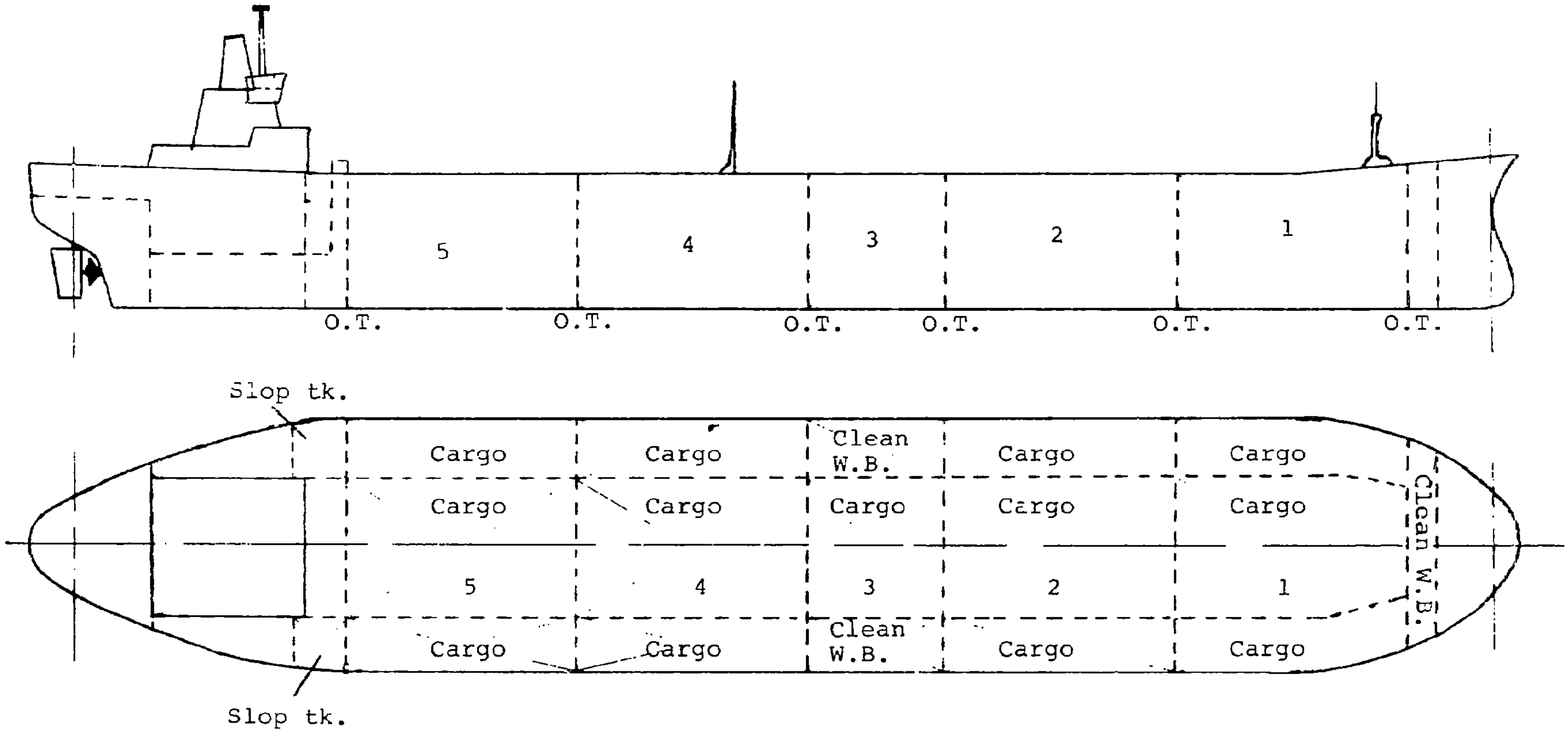
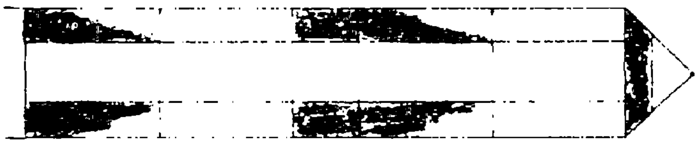


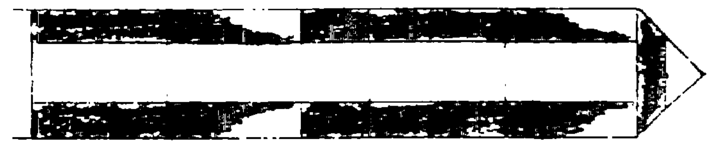
Figure 5.1 Tank Arrangement for VLCC

45%

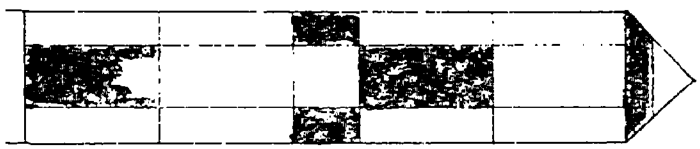
65%



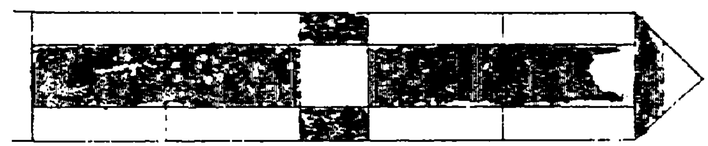
a. Ballast in wing tanks.
Wing tanks no. 2 and 5 p. and stb.
partially filled.



c. Ballast in wing tanks.
Wing tanks no. 1 and 4
p. and stb. partially filled.



b. Ballast predominently in
center tanks. Center tank
no. 5 partially filled.



d. Ballast predominently in
center tanks. Center tank
no. 1 partially filled.

Figure 5.2 Distribution of Ballast at Departure
45% and 65% of Full Load Displacement

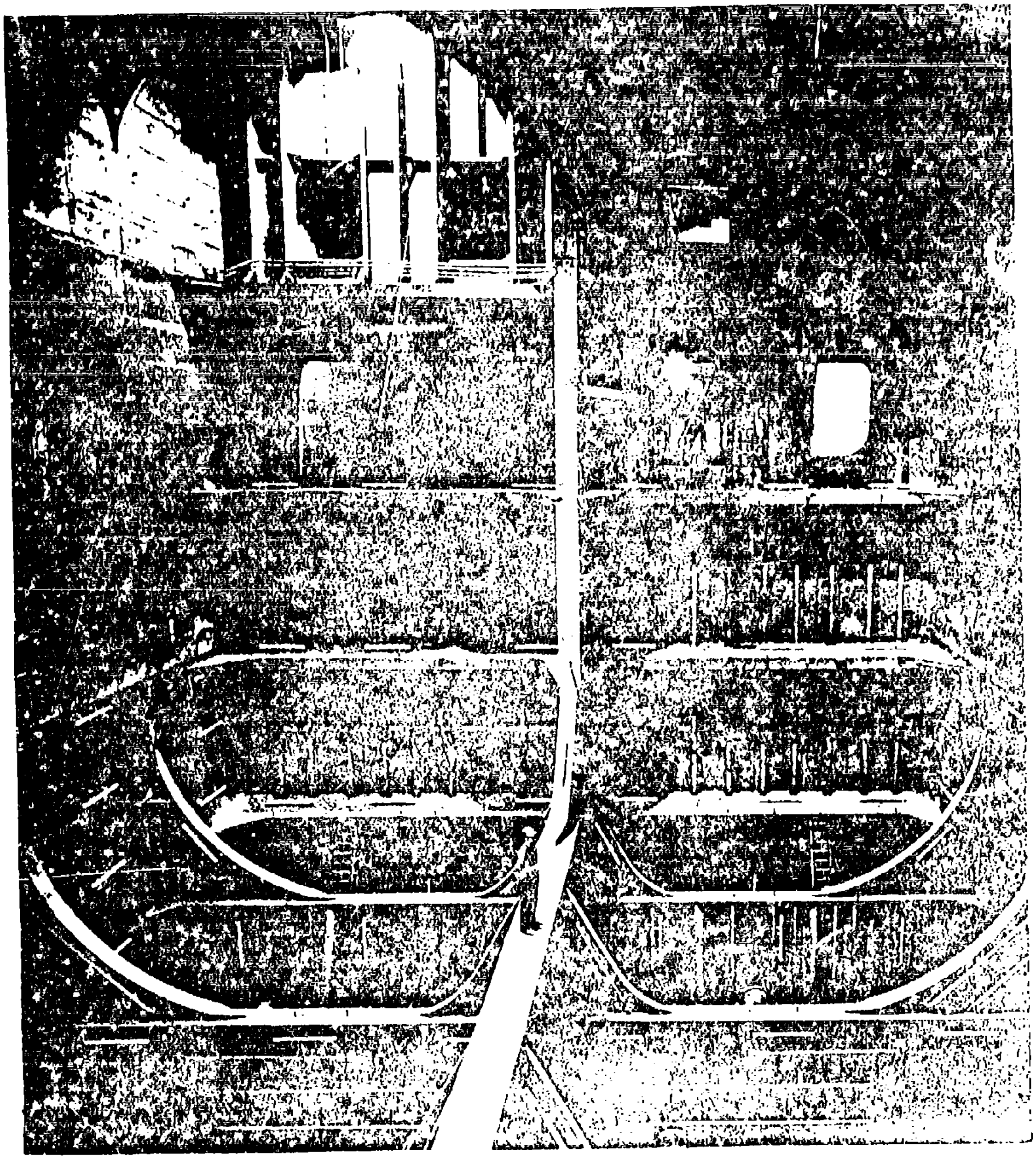


Figure 5.3 Structural Interior of a VLCC Center Tank (ref. 5.3)

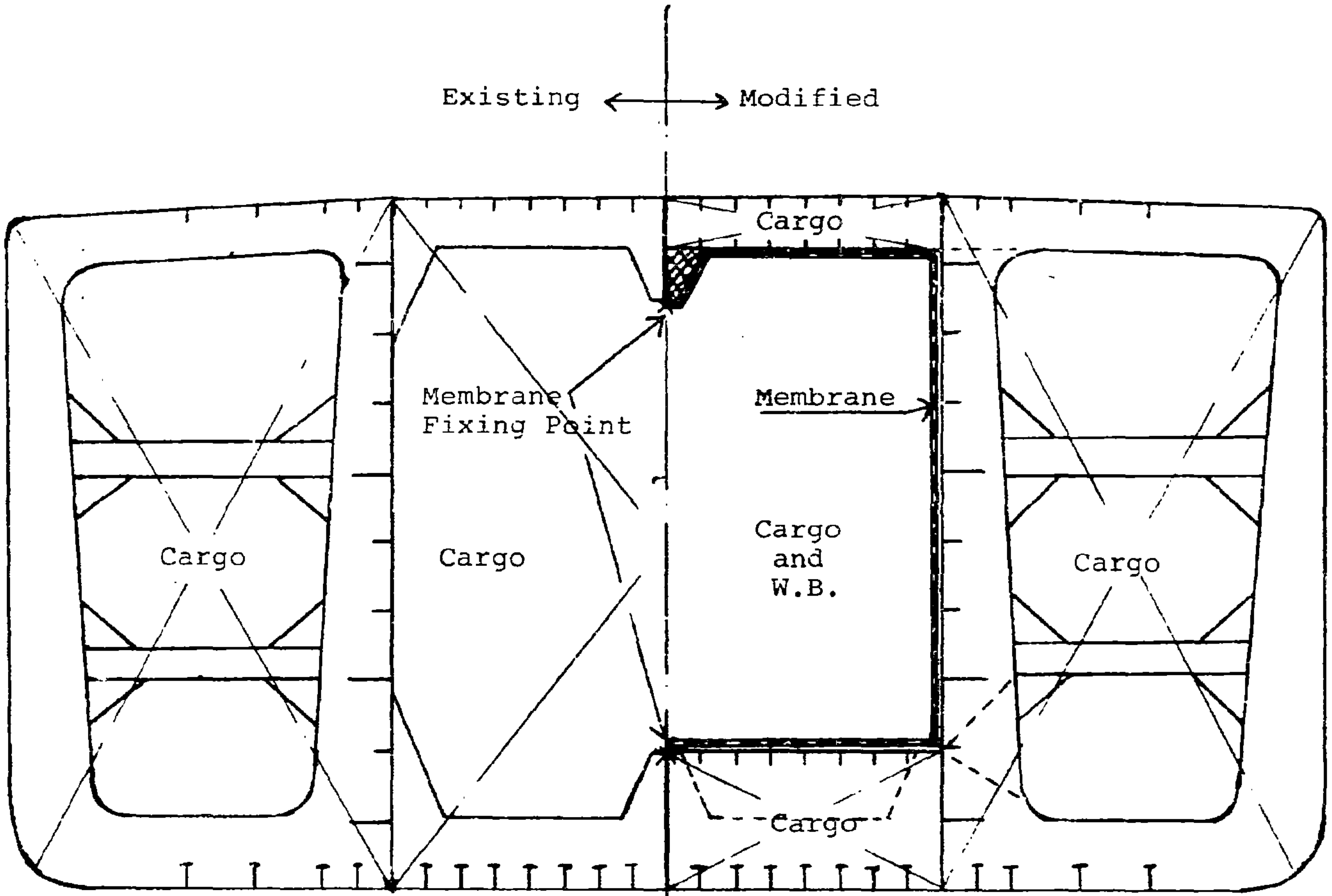


Figure 5.4 Transverse Web Frame of VLCC Existing and Modified

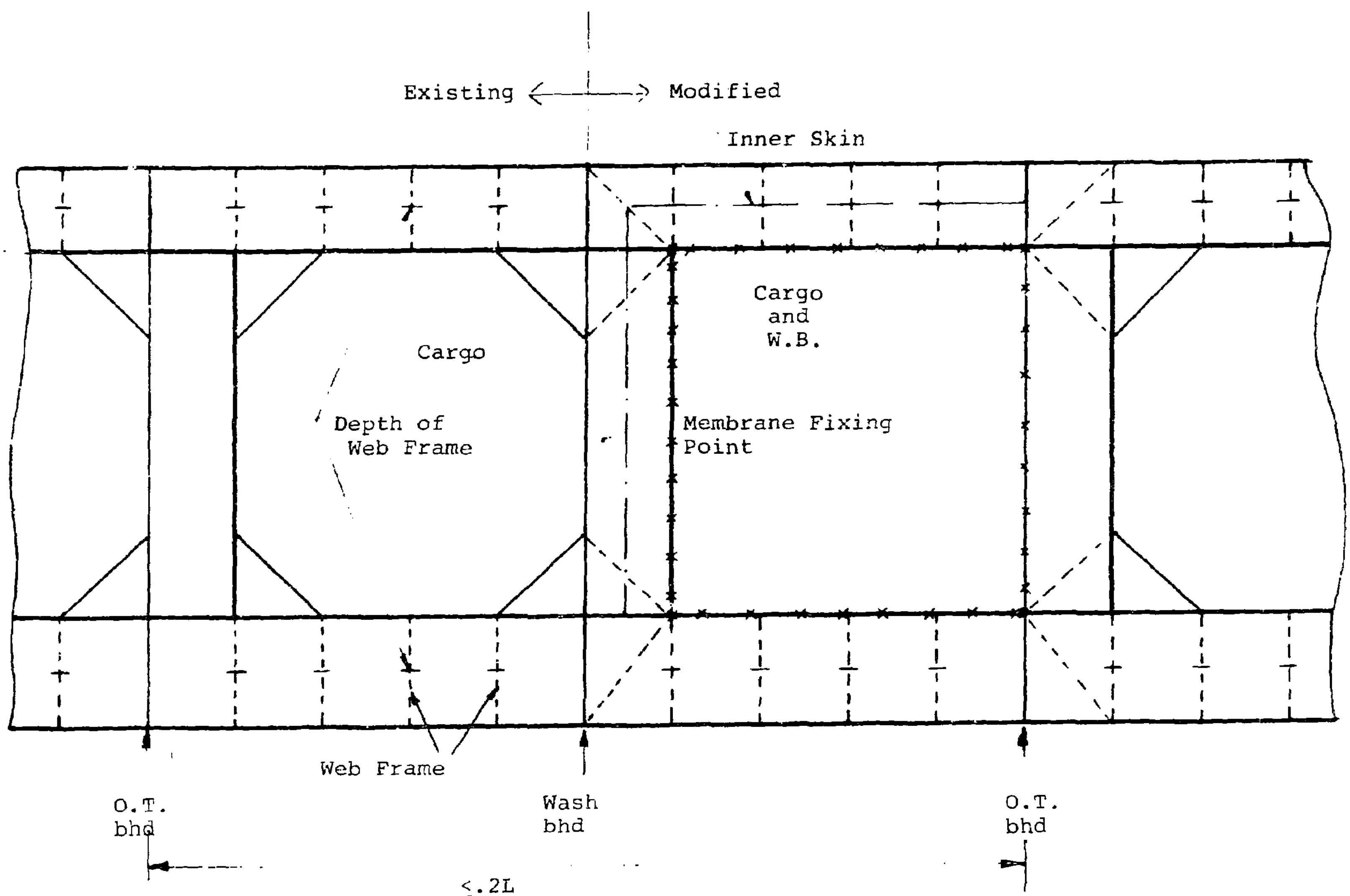


Figure 5.5 Longitudinal Section in Way of Centre Girders. Existing and Modified.

6. ELASTOMER TECHNOLOGY

6.1 INTRODUCTION

The best elastomer for this application has not yet been defined. The purpose of this section is to discuss the important physical properties of elastomers that might be used as membranes in tanks.

6.2 PHYSICAL CHARACTERISTICS OF ELASTOMER MEMBRANES

6.2.1. Oil Resistance and Abrasion

It is well known that natural rubber is degraded by petroleum based oils, however, there are artifical rubbers which operate successfully in contact with such oils. The flexible containers used by the military for the storage of gasoline and diesel fuels are often constructed with a NITRILE type of rubber on the inside and an abrasion resistant rubber such as NEOPRENE on the outside. In such applications the rubber layers have NYLON fabric reinforcement to provide the needed strength and to prevent tearing.

New elastomers are being developed which have some properties intermediate between rubbers and plastics. They tend to be somewhat stiffer (higher modulus) than rubbers and have better abrasion resistance. Examples of such materials are HYPALON and VITON, which are also resistant to degradation by oils.

In addition to compatibility with oil on the cargo side of the membrane and compatibility with sea water on the ballast water side, the membrane must withstand the abrasion anticipated from the relative motion of the membrane and the tank walls. Furthermore, the membrane must be able to tolerate the repeated flexure associated with turning the tank insideout with changes from cargo to ballasting for the currently favored membrane geometry (geometry 5). Other geometries will have similar flexural excursions.

In order to reduce wear through abrasion it is necessary to select a suitably tough elastomer and to compound the material in such a way as to create a relatively hard final product. As the hardness is increased the coefficient of friction is reduced thereby creating a material more resistant to abrasion. Increasing the hardness also tends to increase the stiffness of elastomers. This property may be advantageous if the membrane is thereby prevented from blocking the suction inlet. Unfortunately, increased stiffness will also lower the fatigue properties of the elastomer (i.e. it will take a smaller number of folding or bending operations to create cracks in the membrane). This may not be significant since only a small number of large amplitude reversals is expected; perhaps 20 per year of operation.

6.2.2 Temperature Effects and Other Factors

The membrane is expected to operate satisfactorily over a wide range of temperatures. The most critical conditions would probably occur when one or more tanks are empty. The range of temperatures that could be met in this situation range from about $0^{\circ}F$ ($-18^{\circ}C$) to perhaps $160^{\circ}F$ ($71^{\circ}C$). Cargo heating is not likely to provide a higher temperature than this value.

Flexible fuel containers already developed and in use in many climatic regions have the same range of operating temperatures. It is therefore not anticipated that temperature effects will be a problem.

It is the normal procedure in current tanker designs to provide sacrifical anodes in the tanks to reduce corrosion. The presence of ions from this corrosion protection is not expected to degrade the elastomer, but this should be demonstrated.

6.3 METHODS OF MEMBRANE ATTACHMENT

The membrane must provide complete isolation of the oil from the sea water ballast; there should be a perfect seal. The attachment of the membrane to the tank walls is therefore one of the important design features of the concept.

The attachment should also be designed to minimize the stresses in the membrane and must obviously be inexpensive. A problem area is the attachment at the corners of the tanks.

Two potential solutions of the attachment problem have been developed during this initial phase of the program (see figures 6.1 and 6.2). In both designs it is visualized that the membrane would be wrapped around a cord or rope and bolted to the tank with steel clamps. The clamps would probably be manufactured in segments which would be butted against each other to provide a continuous seal. At the corners special provisions would be required to insure that there are no gaps and leakage paths at the apex.

The first proposed design, shown on figure 6.1, has two parts to the metal clamp. One part is welded to the tank while the second part is bolted to the first. The membrane is gripped between the two parts of the metal clamp. In this design the membrane experiences relatively small excursions in the form of reversals when it changes position from cargo to ballast.

The second proposed design shown on figure 6.2, has a single metal clamp which is bolted to the tank. The membrane is gripped between the clamp and the walls of the tank. In this design the membrane would experience a large excursion and would not have a stress reversal.

It is not clear at this point which of these preliminary designs is superior. However, further clamping methods are sought.

6.4 PRELIMINARY MEMBRANE COSTS

Neither the materials for the proposed membrane nor their thickness have been selected. However, it is possible to provide reasonable preliminary estimates from other similar applications.

It is anticipated that the membrane fabrications could be constructed in rubbers suitable for applications with oil cargoes and sea water ballast and having membrane thicknesses of about 3/16" or 1/4". The cost of such membranes, in the U.S., including the fabrication of the membrane into a simple shape, such as geometry 5, would be about \$3 per $ft.^2$ for 3/16" thick material and \$4 per $ft.^2$ for 1/4" thick. This estimate is based upon nitrile, neoprene rubbers with a light fabric reinforcement.

The rubber membranes for a new 250,000 DWT tanker would have a membrane area of approximately 20,000 $ft.^2$ per tank based on geometries 1, 5, and 6 (see section 3.3) giving 100,000 $ft.^2$ for the tanker. The cost of the membranes for such a tanker are therefore approximately:

$300,000 for 3/16" membrane material

and $400,000 for 1/4" membrane material

These figures, of course, are not the total cost of the application of membranes because of the costs of:

a. Ship structural changes

b. Additional pipe work and valves

c. Installation

d. Maintenance

Figure 6.1 Attaching Mechanism Typifying Reversed Folding

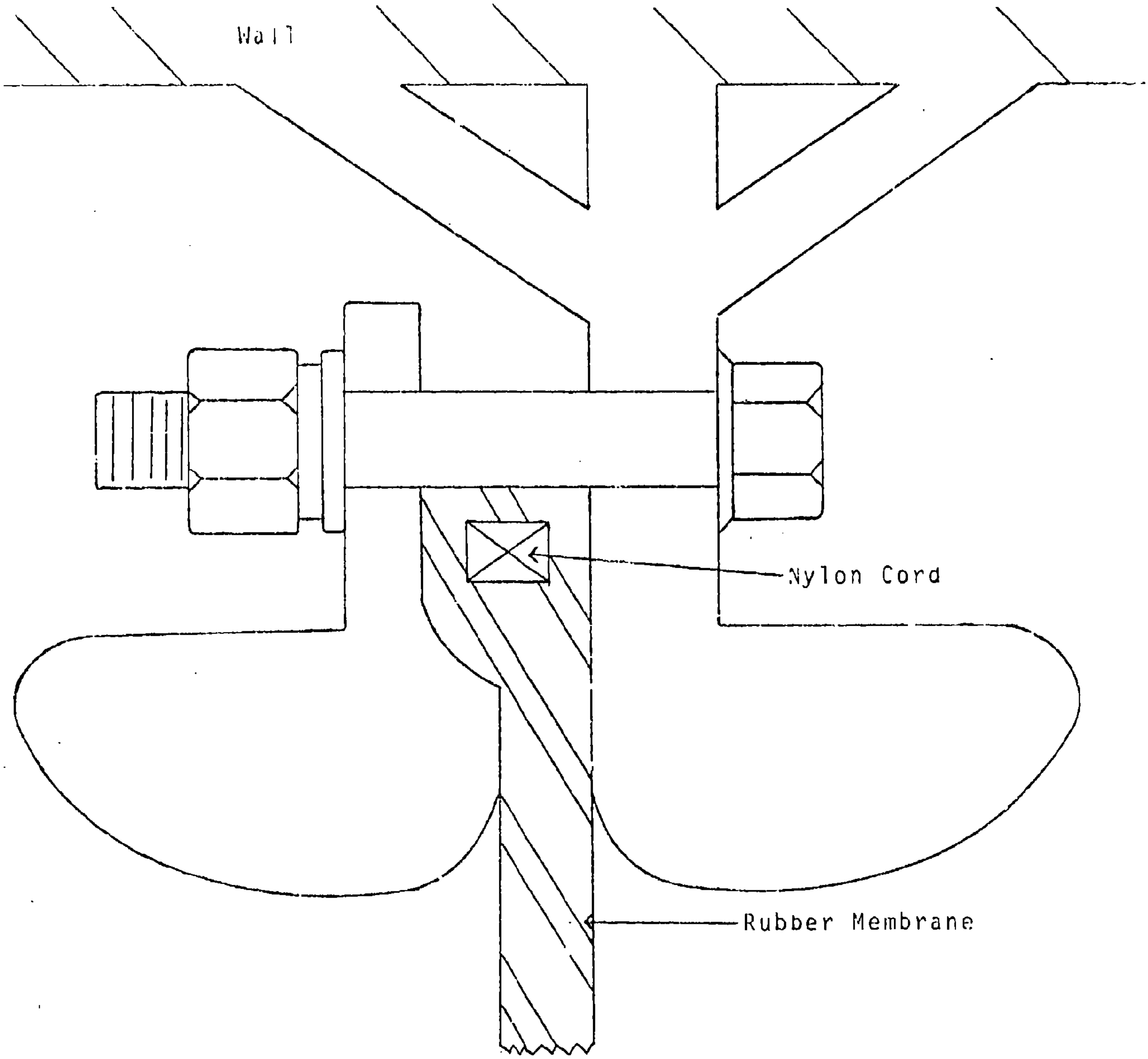
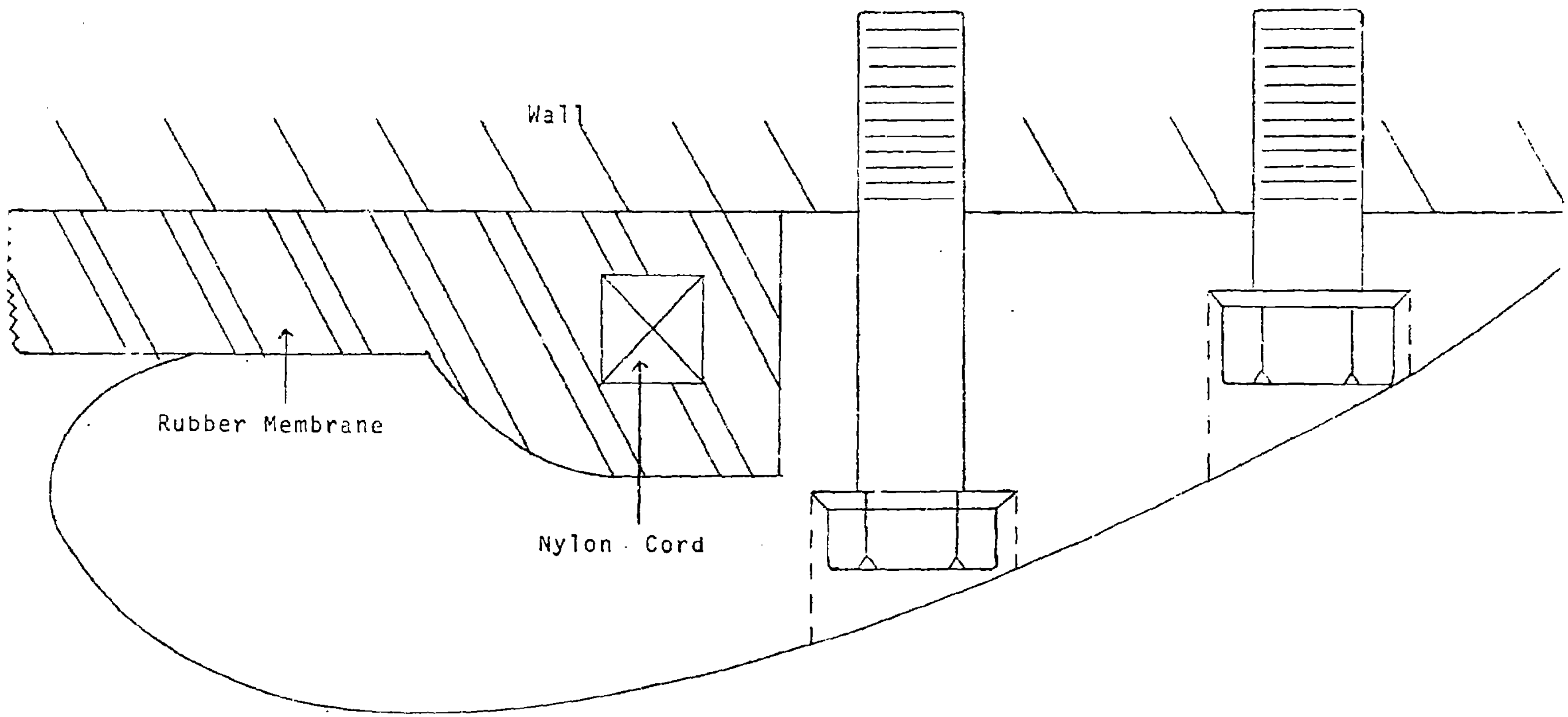


Figure 6.2 Attaching Mechanism Typifying Repeated Folding



7. THE FUTURE PROGRAM

The study described in the previous pages of this report is the first and preliminary phase of a larger task.

It has been demonstrated that there are several geometrical shapes of membranes that are promising, and that the costs of the membranes and their fabrication are not absurdly high. Furthermore, it appears that the structural modification to new and to existing tankers are feasible. There are, however, several problem areas which have not yet been adequately analysed and these will be investigated in the next phase of this study.

7.1 50,000 TON TANKERS

The analysis presented in this preliminary study report has been restricted to 250,000 ton tankers; it is proposed to repeat the effort for both new and existing 50,000 ton tankers. The ballasting calculations, bending moment and shear force calculations, and optimum tank size determination will be carried out as for the 250,000 ton tankers. The structural features of these tankers will also be defined so that the studies of the 50,000 tankers will be brought up to date with the position on the 250,000 ton tankers.

7.2 STRUCTURES

Two programs shall be considered. These are:

7.2.1 New Tankers

As discussed earlier, two typical tankers will be analyzed, a large 250,000 ton dead weight tanker as an example of a VLCC, and a relatively small 50,000 ton dead weight tanker. Once main dimensions within the tankers, such as longitudinal bulkheads spacing, transverse bulkhead spacing, etc., are defined to suit the membrane arrangement and to produce an efficient ballast condition, the following steps will be undertaken:

a. Determination of the Scantlings of the Structural Members:

In general, the Classification Societies Rules for ocean going steel vessels will be used, whenever possible, to determine the thicknesses of the shell and deck plating, dimensions ard thicknesses of web frames, longitudinal girders and stiffeners, scantlings of longitudinal and transverse bulknead platings and stiffeners, etc.

Even though optimization is not the main objective of this study, a reasonably optimum web frame spacing and stiffeners arrangement will be sought. This will require weight calculation and comparisons between models of different arrangements.

The total section moduli of the two ships will comply with societies rules. The effect on these section moduli of introducing the stiffening system on the top of the deck instead of below it as conventionally located, will be quantitatively analyzed.

b. Stress Analysis at Critical Areas:

One of the structural differences between a conventional tanker and the proposed one, is the elimination of the web frames brackets in the center tanks of the proposed tankers. This may be critical, particularly at the connection of the vertical part of the web frame and the bottom floor where stresses are usually high. In effect, the elimination of these brackets will reduce the section modulus of the vertical members and the floors at the ends as well as increasing the effective length of those members. Naturally the corresponding brackets in the wing tanks will have to be strengthened to compensate for these effects. However, transverse strength analysis may be necessary, particularly for the VLCC. The computer program ICES-STRUDL (Integrated Civil Engineering Systems--Structural Design Language) will be used for this purpose. First, a transverse frame analysis will be performed under typical and critical loading conditions of the tanks. From these analyses, the loads at sections near the critical areas in the web frame will be determined. These loads will be then applied to a fine mesh finite element model of the critical areas in order to investigate the stress concentration at these locations.

The buckling strength of the deck plating will be also checked, even though at the present time, there is no reason to believe that it is more critical in the proposed design than in a conventional one.

c. Weight Calculation:

After deciding on the scantlings of the structural members, calculation of the steel weight of the ship will be made.

d. Cost Estimate:

An estimate of the total cost of construction will be made based on prices available from industry and the weight calculation performed above.

7.2.2 Modification to Existing Tankers

Basically similar steps will be followed in this program as the previous one. Minimum amount of modification of the existing tanks will be sought. Additional steel weight will have to be added to preserve the original strength. In critical areas, finite element or other analysis will be performed for the original structure and the modified one, and a comparison will be made between the strength of the two structures. The weight of the removed and added steel will be calculated. Its effect on trim and stability will be checked if necessary. Finally, a cost estimate will be made based on unit costs available.

7.3 MODEL TESTING

The purpose of the proposed model tests will be to examine the operational features of membranes, particularly during the emptying operations and in the simulated ship motions. By careful modelling procedures it should be possible to reproduce in small scale models the phenomena that will be encountered in the full scale device.

The particular problems that may be exposed by model tests are associated with the membrane material blocking the suction outlet during emptying and also with excessive relative motion between the membrane and the tank walls in simulated seaway conditions.

7.3.1 Modelling Parameters

In order to obtain dynamic similarity between a full size membrane in a tank and a small scale model it is necessary to operate the model at the same value of selected non-dimensional parameters as the full scale device. Since there is no experience of the phenomena being modelled the relevent non-dimensional parameters can be determined either formally using the π theorem or intuitively from well established non-dimensional groups in the field of hydrodynamics. The latter approach is used here. The first step is to list the variables thought to be important and then to arrange the variables in non-dimensional groups.

7.3.1.1 Filling and Emptying

The important variables are considered to be

$\rho_{L1}, \rho_{L2}, \rho_m$	densities of the liquid on each side of the membrane and of the membrane respectively
L	length
g	acceleration due to gravity
Q	volume flow rate
EI	membrane stiffness per unit width

Viscosity is not considered to be important in this application.

The non-dimensional groups that can be expected for the membrane modelling correspond to pressure coefficient and Froude number in hydrodynamics, plus a density ratio. These groups are a membrane stiffness number $\left(\frac{EI\ L}{\rho_L Q^2}\right)$, a flow number $\left(\frac{Q}{L^{2.5} g^{1/2}}\right)$ and the density functions $\left(\frac{\rho_m - \rho_L}{\rho_L}\right)$, $\left(\frac{\rho_{L2} - \rho_{L1}}{\rho_{L1}}\right)$.

7.3.1.2 Dynamics

The important variables are considered to be

ρ_L, ρ_m	density of the liquid and the membrane respectively
L	length
g	acceleration due to gravity
EI	membrane stiffness per unit length
ω	frequency of oscillation

The resulting non-dimensional groups correspond to reduced frequency and a further form of pressure coefficient. The form of reduced frequency is $\left(\omega\left(\frac{L}{g}\right)^{1/2}\right)$ and the new membrane stiffness parameter is $\left(\frac{EI}{L^4 \rho_L g}\right)$.

It is possible that other factors may also prove to be important during model testing, such as membrane extension or surface tension effects. These will be investigated.

7.3.2 The Proposed Tests

It is proposed to build a 1/20th scale model of the tank (about 5' x 4' x 4'). This size is about the largest convenient size from the point of view of handling, filling and emptying, and bearing support for simulated seaway conditions.

In the emptying tests the membrane geometries and positions of the suction outlets will be varied. The non-dimensional parameters described previously will be adjusted to cover the range of expected values for the full scale tanks; the main variables are the membrane stiffness and the emptying flow rate. Observations will be made of the action and movement of the membrane during the emptying process.

The other group of proposed tests will be carried out with the model tank oscillating in a simulated ship motion at the appropriate reduced frequency. The purpose is to observe the relative motion of the membrane and tank walls and to attempt to determine the pressure forces at the rubbing points.

7.4 ELASTOMER TECHNOLOGY

The main consideration for the future program are the determination of the best elastomers for tank membranes and the selection of the most practical, efficient, and inexpensive tank attachment arrangement.

The possibilities of tank coating to reduce abrasion will be examined and also the possible sources of membrane degradation in tanks, such as high or low temperature, ionic effects, and possible ozone concentrations will be studied.

7.5 ECONOMIC CONSIDERATIONS

The first phases of this study are concerned with the feasibility of the membrane method of isolating oil from sea water ballast. Once feasibility has been established from engineering studies and model tests it will be necessary to examine the economic impact of the device. In addition to the costs of fabricating the membranes, which at this time appear to be reasonably low, the other costs due to structural changes, additional pipe work, and maintenance costs will have to be established. The costs of modification of existing tankers is of particular concern.