TITLE: DRY DOCKING OF LOADED OR PARTIALLY LOADED SHIPS

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1. INTRODUCTION

The periodical survey requirements, as prescribed by classification societies, stipulate that ships should be dry docked at intervals not exceeding two years. Between these Docking Surveys, an Annual Survey is carried out. Full details of the Society's Survey requirements are set out in Part 1 of the Rules for Steel Ships.

An Annual Survey is mainly concerned with the examination of freeboard marks, steering gear, hatch covers, and other closing appliances.

A bi-annual Docking Survey, in addition to the Annual Survey items, includes the inspection of immersed shell plating, sea inlets, rudder, sternframe, and other parts not generally accessible when the ship is afloat. Particular attention is given to any areas which exhibit an accelerated rate of corrosion or of deterioration due to mechanical causes such as chafing or grounding.

The rapid increase in ship size which took place in the early 1970s led to a situation where the principal dimensions, in particular the breadth, of some vessels exceeded those for which suitable dry docking facilities were generally available. In response, the Society introduced the concept of the In-Water Survey which, subject to the consent of the Committee, may be carried out in lieu of a Docking Survey.

At present, applications for In-Water Survey can be considered in the cases of ships which are less than 15 years old and which satisfy the following conditions:

(a) generally, greater than 30 metres breadth,

(b) the underwater portion of the hull is protected by a high resistance paint system,

(c) approved means of identification is placed on the flat of bottom to enable divers to orientate themselves

However, In-Water Surveys cannot be considered as a complete substitute for periodical dry docking since most external maintenance work, as opposed to pure inspection, could not be carried out under water to an equivalent standard. Generally, dry docking continues to be required at the time of the Special Survey which is due every four years.

In addition to the Society's survey requirements, dry docking is frequently necessary as an emergency measure following accidents such as collision, grounding, fire, or major systems failure. At the time of such an accident the ship could be in a ballast condition, a partly loaded, or a fully loaded condition with a cargo which may or may not be dischargeable.

A non-dischargeable cargo will generally be a bulk cargo of a type classified as hazardous and for which no suitable reception facilities are available. For example, oxidising substances are subdivided by the Port of London Authority 'Schedule of Dangerous Goods' into three groups:

Group 1 - substances which can be deposited in transit sheds for a period not exceeding two weeks

Group 2 - substances which must have direct transit from the ship to land/water conveyance or vice versa

Group 3 - substances which must not be brought onto dock premises without prior approval of the P.L.A. and in accordance with such requirements as may be specified by them.

Should an accident occur to a vessel carrying a cargo within Groups 2 or 3, as defined above, then it is quite likely that temporary discharge would be impractical and consideration would need to be given to arrangements for docking the ship in its existing loaded condition.

Figure 1 is a summary of possible docking circumstances. It can be seen that a distinction is made between open type vessels, such as container ships, and conventional closed form configurations.

The reason for this distinction is that a closed box form with regularly spaced transverse bulkheads, as, for example, in tankers, bulk carriers, and conventional dry cargo ships, has a greater capability for absorbing docking pressures than the more flexible container ship configuration. These ships, having transverse bulkheads spaced at about 30 metres and being of U-form, require greater attention to the control of block pressures, particularly when in a partially loaded condition. A similar observation could be made with regard to some types of multi-purpose dry cargo ships which have narrow deck strips and to conventional dry cargo ships if fitted with long cargo holds.

Before discussing these aspects in greater detail a short review of the various types of dry docking facility would be useful.

2. DRY DOCKING FACILITIES

Figure 2 indicates the various types of dry docking facilities which are currently available or contemplated. It can be seen that three basic divisions can be made. Most conventional docks involve only vertical translation of the vessel to be docked either by lowering the water level within a graving dock or by lifting an open ended floating dock. However, a large number of dockings, particularly of smaller ships, are carried out on installations which involve both vertical and horizontal transfer. In addition to mechanical lift docks, facilities of this type include marine railway or slipway type docks. These consist of a docking platform which can be submerged by running down an inclined track. The ship to be docked is positioned above the platform and then both platform and ship are hauled up the track. Many marine railway installations are used in association arrangements for horizontal transfer of the ship after inhauling.

A new concept, brought about by the rapid development of offshore technology, involves a floating dock with one end permanently closed and the other fitted with dock gates. This enables docking to be achieved without raising or lowering the docked vessel. It is primarily intended as a rig maintenance facility but we are not aware of any examples presently in service.

Since most dockings of large vessels are carried out in either graving or floating docks the remainder of this Paper will assume the use of one of these types.

Whilst the objective of dry docking is to examine or improve the condition of the vessel, structural damage to the ship may occur due to injudicious docking procedure. In such cases the damage is generally attributable to one of the following causes:

(a) unsuitable number, distribution, or type of supporting blocks,

(b) inaccurate ship positioning within the dock,

(c) excessive overhang of ship ends,

(d) relative motion of ship and dock if the operational site is not adequately protected from adverse environmental conditions.

The first of the above is of particular significance. The main function of the supporting blocks is to transmit the weight of the ship to the dock structure whilst providing a gap between the dock and ship sufficient for access and maintenance. The basic criteria to be fulfilled are as follows:

(a) the blocks should have sufficient strength to transmit the applied loads. These can range up to 150 tonnes on a standard sized block,

(b) the part of the block in direct contact with the docked vessel should be sufficiently elastic to avoid excessive local loading,

(c) some or all blocks should be of a design which is able to be removed when fully loaded in order to provide access to damaged areas of the ship's bottom,

(d) side and bilge blocks should have the facility for height adjustment in order to accommodate ships having a rise of floor.

Figure 3 shows the various types of support blocks categorised in accordance with their load bearing capability.

Figure 4 shows an outline of a 'standard' size steel block fitted with wooden cappings. This type of block can, in theory, be removed when loaded and Appendix 1 gives a method for evaluating the horizontal force required to achieve this. However, since the necessary force can be quite large it may not be practical to remove the block when fully loaded unless special equipment is available. An alternative arrangement for facilitating removal of a block under load is to incorporate a sand box, within the base support, which can be emptied to lower the block. Figure 5 shows a 'giant' size concrete block with wooden cappings and a sand box.

3. BLOCK LOADING

A ship will normally be provided with a copy of the 'Docking Plan' prepared by the Shipbuilder. This plan, in addition to the location of drain plugs and shell appendages, will usually indicate a suggested arrangement of docking blocks which is consistent with the structural arrangement of the ship and the 'Docking Condition' given in the loading manual.

The dockyard will generally follow a shipbuilder's proposed arrangement provided that they have available sufficient blocks which can be readily located in accordance with the suggested distribution. In such cases the maximum permissible average block loading, which is recommended be in the order of 120 tonnes on a standard size block, will easily be satisfied.

For docks where support of the vessel is through keel blocks only the required number of blocks can be obtained from:-

$$N_k = \frac{Ws}{F} = \frac{Ws}{120}$$

where Ws = ship weight (t),
F = allowable block load (t
= number of keel blocks.

In cases where the docked ship is supported by a combination of keel blocks and load bearing side blocks, and assuming that 60% of the ship weight will be taken by the keel blocks, then the required numbers of blocks are:

$$N_k = \frac{Ws}{200}$$

$$N_s = \frac{Ws}{600}$$ where N_s = number of side blocks each side.

This distribution would be reasonable for a bulk carrier or for some dry cargo ship configurations. In the case of a tanker it could be anticipated that a greater proportion of the load would be reacted by side blocks arranged in way of the longitudinal bulkheads.

The block force will be applied to the ship over the contact area of the block top which will vary depending on the type of capping used. It is usual for the contact area of a standard block to be in the order of $0.5m^2$ which in association with a block load of 120 tonnes would result in a mean pressure of 240 tonnes/m^2.

During scheduled dry docking there is usually no difficulty in ensuring that the average block load does not exceed the recommended limit of 120 tonnes. However, problems in this respect may occur in the emergency dry docking of a loaded or partially loaded ship. In such a case the following aspects should be considered:

(a) The keel and side block arrangements must be compatible with the ships primary structure. In cargo ships with transverse framing in the double bottom, side blocks should be arranged in way of the floors at their intersection with side girders. Where there is a combination of solid and bracket floors then blocks should be arranged clear of the latter. In cargo ships with longitudinally framed double bottoms, the side blocks should be arranged in way of the floors at their intersection with side girders. In tankers, the side blocks should be arranged in way of bottom transverse preferably at either an intersection with longitudinal bulkheads or alternatively under side girders if these are of substantial construction.

(b) The average pressure on the blocks should not be greater than 240 t/m^2 and, in view of the difficulty in ensuring that the side blocks take their share of the load, divers should fit wedges and caps to these blocks as soon as the vessel takes the keel blocks and before the water level is further reduced.

Although it is considered the figure of 240 t/m^2 is conservative it should be aimed at. In some instances the pressure has been limited still further to about 165 t/m^2 and even less where bottom damage is suspected.

(c) The ships structure must have sufficient strength to withstand the cargo loadings without the counteracting hydrostatic forces which would be present when the ship was afloat. Bilge shores may be required if the overhang between the blocks under the outboard line of girders and ship's side is large in any type of ship. Side shores should be arranged where the cargo exerts pressure on the ship's side, and the framing system consists only of transverse frames without supporting girders and webs. The tendency of the frames to bow outwards should also be borne in mind where there are heavy 'tween deck loads.

(d) When positioning blocks consideration requires to be given to the loading of the vessel and, in particular, to any discontinuities in the loading such as empty tanks where the upward pressure from the blocks could prove detrimental. As the loading tends to be concentrated at transverse bulkheads, it is advisable to double the number of blocks in way of these items. Where there are many bulkheads this precaution is not so important.

(e) Where cargo is loaded on the tank top then it should be confirmed that the double bottom structure is capable of withstanding the direct compression which will occur in way of supporting blocks.

(f) It is important that the arrangement of the dock should be such that concentrated forces in way of load bearing side blocks will not cause structural instability. Hence, it should be confirmed that dock structure is designed accordingly in areas exposed to additional pressures. Some floating dock designs may not automatically satisfy this requirement.

4. SHIP STRENGTH CONSIDERATIONS

The ability of the ship's structure to withstand cargo loadings without counteracting hydrostatic forces is of particular relevance for container ships, which, in addition to possible emergency dockings, are frequently required to undergo scheduled dry docking with a full complement of partially loaded containers in the cargo holds.

The areas of the ship which are of particular interest in such a case are those immediately forward and aft of the parallel mid body where the taper out of the flat of bottom precludes the provision of side blocks. A typical transverse section in this region may be as shown in Figure 6.

In order to verify the capability of the structure to withstand this type of loading the Society has carried out a comprehensive structural analysis of the fore end region of 15500 tonnes deadweight container ship. The support block system was simulated by a number of elastic springs as shown in Figure 7. The mathematical model representing one side of the ship structure and including about 500 grid points having about 2500 degrees of freedom was as shown in Figure 8.

The loading arrangement applied to the model consisted of point loads at the corners of the lowest tier of containers together with the self weight of the structure which was automatically generated within the programme and suitably factored to equal the true steelweight. A typical deformed plot of a transverse section is shown in Figure 9 indicating a maximum deformation in the order of 3.4mm.

The stresses induced in the ship structure due to this type of load/support arrangement, though acceptable, were found to be higher than normally experienced in any still water loading condition. Therefore, it may be advisable for the ability of a container ship's structure to withstand loads due to docking in a partially loaded condition to be given detailed consideration at the design stage.

Since the facility to locate load bearing side blocks at suitable positions may not always be available, it would be useful to also consider the ability of the ship's structure to withstand loadings due to docking on keel blocks only. It is of interest to note that when the analysis described above was repeated with the side blocks at Frames 70 and 73 deleted, the deflections and stresses, though increased, remained acceptable provided that appropriate attention were given to detailed design of the transverse bulkhead adjacent to the keel block contact area.

For types of ship which have configurations approximating to closed box geometry no structural problems need be anticipated when docking in partially loaded conditions provided that the block loading limitations discussed in Section 3 are adhered to.

5. DOCK TYPE CONSIDERATIONS

A number of excellent papers have been published or presented to learned societies on the subject of the operation of graving or floating docks. In references 1, 2 and 3 their relative merits and demerits are discussed in some detail. It is intended here to make special mention of two important differences which are of particular relevance to the subject under discussion. The first is related to the length of ship which can be docked and the second to the distribution of block loading.

A floating dock, in contrast to a graving dock, is able to accept ships having a length greater than the length of the dock provided that the maximum lifting capacity is not exceeded. In such cases the dock operator must decide if the extent of ship overhang at each end of the dock is acceptable. The matter is often referred to the classification society for comment as to whether the lengths of overhang contemplated would be detrimental to the ship's structure. In such cases the two aspects which are of most concern are in plane compressive loads in the bottom shell, particularly in fuller form ships, and the block loadings at the ends of the dock.

The Society normally considers overhangs not exceeding the depth of the ship to be in order. If greater overhangs are proposed, or, if additional loads are to be carried on the overhanging ends, then special investigation may be necessary. In this connection it is noted that in the process of converting the "Manhattan" to an ice breaking tanker, she was successfully dry docked at the Sun Shipbuilding and Dry Dock Co., in Pennsylvania with an overhang of 97 feet, i.e. 1.5 x Depth. (See Figure 10).

In regard to the distribution of block loading, it is important to bear in mind the difference in block rearrangement possibilities between graving and floating docks:

(a) In a graving dock the block support system can generally be easily rearranged to suit the structural configuration of the ship to be docked. The block loads can be calculated with a sufficient degree of precision as a function the weight of the vessel and its distribution.

(b) In a floating dock the block support system normally consists of a centreline row of keel blocks plus side blocks located at fixed positions. Hence, there is less scope for rearrangement than in a graving dock. This fact may have repercussions on the average block pressure which may nominally exceed the value referred to in Section 3 as acceptable. However, the floating dock, unlike the graving dock, is far from an infinitely stiff structure and any localised pressures exerted over a certain part of the length will necessarily cause deformation of the dock and result in a reduction in the peak value of block loading. Thus the ratio between peak and average block loads is likely to be less than in a graving dock, which would justify acceptance of a higher average pressure.

The interaction between a docked ship and a floating dock will depend primarily on the relative stiffness of the two structures and that of the block supports. In association with Hong Kong United Dockyard Ltd the Society has carried out a comprehensive structural analysis utilising a 3-D FEM mathematical model incorporating the dock, docked ship, block support system, and dock securing system as shown in Figure 11. The results of this analysis illustrated the complexity of the interaction between two elastic bodies having a flexibility ratio in the order of 1.0.

Whilst a ratio of 1.0 may be representative when docking ships with lengths in the region of 80% of the dock length, a longer ship docked in the same facility may exceed the stiffness of the dock by a factor of up to 4 or, in exceptional cases, even more. This is not to imply that, in cases where the stiffness of the ship exceeds considerably that of the dock, the stresses in the combined ship/dock system will be distributed in such a way that the ship will be liable to experience unacceptably high levels. In fact the longitudinal stresses in the structure of a docked ship will invariably be less than those occurring in the freely floating condition prior to docking.

6. STABILITY DURING DOCKING

Though not a matter covered by classification, it is essential that the Dockmaster should satisfy himself that the stability of the ship to be docked will be adequate throughout the dry docking procedure. This is of particular importance when docking a ship with bottom or side shell damage where there may be flooded compartments having large free surface inertias.

If a floating dock is to be used then consideration must also be given to the combined stability of the ship and dock. The critical stage, from this point of view, is when the draught of the dock is below the depth to the top of the keel blocks but above that to the pontoon deck. At this point the only water plane area will be that provided by the dock wing walls.

Only initial stability, expressed in terms of metacentric height after correction for all free surfaces, is generally considered since the roll or heel angles during docking will, of necessity, be small. Stability criteria for floating docks are sometimes included in national authority regulations.

The Society comments and advises on the stability aspects of a proposed dry docking if so requested. As a general guide the corrected metacentric height the combined ship and dock should not be less than 1.2 metres at any stage in the docking procedure.

ACKNOWLEDGEMENT

Timur Carriers (Pte) Ltd are thanked for their agreement to the investigation, which was carried out on their behalf, being referred to in Section 4 of this paper.

REFERENCES

	TITLE	AUTHOR	PUBLICATION
1.	Large Floating Dry Dock for Large Ships.	Paul Stuart Cranda	Marine Technology Vol 13, No. 2, April 1976.
2.	Some Aspects of the Design and Building of Large Floating Docks.	Thorsten Andersson Tadeusz Buczkowski & Jerzy W. Doerffer	S.N.A.M.E. Annual Meeting Nov 11-13 1976.
3.	Floating Docks - Development and Modern Trends	K.C. Thatcher	Lloyd's Register Technical Association Paper No. 4 Session 1978-1979.

APPENDIX 1

Horizonta Force Required for Removal of Loaded Block, (See Figure 12)

If $n1$ = coefficient of friction between ship and capping material

$n2$ = coefficient of friction between materials of upper and lower parts of block base

a = angle of division in block base to horizontal

L = load on block

W = weight of upper part of block base plus capping

R = reaction force normal to block base division

F = horizontal force required to remove block

then when upper part of block is about to move,

resolving vertical forces:

$$L+W = R.\cos a + N_2.R.\sin a$$

$$R = \frac{L + W}{\cos a + n_2.\sin a}$$

resolving horizontal forces:

$$F = n_1.W + n_2.R.\cos a - R.\sin a$$

For example et n_1

n_2 0.25

degrees

120 tonnes

tonne

then R $\dfrac{121}{\cos 6^{\circ} \quad 0. \qquad 6^{\circ}}$

118 tonnes

and 5.1: 118. 6° 118 in6°

77 tonnes

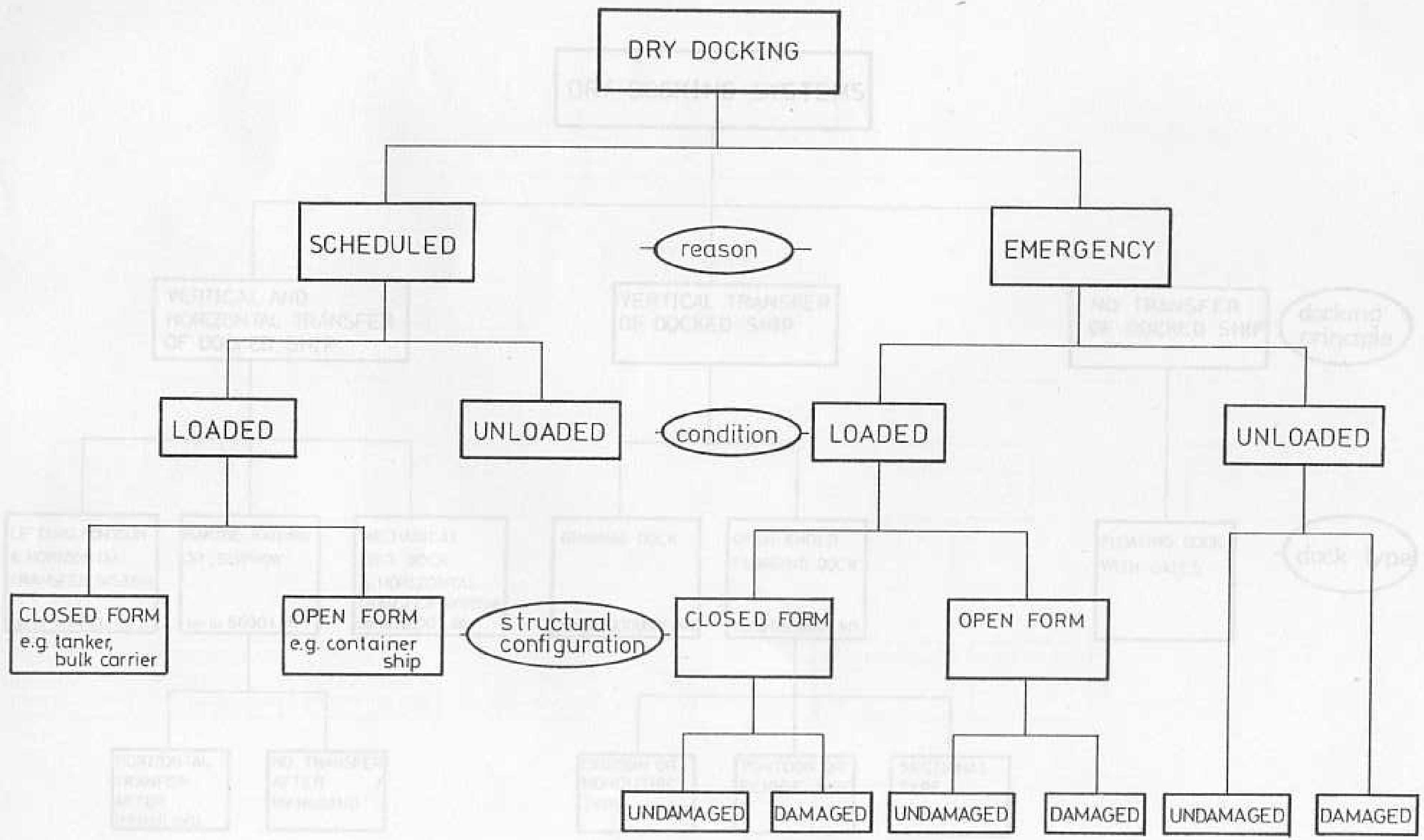
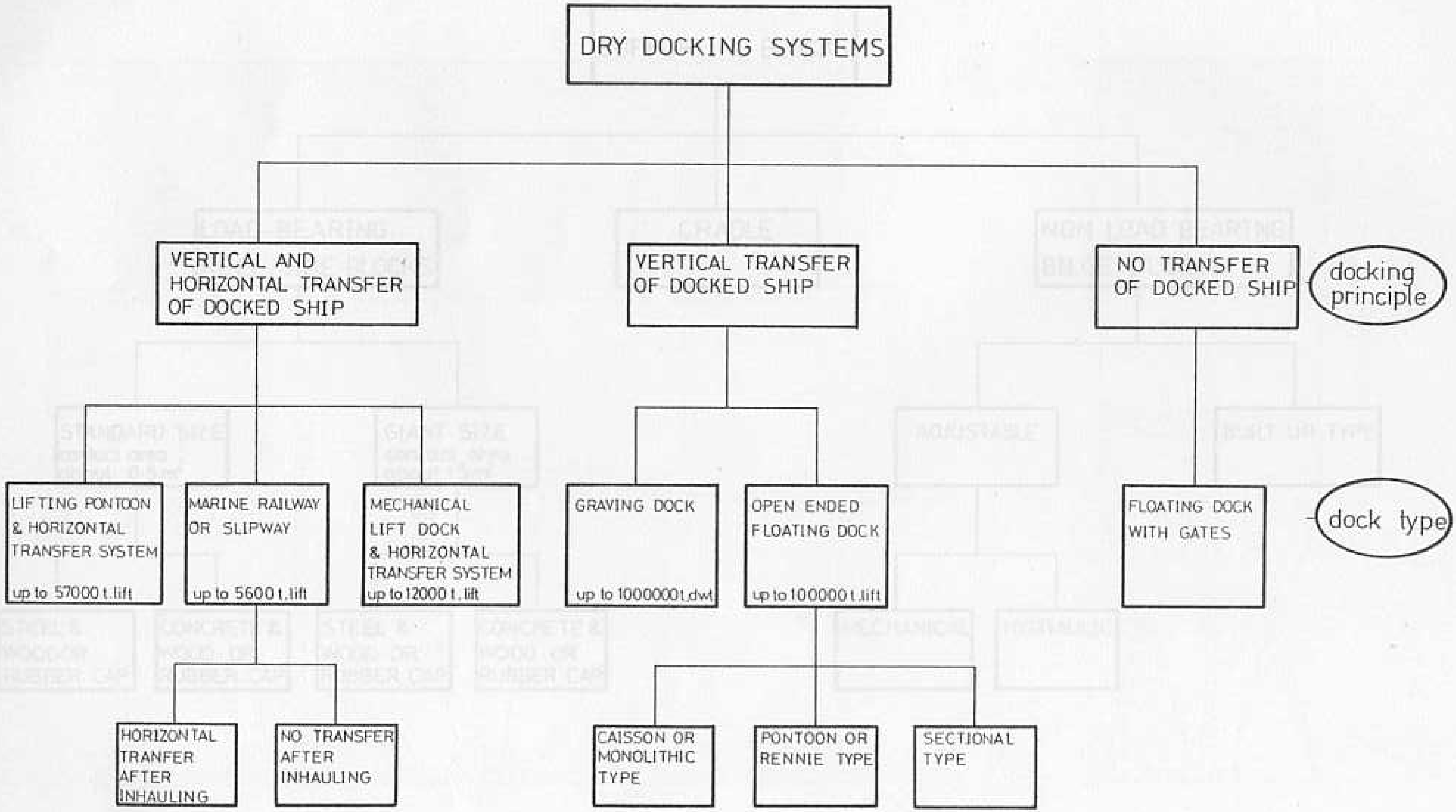
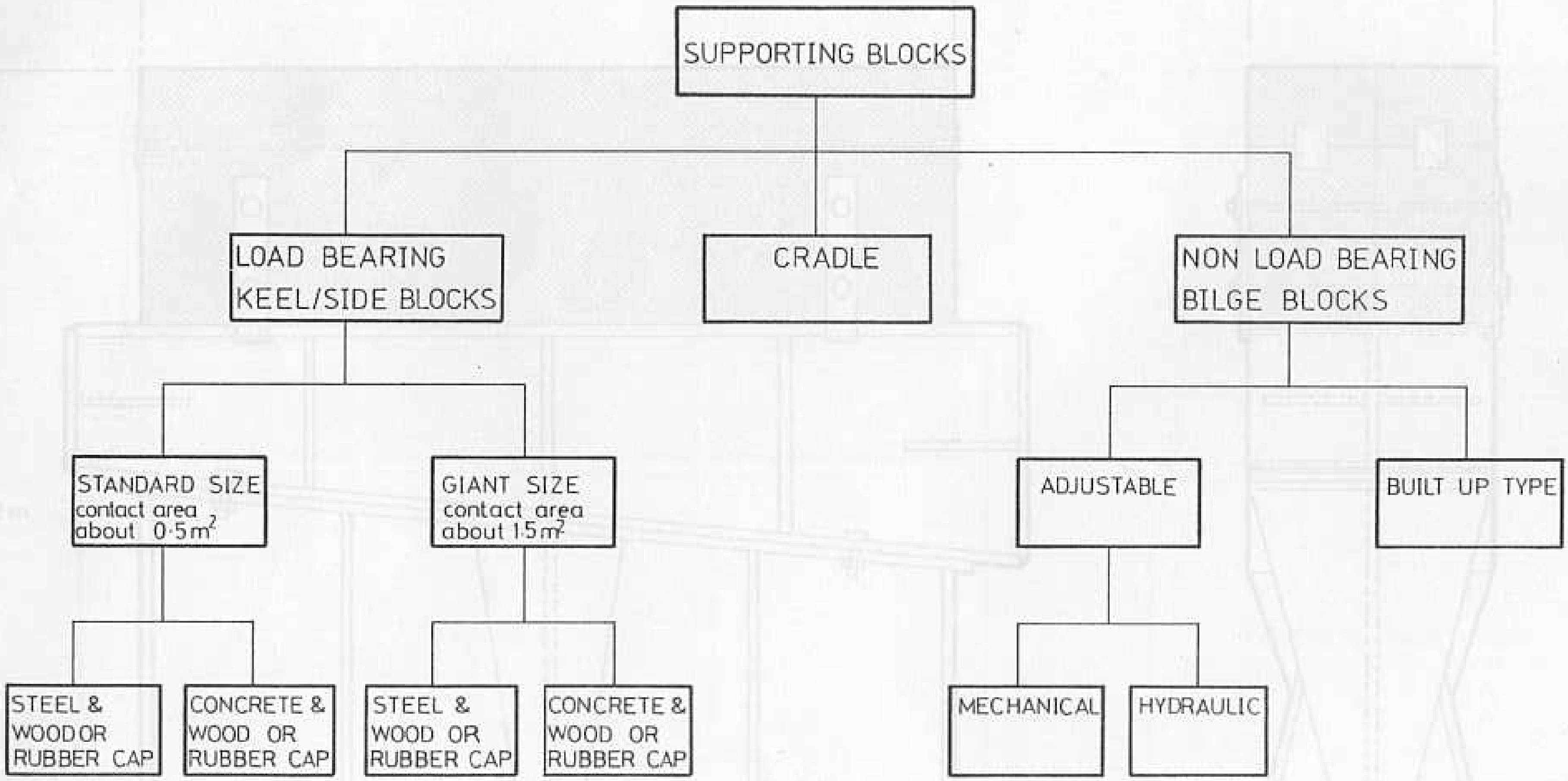


FIGURE 1	LLOYD'S REGISTER OF SHIPPING	DEPT:	SUBJECT DRY DOCKING CIRCUMSTANCES	DATE


DRY DOCKING SYSTEMS
VERTICAL AND HORIZONTAL TRANSFER OF DOCKED SHIP
VERTICAL TRANSFER OF DOCKED SHIP
NO TRANSFER OF DOCKED SHIP
docking principle
LIFTING PONTOON & HORIZONTAL TRANSFER SYSTEM
up to 57000 t. lift
MARINE RAILWAY OR SLIPWAY
up to 5600 t. lift
MECHANICAL LIFT DOCK & HORIZONTAL TRANSFER SYSTEM
up to 12000 t. lift
GRAVING DOCK
up to 1000000 t. dwt
OPEN ENDED FLOATING DOCK
up to 100000 t. lift
FLOATING DOCK WITH GATES
dock type
HORIZONTAL TRANFER AFTER INHAULING
NO TRANSFER AFTER INHAULING
CAISSON OR MONOLITHIC TYPE
PONTOON OR RENNIE TYPE
SECTIONAL TYPE


SUPPORTING BLOCKS
LOAD BEARING KEEL/SIDE BLOCKS
CRADLE
NON LOAD BEARING BILGE BLOCKS
STANDARD SIZE contact area about 0·5m²
GIANT SIZE contact area about 1·5m²
ADJUSTABLE
BUILT UP TYPE
STEEL & WOOD OR RUBBER CAP
CONCRETE & WOOD OR RUBBER CAP
STEEL & WOOD OR RUBBER CAP
CONCRETE & WOOD OR RUBBER CAP
MECHANICAL
HYDRAULIC

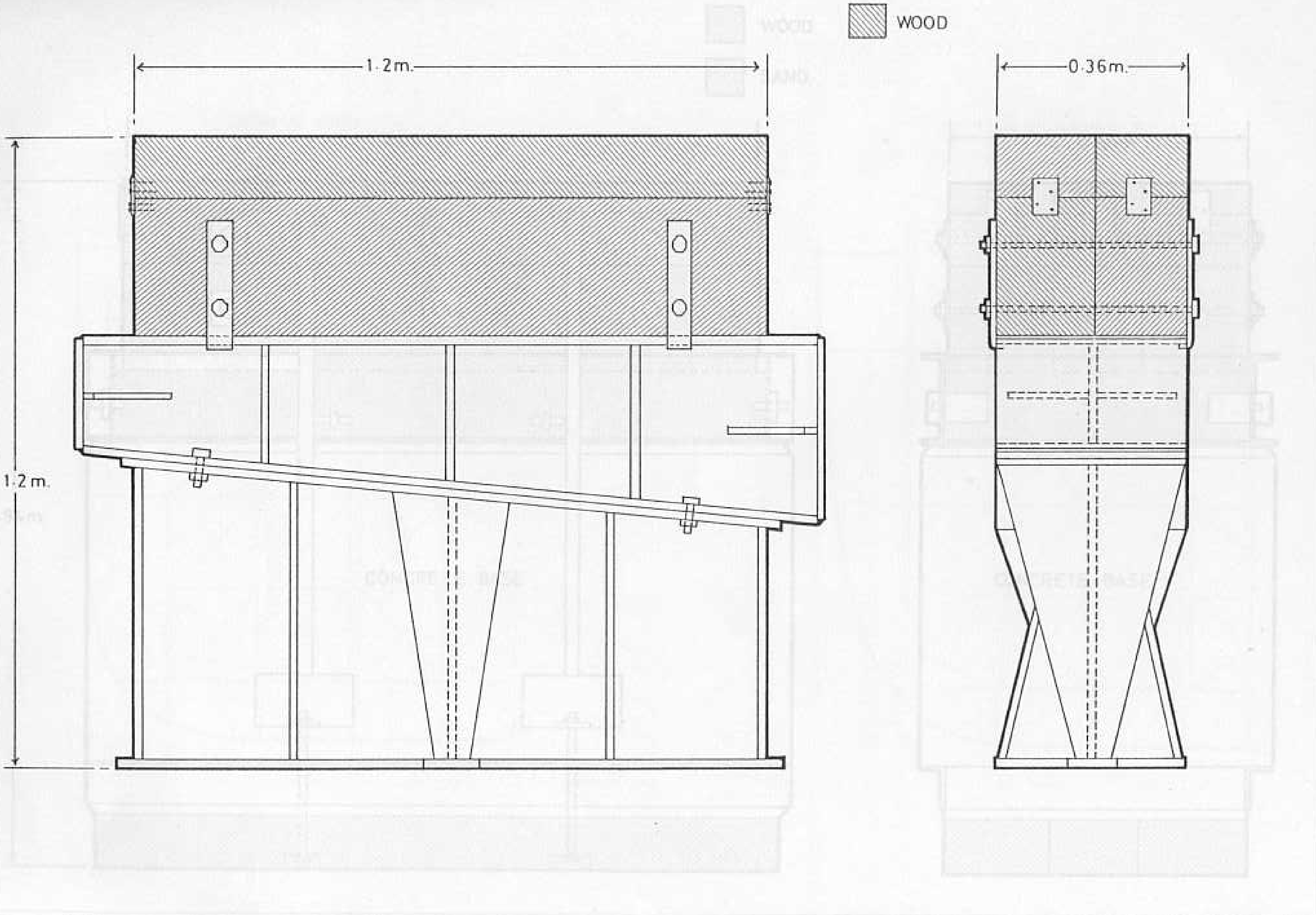
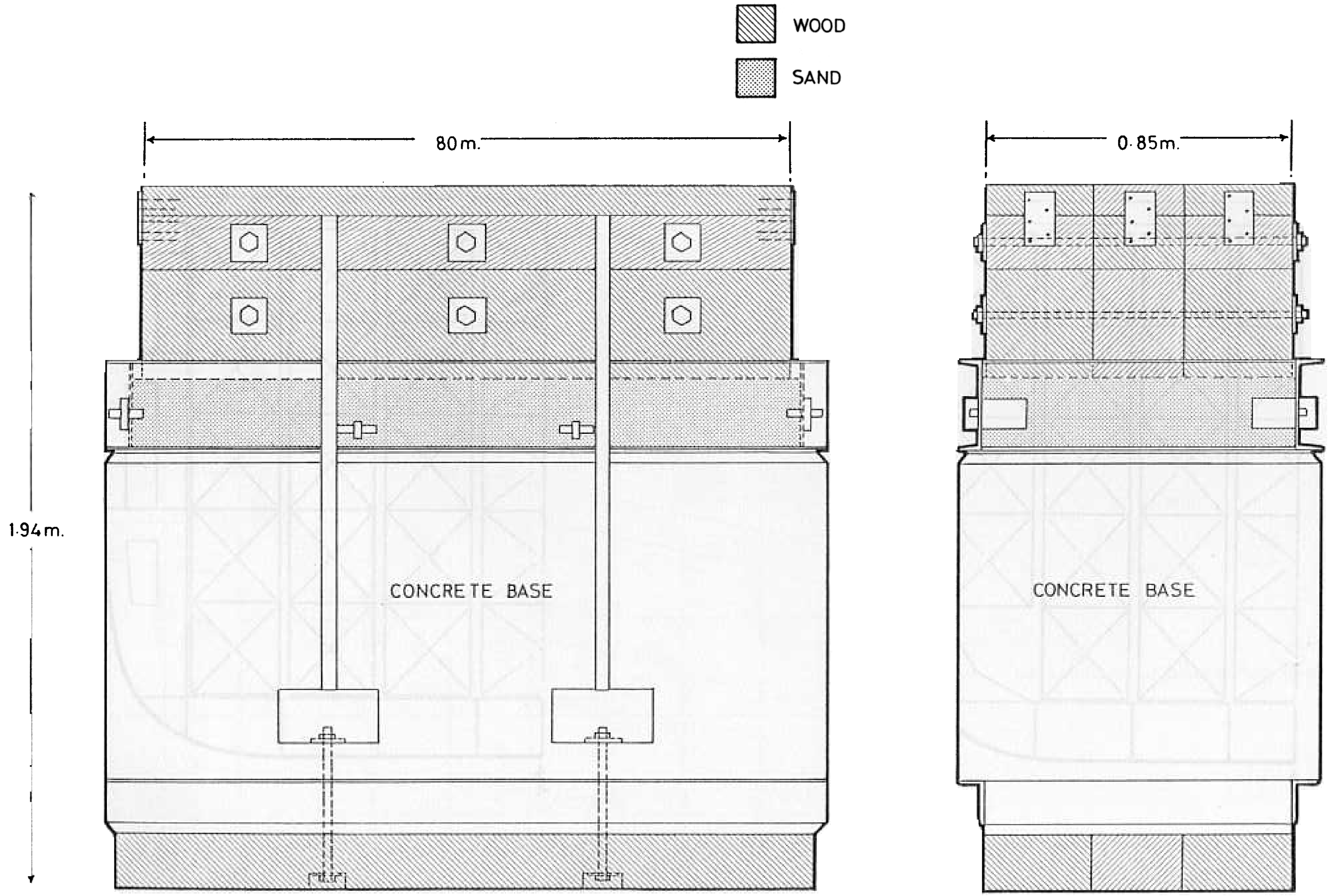
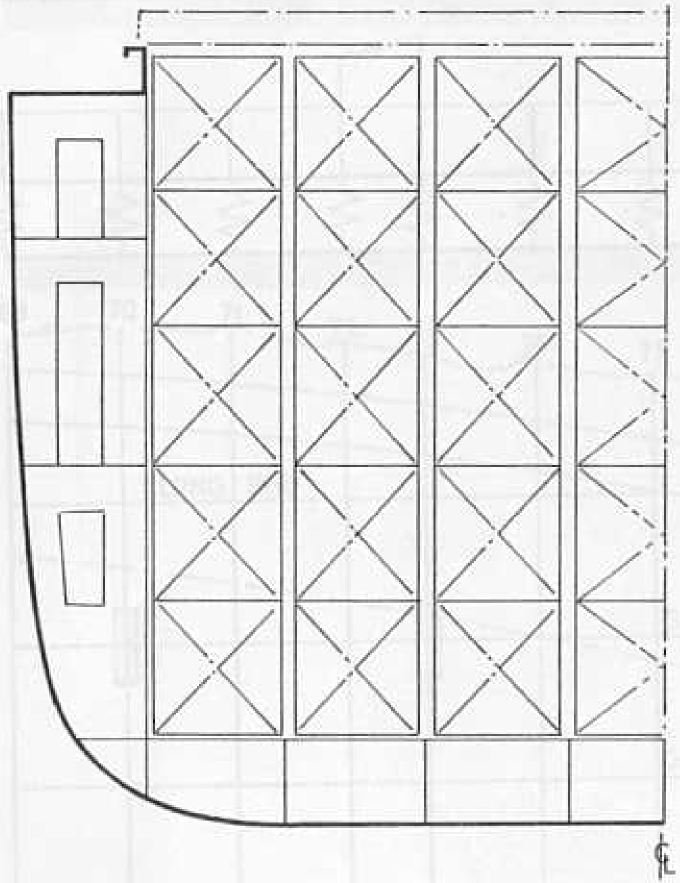


FIGURE 4	LLOYD'S REGISTER OF SHIPPING	DEPT:	SUBJECT STANDARD SIZE STEEL BLOCK	DATE


WOOD
SAND
80m.
0·85m.
1·94m.
CONCRETE BASE
CONCRETE BASE

SECTION AT FRAME 72



SECTION AT FRAME 76

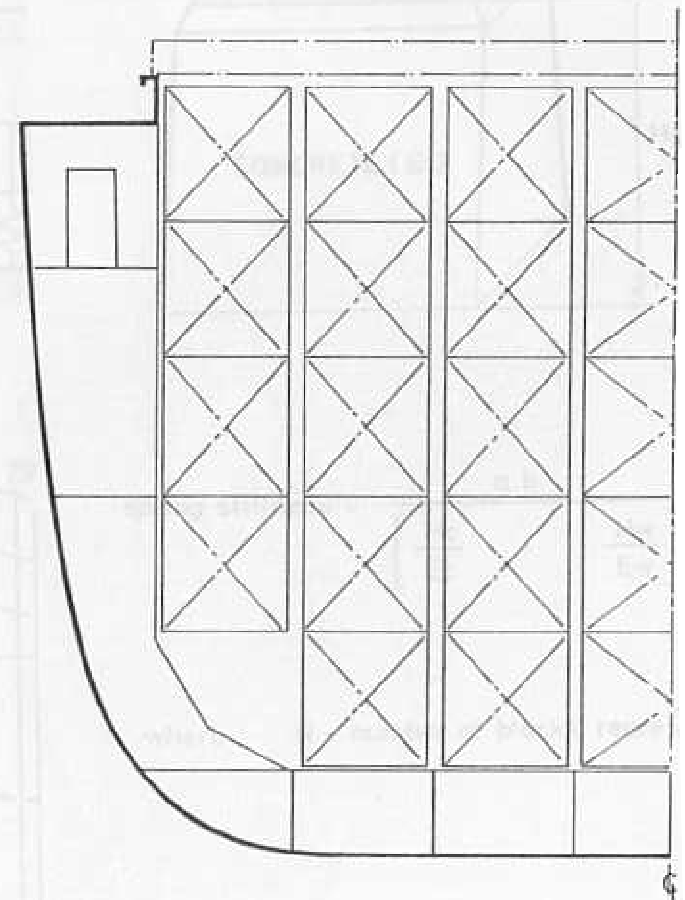
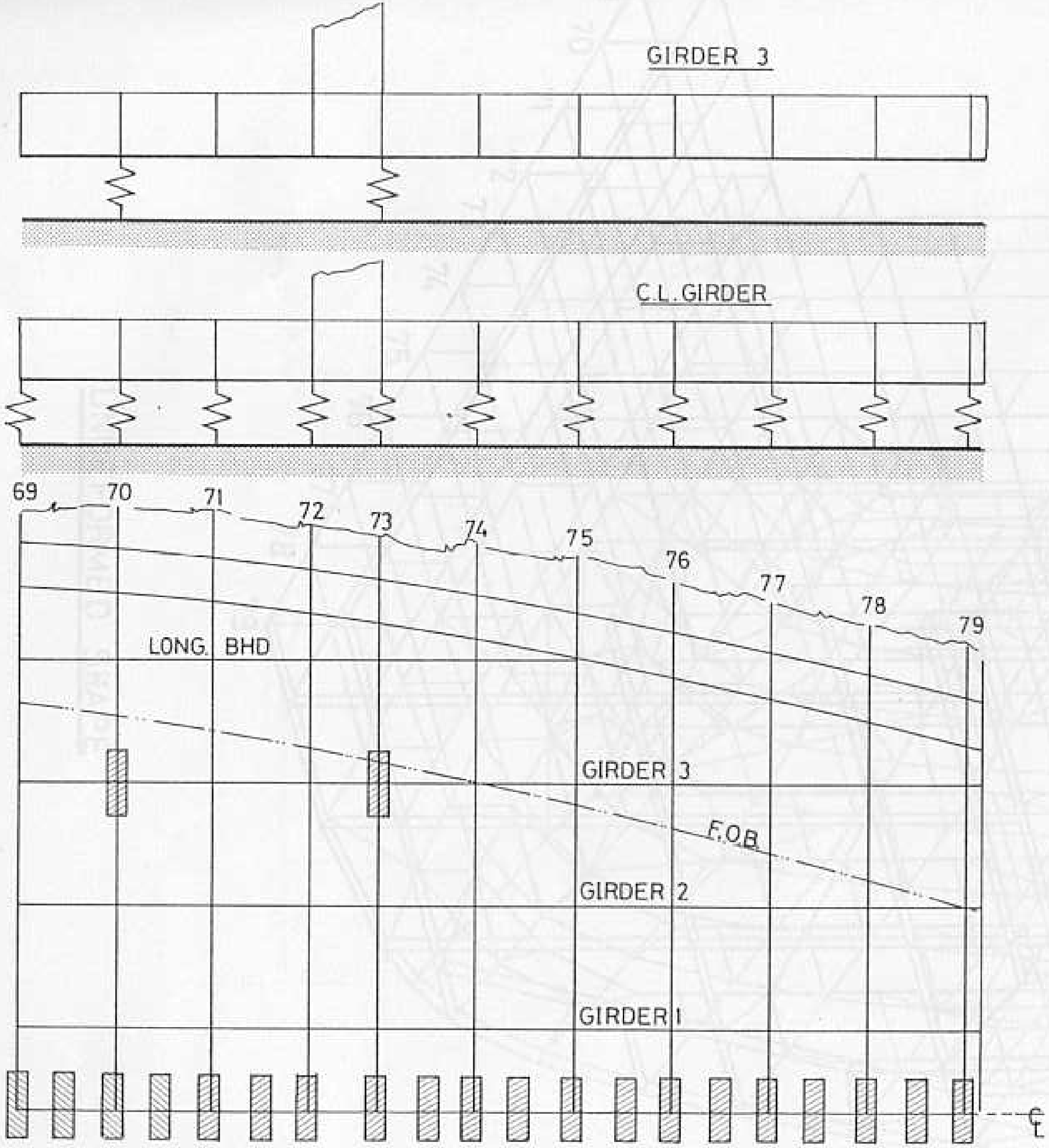
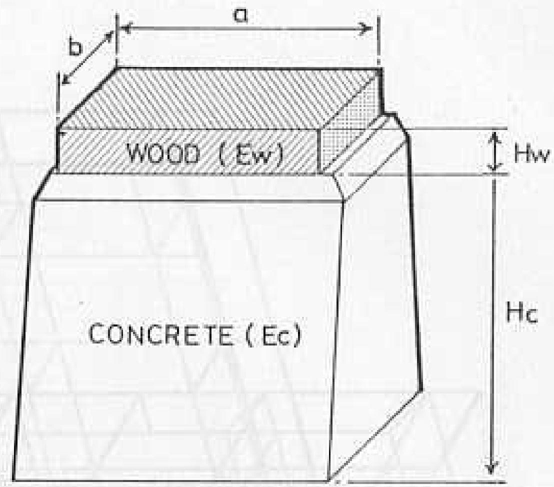


FIGURE 6 | LLOYD'S REGISTER OF SHIPPING | DEPT: | SUBJECT: CONTAINER SHIP CROSS SECTION

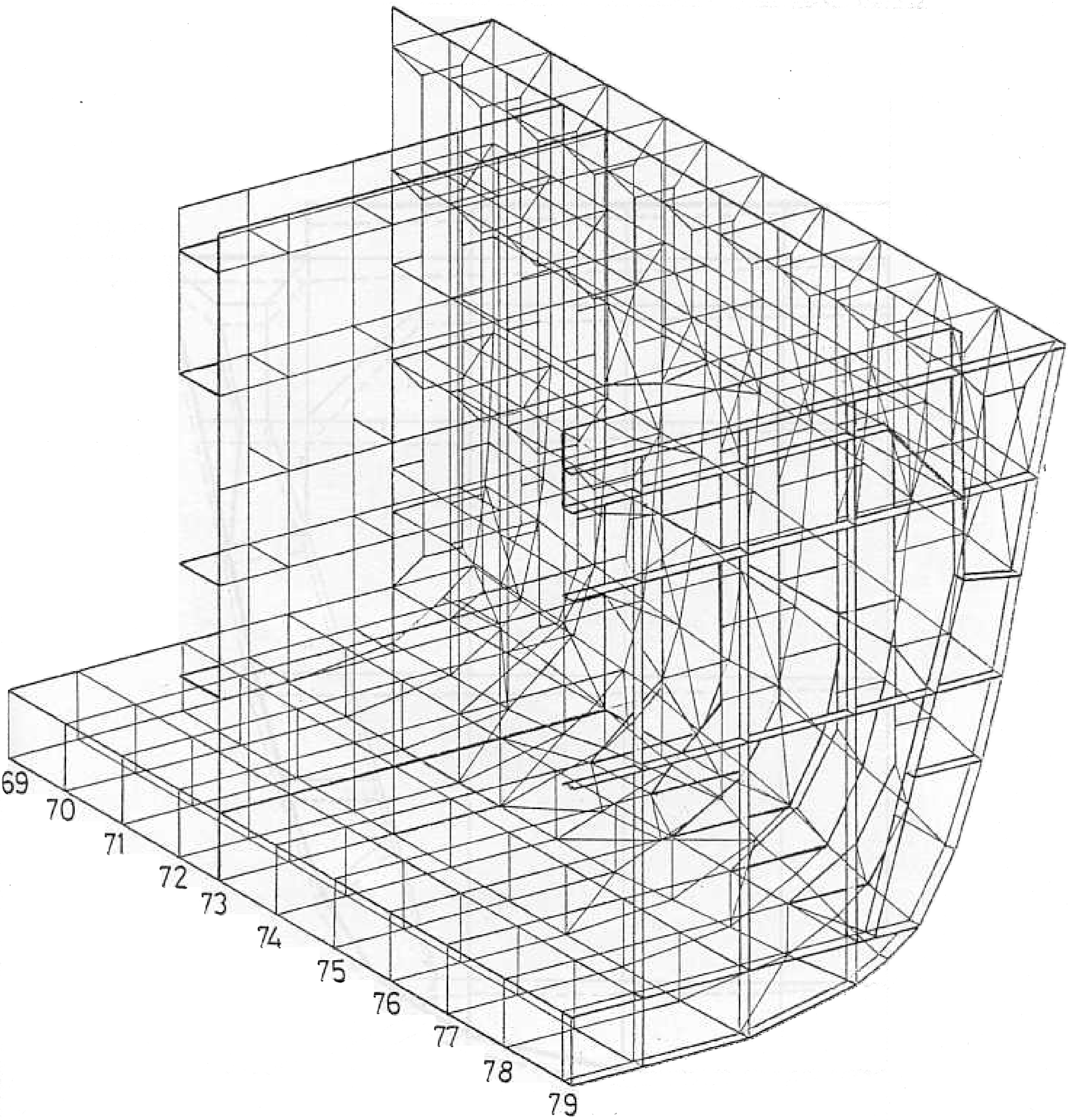




$$\text{spring stiffness} = \frac{a.b}{\left[\frac{Hc}{Ec} + \frac{Hw}{Ew}\right]} \cdot N$$

where N = number of blocks represented.

FIGURE 7	LLOYD'S REGISTER OF SHIPPING	DEPT:	SUBJECT: IDEALISATION OF SUPPORTING BLOCKS	DATE



UNDEFORMED SHAPE

FIGURE	LLOYD'S REGISTER OF SHIPPING	DEPT:	DATE
8	SUBJECT: MATHEMATICAL MODEL		

FRAME 79 – VERTICAL DEFLECTIONS

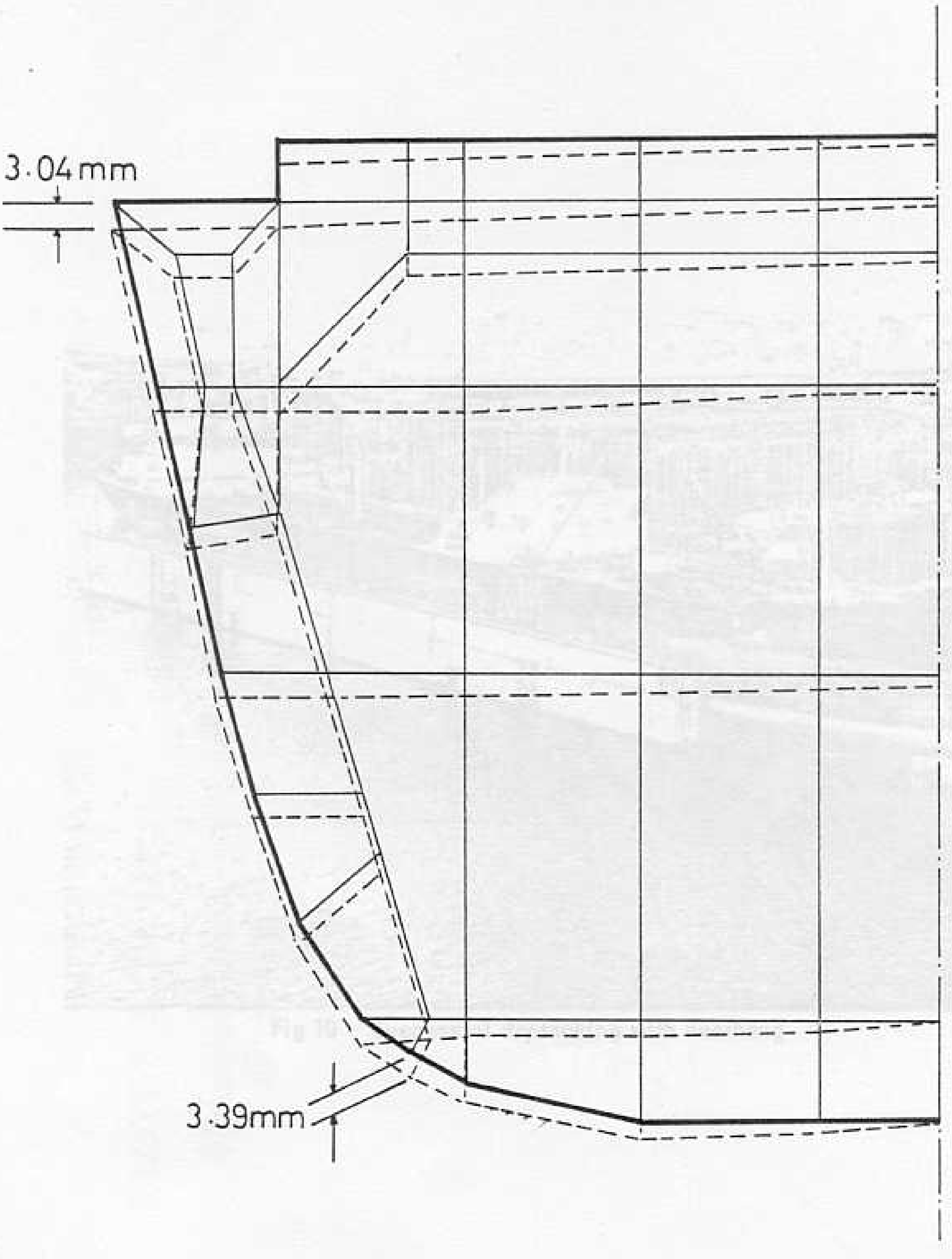


FIGURE 9	LLOYD'S REGISTER OF SHIPPING	DEPT:	DATE
	SUBJECT: DEFORMED CROSS SECTION		

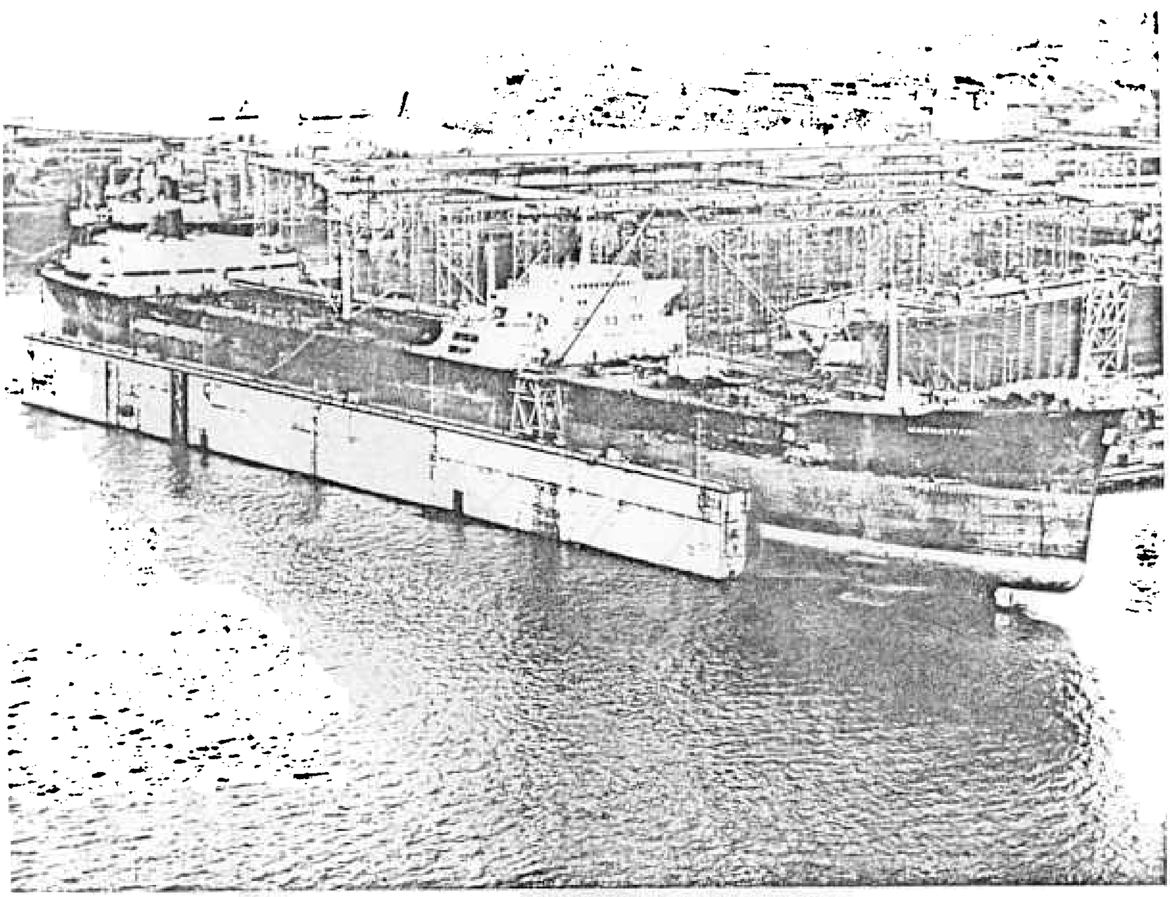


Fig 10 Successful drydocking with overhang

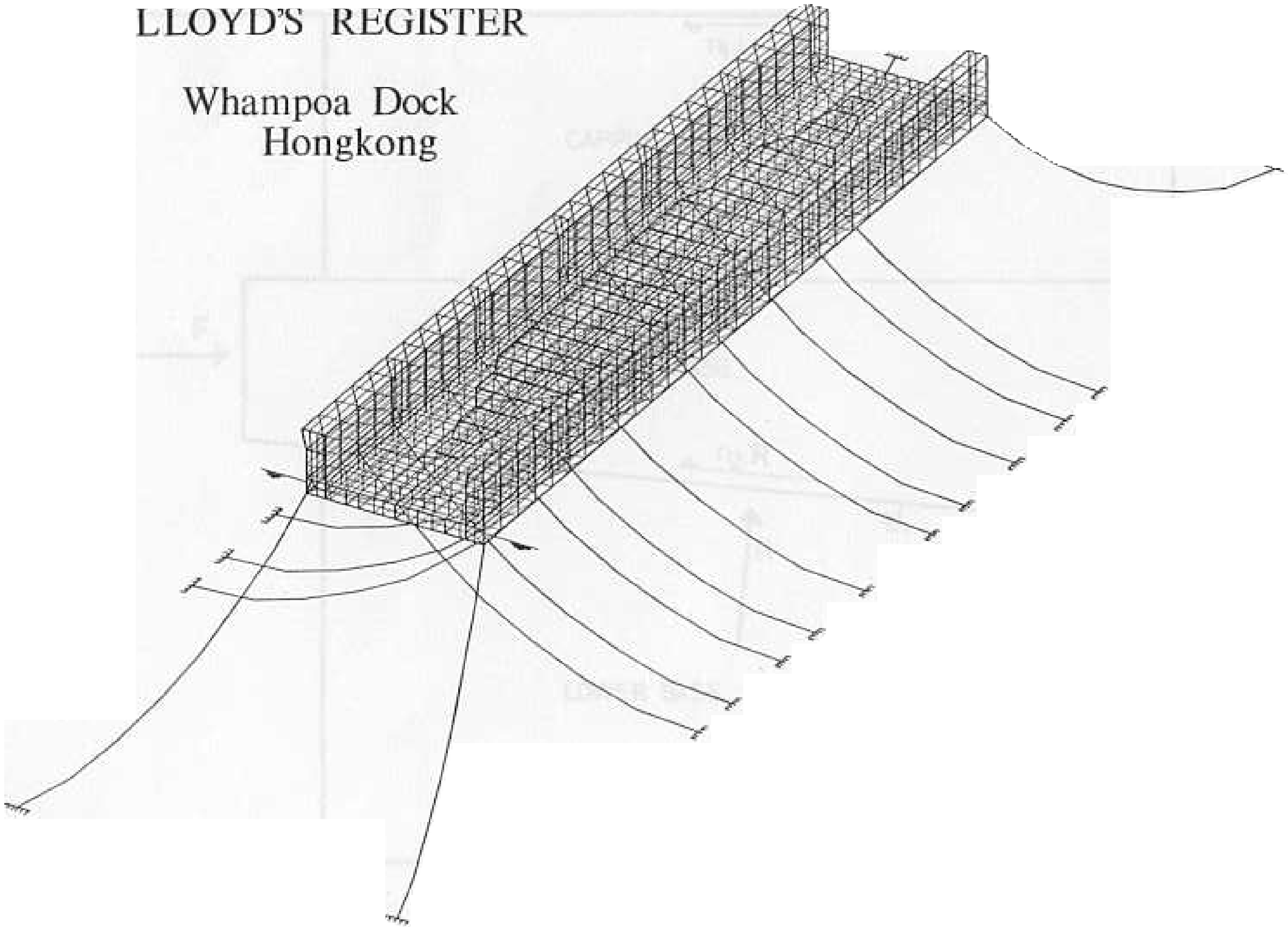


Fig 11 Mathematical model of drydock and securing system

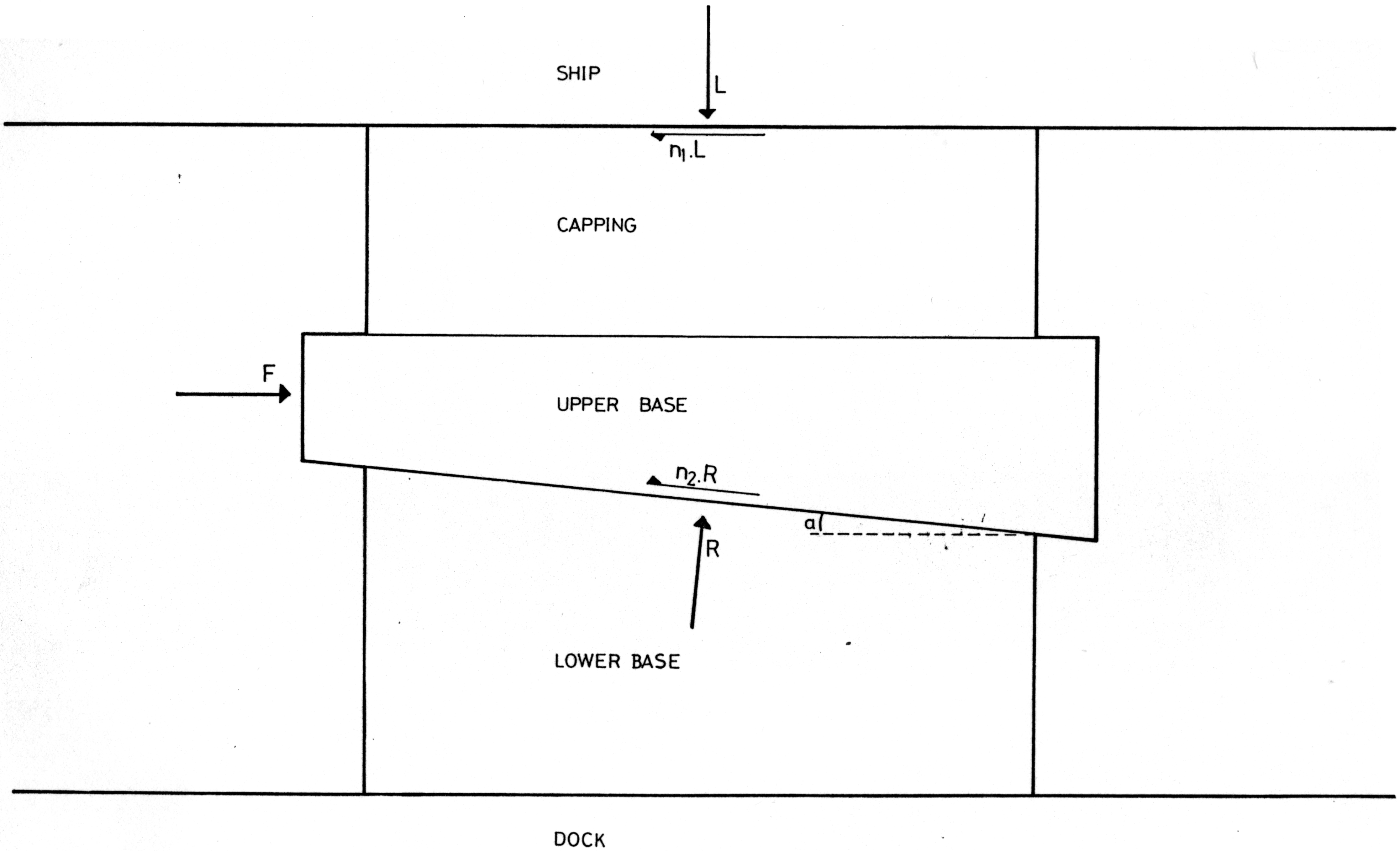


FIGURE 12 | LLOYD'S REGISTER OF SHIPPING | DEPT: | SUBJECT: REMOVAL OF LOADED BLOCK | DATE: