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A GENERAL SURVEY OF THE DESIGN OF ROLL-ON/ROLL-OFF SHIPS

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A B S T R A C T

This paper is intended to present a brief but yet comprehensive account on the main features in the design development of ROLL-ON/ROLL-OFF ships, emphasising: Ro-Ro Types/Classification; Markets and Trends; General Characteristics; Equipment; Basic Design.

1.0 - TYPES OF ROLL-ON/ROLL-OFF SHIPS AND CLASSIFICATION

Before types and classification of Ro-Ro ships are discussed, it will be surely rewarding to have a look over what is "Ro-Ro".

This is a whole system intended for moving goods by sea, in which the loading and unloading operations are mainly performed horizontally by rolling of cargo on and off the vessel; to accomplish this, cargo units are to be provided with wheels (as trailers) or with a temporary moving aid, which can be taken or not on board together with cargo (e.g.: containers on trailers or on fork-lifts, etc). Loads are, hence, either wheeled or mobile.

The ship designed to be the carrier in the Roll-on/Roll-off system is commonly called a "Ro-Ro" ship. This kind of ship is provided with openings on sides, stern or bow; access ramps can be attached to these openings. The ramps on board can be dispensed with, should the vessel be specifically designed to call at specialized terminals; in this case, the ramps are part of the terminal.

There is a wide variety of ships that can take rolling cargo on board.

The ferry-boats pioneered this kind of operation, mainly engaged in

the transportation of both passengers and vehicles within commuting distances. Contrary to a long-term stablished use, mainly in Europe, ships of such kind have not yet spreaded in our country, despite the opportunities which should account for that; their traffic in mainly limited to the northern region.

The main purpose of a Ro-Ro ship is to speed cargo-handling up, so that time ashore is brought down to a minimum; many of the inherent disadvantages of ports can be virtually avoided, then. She also allows full completion of the door-to-door transportation concept. Particularly speaking, the main causes for the use of Ro-Ro system in Brazil coming to mind were deficient operational features of harbours and surpassed labour laws to severely disturb owner's budgets. Those two causes can be always related to personnel: very slow labor has been the character of national ports until not very long ago and laws concerning work of stevedores on board are still very protective.

Ro-Ro ships can be grouped in two big already known main classes: for short and long distance trades. This classification is, nevertheless, not so easily distinctive. We particularly prefer to consider the so-called ships for the short distance trade as coastal vessels, and the remaining to be deep-sea vessels.

Some main particulars that have generally prevailled among coastal ships (both on short or long routes) are:

- Length ranging from 100 to 140m;
- Breadth from 18 to 23m;
- Maximum draft from 5 to 7m;
- Deadweight from 3000 to 8000 tons.

Furthermore, such vessels cargo-carrying capacity in evaluated according to their container, trailer and vehicles loading and the total available lane length for vehicles, which are expected to be, afterall, their typical mainstay.

Two and three-deckers prevail among this kind of Ro-Ro. They also more commonly have accommodation for about nineteen people, internal access by means of lifts or fixed ramps (the latter are preponderant) and a small superstructure (either aft of forward, according to the design philosophy).

Deep-sea Ro-Ro vessels are the result of recent development. They are generally intended to take those types of cargo which afford best use of available volume on board. Certainly this is not always the case for short-route traders, taking trailers, for instance. They have also some other outstanding features, such as:

- Overall length over 170m;
- Breadth over 23m;
- Deadweight about 10000 tons and over;
- Maximum draft of 10m.

Maximum number of fixed decks has been keeping to four. Such ships are generally provided with facilities for refrigerated containers; pallets and containers are more often carried than trailers. Many Ro-Ro vessels intended for a particular trade are supplied with their own means for suitable cargo-handling.

It would be possible to furtherly divide Ro-Ro ships into other categories, but these would become, anyway, sub-classes of the main groups shown. Further sub-division into more classes arise generally as a function of the purpose of the vessel: a container-carrier, a pallet-carrier, a car-carrier, and so forth.

2.0 - CARGO TO BE TRANSPORTED/TRENDS

Unitization of cargo to be handled is currently a process which cannot be reverted. It simply comprises grouping a certain ammount of different items into a standardized unit; the effective quantity of pieces to be handled is then remarkably reduced. As a consequence, transportation can be economically integrated into the production-distribution-consuming cycle (or into the "door-to-door" process), which is quite prominent since 80% of goods can be considered to be fit for carriage in containers.

Getting the most of cargo unitization is being best achieved by the intermodal transportation system, which namely means carriage of modular loads by several integrated means. This, as a natural consequence of unitization is undeniably becoming more and more imposive. In this system, goods are shipped either in containers or on trailers from origin to destination without any disturbance; maximum efficiency with minimum costs are naturally attained.

In Brazil, maximum efficiency has not yet been reached, since the system has seen one of it cornerstones to fall off; namely there has been some handling of cargo out and back again into the containers and onto trailers. According to shipowners, the Customs have still too large an interference on the process, since the regulations make it a point that cargo inspection is to be thoroughly performed. Both ship-owners and government are now engaged in an effort to counteract this problem so as to overcome this ackward position; hence, an overall better usefulness of the system is to be expected.

If we concentrate upon this new philosofy of transportation, the means through which it's accomplished deserve a brief description. These are containers, trailers and vehicles (cars) in general.

There's a large range of types of containers and, nationally, so as to say, the most widely used are the general cargo (commom box-closed type), the truss-framed, the open top, the tank container and the refrigerated one.

The enclosed box-type containers are the most important in the system. They may carry manufactured goods, cannery, bottled items, home appliances, chemicals and so forth. The truss-framed type consists of a group of pallets joined together and can be loaded with nonperishable goods, mini-containers, gas barrels, etc; they are cheaper and low operational costs and good efficiency can be assured. The open-top type is meant for the carriage of heavy items, such as steel sheet coils and general machinery; they may be supplied with a side opening for easy handling, by sliding cargo or with the help of fork-lifts. Tank type containers carry liquids in bulk, as oils, oil prods, acyds or gases, etc. Refrigerated containers take perishable goods, requiring that more expensive facilities are supplied.

Using trailers as a vehicle within the whole system brings some remarkably important advantages, since cargo managing is small and stowage conditions are bettered. In some cases the final price of a certain good can be lowered by from 12% to 20% if correct use is made of the system using trailers.

It's extremely important for the owner to have his ships loaded and/or unloaded as soon as possible. This can be understood when one realizes that the load-carrying capacity of vehicles taken on board of ships is very low. Take, for example, a 40ft trailer: it requires a block, inside the ship, of 12,5m x 3.0m, (inclusive of clearances and lashing fittings) plus a height of 5.0m, which totals up to $190m^3$; nevertheless its internal capacity is to about $70m^3$, which means close to one-third of the volume taken on board.

Transportation of cars and small trucks calls for a broader range of facilities to be supplied. Containers and trailers require lashing and locking fittings; small vehicles also require these and the "cardecks", with all sorts of ramps and additional equipment. Carriage of such items request that ventilation and fire prevention and extinction be performed according to strict regulations, for they usually take fuel in their tanks.

One more concept must be clearly pointed out. Being a country in search of a full development stage, Brazil is particularly engaged in a process which assumes that great works are still to be tackled, as in any emerging country. This fact automatically brings about the need for transportation of heavy machinery, such as oil-discovery and exploration equipment, dam turbines, and so on. Shipowners are currently specifying that the access decks of new ships are to be correspondingly prepared to deal with such items. Brazil has become a well-succeeded weapons exporter, so the possibility of taking this type of cargo on board can never be disregarded.

3.0 - GENERAL CHARACTERISTICS

The basic particulars stated in chapter 1.0 are to be adapted to the national trend, with regards to the several types of loads to be carried, briefly described in chapter 2.0 . First investment required can't be despised, however: shipowners always seek for profits, but the necessary equipment and facilities go against that. In search of a balance, the greater part of national owners have been disregarding the deep-sea Ro-Ro, or ships with such particulars. This is acceptable, as they have little experience in this trade or, in some cases, they have no experience at all, as the road transporters joining the intermodal system. The common trend has been towards using short or long range coastal Ro-Ro vessels.

They generally have the general characteristics outlined in chapter 1.0. When it's not so, the reason is the desired versatility in an-ever increasingly successful system as a whole; that's why the carriage of containers, trailers and cars is always in mind of both the newcoming shippers and the design team. A maximum three fixed decks can be taken as a general rule, but a common line of thinking hasn't been stablished yet as to which type of equipment should be used; this can be explained by our flag's little background on the system.

Brazilian owners have the quarter stern ramp as the top-of-their-lines external access mean. Axial ramps are common too, but there's no case of using slewing ramps or more sophisticated means. Regards to internal access means, the initial trend was to use lifts, but it has evolved to currently adopting fixed ramps, detrimental to cargo stowage areas, excepting the particular case of access to tanktop, in which lifts are still mostly used. Requirements that movable car-decks be installed on board have always been a demand; the only point not entirely agreed upon is the quantity of movable decks in-between each two structural decks. Top priority has been given to access by stern; it has never been reported that a brazilian carrier departed from this.

To prove the growth of Ro-Ro concept among us, the requirements posed by shipowners on minimum clear heights are almost always related to future carriage of two stacks of 40ft containers, or even stacking of containers more than 8 1/2ft high, now a common fact in most of the foreign well experienced trade centers. This mirrors their concern on the current international trend. In the chapter concerned to selection of equipment the reasons for the choices mentioned herebefore will be shown. We will try to analise them under the designer's standpoint, considering their eminent pros and cons.

4.0 - CARGO ACCESS EQUIPMENT

Whichever are the means envisaged for the access of cargo to Ro-Ro ships, the main goal is essentially the same: loading and unloading operations are to be performed as fastly as possible, yet with due accou to the overall mooring flexibility of the vessel.

Cargo access means can be most generaly be considered as "external", through which cargo is brought aboard, or as "internal", through which cargo distributed after placed in the ship, notwithstanding the external means may work as previous cargo sorters.

4.1 - EXTERNAL MEANS

4.1.1 - External Ramps

External ramps are commonly installed on the stern, and can be placed either axially or angled from 30º to 40º with respect to the ship's certerline. They can also be slewing ramps, which can be set to up to 40º on either side of the ship. Their positioning is to consider essentially the offset angle regards to the centerline, if there's any, and the threshold height, that is closely related to the ship's draft.

A shallow, or lower, external ramp can be more easily negotiated by the vehicles, leading to faster load/unloading operations, and it will be slightly shorter too, leading to smaller costs. In this case, the threshold height will result to be lower, and the internal ramps leading down from the access deck shall be also shorter and will be confined to the aftermost portion of the decks located bellow, thus allowing more free space forward, certainly a very important feature on a narrow region ahead, in such a case as the tank top. Placing the threshold in a lower position has some disadvantages, however. The steering gear compartment and machinery space clear heights will be smaller, which will be troublesome when functionalism and arrangement are considered. It should be remembered that a smaller clear height within the machinery space could hamper the use of a low-speed (long stroke) main engine; this point is to be carefully considered when the shipowner's requirements are compared with the design possibilities. The compromise

answer to this question can be a slightly sloped access deck, spanning to the flat portion of the deck at the engine room fore bulkhead or closely forward of it.

It is an obvious fact that the main dimensions of the vessel, such as her depth, draft, minimum freeboard and the planned internal arrangement, should also be taken into account; so should be the ports to be called at, considering quay heights, tidal variations and their facilities. The expected kind of rolling traffic, namely their height and unit loads, also affords and limits the final decision on the positioning of the ramp.

It is generally accepted that a slope of 1:7 (aproximately 8º) is fit for the normal handling of loaded fork-lifts, trucks and roll trailers. This slope should be kept to as much as possible, despite the different quay heights and tidal variations to be encountered; wider tidal ranges lead to longer ramps, so that the optimum gradient can be coped with.

Ramp width is also an outstanding feature, since loading and unloading rates will be a function of it. Common trucks require from 5.0m to 6.0m, and fork-lifts need at least 8.0m when taking a 20ft container. Angled ramps are built with a 50% extra width margin, in order to permit an easy turning of vehicles. Double-lane ramps allow two-way traffic, such as ingoing loaded cargo and outcoming hauling equipment, calling for shorter turnrounds, detrimental to their higher initial cost.

Accounting for harbour facilities and onboard ramp costs are a must, considering the angle between the ramp and ship's certerline. Axial ramps are surely cheaper, shorter and less cumbersome, but the ship will only be able to berth stern-on or in a corner, which are not always available. Generally speaking, it can be stated that these ramps are usually fit for line trading, calling at specific ports.

To the contrary, angled ramps are generally installed on ships meant for a go-anywhere ability. Berthing is accomplished conventionally, though always on a same side.

Its use on small ships is not practical, namely owing to them being heavier and also narrower when related to the ship's breadth, and more costly. Their offset also give rise to large hell angles.

The so-called slewing ramps can avoid all the disadvantages of the foregoing types except in small vessels, where its offset position can still be troublesome, leading to a narrower entrance space and manouverability problems on the threshold zone. They are, however, more expensive and have a high maintenance cost. Slewing ramps are also placed as much aft as possible, not a major concern on the axial or fixed-angle types; this measure brings about the need of a stronger supporting structure and an addition to the overall bending moment acting on the hull-girder. It is quite clear, then, that the choice of ramp type to be adopted requires a very careful analysis of the shipowner's needs.

The access ramp opening on the hull must be made water-tight, and this is accomplished either by means of an appropriate door, quite similar to the common weather deck hatch covers, or by means of the own ramp, which acts as such. In the last case, there are some limitations, regarding the size of ship, threshold height and routes to be served. Door clear width should be fully suited to the ramp and its clear height will depend on the expected traffic, with special attention to long, articulated trucks rolling over short and steep ramps. Less usual arrangements comprise bow and side ramps and doors, as well as twin or triple stern ramps and doors.

4.2 - INTERNAL MEANS

4.2.1 - Ramps

The aforementioned guidelines for the selection of ramp slope are also applied to the internal ramps. Due attention is to be paid, however, to the necessary clear deck heights, their athwarth and longitudinal positioning, structure scantlings (e.g. deep beams web size) and, obviously, the height of the vehicles to be handled.

Particularly speaking, there are two opposite possibilities: a shallow ramp will enable easier upgoing

movements, with lower exhaust gases emission rates, or a steep ramp, rendering to better cargo space utilization. When exhaust gases emission increases, so does the required capacity of ventilation equipment, though it cannot be denied that steeper ramps can still be used for cargo stowage too. Traffic height, deep beam web scantlings and the desired clear space between structural decks are fundamental figures when stablishing ramp gradients, which are normaly around 1:7. One should bear in mind that the access opening on the upper spanned deck is to be kept to a minimum, so that no cargo space is wasted and the dimensions of the opening cover are made as small as possible. This opening cover is always necessary on the freeboard deck.

Ramp gradients at its upper and lower thresholds are to be carefully studied, so as to prevent groundings at those points, specially of long, articulated vehicles or those having a long axle distance or overhang. Steeper ramps normally have their uppermost and lowermost regions built to a smoother angle, to avoid that.

When locating the ramps in the ship one must make allowance for an adequate manouvering area both on top and bottom, specially if the ramps lead to the tanktop, which is normally a narrow zone, or to the weather deck, owing to superstructures and deckhouses..

Internal fixed ramps are not usually placed on the same side on the ship and this fact suggests that three lanes will be arranged, one under each set of ramps and one close to the ship's certerline. It can be clearly seen, then, that the choice for installation of fixed ramps on board keeps close relationship to the vessel's breadth. Since there is always a suporting structure for the ramps (pillaring), coping with a rational distribution of lane widths way become difficult to achieve, since minimum clear width requirements are always present. Clear ramp and lane widths are governed by the type of handled cargo (considering the presence of web frames and pillaring). These widths are dramatically increased in case containers have to be moved by fork-lifts (a minimum of 7:0m to a TEU). These particulars become critical in the case of small ships.

Movable (pivoting) ramps are mainly used in smaller ships. Notwithstanding their bigger cost, the internal arrangement becomes simpler and useful stowage areas can be made optimum, with regards to the extra initial expense, when the ramp works as its own opening cover. This may be not always possible, as is the case of ramps leading specifically to car-decks; the movable ramp will, nevertheless, always enable an easier general arrangement.

Internal access doors are installed on bulkheads located bellow the freeboard deck, placed from side to side athwarthships. This is necessary for the watertight integrity of the vessel. They are, in such case, to be made watertight and fire-resistant too.

Internal doors may be hinged or sliding, the former may be foldable or not, opening to one side or pivoting to the deck located just above. The choice of type depends on the available space around and required width. Their purchasing and maintenance costs should be considered too. In case there is an internal ramp which leads to the weatherdeck, a door is a must. This is generally a simple door, hinged to turn above. Once more, clear height and width are a major concern.

Maximum available stowage space is, evidently, the mainstay of a successful ship design. In a Ro-Ro vessel such ideal space, besides the ones meant for manouvers, may become difficult to achieve, owing to structural items and equipment related to cargo managing, as it could be seen. If this difficulty turns out to be critical or if there is a loss in the arrangement functionality, installing means intended for vertical cargo transferring may be suitable. These are the lifts.

4.2.2 - Lifts

This kind of equipment has an extra advantage: it may he also used as stowage area when not operating. Despite bigger first and operation costs, there is considerable saving in ventilation fittings, since the emission of exhaust gases is much smaller than in the case of using

ramps; this fact can be definite when a decision on its use has to be taken.

There are two basic concepts for employing lifts, and these are marked by the attempt to bring back into use the initially wasted well opening area, on any of the decks. In the first, the stowed lift platform is employed as a cover to close such opening on the deck; it is required that hinged flaps be installed on the lower decks to enable cargo handling. The second one calls for the building of a recessed lowermost deck, the opening above being closed by means of a common hinged cover. This last arrangement is widely used for lifts which go up from the tank top, since the recess depth is not usually small.

Lift platforms can be powered by electrical or hydraulic means. The contrivances which move the platform may be wire or chain systems or a scissors device. The scissors type lift doesn't require necessarily that pillars be installed; in this way, the surrounding area is clear from obtrusive structural items. The big space needed for concealing the actuating mechanism practically limits its use to lifts which go to the tank top. For wire-operated lifs, not less than two (usually four) pillars are to be provided for guiding and balancing the platform. The driving mechanisms are much more unobtrusive, however, and the whole system can be extended to several intermediate decks. Furthermore, at least two pillars can be made removable, that is, they can be installed just prior to beginning of operation, which partly adds to better stowage conditions all round. Chain-driven lifts are a more dependable system, with lower safety margins and greater time between the overhauls, which turns into lower costs and weight. As the driving devices are directly secured to the platform, its stowed position is not usually on the lowermost deck; a flap must be installed, then. Pillaring resumes to normally only two and in case the lift is placed close to the side shell, as usual, they will not be a big obstruction to the manouvering area. Their lifting capacity is normally within the ones for the scissors type (maximum) and the wire type (minimum).

Lifts are to be located where there is enough space forward and aft the platform to account for the standing-by and turning of traffic; attention is still to be paid to the traffic flow on the accessed-to decks. It is, therefore, unwise to have lifts abreast on a same deck. A lift driving from or to the quay access deck should be installed as much aft as practicable, but special care is to be taken if it leads to the tanktop, since the engine room fore bulkhead is always there.

Certain disadvantages become apparent when choice for lifts and their positioning are studied: loaded fork-lifts must be provided with a reasonable athwarth turning area, which must be kept clear until load/unloading operations are off, thus complicating general storage on ship. Adding this to the required pillaring, brings one to the conclusion that lifts should be always placed close to the side shell, as mentioned before. There is another negative point: operation of lifts is not continuos, that is, there's a cycle comprising loading-transferring-unloanding-re-seting. In straight oposition to internal ramps, which enable an almost non-stop traffic flow, lifts require careful ordinance of storage sequence, so that not too many vehicles come to a stand-by situation near the platform. This non-continuous availability of lifts is of crucial importance, regarding their adoption. Usually a complete cycle takes, on average, 7 minutes to be fulfilled. When one considers the expected volume of cargo to be handled, the deck area to be loaded, available personnel (stevedores) and maximum allowable time ashore, the installation of lifts can become prohibitive from the operational standpoint when short turnrounds are a must, combined with a large quantity of containers on fork-lifts to be worked, for example. The decision to use ramps instead of lifts comes out naturally, except in the case when space is at a premium aboard.

All in all, the most severe disadvantage of lifts, which is common to all non-fixed (mechanical) access means, is the

possibility of a failure stopping all the operation, mainly if it is the only access device to one or several decks. Even if correct operation and maintenance are performed, the risk is always inherent to the system in a day-by-day ship's life, and it should surely not be despised when lifts are compared to other access means which are, by their nature, less liable or even not liable at all to mechanical damage. This point is more strongly emphasised in countries whose crews have not yet become acquainted to operating this type of ship. The shipowner then plays a major role in the choice process, for only he knows exactly the operation and maintenance standards that can be counted on. Extra initial cost is another cornerstone in the shipowner's judging.

Mechanical internal means always depend on a power source, either electrical or hydraulic. The ship's facilities are to be duly increased to adequately manage the extra loads, which, by its turn, renders to higher instalation costs.

4.2.3 - Car Decks

Car decks are not exactly access means, but the movable ones give their aid to distribution on board.

Hoistable car decks are generally employed, except in pure car-carriers. When hoisted-up by wires against the structural deck above, they enable a wide cargo-carrying ability. Posible configurations are "cars only" (a car carrier) or cars/trailers. The former is marked by small clear heights between decks, and the second can be described by the mixing-up of all types of loads along the vessel, providing trucks, containers or other items can be taken under one stowed portion of the movable deck.

Car decks are made up of modules, or panels, consisting of a steel grillage covered with plywood or steel sheet deckings. They can withstand normally up to 1.0t axle load or $0.25t/m^2$ uniformly distributed load. Clear deck heights vary from 1.7m to 2.0m, depending on the kind of vehicles to be dealt with.

They are generally hoisted by means of hydraulic jigger winches driving wires through pulleys. The winches can be accomodated in some panels or in some exhisting pillars which also help guiding the panels during rising; hinged guiding and interlocking arms can also link two panels placed one above another. Access of cars in generally via movable ramps, provided with adjusting devices for each required working position. Those are steeper and narrower than all the other general-purpose ones, since they will have to be managed only by light vehicles.

4.2.4 - General Appraisal - Limitations

Whichever non-fixed means are devised for cargo access, they will always raise certain operational limitations of the ship and of the Ro-Ro system as a whole, appart from all their other inherent functional disadvantages, as mentioned herebefore.

External access stern ramps are very sensitive to tide variations, heel and trim of ship as loading or unloading progresses. Ballast shifting is the immediate solution. Typical heel angle values to be expected are from 2º to 3º to big ships and up to 5º for small vessels. These can be accomodated by the flap lying on the quay, by construction or by special self-contained devices, in the ramp. It is desired that the ramp be able to deal with a 2m wide range of distance between ramp threshold and quay; if this range is compared to the ship's length, one can then picture the acceptable trim limits. If trims are excessive, internal ramps can come to be too steep to be fairly or successfully worked by the traffic.

Lifts are the most sensitive items to heel and trim. Common limits are 3º for heel and 2º for trim; platform movement is automatically halted in case those ranges are exceeded.

Car deks are also prone to the same adverse effects of heel and trim, although to a less extent.

Selecting the most adequate access means is naturally a process in which the choices are not exclusive of one

another. Under certain circumstances, for example, the combination lift-plus-fixed ramp is particularly interesting, mainly if the lift leads to lower decks and the ramps lead to upper decks, both from the access deck.

The common practice and some owner's requirements can provide lots more unavoidable limitations. He may, for instance, have in mind quite specific items to be carried, and this will probably unfavor the ideal designer's arrangement, when it all comes to depths, breadths and so forth. Last but not least, the owner should have his own personal "taste" for a certain type of equipment, based on his own previous experience on maintenance, availability, and so on.

4.3 - CARGO HANDLING EQUIPMENT

If it is the owner's intention to have a ship suited for general cargo transportation, even if in unit load modules, then means for horizontal shifting of loads are to be supplied. The most common are the fork-lift and the roll-trailer, the latter being hauled by a heavy-duty tractor. They are specially suited for container handling. Compact stowage of unit loads is always to be aimed at; both the fork-lift and the roll-trailer perform this task with equivalent and good efficiency.

Fork-lifts are very dependable and relatively cheap. Their unfavourable characteristics are, as a system, their high front axle load and troublesome manouvrability and, particularly, potentially dangerous loaded stability conditions when going down a ramp and the additional stacking clearance required. In any case, makers are currently developing new stacking devices for side or top loading, swivelling cabins for better visibility on down slopes (backing-on), as well as more and bigger front tyres. Side spreaders or top lifting are unvaluable in case there are severe clear deck height limitations.

The tractor/roll-trailer combination is very suited to a broad range of uses, and top flexibility is then achieved by an owner's terminal. They have a small turning radius, so that cargo can be accurately stowed on board, and are lower than common road trailers, calling for smaller deck heights. High concentrated loads have to be faced, however, for the roll-trailers are provided with solid rubber tyres. Another negative point is the danger that uncoupling of tractor and trailer happens on top of a ramp.

More sophisticated cargo-handling equipment is becoming available but they are, as far as we can see, less adequate to the current conditions of newcomers to the Ro-Ro trade, such as brazilian shipowners.

5.0 - THE BASIC DESIGN

We shall now present what we suppose to be the most important features in the development of the basic design of Ro-Ro kind of ships. The intention is to highlight, for each specific branch of basic design, not only the particulars of this type of vessel, but also some possible design choices in relation to effects of oil cost rising or unique national shipowner's requirements, for instance, on the current trend.

5.1 - THE NAVAL ARCHITECTURE DESIGN

5.1.1 - Main Dimensions and Hull Form

The choice of dimensions, their ratios and hull form depend on several considerations to be made about hydrodynamics and service conditions, such as types of cargo to be carried and routes, cargo handling equipment, speed, stability and manouvrability.

Envisaged routes may be restrictive in relation to their own limitations, like depths, width of canal or dam locks, clear overhead space under bridges, and so forth.

Types of cargo expected to be carried, with due information on their dimensions and the necessary handling means, will mostly have influence on the selection of ship's breadth and depth.

Speed, stability and adequate manouvrability are sometimes troublesome to be plainly attained together. The relatively high speed demands fine hull forms. The length-to-breadth ratio is to be small, since this adds to good manouvrability, but the breadth is to be as large as possible, for easy stowage of containers and trailers on board and so that stability doesn't become a headache. The best overall performance will only be obtained if thorough examination of all possible combinations is carried out.

Available data for preliminary estimating the characteristics of conventional ships is widely known; the same cannot be said about that on Ro-Ro ships, unfortunatly. The designer's work is a very helpless task, since LCB position, lightweight and main dimensions cannot be easily ascertained for in early stages of design.

5.1.2 - The General Arrangement

This is the step following to preliminary definition of hull form and dimensions.

A successful result of this stage can only be granted if the following items are carefully considered:

- Types, dimensions and means for cargo handling;
- Routes to be worked;
- Position of accomodation (whether fore or aft);
- Position of uptake from machinery space (whether on center or on sides);
- Troubleless cargo handling from marshalling area into the ship and vice versa (external and internal access means);
- Number of passengers intended to be carried on board.

The types of cargo, as well as their dimensions and handling methods, will dictate the quantity of decks and their positioning (clear deck heights); this should have already been roughly done in the foregoing stage. The kind of decks to be adopted is also to be checked against the type of cargo: if, for instance, it is foreseen that high loads and cars are to be taken together in a same trip, it may be interesting to have movable car-decks, which account for greater flexibility of ship use, further reducing the break-bulk character. Expected load types and dimensions, as well as the means envisaged for their moving, the particular trade in which a ship is to become engaged and rate of cargo flowing will also dictate the kind of internal access media, as will be seen latter.

There's still a lot of controversy as to whether accomodation should be placed aft or forward. It can be stated, although not as rule, that deep-sea Ro-Ro ships have their accomodation located aft, while short and long coastal traders commonly have their superstructure arranged forward. The choice process should consider mainly safety and comfort of crew and cargo, adequate weight distribution (trim control) and hydraulic plants.

Comfort in a superstructure situated forward will be better, providing noise and vibration levels emanating from main and auxiliary engines and propellers will be smaller.

Nonetheless, greater amplitude of vertical movement and accelerations call for accommodation to be placed aft. Deep-sea Ro-Ro ships may come to face rough seas; the high waves are a potential danger to superstructures arranged fore.

The high depth of such vessels is, nevertheless, to a certain extent, a shield against this hazard.

Rough sea states are also the major concern when cargo safety is considered. On basis of the foregoing reasoning, the obvious conclusion is: fore superstructures protect cargo but expose the crew, while aft superstructures act on the opposite way.

Better weight distribution is undoubtedly achieved if the accommodation is placed fore, as it will contervail the effect of stern ramps and the engine room, which are normally installed aft.

Hydraulic systems tend to be less complicated when the superstructure is located close to the stern; in this case pump capacities can be smaller and pipework can be shortened. In case the accommodation is placed fore, either the pipework is to be led to the machinery space, or adequate equipment must be provided within it, to supply the required needs.

Position of the machinery casing is another matter to be studied by the design staff. Arrangement within the engine room can be improved by a centered casing, but in such case free moving of cargo along the access deck may be impaired and abboarding of bulky items may become impossible. Placing the uptake, or uptakes, close to the side, or sides, of the ship is the natural solution to add to her overall flexibility.

The design team is also to consider the number of passengers to be taken by the ship. If she is intended to carry more than twelve, then the SOLAS rules applicable to passenger vessels shall be complied with. These mainly concern to hull subdivision bellow the freeboard deck. We will come back to this point when damaged stability is dealt with.

5.1.3 - Freeboard

Upon calculating the required minimum freeboard, the rules for B-type freeboard general cargo ships can be applied to Ro-Ro vessels, provided that the number of passengers is less than twelve. Whenever this limit is not kept to, the rules for passenger ships have to coped with, which mostly affects the general arrangement, as stated herebefore.

It's particularly interesting to notice that Ro-Ro ships generally have their freeboard deck placed below the weather deck. It is then considered that openings on the sides or on the fore or aftmost portions of the vessel are supposed to allow the coming of water into the ship, thus allowing deck immersion under small heel angles. Furthermore, in order for the space in-between the freeboard and weather decks to be considered as a "superstructure", in freeboard calculations, the requirements of paragraph 10, rules nº 3 and 12 of the 1966 International Load Line Convention are to be complied with, which state that openings on boundary bulkheads of superstructures are to be closed by steel doors (or equivalent material); these are to be firmly and definitely secured to such bulkheads, stiffened and provided with adequate closing means. The bulkhead on which a door is installed is to be as weathertight as an intact one and means for opening or closing are to be afforded to either sides. In relation to Ro-Ro ships, specifically, the latter requirement is the only one that can be dispensed with.

In order to cope with the demands stated in the foregoing paragraph, it is generally necessary that the vessel be equipped with a door beyond the external access ramp; in case of ships intended for restricted water service, the need of such door is to be analysed by the design team alltogether with the Classification Society, for it may become not necessary.

Minimum required bow height is also to be checked whenever the ship has as open weather deck, as the special certificate issued in accordance to article 6 of the 1966 International Load Line Convention is hard to be obtained in such case.

5.1.4 - Intact Stability

Whenever the government do not issue specific requirements for Ro-Ro vessels, A-167 IMCO resolution can be applied when checking the ship's intact stability. This resolution is intended for ships of up to 100m length, but it has been very widely used for any lengths in many countries.

Ro-Ro ships are intended to carry a very unique kind of cargo, may possibly take passengers and have a high depth; their stability analysis is to carried out, then, taking due accont of these particulars. The high depth, for instance, leads to a large sail area, which can be dangerous if crosswinds are encountered.

Increasing the GM value (metacentric height) in order to obtain the best intact stabilitty conditions of a loaded ship can be fouling. In relation to that, two comments can be made: first, a good GM value is necessary but is not sufficient, in itself, to assure good overall stability conditions. It is of utmost importance for these conditions to be attained that the statical stability curve (the GZ curve) be good, in compliance with the stability criteria adopted (such as the IMCO A-167, for example); also, typical cargo of a Ro-Ro ship is uniquely sensitive to transverse accelerations. High GM values give rise to small rolling periods which can damage the lashing fittings, leading to disastrous ocurrences.

Aside from an adequate stability for safe navigation, the Ro-Ro vessel is also to rely on an efficient control of heel and trim during loading and unloading, as a must. Heel angle has to be limited during such operations, and compensation by ballast changeover is to be accomplished, either automatically or not, if such limit is exceeded. Trim is mostly related to keeping the threshold height in relation to quay within certain allowable values, so that ramp management is not disturbed. It is obvious that trimming the vessel severely in such a situation cannot be accepted, which claims for careful balance to be seeked after. It can be immediately concluded, then, that a Ro-Ro is to have a lot of ballasting capacity, in tanks distributed adequately all around the ship, so that top-flexibility in dealing with correction of heel and trim can be attained. The ballast capacity-to-deadweight ratio of Ro-Ro vessels is normaly in the range 0.40 to 0.50.

5.1.5 - Damaged Stability and Subdivision

An analysis of damaged stability is only required when the ship is classed as a passenger vessel.

It is of current worldwide practice to consider the drivers taken in a trip to be passengers; there was a disagreement in relation to this untill some years ago, as it was sometimes advocated that they were physically fit for aiding the crew, should an emergency occur. This point-of-view has been debated by an IMCO sub-comitee on "Stability, Subdivision and Load Lines"; this concluded that drivers must be considered to be passengers.

If it happens that a ship takes more than twelve of tham, the requirements prescribed in part 8 - Chapter II.1 of SOLAS 1974, as well as all other applicable regulations, are to be complied with. This will surely lead to some impairance of free circulation of cargo along decks located under the freeboard deck, owing to subdivision needs.

Drivers are sometimes held as "special" passengers; in this way, some Classification Societies and Government, by mutual agreement, can relax some of the restrictions to the benefit of the general arrangement, such as:

- It is allowed that wide watertight doors be installed on watertight bulkheads, to make cargo movement easier;
- It is allowed that the real permeability factor for cargo spaces be applied in lieu of the 60% value as per SOLAS 1974.

Nevertheless, it is wise to perform a detailed analysis of a wide range of loading conditions of the ship, so that her ability to withstand damage can be fully produced, so long as the application of the foregoing is not entirely agreed on, or until new concerning regulations come into

force. Norway and France, among other countries, are currently developing specific regulations on Ro-Ro ships. This procedure should be always followed when the design team is in search of an abatement of a requirement.

If the ship is classed as a B-type freeboard cargo vessel (carrying no more than twelve passengers), it is only necessary that she be built with a collision bulkhead and the machinery space fore and aft bulkheads; since the distance between these watertight bulkheads is generally big and owing to the wide holds, it is recommended that the design office performs an evaluation on the damaged stability and subdivision of the vessel, even though these are not required for the B-type class of ships.

An important source of information to help guide the designer towards safer ships is that concerning accidents, their causes and results. A recent survey, namely ref. (3) showed that main causes have been:

- Collision (28%);
- Damage of machinery (18%);
- Grounding (14%);
- Shifting of cargo and operation (12%);
- Fire and explosions (10%);
- Contact (10%);
- Other causes (8%).

This survey considered a total 243 accidents; 161 of these led to serious consequences and 28 led to ship loss. Main causes of serious accidents have been:

- Collision (24%);
- Damage of machinery (17%);
- Grounding (17%);
- Shifting of cargo and operation (16%);
- Fire and explosions (14%);
- Other causes (12%).

Accidents leading to ship loss have been caused by:

- Shifting of cargo and operation (43%);
- Collision (25%);
- Fire and explosions (18%);
- Other causes (14%);

Shifting of cargo and operation bear the major responsibility for ship losses and comprise:

- Simple shifting of cargo owing to failure of lashing devices;
- Flooding through doors and ramps owing to excessive heel or trim, as a result of cargo handling on board;
- Flooding through doors and ramps owing to failure of equipment or careless closing;
- Flooding through doors and ramps damaged by lose cargo impact.

Collision has resulted to be the second main cause of ship losses. They have generally occured in sheltered waters or at harbours and placed as first responsible for casualties (four out of seven). This can be explained by the short period between collision and ship capsizing or sinking.

From the foregoing, some recommendations can now be inferred, aiming at lower accident risks and less serious consequences. These are listed below:

- Ship subdivision should be planned so as to weaken the adverse effects of flooding. Ideally, a subdivision to comply with SOLAS 1974 requirements for passenger ships or to Resolution A 172 (ES IV) by IMCO (referring to rule 27 of the International Convention on Load Lines, 1966) ought to be worked out. Nevertheless, building a double-skinned vessel all the way up to the freeboard deck can be considered as a step forward.
- Locking devices and lashing fittings are to be adequately designed to withstand the most adverse conditions.
- Crew should be given correct training, mainly on cargo handling and securing, as well as on safe operation of ramps and watertight/doors.
- Ships should be provided with auxiliary steering means for operation in restricted waters and harbour, like bow and/or stern thrusters, owing to their large sail area;

- Ships ought to be equiped with adequate devices for fire detection and extinguishing.

5.1.6 - Propulsion and Hull Form

On Ro-Ro ships the main access and engine room are generally located aft; this will surely tend to affect the choice of type of main power plant. Machinery space is to be kept to a minimum, so that the biggest available space is allowed for cargo carriage on the tank top; also, owing to stern door threshold height limitations, overhead space within the engine room is at a premium. The medium speed engine has been the most used, as it can more easily be concealed to such a small volume.

Ideal hull form will be, in itself, a blend of the best solutions to what is posed by the building-up process, arrangement and hydrodynamic requirements. The forebody is to be shaped according to U or V sections, faired to a bulbous or bulbless bow. The guidelines for the decision are the range of operation drafts and desired stability, manouvrability and seaworthiness. Ro-Ro vessels commonly have a large bow flare, as this feature enchances better deck areas for both cargo and accommodation. This has taken to very unusual designs, which are impressive for the sudden increase of breadths over a short vertical distance immediately above the DWL.

Choosing between a single or twin propeller hull form is the first step on the generation of the afterbody lines. The variables which come into the process are, mainly, the required power to achieve design speed and the operation drafts. Twin propeller underwater after forms provide better stability at full load drafts, fuller hull lines (which account for a decrease of the tendency for trimming by stern), smaller required height of engine room and an increase of propeller efficiency. Their unfavourable characteristcs have to be contemplated, however: their proneness to slamming and the worse flow patterns around the propeller, although the latter can be partly overcome if a twin skeg afterbody is used. Single screw hull forms act on the opposite way.

Vibration must be a designer's major concern, since it may become critical at close-to-maximum-power operation of main engine. Propeller-induced vibrations can be lessened by increasing their tips clearances in relation to hull and by assuring that a smooth flow will take place around the propeller. These two items are hard to be dealt with, as in Ro-Ro vessels LCB is designed to be about 2,5% of LPP aft of midship section, namely owing to the expected position of cargo LCG and to the requirements of large deck area aft, for easy access; propellers of large diameter also preclude fulfilling the foregoing, although using a high-skewed propeller (such that blades never enter the high-wake portions of flow at the same time), installing vortex-generators or locally reinforcing the stern structure can be adopted in an attempt to overcome this.

5.2 - STRUCTURAL DESIGN

Ro-Ro vessels are more critical than any other ship from the structural design point-of-view, which severely affects the internal arrangement. Basically, four points are to be looked into detail: keeping lightship weight to a minimum (structural steel work), local, transverse and longitudinal strengths.

5.2.1 - Lightship Weight

It's designer's dream to fully match and reach the optimum balance between minimum steelweight, higher possible clear deck heights with as few obstructions as possible; unless special grade steel is extensively employed, mainly in structure "corners", this is virtually impossible.

A wide breadth added to high specified deck loadings is surely a very unfavourable mixing, since it will almost certainly make the use of pillars unavoidable, otherwise the scantlings of both web frames and deep beams would impair a sound arrangement and perhaps alter the desired deadweight. Pillaring can avoid, however, large deck deflections. Even

if they are not apparently required, it is well worth the effort to check whether their use could allow smaller deep beam and frame web heights; this may enable another cargo lane to be provided, depending on the ship's breadth and on the unit width of cargo.

Shearing in the double bottom is to be investigated if pillars are used. It's to be pointed out that a higher bottom will be able to accept higher shearing stresses or, in other words, pilars can be more widely spaced, and hence a better arrangement is achieved. Nevertheless, a higher double bottom leaves less room for cargo stowage and may give rise to stability problems.

Bending moments acting on the hull-girder have also to be evaluated, and mainly the hull thicknesses are to be checked then.

5.2.2 - Local Strength

Local strength analysis of Ro-Ro ships comprises studying the behaviour of both decks (and ramps) plating and beams or longitudinals under point or evenly distributed loads. Point loads result from the action of container pockets, tyres of rolling equipment, trailer jacks, and so on. Several characteristics are to be available for figuring the decking thickness and stiffening scantlings: distance between axles, axle width, tyre dimensions and internal pressure, their typeprint, as well as the loads on each axle. Normally these lead to the most unfavourable condition, since evenly distributed loads are generally less severe under this point-of-view, and the container and trailer lashing fittings are commonly connected to local stiffening, such as brackets. The deck thickness will be a function of the applied load on the tyre print and the spacing of stiffeners. Spacing of frames can be slightly varied and the same is done to a wider extent to that of longitudinals; the ideal thickness is reached, then, by means of formulae issued by Classification Societies. To get steel weight to the minimum possible, a finite-element model of both plating and stiffeners can be built, and hence large deflections and plastic behaviour or material could be checked. In this case, the results lead to a comparison with the maximum allowable deflection when permanent setting is reached.

The complete study cycle will only be ready when local strength of longitudinals has been verified, since their spacing can be decreased in order to lower the required plating thickness, but then the stiffeners may result to be over-sized. The data necessary for these calculations are the same as for plating, but the most unfavourable load distribution on board must be known too. The process involves a continuous beam model, or preferrably a grillage model. Considering the practical lower limit for the scantling of longitudinals and the minimum plate thickness, all expressed in standard dimensions, the optimum combination can be found, then.

It should be considered that all cargo will be subjected to ship's accelerations and, in the case of vehicles, to the accelerations owing to their movement. The forces acting on plating and stiffeners are to be proportionally increased, and a common figure is about plus 30% to 40% owing to vertical acceleration of ship or movements. Pneumatic rubber tyres have a larger absorbing ability than the solid rubber ones. This fact partly counteracts the increase of forces owing to accelerations, specially when tyre pressure is low (for example, it is acceptable that huge fork-lift tyres are inflated to 85psi, instead of the normal 120psi). For roll-trailers crutches of trailers or container pockets, the situation is to be very carefully analysed, however.

Openings on decks or side shell have to be compensated for as is usual for other types of ships.

5.2.3 - <u>Transverse Strength</u>

A very careful and detailed study on the transverse strength of the Ro-Ro ship is the main particular of her structural analysis, if compared to traditional vessels.

Pillaring and transverse bulkheads are at a premium in

such ship, so the structural arrangement has an outstanding defficiency to resist racking of upper decks and frames, owing to heeling. The apparently uncomplicated solution is, then, to increase the scantlings of deep beams and web frames, as there will be high bending moments on the foot of frames and high shearing stresses within the beam/frame connections.

The extent to which those scantlings can be increased should be studied in detail by means of a rational analysis.

This is starded by modelling of the most severelly loaded portion of the structure as a three-dimensional beam-element assembly (or a grillage matched to several web frame models). Loadings comprised are the ship's own cargo and external (hydrostatic) pressure. Due attention should again be paid to the vessel's global acceleration on open seas. Several loading conditions are to be studied, namely ship upright or heeled, full load or ballast conditions, including all possible combinations of trailers, containers and general cargo positioning. Heeling the ship to about 30º fully loaded on the uppermost deck is a common practice in order to check the soundness of scantlings. This global preliminary study results in the displacements and actions on the boundary or each transverse web frame within the region under consideration; the displacements and actions are then used as boundary conditions for the thorough analysis of some web frames by means of a more accurate method: the finite-element technic.

The connection of web frame and deep beam can be accomplished with the help of brackets, increasing the deep beam web height, by a radiused corner or simply by a straight cross-joint. If this is used, there's a flange discontinuity which may cause high shearing stresses; thicker webs, special grade steels and top-quality welding and fabrication standards can partly overcome this. If any of the other methods is adopted, there will be a certain impairance to free shifting of high items along that regions or even avoidance to stacking of the desired amount of containers, for example. The current trend is towards building the cross joint all straight, provided that more accurate calculation methods and more reliable construction and welding processes become available. This is now a very common owner's requirement.

Secondary structures, such as uptakes and deckhouses have to be dealt with the same care, regarding racking effects. Another chief point to be inspected is the transverse strength of the superstructures, normaly well above the DWL. Transverse and longitudinal bulkheads within the secondary structures and the superstructures are to be adequately checked and stiffened to avoid fractures at their intersections.

5.2.4 - The Longitudinal Strength

Ro-Ro ship's longitudinal strength is focused on the same concepts of conventional vessels and is normally not very thorny at all, except when there are several large deck openings amidships, which is not common. Owing to local strength requirements, they have thick deck plating and heavy longitudinal stiffeners; the carriage of bulky items (high stowage factors) demands a "bulky" ship, so the deck clear heights and the vessel's depth have to be increased proportionally. These particulars are a benefit to the longitudinal strength.

The Ro-Ro ship is typically a hogging vessel, for the machinery space is located aft, the superstructure is placed forward sometimes, they have generally a low block coefficient with fine bow and stern hull forms, relatively high speed, cargo is evenly distributed along them to well aft and are usually provided with a heavy stern ramp.

Buckling of plates on upper decks is very unlikely to occur, nevertheless bottom and tank top structures are to be given due attention; hence, longitudinal framing is adopted, owing to the high compressive loads. If it happens that deck openings amidships are large it may become necessary to replace the wasted transverse area by deep longitudinal girders or by increasing the deck thickness.

Hull-girder bending moments and shearing forces have to

be at least approximately ascertained for in early stages of basic design. This is done for the several loading and ballast conditions a ship is expected to meet, so that it's stablished whether more longitudinal material is necessary or not. The scope is, then, checking whether a possibly required increase of scantlings will have an akward influence on arrangement and on cargo distribution.

5.2.5 - Rules of Classification Societies

Those parts of the Rules of classification societies which can be applied to Ro-Ro ships, such as frame scantlings, minimum plating thickness of shell and decks, recommended arrangement and scantlings of bow structure, and so on, doesn't mean any surplus difficulty with relation to traditional vessels. It is interesting to notice, however, the fact that the long portion of the hull above the freeboard deck (which is commonly the "main" or "access" deck) is considered to be a superstructure, despite it's uppermost continuous deck acts as the top flange for the hull girder. The explanation comes to be that the secondary transverse steelwork, inclusive of the side shell assembly above the freeboard deck is checked for local strength, leading to reduced member dimensions, while the longitudinal members have yet to be checked for global ship's behaviour and loads.

Air pipes of tanks situated below the normal waterline play an outstanding role in frame design. Mainly in the case of double skin tanks, it may be suitable to lead the air - pipes up to above the freeboard deck (+ 760mm) only, instead of leading them up straightly to the weather deck (+ 450mm). This will enable frame dimensions to be reduced, though it's needed to provide such airpipes with non-return valves for overboard discharge, when applicable. In this way, piping becomes less complicated, but the anti-pollution regulations must be checked for allowance of overboard discharging.

The majority of classification societies issue some specific applicable guidelines for Ro-Ro ships, but those are mainly concerned to basic design procedures or recommended practices, such as load conditions, and the available material for direct calculations is scarce. Since Ro-Ro structures are generally complex, a complete and rational analysis is to be carried out; in such case, the design office is supposed to produce all basic assumptions on load distribution, structural modelling and even the design criteria.

5.2.6 - Additional Comments

Deck framing is to the longitudinal system; the structural assembly thus obtained is of top-efficiency when deep transverse beams are introduced, considering the dimensions of both primary and secondary stiffening and their purposes. If there's a double skin, transverse framing is adopted within the tank region, even for the longitudinal bulkheads, as this allows lighter weight and eases the accomodation of ventilation ducts or access trunks.

Scantlings of frames situated over the freeboard deck can be furtherly reduced if deep side stringers are adopted. They span to every web frame, enhancing to a better overall side structure efficiency, as long as its rigidity is concerned, and may even work out as supports for lowered car-decks.

Deck girders may be particularly adequate, even if not specifically necessary from the longitudinal strength standpoint, since they provide connection between deep beams, becoming a useful point load distribution aid.

If pillaring is necessary for the support of cross members all along an opening located amidships, scantlings of such members and girders can be suitably reduced, for sure. The immediate conclusion is that positioning of such openings can be altered by structural analysis, provided the openings can be placed so that heavy-loaded members come to have smaller spans.

Torsional resistance of Ro-Ro ships is not a serious problem; their closed "boxed" shape is quite suitable to resist such action. In some cases it happens that all the effective support to torsion may be just afforded by the fore

peak and engine room fore bulkheads but, even so, a detailed study of transverse strength can be enough.

Structural decks are to be specified for a certain resistance to point and distributed loading, apart from the requirements of classification societies. Commonly, the specification for adequate behaviour under evenly distributed loads do not comply with the rule requirements, as these are related to height between decks. Point loads result, then, to be generally much more severe to suitable structural response.

In common practice, the maker of all cargo access equipment is meant to produce the actions on structure due to such equipment. Design of supporting structure is the designer's responsibility. Such is the case of the framework which bears the stern ramp. Since limitations to quay pressure cannot be avoided, a certain situation may arise as the ship berths to a quay with an imposed restriction to applied pressure; the supporting frame must then undertake some of the ramp weight in addition to that of traffic flowing, so that quay pressure limits are kept to.

5.3 - THE MACHINERY DESIGN

It is far beyond the scope of our work to make a full comparison of the various choices of arrangements and combinations available to the design team concerned with the machinery space and its appendages. Instead, a brief description of outstanding points to be investigated will be given, bearing in mind the national shipowner's current requirements, expectations and availabilities.

The basic design of the machinery of a Ro-Ro ship should mainly check the engine room arrangement, fuel consumption, propulsion machinery, steam generating plant and the steering gear.

5.3.1 - Engine room arrangement

The engine room is located aft and, generally, so is the main entrance into the ship. These lead to contradictory conditions to be satisfied, owing to entry requirements and specifications on minimum headroom within the machinery space. As a matter of fact, even a detailed study should be carried out on the ideal sequence of blocks sub-assembly, as there is a large ammount of equipment to be fitted into a tiny space.

If the superstructure is placed aft, the best arrangement in a designer's point-of-view will be obtained if the main engine can be located directly bellow the machinery casing. In this way, the casing, not to despise the fact that size should be as small as possible owing to the surrounding access ramps or lifts, could very easily accomodate boilers, topside tanks, and so on. Furthermore, uptakes could be directed to the sides and then taken up and off the machinery space to be joined together above the weather deck, within the superstructure, if so desired.

When the superstructure is arranged fore, the restrictions relating to overhead clearance for dismantling the main engine are virtually non-existent, provided a suitable opening is installed on the deck immediately above and means for accomplishing this operation are fitted underneath the upper deck.

5.3.2 - Fuel Consumption

This a primary factor nowadays; it's to be analysed side-by-side to maintenance and purchasing costs, so that the best solution is achieved. For practical purposes, the fuel rates for medium-speed engines can be expected to be about 155g/BHP.h, using fuel oil of 10100 Kcal/kg lower calorific value. Nevertheless, heavy fuel oil up to 3500 sec Redwood nº 1 at 38ºC can be burned, too. The latest range of low-speed engines can bring this figure down to 125g/BHP.h, with an extra advantage: fuel oil of up to 6000 sec Redwood 1 at 38ºC can be burned.

5.3.3 - Propulsion Machinery

Internal combustion engines are most widely used as the main power plant. For the national conditions, the steam turbine, either burning fuel oil or gasoil, or even the combination steam turbine driving an electric motor has little chances to become viable.

Medium-speed "V" engines are very popular, providing they are turbocharged and are low. The available power range

is adequate to most uses and maintenance is easily tackled due to the low overhead clearance required.

Latest engines are low-speed, long stroke equipment; they can unavoidably only be used when the superstructure is arranged aft and the casing in on the centerline, since they are broader and higher. It can generally be stated that medium-speed engines are ligther than their low-speed counterparts, and this comes to favour cargo-carrying capacity.

If, by any reason, a low-speed engine is to be used in a ship with aft superstructure, its height disadvantage can be at least partly solved if the standard turbo-charger is installed appart from the engine in itself, on the exhaust gases discharge duct. The separate set can then be attached to a platform suitably located.

5.3.4 - Steam Generating Plant

The simplest plant comprises a composite boiler, using the main engine waste gases or an oil burner; the working pressure is normally about 5 kg/cm^2, when burning oil of 1500sec Redwood nº 1 at 38ºC and 7 kg/cm^2 for the 3500sec Redwood nº 1 at 38ºC oil. Steam generation for the ship ashore can be performed by means of an economizer heated by the auxiliary engines waste gases, which leads to valuable cost-saving harbour operations, from this standpoint. It's worth mentioning that research work is currently taking place on use of the wasted heat from the main and auxiliary engines cooling water. The option for directly heating oil through the economizers (or the main engine exhaust outlet) is still not currently available in the national market.

5.3.5 - Steering Gear

The steering gear of Ro-Ro ships is always confined to a tiny area after engine room and under the (low) access deck, within a fine hull-form region. This, in many cases, precludes the use of traditional steering gears, provided there's not enough space for the tiller-driving rams to move freely. The rotary-vane gear is, then, the immediate solution.

Bow thrusters are the soundest means for assuring good manouvering conditions for ships calling at some of the national ports. They're becoming more and more a common requirement of shipowners for this type of vessel.

5.4 - THE ELECTRICAL DESIGN

A very unique feature in the design of the electrical plant of a Ro-Ro ship is the very wide variation in power demand. During a relatively small period this reaches a peak, namely during loading/unloading operations, for cargo access and transfer equipment will be operating. Since the generators have to cope with this demand, a whole plant may result oversized if the ship is forced to wait long for a berth, or if it remains for a long time in port, waiting for cargo. An ideal balance of the generating plant can only be granted if due account of a scheduled service is taken. If the ship is not intended for such a kind of trade, design often becomes critical for the national conditions.

Points to be described here comprise most commonly studied items of a Ro-Ro electrical plant, since there's not, in general, a single design guideline to be followed. The exceptions to this remark will be clearly noticed in the following.

5.4.1 - Electrical Power Supply System

This system is intended to supply alternating or direct current to all needs and would typically comprise:

- The Power System, rated to 440VAC 3ø, 60Hz, 3 insulated wires;
- The Lighting System, rated to 220VAC 3ø 60Hz, 3 insulated wires;
- The Communication System, which normally powers the alarms, radio and navigation equipment, etc. Common ratings are:
  440VAC, 3ø, 60Hz, three insulated wires;
  220VAC, 3ø, 60Hz, three insulated wires;
  24VDC, two insulated wires.

5.4.2 - Electrical Power Generation

A typical Ro-Ro eletrical power generating system would be provided with three main diesel-generator sets (normally syncronous - brushless type). Any of these should be able to stand, on its own, all the power supply requirements when the ship is steaming. Power needs ashore ought to be coped with by only two of the sets. The performance of the

generators must allow an adequate load distribution in case of parallelism.

Installing a shaft generator and two diesel-generator sets can be a suitable option, mainly for a vessel not equipped with a controlable pitch propeller. This will supply the power needs when ship is cruising; the remaining two sets will provide power for harbour requirements. The common practice is to allow parallelism of shaft and diesel generators operation only during changeover periods, namely from shaft to diesel generator or vice versa. Notwithstanding its higher cost, the plant comprising the shaft generator can become profitable after a short time.

An emergency diesel-generator set is normally supplied, which automatically comes into operation should any black-out of the mains system occur for more than 30 seconds; it powers the lighting, navigation aids, steering gear, communication equipment, an air compressor, engine room ventilation, a sludge pump and the galley. These are the essential items to be kept going, if normal power generation fails-off.

Transformers are to be supplied for the lighting system. For example, four transformers can be fitted, one of them as a stand-by source. The remaining three can be connected according to a delta-delta wiring, thus composing a three-phasic station.

One set of lead-acid batteries provided with automatic charger is to be supplied. This set feeds the 24V D.C. emergency lighting system.

5.4.3 - Electrical Power Distribution System

Typically, one main switchboard is installed in a control room within the machinery space. The switchboard is fed by the main generators and power is taken therefrom to all the needs. There are panels controlling each power source, mains distribution and harbour supply.

There is also an emergency switchboard, fed by the emergency generator, via main switchboard. It is normally installed in the emergency generator room. This switchboard comprises sections for the control of the generator in itself and for controlling 440V and 220V feeder lines.

Motors driving big pumps are generally fed directly through the main switchboard; smaller motors and general purpose motors are connected to independent control panels, all linked to the main switchboard.

5.4.4 - Lighting System

This system is commonly spread throughout the ship according to separate classes: lighting for accommodation, for the machinery space, for decks exposed to the weather and for the cargo spaces. Normal lighting is provided by 220VAC, 3Ø, 60Hz fluorescent and incandescent lights. Emergency lighting fed by the 24VDC lines is to be automatically supplied, in case of mains failure.

Adequate lighting of cargo spaces is always to be aimed at, specially around manouvering areas, so that shady structural items are never present. Lamps are to be fixed in-between structural parts so as to avoid damage during operation. The lighting fittings may be either installed underneath the decks or on the sides. The latter account for reducing the number of lamps to be provided and for a shortage in required cabling.

5.4.5 - Internal Communication System

Ro-Ro vessels demand a lot of internal communication between crew members, for better cargo handling, control of ship's trim and heel, and so on. It is essential that the system be very reliable, otherwise a whole loading or unloading operation can be ruined. A typical installation may have interphones, common battery telephones, automatic exchanging telephones, electrical engine order telegraph, rudder angle indicator, public addressing system with talk-back and even "walkie-talkies" (explosion-proof type, for sure).

5.4.6 - Automatic Remote Control System

Main and auxiliary engines, as well as their peripherals are to be controlled and have their working conditions continuously supervised. This is accomplished by the aforementioned system.

The bulk of the system, including the main switchboard and main engine performance analogic measuring devices may be installed in an air-conditioned room - the so-called machinery control room-within the machinery space. It can provide full command of the main engine operation, such as starting or stopping, revertion and speed adjustings as well as of the auxiliary machinery. All sorts of alarm panels are also arranged in such a compartment, allowing thorough management of ship's performance, as a whole.

Since Ro-Ro ships are comparatively more expensive then traditional vessels, the surplus cost of a complete and sophisticated system may be not so high at all, provided that correct operation and reliable maintenance can be counted on. This is, once again, a shipowner's choice; when it comes to national practice, it can be seen that a common trend, towards either this adoption or not, has not been stablished yet.

6.0 - CONCLUSION

In the early sixties, engineer Alonzo de F. Quinn first stated in his book "Design and Construction of Ports and Marine Structures" that the United States Navy were employing ferry-boats for Roll-on/Roll-off operations and pointed out the exhisting limitations of port facilities in relation to that new system of cargo handling.

Nowadays, twenty-odd years after those first steps, the Ro-Ro system is an ever-spreading idea. Current national trend, owing to all that has been mentioned herebefore, is towards vessels intended for short and long coastal trades. This ever-increasing interest on the system will soon give, all in all, a new life to the national coastal trade, as a whole. If we are sucessfull in learning the best from past experience of long-established operators as long as our own attemps progress, and if port facilities, concerning regulations, adequate fares and marshalling structure are equally developed, then the results will be a suitable adjustment of the entire transport complex in our country and the definite settlement of the Ro-Ro system among us.

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