A FERRY DESIGN FOR THE EASTERN MEDITERRANEAN

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NOTATION

A	Attained subdivision index
A_1	Stress factor
A_p	Projection area of propeller
a	Factor in the calculation of probabilistic method
a_s	Buoyancy
B	Breadth of ship
BHP	brake horse power
BMT	Transverse BM
C_B	Block coefficient
C_{ML}	Machinery labour cost
C_{MM}	Machinery material cost
C_{OL}	Outfit labour cost
C_{OM}	Outfit material cost
C_{pr}	Propeller cost
C_S	Capital cost
C_{SL}	Steel labour cost
C_{SM}	Steel material cost
C_{SS}	Cost of Stabilizers
CRF	Capital recovery factor
D	Diameter of propeller
d	Draft of ship
D_{blk}	Depth of ship upto the bulkhead deck
D_{upper}	Depth of ship upto uppermost continious deck
DWT	Deadweight of ship
EHP	Effective horse power
F	Factor of subdivision
F_1	Mean freeboard

Fs	Safety factor of structure members
Fn	Froude Number
GM	Metacentric height of ship
H	Head at propeller shaft
I	Moment of Inertia
$I_{N.A}$	Moment of Inertia at neutral axis
L	Length of ship
L_{bp}	Length of ship between perpendiculars
L_{WL}	Length of ship on waterline
l_e	Effective length of stiffeners
M_B	Moment of beam
M_P	Moment of plate
M_s	Bending moment due to hydrostatic loading
M_w	Bending moment due to wave loading
M_x	Moment due to shear force
N	RPM
N_1	Number of persons for whom life boats are provided
N_2	Number of persons including officers and crew that the ship is permitted to carry in excess of N1
P_o	Power of ship, Horse Pover
P1	Number of berthed passengers
P2	Number of unberthed passengers
P	Axle load
P_w	Tyre load
p	Factor in calculation of probabilistic method
q	Load distribution
QPC	quasi propulsive efficiency

q_T	Total dynamic pressure
Q_x	Shear force in still water
R	Required subdivision index
R_F	Fraction resistance
R_T	Total resistance of ship
S	Factor in calculation of probabilistic method
s	Stiffener spacing
T	Thrust
t	Thickness of plate
u	Longer dimension of tyre print
V	Speed of ship
v	Shorter dimension of tyre print
V_a	Speed of water in way of propellers
VCB	Vertical centre of buoyancy
VCG	Vertical centre of gravity
x	Damage location
$Y_{N.A}$	Neutral axis from base
z	Damage penetration
Z	Section modulus
Z_D	Section modulus at deck
Z_K	Section modulus at keel
Z_R	Required section modulus
Δ	Displacement of ship
δ	Density of water
σ	stress
τ_c	Lift coefficient
θ_f	Angle of flooding
θ	angle of heel
ξ_1,ξ_2,ξ_3	Factors in calculation of probabilistic method

η_h	Hull efficiency
η_o	Propeller efficiency on open water
η_m	Mechanical efficiency
η_R	Relative rotative efficiency
η_p	Propeller efficiency

SYNOPSIS

This thesis studies the design of passenger and vehicle ferries and prepares a preliminary design for a passenger and vehicle ferry for the route between Turkey and Italy serving the ports of Izmir and Trieste.

The design allows a convenient weekly schedule for the round voyage on a long route over the complete year where seasonal differences will exist in the expected cargo. Background information on the route and consideration of existing ferries determined the carrying capacity and the cargo mix among passengers, cars and commercial vehicles.

Particular attention is given to subdivision and damaged stability. The calculation is carried out by both the deterministic and by the probabilistic methods and consideration is given to the relative value of these methods in ensuring safety.

Different arrangements of vehicle decks are examined and the relative advantages of longitudinal and transverse framing are explored by classification society and direct calculation.

The economic analysis is carried out using Western European capital costs and Turkish operating costs. Income estimates are adjusted to suit the expected trading pattern.

The safety of Ro-Ro vessels and further design studies are considered.

CHAPTER ONE
INTRODUCTION

1.1 General

The term ferry is applied to a regular and scheduled sea transport service between ports, usually two ports. Generally the vessels operating the service will carry both passengers and freight although the freight may all be in wheeled vehicles perhaps both road and rail and include many passenger cars. The ports are often relatively close together and the port installations may have been designed in conjunction with the ferries to speed turn around. However even transatlantic passenger services were referred to as ferries at the height of their importance.

There are major differences in design and in operation between ferries that require passenger certificates and those that do not. The latter group may carry up to twelve passengers but it can concentrate on freight convenience, perhaps to the detriment of safety after damage. Such vessels are not considered in this Thesis. The former group have examples over a very wide range of size. The larger ones rival the largest cruise liners and the smallest may only carry few passengers and their cars. However, they must all conform to the international and their national requirements for the award of passenger certificates. Such requirements impose constraints on design.

Demand for passenger and vehicle ferries has grown steadily in response to increased world prosperity, longer holidays, greater car ownership and improved road systems which have taken trade from railways. Increasing trade within the EEC has also dictated steady growth. Historically, any water crossing was first bridged by a ferry but increased traffic ultimately produces a fixed bridge or a tunnel where they are feasible and the expected channel tunnel is a recent illustration. However, ferries are flexible transport vehicles and new services develop as older ones become redundant.

This thesis considers ferry services in general and in particular prepares a design for a ferry linking Izmir in Turkey with Trieste in Italy. Alternative arrangements of vehicle decks are considered and a comparison is made of structural design of vehicle decks. Subdivision and damaged stability are examined by the conventional or deterministic method and by the alternative or probabilistic method. Economic considerations are examined by a study of life cycle income and expenditure.

1.2 Types of Ferry

A vessel to transport passengers and wheeled vehicles brings together characteristics which are found on their own in other ferry types. Since there is interchange of developments, it is useful to consider briefly some of these separate types.

Passenger ferries come in many sizes but are most numerous in urban transport where cities lie around bays or harbours such as Sydney and New York or are divided by straits such as Istanbul. The older designs were usually of the double ended variety with no claim to high speed but recent designs have sometimes favoured hydrofoils or hovercraft with their associated high speed when this is advantageous. The passenger and vehicle middle distance ferry may be in a position to incorporate some of the features of these modern types as they gain in experience and are refined in design.

Train ferries decline in number as freight moves from rail to road but still exist as purely freight wagon carriers as passenger and passenger coach carriers and may have their rail deck also able to carry road vehicles. Terminals and the ferries must be carefully designed to cope with tide changes as rail gradients are minimal. There are almost always of the straight through load and discharge type but usually are single ended for propulsion. Train ferries have a relatively high Length/Breadth ratio partly, because rail lines cannot spread out so readily within the vessel and the cargo is thus very length dependent for stowage. Such design would suit demands for buoyant compartments in the wings of cargo decks to restrict loss of stability when damaged.

Freight vessels of the Ro-Ro type tend to pioneer trades to areas where ports are being developed as they require minimum port facilities. Since they have few if any transverse bulkheads on their several vehicle decks , they represent risk when damaged but can transport some very awkward wheeled vehicles such as earth moving plant . They may be used for container transport with the container placed on special small wheeled trollies or stowed by fork-lift trucks but the cellular container ships are more economic .

Car carriers are a separate class of vessel largely associated with the export of cars made in the Far East. When associated with collapsible car decks they may be useful on the return journey but generally return with little cargo. Their cargo handling equipment such as loading ramps, portable car decks and inside access ramps are also to be found in passenger Ro-Ro ferries.

The present generation of Ro-Ro passenger ferry is the result of careful study of the trends of demand in it's three main cargoes namely passengers, passenger cars and commercial vehicles. The commercial vehicle section is often proved to grow more rapidly than forecast and this causes demands for vehicle space and deadmass that can make ferries readily obsolete. In a perfect world the port terminals would also be within the design package but usually the vessel must accept port constraints which may mean restrictions on both beam and draft. The more intense the service and the shorter the sea crossing, the more likely is the vessel to have both bow and stern doors and in sheltered waters be double ended. Accommodation standards reflect the time on passage. Passengers content with adjustable seats for short journeys of a few hours will demand cabin accommodation when voyage times exceed about 8 hours.

1.3 Passenger Ship Rules and Regulations

Most types of ships must confirm to the many international and national agreements to ensure their safety. Passenger ships have additional such agreements to follow as passenger safety is of particular importance. Internationally these agreements are given in the International Conference for the Safety of Life at Sea 1974 and subsequent amendments as agreed through the International Maritime Organization. Nationally for the United Kingdom, these agreements are contained in "SI 535 Merchant Shipping (Passenger Ship Construction) Regulations 1980 " and subsequent amendments [Ref.25].

In particular, rules concern ;

- Subdivision : the ability to remain afloat after a prescribed amount of damage.

- Damage Stability : the ability to remain at a safe angle of heel and trim with a minimum value of GM after a prescribed amount of damage.

- A minimum standard of fire precautions, lifesaving appliances, communication equipment and crew.

In the United Kingdom, there are six classes of passenger ships but only class I and class II are significant in carrying capacity. Class I vessels are engaged on unrestricted international voyages and today they are mainly cruise ships. Class II vessels serve short international and national voyages and are mainly engaged in ferry services. Their routes are relatively close to land and some relaxation compared to class I vessels is made. The remaining classes are generally smaller vessels in a wide variety of island, estuary and river services and will include undecked pleasure boats.

The important calculations for subdivision and stability in the SOLAS agreements must be submitted and approved either by the traditional deterministic method or by the alternative probabilistic method adopted by IMO regulations A 265 (VIII) [Ref.27]. The alternative method gives more scope for formal consideration of unusual bulkhead arrangements often useful to ferries, and gives a more realistic appraisal of safety.

No regulations are static and it is not long since proposals were considered not to treat truck drivers travelling with their vehicles as passengers. This would be a considerable convenience on long haul routes such as across the Mediterranean but the proposal is dormant at present and had little appeal for the United Kingdom authorities.

SOLAS agreements [Ref.28] include comprehensive protection against fire. An important influence on design is the division of the vessel into fire zones by transverse bulkheads which may be up to 40 meters apart and often coincide with alternate subdivision bulkheads.

The requirements for class I ships by SOLAS are life boats with a total capacity of 75% of the complement and liferafts at level for 25% of the complement. Maximum capacity of each life boat must not be more than 150 persons and the capacity of each liferaft must not be more than 13 persons. IMO requires that ships must have such arrangements that the total number of persons on the board must be capable of being evacuated with their full equipment within a period of 30 minutes. In addition radio life-saving equipment, life jackets and immersion suits must be considered as IMO requires.

1.4 Ro-Ro Passenger Ferry Routes

The passenger and vehicle ferries on short international voyages usually connect areas of similar economic wealth although tourist services exist and some vessels are intended for seasonal use.

Routes can be listed by location and although ferry designs may cater for each route separately, many are transferred or chartered to other services and thus route particulars may be considered as subordinate to the size, speed, endurance and cargo mix of the design.

Northern European services can be subdivided into those for Baltic, North Sea, English Channel and Irish Sea locations. Mediterranean services are generally from Spain and France to North Africa and from Italy to Greece and Turkey while Mediterranean Islands all have a ferry service to their mainland. Black Sea services connect Anatolia with Europe.

In the Americas services are mainly on the Canadian coasts, Caribbean Islands and the River Plate. The relatively scarcity of such ferry services in Asia and Australia is an indication of different levels of economic development between neighbours.

1.5 Trends in Design and Economics

Ferry design evolves in response to demand but must always offer a service at a price that customers can afford and be competitive with rival means of transport. Freight vehicles may need to use ferries but passengers may use air transport and hire cars at their destinations. Weather conditions may help or hinder ferry services as fog is a serious disadvantage to air travel as is rough weather to sea travel.

The demand for lower prices has resulted in the usual search for economies of scale where a service can be met by fewer but larger vessels. The length of the route and the loading and discharge facilities have great influence on size and speed. However as ferries are labour intensive, scale economies remain attractive. Growth in and change of demand often result in premature obsolescence of the vessels in any one route but generally vessels can be sold for use on other routes at different stages of development.

The balance of revenue and costs are shown in Fig.(1.1) and

Fig.(1.2) [Ref.53,december 1981]. Such illustrations alter as oil and other prices alter but the components of the revenue are very important. A successful ferry operation must secure a large income from the spending of passengers when on board in shops, restaurants and bars. The accommodation arrangement is done with this in mind ensuring ample provision of facilities for spending and their convenient location. Because of the requirements for good passenger accommodation and facilities and a great deal of special equipment ferry capital costs are high. However if crew cost can be reduced by low cost manning the savings are considerable.

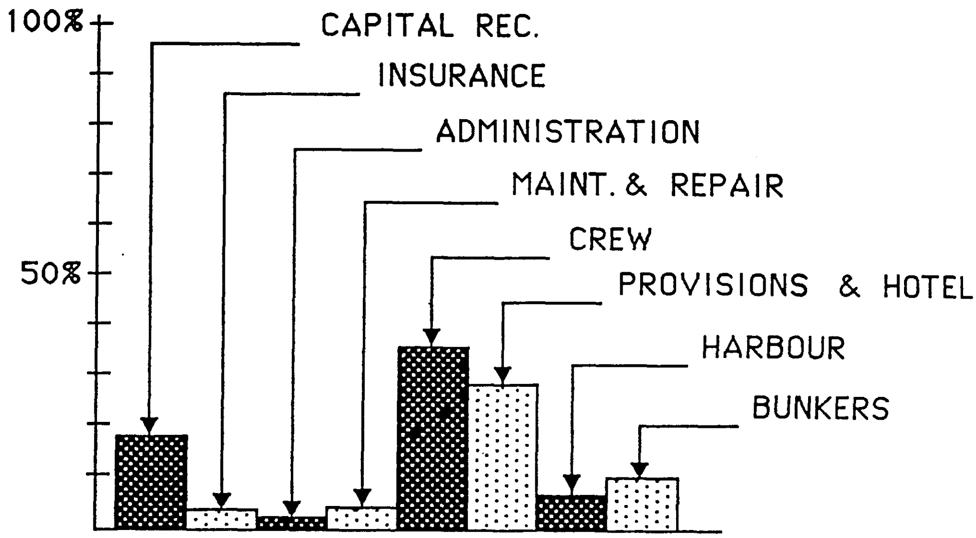

Fig.1.1 The distribution of ferry's operating cost(Ref.53, 1981)

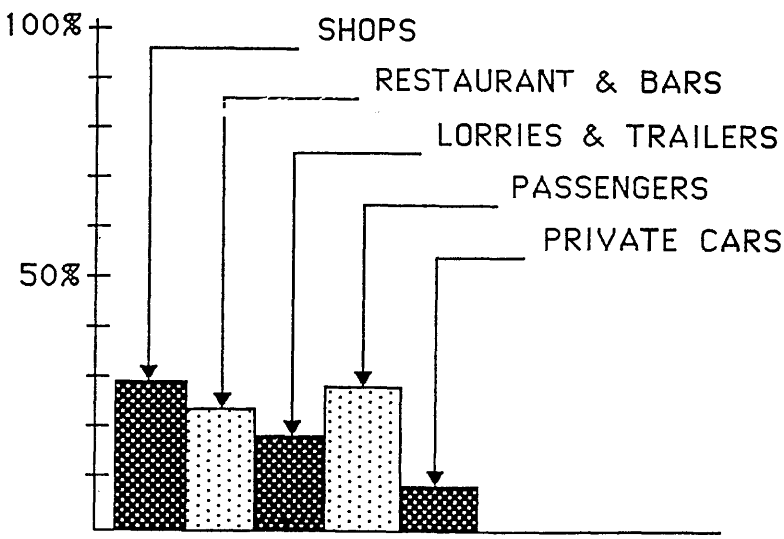

Fig.1.2 The distribution of ferry's income(Ref.53, 1981)

1.6 Turkish Considerations

The political and geographical situation of Turkey means that a ferry is a necessary solution to transport problems. As it is shown in Fig. (1.3) Turkey is surrounded by three generally calm seas namely Mediterranean, Aegean and Black and contains a fourth sea that of Marmara which is an international waterway. Turkey always will be a bridge between Europe and Asia but political considerations mean that road links through Greece and Bulgaria can be difficult. In these circumstances ferry services which connect Turkey to Italy and Romania have advantages. Much heavy traffic to the Middle East is routed through Turkey but steady demand for transport from the large number of Turkish workers in Europe is also important. Such ferry links avoid political frictions and lengthy journeys over crowded and dangerous roads.

One main existing service that connects Turkey with Europe is from Trabzon to Constanta in Romania. This is a Black sea service and much used as a route to the Middle East. Another main service is from Trieste or Venice to Izmir. This is a Mediterranean service and is likely to be the choice for traffic whose destination is Turkey. This service has perhaps most immediate growth prospects as Turkey begins negotiations to enter the E.E.C. and where Turkish agricultural products already travel in some quantity. Even now there are not visa requirements for Turkish citizens in Italy and freedom of movement will increase with E.E.C membership.It is the service between Trieste and Izmir that is chosen for this thesis.

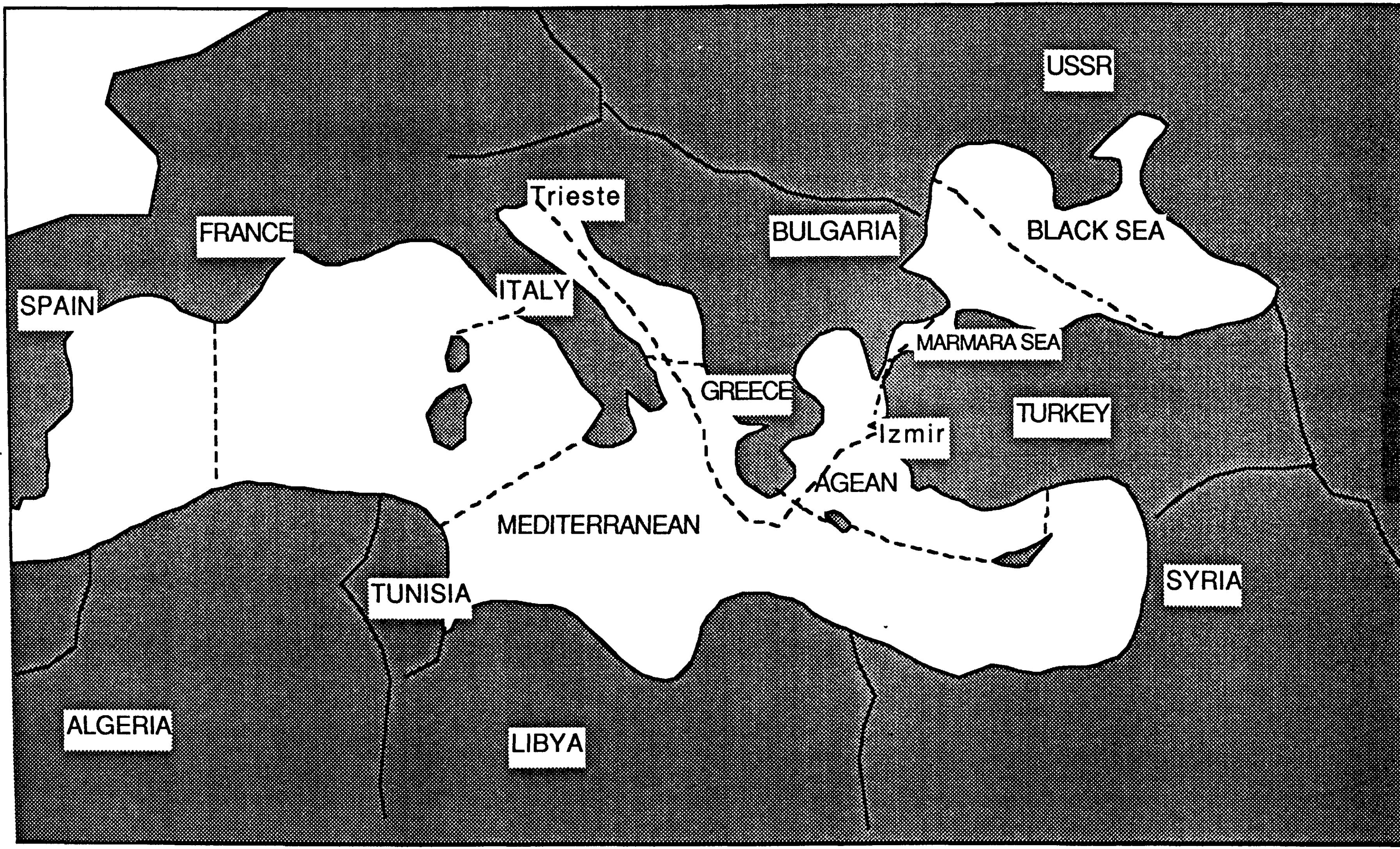

Fig.1.2 Some ferry lines In mediterranean

CHAPTER TWO

GENERAL DESIGN CONSIDERATIONS

2.1 Introduction

The design of any ship begins with a careful study of the demand for the vessel at that time and how the demand may be expected to vary over the service life. It is probably impossible to predict precisely demand over the potential life of the ship but at the end of useful service life it may be sold to other trades.

Often a clear picture of commercial demand is difficult to obtain and in any case design must be related to existing ships. Generally dramatic changes in size and speed from existing vessel are unusual and represent greater risks. In this case consideration must be given to existing vessels serving the route Izmir - Trieste but as the service is comparatively recent then more change may be expected in design. These changes must come in part from a study of information from a wide range of passenger and vehicle ferries which together can from a useful data base.

2.2 Ferry Design

2.2.1 General

Particulars of existing ferries form an important data base for the designer. They are especially important as guidelines for the choice of main dimensions, which once chosen, should ensure the fundamental goals of the design. In addition, the choice of total number passenger, the number with cabins, the lane length, width and height for commercial vehicles and the service speed are matters for commercial analysis and decision. The naval architect matches these requirements with a suitable vessel, subject to technical constraints, which can be built and operated as economically as possible.

2.2.2 Existing Ferries

Table 2.1 shows a representative selection of ferries listed by year of completion with particulars taken from the technical press. Data include the ferries between 1974 and 1986 and most them were selected from Baltic, North Sea and cross channel ferries. The remainder are from Irish sea, Mediterranean Sea, America coasts and just a few ferries from Japan coasts. During the collection of this data it was thought that the ferries chosen over the last 15 years of time span would be enough in quantity and represent the trend in modern ferry designs over this period.

For the initial design, geometrical parameters based on the data selected are established to specify the initial dimensions of the ship. Therefore parameters Length(L)/Beam(B) and B/draft(d) are shown on separate graphs [Fig.2.1 and Fig.2.2] which illustrate changes in these ratios. The mean lines go through points with a good deal of scatter. This scatter is a remainder that whatever trends exist all ferries are related to their particular service conditions.

Careful investigation of the data collected suggests a general trend for change in ferry designs so that until 1978 the ferries had fine hull forms (i.e. high L/B), small passenger capacity but different class accommodation facilities with big differences in standards whereas after 1980, they become larger in size having low L/B and high superstructure with high standards of accommodation facilities in all classes. The entertainment facilities are at the same standard as those of luxury passenger cruise ships. The designs between 1978 and 1980 carry both characteristics from the above grouping.

Therefore at the stage of producing graphs, data were separated to two parts as ferries before 1980 and after 1980. This will help the designer see the differences in designs over the recent years and lead to improved modern, popular and simply better designs.

2.2.3 Subdivision and Stability

The requirements of SOLAS have an important influence on design. The main car deck is almost always the bulkhead deck and the rules control the subdivision below the bulkhead deck in conjunction with the freeboard. In general, the designer chooses minimum spacings of bulkheads giving minimum freeboard and thus keeps the most useful space which is the main vehicle deck and above as large as possible. This design optimization allowed by the deterministic calculation for subdivision and damaged stability may be considered detrimental to true safety and this matter will be considered later.

2.2.4 Vehicle Decks

The main vehicle deck being also the bulkhead deck may be supplemented by a further deck above and perhaps by an inboard vehicle deck below. The wings of the two principal vehicle decks may be fitted with hoistable decks to suit the carriage of cars rather than trailers as demand dictates but clearance height and axle load are always important.

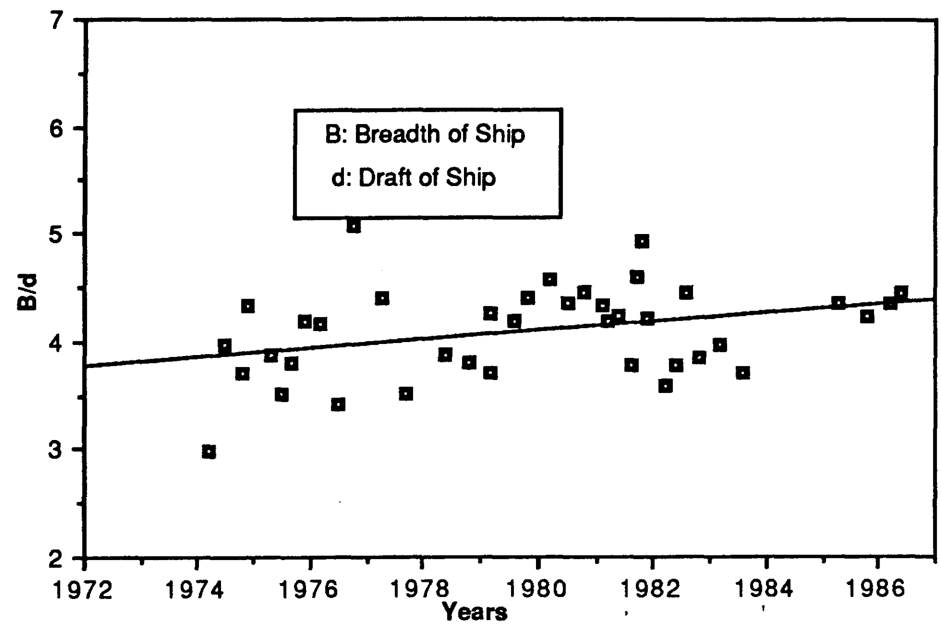

Fig.2.1 The change of ratio B/d with years

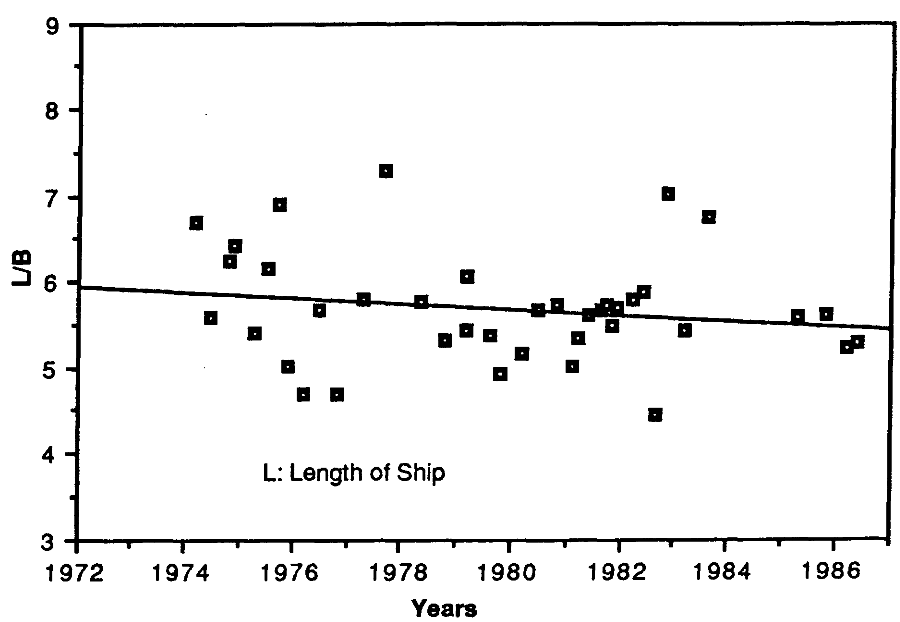

Fig.2.2 The change of ratio L/B with years

2.2.5 Machinery and Casing

Economic propelling and other machinery is central to efficiency. A typical arrangement involves father and son medium speed diesel prime movers delivering power to a gearbox.Through clutches. The gearbox output will be to the propeller shaft.Generators may be driven through step up gear from the small engines and auxilary generators may also be fitted. Reversing is often by controllable pitch propellers and twin screws are usually required to absorb the power and to insure against break down. A single grade of fuel may be used. Such a package allows economy of operation for the total power requirement at all speeds. Machinery uptakes and casings have an important influence on the vehicle decks and the appearance of the vessel. Casings may be along the centre line with central funnels or fully outboard with twin funnels. Partially outboard casings can suit central funnels but in all cases, they break up in a particular way the lanes of the vehicle decks. Outboard casings which are extended fore and aft as watertight compartments may represent a good way to maintain stability damaged but may reduce the total lane length.

2.2.6 Hull

Car vehicle decks may have both bow and stern doors but only ferries on short hauls are truly double ended. If only stern doors are fitted then the vehicle deck breadth must be adequate for turning or turntables are needed or vehicles reverse off. Such an arrangement is usually only acceptable when turn round is leisurely. Ferries usually have low values of block coefficient and intermediate to high values of Froude Number but an increasing proportion of freight traffic means a rising demand for deadmass and thus fuller forms. Fig.2.3 [Ref.4] Comparing hull forms of 1970's and 1980's indicates the demand for more vehicle deck space wider loading apertures and more displacement.

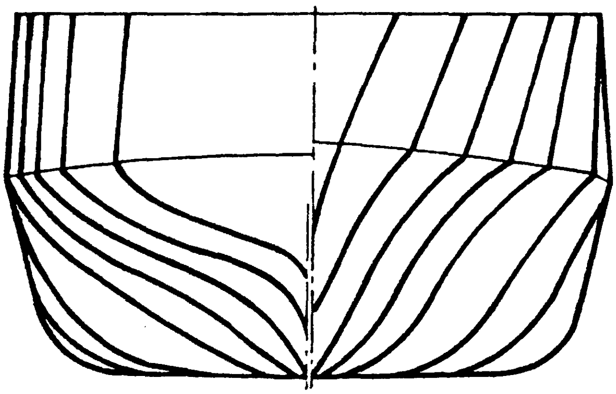

Fig.2.3a The general hull form of 1970's ferries[Ref.4]

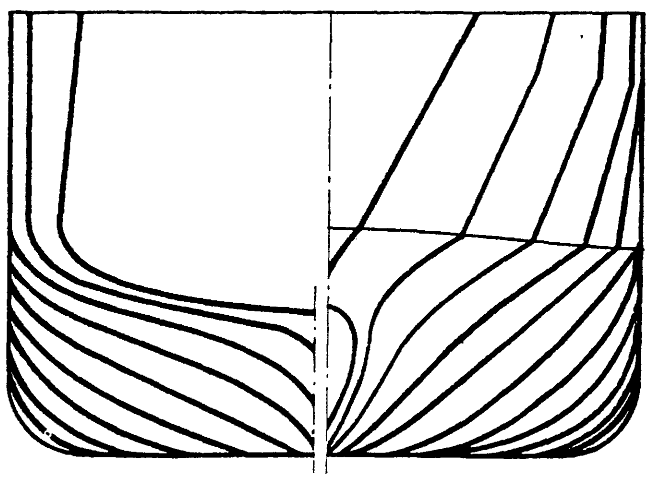

Fig.2.3b The general hull form of 1980's ferries[Ref.4]

2.2.7 Accommodation

Some accommodation for passengers and crew may be below the bulkhead deck but in a ferry this is a cramped space with obvious risks in a fire or accident.

Consequently, it is the space above the vehicle decks that is used for accommodation. If all passengers are to be berthed, great care is given to cabin design and the resulting choice repeated in bulk giving a particularly box like appearance to the superstructure . Public room spaces are very important as they contribute so much to the income of the operator. The total requirement for accommodation becomes more and more demanding adding further decks and more rectangular ends and generally making the ship look top heavy. Permanent ballast may be needed to alleviate true top heaviness but when deadmass is critical, the economic penalty may be serious.

2.2.8 Port Considerations

A good ferry design should be considered in conjunction with port facilities for it, indeed adjusted to suit it. However, most ferries must accept existing ports. This is likely to mean a restriction on draft sometimes a restriction on beam and sometimes on length and occasionally on all these parameters. Ultimately this means a limitation on size and carrying capacity but a beam limitation with its danger of inadequate stability is perhaps the most serious.

2.2.9 Safety and Comfort

This includes the passenger accommodation and reflects the length of the voyage. Journeys up to 8 hours may be accepted on reclining seats but as the time increases each passenger finally requires a berth. Entertainment requirements also increase with journey time. Ship motion can be unpleasant and stabilizers and stability must consider this feature. Vehicles must always be able to be lashed in position.

CHAPTER THREE

DESIGN PROPOSALS FOR A FERRY FOR THE ROUTE IZMIR - TRIESTE

3.1 General

Design decisions must be taken as a sequence although it is an iterative procedure with feed back loops. The sequence in this case is set down as follows.

3.2 Speed

All vessels have an upper limit to speed set by the economics of their trade and the physics of ship resistance which includes size and is expressed as a limit to Froude number. There is no lower limit to speed in physical terms but there is economic disadvantage if the speed is so low that it becomes impossible to earn sufficient profit to cover the capital investment.

In practical terms the itinerary of a ferry is a major influence on speed although within the bounds mentioned. Regular sailings at convenient times are essential. In this longish route a convenient service interval is one sailing a week in each direction with a rest and a repair day at Izmir. The rest day may be used in a auxiliary service during the high season. The load factor for passengers and cargo will be seasonal so that less time is needed for turn round in the low season than in the high season. This indicates some value in two speeds one for the low season and one for the high season.

The journey distance is about 1200 nautical miles and it may be reasonable to add one hour to each journey for manoeuvring. Four hours should be sufficient for low season turn round time and eight hours for the high season. Bunkering will be done at Izmir.

The minimum low season speed is thus ;

V_{smin} =Distance / (one week - one day - 2 hours - 8 hours)

=1200 x 2 / (24 x 6 -10) =18 knots.

The minimum high season speed is ;

V_{shigh} = 1200 x 2/(24 x 6 - 2 - 16) =19 knots.

However for auxiliary cruises a maximum speed beyond 19.0 knots could be an advantage and 21.0 knots may be reasonable. This gives the following low and high season schedules with voyage times of 68 hours and of 61 hours.

Low season:	Wed.	Thurs.	Fri.	Sat.	Sun.	Mon.	Tues.
Leave Izmir	16.00						
Arrive Trieste				12.00			
Leave Trieste				16.00			
Arrive Izmi							14.00

High season:	Wed.	Thurs.	Fri.	Sat.	Sun.	Mon.	Tues.
Leave Izmir	18.00						
Arrive Trieste				07.00			
Leave Trieste				18.00			
Arrive Izmir							07.00

3.3 Capacity and Deadmass

The demands of the particular service fixes rough ratios among the number of passengers, the number of cars and the number of freight vehicles but the latter has the main influence on deadmass. The journey time demands berths for all passengers and the demand for car space is likely to be linked to passenger numbers with freight demand more stable. without access to detailed cargo statistics a study of existing ferries indicated that a suitable capacity would be 800 passengers, 200 cars and 60 trailers each trailer being 40 feet in length. The deadmass in these circumstances being (800 / 7 + 200 + 60 x 30) about 2100 tonnes. However if the tractors are considered together with trailers the total number of trailer+truck will be less than 60 but total mass of one trailer+truck will increase Therefore this does not make any significant difference in mass. Also since ticket fares are increased a certain amount for each additional meter there will be no disadvantage of considering the truck+trailer.

3.4 Port Restrictions

Izmir and Trieste have no particular restrictions on length and beam but draft should not exceed about 6.5 m . The tidal range is small.

3.5 Existing Vessels

The service is maintained at present by Ankara and Samsun both designed for use by Russia in another service but bought new for their present service. The particulars are ;

L_{bp} = 120.70 m.

B = 19.41 m.

d = 5.42 m.

D_{upper} = 12.25 m.

Power = 12527 kW

Passenger= 460 berths , 523 deck passengers.

3.6 Data Base

The vessels listed in table 2.1 are used. They have been divided into vessels built between 1974 - 1979 and between 1980 - 1985 for plotting graphs but the vast majority represent services with shorter voyages.

3.7 Preliminary Design

3.7.1 General

Conventionally preliminary design is the determination of the main dimensions and group masses to satisfy the design requirements. Alterations remain cheap at this stage but the outcome should not require any fundamental changes as the design is developed into working drawings and preparing steel where alterations are very expensive. The main dimensions are length, beam, depth, draft and block coefficient.

3.7.2 Length

This the least well defined dimension although it reflects the basic size needed to meet the cargo requirements. The shortest length can be expected to give the least capital cost but if it produces an unacceptably high Froude Number running costs will be excessive. There may be upper limits to length imposed by port facilities but longer vessels may be more seakindly. A starting point for size is to consider the length as a function of passenger numbers. These can be expressed as berthed passengers plus a tenth of the unberthed passengers as used for the calculation of net tonnage. Existing ferry data gives graphs as shown in Fig.3.1 and Fig.3.2.

For 800 berthed passengers the length is between 130 and 140 meters. As seen in Fig.3.3 and Fig.3.4 values of Froude Number against length indicate an upper limit of about 0.3 . If 130 m. is chosen as the value of L_{bp} then for 18 and for 21 knots respectively the Froude Numbers are 0.259 and 0.302 respectively.

3.7.3 Block Coefficient

The minimum value required will be set by requirements for deadmass while the upper is governed by $V/(L)^{0.5}$. Deadmass requirements reflecting growth in freight traffic dictate rather high values compared to older ships which are shown in Fig.3.5 . Ref.18 indicates an upper limit of 0.65 for a $V/(L)^{0.5}$ of 0.81 although Fig. 3.6 shows lower values have been more usually chosen. A value about 0.63 may be suitable.

3.7.4 Beam

The minimum value of beam is directly related to adequate initial stability but draft restrictions may raise it beyond this minimum for a required displacement. Port restrictions can limit beam but serious limits would require permanent ballast to maintain stability. The demand for higher standards of accommodation has increased top weight and in a ferry all cargo is mainly above the waterline. There has been steady decrease in values of L / B as shown in Fig.3.8 compared to Fig.3.7 and a beam of 26.0 giving L/B =5 seems reasonable.

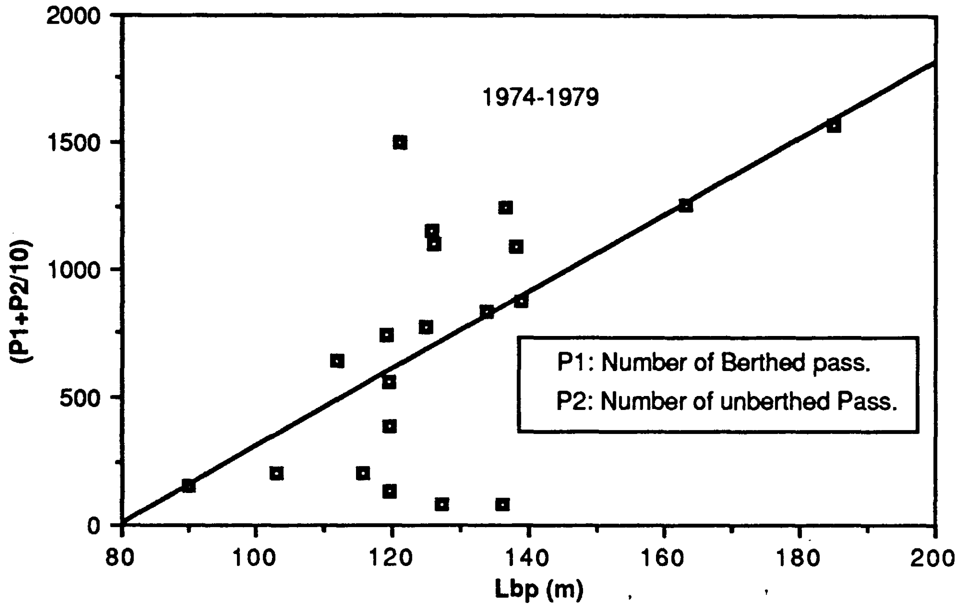

Fig.3.1 The change in the average passenger capacity as the ship length changes for the years between 1974-1979

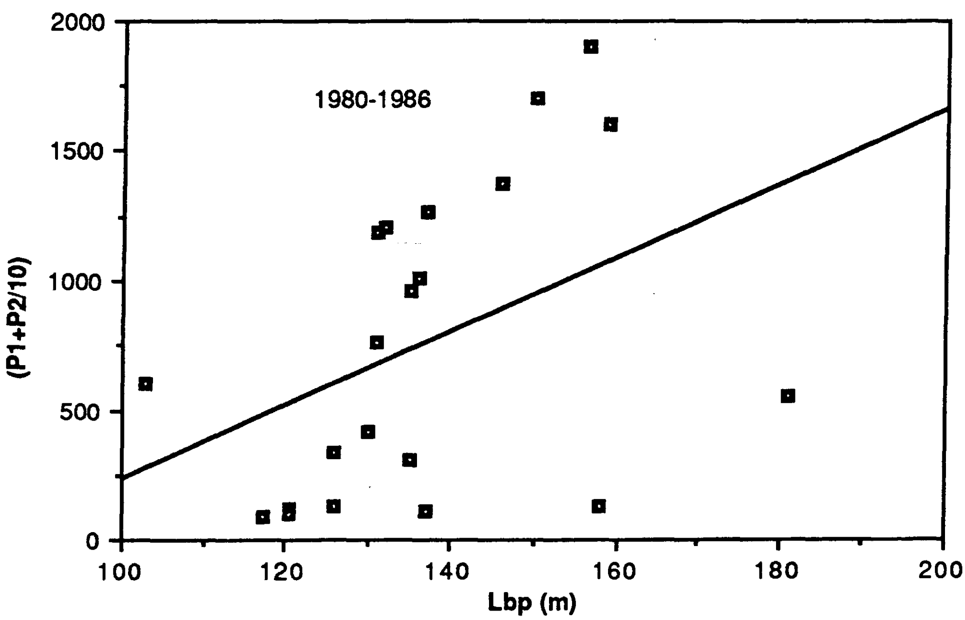

Fig.3.2 The change in the average passenger capacity as the ship length changes for the years between 1980-1986

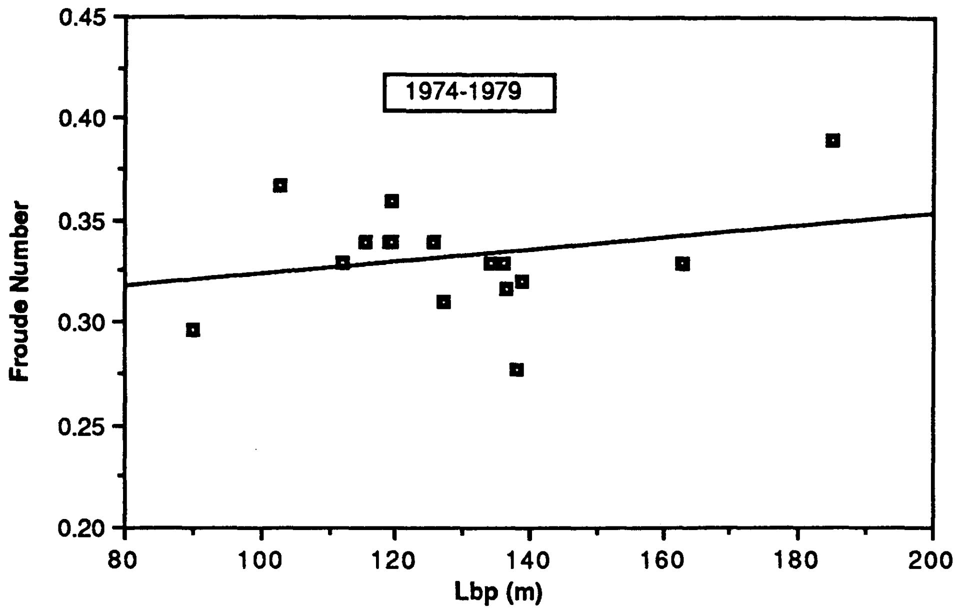

Fig.3.3 The change in Froude Number depending on the ship length for the years between 1974-1979

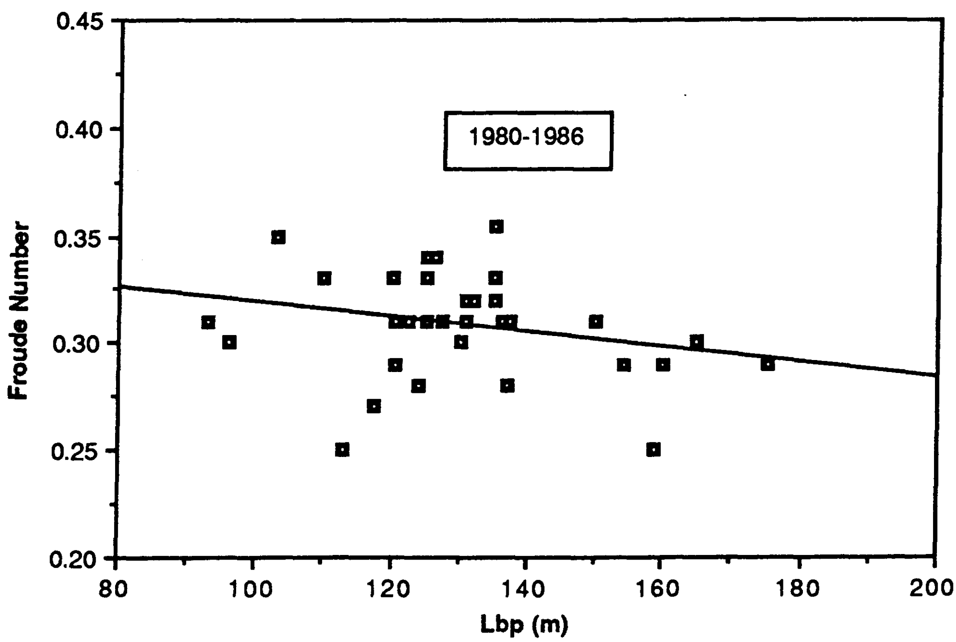

Fig.3.4 The change in Froude Number depending on the ship length for the years between 1980-1986

3.7.5 Draft

Draft is always restricted to some extent by ports and a low draft allows entry to more ports. A minimum draft is required to suit displacement and deadmass and perhaps propeller immersion and seakindlyness. In this case 6.0 m. may be sufficient.

3.7.6 Depth

Depth has several definitions but for a passenger vessel, the most important one is that to the bulkhead deck which is usually the main car deck. Whether the calculation for subdivision and damaged stability are presented in the deterministic or probabilistic way the choice of depth in relation to draft is vital and as a first step must be obtained from existing ships as shown in Fig.3.9 and 3.10. There will be some trade off between the ratios of d/D_{blk} and watertight bulkhead spacing but as modern machinery is very compact, modern values of d/D_{blk} allows the very minimum of freeboard. A value of d/D_{blk} ~0.72 is given in Fig.3.10 but some margin of safety is needed in preliminary design study. If D_f is taken as 8.5 then d/D_{blk} is 0.706 for a draft of 6.0 m.

Depth to the uppermost continuous deck is an important parameter for steel mass, stability and hull girder stiffeness. Generally, the depth to the uppermost continuous deck is that to the bulkhead deck plus the heights of vehicle decks above that level in this case with an allowance for portable decks 8.5+5.5=14.0 m while with an allowance for private car deck D_{upper} is 8.5+5.0+2=15.5 m.

The number of decks required for 800 passengers is important as these will be above the uppermost continuous deck although of assorted

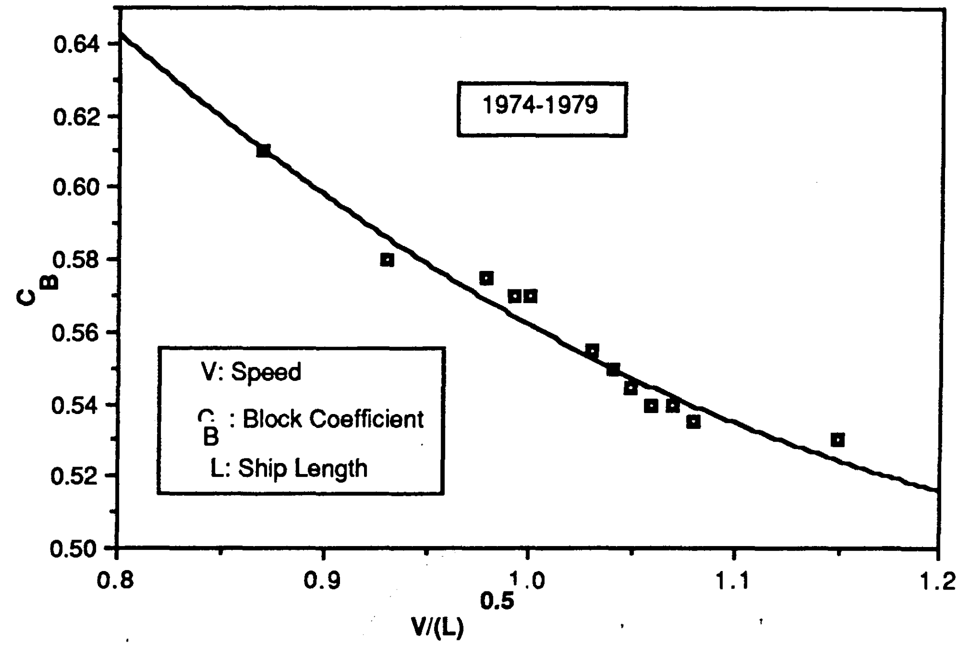

Fig. 3.5 The mean line of Block coefficient along the $v/L^{0.5}$ axis for the years between 1974-1979

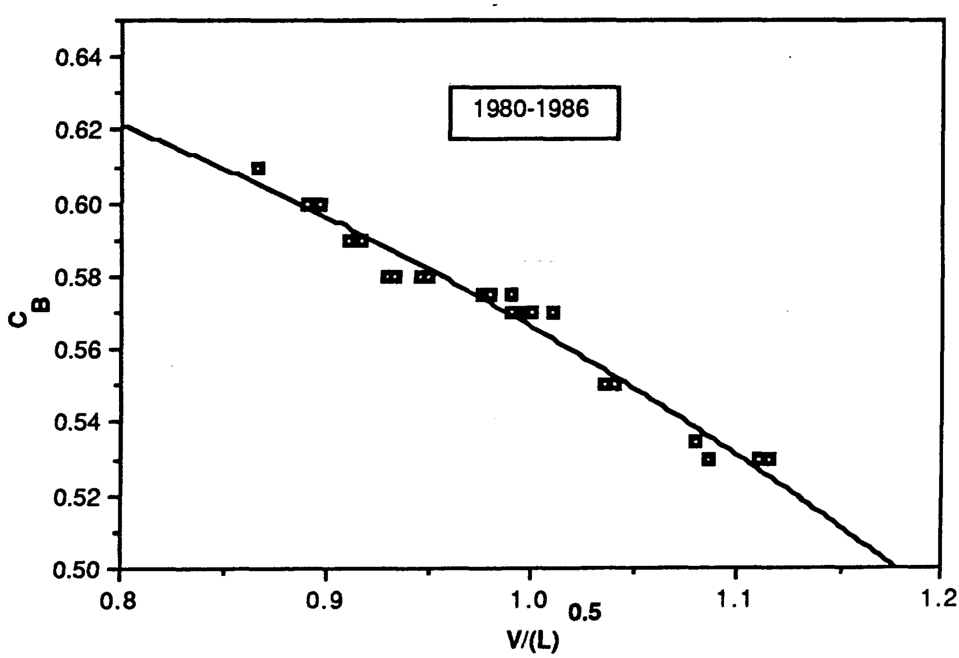

Fig.3.6 The mean line of Block coefficient along the $v/L^{0.5}$ axis for the years between 1980-1986

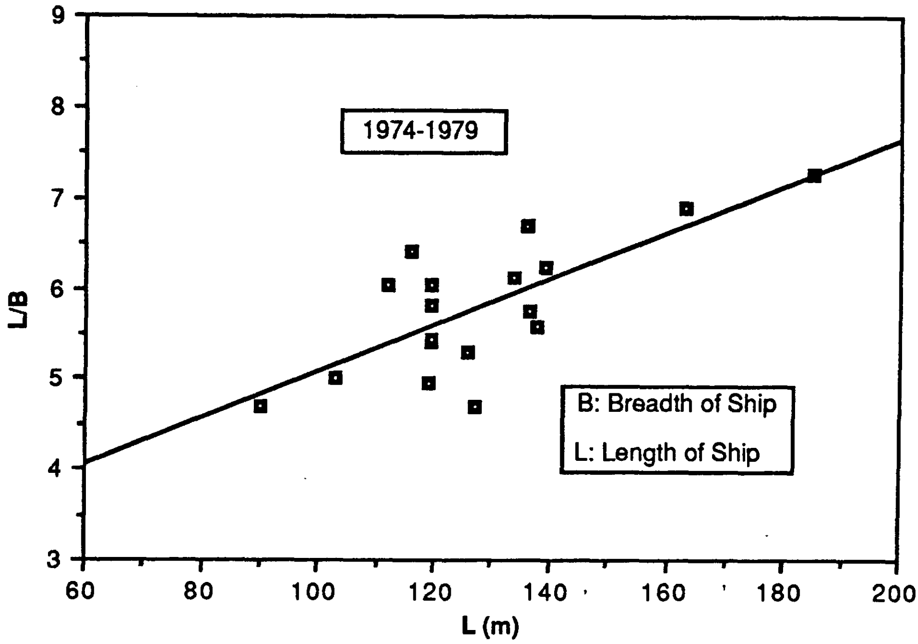

Fig.3.7 The change of ratio L/B with the ship length for years between 1974-1979

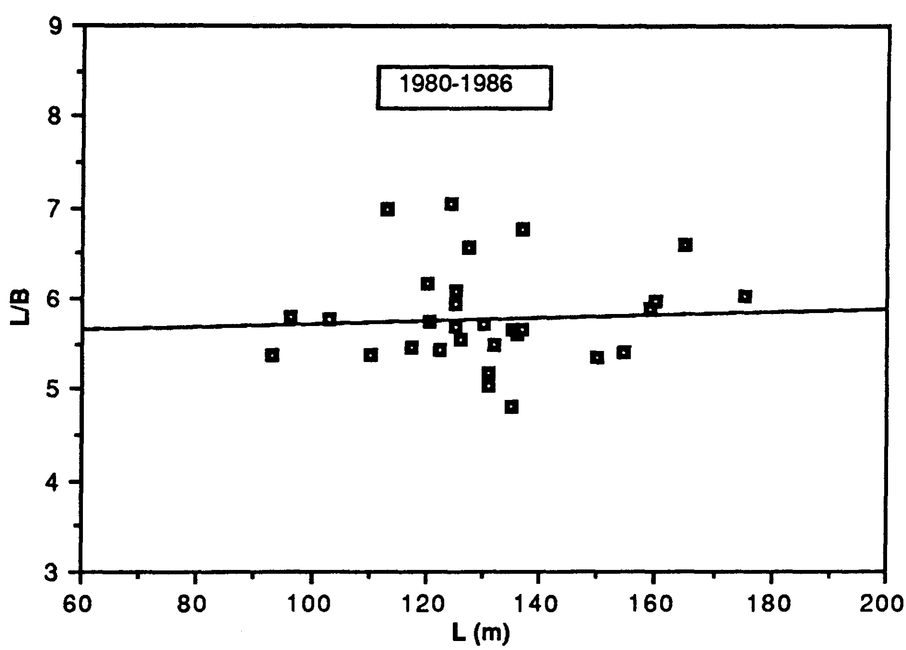

Fig.3.8 The change of ratio L/B with the ship length for years between 1980-1986

lengths. Fig.3.11 gives

0.5 = 800 / 130 x 20 x number of decks

the number of decks is = 4.7 (say 5.0) for passengers only.

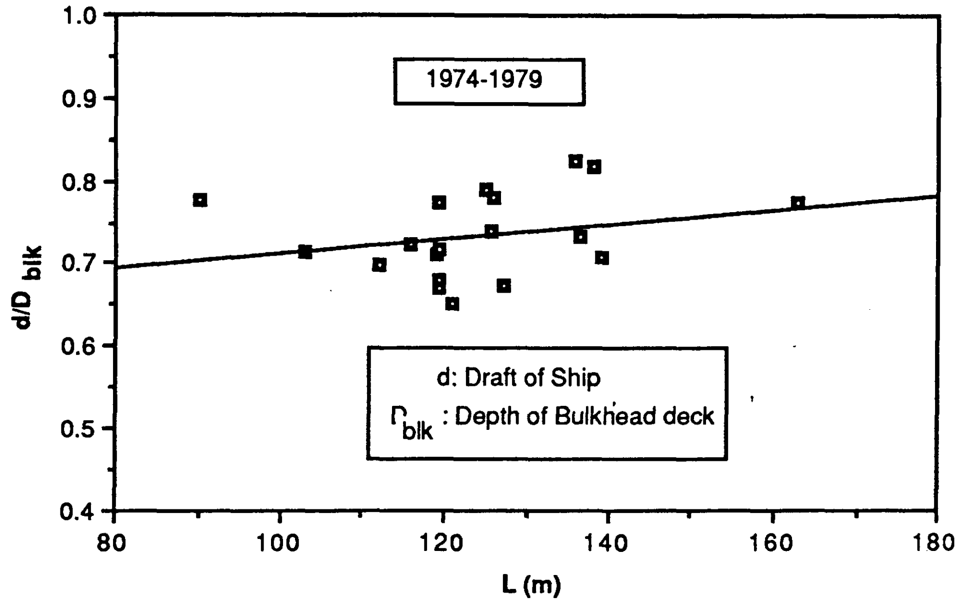

Fig.3 9 The scatter of ratio d/D over ship length for the years between 1974-1979

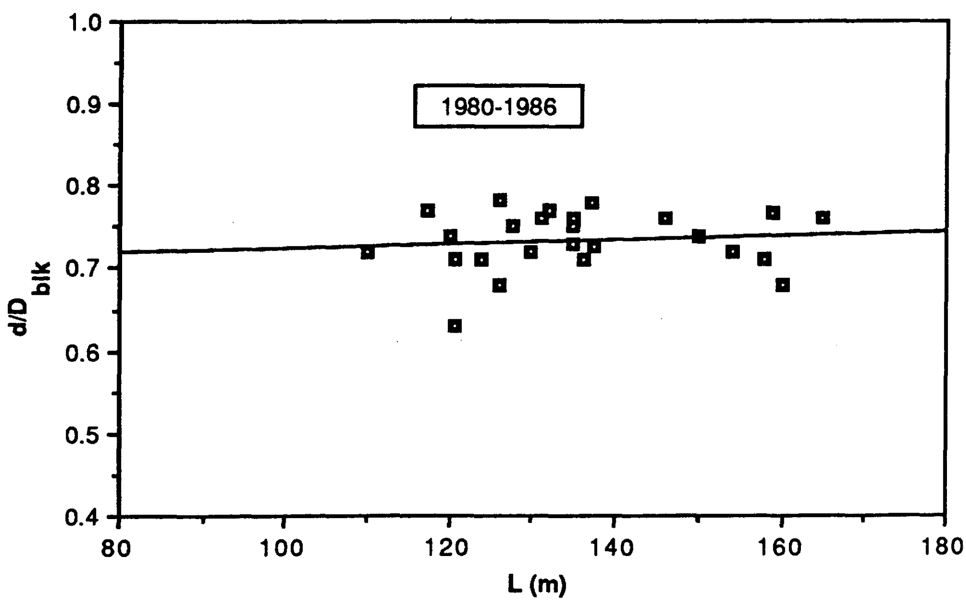

Fig.3.10 The scatter of ratio d/D over ship length for the years between 1980-1986

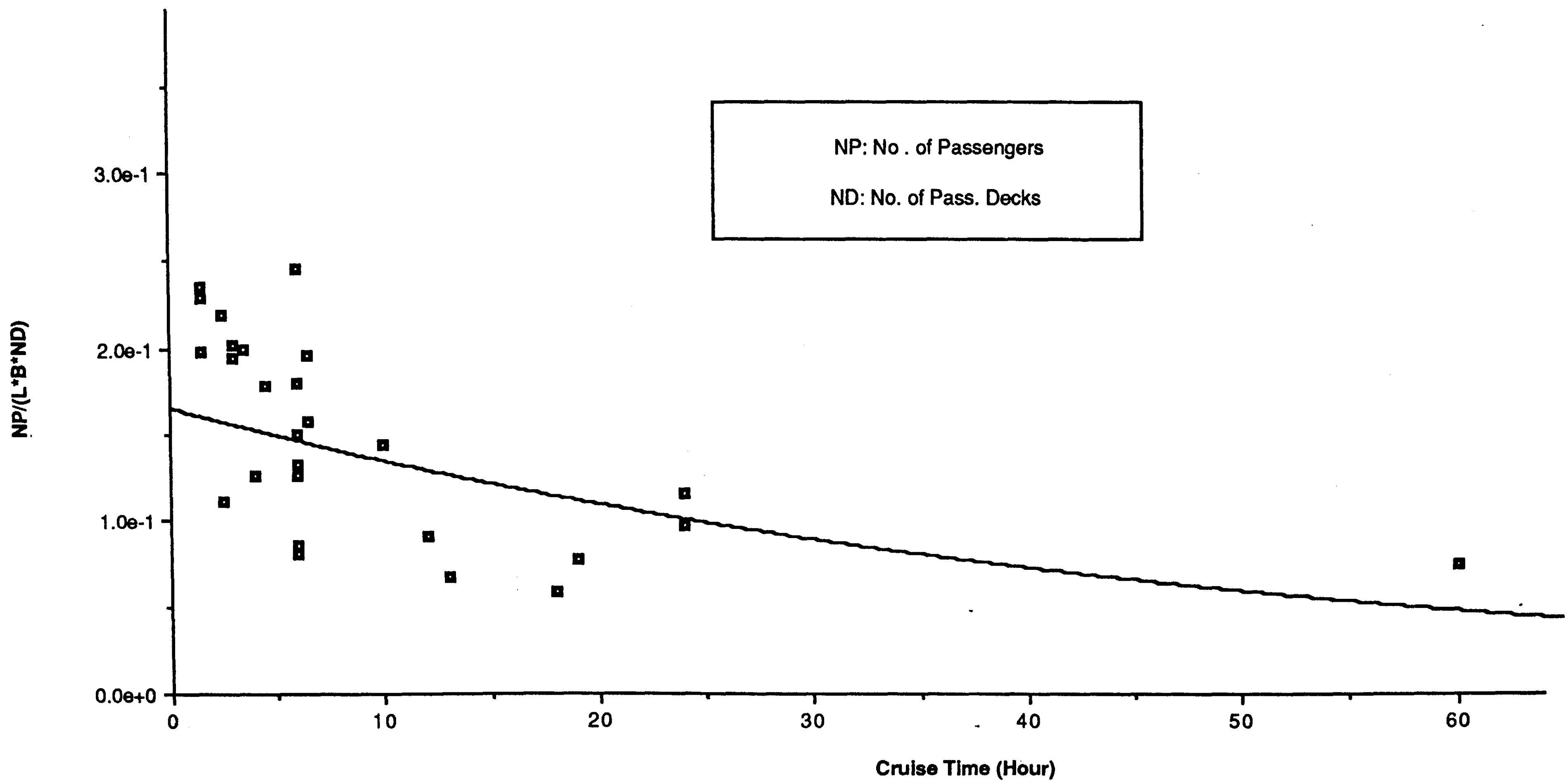

Fig.3.11 shows the dependency of total passenger decks on cruise time

3.7.7 Displacement, Group Masses and Initial Stability

Following the estimation of main dimensions of the ferry an initial displacement can then be calculated as

Displacement (Δ)= Length(L_{bp}) * Beam (B) * Draft (d) * Block Coefficient(C_B) * Density of water (δ). For our design, this gives 13096 tonnes. At this stage, depending on the displacement calculated, group masses and initial stability can be calculated from various graphs, approximate formulas based on the design requirements as shown in Appendix 1 and Ref.19.

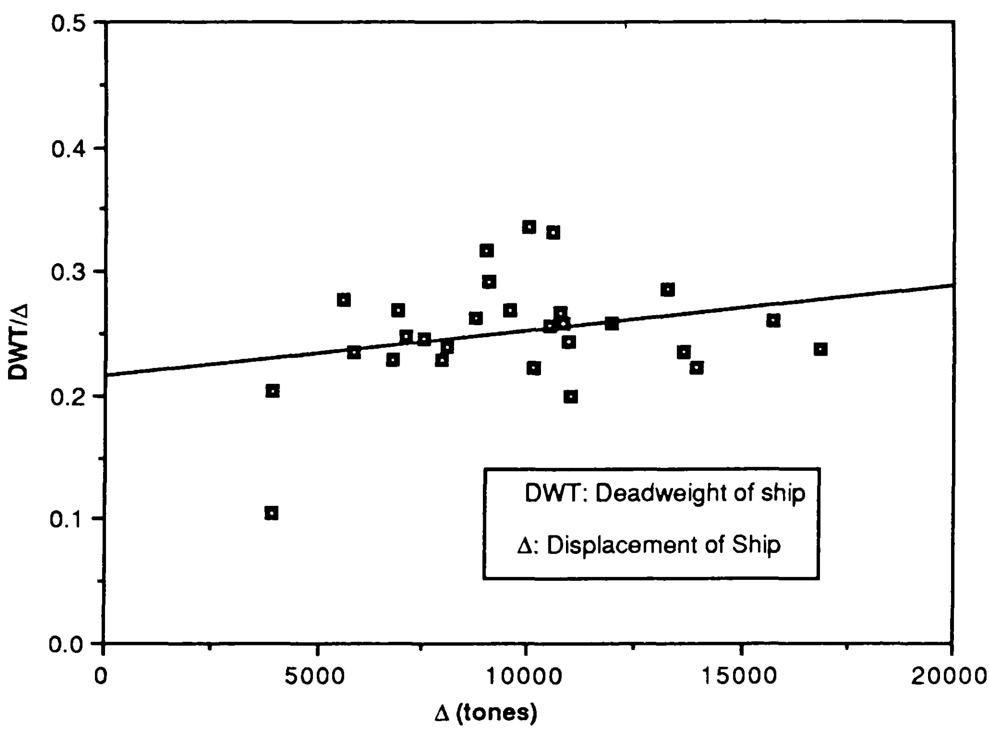

Fig.3.12 The ratio DWT/DISP. shows steady increase as DISP. increases

Fig.3.12 indicates that the deadmass / displacement ratio may be about 0.27 giving a deadmass of 3550 tonnes and this value gives some idea about the lightweight of the ship.

Some items of the deadmass are listed in Table 3.1. Their values are estimated by using data in Ref.19 together with design judgement by considering the voyage and the number of passengers. The estimations in detail are given in Appendix 1. At maximum speed of 21 knots an initial estimation of required power is obtained from Fig.3.14 as 20133 kW. This gives a machinery weight of 1100 tonnes, a fuel - oil weight of 800 tonnes and a lubrication oil of 50 tonnes, as explained in Appendix I. The total weight of 800 passengers, their baggage and 150 crew is estimated to be about 150 tonne s.The fresh water and other domestic items are estimated to be 200 tonnes and 300 tonnes respectively.

One of the design purposes is to have a high vehicle capacity without changing the fixed dimensions. However large vehicle capacity can be obtained by increasing the number of decks which will increase the depth of ship. In addition the length of voyage is considered to be long, so that relatively more passenger decks are required as shown in Fig.3.11. In these cases the vertical centre of gravity of ship increases as the depth of ship becomes high. This situation causes the initial stability of ship to arise as a important problem. This forces the designer to analyse different types of vehicle deck designs in term of initial stability. For this particular ship three different vehicle deck arrangements are considered as follows.

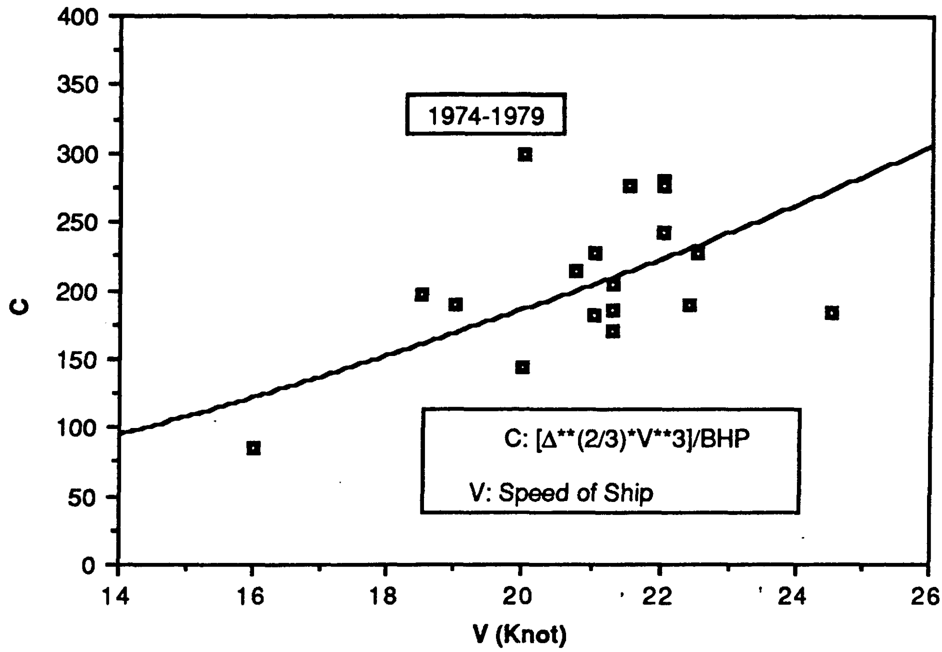

Fig.3.13 shows the required power for the years during 1974-1979

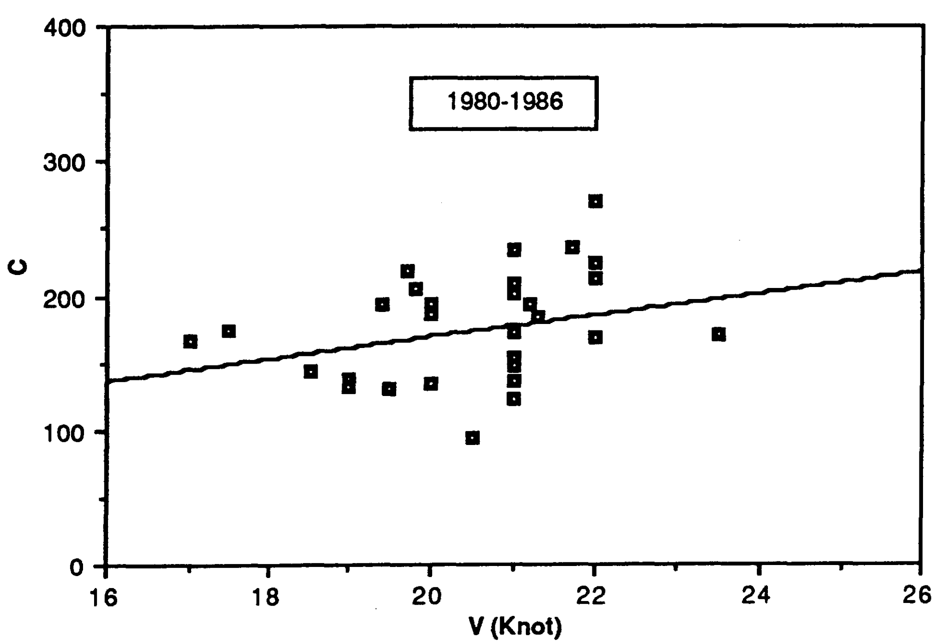

Fig.3.14 shows the required power for the years during 1980-1986

1 - Single vehicle deck design with a portable car deck at the Port side of the main deck for which $D_{upper.}$ become 14 m.

2 - Two vehicle deck design; one mainly for trailers and other for private cars for which $D_{upper.}$ becomes 15.5 m.

3 - Two vehicle decks design both are suitable for stowing the trailers for which $D_{upper.}$becomes 18.5 m. All these design types are shown in Fig.3.15.

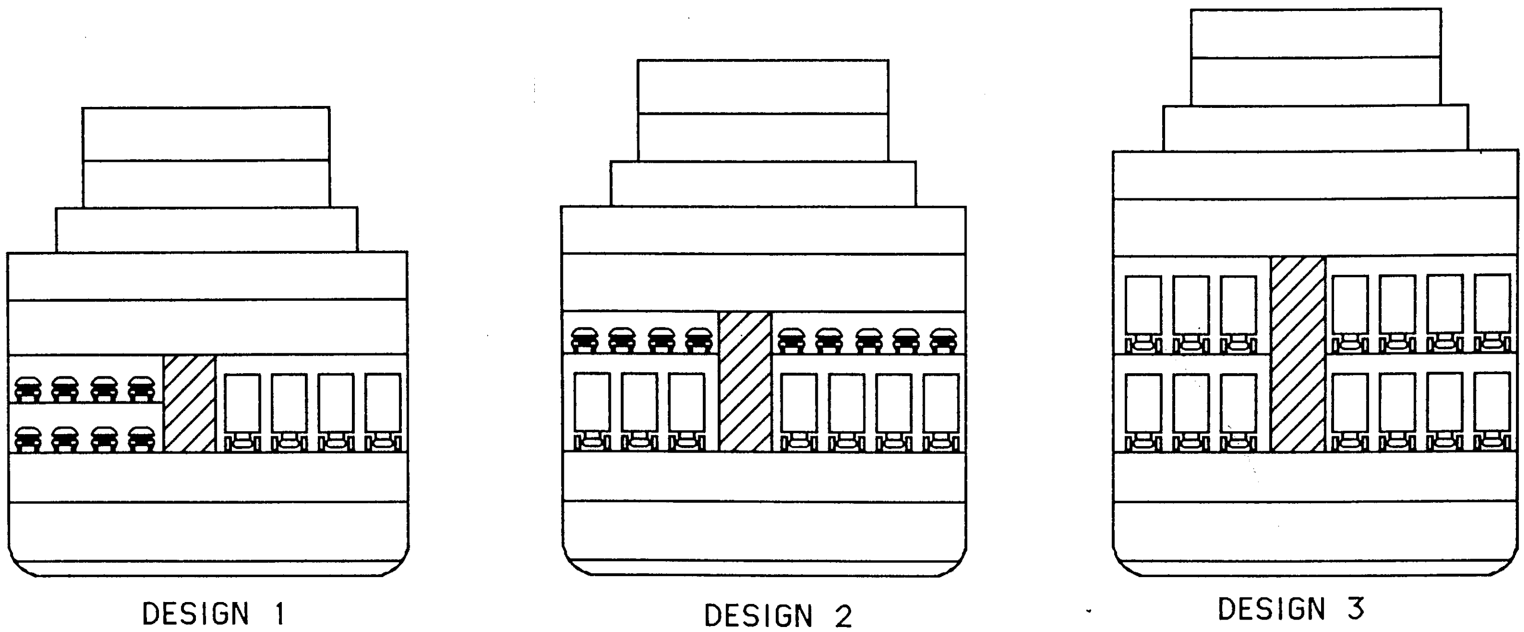

Fig.3.15 Alternative vehicle deck arrangements

Following these estimations for design 1 (see Appendix I) group masses and their centroids become as follows.

Item	Mass(tonne)	VCG (Metre)	VCG*M(t-m)
Steel	4900	12.2	59780
Outfit	2600	16.0	41600
Machinery	1100	5.0	5500
Fuel	800	4.2	3360
Lub. oil	50	4.2	210
F. water	200	4.2	840
Pas+Crew	150	17.5	2625
Stores	300	6.0	1800
Life Boats	270	25.0	6750
vehicle	2600	11.5	29900
Margin	126	14.0	1764
	13096	11.77	154129

Table3.1 The KG of group masses and ship for vehicle design 1

VCB of ship was estimated from 0.55d as 3.30 and BM from $B^2/C_B xd$ as 10.5 m.

GM was found as 1.95 m. which suggests good initial stability. This high GM value also gives some hope for a second car deck to be considered.These estimations for two vehicle deck designs are given in the Tables 3.2 and 3.3.

Table 3.2 shows the group masses and their centroids for design.2.

Item Mass	(tonne)	VCG(metre)	VCG*M(t-m)
Steel	5212	13.37	69688
Outfit	2600	17.0	44200
Machinery	1100	4.5	4500
Fuel	800	4.2	3260
Lub. oil	50	4.2	420
F. water	200	4.2	840
Pas.+Crew	150	18.0	2700
Stores	300	6.0	1800
Life Boats	270	26.0	7020
Cargo(d.4)	200	14.3	2900
Cargo(d.3)	2100	10.5	22050
Margin	114	14	1704
	13096	12.3	161085

Table3.2 The KG of group masses and ship for vehicle design 2

VCB = 3.30 m.

BM =10.50 m.

GM was found as 1.50 m. which seems satisfactory for initial stability.

Table 3.3 shows the group masses and their centroids for design.3

Item	Mass(tonne)	VCG(metre)	VCG*M(t-m)
Steel	5650	15.3	86445
Outfit	2600	20	52000
Machinery	1100	4.5	4500
Fuel	800	4.2	3360
Lub. oil	50	4.2	220
F. water	200	4.2	840
Pas.+Crew	150	21.0	3150
Stores	300	6.0	1800
Life. Boats	270	29.0	7830
Cargo(d.4)	1000	15.5	15500
Cargo(d.3)	1000	10.5	10500
	13096	14.21	186160

Table3.3 The KG of group masses and ship for vehicle design 3

KB = 3.30 m.

BM =10.50 m.

Initial GM was estimated as -0.36 m. which is not acceptable for stability requirements so that third design is disregarded.

The first two designs give good initial stability. Although the second design is bound to give higher building cost than the first, the larger car capacity could be an advantage during the operating life. It seems that the second design is more suitable for this particular ship but the final decision is left to be made after the hydrostatic and damage stability calculations. But the arrangement is carried out for this second design.

3.8 Hull Form

Recent developments require fuller underwater body form and almost rectangular superstructure. The idea of larger trailer capacity forces the body lines out to gain area at trailer deck level. Furthermore more passenger capacity with increased facilities demands larger deck area and ease of cabin manufacture requires little change of shape. As a result of these demands the decks have become rectangular and the ferry has greater depth. However these arrangements bring some disadvantages beside the advantages. Displacement becomes a significant factor and because of restricted draft, a fuller underwater form seems the most suitable solution to that problem.

In the light of these trends a fine hull form of a 1970's ferry has been modified to suit a higher value of C_B and more car deck area. The lines plan of Dana Regina which was built in 1974, was chosen as a basic lines plan. After the modifications the data of new hull form was obtained as shown in Table 3.4. This data indicates a short parallel body with full lines at the 6 m. load draft although Dana Regina has not got a parallel body. The body form plans are given in Fig.3.16

WL / ST.	WL 1/2	WL2	WL2	WL3	WL4	WL5	WL6	WL7	WL8	WL	WL9	WL10	WL12	WL14
0	0	0.4	0.4	0.45	0.65	1.55	4.60	8.15	9.90		10.60	11.55	12.40	12.80
1/2	0	0.4	0.7	1.25	2.50	5.25	8.75	10.50	11.55		12.10	12.5	12.8	13.00
1	0.75	1.0	2.0	3.60	6.60	10.25	11.25	11.60	12.25	KNUCKLE LINE	12.65	12.80	12.95	13.00
2	2.25	3.70	7.10	10.55	11.90	12.45	12.75	12.90	13.00		13.00	13.00	13.00	13.00
3	8.30	10.40	11.90	12.60	12.90	13.00	13.00	13.00	13.00		13.00	13.00	13.00	13.00
4	11.70	12.25	12.85	13.00	13.00	13.00	13.00	13.00	13.00		13.00	13.00	13.00	13.00
5	11.70	12.70	12.85	13.00	13.00	13.00	13.00	13.00	13.00		13.00	13.00	13.00	13.00
6	8.5	10.20	11.60	12.25	12.65	12.90	13.00	13.00	13.00		13.00	13.00	13.00	13.00
7	4.60	6.05	8.05	9.20	10.15	10.88	11.50	12.10	12.60	12.70	12.75	12.85	13.00	13.00
8	1.85	2.65	4.20	5.5	6.78	7.85	8.9	9.90	10.80	11.20	11.35	11.55	12.40	13.00
9	0.7	1.10	1.75	2.25	2.70	3.30	4.15	5.14	7.15	7.90	8.05	8.45	9.9	10.20
91/2	0.45	0.70	1.20	1.55	1.65	1.45	1.75	2.75	4.35	5.05	5.25	5.75	6.70	7.80
10	0.20	0.40	0.88	1.05	0.85	0.0	0.25	0.65	1.15	1.45	1.75	2.35	3.60	5.0

Table3.4 The half breadths of ferry at different stations and waterlines

3.9 Hydrostatic Calculation

After defining the hull form of the ferry, hydrostatic calculations are carried out for the further steps of design. These calculations were done by using the Wolfson Unit package programs Ref.60.

The displacement of the ferry at 6 m. draft was found as 12722 tonnes . The block coefficient was obtained as 0.626 while VCB and BMT values were obtained as 3.36 m. and 10.32 m. respectively. The result of hydrostatic calculations are given in Appendix 2.

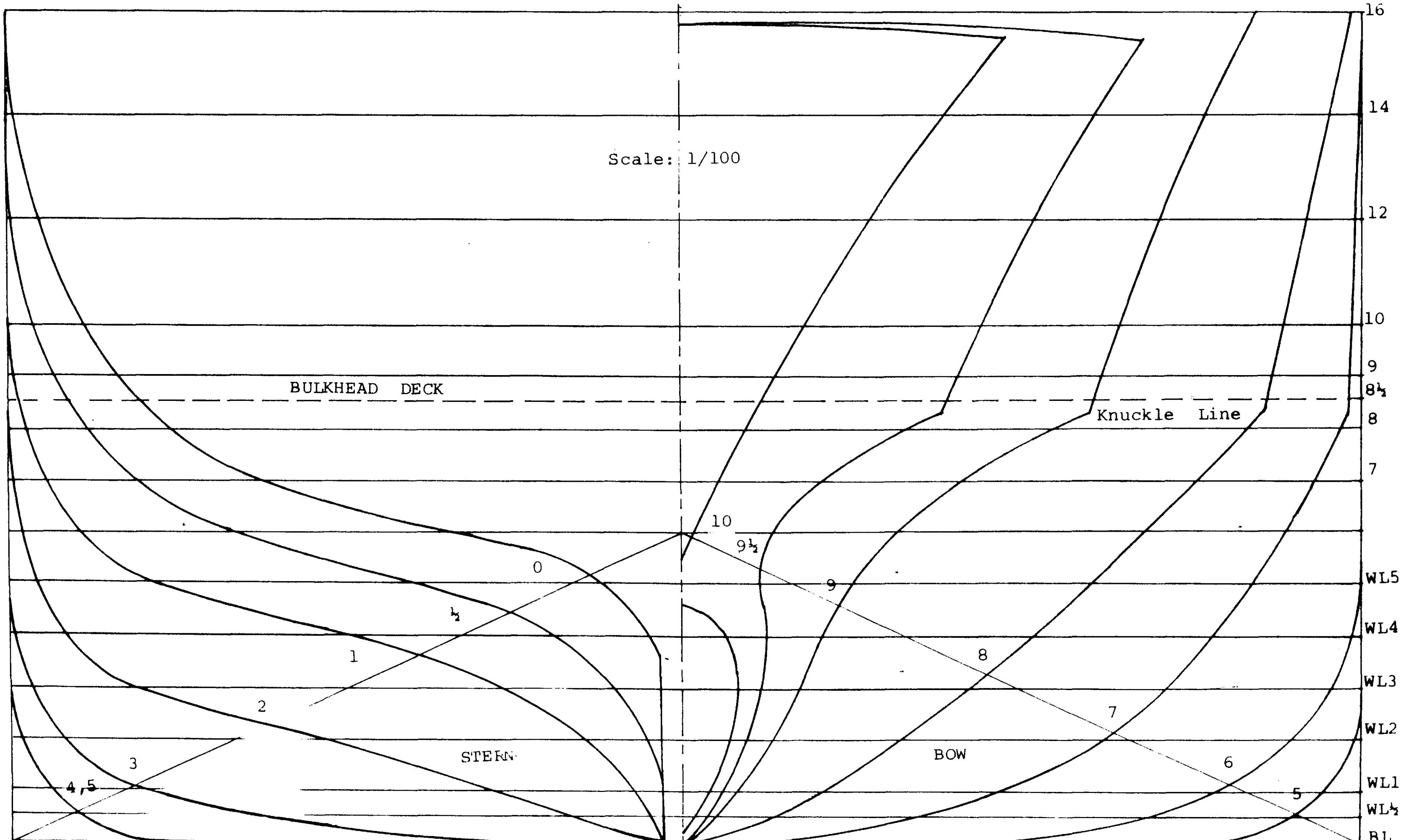

Fig.3.16 Hull form of the particular ferry

3.10 General Arrangement

A relatively long voyage demands substantial passenger facilities. These also depend on the general economic level of passengers for whom this ferry service is planned. Therefore, a comfortable ship is proposed rather than a luxury one.

First of all basic arrangements are required such as location of watertight bulkheads, engine casing, lifts and stairs. As a result of carefully carried out calculations watertight bulkheads are installed along the ship up to the bulkhead deck as shown in Fig.3.18. This suits the subdivision and damaged stability requirements. In order to increase the capacity of vehicle decks the casings were installed off the center line to port. Machinery arrangement was installed around the middle of the ship because the damaged stability requirements allowed long enough compartments in this region of the ferry.

All passenger and crew accommodation areas have been located above the bulkhead deck considering the relative danger of spaces below the bulkhead deck and the comfort of people on board. Passenger cabins, which have a total of 800 berth capacity, have been installed on the sixth and seventh decks. Cabins have been arranged as single, double and four berth cabins. Crew accommodation has been arranged at the deck 8 together with some entertainment facilities. Generally cabins are located at the forward and aft ends of the ship to protect the passengers from engine noise and common passage ways.

Every kind of entertainment facility has been fitted limited only by available space. A large dining room, two lounges, disco, casino, duty free shops, hairdresser, library, conference or cinema saloon and swimming pool have been located on the fifth and ninth decks. Furthermore a sauna and gymnasium room were installed at the second deck.A 60 trailer capacity main vehicle deck and 200 car capacity car deck have been installed at third and fourth decks respectively.

Different type of stores have been arranged at the second deck. At the both ends of first deck, the ballast tanks have been located to correct trim while heeling tanks exist outboard of the machinery spaces. The general profile of the ferry is given in Fig.3.17. The decks are described in more detail as follows.

- Deck 1 (Tank top)

This deck is divided into 13 compartments by watertight bulkheads which go up to the bulkhead deck.

The main machinery was installed in two large spaces around midships considering the stability requirements which also required heeling tanks at both sides of the engine rooms fitted with cross-flooding arrangements. The heeling tanks were installed to stabilize the ship in case of asymmetric loading conditions.The vessel has twin four bladed controllable pitch propellers driven by two father and son engine sets which each supply power to a gearbox as shown in Fig.3.18. The forward compartment contains the larger engines, the aft one contains the smaller engines and the gearbox. Each compartment has a separate auxiliary generator. Shaft generators are coupled to the son engines. The fuel treatment plant is in a separate compartment forward of the main machinery. Auxiliaries and workshops occupy two spaces aft of the machinery.

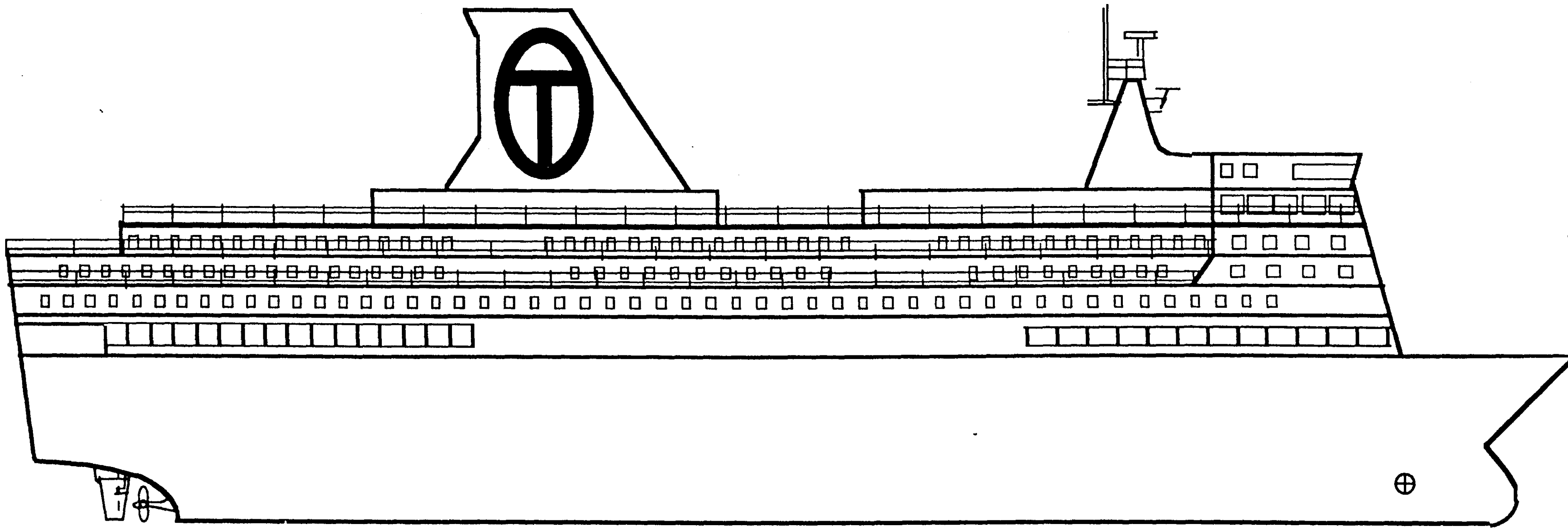

Fig.3.17 The profile of the particular ferry

Compartments at the forward and aft ends are arranged as ballast tanks to control the draft and trim during loading and discharging. All fresh water tanks are also located at this deck. One compartment is arranged as a gymnasium room for crew.

- Deck 2

The full height from deck 1 to deck 3 is required in the main machinery and fuel spaces. A gymnasium area and sauna for passengers have been arranged at forward of the deck. The next compartment has been designed as a laundry space which will serve for passengers and crew.

All stores have been installed at the aft end of this deck. One compartment was kept as a store for shops and cabins. Two compartments have been arranged as food and drink stores including cold and cool rooms. The Control room for all engine systems is located just behind the engine compartments. These arrangements are indicated in Fig.3.19.

- Deck 3

This is the bulkhead and the main vehicle deck. It is designed to take the trailers and heavy vehicles. At the port side of the centerline there is 3.5 m. wide casing along the ship which rises to the upper most continuous deck. Inside the casing there are lifts, stairs and uptakes. The deck has a 4.65 m. Clear height and a total 800 meter length of 3 m. wide trailer lanes where up to 61 - 12 m. trailers can be stowed. Loading and discharging will be done via three stern doors that each have 4 m. wide, 5 m. high openings. Two of them give access only to the main deck. The other gives access to both main and upper car decks.

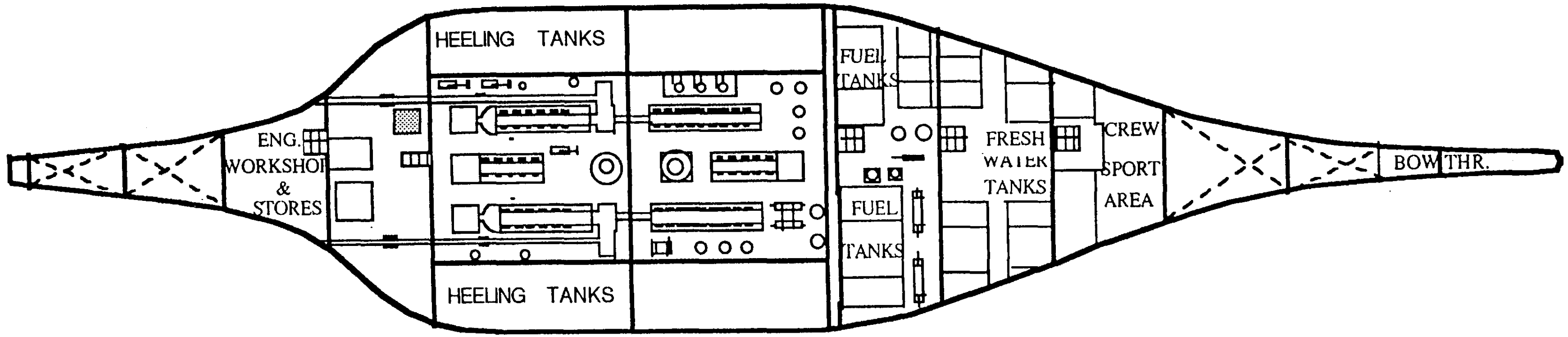

Fig.3.18 Machinery arrangement of ferry at deck 1

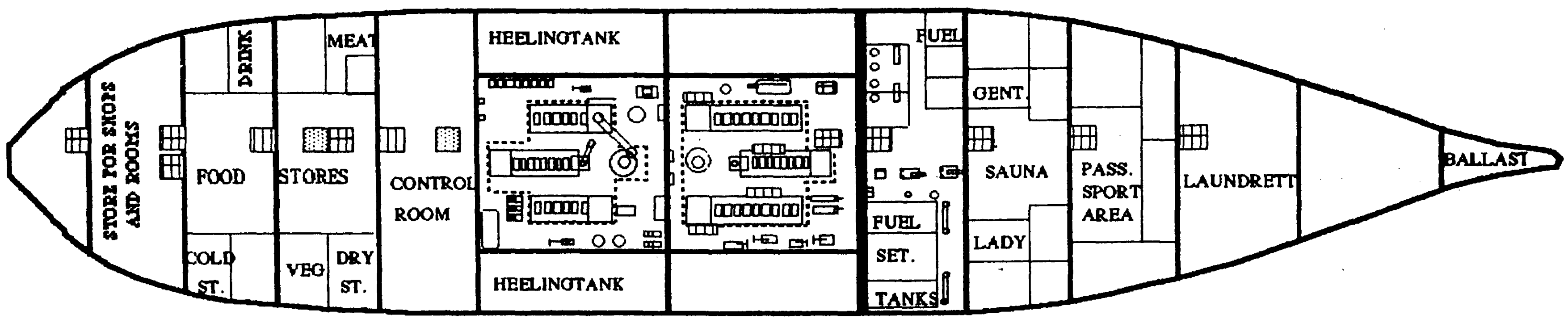

Fig.3.19 General arrangement of stores and sport areas at deck 2

- Deck 4

Considering the many Turkish workers and tourists who travel by car, it was thought that a large capacity car deck was better than movable car decks. Therefore this deck has been designed only for private cars with the clear height of 1.95 m. A total of 1050 meters length of 220 standard cars (4.15 *1.55) can be stowed. Access to this deck is supplied by movable ramp which has 14 m. length and 4 m. wide. The arrangements of deck 3 and deck 4 are indicated in Fig.3.20 and 3.21.

- Deck 5

This is the upper most continuous and the entertainment deck where the main entrance is located. The dining room for 350 persons was located at the aft end of the deck. The officer's dining room is adjacent to this dining room. The galley was located at the Port side of the deck giving access to dining rooms for easy service. The starboard side of the deck is a shopping area. The entrance hall is a large area with easy access to every part of the ship. a total of two 50 seat rooms adjoin the entrance for special use. A 150 passenger capacity lounge exists and a disco and a casino are at the forward end. The arrangements are shown in Fig.3.22.

- Deck 6

A total of 570 passengers can be accommodated in 180 cabins on this rectangular shaped deck. Cabins are either two berth or four berth cabins.

New developments in cabin construction allow the dimensions of cabins to adjust somewhat to available space instead of being dependent on standard sized cabins although the rectangular shape remains.

76 two berth cabins have been located at the aft of the decks and

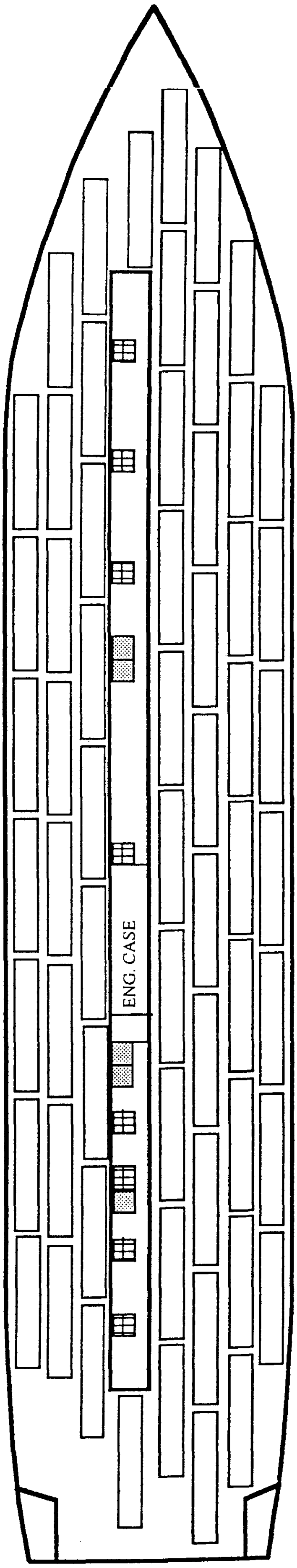

Fig.3.20 The arrangement and stowage of trailer deck

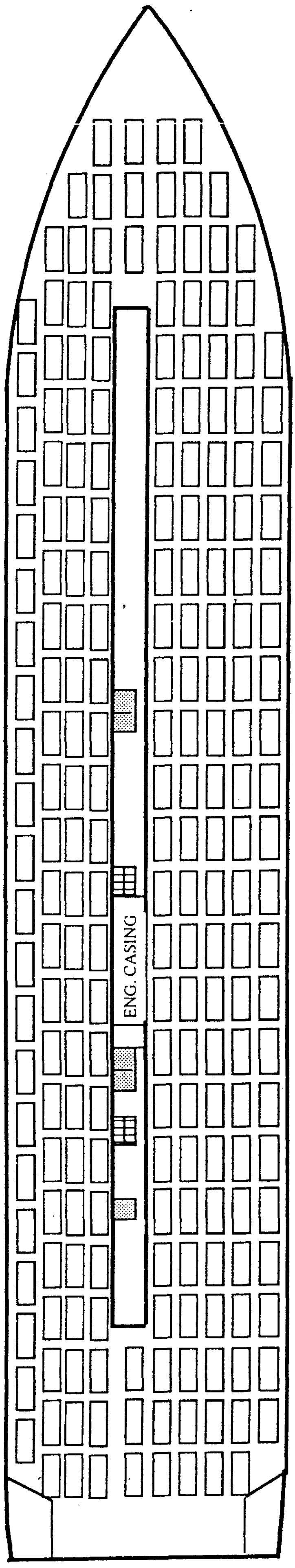

Fig.3.21 The arrangement and stowage of car deck

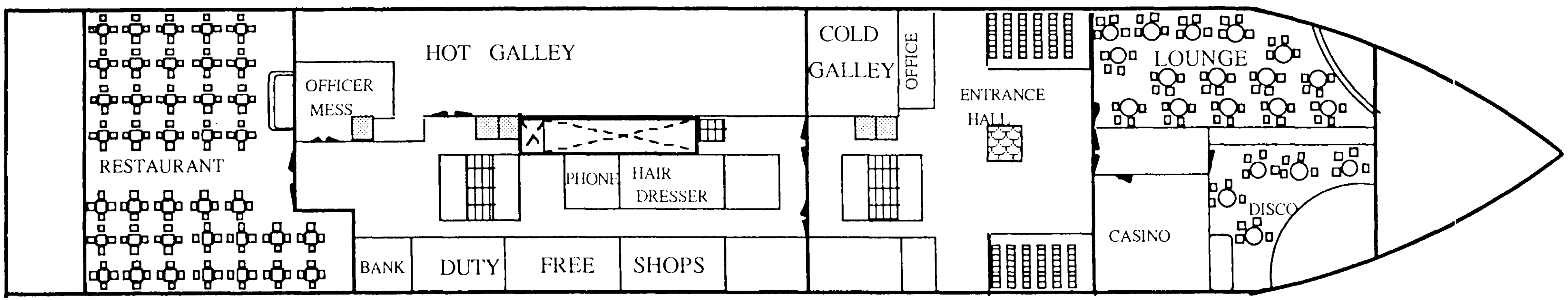

Fig.3.22 The general arrangement of deck 5 where the entertainment facilities are located

each cabin has 10 m^2 space. As it is shown in Fig.3.23 cabins have private toilet and showers. The rest of the deck area has been occupied by 104 four berth cabins Fig.3.24 that have 12.5 m^2 space each including the private toilet and showers.

Apart from accommodation there is one play room for children at the middle of the deck. The general arrangement is indicated in Fig.3.25.

- Deck 7

A total of 252 passengers in 148 cabins have been located through the deck. There is 3 m. wide open promenade at port and starboard of the deck. At the forward end of the deck 10 luxury cabins which have 25 m^2 space each exist.

42 single cabins have been installed at the aft end of the deck . Single cabins have total 8 m^2 space including shower and toilet as shown in Fig.(3.26). There are 96 twin cabins which occupy the rest of the deck. The general arrangement of this deck is indicated in Fig.3.27.

- Deck 8

100 crew and fifty officers are accommodated in twin and single cabins respectively. Cabin areas are the same as passenger cabins. There are 5 cabin suites for owner and senior officers and 48 cabins for officers at the forward end. Crew cabins are at the aft end of the deck. Crew mess and lounge are also at the same region . At the middle of the deck , the pool trunk occupies an area. The hospital, which has ten beds and an operating room is next to the officer cabins.

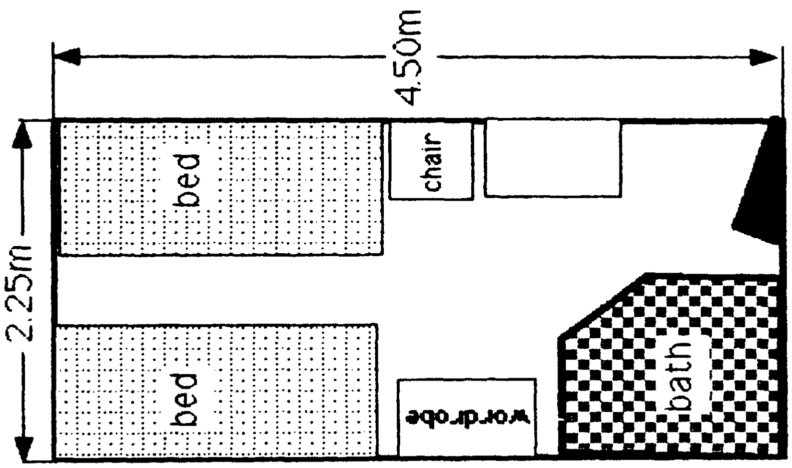

Fig.3.23 Twin berth cabin arrangement

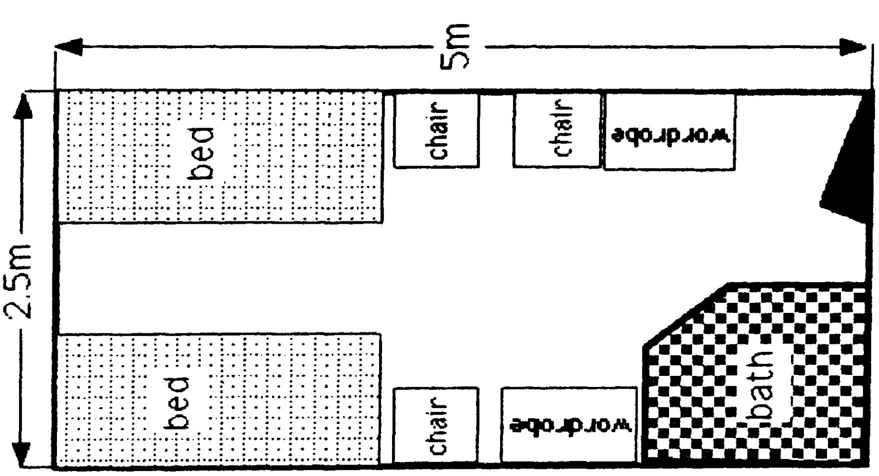

Fig.3.24 Four berth cabin arrangement

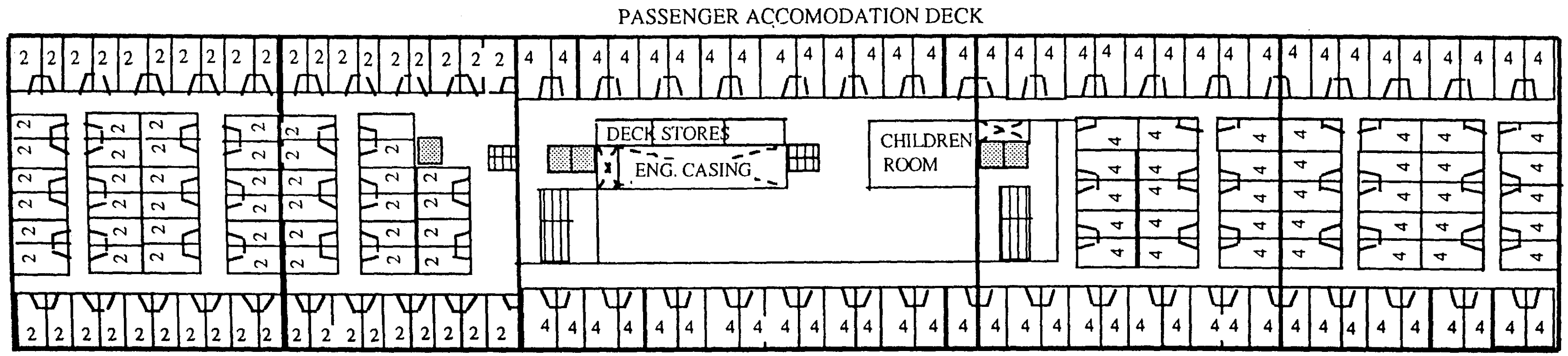

Fig.3.25 General arrangement of passenger accommodation deck, twin and four berth ,cabins are located at deck 6

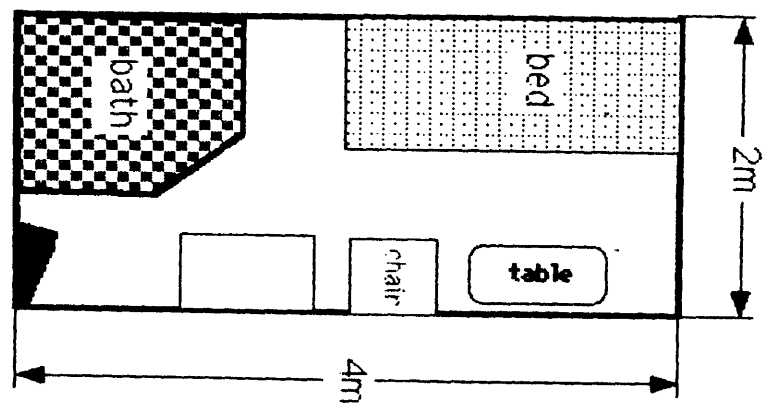

Fig.3.26 Single cabin arrangement

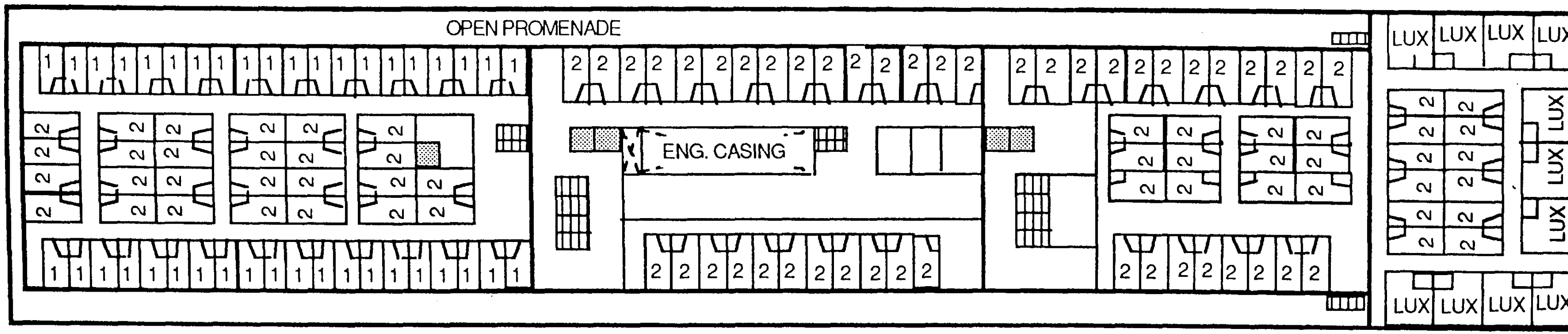

Fig.3.27 General arrangement of passenger accommodation deck, single and twin berth, cabins are located at deck 7

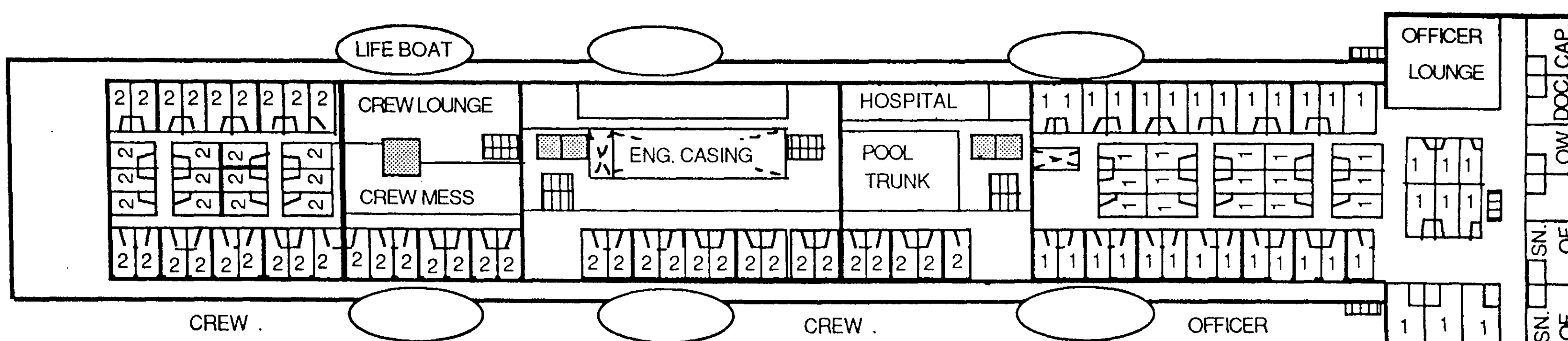

Fig.3.28 General arrangement of crew accommodation deck, deck 8

Large passage ways and emergency exits were located at deck 8, since life boats are at both sides of the deck. According to the SOLAS agreement regulations, for class 1 vessels the total capacity of life boats must be the 75% of total persons on board. Therefore six life boats, which have 125 person capacity each are installed on board. The deck arrangement can be seen in Fig.3.28.

-Deck 9

Remaining passenger facilities are on this deck. The forward part of the deck has been arranged as a passenger lounge, which has 100 passenger capacity. Library and reading room were located next to the lounge. There is also a 150 people capacity theatre ,suitable for entertainment and conference facilities. An open swimming pool is located at the middle of the deck, in front of the funnel to protect the passengers against the smoke.

Air conditioning systems and emergency generator were installed around the funnel. The aft end of the deck was left open for sport facilities. A promenade area was arranged all round the deck.

The bridge and wheel house were located at the front top of the deck nine. This deck includes chart room, radio room and some offices.Two rescue boats are located at the both sides of the bridge deck. The arrangements of the deck 9 and bridge deck are shown in Fig.3.29.

3.11 Power Estimation

3.11.1 General

Recent increase in ferry dimensions has brought some disadvantages as well as some advantages . Having large beam, block

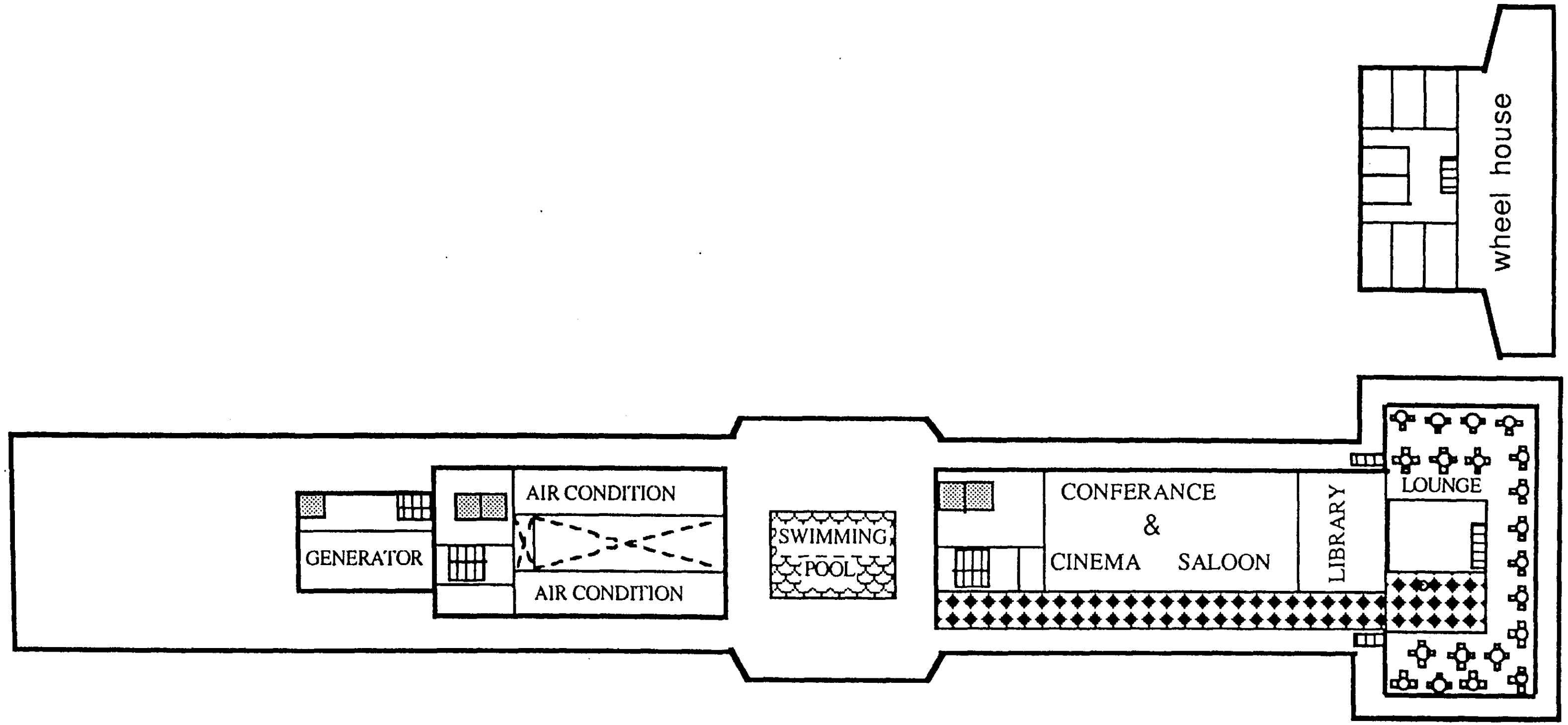

Fig.3.29 Some sport, entertainment facilities and wheel house are located at deck 9 and bridge deck respectively

coefficient and higher superstructure produces higher resistance.

Ferry speed is influenced by market competition but has not increased greatly. The larger value of beam and block coefficient and superstructure has resulted in greater resistance perhaps resulting in about 13% more power compared to 1970` designs as shown in Fig.3.13 and Fig.14.

On the other hand, possible increase in fuel cost due to this excess power necessity has been largely recovered by improvements in the performance of engines. For instance, specific fuel consumption has been reduced from around 160 (gr/bhp-hr) to 140(gr/bhp-hr), therefore, fuel cost has not increased as much as power has increased.

3.11.2 Calculations and Results

Considering the 21 kn. service speed, the required power is estimated to select the machinery system by using the Taylor systematic method extended by the German Democratic Republic [Ref.24]. Although, the final decision for the machinery system would be taken considering the maximum service speed, the calculations were carried out for six different speeds to see the variation of power with the speed. this variation would be necessary during the economic analysis. Calculations are given in appendix 3 and the results of the calculations are presented in Fig.3.30 by EHP of the ship against ship speed. The figure also represents the BHP,which was calculated in Appendix 3.

Fig.3.30 shows the substantial increase of power when speed rises above about 18 knots. While there is advantage in fitting power for 21 knots to allow greater flexibility in operation,the economic speed may be closer to 18 knots.

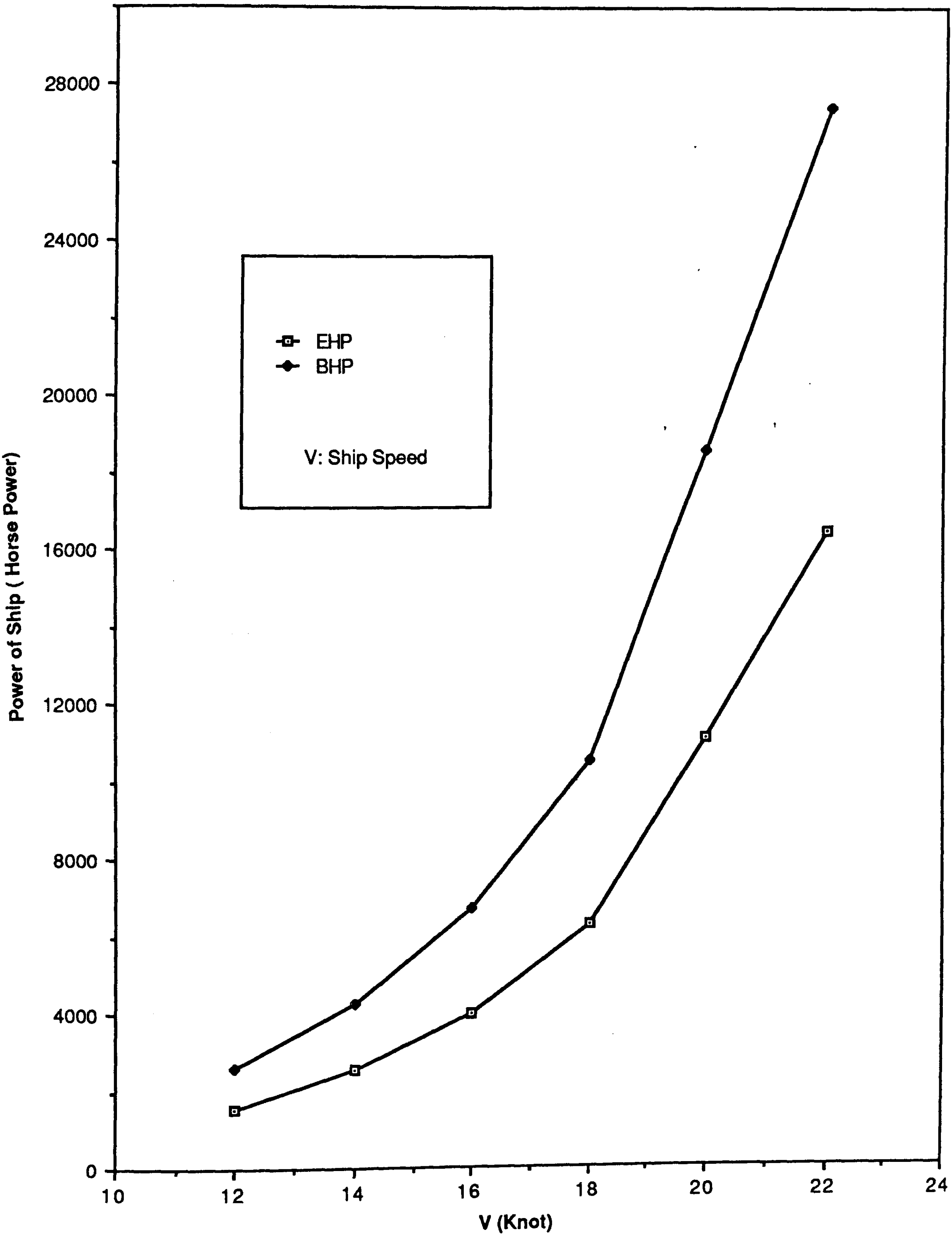

Fig.3.30 Required engine powers for different service speed

3.11.3 Selection of Engines

According to the Father-Son machinery system, two big and two small, in total, four engines are required. SULZER ZA 40 medium speed engines are

chosen as final selection. Each large engine has eight cylinders which have 875 BHP each and total weight of each large engine is 76 tonnes . Each small engine has six cylinders and is 58 tonnes . Each large and small engines are connected to the same shaft by means of gearbox. Furthermore, there are two six cylinder auxiliary engines,driving generators which have 2140 Kw. power each.

3.12 Propeller Design

Passenger ships have usually twin screws which gives additional safety against breakdown and allows a high power to be transmitted successfully with relatively small diameter propellers dictated by shallow draft. Controllable pitch propellers suit medium speed prime movers coupled generators as the gearbox can match the speeds, no reversing is provided on the prime movers and RPM can be kept constant.

The initial propeller design is not more than a first approximation. However, this calculation is necessary to confirm the basic parameters, which are required during design. These parameters are diameter and RPM of propeller, and propeller efficiency. This final propeller design can be expected to improve as a result of the use of modern highly skewed blade shapes.

Design starts from the calculation of the wake fraction and thrust deduction factor by using the approximate formulas although in a twin screw ship the hull efficiency is close to unity. However, since these formulas do not give precise results, they may be used just for the first approximations. As a first approximation, diameter was taken as 4.00 meters considering the 6 meters limited draft. For the calculation, RPM of propeller was taken as 240 relating to the power of engine and gearbox arrangement.The calculations were carried out for Wageningen B series and the types of B4.40, B4.55 and B4.70.These calculations are given in Appendix 3.

Considering cavitation, type B4.70 is the optimum propeller type, although, it has the less thrust compared to the other types. The propeller efficiency was estimated from chart as 0.62 which is equal to the quasi propulsive efficiency, with hull efficiency and relative rotative efficiency unity. As a final result, all these calculations gave the optimum diameter of propeller as 3.77 meters which is sufficient for propulsion system and suitable for the existing draft. Modern highly skewed blades are likely to have better efficiency with less risk of cavitation.

3.12 Midship Section and Longitudinal Strength Calculations

In order to obtain the load line assignment, the structure of a ship must conform to the requirements of a classification society. A principal requirement is to have adequate longitudinal strength to withstand the longitudinal bending moment . The bending moment here is the maximum moment resulting from combined still water and wave loading.The rules set down the minimum required section modulus and the midship section of the vessel is evolved to attain this based on the rule requirements for the structure. All requirements are given in Ref.31.

3.12.1 Minimum Required Section Modulus, Z_R

The minimum hull section modulus required for unrestricted sea-going vessels is calculated from the following equations given by Ref.31.

$$Z_R=C_1 L^2 B(C_B+0.7) \qquad (3.12.1)$$

and

$$Z_R=(M_s+M_w)/\sigma_c\ 103 \qquad (3.12.2)$$

where

L is length of ship, in meter,

B is beam of ship, in meter ,

C_B is block coefficient,(nondimensional),

C_1 is a factor, given in Ref.31 as $10.75((300\text{-}L)/100)^{1.5}$

M_s is bending moment due to hydrostatic loading,(in tonne .f.m)

M_w is bending moment due to wave loading, (in tonne .f.meters)

and σ_c is maximum stress (in kgf/mm^2).

Equation 3.12.1 and 3.12.2 give the section modulus in cm^3.The design section modulus is chosen to be the maximum of Z_R values calculated from the above equations. Rules specify the maximum stress σ_c to be 18.5 kgf/mm^2

Design still water bending moment,M_s, is estimated by considering the distribution of group masses as shown in Fig.3.31, while the wave bending,M_w, is estimated by formulas based on wave and ship geometry given by rules.These formulas and calculations are given in Appendix 4. Introducing the values given above into the equation 3.12.1 and 3.12.2 gives, for Z_R, 4.986 10^6 and 3.781 10^6 cm^3 respectively. The former,i.e. the maximum one, is taken as Z_R.

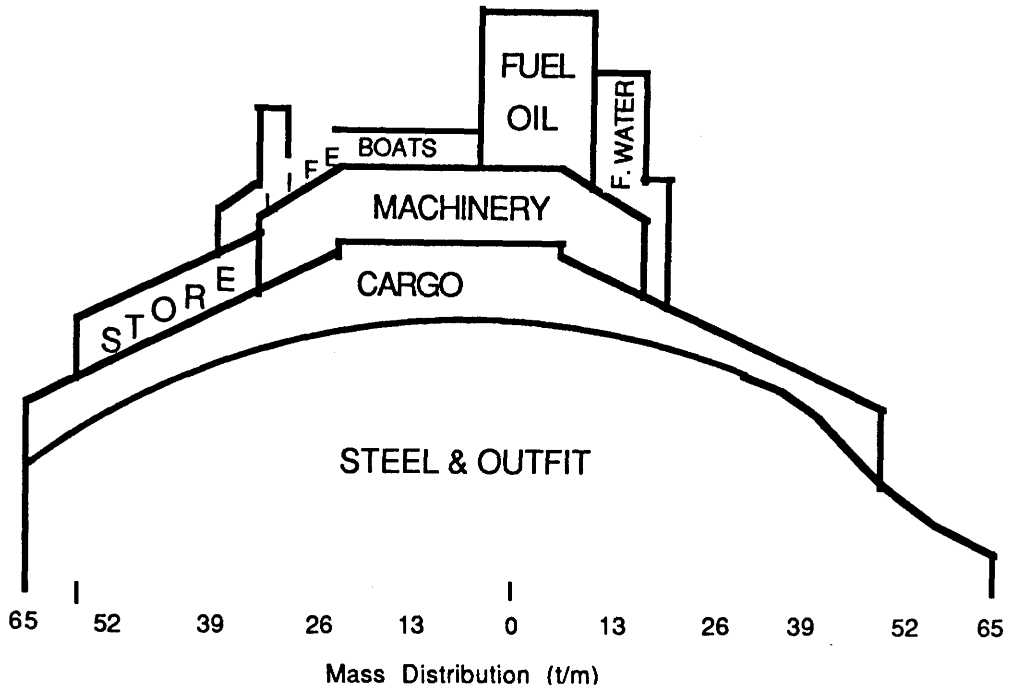

Fig.3.31 Mass distribution of ship along the length of ferry

3.12.2 Defining Dimensions of The Structural System

The structural system of the ferry was chosen as a longitudinal framing system,thus allowing the most efficient disposition of material.The dimensions of each member,such as girders,plates and stiffeners, were chosen in accordance with the Lloyd's Register of Shipping Rules.Detailed calculations are given in Appendix 4 and some of the chosen dimensions are shown in Fig.3.30.

3.12.3 Actual Hull Section Modulus Calculations

In the calculations of the section modulus of the midship section only the effects of the longitudinal members running continuously along full ship length and decks along the full ship beam are considered. The effects of the shorter longitudinal members are assumed to be negligable. However, effects from side shell, deck platings, longitudinal bulkheads,longitudinal stiffeners and double bottom girders are taken into account.These calculations are given in Appendix 3 in detail. The followings are the results calculated for the ferry design .

The neutral axis from the keel;

$Y_{n.a}$=11.47 meters

The moment of inertia at neutral axis;

$I_{n.a}=11.728\ 10^9\ cm^4$,

Section modulus at top deck;

$Z_{dck}= 11.276\ 10^6\ cm^3$,

Section modulus at keel;

$Z_k=10.287\ 10^6\ cm^3$

Results show that the strength of hull is quite sufficient. It is around 2.5 times greater than required strentgh.

3.13. Subdivision and Damaged Stability

3.13. General

Almost all ships must comply with the international agreements on load line assignment which determines maximum draft. Ships with passenger certificates must also comply with the international agreements regarding subdivision and damaged stability which generally result in a lesser draft than load line considerations on their own. International agreements on ship safety measures were introduced following disasters at sea and have been modified in the light of further disasters and this process will continue.

The loss of Titanic in 1912 brought into being the earliest agreement on subdivision and following other important casualties requirements exist for adequate stability after damage and avoidance of asymmetrical flooding. By 1960 changes of trading pattern and the demand

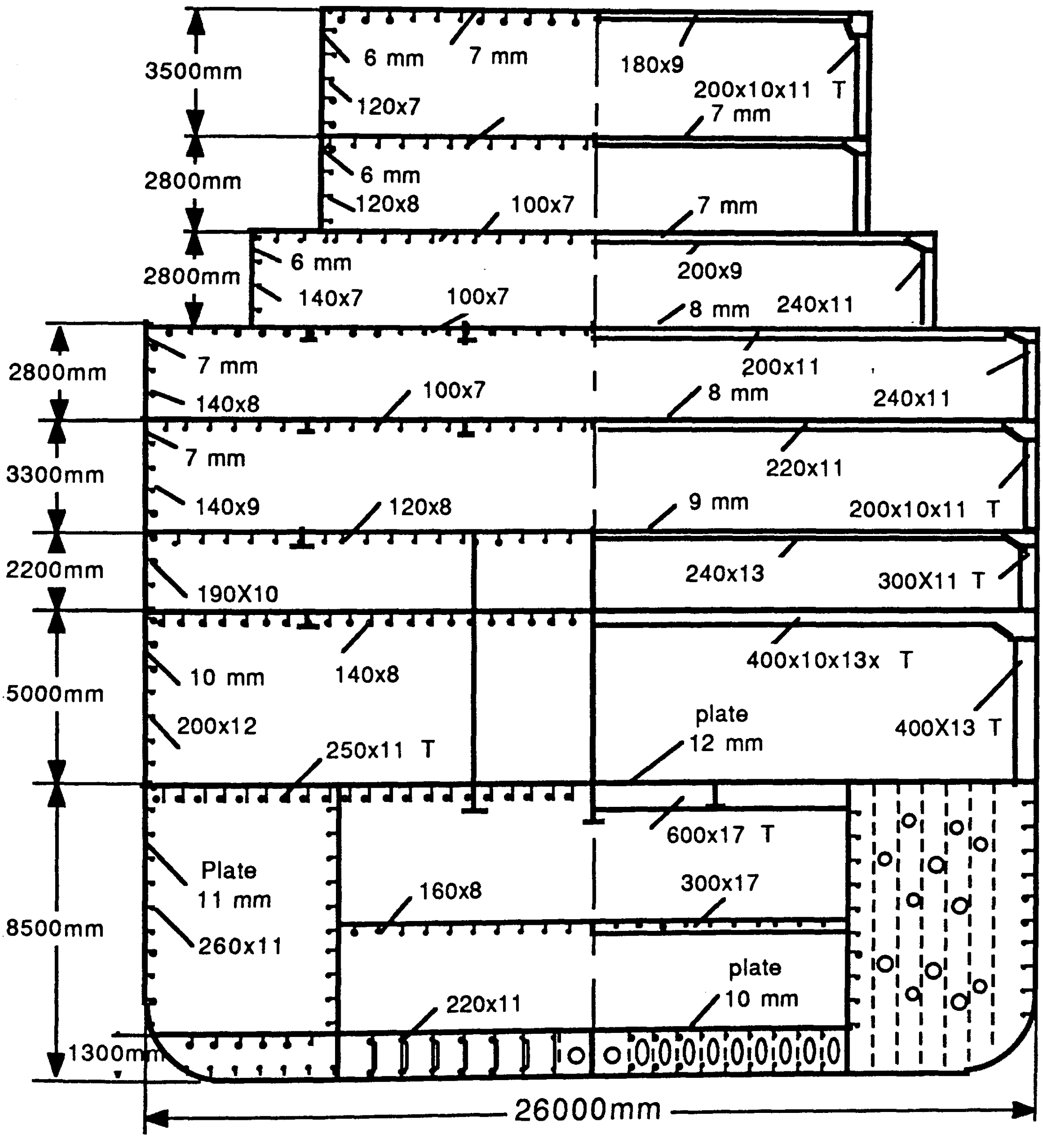

Fig.3.32 The structural arrangement of mid-ship section and chosen dimensions

for new types of passenger ships brought criticism of the methods of calculation and the goals for subdivision and damaged stability regulations.

More fundamental attitudes drew attention to anomalies in the traditional methods of calculation used and since 1974 there have existed two methods of presentation for calculations relating to subdivision and damaged stability.

The deterministic method is the traditional calculation while the alternative method, as it is called, is a probabilistic calculation. In each case, the end requirements are based on attainments that have been found reasonable in the light of casualty experience since records began, but the probabilistic method takes more matters into account and gives a more consistent and realistic appraisal of safety. However it is a more inconvenient calculation to perform and perhaps less easy to understand and has rarely been used, as it remains an option. Making it the mandatory method may be a future development.

3.13.2 Deterministic Method

The most recent international agreement on Safety of Life at Sea or SOLAS is that of 1974. It includes the traditional or deterministic method of calculation for flooding and damaged stability. The deterministic method is in Ref.25 and the probabilistic method is in Ref.27.

In the deterministic method calculations are carried out in two steps.First the floodable compartment length calculation is carried out for the expected full loaded draft. The floodable length at any point in the length of a ship is the length which can be flooded without immersing any part of the margin line. Then factor of subdivision and permissible length calculations are carried out. The factor of subdivision (F) shows the required compartment standard of the ship. If F is bigger than 0.5 , one compartment standard is required, if F is between 0.5 and 0.33 a two compartment standard is required, and a three compartment standard is required if F is less than 0.33. The permissible length at any point of ship is obtained by multiplying the floodable length at that point by the factor of subdivision (F). The actual compartment length should not exceed the permissible compartment length. However, a compartment may exceed the permissible length if the combined length of each pair of adjacent compartments to which the compartment in question is common does not exceed either the floodable length or twice the permissible length whichever is less.

The value of F was found from calculations as 0.96 which requires a one compartment standard. However, considering the demand for more safe passenger ships and the ability to a achieve this improvement, a two compartment standard is attained in this particular ship.

As a second step, taking into account the floodable length, factor of subdivision and permissible length calculations, watertight bulkheads are located to meet target design requirements. This chosen bulkhead arrangement is checked to see whether it is safe or not after a possible damage under the subdivision requirements. All calculations are performed by a direct method using an approved package of programs [Ref.60]. Calculations are given in Appendix 5 and The floodable length, permissible length curves together with actual bulkhead arrangement are shown in Fig.3.33.

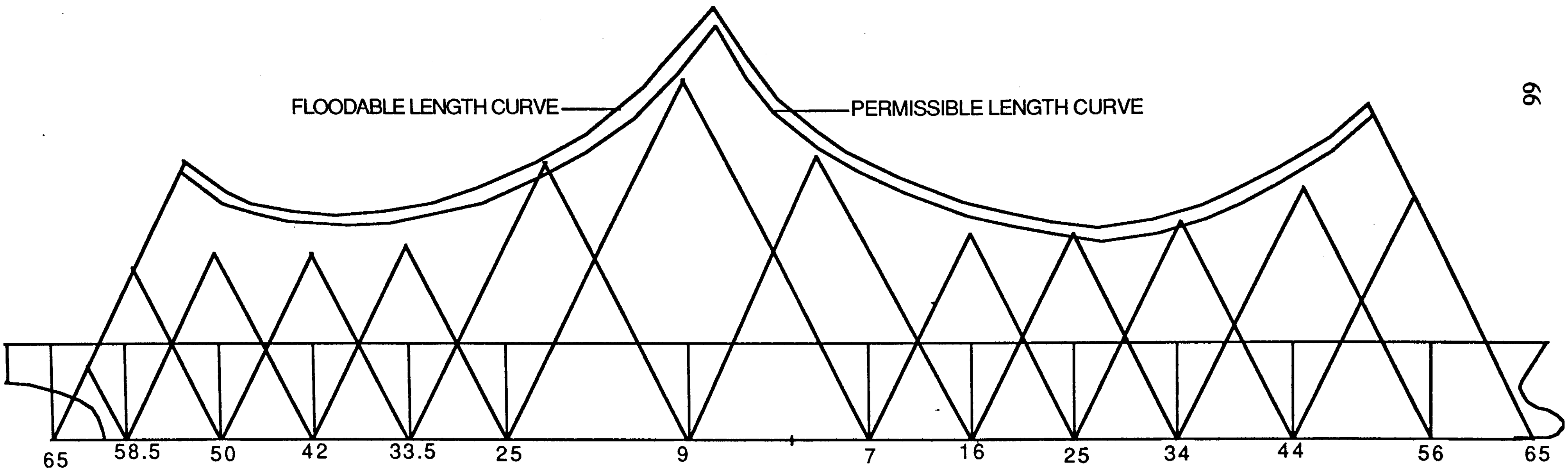

Fig.3.33 Floodable length and permissible length curve together with bulkhead arrangement along ship length

3.13.2 Bulkhead arrangement

Generally the locations of bulkheads are chosen considering the arrangement requirements and the floodable compartment lengths. However, regulations require that collision bulkhead must be watertight and fitted at distance from the ship's forward perpendicular not less than 5% of the length and not more than (3+0.05L).

The machinery spaces must be within the floodable length requirement yet long enough for the equipment within them. This usually means a series of spaces. Therefore the two machinery spaces were located rather aft of midship. In total 13 watertight bulkheads were located along the length of ship and damaged stability checked by using the lost buoyancy method [Ref.60]. The calculations are given in Appendix 5 and final arrangement is shown in Fig.3.33.

3.14 Probabilistic Method (A.265(8))

The international conference on safety of life at sea 1960, recognizing the importance of subdivision and damage stability of passenger ships recommended that the Inter-Governmental Maritime organization [IMO] should undertake further studies of watertight subdivision of passenger ships,because the regulations dealing

with the subdivision of passenger ships in 1960 convention derived from studies carried out prior to and after the first international safety conference of 1913-1914. These studies naturally were based on the design and service requirements of that time. Although regulations have been modified from time to time, present regulations do not take into account the evolution, perhaps revolution in ship design and service requirements and advances in knowledge over the past fifty years.Hence, the deterministic method has become less meaningful as regards safety. It has allowed optimization of ship types that were probably never foreseen by these who formed the original regulations.

As a result of extensive study, the committee developed new regulations dealing with subdivision and stability for passenger ships. The most important and principal distinction of the new regulation is the use of a probabilistic approach. The probabilistic approach is partly the result of the study of the damage statistics and observed sea conditions which have been reported to IMO for long period. Damage statistics contain information of ship length(L), ship breadth(B), damage location(x), damage length(y) and damage penetration(z). IMO has also the voyage reports including operating drafts , permeabilities and stability of those ships.

According to the IMO researchers damage extent depends mainly on structural characteristics, mass, speed of rammed and ramming ship, relative course angle between rammed and ramming ship and location of damage in the ship length and the actual loading of the vessel when damaged. The influence of structural characteristics are considered to be small, and this influence can be neglected. The mass of the rammed ship depends on her size and her loading condition. The influence of the loading condition is small especially for purely passenger ships. Therefore it can be disregarded to make the calculations simple. To take into account the size of rammed ship the damage length has been related to the ship length and damage penetration to the breadth.

Examination of existing data shows that ratio y/L is approximately independent of the ship length and the location of the damage and the highest density of ratio y/L is generally around 0.05. these results can be seen in Fig.3.34 and 3.35. Study also shows that damage length is independent of damage location in the ship. According to IMO an explanation of these independences might be that small vessels are more likely to meet small vessels and large vessels are more likely to meet large vessels.

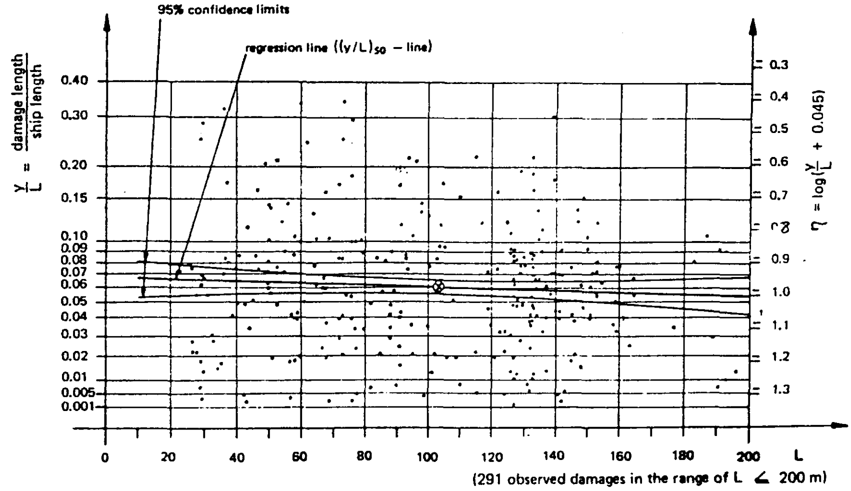

Fig.3.34 The regression of non-dimensional damage length on ship length (Ref.27)

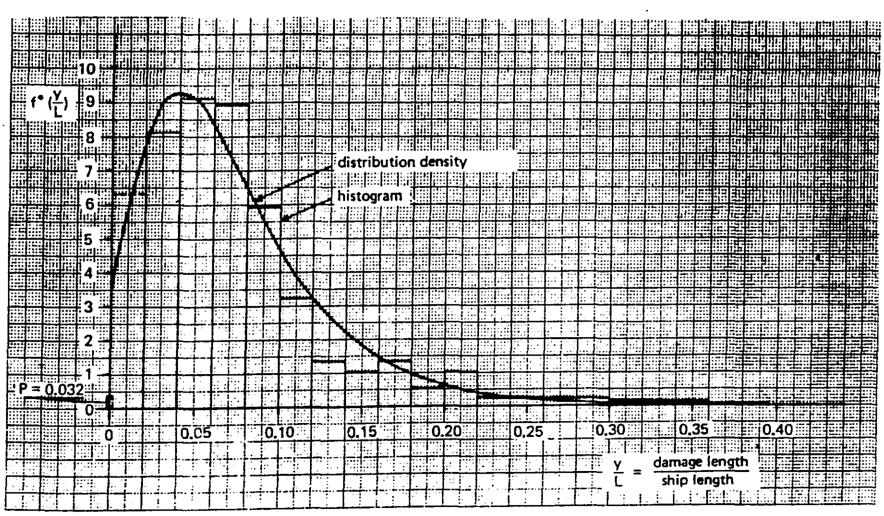

Fig.3.35 Distribution density of non-dimensional damage length (Ref.27)

Increasing speed and size of ships during the recent years suggests that the average size of damage in cases of collision is growing. Fig.4.36 indicates that the damage length increases with time.

Damage statistics show that the ratio z/B is independent of ship's breadth(Fig.3.37) and it is found that average damage penetration is around 0.2B. However there is relation between z/B and y/L as shown in Fig.3.38 where z/B increases on the average with increasing y/L.

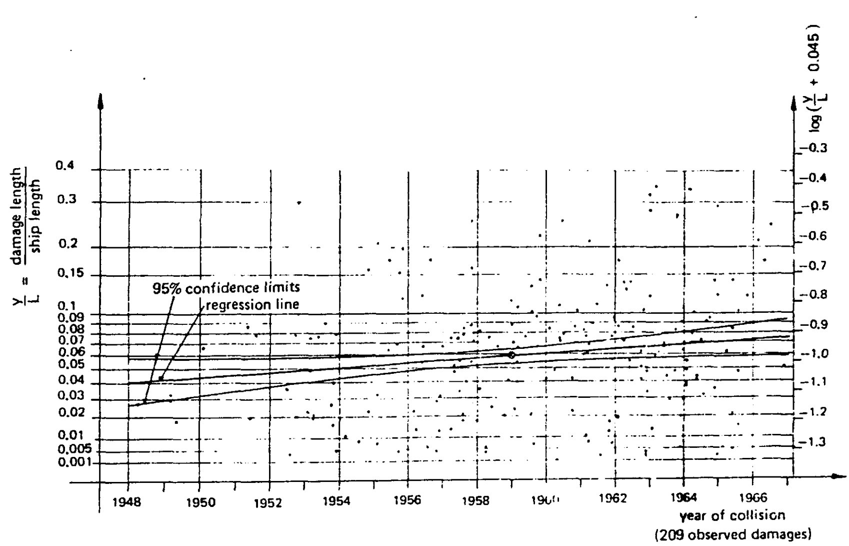

Fig.3.36 Regression of non-dimensional damage length on year of collision (Ref.27)

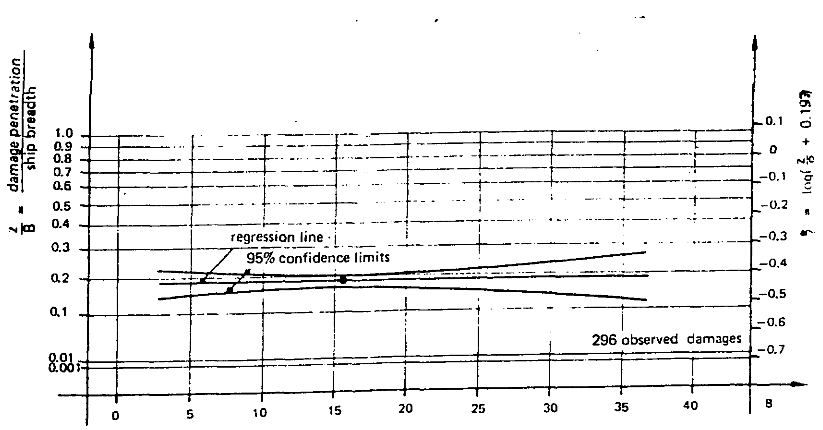

Fig.3.37 Regression of non-dimensional damage penetration on ship breadth (Ref.27)

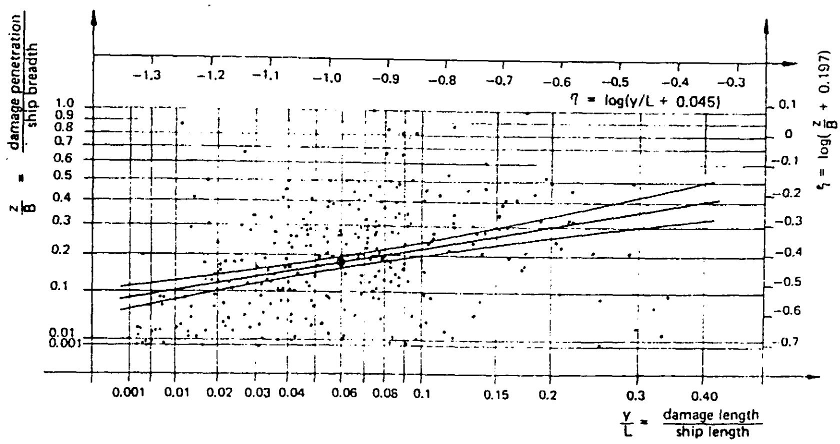

Fig.3.38 shows the change of non-dimensional damage penetration as non-dimensional damage length changes(Ref.27)

According to the damage statistics damages occur more often in the forward half of the ship than in the aft part [Fig.3.39].

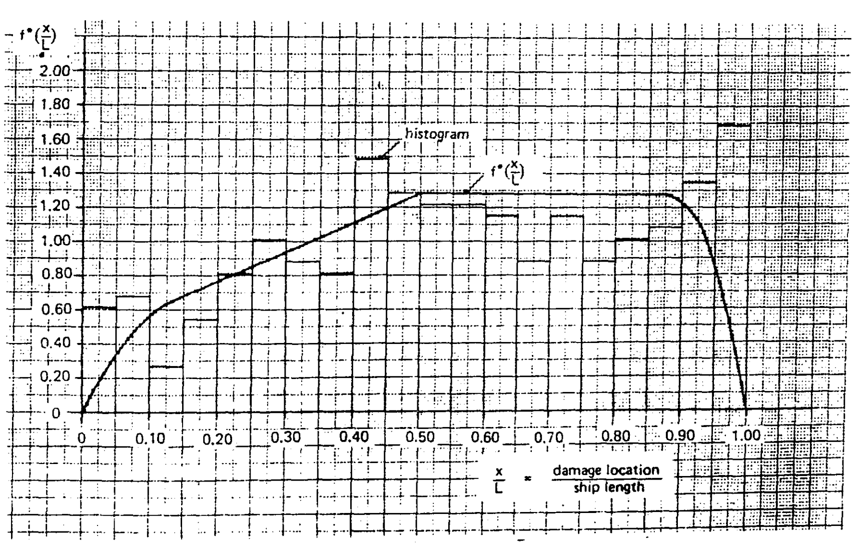

Fig.3.39 Distribution density of non-dimensional damage location(Ref.27)

Apart from those damage statistics the probabilistic approach takes into account the average wave height recorded at different times and different seas. The required GM values for different wave height also has been estimated by some model experiments.

Consideration of these different parameters and different conditions make the probabilistic method more realistic. However because of the complexity of the probabilistic method which is based on the concept of the probability of survival, the Eighth Assembly adopted the regulations as being an equivalent to and a total alternative to the provisions of part B of chapter 2 of the 1960 safety convention. The probabilistic method is based mainly on the following probabilities.

- The probability of flooding each single compartment and each group of two or more adjacent compartments.

- The probability that the residual buoyancy after flooding of a compartment (or a group of two or more adjacent compartments) under consideration will be sufficient to provide for survival

- The probability that the stability after flooding a compartment or group of compartments will be sufficient to prevent capsizing or dangerous heeling due to loss of stability or to heeling moments

During the work on alternative method, it was considered that the effect of damage is dependent on:

- The location of the flooded compartment or group of compartments

- The draft and intact stability at the time of damage

- The permeability of affected spaces at the time of damage

- The sea state, particularly the critical wave height, at the moment of damage.

- Possible heeling moments due to unsymmetrical weights.

All these possible statements are taken into account during the calculation of attained subdivision index (A) which is the base of the probabilistic method. The value of A is calculated on the concept of the probability of survival of the ship in case of collision.For the safety of the ship, it is required that 'A' must be greater than required subdivision index 'R' which is a function of the total number of passengers and crew on the ship based on R values for existing ships. Appendix 5 gives the detailed information and calculations of these parameters.

Perhaps there can be no absolute or objective standard for R. The curve chosen was based on actual ships recalculated by the alternative method whose original design was optimized around the deterministic regulations. The scatter is too obvious. If the alternative method was made mandatory then experience would be gained to indicate whether or not the choice of R was reasonable in service. No doubt it must be somewhat similar to the freeboard by the load line rules in that small ships cannot be made as safe as large ones without impossible economic penalty and that for very large ships the potential for damage is close to a limit.

3.14.1 Calculations and results

During the calculations, the following requirements are particularly considered

- The flooded GM value must not be less than 0.05 meters
- The final angle of heel in the flooded condition is limited to 7 degrees for flooding of one compartment and 12 degrees for flooding of two or more compartments.
- The relevant bulkhead deck must not be immersed at the final stage of flooding.

Calculations were carried out for the existing watertight bulkhead arrangement as shown in Fig.3.40.Since therewas no computer program available, especially developed for probabilistic method, calculations were carried out by using the existing package programs [Ref.60].

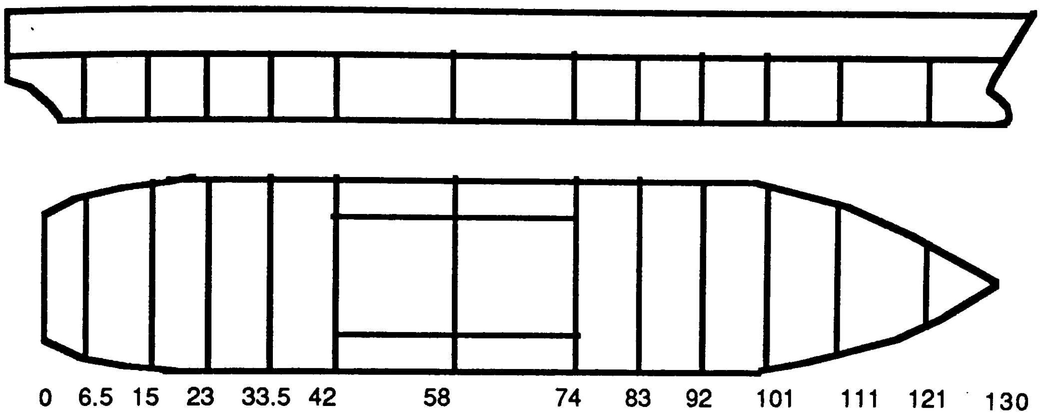

Fig.3.40 Chosen compartment arrangement for this particular ferry

Results showed that compartments 6 and 7 needed cross-flooding arrangement because of the large angle of heel which was caused by the flooding of wing tanks. Incorporating the cross flooding arrangement, the final value of 'A' was obtained as 0.710 assuming that the final angle of heel is 7 degrees and 'R' was found as 0.686. If the final angle of heel is assumed as 3 degrees 'a' is obtained as 0.80. These results suit the requirement of A>R, therefore, the existing subdivision arrangement is sufficient. As calculations show, the ship can withstand the flooding of single or two adjacent compartments but cannot withstand the flooding of three adjacent compartments because of the large trim.

It can be seen from calculations that the most effective way to increase the 'A' value is to increase the freeboard within the limits accepted by the regulations. Another alternative is to have a high initial GM although, a high service GM is not recommended for the comfort of passengers. However,improved fin stabilizers allow a higher value of GM as they reduce the rolling. Higher freeboard may have a bad effect on the GM since it increases the KG of ship.Therefore, these two terms must be considered together.

3.14.2 Consideration of the Deterministic and Probabilistic methods

The deterministic and probabilistic methods are based on two different parameters namely the factor of subdivision (F) and the attained subdivision index (A) respectively. F determines the compartment standard of ship while 'A' determines whether the watertight bulkhead arrangement is safe enough.

Although the deterministic method was improved in 1960, it was originally evolved for the types of passenger ships common in the 1920's.Therefore this method does not seem very convenient for modern ship designs. Shipowners will conform to the Rules and may go beyond them provided no economic penalty is present.This particular ferry design required a one compartment standard but was designed as two compartment ship with advantages for safety. For this chosen subdivision arrangement, the probabilistic method gave an acceptable result but not as good as expected.This example also shows that the deterministic method needs some revisions. However,this method is easy to understand and to apply to ships,therefore, it is normally used.

The probabilistic method is the product of considerable observations, study, experiment and calculation using data from a variety of existing passenger ships. It has a better scientific basis and is less likely to suit merely one type of passenger ship. It has become a method because of clearer understanding of probability and more scientific study of accident damage. It also is well adjusted to ferries as a long inboard car deck [Fig.3.41] is possible below the bulkhead provided it's boundaries are sufficiently distant from sides or bottom and of course 'A' remains greater than 'R'. The probabilistic method makes the calculation of the cross-flooding arrangement precise by giving some reference formulas.

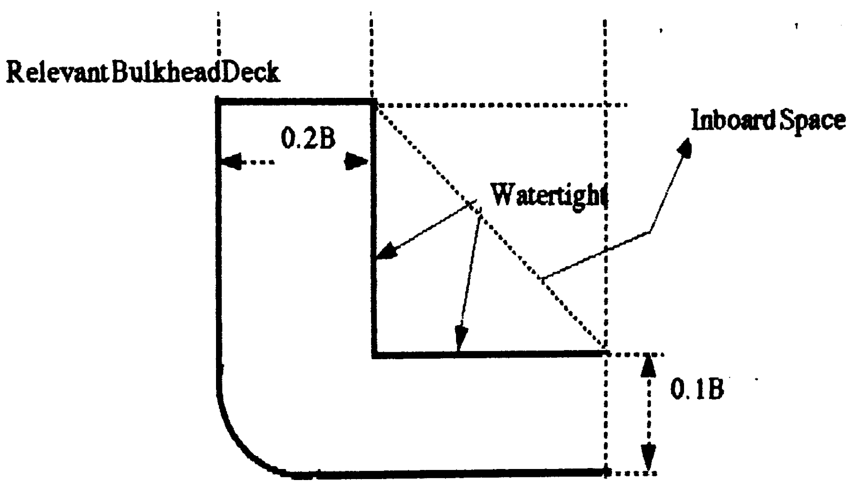

Fig.3.41 Arrangement of long inboard space below bulkhead deck allowed by probabilistic method (Ref.27)

While the probabilistic method may give a more realistic indication of safety no method can indicate perfect safety and there may be arguments that the simple concept of factor of subdivision has more direct meaning than subdivision index. In addition the method is both harder to apply as well as harder to understand and a dedicated computer program is essential to apply it. Consequently it has been seldom used as a method for authority approasal and may have to be made mandatory to ensure that it is used.

Existing computer programs in the department are the package programs developed for different naval architectural problems and suitable for microcomputers.In order to carry out the calculations five different programs were used and total computing time was more than 12 hours although the fast procedure which makes calculation 3.5 times faster was used. In addition, some of the parameters had to be calculated manually,since those can not be obtained using the programs. These difficulties show the necessity of the good computer program for probabilistic method.

The sinking of Herald of Free Enterprise raised many questions about ferry safety. The report of the inquiry is now published. Like all accidents it has particular causes and these seem to be more related to human error than to technological oversight. It may be that regulations will alter as a result of that accident, for example a probabilistic function for human error could be included. However making the alternative method mandatory might be the best practical outcome and so avoid an optimum design by the deterministic method with it's extremely small freeboard. Naturally convenient software for calculation is essential.

CHAPTER 4

ECONOMIC ANALYSIS

4.1 General

The total cost of owning and operating a ship can be subdivided into many items and arranged in many different groups. Traditionally the capital cost of the ship, the cost of the fuel, the cost of the crew, the cost of port dues and of consumable and repair items for the vessel are major subdivisions. The potential income from owning and operating a ship is from the fares charged for cargo and passengers and any final resale value remaining in the vessel on disposal.

There is not always a rational basis behind all these costs and incomes. Many of them are very strongly influenced by market forces. The capital cost of a vessel built in Western Europe currently attracts around 28% subsidy and even then will cost more than a similar vessel built in the Far East. Crew costs depend on the standard of living of the crew's country and differ widely across the world but the crew can be used anywhere in the world. Fuel is perhaps the most uniform world wide cost only responding to the alterations of oil price.

However all decisions are based on comparisons and as economic considerations are important, numbers must be given in a definitive way to all costs and incomes to take the many decisions needed for ship owning and operating. In feasibility studies it is the differentials that are significant even though the absolute economic numbers in service are different.

The estimates for shipbuilding and operational costs are required for various reasons by various authorities. For example, fleet managers need cost estimates for preliminary design purposes to make rational selection between alternative investment opportunities, establishing budgets or predicting charter or insurance rates. Naval Architects need cost estimates for preliminary design purposes. These encompass studies of feasibility, alternative technology and optimization studies aimed at finding the best combination of major design parameters. Cost estimations are also useful in making detailed design decisions and in selecting equipment. Shipyard management needs cost estimation to bid for new construction and to decide whether to make or buy certain items of equipment and for negotiating prices for extras or credits applied to shipbuilding contracts.

This section considers costs and revenue. The capital cost is based on Ref.8 and is intended to represent Western European conditions on the grounds that ferries are complex and there is much expertise in Western Europe. In general crew and service cost and revenues are based on Turkish conditions in Ref.5 and Ref.11.

4.2 Capital Cost

The capital cost is the price to the owner of the new ship. At present it may below the cost of construction from the shipyards point of view. The difference made up by state subsidy or the yard will eventually go out of business. The approach for estimation is that of material and labour applied to hull, machinery and outfit items.

The cost of steel is fairly easy to define although the final figure will depend on discounts, quantities and scrap. The cost of machinery and outfit items will depend on the specification details and sophistication of the vessel. Labour cost for steel will depend on the ship type and is usually expressed through the manhours per tone of worked steel.The shipyard labour cost for machinery and outfit is largely that of putting items into position and making connections as little is nowadays built in the yard.

It is usual to convert the capital costs into an equivalent annual cost over the life of the vessel using an appropriate Capital Recovery Factor. The choice of interest rate will depend on the source of money for the vessel and how profit on the venture is taken into consideration.

4.2.1 **Basis of Capital Cost Estimate**

_ Labour Cost

Man-hours are the basis for the labour costs. The average labour rate changes as the type of work changes and includes appropriate overheads.The labour cost can be divided into three parts namely are steel labour cost, outfit labour cost, machinery labour cost. Steel and outfit labour costs are related to the weights and machinery labour cost is related to the total power of engines. Cost factors for each part are different and related to the profit,overheads and average labour rates as given in Appendix 6.

_ Material Cost

An examination of material cost is again under steel, outfit and machinery. It is calculated in a similar way to the labour cost. The initial estimation of material cost is carried out considering the average price of per tone of steel, and outfit and power of engines.

Some special equipment or facilities used with the ship (i.e. different grades of steel in the hull, thrusters, stabilizers, controllable pitch propellers) are estimated separately.

4.2.2 Results

Calculations were carried out based on the references stated earlier for the ferry considered. Computations are given in Appendix 6 in detail. The capital cost was estimated as £33.6 millions supposing the ship is built in The United Kingdom.The distribution of capital cost as follows.

Steel Labour Cost	C_{SL}= £3.48 millions
Steel Material Cost	C_{SM}= £1.46 millions
Outfit Labour Cost	C_{OL}= £5.6 millions
Outfit Material Cost	C_{OM}= £8.8 millions
Machinery Labour Cost	C_{ML}= £4.0 millions
Machinery Material Cost	C_{MM}= £8.6 millions
Thrusters, propellers, stabilizers	C_{TPS}= £1.5 millions

The estimation varies depending on the shipyard and the type of the ship. One of the major component of the shipbuilding cost is the outfitting cost which may vary over a wide range. For example, in passenger ships the quality of decorating, outfitting and automation of the ship greatly affects the outfitting cost. Nevertheless, these estimations are very useful at the preliminary design stage for designer, shipyard and shipowner for their further decisions.

4.3 Operating Cost

An accurate knowledge of operating cost is important for the efficient management of vessel. Shipowners need the operating cost analysis to arrange the ticket fares or to negotiate for long term charters. Analysts involved in certain studies also require specific information on the components of operating cost.

There are two main types of operating cost. One is the costs which are largely or completely unaffected by the particular employment of the vessel. This can be further subdivided as capital recovery cost, crew cost, repair and maintenance, survey cost, previsions, insurance and general administration. Although the capital recovery cost is considered as a part of operating cost, it can also be considered separately from operating cost. The other is the costs which are affected by the particular voyage of the vessel. The subcomponents of the second type are fuel cost, port charges, agency fees, brokage and canal dues. These subcomponents are explained as follows.

4.3.1 First group costs

-Capital Charges

The capital cost of the vessel must be recovered in order to remain in business. The easiest method of considering capital charges is to convert the capital cost into an equivalent annual cost by means of a capital recovery factor. The choice of interest rate of that factor will depend on the actual source of the money but again a simple view is to consider that it is money owned by the company and the return on that money represent the incentive to remain in business. If the money is borrowed then there will be a known interest rate and perhaps a subsidy if it is from a state bank. This approach is not as complete as a true present worth approach but the only major item ignored is that of resale value. If the vessel is a long time in state ownership this item is negligible.

A minimum value of interest rate would be about 10% and a range of value up to 15% is taken. Tax has not been considered on the grounds that the state owns the ferry company. The life of the vessel has been taken as 15 years at which time the resale a scrap value is about £5x 10^6.

- Crew Cost

One of the most important operating costs is the crew cost. Significant changes in crew cost are possible by changing the nationality of crew although, this may be dependent on the owner's freedom of registry of the ship. In addition some automation and other improved arrangements in the ship may reduce the crew cost. However, passenger ships always need a high number of crew for the hotel services although the number will still vary with number of passengers and standards of service.

For the ferry's technical services it was estimated that a total of 36 crew members are required but 114 are required for the hotel services. They are distributed as shown in Table 4.1. Note that 75% of the total crew is for hotel services. This was thought to be necessary for passenger comfort and quality of services especially for the long journeys the ferry considered to take. For the dining room it was assumed to allocate 1 steward for 3 tables while 1 steward for 20 cabins was considered. Musicians are taken into account considering the need for entertainment in long journeys.

According to the Turkish standards the average annual cost of each crew member at present is as follows.

Officer	£4200/year
Petty officer	£3600/year
Rating	£3000/year

These numbers include basic wages,bonus,overtime and insurance. Crew costs are likely to increase, and as the calculation is carried out for these figures and figures 25% greater.The 150 crew members are a mixture of officers, petty officers and ratings and the breakdown is shown in Table 4.1.

- Maintenance and Repair

Maintenance and repair cost usually consist of the costs related to dry docking of the ship, maintenance of engines and main systems. The cost is also associated with other maintenance and repair to damages. Calculations are carried out in Appendix 6.

- Insurance

The hull insurance is usually a percentage of the capital cost ranging from 1% to 1.5% while the protection and indemnity insurance may relate to the service experience of the owner but is also relateable to the capital cost.

DECK	NO	CLASS	ENGINE	NO	CLASS
CAPTAIN	1	OF	CHIEF ENGINEER	1	OF.
FIRST OFFICER	1	OF	FIRST ENGINEER	1	OF.
SECOND OFFICER	1	OF	SECOND ENGINEER	1	OF
THIRD OFFICER	1	OF	THIRD ENGINEER	2	OF.
RADIO OFFICERS	3	OF	CHIEF ELECTRICIAN	1	OF.
CADET	1	OF	FIRST ELECTRICIAN	1	OF.
CARPENTER	1	P.O	JUNIOR ELECTRICIAN	2	OF.
BOSUN	1	P.O	ENGINE RATINGS	6	RAT.
RATINGS	9	RAT.	STORE KEEPER	1	RAT.
SUBTOTAL DECK	20		SUBTOTAL ENGINE	16	

STEWARS' DEP	.NO	CLASS	FORHOTEL	NO	CLASS
CHIEF STEWARD	1	OF	DOCTOR	1	OF.
SECOND STEWARDS	3	OF	NURSES	2	P.O.
CHIEF COOK	1	P.O	PURSERS	2	P.O
COOK AND BAKER	5	P.O	MUSICIANS	7	P.O.
MESS MEN	5	RAT	PHOTOGRAPHER	1	P.O.
STEWARD FOR OFFICER	3	RAT	LAUNDERETTE	4	P.O.
STEWARDS FOR CABIN	15	RAT	SHOP ATTENDANTS	4	P.O.
STEWARD FOR TABLE	40	RAT.	OTHERS	5	P.O.
LOUNGE AND BARS	10	RAT.	SUBTOTAL	86	
SUBTOTAL	28				

Table4.1 The distribution of crew for different departments of ferry

Protection and indemnity insurance protects the owner against risks not covered by the insurance of hull, machinery and cargo. These are often claims for damages brought as a result of accidents on board and damage or inconvenience that the ship herself causes to others. The premium to be paid is usually based on the size of the ship and number of the crew but will reflect the number of claims made in the past. Since P&I clubs must remain solvent substantial payments may be needed from time to time depending on the needs of all the members of the club. Calculations are in Appendix 6.

- Stores and supplies Cost

Store costs include the cost of deck, engine stores and the cabin stores. The store cost in the deck and engine stores include ropes paints and spares while cabin stores include soft furnishing and laundry. Store and supply costs for passenger cabins such as cleaning,food and drink supplies are not included in this cost since they are considered in the entertainment cost. Food supply cost for crew also is not included here since it is considered together with crew cost. Store and supply cost is estimated as a function of the number of crew.

- Administration Cost

Administration cost includes the expenses for head, rents, advertising, legal expenses, communications and training programs.

4.3.2 Second group costs

- Port Charges and Dues

The cost of entering, leaving and using ports vary widely throughout the world. These expenses can be divided into two groups.First one is entering and leaving cost which includes pilotage, stowage and canal dues. Second one is related to time in the port which consists of daily charges for berth, watchman fees, water, and electricity. Port charge and dues are based on the size of the ship and trade area.

-Fuel Cost

Fuel cost is the important component of operating cost and it is changeable because of the unstable world oil prices. Recently fuel cost has decreased because of the reduction in oil price as well as the improvements in machinery. However fuel cost is mostly dependent on the service speed. Therefore, it might be useful to take into account different service speeds together with total cost, income and voyage time of the ship. Fuel cost is subdivided into the cost of heavy fuel oil,lubrication oil and diesel oil. This estimation is carried out considering the total journey time at the sea and waiting time in ports.

-Entertainment Cost

Entertainment cost includes the various services to passengers such as food and drinks disco, cinema, conference and some sport facilities. However during the income estimations the income from entertainments are estimated as net income, therefore cost of these items are not considered here. Entertainment cost is taken into account for some special entertainment facilities for the special times such as religious holidays(Christmas, Ramadan).

4.3.3 Results

In order to carry out the calculations(see Appendix 6) a computer program was developed. The results were obtained for different capital recovery factors (CRF), fuel and crew costs. The results and the components of operating cost are shown in the Table 4.2 and Fig 4.1 for 18 knots speed and 10% interest rate.The Same distribution for 18 knots speed but for 25% increased cost of fuel and crew can be seen in Table 4.3 and Fig.4.2. As both figures show the most important components of operating cost are the capital recovery cost, crew cost and fuel cost. These components are 48%, 15%, 9% of operating cost respectively for Fig.4.1 and 45%, 17%, 10% for Fig.4.2.

OPERATING COST OF SHIP

Speed= 18 knot   Interest= 10%   Life of ship= 15 years
officer: 4200 £/year, p. officer: 3600 £/year, Rating:3000 £/year
oil=55 £/tonne

Capital Recovery Cost	=4.26 million £/year
Maint. and Repair Cost	=0.31 million £/year
Hull and Machinery Insurance	=0.40 million £/year
Protec. and Indemn. Insurance	=0.23 million £/year
Store and Supply Cost	=0.36 million £/year
Administration Cost	=0.68 million £/year
Port Charges and Dues	=0.16 million £/year
Oil Cost	=0.71 million £/year
Crew Cost	=1.33 million £/year
Entertainment Cost	=0.25 million £/year
Annual Operating Cost	=8.71 million £/year

Table4.2 The components of operating cost of ferry for 18 Kn speed and for original fuel prices and crew wages

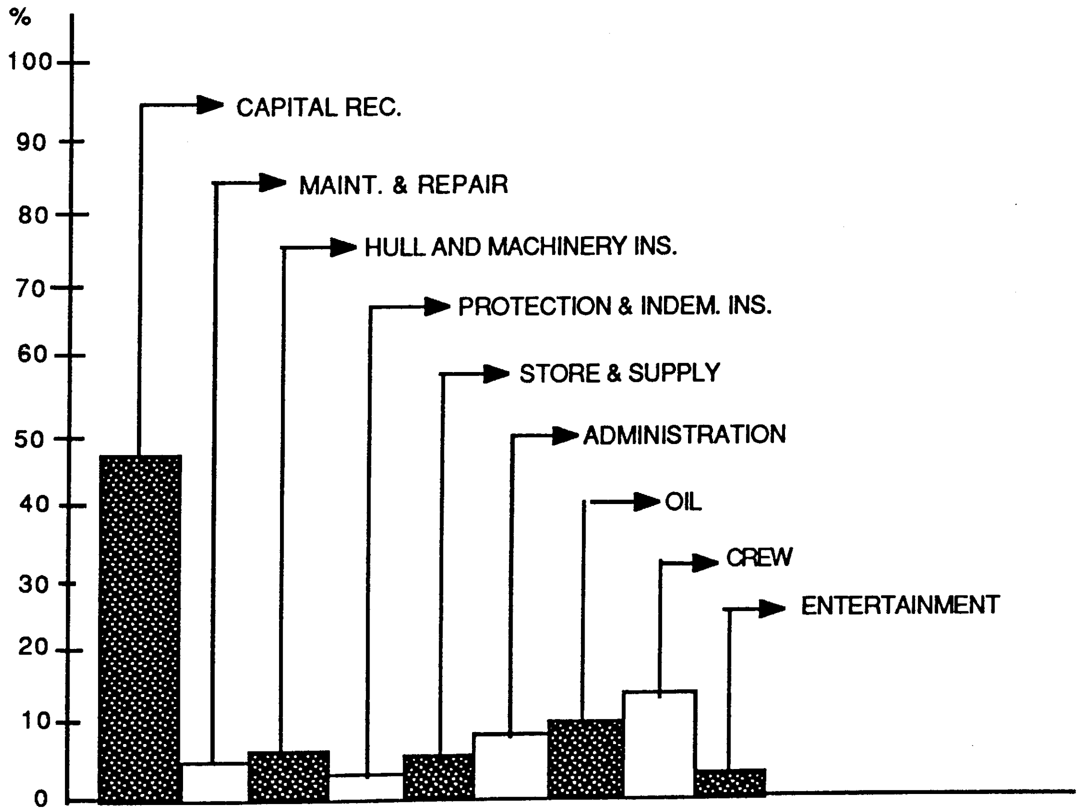

Fig.4.1 The histogram shows the components of operating cost as percentage of operating cost for original fuel prices and crew wages

OPERATING COST OF SHIP

Speed= 18 knot   Interest= 10%   Life of ship= 15 years
officer: 5350 £/year, p. officer: 4500 £/year, Rating:3750 £/year
oil=67 £/tonne

Capital Recovery Cost	=4.26	million	£/year
Maint. and Repair Cost	=0.31	million	£/year
Hull and Machinery Insurance	=0.40	million	£/year
Protec. and Indemn. Insurance	=0.23	million	£/year
Store and Supply Cost	=0.36	million	£/year
Administration Cost	=0.68	million	£/year
Port Charges and Dues	=0.16	million	£/year
Oil Cost	=0.89	million	£/year
Crew Cost	= 1.58	million	£/year
Entertainment Cost	=0.25	million	£/year
Annual Operating Cost	=9.14	million	£/year

Table4.3 The components of operating cost of ferry for 18 Kn speed and for 25% increased fuel prices and crew wages

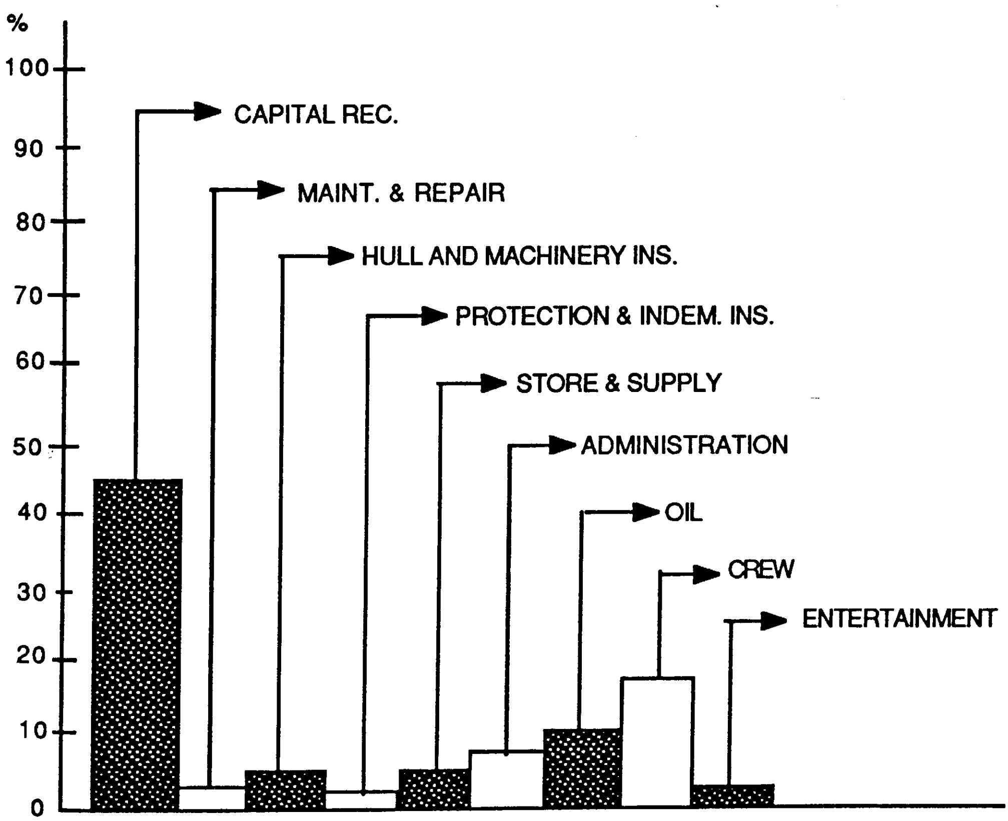

Fig.4.2 The histogram shows the components of operating cost as percentage of operating cost for 25% increased fuel prices and crew wages

The fuel cost is affected by service speed as shown in Fig.4.3. As seen from Fig.4.3 higher service speeds bring extra cost while it reduces the total voyage time which are given for different speeds as follows.

V(speed)	V.Time(h)
15	76.6
16	71.8
17	67.6
18	63.8
19	60.5
20	57.5
21	54.7

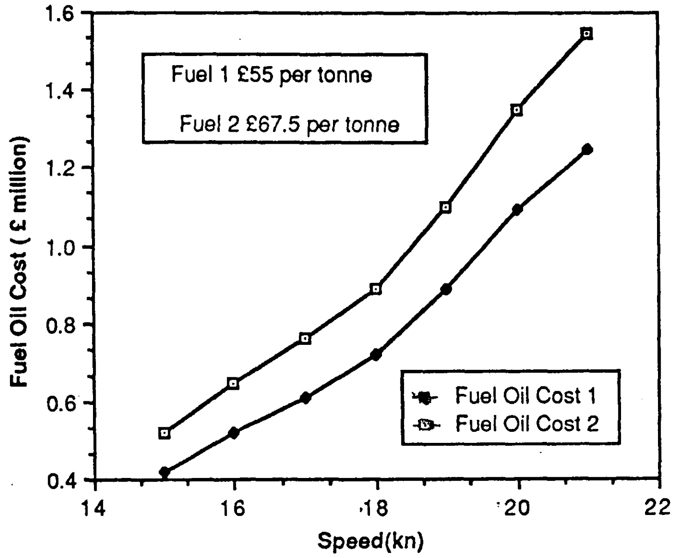

Fig.4.3 The change in fuel cost service as speed changes

Although the service speeds of 15 and 16 knots give the least fuel cost, these speeds require the crew to work a full week because of the increase in voyage time. Besides this, the increase in voyage time may affect the load factor in negative way. The speeds of 17 and 18 knots allow one day off for crew and minor repair of the ship as well as reasonable fuel cost with relatively shorter voyage time. The speed of 20 and 21 knots obviously give shorter voyage time with considerably higher fuel cost. These higher speeds may allow ship to have more off time but the saved time may not be enough for another voyage even to a nearer destination. Therefore speeds less than 19 knots seem to offer more economical advantages over higher speed on this line.

Calculations were carried out for different interest rates to see the changes in capital recovery cost. These different interest rates may affect the ticket fares to obtain profitable income. Total operating cost for different speed and different interest rates are shown in Fig.4.7 and Fig.4.8.

There is big difference between the capital recovery cost and the other components as a percentage of the operating cost in comparison with the values presented in Fig.1.1. This is because the capital cost was estimated according to the British cost standard and capital recovery cost is the function of capital cost. However, operating cost (i.e crew cost, fuel cost, port dues, stores, provisions etc.) was estimated according to the Turkish cost standards. Since the British cost standard is almost three times of Turkish cost standard, this big difference appeared. Capital recovery cost may be reduced by building the ship a country where material and labour are cheap. However, to build such a complex ship needs good experience, management and modern facilities. It must be considered whether these facilities can be available and ship can be completed within the expected time in that country.

4.4 Prediction of Annual Income

Since ships are built to earn money (except some special ships) from their operation, demand estimation is important parameter.

The accuracy of demand estimation is significant for the cost of tickets. However the accurate estimation is very difficult. Because, this line was introduced a few years ago and existing ferries operate on this line for half of the year. Passengers are mainly tourists and consequently very seasonal. A steady demand exists for return visits of Turkish workers in Europe which are again seasonal although perhaps over more of the year than tourists. In general demand is expected for winter holidays. Truck drivers are important for winter demand.

There are two passenger-vehicle ferries running between Italy and Turkey from April to October which is the peak tourist season. MV Orient Express follows the route of Venice-Piraeus-Istanbul-Kusadasi-Patmos-Katakolon-Venice. MV Ankara has the direct route which is Izmir-Venice-Izmir. MV Orient Express has 800 passenger capacity while MV Ankara has 542 passenger capacity.

4.4.1 Ticket fares

The estimation of ticket fares are carried out considering the existing ticket fares given as follows .

MV ORIENT EXPRESS(Venice-Istanbul-Kusadasi)

cabins	fare (single)	(return)
state c.(2)	£475	£855
Deluxe		
2	£395	£710
3	£325	£585
Class A		
2	£330	£595
3	£280	£505
4	£250	£450
Class B		
2	£300	£540
3	£250	£450
4	£220	£395
Clas C		
2	£245	£440

Vehicle Fares	Single	Return
Car	£100	£180
Trailer		
(up to 3 m.)	£75	£135
additional m	£25	£45

Class D

2	£220	£495
3	£200	£360
4	£175	£315

(Ticket fares include meals on board and port tax)

MV ANKARA (Venice-Izmir)

Cabins	Fares(single)	Vehicle	Fares(single)
Deluxe(2)	£270	Car	£100
Class A		Trailer	
2	£220	1-4000 kg	£250
3	£200	4000-6000 kg	£340
4	£185	over 6000 kg	£500
Class B		Minibus	£130
2	£200	Motorcycle	£50
3	£185	cycle	£10
4	£175		
Class C			
2	£185		
3	£165		
4	£135		

(Fares exclude port tax and meals(lounge and dinner))

Taking into account these fares average ticket fares for our estimations are considered as follows.

Passenger	£180 (single)
Cars	£100 (single)
Trailer (12 m.)	£500 (single)

(exclude meals and port tax)

4.4.2 Entertainment Incomes

Generally it includes the incomes from foods, drinks, shops, gaming and some others. According to the examination of cruise market researchers, the average revenue from entertainment facilities is £18 (per.day/per pas.). The distribution of this revenue is shown in Fig.4.4.

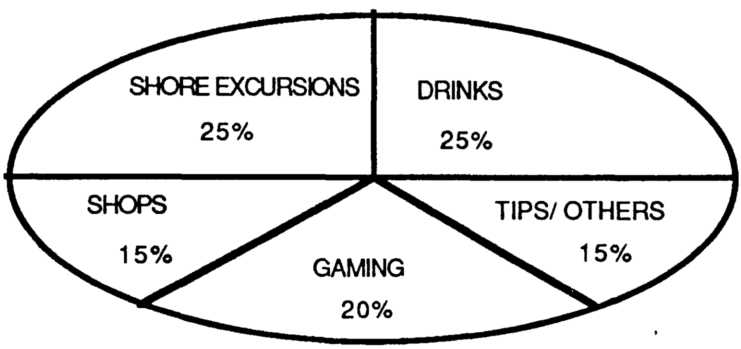

Fig4.4 The distribution of revenue obtained from facilities on board according to the Ref.6

As total amount, this prediction is same to author's estimation but the distribution is slightly different. Since the considered line is direct line, there is no shore excursions but there is income from food at around the same percentage. Ticket fares include only breakfast. The income from drink and tips are less than given in Fig.4.4. The distribution of entertainment income for the particular ship design is given in Fig.4.5.

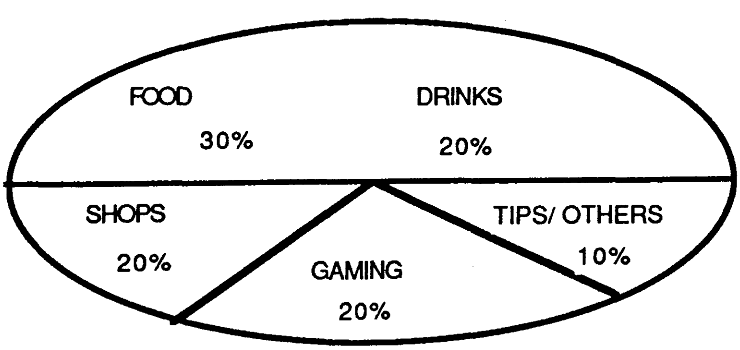

Fig.4.5 The distribution of revenue obtained from facilities on board for this particular ship

Entertainment incomes also depend on the voyage time, therefore the speed of ship affects the entertainment income as shown in Fig4.6

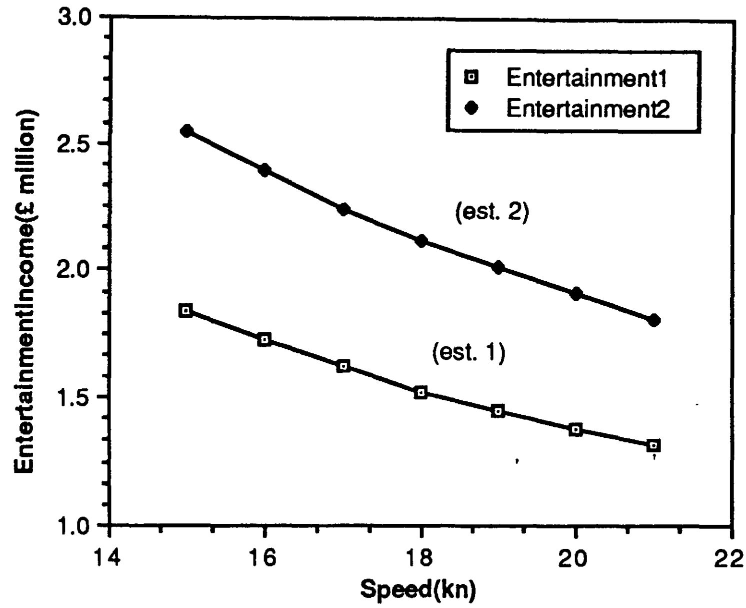

Fig.4.6 shows that entertainment incomes decreases as speed increases

4.4.3 Estimation of Demand

Two different estimations are carried out considering the capacity of existing ferries and the capacity of this particular ship. Demand was estimated month by month for the most realistic calculation. According to the design plan the ferry is withdrawn from service during the November for repairing and maintenance.

- First Estimation

For the first estimation, demand for trailers is estimated that during the winter vessel is 80% of full capacity while demand is 50% of full capacity during the summer time considering the condition of roads. Demand of private cars is 33% of full capacity during the winter time and 75% of full capacity during the summer time considering the travellers on holiday. Passenger capacity is estimated around 2.5 times of the total vehicles on board. Demand estimation can be seen in the Table4.4 for the first estimation.

	AV	BV	CV	DV	EV	FV	GV
JANUARY	8	50	400	70	560	270	2160
FEBRUARY	8	50	400	70	560	270	2160
MARCH	10	50	500	70	700	270	2700
APRIL	8	40	320	80	640	300	2400
MAY	8	40	320	100	800	350	2800
JUNE	8	30	240	150	1200	470	3760
JULY	10	30	300	150	1500	470	4700
AUGUST	8	30	240	150	1200	470	3760
SEPTEMBER	10	30	300	140	1400	440	4400
OCTOBER	8	40	320	90	720	300	2400
NOVEMBER			REPAIR AND REFIT				
DECEMBER	10	50	500	70	700	270	2700
TOTAL			3840		9980		33940

Table4.4 The distribution of predicted demand 1 through year

AV: Number of voyage

BV: Number of trailers per voyage

CV: Number of trailer per month

DV: Number of cars per voyage

EV: Number of cars per month

FV: Passenger per voyage

GV: Passenger per month

The total income for first estimation are estimated as follows.

Passengers £6.1 10^6per year

Trailers £1.9 10^6per year

Cars	£1.0	10^6per year
Entertainment(18 kn)	£1.5	10^6per year
TOTAL INCOME	£10.4	10^6per year

As the results show, the annual profit of the ferry was estimated as £1.5 millions with the average 66% of trailer, 50% of car, 44% of passenger capacities.

-Second Estimation

For this estimation, the demand of trailer was considered as constant which is 80% of full capacity for whole year. The demand for private cars changes from 50% to 90% of full capacity while the demand for passengers changes between 40% and 90%. Demand estimation is shown in Table 4.5.

	AV	BV	CV	DV	EV	FV	GV
JANUARY	8	50	400	100	800	320	2560
FEBRUARY	8	50	400	100	800	320	2560
MARCH	10	50	500	120	1200	400	4000
APRIL	8	50	400	120	960	400	4000
MAY	8	50	400	140	1120	480	3840
JUNE	8	50	400	140	1120	480	3840
JULY	10	50	500	180	1800	720	7200
AUGUST	8	50	400	180	1440	720	5760
SEPTEMBER	10	50	500	160	1600	640	6400
OCTOBER	8	50	400	140	1120	560	4480
NOVEMBER	REPAIR AND REFIT						
DECEMBER	10	50	500	100	1000	320	3200
TOTAL			4800		12960		47040

Table4.5 The distribution of predicted demand 2 through year

The total income is estimated for second demand estimation as follows.

Passengers	£8.46 10^6	per year
Trailers	£2.4 10^6	per year
Cars	£1.29 10^6	per year
Entertainment(18 kn)	£2.12 10^6	per year
TOTAL INCOME	£14.28 10^6	per year

The total profit from second estimation was obtained as £5.0 millions with 83% of trailer,61% of car and 62% of passenger capacity. This profit is quite high by Turkish standards.

For both estimations the ship obtains quite good profit. However, £180 is an expensive ticket fare compare to rival types of transport. Therefore, it is not easy to establish a popular line with high fares. Assuming the ticket fare for passenger £100 which is competitive against other transport facilities, an estimation was done and it showed that the ship gets £1.25 millions profit per year for the second demand estimation. Total operating cost and income for different values can be seen in Fig.4.7 and Fig.4.8.

4.5 Results

As the income estimations and figures show the most important factor for the income is the number of passengers. According to the results for both estimations the income from passenger ticket fares is three times higher than other components of total income.

Because of the different tourist attractions in Turkey there is a considerable increase in demand to go to Turkey. Turkish Maritime Line increased the passenger capacity on Turkey-Italy line from 13000 to 19000 during the operating period in one year considering the demand in previous

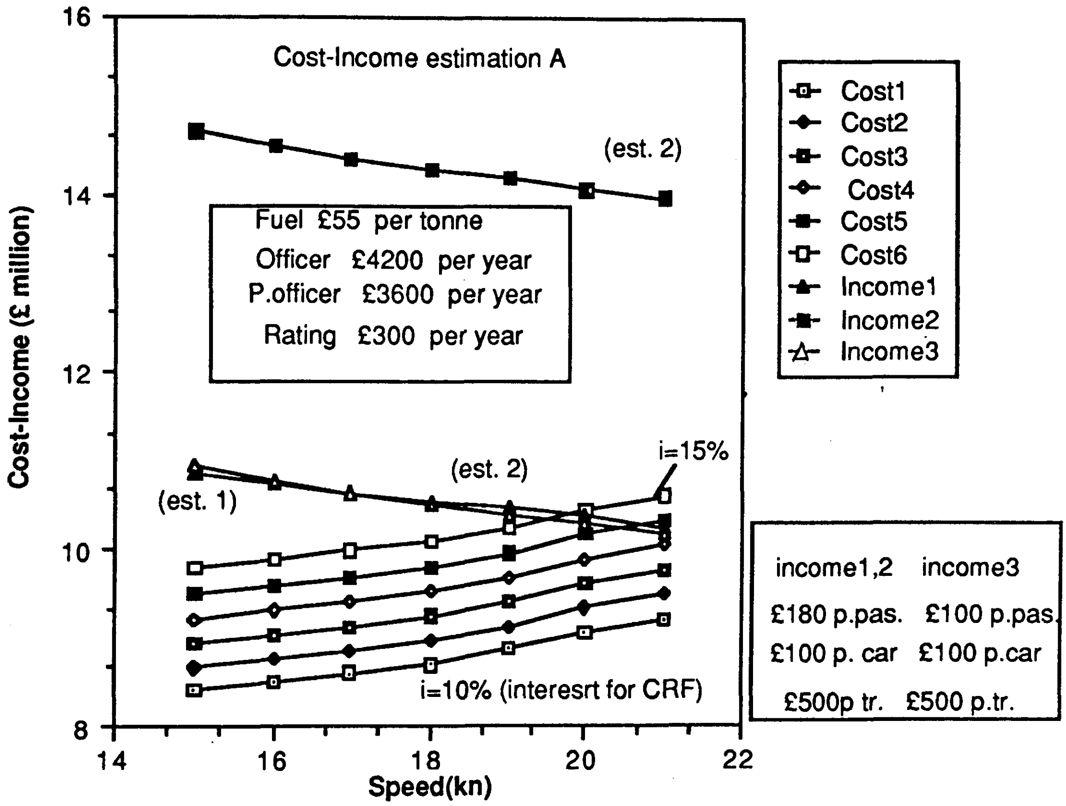

Fig.4.7 Cost-income balance considering different factors for original fuel prices and crew wages

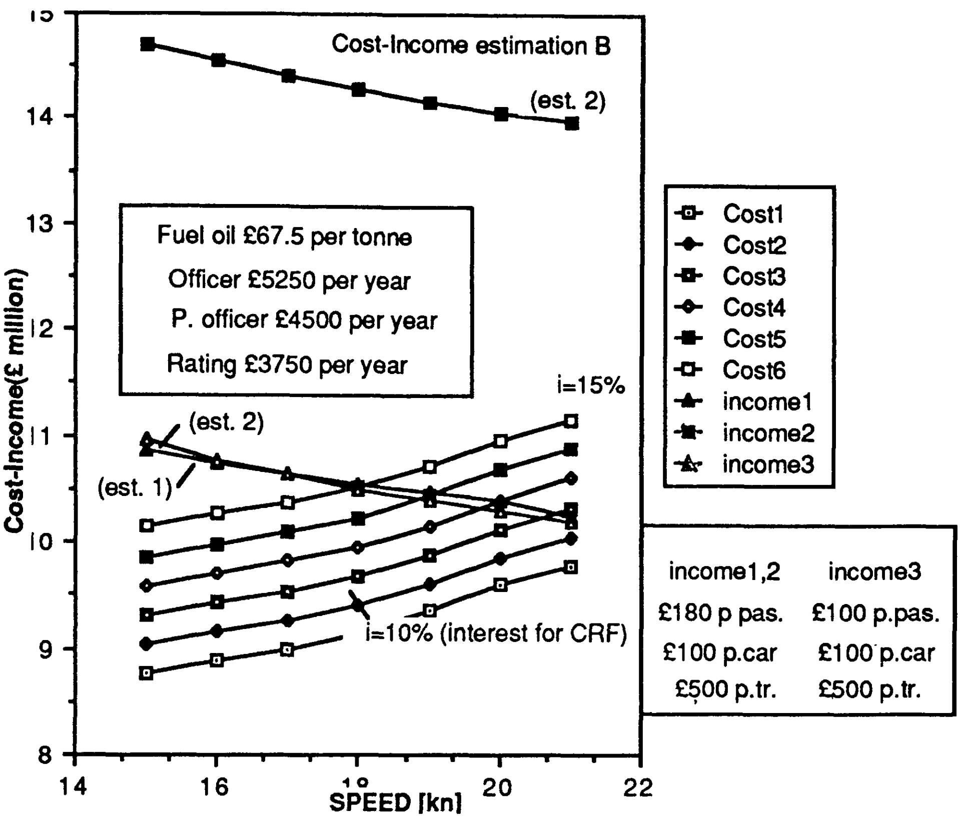

Fig.4.8 Cost-income balance considering different factors for 25% increased fuel prices and crew wages

and coming years. However these arrangements are mainly relying on tourists (during the April-October period). Therefore demand prediction for the rest of the year becomes difficult. It can be said that first estimation seems more realistic for, say next 2 years while the second estimation is more realistic over a longer period, say in the following 4 years.

It can be seen from Figures 4.3 and 4.6 that high speed means a substantial increase in fuel cost although it naturally gives less voyage time. If fares are dependent on speed then speeds around 15 or 16 knots represent a reasonable level of fuel cost associated with a somewhat long voyage. Tourists may view the voyage as part of their holiday but Turkish workers and truck drivers would prefer less time on board. Consequently 17 and 18 knot service speeds appear to represent the best balance between fuel cost and time for fares independent of time on voyage. Certain speeds and times on voyage could maximize the entertainment income which is largely gained in the evening but this is a matter of schedules rather than time on voyage.

Fig.4.7 and Fig.4.8 shows that income-cost balance is always positive for both estimations up to the 19 knot speed even for a CRF with the interest rate at 15% for the first demand estimation. However the balance gives negative result over 19 knot speed and over 13% interest for the same demand estimation. For the second demand estimation profit is very high even for the higher speeds. Income curve C of second estimation which was estimated considering the passenger ticket fare is 45% cheaper gives same income as first demand estimation with original ticket fare gives. This is positive sign for the cheaper fare idea and it will make this line popular because of the competitive ticket fare against other transport facilities.

4.6 Conclusion

In general it can be said that in order to establish a regular, popular and profitable line low capital cost seems the main and most effective solution and consequently the capital recovery cost must be reduced. Thus cheaper ferry services by keeping the same standard in available facilities can be offered to passengers.

In today's market Far Eastern countries such as Japan and South Korea offer prices up to 40% less than european prices. However passenger ships are mainly built in Europe. This is due to the complicated hull structure of such ships and experienced workforce. This may not continue to be the case in the future.

High speed may be an advantage if it increases the number of voyages and the demand for the service is not reduced. However over short distances high speed may have little effect as relatively little time is spent at sea. In the service considered, demand, while hard to predict is not particularly high and a round trip a week seems an ideal pattern of service. Consequently the direct benefit of high speed is limited to attracting business that is keen on reducing voyage time by a few hours. A low speed that fills up the week with the round trip may increase crew cost without any increase in revenue although fuel cost will reduce. A seasonal relatively high speed may allow an auxiliary cruise over about a day and a half to take place from Izmir. If the auxilary cruise is popular, it would assist profitability and justify the power to be fitted for a higher speed for occasional use.

At the moment, other transport facilities are considerably cheaper than ferry transportation in this area of the Mediterranean Sea. Therefore ferries operate during the summer time when the number of tourists is very high and there is no ferry which operates during the winter time. Although there is no large passenger demand in the winter there is always a high trailer demand. Estimation shows that the line considered is profitable for the whole year operation. The difficulties of the roads from Europe to Turkey force the travellers to find other alternatives which are suitable for their budget. Considering this point, the main purpose of ferry operators must be a low fare arrangement which is always competitive against other transportation alternatives.

CHAPTER 5

DECK DESIGN

5.1 General

The structural design of vehicle decks is an important part of the design of ferries. Such decks are generally fairly close to the neutral axis of the vessel and thus carry little longitudinal stress or shear. Indeed longitudinal stresses are rarely serious even at the extreme fibres of ferries with their short length, light loads and low value of length/depth to uppermost continuous deck.

The design basis for vehicle decks is that of wheel load and such loads must be acceptable when applied in any pattern at any part of the deck. Space is often vital in ferries and depth of deck support structure may need to be kept to a minimum to maintain headroom for vehicles on adjoining decks without compromising ship stability by increasing the depth of ship.

When the vessel is mainly designed to carry passenger cars then additional structural mass to minimize the space lost in stiffening is always possible but as trade changes to carrying more and more heavy trucks then the deadmass of the vessel becomes important and there is need to compromise between structural mass and the space occupied by stiffening.

The plate thicknesses must be able to transfer the wheel loads to the adjoining stiffening members and there is an almost infinitive variety of plate thicknesses and stiffener spacings that can be chosen. However a main choice is between longitudinal and transverse framing. This chapter considers the design of a vehicle deck by the rules of Lloyds Register of Shipping for transverse and for longitudinal framing. Classification Society Rules generally take a balanced view of plating design with due regard for beam theory, membrane theory, plastic design and corrosion and wear and tear allowances. More basic analysis is also possible and a later section considers plating thicknesses by specific approaches. These would still need service experience to translate into working thicknesses.

5.2 Design Consideration

Deck design is based on Lloyd's Register of Shipping Rules which has a special chapter for ferries and roll-on roll-off ships. Since there is no restriction on the structural system, both the longitudinal and transverse framing are considered [Fig. 5.1 and 5.2].

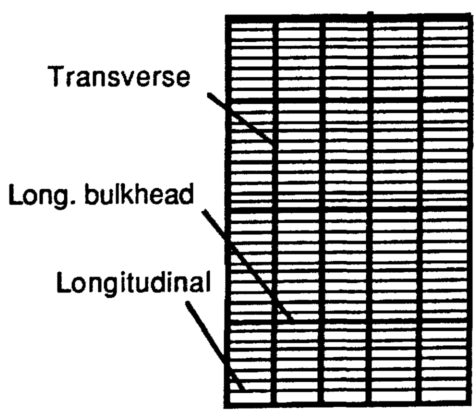

Fig.5.1 Longitudinal framing arrangement for vehicle deck

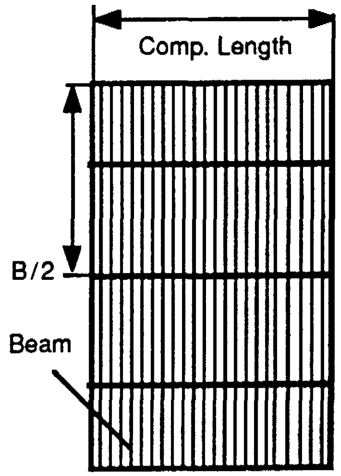

Fig.5.2 Transverse framing arrangement for vehicle deck

Each system is supported by one centre girder and two side longitudinal bulkheads which are 7.5 meters off the center line. In the region where there is no side longitudinal bulkheads, the deck is supported by side girders. The longitudinal framing system is also supported by transverses every 3.2 meters length along the ship. Therefore the effective length of longitudinals in the longitudinal framing is rather shorter than the length of deck beams in the transverse system. The centre girder is supported by two pillars in every compartment to reduce the effective span. As is mentioned before there is no significant hull stress problem at vehicle deck, therefore optimization of the deck design is carried out considering the mass of deck and the depth of stiffening members is determined and noted. The study is for a panel bounded by the centre line, side girders and adjoining transverse bulkheads.

In order to calculate the dimensions of deck members a computer program based on Lloyd's rules was developed. The program carries out:

a-Calculation of deck plate thickness,

b-Calculation of section modulus of each stiffening member using Lloyds' rules,

c-Determines the dimensions of stiffening members to suit the required modulus,

d-Carries out the stress analysis as required by Lloyds' Register to ensure that stress values are within the classification society limits,

e-Calculates the deck weight for a panel of plating and stiffeners.

5.2.1 Calculations

Calculations are carried out by taking into account some parameters which effect the design. The most important one is the axle load which is generally considered up to about 15 tonnes for passenger-vehicle ferries. Other factors are tyre print load, tyre print ratio and plate panel ratio as shown in Fig.5.3 and expressed with the following formulas.

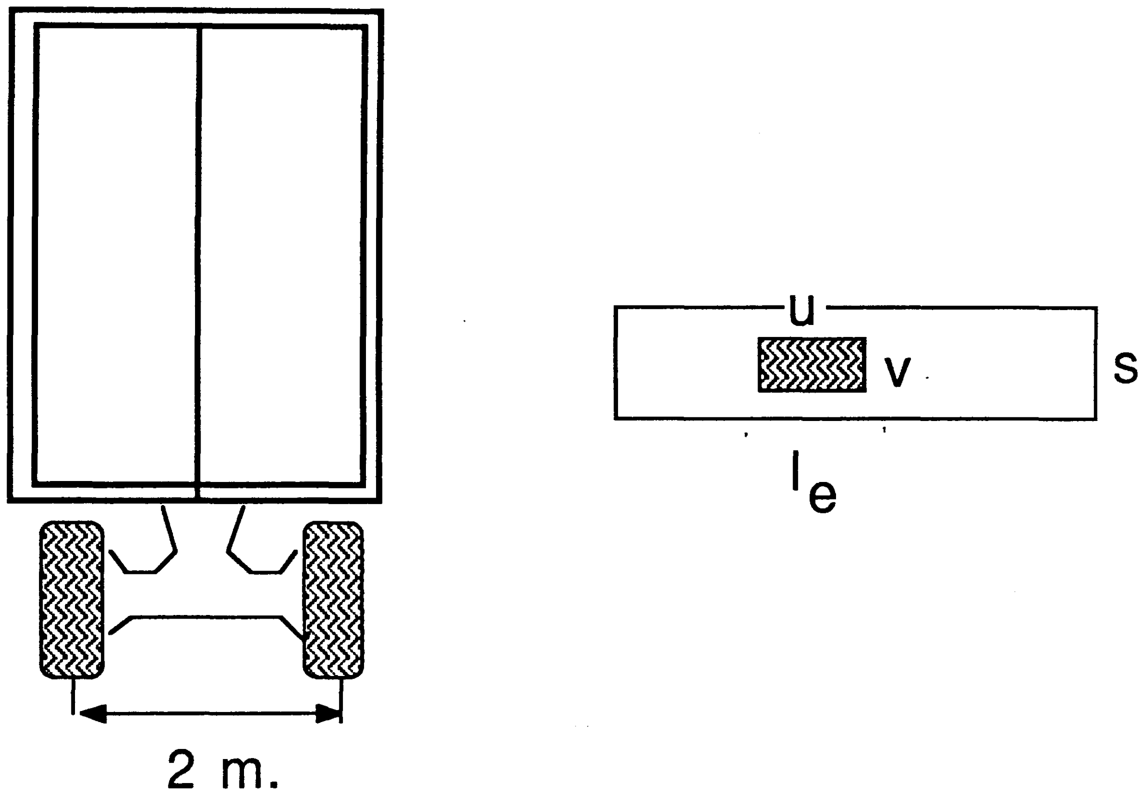

Fig.5.3 shows the dimensions of tyre print and axle

For the deck plating general formula is;

$$t = 4.6\,k^{1/6}\sqrt{A\,P_w} + 1.5 \qquad \text{(mm)} \qquad (5.1)$$

where t is thickness of the plate, P_W is the load in tonnes, A is tyre print local stress factor which is obtained from graph (v/s vs A) in the Ref.31. In order to find the value of A , l/s (plate panel ratio) and U/V (tyre print ratio) must be taken into account. Here l is the effective length of stiffener, s is the stiffener spacing, u and v are the dimensions of the tyre prints. The computer program can be run for different values of these ratios within the rule limits.

In order to determine the dimensions of the deck beams and longitudinals, the formula for section modulus for the permanent vehicle deck carrying wheeled vehicles is used as follows [Ref.31].

$$z = (0.536\, K_1\, P\, l_e + 0.00125\, K_2 h\, s\, l_e^2) \qquad (5.2)$$

where, K_1 and K_2 are constants obtained from rules, P is axle load in tonnes, h is the normal load height on the deck and need not exceed 2.5 meters. Besides this formula the rules suggest that the bending stress must not be greater than 100 (N/mm^2). For the stress analysis the beam is assumed to have 100% end fixity.

As shown in Fig.5.4 if we take into account the actual loading, the deck beams in transverse framing are loaded by several axle loads. Considering the worst loading condition which is 2.5 times one of axle load, the dimensions of the beam are specified by using the stress analyses.

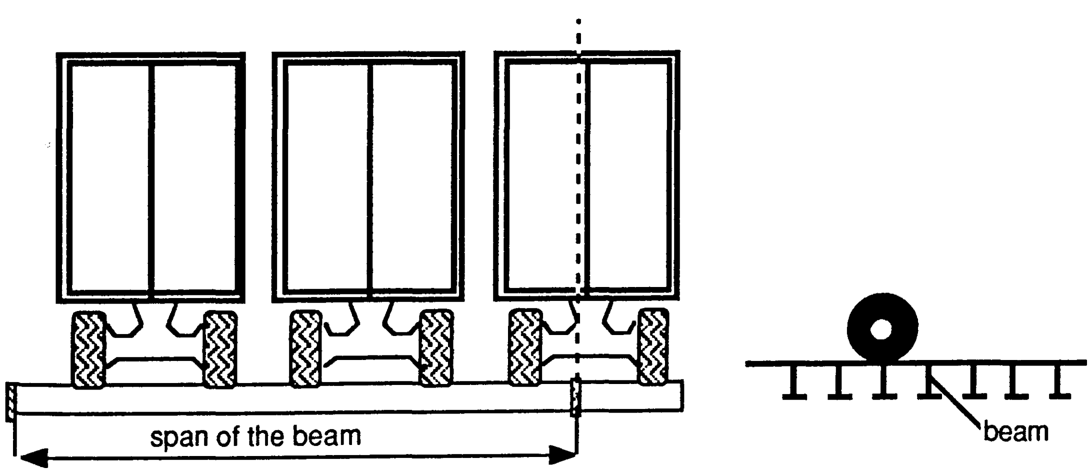

Fig.5.4 Possible maximum loading of deck beams in transverse framing

For the deck girders and transverses, Lloyds suggests that specification of the dimensions must be based on a maximum stress of 123.6 (N/mm^2) assuming the 100% end fixity. The Lloyd's Register of Shipping Rules also gives a formula for uniformly distributed load on deck for girders and transverses as follows:

$$Z=4.75\ b\ h\ l_e^2 \quad cm^3 \qquad (5.3)$$

where b is the mean width of plating supported by girders or transverses. This formula is used to specify the initial dimensions of members. The final dimensions are estimated by using the actual stress analyses. The worst loading condition of deck transverses is the loading of tandem axle load Fig.5.5 which is considered as double that of single axle load.

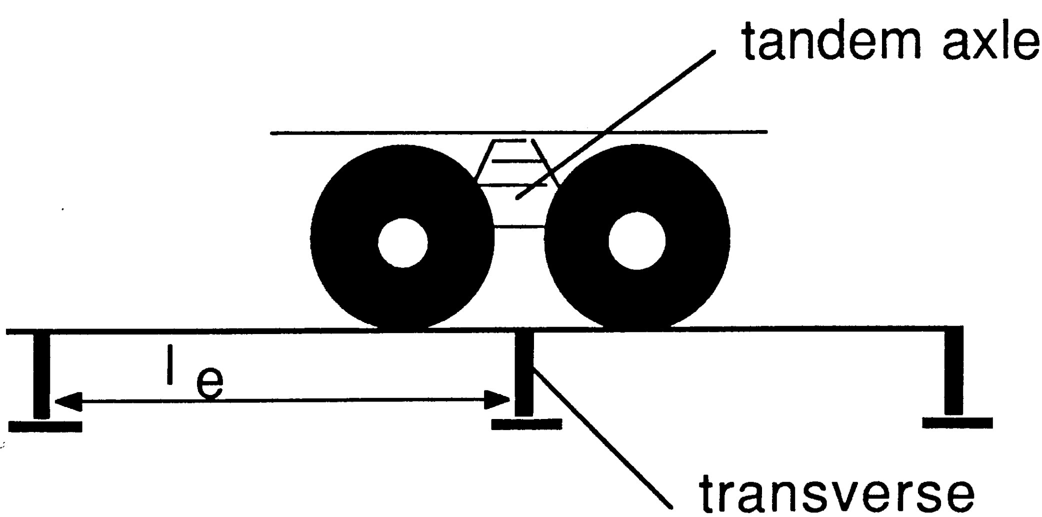

Fig.5.5 The tandem axle load which is assumed to be loaded on deck transverse and taken as double of single axle load

After specifying the dimensions of deck members, the computer program estimates the weight of the deck for the areas considered at the final stage of the program.

5.3 Results

The computer program was run for different stiffener spacings to determine how the scantlings of the deck change as stiffener spacing changes. As mentioned before, optimization of the deck design is done by considering minimum mass of the deck structure but noting the depth of stiffening. Computer results can be seen in Appendix 7.

The comparison between transverse framing and longitudinal framing systems was done using Fig.5.6 which shows the changes in weight as frame spacing changes for both framing systems. As Fig.5.6 shows the longitudinal framing system is around 20% lighter than the transverse framing system in weight. Obviously such a difference in weight is a big advantage for optimum design.

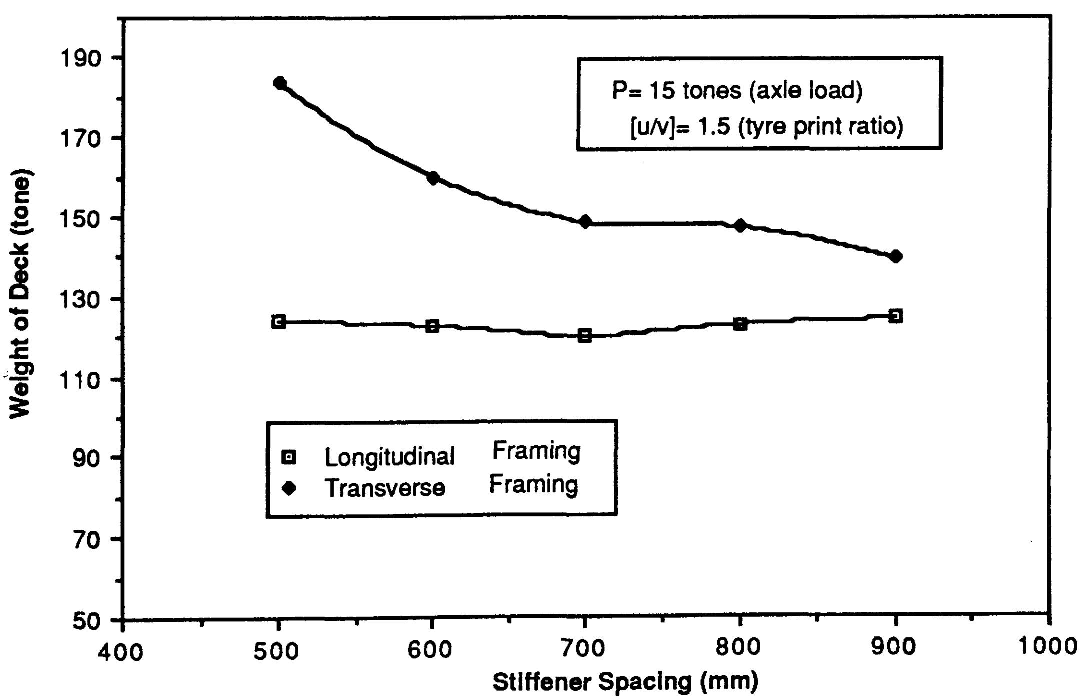

Fig.5.6 The comparison between transverse and longitudinal framing system based on deck weight and stiffener spacing

The main reason of this big difference is that the unsupported deck beams must be designed to carry 2.5 axle loads. In order to meet the maximum stress condition the dimensions of deck beams had to be increased, thus the weight of the transverse framing deck appeared as 20% heavier than longitudinal framing deck. Additional longitudinal girders could reduce the beam span but might give headroom difficulties in the space below.

If we compare the depths of the stiffening members between two framing systems, it is seen that transverses in longitudinal framing are slightly deeper than deck beams in transverse framing while those deck beams are twice as deep as longitudinals in longitudinal framing system. In general the depth of stiffening members below a vehicle deck is an important factor in maintaining ample clear deck height especially if there is a further vehicle deck below. Even if there is not clear deck height is always valuable and minimum depth of deck stiffening allows minimum depth of ship.

The results show that longitudinal framing is the optimum selection considering the advantage of the lighter deck. Optimum stiffener spacing appeared as 700 mm which gives the minimum weight deck. This stiffener spacing is the same value as the stiffener spacing suggested by the Lloyd's Register of Shipping.

5.4 Consideration of Different Design Methods

There are several design methods as well as society rules on deck design. The society rules are the mandatory guidance for the structural design of commercial ships. Design of decks for wheeled vehicles is not limited to ferries carrying trucks. There is considerable interest for helicopter landing platforms and decks for aircraft carriers. The classification societies are usually willing to offer guidance in novel situations but their rules are only issued after a good deal of service experience. Consequently a first principles approach backed up by experimental evidence is often needed. Some approaches give similar results while others do not. Generally, it is accepted that the society rules give conservative results compared to other approaches. This section considers particular approaches to the design of deck plating with comparison of results.

While plating is an area of particular interest for first principles approaches,stiffeners are also significant. They are analysed by elastic design taking into account the safety factor.In this section deck members are examined separately as plating and stiffeners

5.4.1 Plate Design

Depending on the actual pattern of loading the stress in the plate may become significant before the stiffening members carry much stress. Consequently the plate thickness is an important feature of deck structure. It may be chosen on the basis of elastic, elasto-plastic and plastic design methods. It can be argued that as vehicle decks are not always prime watertight boundaries, deck thicknesses should not be conservative provided the stiffening is conservative. However deformation associated with relatively thin plating can be unacceptable.

Deformation is also expected as a result of manufacture with relatively thin plate but where the only substantial loads are applied transversely to the plane of the plate, deformation has little effect on strength. Acceptable levels of deformation are generally associated with practical convenience in moving vehicles. Figure of s/50 have been guoted for aircraft loading deck while this figure is between s/100 and s/150 for Ro-Ro vehicle deck [Ref.30 and Ref.10].

The plate design can be examined in a two different groups as follows

a) Elastic Design

In order to carry out the calculation for elastic design, the following methods are considered:

- Continuous Beam Theory
- Haslum's approach [Ref.23]
- Simply Supported Rectangular Plate [Timeshenko Ref.54]

Continuous Beam Theory : Authors think that continuous beam theory is a convenient approach to find the maximum moment and then the maximum stress in a plate. Calculations are carried out along the A-A strip (Fig.5.7) considering the actual loading.

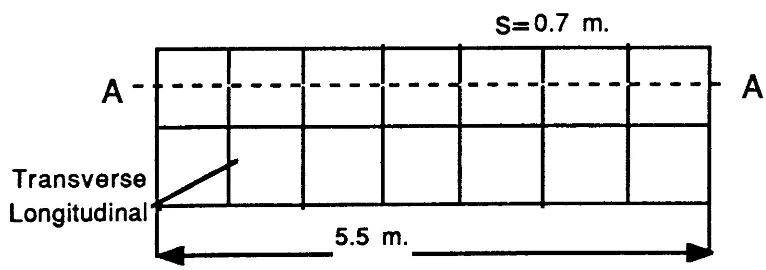

Fig.5.7 A-A line is assumed as continuous beam

Tyre loads are considered uniform loads since length of tyre print occupies the half of the stiffener spacing. Also the ends of beam are considered as simple supported edges. Loading condition and moment diagram can be seen in Fig.5.8. Wheel load (P) is chosen as 6 tonnes for this design as well as others.

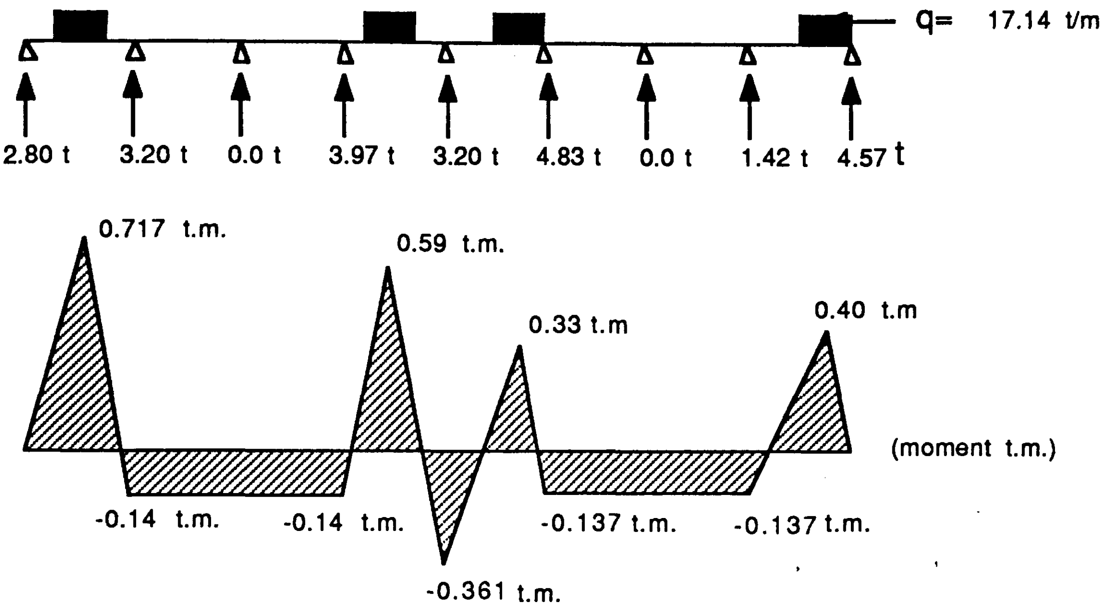

Fig.5.8 The moment diagram of continuous beam theory,tyre load is 6 tones

As can be seen from the moment diagram, maximum moment occurred at the middle of the beam which is symmetrically loaded between two longitudinals.

Haslum's Approach : According to this approach, Ref.23, the maximum moment is calculated at two steps. The first step is to calculate the beam moment on a unit strip of the plate. The strip of the plate is taken into account as a continuous beam on a rigid, knife edge support which is provided by the transverse frames. The second step is to make a correction for this moment to take into account the two-way action of the plate. During the calculations the deformation of plate because of stiffeners and welding is not taken into account.

For the first step M_B is obtained from graph (u/l vs M/P l) in Ref.23 Having obtained the moment for continuous beam solution, the second step was applied to make the correction to the moment for the plate. Since the maximum moment was found at midspan , plate moment (M_p) is determined by using the graph (M_p/M_B vs. u/s). The results are as follows

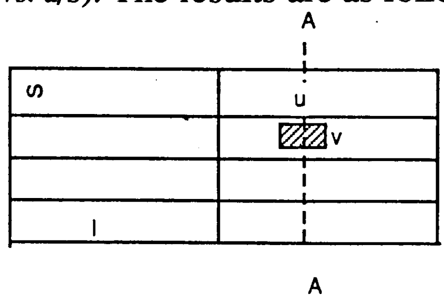

Fig.5.9 Calculation way of Haslum

V/s=0.75

M/Pxl=0.09

M_B=0.38 tm

u/s=0.75

M_p=0.234 tm(after the reduction for two way action)

where P : wheel load (tonne), 6 tonnes

Simply Supported Rectangular Plate (Timoshenko) : In order to find the bending moment for simply supported rectangular plate under a load uniformly distributed over the area of rectangle [Fig.5.10], the following formulas are used:

$$M_x = \frac{P}{8\pi}\left[\left(2\log\frac{4s\sin\pi\zeta}{\pi h} + \lambda - \varphi\right)(1+\upsilon) + (\mu+\psi)(1-\upsilon)\right] \quad (5.4)$$

$$M_y = \frac{P}{8\pi}\left[\left(2\log\frac{4s\sin\frac{\pi\zeta}{s}}{\pi h} + \lambda - \varphi\right)(1+\upsilon) - (\mu+\psi)(1-\upsilon)\right] \quad (5.5)$$

$$M = \frac{M_x + M_y}{1-\upsilon} \quad (5.6)$$

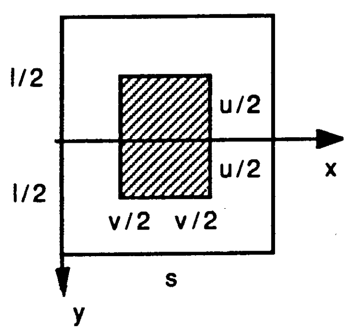

Fig.5.10 Simple supported rectangular plate

In case of ratio l/s>3, the plate is considered as l/s=∞. Since this particular deck plate has the ratio l/s=4.5, the calculations are carried out as if the plate is infinite long rectangular plate with l/s=∞ and moments are calculated along the short side of the plate(x axis). The results are as follows.

$$M_x = 0.752 \text{ t.m}$$

$$M_y = 0.342 \text{ t.m}$$

$$M = \frac{M_x + M_y}{1-\upsilon} = 0.841 \text{ tm}$$

- **Results**

All calculations were carried out for a 6 tonnes tyre load.Using the maximum moments, the maximum stress is found for a given plate thickness which was taken as the required thickness estimated from rules. Also the required thicknesses to generate yield stress are estimated for each method as shown below:

$$\sigma = \frac{M_{max}}{w}$$

σ = max. stress

w = section modulus of plate $= \frac{t^2}{6}$

t = plate thickness ; 11mm (obtained from rules)

	Cont. beam	Haslum	Timoshenko
M_{max}(N mm)	7026000	2340000	8241800
σ_{max}(N/mm^2)	348.42	116.41	408.6
t_R(mm)	13.26	7.65	14.36

t_R= required thickness considering the effective yield stress which is 240 N/mm^2

As can be seen from the results the continuous beam and Timoshenko's methods a give greater stress than yield stress for elastic design while Haslum's approach gives nearly half of the yield stress. To reduce the stress a thicker plate is required for Timoshenko and continuous beam theory. This, of course increases the weight of the deck. However Haslum's approach requires about 3mm less thickness compared to the thickness required by society rules.This result can indicate that Lloyds Register rules are conservative on deck design but Lloyds Register takes into account some safety factors (i.e against corrosion, wear and some uncertainties.) while Haslum's approach does not take into account these factors. If the differences on results between Haslum's approach and other two are considered it can be seen that these different results are obtained, since Haslum's approach takes into account two way action and has differences in fixity assumptions.

b) **Plastic and Elasto-Plastic Design**

In practical design of deck plating considering plating behaviour, there are two general approaches to calculate the deck plate thicknesses: The Plastic design approach and the Elasto-Plastic design approach. For instance Jackson and Frieze [Ref.30] used Elasto-Plastic design philosophy in which they estimate the thickness of plate from consideration of allowable permanent set between stiffeners resulting from wheel loading. In general this reference is very useful for deck design. However the design curves produced from the data of some experiments are not in the same range with our design range. Because these experiments were carried out by modelling the impact loading of aircraft's tyre on deck and these loads are considerably greater than our design loads. There is no design curve for our load ranges. Considering this point these experimental results are not included in the comparison. Haslum [Ref.23] used the plastic design approach to find the plate thicknesses without a permanent set. On the other hand Clarkson presented a set of curves for the thicknesses of uniformly loaded long and short clamped plate by using Elasto-Plastic design philosophy. Although Clarkson's [Ref.10] curves are given for uniform pressure loads, one can utilize them for a large class of concentrated loads. In his analysis, Clarkson has two types of design which are with permanent set and without permanent set. In this thesis for comparison of various methods to calculate the plate thicknesses, Clarkson curves take into account permanent set.

Three different methods, which are Haslum's [Ref.23], Lloyd's Register [Ref.31] and Clarkson's [Ref.10] are compared for two types of tyre prints which are square and rectangular as shown in Fig.5.11. and Fig.5.12. They show comparison of the Haslum's approach and the Lloyd's Register's approach for a square loaded surface. In the same figure the comparison is also made between the Lloyd's Register and Clarkson approach (short clamped) for a uniformly distributed rectangular load. In order to make this comparison, Clarkson's results for long clamped plates are used. Then, the thickness for short clamped plates ($u/v \leq 2.5$) is obtained after performing the necessary corrections.

The comparison for square loads shows that Lloyd's and Haslum's curves are nearly the same for the plates satisfying a ratio of s/v : 1.0-2.2. Since Lloyds' does not give any formula for the ratio $s/v<1$, we can not deduce any conclusion for this range.

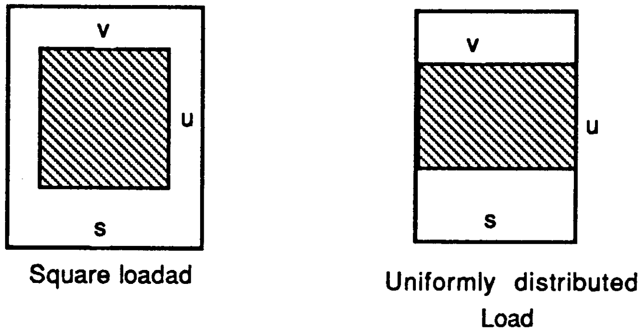

Fig.5.11 considered tyre prints

For the second comparison as seen in Fig.5.12 Clarkson's curve gives less thickness than Lloyds' for s/v>1.2, while both curves give almost the same values for s/v<1.2. If the whole curves are examined, it can be seen that for s/v=1, the dimensions of tyre prints, (i.e. u and v) and the loads on the prints become equal. As shown in the same figure, at s/v=1 four curves obtained from different approaches give the approximately same plate thicknesses.

From this comparison one can conclude that the three different approaches for the plastic and elasto-plastic design present similar results.

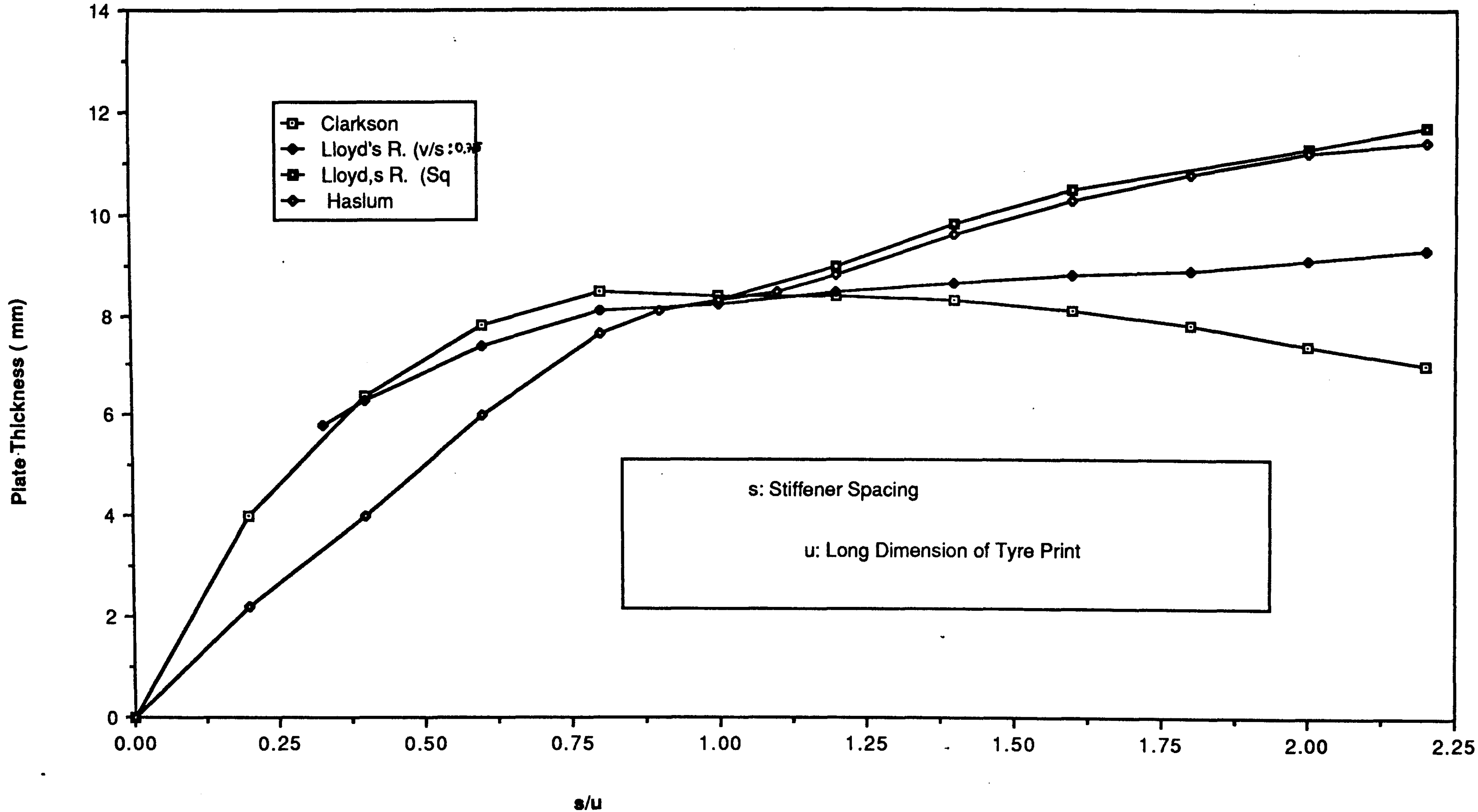

Fig.5.12 THe comparison of different approaches to plate design

5.4.2 Stiffeners

The role of the stiffeners in deck design is very important. Their failure means collapse of the deck while deck plating failure would not be as catastrophic as side shell plating failure. Generally the stiffeners are designed by elastic method and thus are treated conservatively. In the choice of the usual elastic theory, safety factor is important. Safety factor should depend on:

a) uncertainty in the loads,

b) uncertainty in structural response arising from variable material and fabrication properties, incomplete mathematical models and doubt about boundary conditions, design and human errors,

c) the economic and social consequences of failure.

Safety factor, (F_s), is calculated using following formula :

$$F_s=\sigma_y/\sigma_a$$

σ_y: Yield stress

σ_a: Actual Stress

Typical values for primary structure are :

F_s = 1.25 to 1.5 in aircraft carriers and some other naval ships,

= 1.75 in box girder bridges and civil engineering structures generally where the load can be estimated accurately,

= 1.5 to 3 in merchant ships.

Designers can take the view that the safety factors suggested by the classification societies are too high but actual loading may be worse than expected loading. Greater precision always reduces the factor of ignorance as safety factors may be called but societies are always likely to err on the side of safety.

Taking into account the safety factor, (F_s), calculations are carried out using the following methods:

a) First principles calculation,

b)Haslum's method,

c) Lloyd's rules.

First principles calculation : This is carried out using the continuous beam theory by taking into account the actual loading as shown in Fig.5.13.The loading and bending moment diagram was found as in the Fig.5.13. Since u/l is very small it is accepted that the load is a point load.

Haslum's method : Using the graph (u/l vs. M/Pxl), maximum moment was obtained as 2.88 tm.

Lloyd's Rules : It gives the maximum permissible stress for the stiffeners as 100 N/mm^2.

Considering the maximum stress, the stiffener was specified and the section modulus of stiffener was found as 355 cm^3. The safety factor was estimated as 2.4.

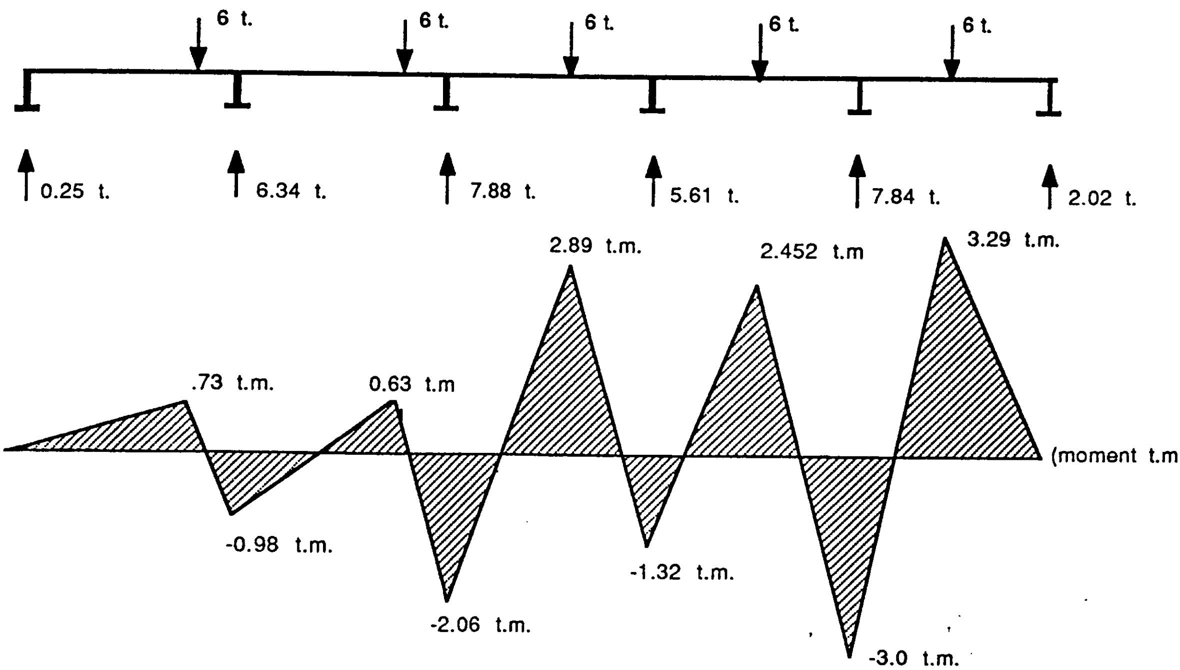

Fig.5.13 The moment diagram of stiffener under the actual loading

5.4.3 Results

Taking into account the same safety factors and same stress factor, the stiffeners for other methods were specified as follows:

	First Principles	Haslum's	Lloyd'sRegiser
Moment (kg cm)	329000	288000	–
Required Section Modulus (cm^3)	329	288	355

As seen from results, Lloyd's requires greater section modulus than other methods require for stiffeners. However this difference is not too much to conclude that the design is a conservative design.

5.5 Conclusion

The structural design of a ship is carried out by taking into account the classification society rules as main requirements. Besides the Lloyd's guidance some other methods and new approaches were analysed and compared with the Lloyd's Register of Shipping rules. A computer program was developed to specify dimensions of deck members and to investigate the changes in deck weight, and dimensions of stiffening members, due to changes in some parameters such as load, tyre print and stiffener spacing.

The vehicle deck of the ferry is situated very close to the neutral axis providing a small longitudinal stress which is the main criteria for the structural deck design according to the society rules. Since the society rules do not specify any special framing system, the lighter weight of the vehicle deck becomes the most important requirement having satisfied the society rules for stress in the deck.

As a first conclusion of this chapter, the longitudinal framing system appeared as a better disposition of deck members to the transverse framing system providing a lighter deck structure (at about 20% lighter than the transverse system).

The comparison of various different methods based on the elastic, plastic and elasto-plastic design has indicated that the deck plating by the elastic design method is unnecessarily more conservative compared to the latter two methods while the plastic, elasto-plastic design provide approximately same thickness of deck plating.

The comparison for stiffeners showed that Lloyd's rules require bigger stiffener dimensions in comparison with other methods in the literature. However the differences are not so significant.

From the simple analysis in this chapter the above conclusions were drawn for the structural deck design of the ferry considered. It is well known that some designers and researchers disagree with the society rules on the ground of the rules being more conservative in terms of the structural design. As the overall conclusion of this chapter stated, it is hard to draw any solid conclusions to clarify the above disagreements. This requires special research work purely dedicated to the structural design with more detail.

CHAPTER 6

SAFETY IN PASSENGER RO-RO VESSELS

The recent accident to Herald of Free Enterprise means a re-examination of passenger Ro-Ro safety. This is not to say that existing vessels are unsafe but more safety becomes very important for Ro-Ro ships especially with passenger certificates although extra safety arrangements may bring extra costs. Therefore minimum standards still have to be agreed internationally.

6.1. Recent Accidents and Reasons

Unfortunately sea accidents may become more common as sea traffic increases. Causes of accidents are different such as human and operational errors, insufficient safety regulations, heavy sea conditions, structural failure. However, generally the worst one is the passenger ship disaster as the human is the most important factor. In addition, passenger ships are the most expensive ones, so that loss of this type of ships is another important problem. In recent years two important ferry disasters happened in 1982 and 1986.

In 1982 The European Gateway sank just outside Harwich harbour. It took six minutes to sink and 6 of the total 72 on board died. An independent investigation commitee has concluded that the reason for capsizing was the watertight doors in the engine room were left open. However it was not a operational error, because regulations did not require these doors to be kept closed during the voyage except in fog or severe weather conditions. Also regulations now require all such doors to be power operated.

In the winter of 1987 Herald of Free Enterprise capsized which took between 45 seconds and two minutes just outside the harbours of Zeebrugge. 183 of the 600 passengers on board died. According to the inquiry report the reason of capsizing is the bow doors of the ferry were left open. The initial trim to the bow also helped the disaster. The water entering car deck created large angle of heel because of the large free surface effect, then ship capsized. Investigation showed that human error allowed the vessel to sail with the bow doors open.

6.2 Safety Features

While ferries are popular, they bring safety problems as well as advantages in service. The studies on safety problems have been continiuing and some new ideas have been put forward. Some of them may be accepted as reasonable ideas while some of them are unreasonable because of their uneconomical sides or uneasy practical applications. Some of the ideas and applications are introduced below.

6.2.1 The Probabilistic Method

The deterministic method which optimize the design generally results in close bulkhead spacing and small freeboard with bulkhead deck. In designs bulkhead deck is cranked up at the ends to increase the safety in case of high trim conditions and to have required minimum freeboard at any point of length. Although there is no vehicle deck below bulkhead deck in passenger–vehicle ferries, closely spaced bulkheads may create some problems in designing the lower deck particularly access, engine rooms and stores.

As mentioned in chapter 3, the probabilistic method takes several important parameters into account. This combination gives flexibility in bulkhead design as well as more realistic safety standards. The bulkhead arrangement can be adjusted to increase the efficiency of loading such as having a long inboard space, which is not acceptable under the deterministic method. The deterministic method does not reflect the today's modifications on ship design very deeply. This is because the rules are originated for classical passenger ship types which were from early 1900's. Considering realistic standards, all calculations should be submitted by the probabilistic method, which reflects the modifications on passenger ships and related to service and possible damage conditions.

In the probabilistic method,in order to meet target requirement, the most effective way is to increase the freeboard by increasing the depth of bulkhead deck. It will give appropriately high freeboard in both service and damage conditions. However the need to maintain adequate values of GM upright will limit freeboard in Ferry designs. Because increasing the freeboard causes an increase in vertical centre of gravity of the ship which may lead to unsufficient stability. Also acceptable freeboard in damaged condition should not be taken more than [$0.33B \tan\theta_f$] where θ_f is the angle at which stairway or other openings in the bulkhead deck are immersed.

6.2.2 Car Deck

The car deck design of passenger-vehicle ferries is different than that of Ro-Ro's. In Ro-Ro there is no transverse subdivision requirements therefore vehicle decks also exist below the bulkhead deck usually below the waterline. This arrangement makes the Ro-Ro sensitive to damage. However Passenger-Vehicle ferries subject to watertight subdivision regulations, so that the vehicle decks have to be located above the bulkhead deck level. In this case the possibility of water entering to the vehicle deck is very low. This makes ferries much safer and in addition some existing problems of Ro-Ro's are generally not encountered for Passenger-Vehicle ferries. Of course if considerable water comes in to the vehicle deck it would lead to diaster as seen in the case of Herald of Free Enterprise. However this accident was not because of the unsufficient safety requirements but because of the human error.

In the light of above information, the problem in vehicle deck of ferries might be only the fire fighting water. In case of fire, The water used against fire will reach in bulkhead deck. This water can be drained very easily to sea directly by locating non-return valves at bulkhead deck.

The idea of subdividing the trailer deck transversely has been put forward as an safety arrangement. This may be considerable for Ro-Ro which has large open vehicle deck below waterline while it is unduly conservative safety approach for open car deck in ferries. The flooding of trailer deck in passenger-vehicle ferry is unlikely and to subdivide the deck transversely would be unacceptable economical penalty, especially for the trade at the ferry lines with limited time schedule such as cross channel.

6.2.3. Watertight Wing Compartments

Double hull arrangement is very useful and provides efficient safety against damages especially minor ones. As long as the inside hull is not penetrated, the ship will have only asymmetrical flooding with a small angle of heel that can be corrected very easily by cross flooding arrangement. Continious double skin arrangement up to uppermost continious deck might be useful to protect the ship hull as well as cargo against collosion. In addition, to arrange them as watertight may help to have high reserve buoyancy and high KB like submarines [Fig.6.2]. Of course required 0.2B depth will bring economical penalties. This depth might be reduced by using the strengthened cell structure double skin (Fig.6.3). With this arrangement the energy absorbing potential of the hull structure will be increased. This may reduce 0.2B depth but it is obvious that it will increase the weight of the ship.

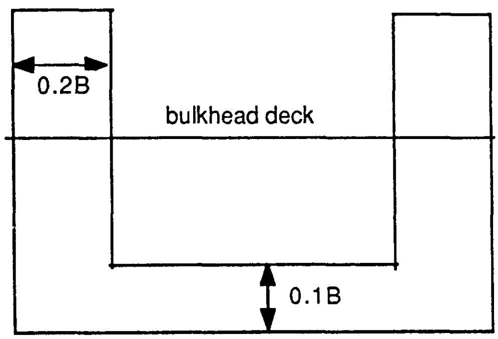

Fig.6.2 Watertight wing tanks

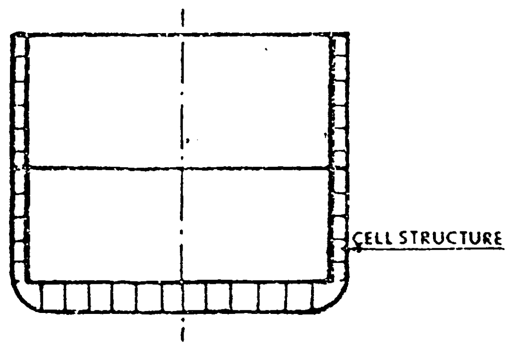

Fig.6.3 Cell structure double skin (Ref.42)

6.2.4. Hull Shape

Significant improvements could be made to the survivability of Ro-Ro vessels by incorporating modest flare and subdivided side chambers as shown in fig.6.4 [Ref.2].

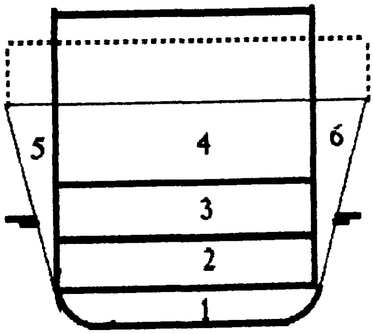

Fig.6.4 Modified form (Ref.2)

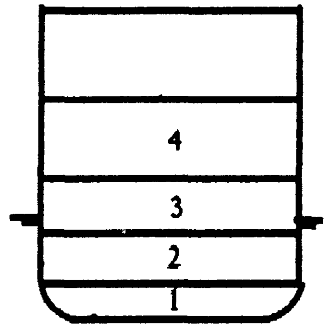

Fig.6.5 Baseline form (Ref.2)

The hull modification incorporates side compartments formed by 15 degrees flare from the turn of bilge to another deck. Side protection compartments are located at these regions and these are examined to see the effects of incorporating sub-divided wing tanks at vehicle deck or below the bulkhead deck. Comparison was done between modified and base hulls [Fig.6.5] by carrying out some experiments. Experimental results showed that this modified ship gives better stability results in case of service and damaged conditions [Ref.2]. There is a penalty in increased beam above water. It is obvious that the ship with base line form which is equal to the largest point of beam in modified form will always have better stability and cargo capacity. Also it will allow to have watertight wing tanks below waterline without sacrificing any extra volume compared to modified form.

6.2.5 Pumping Arrangement

Engineering crews adjust the ships' longitudinal trim which changes the position of her bow relative to the water by pumping sea water in or out of ballast tanks. However this routine work needs powerful pumps to do quickly. For instance it may take a vessel 75 minutes to cross from Dover to Calais and the pumps 2 hour 30 minutes to empty a full ballast tank [Ref.41]. At Zeebrugge ships often have to fill their ballast tanks at the bow because of the tide to discharge the vehicles. According to the inguiry report the disaster night same things happened and Herald of Free Enterprise left the harbour with 0.75 m. trim to her bow. Also her pumping capacity was not sufficient to discharge the water in a short time. This example shows how important it is to have high powered pumping arrangement with good connection between ballast tanks. High powered pumping capacity is also useful against fire fighting.

6.2.6 Lashing Arrangements

In recent years, there has been a number of maritime accidents caused by shifting of cargo on board of ships. During the 1980 the Swedish Shipping Industry had two very severe accidents, directly or indirectly caused by the shifting of cargo on board (Ref.1). In 1986 10 trailers fell into Black Sea from a Turkish Ro-Ro due to insufficient lashing.

The securing of trailers is a major problem. Shipowners often claim accidents to be caused by insufficient securing of goods which are put on road trailers with only symbolic lashing or no lashings. Accidents with road trailers also happen because the trailers are unsuitable for sea transport with insufficient or non-existing lashing points.

The research work has been carried out by some Swedish institutes with full scale measurements for long period. It was observed that the ship motions at sea affect the cargo in the form of accelerations. The transverse acceleration causes the main stresses in the lashing equipment on a ship. The acceleration increases with increasing metacentric height and increasing vertical distance to roll centre.

Also wrong application of securing equipment such as lashing with wrong angles or ignoring the existing equipment causes problem. In order to reduce such problems the training of crew as well as providing the strong enough lashing equpment are necessary. The problem must be considered also by the manufacturers of road trailers.

6.2.7 Human Errors

It has been seen that human and operational errors have a big role on sea disasters. These errors may be because of the marketing competetion and not well trained officers and crew. To sail with bow doors open and trim to bow are operational and human errors. According to the Ref.45 prior to Zeebrugge disaster it has been witnessed that some ships had proceeded to sea with bow or stern doors open.

In 1982 in Iskenderun, Turkey a Turkish Ro-Ro [Ibrahim Baybora] capsized during the loading. The Ro-Ro trimmed to immerse the stern door due to error in loading. The second captain wanted to fill the ballast tanks to correct the trim but he filled the wrong ballast tanks and the Ro-Ro capsized.It may be said that crew especially officers may not be well trained. Simulation for crew training should go beyond navigational exercises into the area of response to crisis. Software could be developed to generate difficulties such as hull damage or cargo shift and appropriate crew response would be able to be practiced on the simulator. However, although training may reduce the human errors, it is inevitable that human errors will exist as long as ships are sailed by crew.

6.3 Concluding Remarks

The Passenger-Vehicle ferry becomes popular as a multi-purpose ship. As design changes ferries need extra safety arrangements. As long as new safety arrangements do not bring heavy economical penalties they are always welcome.

The safety of ferries mainly depend on the crew since small mistakes may lead to disasters. Human errors can not be rid off completely but may be reduced by training well and locating warning equipment. Also the improved communication amongs the crew is useful to prevent possible incidents.

Accepting the probabilistic method as mandatory regulation, in general, will be the more realistic approach to safety of passenger ships. Also double skin construction is highly recommended idea. This may contribute to a significant increase of safety in case of minor damages and also reduce the risk of of shifting cargo damaging the hull.

High powered pumping arrangement is always useful for the stability of ship during the loading, unloading and in minor damages.

To increase the popularity of ferries as cargo carriers, as well as passengers, proper lashing facilities must be provided. This not only protects the ship itself from damages caused by moving cargo and changes in the weight balance but also protects the goods from being damaged.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1. General

Design studies are usually able to consider matters of technology quite well and reasonable comparisons and conclusions can be drawn between different proposals. However the full value of design is in practical application where decisions are essentially economic. In this field design studies are usually at a disadvantage because they are not based on detailed economic information. However the influences of the main items such as capital cost, fuel cost and crew cost can be quantified.

7.2 Ferry Services

In recent years ferries have grown in size and now have standards of comfort and service equal to those of passenger cruise vessels. Indeed it must be one attraction to encourage the marginal passenger, that the voyage can become part of tourism. Demand for ferry services has increased by 10% a year over the last decade but bridges or tunnels must supersede ferries on short distance crossings as time passes. However this trend of demand will encourage longer ferry routes and the main thrust of recent improvements has been in the Baltic and North Sea. The use of ferries to allow duty free purchases appears one profitable side line. In general new vessels seem most appropriate when the countries they serve are at similar economic levels such as those bordering the North Sea and Baltic and the vessels so displaced take up duties in Mediterranean and similar services where older standards of comfort match better the need for lower fares.

Services that are largely seasonal in response to tourism pose particular problems and may need designs which have two or more classes and accommodation that can be switched between classes. Perhaps during some months only trucks and truck drivers can be expected although that fortunately is a growing market.

7.3 Main Dimensions And Hull Form

The decisions regarding size, speed and breakdown of cargo are those of management although it is usually impossible to look into the future with any real accuracy. Whatever numbers are placed on these decisions the naval architect must transform them into a vessel. A reasonable data base is always available from the technical press. Analysing this data base for different time periods can give some indication about how design has changed in the past and what the trend is likely to be in the future. Speed will have particular influence on both capital and running cost. However the speed of a ferry is likely to be defined by service convenience as long as upper limits of Froude number set by economics are not exceeded. A regular schedule and convenient times of departure and arrival must be met together with a reserve of power able to match unforeseen delays.

Since deadweight grows with the importance of trailer cargoes the block coefficient is probably higher than a first look at Froude number would suggest but the number of voyages that will be made with the maximum deadmass is probably small .However average trailer mass has been increasing gradually as transportation by trailer grows. In this case the already relatively high C_B may not be enough to carry desirable number of trailers because of the limited deadweight capacity. So that C_B may have further increase to have high deadweight capacity which may be suitable especially for long voyages where high speed may not be required.

Ferries are often victims of port limitations on their dimensions. Restrictions become very important when heavy loads such as trailers are to be carried in passenger-vehicle ferries. Especially draft is restricted very much by existing conditions of ports. This draft restriction has been reflected in design by taking the beam of ship greater than the data base suggests and relatively high C_B. The large beam with same C_B maintains not only the maximum area of the main vehicle deck over as much of ship length as possible but also gives high deadweight capacity by increasing displacement. Furthermore large beam gives ample initial stability because of the high B/d. Stabilizers can correct the abrupt rolling encouraged by too much initial stability. However any possible restrictions on beam may be fatal to success of the design.

The depth of ship up to bulkhead deck is generally the minimum possible compatable with subdivision loadline requirements. Consequently if the required draft is known the depth to the bulkhead deck is usually easy to appropriate from existing vessels. The depth to the uppermost continious deck will depend on the number of vehicle decks and the clear height required for vehicles. Thus this depth is hard to determine from a data base.

7.4 Accommodation

The main vehicle deck which will suit trailers must be easy of access although on a route with ample turn around time only stern doors are required. Passenger cars can usually be put on a lighter vehicle deck with less headroom. The accommodation of trailers on two decks above the bulkhead deck in passenger-vehicle ferries is generally not suitable since it causes insuffcent stability because of the high KG. A central garage space may exist below the main vehicle deck but as that will be an influence on the subdivision calculation and hard to enter and leave, it is not a universal choice. However this design is able to be considered for long voyages where generally there is relatively longer turnaround time. A major choice is the maximum axle or wheel load to be accepted. In this matter the expectation of highway authorities are important as they set the limits for trucks and history shows a steady increase in load. In this design the axle load was taken as 15 tones.

The cabin and public room accommodation reflect the general level of sophistication expected and the income expected from fares. The popularity of a ship is significantly dependent on the entertainment arrangements as well as the ticket fares for long voyages. A two class ship means a wider range of fares and of expectations but even a one class ship will have a range of cabin quality associated with different fares as it is in this design. However the public rooms will be open to all and must be designed accordingly. The modern cabin is prefabricated to include all plumbing and wiring and only needs to be connected on board. Sufficient air conditioning in cabins is always a desirable arrangement especially in hot regions such as the Mediterranean.

Cabins need to be as remote as possible from sources of noise and vibration and thus machinery spaces, public rooms and cabins should form distinct blocks in the vessel. All cabins are above the bulkhead deck, indeed above the vehicle decks is a useful dictum for safety and the machinery is usually as far aft as the hull form will allow. Having a flexible machinery arrangement is big advantage especially in long voyages since ship is able to have different speeds using alternative engines and high survivability of power in case of any damages to engine compartments although it occupies more deck area than usual machinery arrangement.

7.5 Rules And Regulations

The role of the designer can be viewed as merely optimizing around the constraints of rules and regulations or perhaps exploiting their loopholes. In passenger vessels this really means securing the maximum cargo carrying ability within the agreed regulations for subdivision generally calculated by the deterministic method. The safety of passenger ship and passengers are reinforced by other SOLAS regulations as well as subdivision regulations. The resulting optimization generally means as short as possible machinery spaces and minimum freeboard which probably increases at the ends to match the usual shape of a flooding curve. The most important constraint in way of the machinery spaces is damaged stability and in this respect the regulations are usually hard to meet. Whether or not this represents an ideal approach in a safety sense is presently under debate and these in favour of making the probabilistic method mandatory will claim that safety would be improved and this will be considered in section 7.8. However the economic effects of alteration to regulation may have a big effect on the acceptance of the alternative regulations.

7.6 Structural Design Of Vehicle Decks

Longitudinal strength is rarely a problem in ferries with their relatively low value of L/D (to uppermost continuous deck) ratio. Transverse strength can be a problem as racking resistance may be low above the bulkhead deck and needs careful consideration. The vehicle deck members are generally carrying loads perpendicular to their surfaces. These loads are specified by axle loads and tyre prints which may take up any pattern but naturally have limits in any one region of deck. Since thelongitudinal stress is not significant at vehicle deck, the least mass of deck was the main base of the comparison. A study of designs indicated a clear advantage in longitudinal framing having around 20% lighter deck although the depth of the associated transverses is greater than transverse beams. This advantage is really because the axle loads are more readily shared by adjoining transverses in longitudinal framing than by the adjoining longitudinal girders in transverse framing and would not necessarily be the conclusion if the loading was uniform per unit area over the deck.

There will be instances of minimum depth of stiffening taking precedence over minimum mass of structure and in such a case transverse framing would be advantageous. The least depth of stiffening might be associated with some form of sandwich construction but the need to run pipes and ducts probably dictates traditional methods otherwise such items will be buried or project even more.

The actual differences in mass produced by the study were quite significant although at the price of rather reduced headroom fortunately in spaces where headroom was not vital. However considerable attention to detailed design could bring further savings. The important matter of economic preparation of the steel was not considered. However the usual dictum that cheap assembly cost comes from fewer individual components which is traded off against the extra mass of such a design probably applies. The additional cost of more detailed design must also be considered when applied to a single ship which is often the case with a ferry. Indeed compared to aircraft, space vehicles and submarines a ship is a relatively simple structure where loads are not known with precision and factors of safety need to be relatively high. In general a ship may be built with ample margins at some expense to initial efficiency but as the owners often are keen to keep it in service beyond it's original life then these margins are valuable. Of course this argument strays in to the field of whether failure is by technological obsolesence or by wear and tear.

In elastic theory, designing the plate as a unit strip gives a conservative plate thickness estimation while the two-way action procedure of Kristian Haslum results in a more accurate estimation. Existing practical design methods of deck plating, in general assume plastic or elasto-plastic behaviours and these two approaches give optimum plate thickness estimation when compared to elastic design. A comparision of the methods of Kristian Haslum, Clarkson and Lloyd's register rules showed little differences in plate thicknesses but the elastic approach of Kristian Haslum showed about 30% lees thickness than the society rules. It may be thought that classification society rules are conservative when compared with first principles methods but the societies have a considerable data base of service experience and well realize the disadvantage of risk.

7.7 Economics

The different basis on which the capital cost and the crew cost has been taken namely Western Europe and Turkey accentuate the importance of capital cost.

Demand, capital cost and running cost are related to each other. At the moment other transport facilities are much cheaper than ferry fares in this region of Mediterranean sea. However in order to increase the demand there must be competitive ticket fares against other transport facilities. The usual solution of that problem is a minimum capital cost which results from by buying second hand ferries for Mediterranean services while Western European and Scandinavian countries may go to the Far Eastern countries which offer up to 40% less price than European countries for new ship.

However the Mediterranean sea is the passage way between high GNP (Gross National Product) and low GNP countries. Therefore the expenses on board as well as ticket fares may not be suitable for some passengers while it is acceptable by others. Two class passenger facilities might attract more passengers.

Service speed is an important factor in total voyage time, on fuel cost and indirectly on crew cost. Very high speed might be useful if an auxiliary cruise can be arranged during the spare time of a regular schedule. This is dependent on the profitability of the auxiliary cruise. Otherwise high speed is undesirable because of the high fuel cost. On the other hand low speed is also undesirable since a long voyage is not preferred by Turkish workers and truck drivers and it causes the crew to work a full week which means higher crew cost.

The revenue of the ship is estimated by taking into account the existing ships on this line. Existing ferries are seasonal and rely mainly on tourists although there exists demand for truck over the whole year. Truck and truck drivers are the main income sources during the winter time for our income estimations. Cheaper ticket fares are possible as demand increases. Profit of ship is changeable depending on the total service years of ship. Total service year of the ship is much longer when the owner is the state and this reduces the capital recovery cost although the scrap value becomes negligible.

7.8 Safety

Deterministic method does not take into account very deeply the evolution in ship design while the probabilistic method is more independent of particular ship types. the probabilistic method also appears as more realistic taking into account the recorded damage statistics and service experiences in detail. In this particular ship the subdivision arrangements have been designed beyond the requirements of the deterministic method and gave acceptable results but not well beyond the requirements of the probabilistic method. The reason is both methods are mainly based on different factors.

An improvement in safety should come if the alternative or probabilistic method of presenting the subdivision calculation is made mandatory. However it will take some more years of experience of this method to set values of R that are based on experience of ships designed by this method. Naturally a computer program is essential to apply the method. Modern machinery layouts and cargo requirements allow the deterministic method to accept quite small values of freeboard while the probabilistic method is able to consider the freeboard proposed as part of the calculation.

Generally many accidents occur because of human errors as seen in last accident (Herald of Free Enterprise, Zeebrugge, 1987). The repetition of the same task may cause persons to loose their attention to work. Although training of crew is essential it's usefulness is limited. The most important precaution can be the force to draw crew's attention to their work by applying some money penalties. This method's efficiency can be seen on regulation of seat belts in the car in U.K. The surveyers can control the ferries more often and effectively during the service to see how the existing operating regulations are applied. It may be thought that money penalties and strict controls can cause ship owners to lose their interest to ship operation. However these controls and penalties do not bring extra regulations they just help enforce existing regulations

Recent accidents such as Herald of Free enterprise and European Gateway have been by rapid capsizing which in each case was limited to a 90 degree rotation because of relatively shallow water. Otherwise the rotation would have been 180 degrees and followed by total sinkage. In each case the whole incident was over in less than 15 minutes and this gives large if not insuperable problems for escape from the vessel. At the early stages of such a disaster it is not clear what is going to happen so reaction and decision time reduce the escape time still further. One possible improvement is to ensure loss by sinking in an even keel upright rather than capsizing if loss must be accepted. This would or should allow a reasonable time for passenger evacuation. The essential feature of such a loss would be to ensure that KM was always above KG. Bearing in mind that there is much flooding and thus there must be little BM but large KB(as submarines have) which means watertight compartments are high in the vessel preferably in the wings and at the ends [Fig.7.1]. It would seem reasonable to explore such designs but whether they can be completely applied to ferries is uncertain since the KG value is inevitably high in ferries and this arrangement needs high reserve buoyancy.

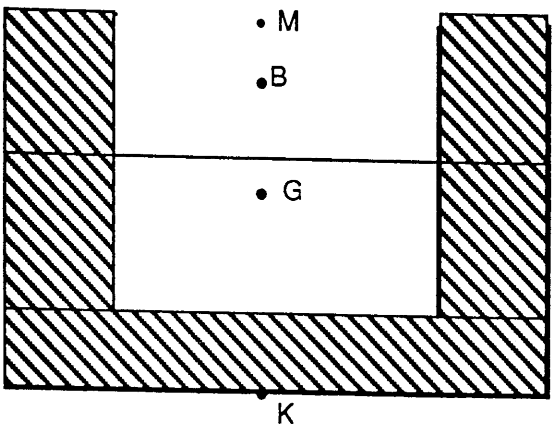

Fig.7.1 Submarine idea in the ferry

In case of flooding, evacuation of passengers must be quick and easy. Therefore the location of life saving equipments, the escape points should be well considered and showed to passengers in clear way. Also safety equipments such as lifeboats and liferafts should be far beyond the requirements against any unforeseen problems during the evacuation.

Accidents have a wide range of causes and precautions against flooding and capsizing may be the opposite of these needed to prevent fire. Vertical fire zones already exist but good horizontal fire zones might be useful against other types of accidents as well.

The main human problem is perhaps the repetitive nature of the work which must promote boredom and thus a considerable addition in automatic equipment with suitable interlocks may be required. This would ensure audible and visual alarm if all safety precautions were not correct when the ship moves. Human resources are best left to check the automatic equipment. Specialist repair facilities are usually available at each end of a short run for automatic equipment.

7.9 Considerations For Further Investigations

There is almost no end to the variety of designs that may be prepared for a ferry route but without access to a detailed commercial data base it is hard to come to conclusions or choice. Only the major options can be studied remote from details of operating economics. Among these, major options are designs specializing in freight and in passengers. In each case vehicle decks are needed but a design for trailers and tractor drivers is rather different from a design for passengers and passenger cars. Unfortunately there is no absolute interface between commercial vehicles and private vehicles as camper vans and light trucks have similar dimensions and masses. However in their expectations of comfort and entertainment it may be claimed that at least the tourists and truck drivers will be distinct and best served on distinct vessels.

Starting from this point a small passenger capacity passenger-vehicle ferry which is mainly for trailers and truck drivers can be a useful design concept.

Existing passenger ticket fares are expensive compared to other transport facilities and the budget of expected passengers. Perhaps a design needs to be started by choosing the acceptable ticket fares and with due regard for running costs and determine the maximum capital cost acceptable. In order to meet the desirable capital cost, alternatives such as different size and design arrangements or building the ship in different countries or buying second hand ship can be considered.

More complex stiffening system can be taken into account to reduce the effective length of deck beams in vehicle deck. Thus the weight difference between longitudinal and transverse framing systems is expected to decrease. In that case comparison can be done by considering the fabrication cost such as labour and welding arrangement.

Wing tanks encouraged by the probabilistic method are very promising for the safety of ship although they occupy 0.2B of the ship's breadth each side. This reduces the economical efficiency of ship although they can be used to store liquids. Considering the average speed of ferries and their mass, collisions can be modelled. Thus the depth of penetrations at different parts of the ship for different speeds and masses can be found. These results will help to see whether this 0.2B depth is too much, satisfactory or not enough. Using the experimental results the adaptation of wing tanks to ships can be improved in more economical and more safe way. Structure would be added to wing tanks to absorb more energy in deformation and thus reduce penetration of damage

Considering different flooding conditions at different regions of ship some series of experiment can be done to see the reaction of ship against damages. In modelling for losses the time between starting of flooding and capsizing or immersing can be measured. These results will give us some idea about quick capsizings and the reasons. Taking into account the results some improvements can be done to prevent or to delay the capsizing. Thus the chance of evacuation of passengers can be increased.

More software development may be useful to allow the probabilistic method to be applied easily.

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APPENDIX 1

A.1.1 Data Base

No	Year	Name	Service	Loa	Lbp	B	Dblk	Dup	d	Disp.	C_B	DWT.	Gross	Vs	Fn
1	1974	Monte Toledo	London-Spain	151.4	136.0	20.3	8.25	13.25	6.80	10567.0	0.55	3500	13500	22.0	0.33
2	1974	Norland	England-Neth.	153.0	138.0	24.7	7.6		6.22	13256.0	0.61	3800	12988	18.5	0.27
3	1974	Dana Regina	England-Den.	150.0	139.0	22.3	8.5	14.30	6.02	10902.0	0.57	2660	12192	21.5	0.31
4	1974	Free Ent. 8	Dover-Zeebr.	123.6	115.8	19.0	6.04		4.37	5618.4	0.54		5200	20.7	0.33
5	1975	St. Edmund	England-Neth.	131.0	119.4	22.0	7.6	12.8	5.18	7980.0	0.54	1830	8987	21.0	0.33
6	1975	Belorussia	Black Sea	157.0	134.0	21.8			6.21	10133.8	0.54	2250	16631	22.0	0.33
7	1975	Tor Britannia	England-Fran.	182.3	163.0	23.6	8.0	16.0	6.20	13579.2	0.53	3200	15657	24.5	0.32
8	1975	Mette Mols	Danish line	115.3	103.0	20.5	6.85	14.9	4.90	5620.2	0.53	1560	4948	21.3	0.36
9	1976	JJ. Sister	Mediterranean	140.8	125.0	22.0	8.1	13.2	6.4	9562.0	0.53	2577	9120	22.4	0.35
10	1976	Earl Godwin	Channel Isl.	99.2	90.0	18.3	5.65		4.39	3937.0	0.58	421	4000	16.0	0.29
11	1976	Queen	North Pasific	139.3	127.7	27.1	7.92		5.33	10822.6	0.57		3500	20.0	0.31
12	1977	St Columba	The Irish sea	129.2	119.5	20.6		11.90	4.67	6775.0	0.57	1550	7836	22.5	0.36
13	1977	Finnjet	Finland-Ger.	212.8	185.0	25.4			7.2		0.57	2500	23000	30.5	0.39
14	1978	Dana Anglia	England-Den.	152.9	136.5	23.7	8.32	16.5	6.1	11529.0	0.57		14400	21.0	0.31
15	1978	Habib	Tunisia-Italy	143.3	125.7	23.5	8.35	13.9	6.17	9994.6	0.53	3372	11179	22.0	0.34
16	1979	El Arish	Egypt	105.9	93.0	17.3	5.6		4.12	3906.0	0.57	800		19.0	0.31
17	1979	Connacth	The Irish Sea	122.0	112.0	18.5	7.1		5.0	5840.0	0.55	1373	6812	20.0	0.33
18	1979	P. Beatrix	England-Neth.	131.0	119.5	22.0	7.60	13.0	5.15	7494.0	0.54	1850	9000	21.3	0.34
19	1979	Turella	Finland-Swed.	136.1	119.0	24.2	7.7	13.0	5.5	8766.0	0.54	2300	10600	21.3	0.34
20	1980	S. of F. Entp.	England-Fran.	131.9	126.1	22.7	7.3	12.7			0.53	2000	8300	22.0	0.34
21	1980	Viking Saga	Sweden-Fin.	145.0	131.0	25.2	7.2	13.30	5.5	10720.0	0.57	2870	13000	21.3	0.31
22	1980	Viking sally	Sweden-Eng.	155.4	137.4	24.2	7.65		5.55	10781.0	0.57	2800	15500	21.2	0.31
23	1980	St. Alsem	England-Ger.	129.4	120.7	21.0		13.2	4.72	7051.0	0.57	1755	8200	19.5	0.31
23	1981	Galloway P.	British Line	129.4	120.7	21.0	6.4	13.2	4.57	6886.0	0.58	1850		18.5	0.3
24	1981	Visby	Swedish Line	142.3	132.0	24.0			4.85	8976.0	0.57	2800	15000	21.0	0.32
25	1981	K. Victoria	Sweden-Eng.	150.0	131.	26.0	7.80		6.0	11939.0	0.57	3100	15000	21.1	0.31
26	1981	Finlandia	Finland-Swed.	166.1	150.0	28.4	9.10	14.65	6.77	16849.0	0.57	4000	25680	22.0	0.31
27	1981	Olau Holland	England-Neth.	153.4	136.0	24.2	8.0	13.6	5.7	10476.8	0.57	2700	14990	21.0	0.31
28	1981	Esterel	French Line	145.0	135.0	23.8	8.4	16.6	6.3	10996.4	0.53	2200	10996	23.5	0.35
29	1982	St. Colum 1	British Line	119.0	103.0	17.8			4.95	4930.0	0.53		5285	20.5	0.35
30	1982	Scandinavia	Americ. Costs	185.0	158.9	27.0	9.0		7.15			4200	27000	18.0	0.25
31	1982	Stena Danica	Sweden-Ger.	152.2	135.0	28.0	8.2	13.6	6.30	13913.0	0.57	3100	16000	21.0	0.32

No	Year	Name	Service	BHP	C	dwt/Δ	B/Dblk	B/d	L/B	L/Dup	d/Dblk	Pass	Vehicle
1	1974	Monte Toledo	London-Spain	.17800	280	0.33	2.45	2.98	6.70	10.26	0.82	800	275 C
2	1974	Norland	England-Neth.	18000	197	0.28	3.25	3.97	5.58		0.82	1244	520 C or 50 T
3	1974	Dana Regina	England-Den.	17600	277	0.24	2.62	3.7	6.23	9.72	0.71	900	250 C or 50 T
4	1974	Free Ent. 8	Dover-Zeebr.	13200	213		3.14	4.34	6.42		0.72	1200	350 C
5	1975	St. Edmund	England-Neth.	20400	181	0.23	4.24	3.87	5.42	9.32	0.68	1400	296 C or 40 T
6	1975	Belorussia	Black Sea	18000	277	0.22		3.51	6.14	8.22		1009	255 C or 23 T
7	1975	Tor Britannia	England-Fran.	13750	183	0.23	2.95	3.80	6.90	10.15	0.77	1507	470 C or 70 T
8	1975	Mette Mols	Danish line	45600	186	0.28	2.99	4.18	5.02	6.91	0.71	1500	420 C
9	1976	J.J. Sister	Mediterranean	26800	188	0.27	2.73	3.43	5.68	9.46	0.79	1080	250 C
10	1976	Earl Godwin	Channel Isl.	12000	85	0.11	3.22	4.17	4.70		0.77	1000	174 C
11	1976	Queen	North Pasific	13024	299		4.41	5.07	4.70		0.67	1100	362 C or 50 T
12	1977	St Columba	The Irish sea	18000	226	0.23		4.41	5.80	10.0		2400	335 C
13	1977	Finnjet	Finland-Ger.	75000				3.52	7.28			1532	350 C
14	1978	Dana Anglia	England-Den.	20800	227		2.84	3.88	5.75	8.26		1249	470 C
15	1978	Habib	Tunisia-Italy	20400	242	0.34	2.81	3.80	5.31	9.02	0.74	1150	350 C
16	1979	El Arish	Egypt	9000	189	0.20	3.1	4.20	5.37		0.73	564	150 C
17	1979	Connacth	The Irish Sea	17000	144	0.23	2.60	3.70	6.05		0.70	1500	350 C or 35 T
18	1979	P. Beatrix	England-Neth.	22000	205	0.25	2.89	4.27	5.43	9.19	0.67	1500	330 C
19	1979	Turella	Finland-Swed.	24000	171	0.26	3.14	4.40	4.95	9.15	0.71	1700	550 C or 40 T
20	1980	S. of F. Entp.	England-Fran.	24000			3.10		5.55	9.93		1300	168 C or 35 T
21	1980	Viking Saga	Sweden-Fin.	25280	184	0.28	3.5	4.57	5.19	9.84	0.76	1104	540 C or 60 T
22	1980	Viking sally	Sweden-Eng.	24000	193	0.26	3.16	4.36	5.67		0.72	2000	460 C or 52 T
23	1980	St. Alsem	England-Ger.	20800	131	0.25		4.45	5.74	9.14		1000	309 C or 62 T
23	1981	Galloway P.	British Line	16000	143	0.27	3.28	4.59	5.74	9.14	0.71	1000	309 C
24	1981	Visby	Swedish Line	29200	136	0.32		4.94	5.50			2000	515 C
25	1981	K. Victoria	Sweden-Eng.	21000	235	0.26	3.33	4.33	5.03		0.76	2100	700 C or 70 T
26	1981	Finlandia	Finland-Swed.	31200	224	0.24	3.12	4.19	5.35	10.23	0.74	2000	400 C or 70 T
27	1981	Olau Holland	England-Neth.	20800	201	0.26	3.02	4.24	5.61	10.0	0.71	1600	550 C or 65 T
28	1981	Esterel	French Line	37440	171	0.2	2.83	3.77	5.67	8.12	0.75	2100	700 C
29	1982	St. Colum 1	British Line	12000	207			3.59	5.78			1040	210 C
30	1982	Scandinavia	Americ. Costs	19800			3.0	3.77	5.88		0.79	1600	530 C
31	1982	Stena Danica	Sweden-Ger.	34800	153	0.22	3.41	4.44	4.82	9.92	0.76	2300	550 C or 90 T

No	Year	Name	Service	Loa	Lbp	B	Dblk	Dup	d	Disp.	C_B	DWT.	Gross	Vs	Fn
32	1981	New Katsura	Japan Line	141.3	130.0	22.7	7.50	13.0	5.40	9310.0	0.57		7000	19.7	0.30
33	1982	Trelleburg	Sweden-Ger.	170.7	158.0	22.5	8.15	15.25	5.81	13713.0	0.65	3800	10000	17.5	0.24
34	1983	Abegweight	Canadian Line	122.3	117.0	21.5	7.85	13.0	5.40	9618.0	0.61	2300	9547	17.0	0.28
35	1983	Arahura	New Zeland	148.3	137.0	20.2	6.90	11.80	5.47	9332.0	0.60	2500	7583	19.0	0.28
36	1985	Mariella			159.0	28.4		14.65	6.51	18078.8	0.60			20.5	0.29
37	1985	Svea			156.4	27.6		14.45	6.51	16418.0	0.57			22.0	0.31
38	1986	Peder Paars	Danish Line	134.0	126.0	24.0	8.00	13.45	5.50	9887.0	0.58	2400		19.4	0.30
39	1986	Kon. Beatrix	England-Neth.	161.0	146.0	27.6	8.10	15.80	6.20	14596.0	0.57	4100	31189	21	0.30
40		SHIPS ON ORDERS & SHIPBUILDER COUNTRIES	Chine		124.0	17.6	8.40		6.00	8053.0	0.60	2500		18.1	0.28
41			Denmark		113.0	16.1	7.60		3.60			3700		15.5	0.25
42			New Zeland		137.0	20.2	6.90		6.30	9042.0	0.60	2650		19.0	0.28
43			France		122.5	22.5			5.02	8033.0	0.57		8450	20.0	0.31
44			France		135.0	28.0	8.20		6.05	12892.0	0.55		16000	22.0	0.33
45			Japan		160.0	26.8	9.00		6.18	16025.7	0.59		13000	21.0	0.29
46			Japan		110.0	20.4	7.20		5.20	6578.0	0.55		4000	19.8	0.33
47			Poland		154.0	28.5	8.60		6.20	16198.0	0.58		20000	21.0	0.29
48			Poland		127.5	19.4	7.05		5.30	7726.4	0.57		6700	20.0	0.31
49			Spain		125.0	20.5			5.57	8046.4	0.55		7400	21.0	0.30
50			Finland		165.0	25.0	8.4		6.40	15694.8	0.58	4000	15300	22.0	0.28
51			Finland		175.0	29.0			6.30	19357.4	0.59		36400	22.0	0.29
52			Poland		125.0	21.0			6.60	8663.0	0.57		9800	20.0	0.31

No	Year	Name	Service	BHP	C	dwt/Δ	B/D_{blk}	B/d	L/B	L/D_{up}	d/D_{blk}	Pass.	Vehicle
32	1981	New Katsura	Japan Line	16600	219		3.02	4.2	5.72	10.0	0.72	1070	48 C+100 T
33	1982	Trelleburg	Sweden-Ger.	24000	120	0.27	2.75	3.86	7.03	10.34	0.71	800	
34	1983	Abegweight	Canadian Line	13200	167	0.25	2.73	3.98	5.44	9.0	0.77	900	250 C+40 T
35	1983	Arahura	New Zeland	22400	137	0.26	2.93	3.70	6.76	11.9	0.79	1085	232 C or 27 T
36	1985	Mariella		34800	172			4.36	5.59	10.85		2500	580 C Or 60 T
37	1985	Svea		30250	213			4.23	5.62	10.82		2000	231 C
38	1986	Peder Paars	Danish Line	17000	193.	0.24	3.00	4.36	5.25	9.36	0.68	2000	350 C or 27 T
39	1986	Kon. Beatrix	England-Neth.	17800	234	0.28	3.40	4.45	5.28	9.24	0.76	2100	530 C or 80 T
40	SHIPS ON ORDERS & SHIPBUILDER COUNTRIES		Chine	9000	249	0.31	2.09	2.93	7.04		0.71		
41			Denmark	4400			2.12	4.48	6.99		0.47		
42			New Zeland	11120	252	0.29	2.93	3.78	6.76		0.76		
43			France	23900	126			4.48	5.44				
44			France	34800	158		3.41	4.62	4.82		0.73		
45			Japan	24000	229		2.97	4.33	5.97		0.68		
46			Japan	13500	190		2.83	3.92	5.39		0.72		
47			Poland	40000	77		3.31	4.59	5.41		0.72		
48			Poland	16800	175		2.75	3.66	6.57		0.75		
49			Spain	17800	196			3.68	6.09				
50			Finland	28000	223	0.26	2.97	3.90	6.6		0.76		
51			Finland	36000	199			4.50	6.04				
52			Poland	17400	182			3.48	5.95				

A.1.2 **Steel Weight**

For the estimation of the weight of the steel Ref.(1) was used. As a first step the value of E (hull numeral) was calculated by using the following formula

$$E = L\,(B+T) + 0.85\,L\,(D-T) + 0.85\,\Sigma\, l_1 h_1 + 0.75\,\Sigma\, l_2 h_2$$

Length of ship

B: the beam of ship

T: the draft of ship

D_{upper}: the depth of uppermost continuous deck

l_1, l_2: the length of superstructure deck l_1 for full width l_2 for others

h_1, h_2: the height of deck h_1 for full width decks h_2 for others

$E=130\ (26+6) + 0.85*130\ (15.7-6) + 0.85\ \Sigma\ (120*3.3+127.5*2.8)+$

$0.75\ \Sigma\ (127*2.8+118*2.8+90*3.5+15*2.8)$

$E= 6652$

Using the value of E W_{S7} which is the weight of steel at C_B' of 0.7 can be found as 5200 tonnes from Fig.(A.1.1), then;

$W_S=W_{S7}*(1+0.5*(C_B'-0.70)$ can be calculated

W_S=Weight of steel for actual C_B' at $0.8*D_{upper}$

$C_B'=C_B+(1-C_B)(0.8*D_{upper}-T)/(3*T)$ where C_B is 0.62 at max draft

$C_B'= 0.755$

then final weight of steel is:

$W_S=5334.75$ tonnes

A.1.3 **Outfit Weight**

Outfit weight was estimated as 2900 tonnes by using Fig.(A1.2) in Ref.21.

A.1.4 Machinery Weight

Total machinery weight is the combination of the main engine weight and the remainder machinery weight. These estimations were done considering the estimated power of 2700 BHP.

–The netweight of main engines was estimated as 300 tonnes from Ref. 19

–The reminder machinery weight was estimated as 800 tonnes from Ref. 19

–Total machinery weight was estimated as 1100 tonnes

A.1.5 Fuel Weight

Fuel oil consumption is calculated by following formula

$F.C = \delta * BHP_{ser} * 24 * 10^{-6}$ tonnes/day

δ : specific fuel consumption 160 gr/hp-hr

$F.C = 160 * 27000 * 24 * 10^{-6}$

$= 103$ tonnes/day

The total voyage return time (Izmir-Trieste-Izmir) is around five days so that necessary fuel is around 500 tonnes. Furthermore if the fuel consumption of auxiliary engines and of some other necessities total fuel storage will be ample around 700 tones. Also we can consider the weight of lubrication oil included.

A.1.6 Fresh Water

Fresh water is needed for cooling systems of engines and basic needs such as washing, drinking, cooking. Required fresh water was estimated for initial estimation as around 200 tonnes but it was taken 350 tonnes as a final estimation.

A.1.7 Stores

Stores are mainly two parts. One is for the storage of foods and drinks for passengers and crew. Second is for the storage of spare equipments for engines and hotel goods. Foods are considered that all of them will be taken in Izmir and it must be enough for return voyage. Some fresh fruits and vegetables and dairy products can be supplied in Trieste. Total weight of stores was estimated as 300 tonnes.

A.1.8 Passenger and Crew

Average weight of each person is estimated as 75 kg and the baggage of 75 kg for each person was estimated so that total weight estimation of each person with their baggage is 150 kg and 5% extra weight allowance is added.Final total weight of whole passenger and crew is estimated as 150 tonnes.

A.1.9 Cargo

The average weight of each private car is considered as 1 tonne and the average weight of each 12 m trailer is considered as 30 tonnes.

The approximated capacity of second car deck is 200 european cars. The trailer capacity of main vehicle deck is estimated around 60 trailers so that required deadmass for cargo is around 2000 tonnes. Considering some extra weight allowances it may be estimated as 2120 tonnes.

A.1.10 Estimation of the Vertical Centre of Gravity of Group Masses

–Steel

VCG of steel changes depending on the number and height of decks. The estimation of VCG of steel was carried out for different vehicle deck arrangements. The VCG of total steel weight for the arrangement of one trailer and one car deck was found as 13.06 m. [page 174]. VCG of steel weight for the arrangements of one trailer deck and two trailer decks were estimated as 12.2 m. and 15.3 m. respectively.

–Machinery

All machinery arrangements are taken place at first and second deck so that the level of second deck is considered as the VCG of machinery weight which is 4.5 metres.

–Outfits

Outfit items are installed at every part of the ship. Considering that distribution it might be taken as 17 metres which is around the half depth of the ship although the boats are included in the outfit weight they are settled at 23 metres of ship height so that they are considered separately.

–Fuel

Fuel tanks are located at first and second decks but greater parts of the tanks are at first deck so that VCG of fuel weight was estimated as 4.2 metres.

–Fresh Water

Fresh water tanks are also located like fuel tanks so that VCG of fresh water were taken a 4.2 metres.

–Passengers and Crew

Passengers and crew living areas are designed between 15.5 and 25 meters so that VCG of 17.5 meters is reasonable.

APPENDIX 2

A.2.1 Output of hull definition computer program for this particular ferry

TRIM= 0
SHIPLENGTH= 130

SECTION= 1 X= -65 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.400248219	.199458653	.0515417077	.0400910188	1.23627855
1	.400524873	.402099403	.210481478	.0811989337	1.73630498
2	.4086652	.811885186	.850576535	.16534335	2.73640342
3	.426921551	1.22767668	1.92029228	.252059216	3.7365626
4	.607266645	1.6417537	3.20190116	.221002621	4.74667813
5	1.55841084	2.73038683	8.32372145	.916444857	6.15726245
6	4.31063048	5.33053348	22.8454284	4.65797687	9.11033763
7	8.074824	11.7781754	65.036773	26.0356098	13.011267
8	9.85434775	20.8270346	133.079579	67.132415	15.059698
8.5	10.4075323	25.932418	175.164046	93.2075661	15.8004095

TRIM= 0
SHIPLENGTH= 130

SECTION= 2 X= -58.5 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.382996081	.293382768	.0483374648	.057280154	1.06946623
1	.395378936	.489989024	.201109152	.0960300879	1.56994067
2	.643045504	.943912141	.809865952	.163032599	2.60711642
3	1.2846693	1.91168798	3.40067987	.687112773	3.8046589
4	2.41903979	3.66156076	9.53169058	2.1910055	5.32037018
5	4.95884792	7.21380047	25.7562466	8.80580141	8.05857524
6	8.47551363	14.0744448	63.7800073	32.8858554	11.7191506
7	10.4264524	23.6411009	126.109313	78.8081559	13.9169053
8	11.4770614	34.6413752	208.723038	139.371178	15.3744738
8.5	11.828724	40.4754983	256.8629	173.415707	15.9854777

TRIM= 0
SHIPLENGTH= 130

SECTION= 3   X= -52 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.758637687	.302720505	.0769632102	.0927065525	1.02876413
1	1.06324663	.757972494	.455646689	.31127507	1.61424798
2	1.90300908	2.18148589	2.60118845	1.31095138	2.92682045
3	3.50396259	4.82300527	9.35268326	4.91903551	4.819559
4	6.26402919	9.5848672	26.2615987	16.5890906	7.75952613
5	9.98216301	17.7820864	63.4603482	50.8203436	11.6102006
6	11.5148971	28.7065348	123.640238	110.553802	13.466169
7	12.1909368	40.5683922	200.873525	180.951612	14.678572
8	12.5929707	52.9914259	294.003002	258.097514	15.7549745
8.5	12.7394487	59.3205158	346.24603	298.159121	16.2766824

TRIM= 0
SHIPLENGTH= 130

SECTION= 4   X= -39 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	2.0869553	.684319793	.208575618	.523761701	2.17209364
1	3.48933259	2.07342517	1.26353698	2.46340405	3.6610979
2	6.84547213	7.21130641	9.28529891	16.196289	7.16331397
3	10.3161932	15.8574332	31.1665418	54.0768268	10.7751332
4	11.739005	27.065703	70.4785798	116.923009	12.5442154
5	12.3755747	39.1465132	124.941554	189.937912	13.7322778
6	12.7406553	51.708748	194.092488	268.848562	14.8025716
7	12.8747219	64.540115	277.430131	351.149984	15.8086504
8	12.9580335	77.4585937	374.329031	434.593881	16.8122228
8.5	12.9661348	83.942795	427.816339	476.638659	17.3123065

TRIM= 0
SHIPLENGTH= 130

SECTION= 5   X= -26 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	7.87263083	3.12134291	.865775309	10.065084	7.90731836
1	10.0949222	7.62717822	4.28840975	30.4522109	10.1850318
2	11.8635974	18.8612156	21.2460595	93.633916	12.2557871
3	12.5332245	31.0915111	51.8946703	168.4468	13.4666128
4	12.8912255	43.8301126	96.5204413	249.588955	14.5325026
5	12.9887412	56.7764882	154.77032	333.390678	15.5422345
6	12.9911816	69.766443	226.21795	417.760167	16.5437305
7	12.9943807	82.7603811	310.685935	502.181395	17.543735
8	12.9969806	95.7556289	408.160838	586.619642	18.5437386
8.5	12.998056	102.253744	461.775883	628.845147	19.0437402

TRIM= 0
SHIPLENGTH= 130

SECTION= 6   X= -13 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	11.6220742	5.43592648	1.40176826	29.4014975	11.7039314
1	12.1558649	11.4073416	5.85922685	65.0175223	12.4162116
2	12.7759044	23.9255535	24.6827822	143.378194	13.6045675
3	13.0055193	36.8525941	57.0318517	226.937048	14.6447189
4	13.0010136	49.8866381	102.639021	311.878735	15.6426259
5	13.0055267	62.9290598	161.418878	396.930937	16.6426229
6	13.0084126	75.9702919	233.211105	481.967663	17.6426202
7	13.0095901	89.0082884	317.989743	566.962276	18.6426229
8	13.0090594	102.043049	415.754793	651.914776	19.6426312
8.5	13.0081534	108.559216	469.507222	694.375233	20.1426375

TRIM= 0
SHIPLENGTH= 130

SECTION= 7 X= 0 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	11.6220742	5.43592648	1.40176826	29.4014975	11.7039314
1	12.1558649	11.4073416	5.85922685	65.0175223	12.4162116
2	12.7759044	23.9255535	24.6827822	143.378194	13.6045675
3	13.0055193	36.8525941	57.0318517	226.937048	14.6447189
4	13.0010136	49.8866381	102.639021	311.878735	15.6426259
5	13.0055267	62.9290598	161.418878	396.930937	16.6426229
6	13.0084126	75.9702919	233.211105	481.967663	17.6426202
7	13.0095901	89.0082884	317.989743	566.962276	18.6426229
8	13.0090594	102.043049	415.754793	651.914776	19.6426312
8.5	13.0081534	108.559216	469.507222	694.375233	20.1426375

TRIM= 0
SHIPLENGTH= 130

SECTION= 8 X= 13 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	8.71795394	3.89278176	.973024671	14.4454883	8.76440132
1	10.2282505	8.64070168	4.60117312	37.085764	10.3602314
2	11.5788834	19.6389463	21.1910318	97.5689292	12.0489756
3	12.2391349	31.6084958	51.0643781	169.156393	13.2484287
4	12.6296646	44.0444801	94.6822222	246.502055	14.3234758
5	12.8894238	56.8206551	152.155265	328.109706	15.3572616
6	12.9879642	69.7732954	223.392878	411.99567	16.3639599
7	12.9916945	82.763125	307.806382	496.363467	17.3639669
8	12.9954248	95.7566849	405.258894	580.779766	18.3639738
8.5	12.9972899	102.254864	458.874779	623.006105	18.8639773

TRIM= 0
SHIPLENGTH= 130

SECTION= 9 X= 26 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	4.51357475	4.6106743	.486039278	7.35712694	4.56745437
1	5.99569008	7.25730323	2.49863381	14.3970043	6.13204725
2	7.9958233	14.3214999	13.2603264	39.4963919	8.371443
3	9.21027534	22.9698069	34.9730359	76.9461489	9.94660095
4	10.0754174	32.6306934	68.8114625	123.622588	11.2690567
5	10.8455971	43.0944486	116.072852	178.43544	12.5373611
6	11.4438218	54.2406388	177.307494	240.520668	13.7024873
7	12.0395457	65.9844032	253.772041	309.516966	14.868033
8	12.6793029	78.3789832	346.776865	386.351359	16.0727501
8.5	12.7261326	84.7212987	399.028707	426.577221	16.5862329

TRIM= 0
SHIPLENGTH= 130

SECTION= 10 X= 39 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	1.82347181	.571516599	.183640804	.380924846	1.90638575
1	2.68811778	1.71390866	.99970645	1.64096813	2.90204286
2	4.23119968	5.19988436	6.320214	7.80219798	4.74158273
3	5.538647	10.090553	18.7502187	19.9036106	6.3878317
4	6.73757044	16.2319715	40.4593933	38.8827261	7.94931791
5	7.82398836	23.5218781	73.1890039	65.3970149	9.42581258
6	8.90149745	31.8846196	119.461941	100.514418	10.8958554
7	9.91242652	41.3092068	180.477699	144.812422	12.3179417
8	10.8419741	51.6831775	258.612529	198.779436	13.6835538
8.5	10.95699	57.1626073	303.749538	228.769543	-2.27537146

TRIM= 0
SHIPLENGTH= 130

SECTION= 11 X= 52 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.673386967	.212005248	.0639802654	.0507631735	.862756062
1	1.07445064	.651756919	.405790834	.247950827	1.50435145
2	1.70882347	2.05240411	2.55729706	1.24616035	2.68852315
3	2.23319529	4.03667504	7.51980653	3.21455365	3.81919816
4	2.66785364	6.48540306	16.1762939	6.23057427	4.9101005
5	3.23928966	9.41315791	29.3738043	10.5230635	6.06400755
6	4.09092401	13.0378109	49.3319889	17.0856989	7.38234972
7	5.3963744	17.7720017	80.3047984	28.4214478	9.02748506
8	7.19342089	24.0046104	127.16069	47.9571235	11.0870519
8.5	7.88407605	27.8217936	158.667595	62.5414803	11.9896447

TRIM= 0
SHIPLENGTH= 130

SECTION= 12 X= 58.5 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.444186645	.114693588	.0464818943	.0204974412	.672481791
1	.711365629	.415769962	.238462196	.0998547872	1.23704723
2	1.18374837	1.36714355	1.76022491	.576157464	2.34410626
3	1.53435716	2.75695512	5.26448224	1.54149461	3.39827773
4	1.64179306	4.35051871	10.8927261	2.81430487	4.41556055
5	1.43651488	5.90969017	17.8541427	4.03374623	5.43347046
6	1.75375725	7.44982075	26.3503037	5.22294505	6.508394
7	2.78683272	9.65828744	40.8051738	7.71562933	7.95668529
8	4.35033198	13.1607527	67.1919948	13.9448013	9.82038104
8.5	5.03885461	15.5519414	86.9048929	19.6704998	10.7083652

TRIM= 0
SHIPLENGTH= 130

SECTION= 13 X= 65 MTRS

MTRS WATERLINE	MTRS OFFSET	MTRS^2 BONJEAN	MTRS^3 VERTMOM	MTRS^3 HORIZMOM	MTRS GIRTH
.5	.219407527	.0456705395	2.3758993E-03	8.84102393E-04	.578979371
1	.435136283	.208520556	.149995804	.0329176214	1.12360774
2	.846424209	.859929129	1.1602307	.254333594	2.20148805
3	1.05701465	1.8144915	3.59399576	.716421426	3.23701113
4	.861840767	2.85902368	7.24389923	1.23150037	4.25586766
5	-7.06641717E-03	3.14045086	8.3181024	1.31890465	5.7223766
6	.18890727	3.23222053	8.83665722	1.32034827	6.75546603
7	.669585838	3.65110887	11.5662805	1.41058966	7.86593425
8	1.16653232	4.57221792	18.6400619	1.87738451	8.98341329
8.5	1.44637957	5.22283922	24.003413	2.30264912	9.55633679

A.2.2 The results of hydrostatic calculations

TEST
SP[illegible]
SHIPLENGTH= 130 MTRS
MOULDED BEAM= 26 MTRS
VCG= 12.36 MTRS
KEELDEPTH= 0 MTRS
MEAN SHELL THICKNESS= 0.0110 MTRS
TRIM[illegible]

WL MTRS	MLDDISP TONNES	FULLDISP TONNES	LCB MTRS	LCF MTRS	VCB MTRS	IMMERSION TONNES/CM	WSA MTRS^2
0.500	625.252	640.278	-0.758	-2.495	0.241	13.247	1332.703
1.000	1351.657	1369.866	-1.543	-2.261	0.5[illegible]	15.685	1616.738
1.500	2185.197	2206.150	-1.857	-3.453	0.797	17.620	1858.359
2.000	3108.528	3131.930	-2.091	-2.809	1.080	19.249	2075.595
2.500	4109.596	4135.390	-2.345	-3.421	1.366	20.777	2287.677
3.000	5184.420	5212.483	-2.625	-4.049	1.673	22.119	2488.989
3.500	6315.666	6345.758	-2.916	-4.460	1.941	23.170	2669.764
4.000	7497.444	7529.466	-3.196	-4.840	2.225	24.055	2840.105
4.500				-5.504	2.510	24.969	3019.580
5.000	9995.950	10032.057	-3.784	-6.233	2.795	25.907	3202.432
5.500	11310.560	11351.710	-4.097	-6.305	3.032	26.851	3384.091
6.000	12678.729	12718.817	-4.405	-6.997	3.369	27.692	3555.573
6.500	14094.070	14126.063	-4.653	-6.944	3.636	28.485	3724.362
7.000	15526.406	15570.221	-4.862	-6.630	3.944	29.190	3886.015
7.500	17002.741	17047.647	-4.975	-6.154	4.231	29.860	4044.858
8.000	18512.130	18559.562	-5.064	-5.489	4.513	30.524	4205.084
8.500	20050.[illegible]14	20093.127	-5.078	-5.155	4.804	30.910	3780.269

WL MTRS	BMT MTRS	GMT MTRS	BML MTRS	MCT TONNES MTRS/CM	CB	CP	CM	CW
0.500	62.944	50.326	937.652	44.610	0.3609	0.4315	0.8862	0.3823
1.000	36.391	27.147	601.861	61.346	0.3901	0.4446	0.8774	0.4527
1.500	29.266	17.704	4[illegible]3.861	76.868	0.4204	0.4667	0.9009	0.5085
2.000	23.520	12.241	39[illegible].647	92.148	0.4486	0.4875	0.9202	0.5556
2.500	20.180	9.184	350.718	107.394	0.4744	0.5079	0.9341	0.5997
3.000	17.853	7.147	316.224	121.841	0.4988	0.5278	0.9449	0.6384
3.500	15.876	5.458	286.476	134.114	0.5208	0.5464	0.9532	0.6687
4.000	14.136	4.002	262.551	145.575	0.5410	0.5639	0.9593	0.6945
4.500	12.949	2.999	245.101	157.871	0.5595	0.5803	0.9642	0.7207
5.000	11.873	2.309	232.825	171.670	0.5776	0.5960	0.9681	0.7477
5.500	11.053	1.776	224.886	187.[illegible]39	0.5937	0.6112	0.9713	0.7750
6.000	10.322	1.332	217.097	202.964	0.6099	0.6261	0.9739	0.7993
6.500				18.651	0.6254	0.6406	0.9762	0.8222
7.000	9.137	0.721	203.613	233.132	0.6402	0.6545	0.9781	0.8425
7.500	8.668	0.540	196.578	246.85[illegible]	0.6547	0.6678	0.9797	0.8614
8.000	8.248	0.407	191.285	261.227	0.6679	0.6807	0.9811	0.8810
8.500	7.759	0.204	182.899	270.439	0.6809	0.6930	0.9824	0.8921

APPENDIX III

A.3.1 Power Estimation

Necessary parameters

Volume: $12426.34\ m^3$

Δ=12737.00 tonnes

L_{bp}=130.00 m

L_{WL}=136.00 m

B= 26.00 m

d=6.00 m

B/d= 4.33 m

C_B=0.60 m

C_M= 0.975

$$C = \frac{Volume}{L_{wl}^3} 10^{-3} = 4.94 * 10^{-3}$$

C_S=2.747

S=$3572.258\ m^2$

Calculation

B/d of particular ship is 4.33 so that calculation is done for

$(B/d)_1=3.75$ $\qquad$ $C_{\Lambda_1} = 4.00\ 10^{-3}$

and

$(B/d)_2 = 4.50$ $\qquad$ $C_{\Lambda_2} = 5.00\ 10^{-3}$

C_Λ interpolation

$K_1 = (C_\Lambda - C_{\Lambda_1})\ 10^{-3}$

$K_1 = (4.94\ 10^{-3} - 4\ 10^{-3})$

$K_1 = 0.94$

B/d interpolation

$K_2 = 1.334\ [B/d - (B/d)_1]$

$K_2 = 0.773$

coefficients

$$K_3 = 6.088\sqrt{L_{WL}}$$

$K_3 = 70.98$

$$K_4 = 41.76\ 10^{-3}\sqrt{L_{WL}}$$

$$= 0.487$$

Reynolds number

$$K_5 = 3.132\ \frac{\sqrt{L_{WL}^3}}{v}$$

$K_5 = 40.38\ 10^5$

Fn	C_∇ interpolation										B/T interpolation		
	R_R/Δ for $(B/T)_1 = 3.75$					R_R/Δ for $(B/T)_2 = 3.75$							
	$\left(\frac{R_R}{\Delta}\right)C_\nabla$	$\left(\frac{R_R}{\Delta}\right)C_\nabla$	$\left(\frac{R_R}{\Delta}\right)$	K	$\left(\frac{R_R}{\Delta}\right)C_\nabla$	$\left(\frac{R_R}{\Delta}\right)C_{\nabla 1}$	$\left(\frac{R_R}{\Delta}\right)C_{\nabla 2}$	$\Delta\left(\frac{R_R}{\Delta}\right)C_\nabla$	$K_1\left(\frac{R_R}{\Delta}\right)$	$\left(\frac{R_R}{\Delta}\right)C_\nabla$	$\Delta\left(\frac{R_R}{\Delta}\right)$	$K_1\ \Delta\left(\frac{R_R}{\Delta}\right)$	$\left(\frac{R_R}{\Delta}\right)$
1	2	3	4	5	6	7	8	9	10	11	12	13	14
			3-2	K1*4	2+5			8-7	K1*9	7+10	11-6	K2*12	6+13
0.173	0.350	0.370	0.020	0.018	0.368	0.420	0.440	0.020	0.018	0.438	0.070	0.054	0.422
0.202	0.500	0.550	0.050	0.047	0.547	0.650	0.650	0.000	0.000	0.650	0.103	0.080	0.626
0.230	0.800	0.850	0.050	0.047	0.847	1.000	1.020	0.020	0.018	1.018	0.171	0.132	0.979
0.260	1.480	1.450	-0.030	-0.028	1.450	1.700	1.730	0.030	0.028	1.728	0.228	0.176	1.626
0.288	3.100	3.200	0.100	0.094	3.194	3.350	3.600	0.250	0.235	3.585	0.391	0.302	3.496
0.310	4.750	5.100	0.350	0.329	5.079	5.200	5.500	0.300	0.282	5.482	0.403	0.311	5.390

Fn	V	R_R/Δ	R_R	R_F/S	R_F	R_T	P_{ET}/Fn	P_{ET}
--	kn	kg/tonne	kg	kg/m^2	kg	kg	HP	HP
1	2	3	4 (3*Δ)	5 (chart)	6 (5*S)	7 (4+6)	8 (K_4*7)	10(1*8)
0.173	12	0.422	5375.01	3.7	13217.35	18592.35	9054.47	1566.52
0.202	14	0.626	7973.36	5.0	17861	25334.56	12531.43	2541.44
0.230	16	0.979	12469.52	6.5	23219.6	35868.81	17468.11	4017.66
0.260	18	1.626	20710.2	8.1	28935.29	49645.65	24177.57	6286.76
0.288	20	3.496	44528.55	9.7	34650.9	79179.45	38560.39	11105.39
0.31	22	5.39	68652.43	11.25	40187.9	108840.33	53005.02	16431.60

A.3.2 **Propeller**

Required Parameters

V=22 knots

W_1: wake fraction= 0.152

th: thrust deduction factor= 0.17

η_h : hull efficiency = 1 for twin screw ship

η_o : propeller efficiency on open water =1

η_m: mechanical efficiency factor = 0.97

η_R : relative rotative efficiency =1

η_p : propulsive efficiency =0.62 QPC= $\eta_p \, \eta_R \, \eta_h$ 0.63

N : 240 rev/min (propeller)

$V_a = V\,(1 - W_T)$

V_a= 17.808 knots

EHP is taken from fig.3.33 as 13700 hp.

Considering the efficiency DHP can be estimated as fallow

$$DHP = \frac{EHP}{QPC\,\eta_m} * \text{correlation factor } (0.90) * \text{weather service allowance } (1.15)$$

DHP = 23203, 14 horsepower

DHP = 11601 for each shaft

Then

$$B_p = \frac{N * \sqrt{DHP}}{V_a^{2.5}}$$

and

$$\delta = \frac{N * D}{V_a} = 175.28$$

Cavitation number σ is found by using the formula following

$$\sigma = \frac{\text{static head}}{\text{dynamic head}} = \frac{P\text{-}e}{q_T}$$

P-e = 14.45 + 0.45 H = 20.975 ft

H : Head above shaft .... in ft

$$q_T = q_V + q_R = (\frac{V}{7.12})^2 + (\frac{N * d}{329})^2$$

q_T = 6.25 + 89.96 = 96.18psi

Lift coefficient τ_c is estimated by using the following formula :

$$\tau_c = \frac{\text{thrust per sq inc}}{\text{dynamic pressure}} = \frac{T}{A_p q_T}$$

$$T = \frac{DHP * QPC * 2.26}{V_a} \quad \text{lb per sq in}$$

and

$$A_p = \frac{M D^2}{4} * \text{blade ratio} * (1.067 - 0.229 * \frac{p}{D})$$

p/D = pitch ratio (obtained from B series charts)

Using the given formulas and charts the results are estimated as follows

$B_P = 19.33$ $\quad q_T = 96.18$ $\quad \sigma = 0.218$

Blade Type	P/D(chart	η_O(chart)	δ	A_P(sq ft)	T(lb/sq i	τ_c
4.40	0.8	0.655	185	46.92	19.77	0.205
4.55	0.87	0.625	173	63.34	14.65	0.12
4.70	0.89	0.620	167	80.20	11.57	0.10

According to the chosen type 4.70 final diameter of propeller

$$D_{fin} = \frac{\delta * V_a}{N} = \frac{167 * 17.8}{240} = 12.38 \text{ ft (3.27 meters)}$$

APPENDIX 4

A.4.1Design Still Water Moment, Ms

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	q	a	p 1-2	Σp	cor.	4+5	ΣΣp	Q_x Δl 6	M_x Δl^2 8	Σa_x	cor e 2	cor. e Δl 10	Q_x 8+11	M_x 9+12
0	67	12.4	54.6	0	0	0	0	0	0	0	-9.4	0	0	0
1	73	30.5	42.5	53.37	-0.925	52.44	26.22	340.89	1107.7	21.45	-22.45	-101.7	368.6	1006.02
2	93	60.5	29.5	89.37	-1.85	87.52	96.05	568.88	4058.2	66.95	-44.1	-317.5	524.78	3740.62
3	97	85.15	11.8	110.03	-2.77	108.3	193.9	703.7	8194.0	139.7	-62.5	-663.0	641.12	7531.0
4	107	107.5	-0.5	115.5	-3.7	111.83	304.3	726.9	12873.5	236.1	-78.44	-1119.9	648.45	11753.6
5	116	128.5	-12.5	109.0	-4.65	104.45	412.3	678.6	17423.4	354.1	-93.7	-1679.6	684.8	15743.7
6	120	148.0	-2.5	90.28	-5.5	84.73	506.9	550.7	21418.6	490.9	-105.8	-2328.8	444.9	19089.8
7	125	155.0	-30.0	62.78	-6.4	56.3	577.5	365.9	24398.5	640.9	-113.7	-3040.3	252.3	21358.2
8	126	157.0	-31	32.28	-7.4	24.8	618.0	161.6	26113.0	796.9	-114.6	-3780.3	47.0	22332.7
9	127	158.0	-31.0	1.28	-8.32	-7.0	626.9	-45.8	26489.4	954	-115.3	-4525.2	-150.0	21964.1
10	127	156	-29.0	-28.72	-9.25	-37.9	604.4	-246.8	25538.4	1111	-113.8	-5269.9	-360.6	20268.4
11	154	151	3.0	-41.72	-10.17	-51.9	559.5	-337.3	23639.7	1264	-110.2	-5998.1	-447.5	17641.6
12	154	140	14.0	-33.2	-11.1	-44.3	511.4	-288.0	21607.0	1510	-102.2	-7162.6	-390.3	14444.7
13	136	130	6.0	-23.2	-12.0	-35.3	-471.6	-229.0	19925.9	1645	-94.8	-7803.0	-323.9	12122.9
14	86	106	-20.8	-30.6	-12.9	-43.6	-432.2	-283.2	18260.8	1763	-77.9	-8364.6	-361.1	9896.2
15	82	87	-5.0	-43.5	-13.8	-57.4	361.7	-373.0	16127.7	1860	-63.46	-8824.6	-436.5	7303.4
16	75	64.5	10.5	-40.7	-14.8	-55.5	325.2	-360.7	13742.6	1966	-47.06	-9326.0	-407.8	4416.6
17	68	45.0	21.0	-25.0	-15.7	-40.7	277.1	-264.7	11710.0	2020	-32.83	-9581.9	-297.5	2129.0
18	50	26.0	24.0	-25.0	-16.6	-31.6	240.9	-205.7	10180.0	2055	-18.97	-9750.2	-47.87	431.0
19	20	16.0	4.0	12.0	-17.5	-5.5	222.4	-36.2	9413.7	2076	-11.67	-9849.8	-47.87	-434.0
20	15	7.0	8.0	18.5	-18.5	0.0	220	0.0	9295.0	2080	-5.1	-9866.4	-5.18	-571.0

Q_x:(tonne) , M_x:(tonne meter)

A.4.2 Rule Wave Bending Moment, M_W

$$Mw = f\, C_1\, L^2 B (c_b + 0.7)\, 10^{-3} \quad \text{tonne - fm}$$

f= 10.0 for unrestricted seagoing service

$$C_1 = 10.75 - \left(\frac{300-L}{100}\right)^{1.5} \qquad \text{for } 90<L(m)<300 \text{ in metre}$$

L= 130 meters

B=26 meters

C_B=0.626

M_W=47628.763 (tonne-f.m.)

A.4.3 Minimum Required Section Modulus, Z_R

$$Z_{R1} = C_1\, L^2\, B\, (C_B + 0.7) \quad cm^3$$

or

$$Z_{R2} = \frac{M_s + M_w}{\sigma_c}\, 10^3 \ cm^3$$

whichever is greater.Where L, B, C_B are as given above and

C_1=8.15

M_s=22322 (tonne-f.m)

M_w=47628.763 (tonne-f.m)

σ_c=18.15 (kgf/mm^2)

Z_{R1}=4762876.3 cm^3

Z_{R2}=3781122.16 cm^3

The Neutral Axis (NA) $= \Sigma A\ Y / \Sigma A$

$= 11.47$ metres from base

–The moment of inertia at N.A., I_{NA}

$(I_{N.A.}) = [\Sigma A\ Y^2 - \Sigma A\ (NA)^2]\ 2$

$= 117.28\ m^4$

–Section Modulus at Deck, Z_D

$ZD = (I_{NA})/(Y-NA)$

$= 11.27\ m^4$

–Section Modulus at Keel, Z_K

$Z_D = (I_{NA})/NA$

$= 10.28\ m^4$

A.4.4 **The Members of Midship Section**

A.4.4.1 **Double Bottom Structure**

–The Center Girder Depth

$d_{DB} = 28B + 205k(d)^{0.5}$

$d = 6$ m. (draft of the ship)

$B = 26$ m. (beam of the ship)

$k = 1.0$ (tensile strength factor of steel)

$d_{DB} = 1230$ mm. It was taken as 1250 mm.

–The Thickness of Center Girder

$t = (0.08 d_{DB} + 4)(k)^{0.5}$

$t = 14$ mm

–The Thickness of The Watertight Side Girders

$t = (0.007 s\ d_{DB} + 2)\ (k)^{0.5}$

$s = 700$ mm (Stiffener Spacing)

$t = 11.5$ mm

–Inner Bottom Plating

$t=0.00136(s+660(k^2L\ d)^{0.25}$

$L= 130$m (the length of the ship)

$t= 10$ mm

–Plate Floors

$t=0.009d_{DB}+L)\ (k)^{0.5}$

$t=12.5$ mm

–The Thickness of Watertight Floors

$t= (0.008d_{DB}+3)\ (k)^{0.5}$

$t= 13$ mm

–Bottom Longitudinals

$Z=0.0106s\ k\ l_e^2\ K^3$

$K_3= 5.09$ (factor obtained from Lloyd's)

$l_e=3.2$ m. (effective length of the stiffener)

$Z=296.308\ cm^3$ Chosen stiffener is (220x11 mm)

–Bottom Side Longitudinals

$Z=0.0106s\ k\ l_e^2\ K_2$ (for the lowest one)

$Z=296\ cm^3$ Chosen stiffener is (220x11 mm)

A.4.4.2 **Deck Longitudinals**

–Deck 2

$Z=s\ k(5.9\ L_1+25h^2l_e^2)\ 10^{-4}$

$h_2=2.6$ m.(head of cargo for machinery space)

$L_1=130$ m

$Z=100.2\ cm^3$ Chosen stiffener is (160x8 mm)

–Deck 3

$Z=(0.536K1P\ l_e+0.00125K2\ \ h\ \ s\ l_e^2)$

K1=10.1 K2=1.3

h=2.5 m. P=15 tonne (axle load)

$Z=288.97\ cm^3$ Chosen stiffener is (220x11 mm)

–Deck 4 (car deck)

$Z=sk\ (5.9L_1+25h_2\ l_e^2)\ 10^{-4}$

$h_2=\ 1.2$ m.

$l_e=3.2$ m.

$Z=\ 75.41\ cm^3$ Chosen stiffener is (140x8 mm)

–Uppermost Continuous Deck

$Z=\ sk\ (5.1\ L_1+25h_3\ l_e^2)\ 10^{-4}$

$h_3=0.95$ (for first tier)

$Z=63.43\ cm^3$ chosen stiffener is (120x8 mm)

–Supertructure Deck Longitudinals

$Z=sk\ (5.1L_1+25h_3\ l_e^2)\ 10^{-4}$

$h_3=0.65$ (for deck 6)

$h_3=0.5$ (for upper decks)

For deck 6,

$Z=58.05\ cm^3$ Chosen stiffener is (120x8 mm)

For decks 7,8,9,10,

$Z=55.37\ cm^3$ Chosen stiffener is (120x7 mm)

A.4.4.3 **Side Longitudinals**

–Side Longitudinals Above D/2

$Z=0.0106s\ k\ l_e^2\ K_1$

$K_1=3.38$

$Z=256.81\ cm^3$ Chosen stiffener is (200x12 mm)

–Side Longitudinals Below D/2

$Z=0.0106 s\ k\ l_e^2\ K_2$

$K_2=5.82$

$Z=442.2\ cm^3$ Chosen stiffener is (260x11 mm)

–Side Longitudinal at Superstructure Decks

$Z=0.0035\ h\ s\ l_e^2\ k$

$h=2.5+0.01L_2$ (for the lowest tier)

$h=1.25+0.005L_2$ (for other locations)

$L_2=130$ m.

For deck 5,

$h=3.38$ m. $Z=84.9\ cm^3$ Chosen stiffener is(140x9 mm)

For deck 6,

$h=3.1$ m. $Z=77.77\ cm^3$ Chosen stiffener is(140x8 mm)

For deck 7,

$h=2.8$ m. $Z=70.24\ cm^3$ Chosen stiffener is(140x7 mm)

For deck 8,

$h=2.5$ m. $Z=62.72\ cm^3$ Chosen stiffener is(120x8 mm)

For deck 9,

$h=2.2$ m. $Z=55.19\ cm^3$ Chosen stiffener is(120x7 mm)

A 4.4.4 Side Transverses

–Deck 1

In tanks,

$Z=11.71\rho\ k\ S\ h_4\ l_e^2$

l_e=7.0 m.

h_4=5.5 m.

S=3.2 m.(spacing between transverses)

Z=10098 cm^3

In dry spaces

$Z=10L\ S\ h_5\ l_e^2$

For deck 1,

l_e=4.5 m. h_5=2.25 m. Z=1458 cm^3

For deck 2,

l_e=4 m h_5=2 m Z=1024 cm^3

For deck 3,

l_e=5 m. h_5=2.5 m. Z=2000 cm3

chosen transverse is(400x12x13 T)

For deck 4,

l_e=2.2 m h_5=1.1m. Z=170.6 cm3

chosen transverse is (180x10 mm)

For deck 5,

l_e=3.5m. h_5=1.75m. Z=686 cm3

chosen transverse is (200x11 T)

For deck 6,

l_e=2.8m. h_5=1.4m. Z=351.23 cm3

Chosen transverse is(240x11 mm)

For deck 7,

l_e=2.8m. h_5=1.4m. Z=351.23 cm3

Chosen transverse is (240x10x11 mm)

For deck 8,

l_e=2.8 h_5=1.4 Z=351.23 cm3

Chosen transverse is (240x11mm)

for deck 9,

l_e=3.5 m. h_5=1.75 m. Z=686 cm3

Chosen tranverse is(200x10x11 T)

A.4.4.5 Deck Transverses

–Deck 2

$Z=4.75k\ S\ l_e^2\ H_g$

l_e=7.5 m. H_g=2.0 m.(height of the deck)

Z=1710 cm^3 Chosen Transverse is (300x10x17 T)

–Deck 3

$Z=4.75b\ h\ l_e^2$

b=3.2 m. h=2.5m. l_e=7.5m.

Z=2308.5 cm^3

–Deck 4

$Z=4.75b\ h\ l_e^2$

l_e=13 m. b=3.2m. h=1.2 m.

Z=3082 cm^3 Chosen transverse is(400x15x20 T)

–Deck Transverses for superstructure

$Z=4.75\ k\ SHg\ le^2$

For deck 5,

l_e=4.5 m. H_g=1.2m S=3.2 m.

Z=369.36 cm^3 Chosen stiffener is (240x13 mm)

For Deck 6,

l_e=4.5 m. H_g=0.95m.

Z=292.02 cm^3 Chosen transverse is (200x11 mm)

For deck 7,

l_e=4.5 m. H_g=0.65 m.

Z=200.07 cm^3 Chosen transverse is (200x9 mm)

For deck 8 and 9,

l_e=4.5m. H_g=0.5 m.

Z=153.9 cm^3 Chosen transverse is (100x9)

A.4.4.6

–Bottom Shell and Bilge Plating

$t=0.001s(0.043L_1+10)$

t=12 mm.

–Deck 2

$t=0.012s(k)^{0.5}$

t=9 mm.

–Deck 3

$t=4.6\ (k)^{0.16}\ (A\ P_w)^{0.5}+1.5$

A=0.65 (load stress factor)

P_w=7.5 tonne (tyre load)

t=12 mm.

–Deck 4

$t=4.6\ (k)^{0.16}(A\ P_w)^{0.5}+1.5$

A=1.1 P_w=0.5 tonne t=7mm

–Superstructure Deck Plating

For first tier,

$t=7.5(k\ s/s_b)$

$s=700$ mm. $s_b=610$mm (standard stiffining spacing)

For second tier,

$t=7.0(k\ s/s_b)$

For third and upper tiers,

$t=6.5(k\ s/s_b)$

The estimated deck plating thicknesses are as follows.

deck 5	t=9 mm
deck 6	t=8 mm
deck 7	t=8 mm
deck 8	t=7 mm
deck 9	t=7 mm
deck 10	t=7 mm

–Side Shell Plating
For the shell above D/2 from base,

$t=0.001s(0.0059L_1+7)\ (F_D/k)$

$F_D=0.66\ (Z_{RD}/Z_D)$

t=10 mm

–Upper Turn of Bilge

$t=0.0059s\{d\ k/(2-F_B)\}$

$F_B=0.66\ (Z_{RB}/Z_B)$

t=11mm taken.

–Side Shell Plating at Superstructure

For the lowest tier,

$t=(5.0+0.01L_3)(k)$

$L_3=130$ m.

For the upper tiers,

$t=(4.0+0.01L_3)$ (not less than 5 mm)

The estimated thicknesses of side shell plating are as follows.

deck 5	t=7 mm
deck 6	t=7 mm
deck 7	t=6 mm
deck 8	t=6 mm
deck 9	t=6 mm
deck 10	t=6 mm

A.4.4.6 Actual Hull Inertia Calculation

item	dimension (m)	A (m^2)	Y(m)	A*Y	A*Y^2
1	0.009x13	0.117	21.8	2.5506	55.60
2	0.009x13	0.117	19.0	2.223	42.23
3	0.009x13	0.117	15.7	1.8135	28.109
4	0.01x13	0.13	13.5	1.755	23.69
5	0.013x12	0.156	8.5	1.326	11.271
6	0.09x7.5	0.067	4.5	0.303	1.363
7	0.01x7.5	0.075	1.25	0.093	0.116
8	0.012x13	0.156	0.006	0.009	0.0
9	0.007x8.5	0.059	4.25	0.252	1.071
10	0.012x8.5	0.102	4.25	0.403	1.840
11	0.012x5	0.06	11	0.66	7.26
12	0.011x2.2	0.0242	14.6	0.353	5.1538
13	0.01x3.3	0.033	17.35	0.572	9.924
14	0.01x2.8	0.028	20.6	0.5768	11.88
15	0.007x2.2	0.014	14.5	0.203	0.296
16	0.007x5	0.035	11	0.385	4.235
17	1.25x0.013	0.0162	0.65	0.010	0.0065
18	0.013x1.25	0.0162	0.65	0.010	0.0065
19	(0.015x0.3)x16	0.072	8.35	0.6012	5.02
20	(0.009x0.2)x16	0.0288	13.4	0.385	5.159
21	(0.008x0.2)x16	0.02304	15.6	0.359	5.606
22	(0.008x0.2)x16	0.02304	18.8	0.4331	8.142
23	(0.008x0.2)x16	0.02304	21.7	0.5	10.85
Total		1.3755		15.776	238.849

* The height of material, Y is taken from base line to centerline of material

APPENDIX 5

A.5.1 KG Calcululation of Ship

–The KG of Deck Plating

1	2	3	4	5	6
Deck No	area(m^2)	thick.($m10^{-3}$)	2x3	KG(m	4x5
1	1874	10	18.74	1.25	23.45
2	2605.9	9	23.45	4.5	105.52
3	2886.8	12	34.62	8.5	294.45
4	3485.0	9	31.4	13.5	423.45
5	3485.0	9	31.4	15.7	497.22
6	3315.0	8	26.5	19.0	503.9
7	3315.0	8	26.5	21.8	578.13
8	2640.0	7	18.48	24.6	454.6
9	2038.0	7	14.20	27.4	389.08
10	900.0	7	6.3	30.9	194.67
B.deck	285.0	7	1.99	33.7	67.23
			233.57		3531.7

KG of deck =(Σ6/Σ4)=15.12 meters

Total weight of deck plating is 1833.52 tones.

–The KG of Side Shell Plating

1	2	3	4	5	6
deck no	area(m2)	thick.(m10-3)	2x3	KG(m)	4x5
1	2083	12	24.99	0.75	18.74
2,3,4	3894.1	11	42.83	8.37	358.3
5	1022	7	7.15	17.25	123.4
6	856.8	7	5.99	20.4	122.5
7	823.3	6	4.93	23.2	114.6
8	750.4	6	4.50	26.0	117.6
9	679.5	6	4.07	29.15	118.4
B. deck	168	6	1.008	32.3	32.55
			95.48		10068

The KG of side shell plating=($\Sigma 6/\Sigma$ = 10.54 meters

The total weight of side shell plating is 749.5 tones.

–Bulkheads

1	2	3	4
location	weight(ton.)	KG(m)	2x3
deck 1,2	99.05	4.25	420.9
deck 3	54.9	11	603.9
deck 4	21.98	14.5	318.71
deck 5	44.25	17.25	763.31
deck 6	35.28	20.4	719.71
	255.46		2826.59

The KG of bulkheads is 11.06 meters.

–The KG of total steel weight

Considering the total steel weight estimation is carried out as follows.

1	2	3	4	5	6
item	weight(t.)	sup.(%)	tot. weight	KG	4x5
deck plat	1833.5	55%	2841.95	15.12	42970 3
shell plat.	749.53	50%	1124.3	10.54	11848.9
bulkheads	255.46	50%	383.19	11.06	4238.08
d.bottom	60	60%	96	0.65	62.4
tank boun.	70	60%	112	4.2	470.4
extra w.	477	----	477	13.06	6229.62
			5033		65819.72

The KG of total steel weight is 13.06 meters.

–The Final KG of The Ship

1	2	3	4
item	weight(tonne)	KG	2x3
steel	5033	13.06	65730.98
outfit	2600	17	44200
machinery	1100	4.5	4500
fuel oil	650	4.2	2730
fresh water	350	4.2	1470
pas.+crew	150	18	2700
stores	300	6	1800
life boats	270	26	7020
cargo(deck3)	220	14.3	3146
cargo(deck3)	2000	10.5	21000
	12732		154296.98

The KG of the ship=$\Sigma 4/\Sigma 2$

=12.118 meters

A.5.2 Deterministic Method

A.5.2.1 Calculation of Factor of Subdivision

- Criterion Numeral

$$C_s = 72\frac{M+2P}{V+P_1-P}$$

M= 11500 m^3 [Volume of machinery space]

P= 0 [Whole volume of the accomodation spaces below margin line]

P_1= 0.056L N

N= 800 [Number of passengers which the ship is to be certificated]

V= 19500 m^3 [Whole volume of vessel below margin line]

C_s=32.69

- Factor of Subdivision

$$F= 1- \frac{(1 - B)\,(C_s - S)}{123 - S}$$

$$S= \frac{3574 - 25L}{13} = 24.92$$

$$B= \frac{30.3}{L-42} + 0.18 = 0.524$$

L=130 m. [the length of the ship]

F=0.961

-The Permissible Length

L_p= L_f x F

L_p= Permissible compartment length

L_f= Floodable compartment length

A.5.2.2 The Results of Floodable length Calculations

FLOODABLE LENGTH

					COMPARTMENT				
PERM	DRAUGHT	TRIM	VCB	BMT	AFTBHD	FWDBHD	CENTRE	LENGTH	ADD VOL
	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS^3
0.850	7.900	1.000	4.694	8.673	-27.651	4.555	-11.547	32.206	5551.389
0.850	7.400	2.000	4.368	8.917	-31.514	-5.216	-18.365	26.297	4262.520
0.850	6.900	3.000	4.019	9.146	-41.155	-20.156	-30.656	20.998	3030.872
0.850	6.650	3.500	3.806	9.140	-50.911	-30.797	-40.854	20.114	2432.178
0.850	6.550	3.750	3.714	9.088	-57.036	-36.171	-46.604	20.865	2205.810
0.850	6.500	3.850	3.666	9.064	-60.906	-39.030	-49.968	21.875	2087.989
0.850	8.400	0.000	5.014	8.497	-25.643	12.665	-6.489	38.308	6910.671
0.850	7.900	-1.000	4.633	8.907	-17.331	13.958	-1.686	31.290	5289.396
0.850	7.400	-2.000	4.241	9.226	-4.767	18.964	7.098	23.732	3699.614
0.850	6.900	-3.000	3.816	9.519	17.002	35.305	26.154	18.302	2164.092
0.850	6.700	-3.400	3.636	9.891	32.947	58.782	45.865	25.834	1571.673

LOST BUOYANCY

PERM	DRAUGHT	TRIM	VCG	VCB	BMT	AFTBHD	FWDBHD	DBLEVEL	ADD VOL
	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS	MTRS^3
0.850	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
0.850	6.516	2.950	11.070	3.696	9.274	-50.000	-32.000	1.250	1951.105
0.850	6.578	2.402	11.070	3.742	9.349	-42.000	-25.000	1.250	2016.936
0.850	6.974	1.815	11.070	3.958	8.971	-32.000	-9.000	1.250	3019.090
0.850	7.567	0.349	11.070	4.245	8.483	-25.000	7.000	1.250	4480.828
0.850	7.235	-1.432	11.070	4.011	8.923	-9.000	16.000	1.250	3279.246
0.850	6.855	-2.101	11.970	3.776	9.338	7.000	25.000	1.250	2113.833
0.850	6.809	-2.713	11.070	3.722	9.445	16.000	34.000	1.250	1930.146
0.850	6.710	-2.955	11.070	3.648	9.643	25.000	44.000	1.250	1629.973
0.850	6.558	-2.770	11.070	3.566	9.973	34.000	56.000	1.250	1216.051

A.5.3 Probabilistic Method

· –The Required Subdivision Index

$$R = 1 - \frac{1000}{4\ L_S + N + 1500} \qquad \text{(in metres)}$$

L_S= 130 m (the length of ship)

$N = N_1 + 2\,N_2$

N_1= 750 (Number of persons for whom life boats are provided)

N_2= 200 (Number of persons including (offices and crew) that the ship is permitted to carry in excess of N_1.)

–GM:

In the final stage of flooding, there shall be a positive metecantric length, GM calculated by the constant displacement method and for the ship in upright position will be

$$GM = 0.003 * B_2 * \frac{(N_1 + N_2)}{\Delta * F_1}$$

or

GM = 2 inches (0.05m) wich ever is greater.

B_2 = 26 (beam of ship)

F_1 = mean freeboard

–Angle of Heel

Heel during the intermediate flooding, due either to negative metecantric height above or in combination with asymmetrical flooding heel shall not exceed 20 degrees. In the final state of flooding, heel shall not exceed 7° degrees. For the simultaneous flooding of two or more adjacent compartments, a heel of 12 degrees may be permitted

–Draft

Calculation are carried out for the operating rage of drafts between d_s and d_o which are the maximum and minumum operating drafts. If $(d_s - d_o)$ exceeds $0.1d_s$ damage stability calculation shall also be made for at least one additional draft apart from for d_s and d_o. Calculations were carried out for d_o(5 meters), d_{in}(5.5 meters), d_S(6 meters).

–Cross Flooding Arrangement in Asymmetrical Flooding

To complete the equilibrium from the angle at the final stage of flooding to upright position may take longer but it was considered that the time to attainment of those heel limits should not be more than 10 minutes.

5.4.2 Attained Subdivision Index 'A'

$A = \Sigma \, a \, p \, s$

a accounts for the probability of damage as related to the position of the compartment on the ship length

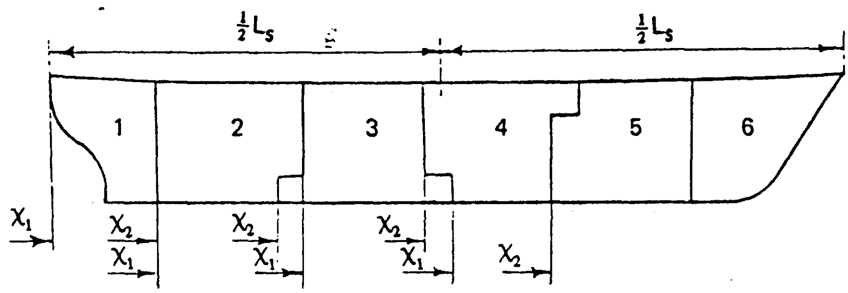
p : It evaluates the effect of the variation in longitudinal extent of damage on the probability that the compartment or group of compartments under consideration may be flooded.

s: It evaluates the effect of freeboard, stability and heel in the final flooded condition for the compartment or group of compartments under consideration.

Calculation of a

a is calculated by using the following formula

$$a = 0.4\left[\,1 + \xi_1 + \xi_2 + \xi_{12}\right] \qquad (7)$$



$\xi_1 = \frac{\kappa_1}{L_s}$

$\xi_2 = \frac{\kappa_2}{L_s}$ If κ_1 and κ_2 are equal to or less than 0.5 L_s otherwise ξ_1 and ξ_2 equal to 0.5

$\xi_{12} = \frac{\kappa_1 + \kappa_2}{L_s}$ (if ($\kappa_1 + \kappa_2$) is equal to or less than 0.5 L_s otherwise ξ_{12}=1)

κ_1: the distance from from the aft terminal of L_s to the aft end of the considered compartment or group of adjacent compartments

κ_2: the distance from the aft terminal of L_s to forward end of the considered compartment or group of adjacent compartments

Calculation of p

In general p is calculated by using the following formula

$$p = W\left[4.46 \left(\frac{1}{\lambda}\right)^2 - 6.20 \left(\frac{\lambda}{1}\right)^3 \right] \text{(for } \frac{1}{\lambda} \text{ equals to 0.24 or less)} \qquad (8)$$

Otherwise

$$p = W\left[1.072 \frac{1}{\lambda} - 0.086 \right] \qquad (9)$$

1 : length of compartment or group of compartments

W = 1.0 and λ=L_s for L_s= 655 feet (200 meters) or less

Otherwise

$$W = \frac{602.5}{L_s - 52.5} \quad \text{and } \lambda = 655 \text{ m (in feet)}$$

$$W = \frac{184}{L_s - 16} \quad \text{and } \lambda = 200 \text{ m (in meter)}$$

In order to evaluate 'p' for compartments taken singly, formula is applied directly. For the calculation of a group of compartments different way is followed.

For compartments taken by pairs p is

$$p = p_{12} - p_1 - p_2 \quad \text{or} \tag{10}$$

For compartments taken by group of three p is

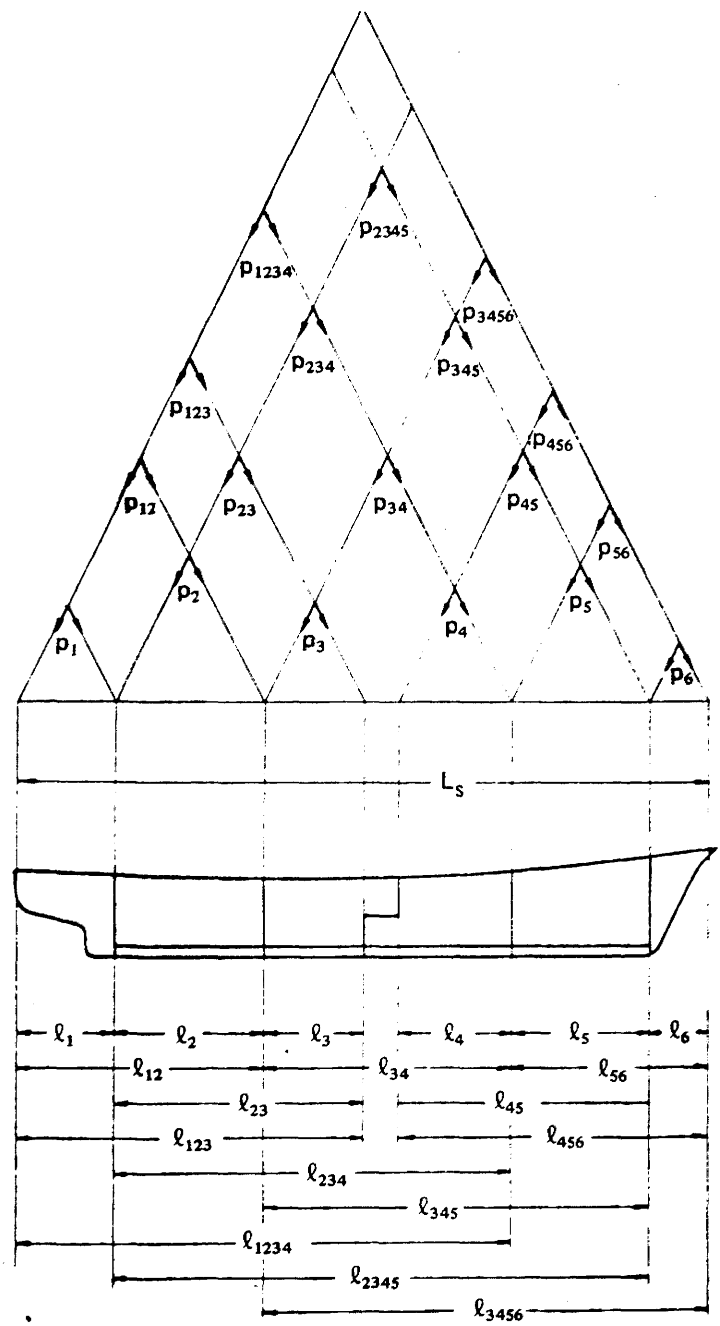
$$p = p_{123} - p_{12} - p_{23} + p_2 \tag{11}$$

or

$$p = p_{234} - p_{23} - p_{34} + p_3 \quad \text{etc.}$$

For compartments taken by groups of four

$$p = p_{1234} - p_{123} - p_{234} - p_{23} \quad \text{etc.} \tag{12}$$



p_{2345}
p_{1234}
p_{3456}
p_{234}
p_{345}
p_{123}
p_{456}
p_{12}
p_{23}
p_{34}
p_{45}
p_{56}
p_2
p_5
p_3
p_4
p_1
p_6
L_s
ℓ_1
ℓ_2
ℓ_3
ℓ_4
ℓ_5
ℓ_6
ℓ_{12}
ℓ_{34}
ℓ_{56}
ℓ_{23}
ℓ_{45}
ℓ_{123}
ℓ_{456}
ℓ_{234}
ℓ_{345}
ℓ_{1234}
ℓ_{2345}
ℓ_{3456}

This calculation is done for each group of compartment and final p value is found using one of the formulas 10,11,12 which were given before.

All those calculations about p are valid for symmetrical flooding. In the case of asymmetrical flooding these calculated p values are multiplied by reduction factor 'r' which is calculated as follows.

$$r = \frac{b}{B_1}\left[\frac{2.8 + 0.08}{(\frac{l}{L_s} + 0.02)}\right] \qquad (13)$$

(if b/B_1 is equal to or less than 0.2)

$$r = \frac{0.016}{(\frac{l}{L_s} + 0.02\ )} + \frac{b}{B_1} + 0.36 \qquad (14)$$

(if b/B_1 is greater than 0.2) where l/L_s is equal to more than 0.2 b/B_1.

Application of r is changeable depending on the flooding condition. If only the wing tank is flooded and inboard space is not flooded

$p' = p * r$ (15)

If wing tank at one side and inboard spare are flooded

$p' = p * (1 - r)$ (16)

Calculation of S

$$S_i = t\left[(\frac{F_1}{B_2} - \frac{\tan\theta}{2})\,(GM_R - MM_s)\right]^{1/2} \qquad (17)$$

t = 4.9 (when units are in meters)

t = 2.7 (when units are in feet)

However S_i can not exceed one; ($S_i \leq 1$)

θ : The angle of heel due to asymmetrical flooding in the final condition after cross flooding if any

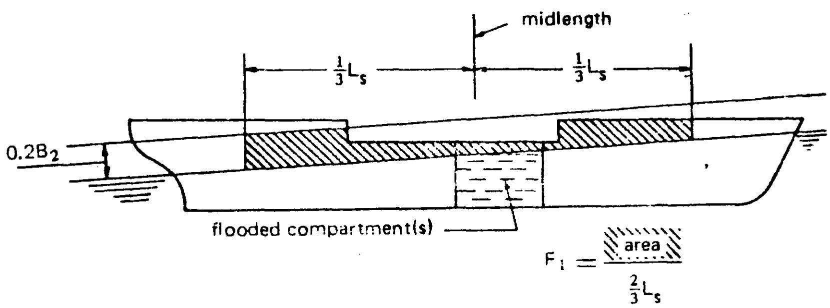
GM_R: The highest required intact metecantric height

MM'_S: The reduction in height of the metacentre as a result of flooding

S value is calculated for three initial drafts which are d_1, d_2, d_3 and final S value is obtained by using the following formula.

$$S = 0.45\ S_1 + 0.33\ S_2 + 0.22\ S_3 \qquad (18)$$

Mean Damage Freeboard (F_1)



Mean freeboard is mean distance from damaged waterline in the 2/3 of ship in the midship to relevant bulkhead deck in order to find the F_1 following formula can be used

$$F_1 = \frac{\text{Area}}{\frac{2}{3}L_s} \qquad (19)$$

Angle of Flooding (θ_f)

Angle of flooding θ_f is the angle of heel that stairways or other openings on the relevant bulkhead deck are immersed as shown in fig.1.10. This angle is needed because in any case F_1 can not be taken as more than $1/3 * B_2 * \tan \theta_f$. All calculations are in the following tables.

comp.	ξ_1	ξ_2	ξ_3	a	$\lambda/1$	P	F_{11}	F_{12}	F_{13}	θ_{f1}	θ_{f2}	θ_{f3}	GM_1	GM_2	GM_3	θ_1	θ_2	θ_3	S_1	S_2	S_3	S	ΣA
1	0	0.09	0.09	0.47	0.09	0.030	3.48	2.98	2.47	32.2	28.4	24.3	2.05	1.63	1.27	0	0	0	1	1	1	1	0.0141336
2	0.09	0.15	0.23	0.59	0.06	0.015	3.45	2.93	2.41	31.9	27.9	24.1	1.80	1.35	1.04	0	0	0	1	1	1	1	0.00905
3	0.15	0.20	0.35	0.68	0.06	0.015	3.38	2.86	2.34	31.2	27.5	23.5	1.63	1.24	0.98	0	0	0	1	1	1	1	0.01023
4	0.20	0.27	0.48	0.78	0.06	0.016	3.28	2.77	2.24	30.7	27.1	21.4	1.71	1.36	1.0	0.2	0.3	0.5	1	1	1	1	0.0124656
5	0.27	0.33	0.61	0.88	0.06	0.016	3.23	2.71	1.9	30.3	26.7	21.6	1.70	1.39	1.15	1.0	1.2	1.4	1	1	1	1	0.0140556
7	0.33	0.45	0.78	1.02	0.12	0.016	2.95	2.4	1.85	28.2	24.1	18.6	1.23	1.01	0.83	2.0	2.0	2.0	1	1	1	1	0.0170
7	0.45	0.5	1.0	1.18	0.12	0.016	2.87	2.32	1.80	27.7	23.3	24.2	1.03	0.88	0.38	2.0	2.0	2.0	1	1	0.9	0.87	0.022
8	0.5	0.5	1.0	1.20	0.07	0.018	3.11	2.58	2.05	29.7	25.2	20.6	1.5	1.26	1.10	1.5	2.0	2.3	1	1	1	1	0.02112
9	0.5	0.5	1.0	1.2	0.07	0.018	3.12	2.59	2.06	29.7	25.4	20.7	1.58	1.30	1.09	1.0	1.2	1.3	1	1	1	1	0.02112
10	0.5	0.5	1.0	1.2	0.07	0.018	3.27	2.64	2.11	30.0	26.0	21.4	1.78	1.41	1.18	0.2	0.3	0.4	1	1	1	1	0.02112
11	0.5	0.5	1.0	1.2	0.07	0.024	3.24	2.71	2.18	30.5	27.2	21.8	1.92	1.54	1.29	0.1	0.1	0.2	1	1	1	1	0.0288
12	0.5	0.5	1.0	1.2	0.09	0.030	3.36	2.83	2.31	31.5	27.5	23.2	1.95	1.56	1.30	0.0	0.0	0.0	1	1	1	1	0.03624
13	0.5	0.5	1.0	1.2	0.07	0.024	3.46	2.95	2.45	32.0	28.2	24.2	2.01	1.64	1.36	0.0	0.0	0.0	1	1	1	1	0.0288
1+2	0.0	0.15	0.15	0.51	0.15	0.048	3.42	2.89	2.35	31.6	27.6	22.8	1.79	1.25	0.84	0.0	0.0	0.0	1	1	1	1	0.024844
2+3	0.09	0.20	0.30	0.63	0.12	0.021	3.27	2.72	2.17	30.5	26.8	21.6	1.4	1.0	0.68	0.0	0.0	0.0	1	1	1	1	0.0133308
3+4	0.15	0.27	0.43	0.73	0.13	0.030	3.12	2.57	2.02	29.7	25.2	20.1	1.28	0.96	0.68	0.4	0.6	0.8	1	1	1	1	0.0214641
4+5	0.20	0.33	0.53	0.83	0,12	0.025	2.97	2.43	1.87	28.7	24.2	19.7	1.31	1.01	0.78	1.5	1.7	2.0	1	1	1	1	0.020865
5+6	0.27	0.45	0.72	0.98	0.17	0.033	2.62	2.04	1.45	25.2	20.1	14.8	0.87	0.65	0.51	4.0	4.0	4.0	1	0.8	0.5	0.83	0.026
6+7	0.33	0.56	0.90	1.11	0.23	0.062	2.17	1.55	0.93	21.3	15.8	9.7	0.36	0.33	0.37	4.0	4.0	4.0	0.64	0.4	0.1	0.45	0.03123
7+8	0.45	0.50	1.0	1.16	0.18	0.042	2.43	1.84	1.65	24.2	18.6	13.0	0.55	0.54	0.57	4.0	4.0	4.0	0.87	0.68	0.6	0.75	0.0360

comp.	ξ_1	ξ_2	ξ_3	a	$\lambda/1$	P	F_{11}	F_{12}	F_{13}	θ_{f1}	θ_{f2}	θ_{f3}	GM	GM	GM_3	θ_1	θ_2	θ_3	s_1	s_2	s_3	S	Σ A
8+9	0.5	0.5	1.0	1.2	0.13	0.028	2.67	2.12	1.55	26.8	21.6	18.6	1.06	0.90	0.87	3.9	4.0	4.1	1	1	0.71	0.94	0.031095
9+10	0.5	0.5	1.0	1.2	0.14	0.028	2.72	2.15	1.60	27.4	21.3	19.0	1.23	0.98	0.92	1.6	1.9	2.2	1	1	1	1	0.03336
10+11	0.5	0.5	1.0	1.2	0.14	0.027	2.84	2.28	1.71	27.9	22.7	19.2	1.52	1.19	1.0	0.5	0.6	0.7	1	1	1	1	0.03288
11+12	0.5	0.5	1.0	1.2	0.16	0.035	3.02	2.46	1.89	29.5	24.4	20.0	1.86	1.45	1.20	0.14	0.18	0.15	1	1	1	1	0.04176
12+13	0.5	0.5	1.0	1.2	0.16	0.035	3.28	2.74	2.21	30.6	26.8	21.3	2.13	1.72	1.49	0.0	0.0	0.0	1	1	1	1	0.04176
1+2+3	0	0.2	0.2	0.57	0.21	0.08	3.22	2.65	2.07	30.0	25.3	23.5	1.25	0.71	0.30	0.0	0.0	0.0	1	1	0.76	0.96	0.0429649
2+3+4	0.1	0.27	0.36	0.69	0.18	0.11	3.0	2.40	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
3+4+5	0.15	0.33	0.33	0.48	0.78	0.18	2.80	2.21	L.T	*	*	*	*	*	*	*	*	*	*	*	*	*	**
4+5+6	0.2	0.45	0.65	0.92	0.24	0.13	2.27	L.T	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
5+6+7	0.27	0.5	0.77	1.02	0.28	0.19	1.71	1.06	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
6+7+8	0.33	0.5	0.83	1.06	0.30	0.18	1.61	0.96	L.T	*	*	*	*	*	*	*	*	*	*	*	*	*	**
7+8+9	0.45	0.5	1.0	1.18	0.26	0.14	1.92	L.T.	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
8+9+10	0.5	0.5	1.0	1.2	0.20	0.09	2.3	L.T.	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
9+10+11	0.5	0.5	1.0	1.2	0.20	0.09	2.4	L.T	L.T	*	*	*	*	*	*	*	*	*	*	*	*	*	**
0+11+12	0.5	0.5	1.0	1.2	0.22	0.12	2.6	L.T.	L.T.	*	*	*	*	*	*	*	*	*	*	*	*	*	**
1+12+13	0.5	0.5	1.0	1.2	0.24	0.12	2.9	2.35	1.75	28.6	24.1	19.1	1.87	1.42	1.19	0.13	0.18	0.16	1	1	1	1	0.150

Σ A=0.803

APPENDIX 6

A.6.1 Capital Cost

- Steel Labour Cost, Csl

$$C_{sl} = \frac{A' W_s^{2/3} L^{1/3}}{C_b} \quad £$$

A'= Steel labour wage factor, it is taken as £2400 for 1986.

Ws= Steel weight,5200 tonnes

L= Length of ship, 130 meters

CB= Block coefficient, o.63

- Outfit Labour Cost, Col

Col=C' Wo2/3 £

C'= Outfit labour wage factor, it is taken as £2800 for 1986.

Wo= Outfit weight, 2900 tonnes

- Machinery Labour Cost, CMl

CMl=F' P0.82 £

F'= Machinery labour wage factor, it is taken as £1100 for 1986.

P= Full power of ship, 24600 BHP

- The Material Cost Of Steel, Csm

Csm=B' Ws

B'= Material cost, 270 £/per tonne

- The Material Cost Of Outfit, Com

Com= D' Wo0.95 £

D'= Outfit Material cost, 4800 £/per tonne

-The Material Cost Of Machinery, CMm

CMm= G' P0.82 £

G'= Outfit material cost, it is taken as 2350 £/per hp

- Shaft And Propellers

Controllable pitch propellers are more expensive than fixed pitch propellers therefore a cost addition must be made.

Cp= 66000 Qo0.5 £

Qo=(0.72 P/N)

N= RPM of propeller, 240

- Thrusters, CT

CT= £ 100000 + 73500 T £

T= Thrust in tonne, 6 tonnes

- Stabilizers, CST

CST= £695 Δ3/4 £

Δ= Displacement in tonnes, 12732 tones

A6.2 Operating Cost

- Crew Cost

4200 £/per year for Officers

3600 £/per year for Petty Officers

3000 £/per year for Ratings

- Capital Recovery Cost, CR

CR=(Cs-Fv) A1+ P i   £

A1= i/((1+i)Nl-1)

Fv= Salvage value of ship it is taken as £5 million.

Cs= Capital cost of ship, £33.6 millions

Nl= Service life of ship, 15 years

i= Interest, it is taken in range between 10% and 15%

- Maintenance And Repair, M&R

M&R=f3 (LBD)0.685+f4 P + f5 P0.6+ K1   £

Typical 1986 values for the coefficients

f3= £8.67 (for dimensions in feet)

f4=£5.13

f5=£81.22 for slow or medium speed diesels

K1= £17100 for single screw

B= Breadth of ship, 26 metres

Dupper=The depth of uppermost continues deck, 15.5 meters

- Hull and Machinery Insurance, H&M

H&M=0.0125 Cs £

- Protection And Indemnity Insurance, P&I

P&I= f6 (LBD) + f7 Nc   £

f6=£0.33   for 1986

f7=£1717   for 1986

Nc= Number of Crew, 150

- Stores And Supplies, S&S

S&S=Co Nc £

Co= cost factor, it is taken as £2852.2 for 1986

- Administration Cost, Cad

Cad= 2210 Nc+0.01 Cs £

- Port Entry And Exit Cost, PE

PE= Ki el (GRT) 0.685 £/call

l=Labour ratio in trade area, it is taken as o,33 for Italy.

Ki= Port entry and exit cost constant, it is taken as £19.17

-Daily Cost In Port, PD

PD= 34+ KJ L0.5 (GRT)0.67 £/day

KJ=daily cost constant £2.55

- Fuel Oil Cost At Sea,CF

Fuel oil consumption at sea

FC=∂ BHPser 24/106 tonnes/day

∂= specific fuel consumption, 142 gr/hp-hr

The price of per tone heavy fuel oil is taken as £55

-Diesel Oil Cost For Auxiliary Engine at Sea,CDA

diesel oil consumption for auxiliary engine

FDC= ∂ BHPaux (24/106) (0.5/0.9) tonnes/day

∂= 143 gr/hp-hr

BHPaux=4240 hp

The price of per tonne heavy fuel oil is taken as £55

-Diesel Oil Cost At Port,CDP

Diesel oil consumption at port

$DC= \partial$ BHPaux (0.75/0.9) (24/106) tonnes/day

- Cylinder Lubrication Oil Cost

lub. oil consumption

CLC=0.37 BHPser 0.9 (24/106) tonnes/day

£350 is taken for per tonne lub. oil

- System Lub. oil Cost

lub. oil consumption

SLC=0.26 BHPaux 0.9 (24/106) tonnes/day

A.6.2 Computer Program For Economical Analysis

```
      PROGRAM COST
C     THIS PROGRAM CALCULATES THE CAPITAL AND OPERATING COST
C     ALL INPUT DATA IS FOR 1986
C     THE MEANING OF INPUT DATA IS AS FALLOWS
C     AI:FACTOR OF LABOUR COST FOR STEEL
C     BI:FACTOR FOR MATERIAL COST
C     CI:FACTOR FOR OUTFIT LABOUR COST
C     DI:FACTOR FOR OUTFIT MATERIAL COST
C     FI:FACTOR FOR MACHINERY LABOUR COST
C     GI:FACTOR FOR MACHINERY MATERIAL COST
C     L:LENGTH OF SHIP
C     B:BREADTH OF SHIP (M)
C     DR:DRAUGHT OF SHIP (M)
C     CB:BLOCK COEFFICIENT OF SHIP
C     WS:
C     WS:STEELWEIGHT OF SHIP (TONNES)
C     WO:OUTFITWEIGHT OF SHIP (TONNES)
C     P:MAXIMUM POWER OF SHIP (HP)
C     T:THRUST OF BOW THRUSTERS (TONNES)
C     RN:PROPELLER RPM
C     YI:INTEREST FOR PER YEAR
C     N:THE LIFE OF SHIP (YEAR)
C     F:SALVAGE VALUE OF SHIP
C     FA:FACTOR FOR HULL
C     FB:FACTOR FOR MACHINERY
C     FC:FACTOR FOR MACHINERY
C     PK:REPAIR COST OF PROPELLER
C     FD:FACTOR FOR PROTECTION INSURANCE
C     FE:FACTOR FOR PROTECTION INSURANCE
C     NC:NUMBER OF CREW
C     COS:CONSTANT FOR STORES AND SUPPLIES
C     COM:CONSTANT FOR MISCELLANOUS COST
C     OI:CONSTANT FOR EXIT AND ENTER COST TO PORT
C     TL:LABOUR RATIO IN TRADE AREA
C     GRT:GROSSTONNAGE OF SHIP
C     OJ:CONSTANT FOR PORT COST
C     SBHP:SERVICE HORSEPOWER
C     SDS:TOTAL CRUISE DAYS AT SEA IN A YEAR
C     PPT:RATE OF HEAVY FUELOIL FOR PER TONNE
C     PL:RATE OF CYLINDER LUBOIL FOR PER TONNE
C     BHPAUX:TOTAL POWER OF AUX.ENGINES
C     SPL:RATE OF CYLINDER LUBOIL FOR PER TONNE
C     DP:TOTAL DAYS IN PORT IN A YEAR
C     OF:ANNUAL PAYMENT FOR  PER OFFICER
C     POF:ANNUAL PAYMENT FOR PER PETTY OFFICER
C     RAT:ANNUAL PAYMENT FOR PER RATING
C     NOF:NUMBER OF OFFICERS
C     NPOF:NUMBER OF PETTY OFFICERS
C     NRAT:NUMBER OF RATINGS
C     NC:TOTAL NUMBER OF CREW
C     EPP:COST OF PROVISION FOR PER PERSON/DAY
C     COE:COST OF ENTERTAINMENT
      DIMENSION SBHP(7)
      REAL MIL
      READ(5,*) AI,BI,CI,DI,FI,GI,L,B,DR,CB,DH,T,WS,WO,P,RN,YI,N,F,
     1 FA,FB,FC,PK,FD,FE,NC,COS,SSM,OI,TL,GRT,OJ,PPT,
     2PL,BHPAUX,SPL,OF,POF,RAT,NOF,NPOF,NRAT,NC,EPP,COE,V0,MIL
     3,(SBHP(I),I=1,7)
C*****CALCULATE THE CAPITAL COST OF SHIP
      I=1
      CSL=(AI*WS**(2./3.))*(L**(1./3.)/CB)
      CSM=BI*WS
```

```
      COL=CI*WO**(2./3.)
      COM=DI*WO**(0.95)
      CML=FI*P**0.82
      CMM=GI*P**0.82
      Q=0.728*P/RN
      CP=66700.*Q**0.5
      CT=100000.+73500.*T
      DISP=L*B*DR*CB*1.025
      CST=695.*DISP**(3./4.)
      CS=(CSL+CSM+COL+COM+CML+CMM+CP+CT+CST)*1.0E-6
C*****CALCULATE THE CAPITAL RECOVERY COST
      V=V0
  200 CONTINUE
      AF=YI/((1.+YI)**N-1.)
      BF=F*1.0E-6
      CR=((CS-BF)*AF+CS*YI)
C*****CALCULATE THE COST OF MAINTENANCE AND REPAIR
      CMR=1.0E-6*(FA*((L*B*DH)/(0.3048)**3)**0.685+FB*P+FC*P**0.6+PK)
C*****HULL AND MACHINARY IINSURANCE
      CHM=0.012*CS
C*****PROTECTION AND INDEMNITY INSURANCE
      CPI=(FD*(L*B*DH)+FE*NC)*1.0E-6
      TCIN=CHM+CPI
C*****STORES AND SUPPLIES
      CSC=COS*NC*1.0E-6
C*****MISCELLANEOUS COST
      CMISC=SSM*NC*1.0E-6
C*****PORT CHARGES AND DUES
      CPE=OI*EXP(TL)*GRT*0.585
      CPD=34.+OJ*TL**0.5*GRT**0.67
      TCED=(CPE+CPD)*1.0E-6
C*****OIL CONSUMED
  210 CONTINUE
      SDS=MIL/(24.0*V)*96.0
      SPC=143.
      FUC=SPC*SBHP(I)*24./1.0E+6
      AFC=SDS*FUC
      CAFC=AFC*PPT
      ASPC=144.
      AXFC=ASPC*BHPAUX*(2.4/1.0E+6)*(0.5/0.9)
      AAXFC=AXFC*SDS
      CAAXFC=AAXFC*PPT
C*****CYLINDER LUBOIL CONSUMPTION AND COST
      SLP=0.37
      clc=SLP*SBHP(I)*0.90*24./1.0E+6
      ACLC=CLC*SDS
      CACLC=ACLC*PL
C*****SYSTEM LUBOIL CONSUMPTION AND COST
      SSP=0.26
      SLC=SSP*SBHP(I)*0.9*24./1.0E+6
      ASLC=SLC*SDS
      CASLC=ASLC*SPL
C*****FUEL CONSUMPTION AND COST AT PORT
      DP=366.-(28.+SDS)
      OCP=0.30*FC
      AOCP=OCP*DP
      CAOCP=AOCP*PPT
      AXOCP=ASPC*BHPAUX*(0.75/0.9)*(24./1.0E+6)
      AAXOCP=AXOCP*DP
      CXOCP=AAXOCP*PPT
      CTOC=1.0E-6*(CAFC+CAAXFC+CACLC+CASLC+CAOCP+CXOCP)
C*****CREW COST
```

```
      CAC=(NOF*OF+NPOF*POF+NRAT*RAT)*2.*1.0E-6
      COP=EPP*NC*365*1.0E-06
      CAC=CAC+COP
C*****ADMINISTRATION COST
      CA=0.012*CS
C*****ENTERTAINMENT
      ENT=COE*1.0E-6
C*****TOTAL ANNUAL OPERATING COST OF SHIP
      TACS=CR+CMR+CHM+CPI+CSC+CMISC+TCED+CTOC+CAC+CA+ENT
      WRITE(6,10)
      WRITE(6,15) V,100.0*YI
      WRITE(6,20) CS
      WRITE(6,30)
      WRITE(6,40) CR
      WRITE(6,50) CMR
      WRITE(6,60) CHM
      WRITE(6,70) CPI
      WRITE(6,80) CSC
      WRITE(6,90) CMISC
      WRITE(6,100) TCED
      WRITE(6,110) CTOC
      WRITE(6,120) CAC
      WRITE(6,130) CA
      WRITE(6,150) ENT
      WRITE(6,160)
      WRITE(6,170) TACS
      V=V+1
      I=I+1
      IF(V.LE.21.0) GO TO 210
      I=1
      V=V0
      YI=YI+0.01
      IF(YI.LE.0.15) GO TO 200
   10 FORMAT(3X,'CAPITAL AND OPERATING COST OF SHIP'/)
   15 FORMAT(3X,'SPEED=',F4.1,1X,'KNOTS',4X,'INTEREST=',F4.1,'%')
   20 FORMAT(3X,'CAPITAL COST',10X,'=',F5.2,'E06')
   30 FORMAT(3X,22('-'))
   40 FORMAT(3X,'CAPITAL RECOVERY COST',1X,'=',F6.3,'E06 £/year')
   50 FORMAT(3X,'MAINT.AND REP.COST',4X,'=',F5.2,'E06 £/year')
   60 FORMAT(3X,'HULL AND MACH.INSUR.',2X,'=',F5.2,'E06 £/year')
   70 FORMAT(3X,'PROTEC.AND INDEM.INSUR','=',F5.2,'E06 £/year')
   80 FORMAT(3X,'STOR.AND SUPP.COST',4X,'=',F5.2,'E06 £/year')
   90 FORMAT(3X,'MISCL.COST',12X,'=',F5.2,'E06 £/year')
  100 FORMAT(3X,'PORT CHARG.AND DUES',3X,'=',F5.2,'E06 £/year')
  110 FORMAT(3X,'OIL COST',14X,'=',F6.3,'E06 £/year')
  120 FORMAT(3X,'CREW COST',13X,'=',F6.3,'E06 £/year')
  130 FORMAT(3X,'ADMINISTRATION COST',3X,'=',F5.2,'E06 £/year')
  150 FORMAT(3X,'ENTERTAINMENT COST',4X,'=',F5.2,'E06 £/year')
  160 FORMAT(3X,22('-'))
  170 FORMAT(3X,'ANNUAL OPER.COST',6X,'=',F8.4,'E06 £/year')
      STOP
      END
```

A.7.1 Computer Program For Structural Deck Design

```
      PROGRAM DEKDSNG
      DIMENSION A(1000),MN(20),XX(200),T(200),E(10)
      COMMON/BIR/A,MN
      COMMON/ES/ E
      CHARACTER*7 GIRDER
      REAL LS,LP,LNC,LNT,LNT1,LG,MM
      READ(26,*) NX,XMN,XINT
      NX1=NX*6
      READ(26,*) (XX(I),T(I),I=1,NX1)
      WRITE(6,'(A)') 'ENTER HB, P,GH,XMIN,XI,NS'
      READ(5,*) HB,P,GH,XMIN,XI,NS
      WRITE(6,'(A)')'ENTER G :1,IF THERE IS L.B.HEAD,REST :0'
      READ(5,*) G
      WRITE(6,'(A)') 'ENTER AK,H1,H2,N,LNT1,NP'
      READ(5,*) AK,H1,H2,N,LNT1,NP
      WRITE(6,'(A)') 'ENTER GIRDER YES OR NO'
      READ(5,*) GIRDER
      WRITE(6,'(A)') 'ENTER NXPR,V'
      READ(5,*) NXPR,V
      WRITE(6,'(A)') 'ENTER PRIMEM,0 OR 1 OR 2'
      READ(5,*) PRIMEM
      WRITE(6,'(A)') 'ENTER SYSTEM,LONG=0,TRAN=1'
      READ(5,*) SYSTEM
      WRITE(6,'(A)') 'ENTER E(1),E(2),E(3)'
      READ(5,*) E(1),E(2),E(3)
      CALL CURVF
    5 X=XMIN
      WRITE(6,'(A)') 'ENTER S,LNC'
      READ(5,*) S,LNC
      IF(SYSTEM.EQ.0) THEN
      WRITE(16,100)
      WRITE(15,105)
      ELSE
      WRITE(16,110)
      WRITE(15,115)
      END IF
      WRITE(16,120) S
      WRITE(15,125) S
      WRITE(16,130)
      WRITE(15,135)
      WRITE(16,140)
      WRITE(15,145)
   10 SA=0.0
      T1=0.0
      T2=0.0
      DO 20 IN=1,N
      WRITE(6,'(A)') 'ENTER LS,LNT'
      READ(5,*) LS,LNT
      LNT2=LNT
      XK=V/S
      IF(XK.LE.(.5*(XX(1)+XX(2)))) THEN
      XK=XX(1)
      ELSE IF(XK.GE.(0.5*(XX(NX-1)+XX(NX)))) THEN
      XK=XX(NX)
      ELSE
      I=2
   15 XR=0.5*(XX(I)+XX(I+1))
      XL=0.5*(XX(I-1)+XX(I))
      IF(XK.GE.XL.AND.XK.LT.XR) THEN
      XK=XX(I)
      ELSE
      I=I+1
```

```
      GO TO 15
      END IF
      END IF
      NNX=NINT((XK-XMN)/XINT)+1
      NNX=NNX+(NXPR-1)*NX
      TX=T(NNX)
      NTX=INT(TX)
      DF=T(NNX)-FLOAT(NTX)
      IF(DF.LE.0.4) THEN
      TX=FLOAT(NTX)+.5
      ELSE
      TX=FLOAT(NTX)+1.0
      END IF
      CALL STIF(S,P,GH,X,AK,H1,H2,TX,NS,N,LP,LS,LNC,LNT,C,D
     1,LNT1,PA,PRIMEM,SYSTEM)
      PA=LNC*LNT2
      T1=T1+C
      IF(PRIMEM.EQ.0) D=0
      T2=T2+D
      SA=SA+PA
   20 CONTINUE
      VP=SA*TX*1.0E-3
      WP=VP*7.85
      WTS=T1+T2
      TWD=WTS+WP
      STWD=TWD*4
      IF(GIRDER.EQ.'YES') THEN
      B=LNT1
      H=H1
      CALL GIR(B,GH,LNC,TX,BF,TW,LP,H,TF,SM,Z,WG,NP,LS,LG,LNT1
     1,SYSTEM)
      IF(G.EQ.1) GO TO 25
      TNG=HB/LNT1
      NTNG=INT(TNG)
      DFG=TNG-NTNG
      TOG=NTNG-1
      IF(DFG.GE.(.2*LNT1)) TOG=NTNG
      WG=(2*TOG+1)*WG
   25 STWD=STWD+WG
      ELSE
      END IF
      IF(GIRDER.EQ.'NO') GO TO 30
      WRITE(16,150) X,LG,Z,SM,LP,H,BF,TX,TW,TF
   30 CONTINUE
      IF(GIRDER.EQ.'NO') THEN
      WRITE(15,155) X,WTS,WP,STWD
      ELSE
      WRITE(15,160)X,WTS,WP,WG,STWD
      END IF
      X=X+XI
      IF(X.LE.(0.5+.5*XI)) GO TO 10
      WRITE(6,'(A)')'ENTER K  WRITE 1 IF S HAS DIF. VALUE'
      READ(5,*) K
      IF(K.EQ.1) GO TO 5
      STOP
  100 FORMAT(40X,'LONGITUDINAL SYSTEM')
  110 FORMAT(41X,'TRANSVERSE SYSTEM')
  120 FORMAT(40X,'S=',F5.1)
  130 FORMAT(3X,'V/S',3X,'N.OF.MEM.',3X,'EF.LE.',3X,'Z(CU.CM)',3X
     1,'SM(CU.CM)',3X,'LP(MM)',3X,'H(MM)',3X,'BF(MM)',3X,'TX(MM)',3X
     1,'TW(MM)',3X,'TF(MM)')
  140 FORMAT(3X,3('-'),3X,9('-'),3X,6('-'),3X,8('-'),3X,9('-'),3X
```

```
     1,6('-'),3X,5('-'),3X,6('-'),3X,6('-'),3X,6('-'),3X,6('-'))
 150 FORMAT(3X,F3.1,4X,'GIRDER ',4X,F4.2,4X,F8.2,3X,F9.3,3X,F6.1
     1,3X,F5.1,3X,F6.1,3X,F6.2,3X,F6.2,3X,F6.2)
 105 FORMAT(25X,'LONGITUDINAL SYSTEM')
 115 FORMAT(26X,'TRANSVERSE SYSTEM')
 125 FORMAT(25X,'S=',F5.1)
 135 FORMAT(4X,'V/S',5X,'WTS(TONNE)',5X,'WP(TONNE)',5X
     1,'WG(TONNE)',5X,'STWD(TONNE)')
 145 FORMAT(4X,3('-'),5X,10('-'),5X,9('-'),5X,9('-'),5X,11('-'))
 155 FORMAT(4X,F3.1,8X,F6.2,8X,F6.2,24X,F7.2)
 160 FORMAT(4X,F3.1,8X,F6.2,8X,F6.2,8X,F6.2,8X,F7.2)
     END
     SUBROUTINE STIF(S,P,GH,X,AK,H1,H2,TX,NS,N,LP,LS,LNC,LNT
    1,TWL,TWT,LNT1,PA,PRIMEM,SYSTEM)
     REAL LP,LS,LNC,LNT,LNT1,MM
     DIMENSION A(1000),MN(20),E(10),MX(50),VN(10)
     COMMON/BIR/A,MN
     COMMON/ES/E
     NFIRST=1
     DO 40 NPR=1,NS
     SK1=0
     SK2=0
     DO 50 I=1,MN(NPR)
  50 SK1=SK1+A(NFIRST-1+I)*X**(I-1)
     NSCND=NFIRST+MN(NPR)
     DO 60 I=1,MN(NPR+1)
  60 SK2=SK2+A(NSCND-1+I)*X**(I-1)
     Z=(.536*SK1*P*LS+.00125*SK2*GH*S*LS**2)*AK
     IF((NPR+1).EQ.NS) GO TO 80
  40 CONTINUE
  80 CONTINUE
     O=1
     R=34
     H=H1
  90 TW=H/R
     LP=40*TX
     A1=LP*TX
     IF(LP.LT.600) LP=600
 100 A2=H*TW
     A3=TW*H/1.5
     BF=SQRT(A3/.1)
     TF=.1*SQRT(A3/.1)
     AS=A2+A3
     AT=A1+A2+A3
     Y=(A1*(TF+H+TX/2)+A2*(TF+H/2)+A3*(TF/2))/AT
     SI1=(LP*TX**3)/12+A1*(Y-(TF+H+TX/2))**2
     SI2=(TW*H**3)/12+A2*(Y-(TF+H/2))**2
     SI3=(BF*TF**3)/12+A3*(Y-TF/2)**2
     SIT=SI1+SI2+SI3
     SM=(SIT/Y)*1.0E-3
     DZ=SM-Z
     IF(SYSTEM.EQ.0.AND.O.EQ.1.0.AND.SM.LE.Z) THEN
     H=1.05*H
     ELSE IF(SYSTEM.EQ.0.AND.O.EQ.1.0.AND.DZ.GT.(.15*Z)) THEN
     H=.95*H
     ELSE IF(SYSTEM.EQ.0.AND.O.EQ.1.0) THEN
     GO TO 105
     ELSE
     GO TO 103
     END IF
     GO TO 90
 103 CONTINUE
```

```
      ELSE
      TNT=LNT/B
      END IF
      NTNT=INT(TNT)
      DFT=TNT-NTNT
      NOP=NTNT-1
      IF(DFT.GE.(.2*B)) NOP=NTNT
      VT=AS*LNT*1.0E-6
      WT=VT*7.85
      TWT=WT*NOP
      WRITE(16,220)X,LNT,Z,SM,LP,H,BF,TX,TW,TF
  200 FORMAT(3X,F3.1,4X,'LONGITU',4X,F4.2,4X,F8.2,3X,F9.3,3X,F6.1
     1,3X,F5.1,3X,F6.1,3X,F6.2,3X,F6.2,3X,F6.2)
  210 FORMAT(3X,F3.1,4X,'BEAM   ',4X,F4.2,4X,F8.2,3X,F9.3,3X,F6.1
     1,3X,F5.1,3X,F6.1,3X,F6.2,3X,F6.2,3X,F6.2)
  220 FORMAT(3X,F3.1,4X,'TRANSV.',4X,F4.2,4X,F8.2,3X,F9.3,3X,F6.1
     1,3X,F5.1,3X,F6.1,3X,F6.2,3X,F6.2,3X,F6.2)
  500 RETURN
      END
      SUBROUTINE GIR(B,GH,LNC,TX,BF,TW,LP,H,TF,SM,Z,WG,NP
     1,LS,LG,LNT1,SYSTEM)
      REAL LS,LP,LNC,LNT,LG,LNT1
      B=LNT1
      LG=LNC/(NP+1)
      IF (SYSTEM.EQ.0.0) THEN
      SO=LG/LS
      NSO=INT(SO)+1
      LG=LS*NSO
      ELSE
      END IF
      Z=4.75*B*GH*LG**2
      F=.3*(LG/B)**(2./3.)
      A1=10*F*B*TX
      LP=(A1*1.0E2)/TX
      TW=.02*H
      IF(TW.LT.7.0) TW=7.0
  100 A2=H*TW
      A3=TW*H/1.5
      BF=SQRT(A3/.1)
      TF=.1*SQRT(A3/.1)
      AS=A2+A3
      AT=A1+A2+A3
      Y=(A1*(TF+H+TX/2)+A2*(TF+H/2)+A3*(TF/2))/AT
      SI1=(LP*TX**3)/12+A1*(Y-(TF+H+TX/2))**2
      SI2=(TW*H**3)/12+A2*(Y-(TF+H/2))**2
      SI3=(BF*TF**3)/12+A3*(Y-TF/2)**2
      SIT=SI1+SI2+SI3
      SM=(SIT/Y)*1.0E-3
      DZ=SM-Z
      IF(SM.LE.Z)THEN
      H=1.05*H
      TW=MAX(TW,0.02*H)
      GO TO 100
      ELSE IF(DZ.GT.(Z/10)) THEN
      H=.95*H
      GO TO 100
      ELSE
      END IF
      VG=AS*LNC*1.0E-6
      WG=VG*7.85*2
      RETURN
      END
```

```
      SUBROUTINE STRESS (F,MM,LNT)
      DIMENSION E(10),MX(50),VN(10)
      COMMON/ES/ E
      REAL LNT,MA,MM,MC,MX
      PL=LNT/E(2)
      NI=INT(PL)
      NI=NI*2+2
      IN=1
      SN=0
      RA=0
      MA=0
      DO 25 NT=1,NI
      SN=SN+E(IN)
      RA=F*((LNT-SN)**2/LNT**3)*(3*SN+(LNT-SN))+RA
      MA=F*SN*((LNT-SN)**2/LNT**2)+MA
      IN=IN+1
      IF(IN.GT.3) IN=IN-2
      IF((LNT-SN).LT.(E(IN))) GO TO  30
   25 CONTINUE
   30 CONTINUE
      IN=1
      SN=0
      RC=0
      MC=0
      DO 35 NT=1,NI
      SN=SN+E(IN)
      RC=F*(SN**2/LNT**3)*(3*(LNT-SN)+SN)+RC
      MC=F*(SN**2*(LNT-SN)/LNT**2)+MC
      IN=IN+1
      IF(IN.GT.3) IN=IN-2
      IF((LNT-SN).LT.(E(IN))) GO TO 40
   35 CONTINUE
   40 CONTINUE
      MX(1)=MA
      IN=1
      VN(1)=0
      DO 45 NT=2,NI
      VN(NT)=VN(NT-1)+E(IN)
      IF(VN(NT).GE.LNT) VN(NT)=LNT
      TM=0
      J=1
      DO 50 I=1,NT
      IF((NT-J).EQ.1) GO TO 55
      TM=F*(VN(NT)-VN(NT-J))+TM
      J=J+1
      IF(J.GE.(NT-1)) GO TO 55
   50 CONTINUE
   55 MX(NT)=-MA+RA*VN(NT)-TM
      IN=IN+1
      IF(IN.GT.3) IN=IN-2
      IF((ABS(MX(NT))).GE.(ABS(MX(NT-1)))) THEN
      MM=MX(NT)
      ELSE
      MM=MX(NT-1)
      END IF
      IF(VN(NT).EQ.LNT) GO TO 60
   45 CONTINUE
   60 RETURN
      END
```

A.7.2 The Example of Program Output

LONGITUDINAL SYSTEM
S=700.0

V/S	N.OF.MEM.	EF.LE.	Z(CU.CM)	SM(CU.CM)	LP(MM)	H(MM)	PF(MM)	TX(MM)	TW(MM)	TF(MM)
0.1	LONGITU	3.20	438.55	473.072	600.0	257.2	113.9	11.50	7.57	11.39
0.1	TRANSV.	7.50	2137.50	4607.789	1693.9	729.3	266.3	11.50	14.59	26.63
0.1	LONGITU	3.20	438.55	473.072	600.0	257.2	113.9	11.50	7.57	11.39
0.1	TRANSV.	5.50	1149.50	2327.818	1377.5	570.0	213.5	11.50	12.00	21.35
0.1	GIRDER	6.40	3648.00	3892.548	2024.2	687.6	251.1	11.50	13.75	25.11
0.2	LONGITU	3.20	416.94	473.072	600.0	257.2	113.9	11.50	7.57	11.39
0.2	TRANSV.	7.50	2137.50	4607.789	1693.9	729.3	266.3	11.50	14.59	26.63
0.2	LONGITU	3.20	416.94	473.072	600.0	257.2	113.9	11.50	7.57	11.39
0.2	TRANSV.	5.50	1149.50	2327.818	1377.5	570.0	213.5	11.50	12.00	21.35
0.2	GIRDER	6.40	3648.00	3892.548	2024.2	687.6	251.1	11.50	13.75	25.11
0.3	LONGITU	3.20	382.24	408.810	600.0	244.4	108.2	11.50	7.19	10.82
0.3	TRANSV.	7.50	2137.50	4607.789	1693.9	729.3	266.3	11.50	14.59	26.63
0.3	LONGITU	3.20	382.24	408.810	600.0	244.4	108.2	11.50	7.19	10.82
0.3	TRANSV.	5.50	1149.50	2327.818	1377.5	570.0	213.5	11.50	12.00	21.35
0.3	GIRDER	6.40	3648.00	3892.548	2024.2	687.6	251.1	11.50	13.75	25.11
0.4	LONGITU	3.20	338.30	353.155	600.0	232.1	102.8	11.50	6.83	10.28
0.4	TRANSV.	7.50	2137.50	4607.789	1693.9	729.3	266.3	11.50	14.59	26.63
0.4	LONGITU	3.20	338.30	353.155	600.0	232.1	102.8	11.50	6.83	10.28
0.4	TRANSV.	5.50	1149.50	2327.818	1377.5	570.0	213.5	11.50	12.00	21.35
0.4	GIRDER	6.40	3648.00	3892.548	2024.2	687.6	251.1	11.50	13.75	25.11
0.5	LONGITU	3.20	288.97	304.980	600.0	220.5	97.7	11.50	6.49	9.77
0.5	TRANSV.	7.50	2137.50	4607.789	1693.9	729.3	266.3	11.50	14.59	26.63
0.5	LONGITU	3.20	288.97	304.980	600.0	220.5	97.7	11.50	6.49	9.77
0.5	TRANSV.	5.50	1149.50	2327.818	1377.5	570.0	213.5	11.50	12.00	21.35
0.5	GIRDER	6.40	3648.00	3892.548	2024.2	687.6	251.1	11.50	13.75	25.11

LONGITUDINAL SYSTEM
S=700.0

V/S	WTS(TONNE)	WP(TONNE)	WG(TONNE)	STWD(TONNE)
0.1	12.25	17.33	3.96	122.31
0.2	12.25	17.33	3.96	122.31
0.3	11.66	17.33	3.96	119.92
0.4	11.12	17.33	3.96	117.77
0.5	10.64	17.33	3.96	115.83

TRANSVERSE SYSTEM
S=700.0

V/S	N.OF.MEM.	EF.LE.	Z(CU.CM)	SM(CU.CM)	LP(MM)	H (MM)	RF(MM)	TX(MM)	TW(MM)	TF(MM)
0.1	BEAM	7.50	1161.19	2473.150	600.0	465.4	206.1	11.50	13.69	20.61
0.1	BEAM	5.50	806.06	1263.301	600.0	364.7	161.5	11.50	10.73	15.15
0.1	GIRDER	5.33	2533.33	2629.563	1792.6	592.5	222.0	11.50	12.47	22.20
0.2	BEAM	7.50	1107.33	2473.150	600.0	465.4	206.1	11.50	13.69	20.61
0.2	BEAM	5.50	767.66	1263.301	600.0	364.7	161.5	11.50	10.73	15.15
0.2	GIRDER	5.33	2533.33	2629.563	1792.6	592.5	222.0	11.50	12.47	22.20
0.3	BEAM	7.50	1017.98	2473.150	600.0	465.4	206.1	11.50	13.69	20.61
0.3	BEAM	5.50	704.87	1263.301	600.0	364.7	161.5	11.50	10.73	15.15
0.3	GIRDER	5.33	2533.33	2629.563	1792.6	592.5	222.0	11.50	12.47	22.20
0.4	BEAM	7.50	902.19	2473.150	600.0	465.4	206.1	11.50	13.69	20.61
0.4	BEAM	5.50	624.32	1263.301	600.0	364.7	161.5	11.50	10.73	15.15
0.4	GIRDER	5.33	2533.33	2629.563	1792.6	592.5	222.0	11.50	12.47	22.20
0.5	BEAM	7.50	769.01	2473.150	600.0	465.4	206.1	11.50	13.69	20.61
0.5	BEAM	5.50	532.65	1263.301	600.0	364.7	161.5	11.50	10.73	15.15
0.5	GIRDER	5.33	2533.33	2629.563	1792.6	592.5	222.0	11.50	12.47	22.20

TRANSVERSE SYSTEM
S=700.0

V/S	WTS(TONNE)	WP(TONNE)	WG(TONNE)	STWD(TONNE)
0.1	19.04	17.33	3.09	148.57
0.2	19.04	17.33	3.09	148.57
0.3	19.04	17.33	3.09	148.57
0.4	19.04	17.33	3.09	148.57
0.5	19.04	17.33	3.09	148.57