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INTACT AND DAMAGE STABILITY ASSESSMENT FOR THE PRELIMINARY DESIGN OF A PASSENGER VESSEL

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Abstract

Vessel Lightship weight estimate and centre of gravity location are one of the main concerns for the ship designer, especially for a passenger vessel in a preliminary stage. One of the more accurate ways to obtain these values is the application of the Profile Method. Therefore, in this paper it is described the development of this method based on the lightship weight and the ordinates of centre of gravity known of similar vessels. Also it will be proposed some tools to have a clear idea of the capability of the vessel to fulfil the intact and damage stability requirements.

1. INTRODUCTION

Vessel's stability is a combination of intact and damage stability. All relevant information dealing with this matter can be summarized in a minimum GM's curve. When starting a new design, it is very useful to have the possibility of predicting this information. All parameters as waterline, block and midship coefficients and even the longitudinal buoyancy centre position should be accurately defined, in the first stage of the design process, in order to comply with the vessel required stability standards.

Especially for passenger vessels, stability is one of the more critical aspects in the ship design and even during the vessel operating life. Passenger safety has been one of the main aspects which has been tried to be covered by the international rules and regulations. As passenger vessels normally have associated a high ship volume and consequently a high depth, in comparison with their draught and beam, weights and their position must be carefully studied and always connected to the bodylines coefficients.

2. LIGHTWEIGHT ESTIMATE: THE PROFILE METHOD

2.1 Introduction

There are at least three reasons because all merchant ships could be rejected during their delivery: payload, speed and stability, and in all of these the lightweight of the ship is one of the more relevant factors.

When a new project is started, the first issues which normally are contemplated are the vessel capacities (cargo and own consumptions), performances and layout. Nevertheless, in a very early stage of the project, the lightship weight and centre of gravity location need to be estimated in order to consolidate the design. The lightship weight estimate method used

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during the conceptual phases has to be quick, reliable and flexible in order to be able of quickly react under the continuous changes which normally happens at this stage of the project. Weight estimate is based on direct calculation of areas, volumes and statistical figures of previous projects.

In the basic design phase, weights are based on more accurate design information and direct calculations carried out during this second phase (general arrangement drawing, midship section drawing and ship's specification). When the ship is close to be signed, weight calculations have to be updated with the information of the purchased equipment and the steel weight based on the classification drawings.

The third step in the weight calculation will be based on detail design information and workshop drawings, and this weight will be updated during the building period based on weight control methods.

In this report a lightweight estimate method for the conceptual design phase is presented.

2.2 General Lightweight Breakdown

Typical lightweight breakdown is divided as following:

- Steel weight
- Machinery weight
- Equipment weight (including interior outfitting)

There are not specific rules and majority of design office will have their own distribution. In any case, the most important thing is to follow the same criteria from one project to another taking into account that any particular concept has to be in the same pool and no main concept has been excluded.

As a first approach it could be considered that steel weight will include the weight of every structural element and those items associated to the steel weight as paint and preservations.

Machinery weight will include the weight of the propulsion system, auxiliary engines, generators, boilers, ballast system, fuel oil / diesel oil system, lubricating oil system, etc

Finally, equipment weight will include anchoring and mooring equipment, Ro-Ro equipment, sundry doors, steering and manoeuvre equipment, fin stabilizers, life saving equipment, fire fighting system, waste handling system, interior outfitting, etc.

Depending on the passenger ship type, steel weight represents between 55 and 75% of the total lightweight of the ship, machinery weight represents between 10% in slow passenger vessels and 20% in fast passenger ships with high demand of electrical power, and equipment weight represents between 15% and 25 % of the total lightship weight, depending on the passenger ship type and their functions.

The following figure shows the typical lightweight breakdown in a Passenger Ferry:
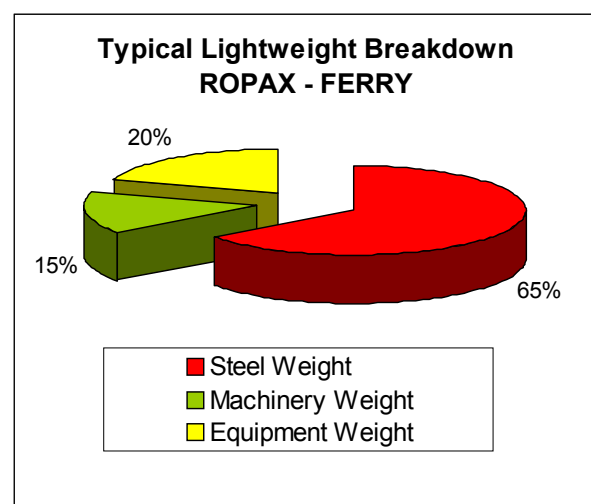

Figure 1: Lightweight breakdown

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The above breakdown is very useful when the project is in the basic design phase and the main systems and equipment have been defined, but in a very preliminary conceptual phase is also necessary to split the above breakdown in order to get parametric and local values.

The more detailed breakdown allows to estimate those items that depends on the main characteristics of the ship and those ones that are affected by one special equipment or performance that is specific for one project (e.g. in a Ro-Ro passenger vessel a hoistable ramp in a car garage is a local weight that depends on the specific performances of the ship meanwhile the fire fighting insulation will be function on the garage dimension).

As a first approach, it could be considered that parametric steel weight will be the continuous longitudinal steel weight meanwhile local steel weight will be the weight of every superstructure, funnel and interior longitudinal or transversal bulkheads that have an specific function (e.g. central or side casing, etc).

Local machinery weight will include the weight of the machinery equipment as main engines, reduction gear, auxiliary engines, generators, etc. and other weights will be considered as parametric machinery weight (fuel oil / diesel oil system, lubricating oil system, etc)

Finally, local equipment weight will include the weight of every specific equipment as garage doors, ramps, rudders, steering gears, etc. and the parametric equipment weight will include those items that will be function of the dimension of the ship or specific space in which is included (e.g. hydraulic system, lashing equipment, AC-ducting, sprinklers system, insulation and linings, etc.)

In the following table it is indicated the percentages of lightweight corresponding to parametric and no parametric items according to main principal lightweight breakdown.

Table 1: Lightweight breakdown in % of parametric and local weights

	LightW.	Parametric Weight		Local Items	
	% LightW.	%Partial	% LightW.	%Partial	% LightW.
Steel Weight	55-75%	60-75%	33-56%	25-40%	14-30 %
Machinery Weight	10-20%	55-65 %	5.5-13 %	35-45%	3.5-9%
Equipment Weight	15-26%	40-70 %	40-70%	30-60%	9-17%
%Total	100%		44-87%		26-56%

It can be seen that parametric steel weight represent between 60% and 75% of the total steel weight of the ship, parametric machinery weight represents between 55% and 65% of the total machinery weight, and parametric equipment weight represents between 40% and 70% of the total equipment weight. With these figures between 44% and 87% of the lightweight of the ship is parametric weight.

Focusing now in local machinery and equipment weight they can be classified in primary and secondary local weights. The boundary between then is not clear but in a first approach it can be considered as primary weights those that are bigger than 0,1% of the total lightweight. Those items, that in a ship of 10.000 tonnes of lightweight have to be bigger than 10 tonnes, are usually known or at least easily estimated using well-known Naval Architects formulas.

Primary local equipment and machinery weights are main and auxiliary engines, steering gears, reduction gear, boilers, Ro-Ro equipment etc. These weight can be between 85 and 90% of the local equipment and machinery weight in a passenger vessel meaning between 10 and 23% of the total lightweight.

Finally, local steel weight can be estimated using volumetric parameters: 40-50 kilograms/m3 depending the ship type and the

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height of the superstructure above resistant deck.

2.3 Profile method

All new ship projects respond to specific shipowner demands, who normally require some capacities, spaces and performances for the new vessels. For that reason, new projects must start with a clear idea of the implications of these owner requirements in the general arrangement.

A preliminary ship lightweight estimate cannot be done if it isn't known the main dimensions of the vessel (Length, Breadth and total height of the project) necessary to meet the owner required space for cargo and passengers.

Once the designer has developed the preliminary ship concept, the lightweight of the ship and their centre of gravity location should be estimated in order to consolidate the design.

The lightship weight estimate method used in this conceptual phase has to be quick and flexible as at the beginning of the project every design factor continually changes, but the method should be reliable in order to assure the design. One lightship weight estimate method which present the above characteristics is the "Profile Method".

As has been described in previous section, the lightship weight can be breakdown in steel, machinery and equipment weights and inside this classification into parametric, primary local and secondary local weight.

This method is based on the control of parametric and primary local weights that suppose, as has been indicated previously, up to 95% of the total weight of the ship

For their application it is necessary to have a reference vessel and the main characteristics of the new design (length, Breadth, height and initial space distribution). However, the more relevant information of the reference vessel that it is needed is its "Profile". With this profile, it is calculated the lateral area and the position of the centre of gravity of this area, needed to apply this method. In the next figure, the profiles of different reference vessels are shown.
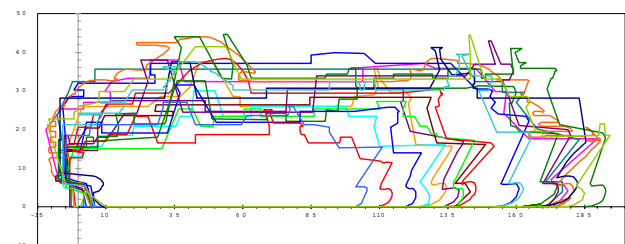

Figure 2: Profiles of different vessels

As in any estimate method, as much information from the ship to estimate is known and more close to the reference ship is, bigger reliability will be obtained and therefore smaller design margin will be necessary to take.

The first step in the process consists on deciding a suitable reference vessel (two better than one).

In order to properly choose the reference vessel, special attention should be paid to the design criteria, vessel functionality, number of decks (cargo, passengers), … etc. The size of reference vessel is also important but is not the more critical factor.

The second step will be to modify the reference vessel (keeping fixed their original dimensions), trying to get the modified reference vessel characteristics as similar as possible to the new project. Therefore, it will be necessary to add and to remove the local weights that make these ships different. Sometimes a superstructure must be added or removed, cargo ramps, car decks, … etc. If as

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a consequence of the reference vessel modifications, the profile of the vessel changes, a new profile of the reference vessel should be obtained. The Lightship weight centre of gravity of the modified reference vessel must be also updated.

Some of those weights will be known (e.g. the weight of the majority RoRo equipment, lifeboats, etc) getting the information of the purchased equipment for other previous ships built, but other have to be estimated (main engines, additional accommodation decks, etc).

To estimate the unknown weight is possible to use well-known estimation formulas (see reference [1] and [2]). But, in this preliminary stage, it is possible to use some simplifications. For example, to estimate the weight of additional accommodations deck it can be supposed that steel weight would be around 40 ton/m3 of new accommodation volume, and that 120 kg/m2 is the weight of the furnishing of the additional accommodation area.

In conclusion, an equivalent Profile and lightweight (LWeq) and centre of gravity (KGLWeq, XGLWeq) will be obtained for the modified reference vessel.

The third step once two ships are similar is to do the parametric transformation. This transformation is based on the following relation:

$$\frac{LW}{LA \times B^{0,8}} = \frac{LWeq}{LAeq \times Beq^{0,8}}$$

Where:

LWeq Lightweight of the equivalent ship
Beq   Breadth of the equivalent ship
LAeq Lateral Area of the equivalent ship
LW   Lightweight of the ship to be estimated
B   Breadth of the ship to be estimated
LA   Lateral Area of the equivalent ship

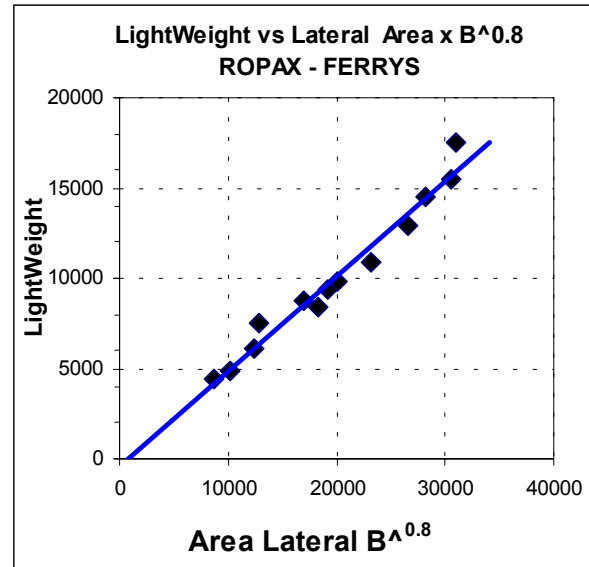This is a very good approach as shows the following figure (figure 3)

Figure 3: Lightweight versus lateral area x B^0,8

Estimation of the centre of gravity is obtained using this other expression:

$$\frac{KGLW}{KGLA} = \frac{KGLWeq}{KGLAeq}$$

$$\frac{XGLW}{XGLA} = \frac{XGLWeq}{XGLAeq}$$

Where:

KGLAeq – Vertical Centre of gravity of the equivalent ship lateral area.
KGLA   – Vertical Centre of gravity of the lateral area of the ship to be estimated.
KGLWeq – V.C.G. of the equivalent ship
KGLW   – V.C.G of the ship to be estimated
XGLWeq – V.C.G. of the equivalent ship
XGLW   – V.C.G of the ship to be estimated
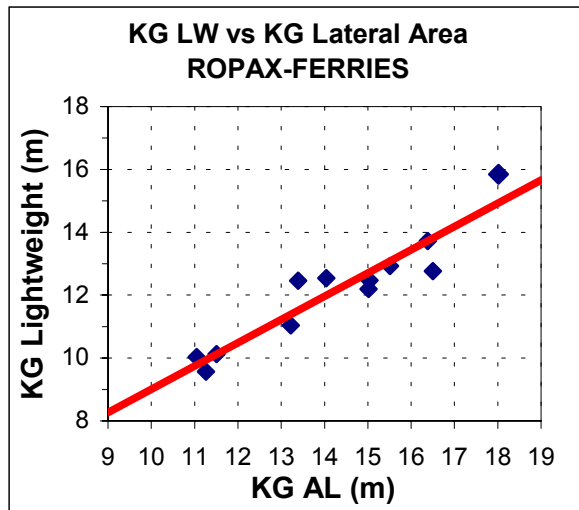
**KG LW vs KG Lateral Area
ROPAX-FERRIES**

Figure 4: KG Lightweight versus KG lateral area

And finally, the last step will consist in to fix the design margin. If several reference vessels have been taken, the margin that should be considered could be lower. This margin has to cover the uncertainty of the estimate method, the relative similitude between ships and the secondary local weights. In any case, as the secondary local weight has been taking into account by the parametric transformation the implication of those weights is minimum and a design margin of 5-7% could be enough.

3. INTACT STABILITY CONCEPT

In this subchapter different parameters involved in intact stability concept will be analysed.

But, before of this, it is underlined the importance of intact stability evaluation as it takes into account the dynamics of motion that can lead to a ship loss through a certain chain of factors, even without any damage ship condition.

Intact Stability characteristics depend on the deadweight and lightweight distribution, because it will define the final displacement

(draughts) and the position of gravity centre (KG), principal parameters that determine the GZ curve of the vessel for each loading condition.

Nevertheless, there are also others important parameters to take account for intact stability evaluation, because they affect the final allowable range of possible load conditions that fulfil the stability criteria. One coming from certain vessel geometry (hull coefficients, etc…), other from some factors depending of arrangement of vessel (openings, etc…) and finally one third coming from all requirements to be fulfilled included in rules and international conventions.

It is remarkable that at present, the requirements included in the international rules and regulations are only based on a pure static analysis. But it is necessary to point out that there are dynamic phenomena where stability is involved. For example, it is demonstrated that for fast vessels transverse stability decrease and it is possible to have permanent heel due after certain Froude values.

In the next future the intact rules should progress within a width scenario, introducing dynamic aspects in the evaluation, using relevant and powerful tools like model basin stability tests and numerical models.

These tools would allow to have a more relevant information about a dynamic GZ curve when a vessel is sailing in still or irregular wave seas and even other information of interest as parametric rolling, washing or broaching related to different resonance's of vessel according with their movements.

Below, it is described the more significant parameters related with geometry, general arrangement and requirements:

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–   Geometry:
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- Lines plan
- Lines coefficients
- Metacentric height
- Buoyancy centre ordinates
- Arm heel values

–   General arrangement:

- Windows and portholes arrangement
- Main and freeboard deck situation
- Aft, fore and side hull doors
- Flooding opening points
- Tanks configuration related to free surfaces configuration
- Cross-flooding features
- Empty spaces configuration to avoid asymmetrical damages

–   Requirements

- Statistical Criterion (Imo Res. A.167) dealing with GZ curve characteristics
- Heeling moment produced by passenger at side
- Rudder at side (Turning criterion)
- Weather criterion (Imo Res. A.562)
- Code on Intact Stability for All Types of Ships Covered by IMO Instruments (Imo Res. A.749)
- Other criteria according to flag administration

One of the main designer targets would be to perfectly know how the different design parameters can affect to the intact stability results. In this way, it would be possible to properly choose these parameters from the very beginning, being confident that the vessel will fulfil the required stability criteria along the vessel life.

3.1 Vessel geometry (hull form)

Intact stability is among others factors very dependent of hull form characteristic. Three important hydrodynamic coefficients are related with the intact stability performance of each project. They are:

- Waterline coefficient that has a big influence in the waterline inertia
- Midship coefficient related with bigger heeling arm, and
- Block coefficient

As shipowners are requiring more cabins and public spaces together with more speed with a minimum length, beam and draft, these coefficients are in a permanent evolution.

Most of the times recommendations for these coefficients coming from statistic values are not appropriated for passenger vessels, because stability is usually so critical than bigger values are required.

When it is analysed today waterline's coefficients compared with figures of ten years ago, it can be easily appreciated the evolution of requirements of stability. There were waterline coefficients about 0.80 ten years ago and at present there are values of 0.86 and 0.87 for same blocks coefficients.

A similar evolution can be observed about midship section coefficient where they have increased until values of 0.99 for blocks coefficients of 0.6 and 0.63. One reasons of this evolution is that heel arm values are increased for bigger midship coefficients.

Consequences of this new values coming from general stability and ship owners requirements, have been that today modern ferries are able to have two and even three ro-ro cargo decks above main deck and also more number of cabins in the high part of vessel.

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Actually hull lines coefficients for both ferry and cruise vessels can be obtained by the formulation below:

- For block coefficient values:
$0.56 \leq \delta \leq 0.68$

- Waterline coefficient:
$(2x\delta/3 + 0.38) \leq \alpha \leq (2x\delta/3 + 0.43)$

- Midship coefficient:
$(1 - 6x10^{-3} / \delta^2) \leq \beta \leq (1 - 9x10^{-3} / \delta^2)$

Where

δ Block coefficient,
α waterline,
β midship coefficients.

Design waterline coefficient should be chosen for values included in the above formulation. β must be chosen according to stability, constructive and propulsive criteria.

Other coefficients could be decided according to design criteria; nevertheless block coefficient and longitudinal position of buoyancy centre are also related to stability, but also with relation to propulsion and sailing conditions.

Geometric aspects have been also modified in last few years, dealing with a very smooth and plane after shapes with a philosophy more involved in hydrodynamic parameters that in stability and manoeuvrability matters. For this reason it is necessary to add a centreline keel to avoid this manoeuvrability problem. This solution, in opinion of some captains of this type of vessels, has a worst behaviour dealing to manoeuvrability compared to a traditional line. Few days ago a captain opinion was that those traditional lines were more "noble" than lines today.

3.2 General Arrangement

In the following paragraphs it is commented some aspects and decisions related to general arrangement: freeboard deck, flooding points and tank's configuration.

Freeboard deck should be positioned in relation to design or maximum compartimentation draft to avoid problems with intact and damage stability. From the point of view of damage stability a higher position of this deck allow a better answer to requirements, but it is necessary to take care as also it is increased the vertical centre of gravity both lightweight ship and cargo.

These two concepts are in a certain opposition and it is needed to get a compromise in order to find an optimum solution. Nevertheless, in most of the cases is more critical damage than intact stability to this respect.

Flooding points should be arranged avoiding to be below of 40 or 50 degrees according to intact stability requirement in order to have a certain area between 30° and 40° degrees or 30° and opening flooding angle if it is less. It should be considered the possibility of locating these openings as near as possible to 50° degrees according to application of wind and waves criteria. In this respect is very useful to decide their positions according to limit angle curve with heeling arm cross curves corresponding to displacement design.

Finally it is necessary to take care of the position and configuration of tanks to avoid big **surface corrections** both for small and big angles. Not only to reduce the own correction, as static concept as is allowed by the requirements; but also, having in mind, a possible bad influence in intact stability by dynamics effects in resonance with own vessel period balance and waves frequency. Therefore, it is also highly recommended that the maximum Breadth of this tank should be

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not bigger than a half of the vessel beam. As prevention of asymmetrical damage cases, these tanks (fuel, oil, fresh water and ballast) should be situated inside of a space limited by B/5.

3.3 Requirements

A minimum GM required curve, related to intact and damage stability requirements, is obtained as a result of superposing the minimum GM intact and damage stability curve. Normally, this GM curve is governed by intact stability criteria for low draughts and by damage stability criteria for higher draughts.

Usually, the more demanding intact stability criteria is resulting from the application of passenger at side, turning and weather criteria. Others GZ requirements coming from:

- different values of GZ at 20º,
- maximum GZ ,
- minimum corresponding angle and
- minimum area required between 30º and 40º

are fulfilled with a smaller GM as required by other requirements mentioned above. For passengers and roro vessels, these requirements are normally easy to meet because the high superstructure. Only the flooding points position make difficulties when they are located below 40º and when the KG is high.

Passengers at side Criterion

Passengers at side criteria could have difficulties when passengers' number is no adequate to the size of the vessel. It is more critical for small vessels than big vessels because the heeling moment is relative bigger than for big vessels. Moreover, there is more passenger density of passengers in a small

vessel normally because passenger spaces are more restricted.

Considering a passenger density parameter, it is possible to predict those difficulties mentioned above:

$$PD \times L \times B^2 / n \times GMR \times \Delta \leq tang\ 10º$$

Where

PD is passenger density,
L length of vessel,
B Beam of vessel,
n number of decks where passengers could have as more pessimist way ,
GMR minimum GM required according to previsions and
Δ Displacement of vessel.

GMR could be established at first step of the project according to experience values. If the above formulation is not fulfilled, it will be necessary to increase the GMR through design changes in specific parameters: waterline coefficient, dimensions etc…

Turning Criterion

According to formulation, the heeling moment due to rudder action is depending of maximum vessel speed, displacement, length and relative position between vertical centre of gravity and vertical position of centre of buoyancy. This formula is not depending of rudder area nor rudder type as active rudder or pod's installation. Sometimes, heeling vessel answer when the vessel is turning at maximum speed could be appreciably higher that corresponding value given by formulation. Based on the above, it seems convenient to consider this specific circumstance.

This heeling moment is starting to be critical for fast ships corresponding to Froude numbers above 0.30. From this point we should take

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care of it and it is frequently necessary to introduce some modifications in lines plan near of draft, increasing beam values to obtain the necessary heeling arm figures to get a heel angle less than 10º.

One approximation to be used during the first steps of the design process could be given by:

$$0.02 \times V^2 \times (KG - d/2) / L \times GMR \leq tang\ 10$$

Where

GMR minimum GM required according to previsions, KG corresponding to GMR,
L length of vessel,
d draft considered and
V maximum speed.

When this value is bigger than 10º we must to increase GMR or to carry out some modifications in the lines plan of vessel.

It is remarkable that a not equilibrated superstructure profile, for instance passenger vessels with a higher superstructure at fore part produce some steering perturbation related to vessel maniobrability especially in emergency situation.

Finally, it is also remarkable that a "Pram" after bodylines produces also some dangerous des-equilibrium in critical situations. Therefore, these types of problems must be considered when analysing the turning criteria and they must be considered in a correct way.

Weather criterion

Many circumstances have big influence in this criteria, vessel profile above waterline, and vessel profile below waterline.

Most of times this criteria is the governing criteria especially for light service drafts.

Other lateral areas as centreline keel, balance keel, longitudinal rudder area, fin stabilizer area, pod's profile and all longitudinal area independent of lines plan of vessel allow to reduce wind moment according to IMO RES 562 (14).

If it is calculated a heeling moment according to the required wind pressure (504 N/m2), it is possible to estimate the heeling angle.

$$P \times A \times Z / (1000 \times g \times GMR \times \Delta) \leq Tang\ 10º$$

instead 16º as recommend by criteria, but if difficulties are found, it may be necessary to increase this GMR value or reduce the lateral area of the vessel above waterline in order to reduce the heeling angle upto a value lower than 10º.

Where:

 P= 504 N/m2
"A" Lateral area above waterline
"Z" Wind arm (geometric vertical profile gravity centre above waterline and T/2)
"T" draft of vessel

In any case it must be necessary to carefully analyse the full wind and waves criteria for all loading conditions.

Moreover, it is here also remarkable that profiles of vessel with unbalance in the longitudinal profile produce certain difficulties in behaviour of vessel when it is sailing.

3.4 Intact GM required for design

As outcome of intact stability calculations, a limiting curve for GM or KG as a function of ship draught is obtained.

As those Curves should be similar for families of ships of same topology, they can be used as reference in the preliminary steps of vessel design. Based in these statistical curves, a

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preliminary GM for the new project must be chosen in order to define all lines plan coefficients being "sure" that these coefficients will allow fulfilling with all intact stability regulation requirements.

Therefore, based on the selected GM curve, the different parameters should be identified accordingly (geometry coefficients, etc…).

4. DAMAGE STABILITY CONCEPT

4.1 Subdivision

Damage stability, especially in Ferries and passenger's vessels are directly linked to the vessel subdivision.

Appropriated subdivision is one of the more relevant targets of a ferry designer. Aspects as the implementation of latest safety criteria with the minimum weight and cost give a competitive characteristics and performances of the product to revert the biggest benefit for shipowner and shipyard. Easy operation of the vessel is also other important aspect to take in mind.

In a very early stage of the new project the vessel should be subdivided based on our experience, reference vessels or new tools. Principal factors that must be considered are the spaces between frames, web frames, watertight bulkhead systems (longitudinal and transversal) and the height of main deck.

Therefore, the subdivision bulkheads' position is one of the problems to be solved in a first step. Number and location of transversal bulkheads will determine the different damage scenario that must be evaluated. Selection of these parameters should be properly done, taking into account that the distance between watertight bulkheads must be bigger than the longitudinal extent of damage according SOLAS (3m plus 3% of the length of the ship,

or 11m whichever is the less) to make effective all transversal watertight bulkhead.

In Ferry vessels with a lower hold, the SOLAS transversal extension of the damage (B/5) must also be considered and the vertical penetration of bottom damage (B/10) too, in order to arrange suitably the lower hold cargo spaces avoiding lower hold damage cases

Concerning the height of main deck, some studies carry out show that the intact freeboard must be between 2.8 and 3.2 meters, but it depend on the vessel length and also compartment length in fore and aft part of vessel. These values have been obtained according the formulations below taking whichever is bigger:

$$H - T = 3 \times [1 + (Ca,f / Lpp - 12/100) \times Lpp/100] \text{ m}$$

$$Hp - T = 3 \times [(Ccc/Lpp - 14/100) \times Lpp/100] \text{ m}$$

With:
- Hp   depth to main deck,
- Lpp   length between perpendiculars
- Ca,f   length of biggest two consecutive compartments at half aft or fore part of vessel length, and
- Ccc   length of biggest two consecutive compartments at midship.

Regarding new tools developed for making easy the subdivision task, it is important to underline that as optimisation methods have improved and computing capability has increased, it is possible to use optimisation tools getting appropriated subdivision of passengers vessels in the preliminary stage of a new ship project.

These optimisation tools are based on probabilistic concept that will be the base of the new harmonized applicable standard for all types of vessels in a next future (2006) and will be very important because the probabilistic

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concept, by itself, do not easily allow to optimise the position of the watertight bulkheads, longitude and its configuration in a project.

One of this optimisation tools has been developed in the ROROPROB project carried out under the Safer EuRoRo Thematic Network in which IZAR has participated.

4.2 Today applicable standard

Some years ago, when the stability damage requirements were not so critical as today, floodable length curve was a good criterion to evaluate the position of the watertight bulkheads for a ferry vessel in order to fulfil the damage stability. But this tool is very related to the margin line of the vessel and, nowadays, is not very useful because the freeboard needed to fulfil damage stability criteria is higher now, and because this criterion cannot be applied to arrangements with lowerhold.

At present time, for conventional ferries, especially with lower hold, there are several different regulations and approaches in force that can be applied for damage stability evaluation. By that reason it doesn't exist a clear way to proceed for damage stability calculation and they usually are, owner ship and flag administration, who specify, define and choose those regulations and approaches that should be evaluated for a concrete project.

Besides this, some owner can require more strict criteria than those generally applied for similar vessels. But they can be considered to be more in line with the general safety policy giving to the owner more margins for further extensions and conversions

In the following paragraphs it is briefly reviewed the effective regulations for this passenger ship type:

a) Passenger Ship with transverse subdivision below the main deck. Traditional ships with compartments formed by continuous transverse watertight bulkheads that extend from port to starboard side.

In this case, the ship would have to meet or with SOLAS 90:

- Calculation of floodable lengths defined in the rules 4 at 7 inclusive of the chapter II-1 of SOLAS, and

- Calculation of stability in damage condition with the rule 8-1 and 8.2 of the chapter II-1 of SOLAS for two adjacent compartments for vessel carrying 400 persons or more.

Or, we would have to fulfil an alternative procedure based on a probabilistic approach. Res, A. 265 (VIII). Instead of the requirements of chapter II-1 part B of SOLAS.
However, it must be remarkable that Rule 5 of the Resolution A265 evaluates the subdivision and the damage stability.

b) Passenger Ship with longitudinal subdivision below the main deck. Ship with lower holds.

In this case it cannot be applied the conventional concept because it doesn't have side to side transversal bulkhead needed for strict calculation of flooding lengths. For it, in principle, it should only apply the Resolution A. 265 VIII.

Apart from the above-mentioned, consequence of the sinking of the Estonia, a new criterion has been required for the majority of passenger ferries built after the year 95. The

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STOCKHOLM AGREEMENT (consideration of water on deck).

In this case, the amount of assumed accumulated sea water is calculated on the basis of a water surface having a fixed height above the lowest point of the deck edge damaged compartment of the roro deck or, when the deck edge in way of the damaged compartment is submerged then the calculations is based on a fixed height above the still water surface at all heel and trim angle as follows:

- 0.5 m if the residual freeboard is 0.3m or less
- 0.0 m if the residual freeboard is 2.0 m or more; and
- intermediate values to be determined by linear interpolation, if the residual freeboard is 0.3 m or more but less than 2.0m

It must be highlighted that the application of this agreement is today mandatory for the new ships as for the existent ones that will navigate for the area of the north of Europe and that in a future not very far-away it can be mandatory for all the passage ships that navigate in waters of the European Union.

As the execution of this agreement it is applicable to ships with longitudinal or traverse subdivision, adding three additional requirements to those already defined in the rule 8-1 of the SOLAS, it implicitly means that all vessels with longitudinal subdivision have to also fulfil with rules 8-1 and 8-2 of SOLAS.

In conclusion, exist a disparity of criteria for the realization of these damage calculations that on the other hand are necessary to carry out when being part of the basic concepts of the ship project.

In view of this situation, it is very normal that flag administrations and ship owner request complementary calculations that usually imply the application of the damage stability for deterministic method according rule 8-1 of the chapter II-2 before mentioned, sometimes including lowerhold garage.

Therefore the final regulations coming from the harmonization of damage stability promoted by IMO and dealing with HARDER and ROROPROB projects, are really necessary to designers of conventional passenger ferries as soon as possible.

4.3 New harmonized damaged stability regulations

Objective of the new harmonized damage stability regulations is to develop the probabilistic concept and extent it to all family vessels. The new regulations will be applicable to all ships covered by SOLAS today.

It is however an open question of whether the so-called "footnote" in Part B-1 is to be retained or not. This footnote excludes certain ships from the probabilistic regulations, but not passenger vessels.

As summary of New Proposals we can to highlight:(see reference [5])

- New and updated formulations on p,r and v have been established based on new and updated damage distributions, as well as theoretical simulations.
- The s-factor is based on the main concept developed during the A.265 development
- Factors such as transient effects, progressive flooding, cargo shifts etc., are under development, but has not been decided yet how to handle
- The subdivision index is to be based on three draughts, as follows:
    o Deepest subdivision draught
    o Partial draught
    o Light draught

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- The required index (R) should be found such that an "equivalent level" of safety with the current SOLAS regulations is maintained; it probably will have impact on the allowable VCGmax or GMmin curves.
- In principle the GM's used for calculating the index will become the limiting GM's for the vessel.

4.4 Damage GM required curve

As happens in intact stability the outcome in damage calculations is also a limiting curve for GM or KG with independence of the applicable standard used for the evaluation.

Statistics of these KG/GM limit curves for a same family of vessels will give values that we can used as first reference in new design.

In the following figures some graphs are introduced. They shown the relation between the minimum GM required and the breadth of the vessel versus length for ropax and cruise vessels.

It must be indicated that GM's figures has been taking of ferrys fulfilling intact stability code and SOLAS 90 plus Stockholm Agreement and cruise vessel fulfilling intact stability code plus SOLAS as damage stability.
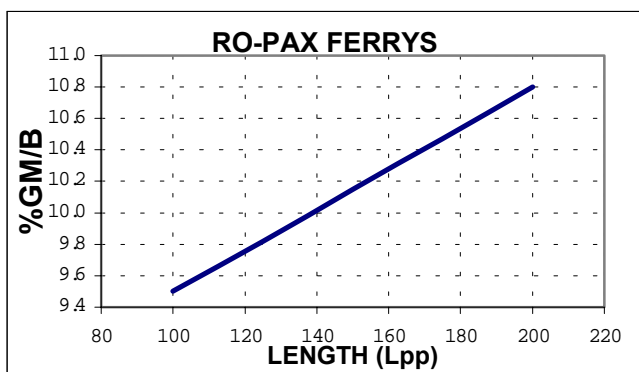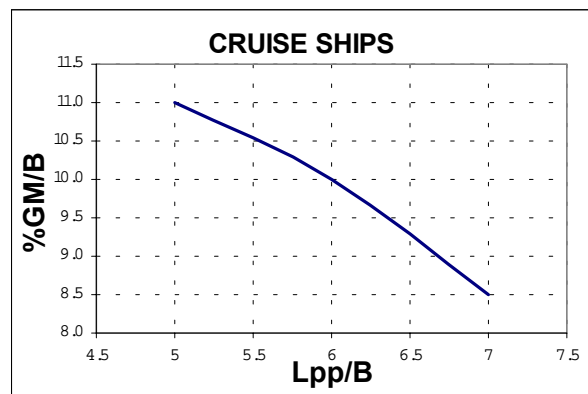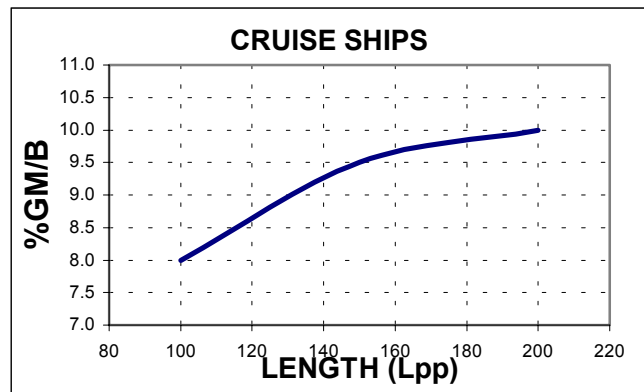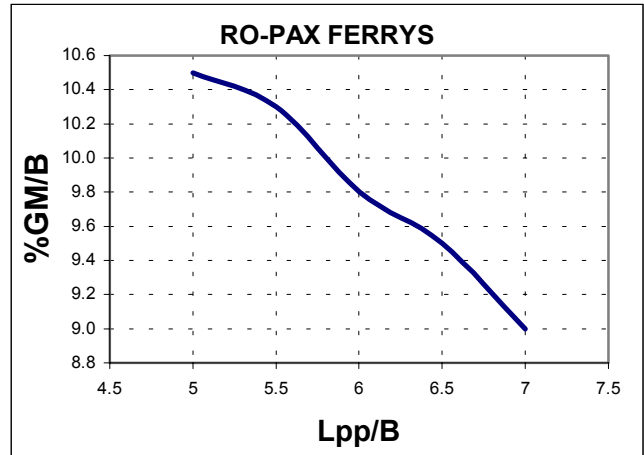
Based in these graphics, it can be decided a preliminary GM Required for our project, which will be tested later on according to appropriated applicable standards (intact and damage).

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5. CONCLUSIONS

An easy estimation of lightweight ship and position of centre of gravity of the vessel has been presented for a preliminary step.

In addition, it has been summarise applicable standards to evaluate intact and damage stability giving some formulation that can be used in the preliminary stage of a new project

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