REVIEW OF DESIGN FEATURES AND STABILITY CHARACTERISTICS OF PRE- AND POST SOLAS 90 RO-RO PASSENGER SHIPS

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SUMMARY

This paper presents an analysis of results of systematically collected technical data of Ro-Ro Passenger ships operating mainly in European waters. The data are derived from collaborative work within the EU-projects SAFER-EURORO [1] and ROROPROB [2] as well as from data of an NTUA-SDL in-house technical database. The study enables a variety of conclusions on the past, presently adopted and foreseeable practices in Ro-Ro Passenger Ship Design pertaining to stability and safety characteristics.

1. INTRODUCTION

The Ro-Ro concept is a very popular and efficient mode of transportation especially in Europe, where 50% of the world's Ro-Ro shipping fleet operates.

From the economical point of view, the capability of carrying simultaneously a wide variety of cargoes with minimum infrastructure and shore-based equipment make the particular ship type most competitive. In terms of safety/stability, the vulnerability of large vehicle spaces creates a serious stability and floatability problem in case of flooding due to collision or other incidents leading to car deck flooding (e.g., bow door opening).

The presented work is within the scope of the ROROPROB project, aiming at developing and implementing a new formalized design methodology for optimal subdivision of Ro-Ro Passenger ships based on the probabilistic damage stability approach.

2. TECHNICAL DATABASE

The present RORO Technical Database serves a comprehensive and stand-alone reference of European Ro-Ro Passenger Ferry fleet. It currently includes data of 780 ships of the following types: Passenger/Car Ferries, Passenger/Train/Car Ferries, Vehicle Carriers, Ro-Ro Cargo ships. With respect to the Passenger/Car Ferries, the database is considered to be fully representative of the present status of the entire European Passenger/Car ferry fleet.

2.1 DATABASE STRUCTURE

The database has been developed under MS Access 2000. The registered data refer to available information on the following ship characteristics:

- General characteristics of the vessels (name, former names, owner, flag, area of operation, class, crew, builders, year of build, year of major modifications).
- Main technical characteristics, such as main dimensions, lightship weight, displacement and payload, powering, life saving equipment.
- Special devices such as: propellers, rudders, thrusters, stabilizers, sponsons, stern/bow doors.
- Information on intact stability and loading conditions.
- Basic subdivision below and above main car deck.
- Damage stability information on worst case (equilibrium and values of residual stability)
- Stability standard currently in compliance as well as the next relevant regulation to be in compliance.
- Severe Casualties Records.
- Outline of general arrangement.

2.2 DATABASE ANALYSIS

The following analysis has been carried out with respect to category Ro-Ro Passenger/Car Ferries and attempts to relate technical and global economic ship characteristics to their stability and eventually safety. The sample of analysed data contains 498 ships and is given in *Table 1*.

		Average	Min - Max	Sample
Length Over All	m	126.95	33.02 - 214.9	497
Length Between Perpendiculars	m	116.51	28.01 - 198	486
Breadth Moulded	m	20.19	6.66 - 32	472
Depth to the Main Deck	m	7.03	1.99 - 12.6	269
Draught	m	5.14	1.25 - 8.22	486
Deadweight	t	2716	39 - 15500	476
Lightship	t	6904	317 - 21800	252
Displacement	t	9465	196 - 25300	264
Gross Register Tonnes		12437	198 - 59912	498
Speed	kn	18.98	8 - 31	478
Total Power of Main Engines	HP	16772	456.3 - 90500	496
Year of Built		1980	1952 - 2001	497
Year of Mod/cation of Major Char.		1990	1971 - 2000	80

Table 1: Sample of analysed data

For the study, a major separation into two main categories has been considered, namely: sample of data for ships built before 1990 and ships built after 1990. This breakdown was essential, firstly because of the change of design philosophy in the last decade and secondly because of the request for compliance with higher stability standards after the introduction of SOLAS 90. Further categorizations have been also considered such as: ships built after 1993 or 1997, in order to have more clearly the effect of the SOLAS 90 and SOLAS 95 requirements. In some cases, the differences are not significant compared to the post-1990 results. In some others, the sample is not considered satisfactory in order to conclude, *Figure 1*. Finally, results based on different stability standard are also provided.

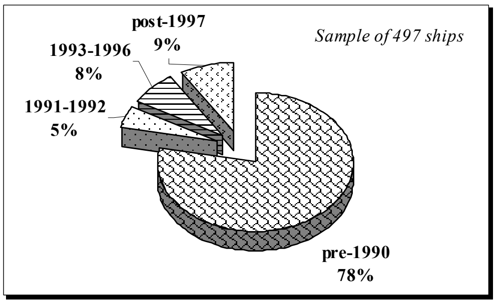

Figure 1: Distribution of sample acc. to Year of Built

3. REVIEW OF RESULTS

3.1 SIZE OF VESSELS

The size of vessels has significantly increased in the last decade along with higher service speeds and powering requirements, creating different generations of Ro-Ro Passenger Ferries and expressing the demand for faster, more comfortable and safer sea transport, *Figure 2* and *Figure 3*.

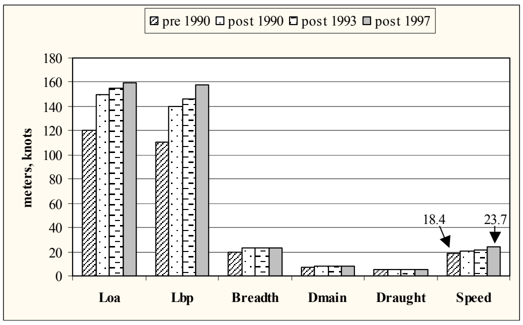

Figure 2: Averages of main dimensions and speed

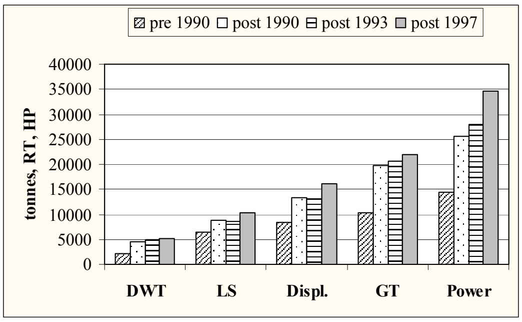

Figure 3: Averages of weights and power of M.E.

3.2 DIMENSIONAL RATIOS & COEFFICIENTS

- L/B ratio: there is no clear trend of the particular ratio. Analysis based on different Lbp categorisation indicates that the ratio decreases for ships built post-1990, especially in the range of Lbp up to 160m. This reflects the relative increase of beam in order the enhanced stability standards to be achieved. On the other hand, length is one major parameter that greatly affects building cost, but also depends on harbour and route limitations.

L/B	Ships of Lbp 100-130m	Ships of Lbp 130-160m	Ships of Lbp >160m
Pre 1990	5.0 - 7.4	4.7 - 7.4	5.8 - 7.4
Post 1990	4.9 - 6.9	5.0 - 6.7	5.3 - 7.4

L/B	Ships Built post 1993	Ships Built post 1997	Ships Built post 1993
	4.9 - 7.4	4.9 - 7.4	
Vs ≥24			5.1 - 7.4

- B/T ratio: Clearly increasing for the new vessels, an indication of increased stability requirements. Draft remains constant or slightly decreasing (shallower ships) for enabling docking of large ferries at existing port infrastructure and accounting for restricted draft routings.

B/T	Ships of Lbp <130m	Ships of Lbp 130-160m	Ships of Lbp >160m
Pre 1990	2.9 - 4.9	2.9 - 4.6	3.3 - 4.7
Post 1990	3.6 - 4.9	3.7 - 4.6	3.2 - 4.7

B/T	Ships Built post 1993	Ships Built post 1997	Ships Built post 1993
	3.2 - 4.9	3.6 - 4.9	
Vs ≥24			3.6 - 4.6

- T/D ratio: The T/D ratio is of particular importance for the damage stability, because of its direct relation to the ship's intact (and damage) freeboard. It is notable that this ratio obviously decreased (indicating increased freeboard), *Figure 4*.

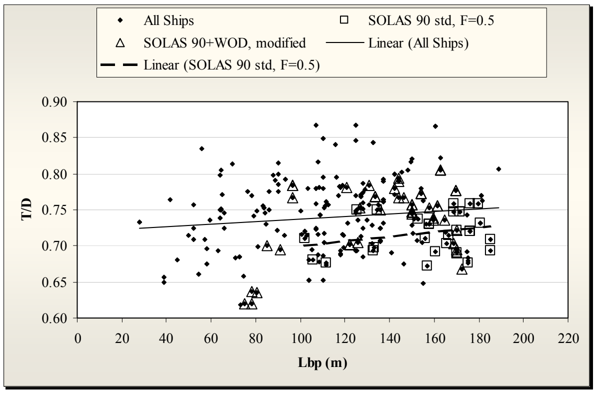

Figure 4: T/D ratio acc. to stability standard

Ships with enhanced stability standard, as built, have a T/D ratio within the range of 0.67-0.76.
Regarding ships that are modified to comply with the enhanced regulations, i.e. SOLAS 90+WOD, high T/D ratios are due to external or/and internal modifications such as sponsons, ducktails, barriers, etc.

- Block Coefficient: typically increased in the average indicating increased hull form efficiency in terms of space and floatability requirements, *Figure 5*.

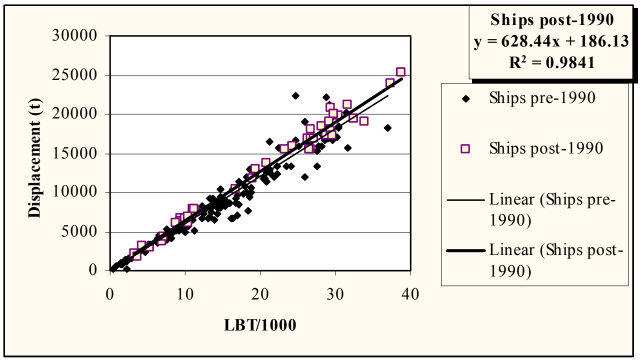

Figure 5: Displacement vs. (LBT/1000)

Regarding pre-1990 results, there is a wide spread of the analysed data, *Figure 6*.

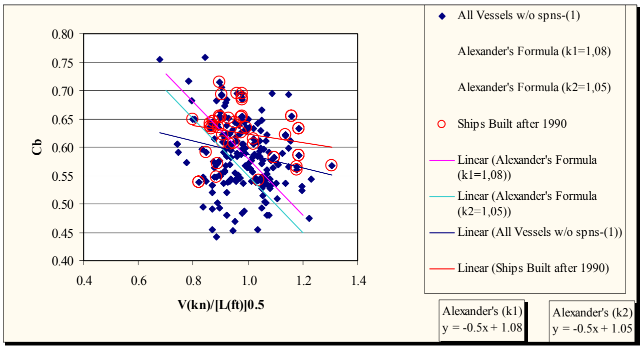

Figure 6: Cb vs. V/$\sqrt{L}$

With respect to minimum values of block coefficients, the significant point is that registered values of 0.45 for some older ships now disappeared.

Cb	Ships Built post 1993	Ships Built post 1997	Ships Built post 1993
	0.54 - 0.72	0.56 - 0.65	
Vs ≥24			0.56 - 0.65

- Powering and related coefficients: The coefficient of the English Admiralty, Cn, reflects the hydrodynamic efficiency of the ship's hull form. It can be noted that vessels built post-1990 have improved hydrodynamic efficiency, *Figure 7,* despite the fact that operational speeds (Froude numbers) and the block coefficients are in the average higher.

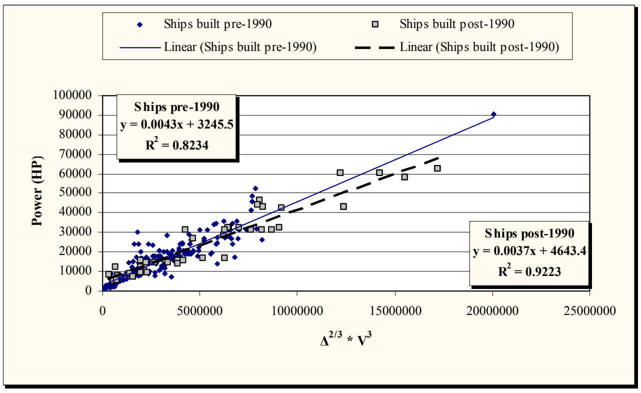

Figure 7: Power vs. [(Displacement$^{2/3}$ * Speed^3)

For ships built post-1993, Cn varies as indicated in the next table.

Cn	Ships Built post 1993	Ships Built post 1997	Ships Built post 1993
	112-312	126-312	
Vs ≥24			202-312

For a given speed, the required horsepower per ton displacement of newer ships is less than for the older ones, *Figure 8.*

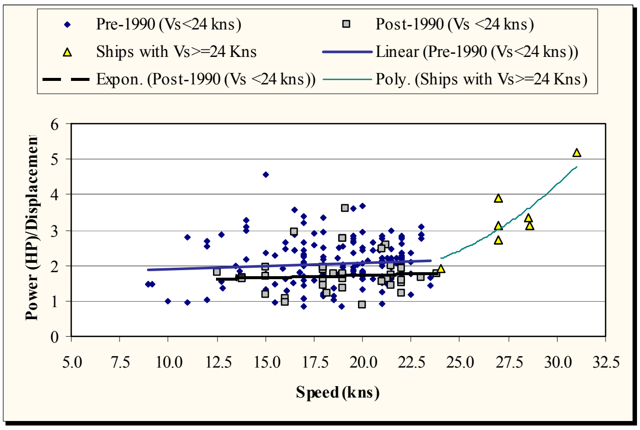

Figure 8: (Power/Displacement) vs. Speed

Figure 9 shows the installed power of Main Engines per passenger with respect to ships carrying more than 1000 passengers.

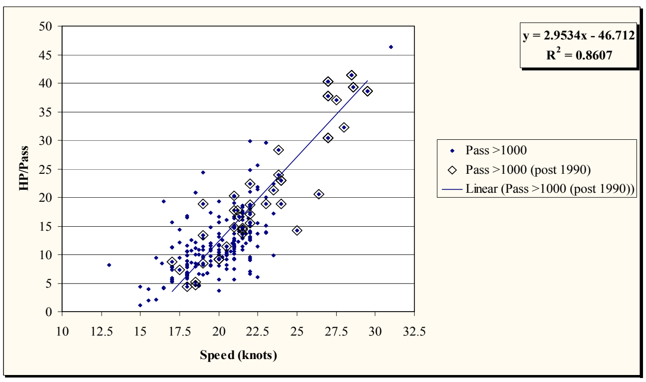

Figure 9: HP/Passengers vs. Speed

3.3 MAIN DIMENSIONS

Regarding the main dimensions, some formulae were deduced that could be useful for the conceptual design stage, *Figures 10 and 11*.

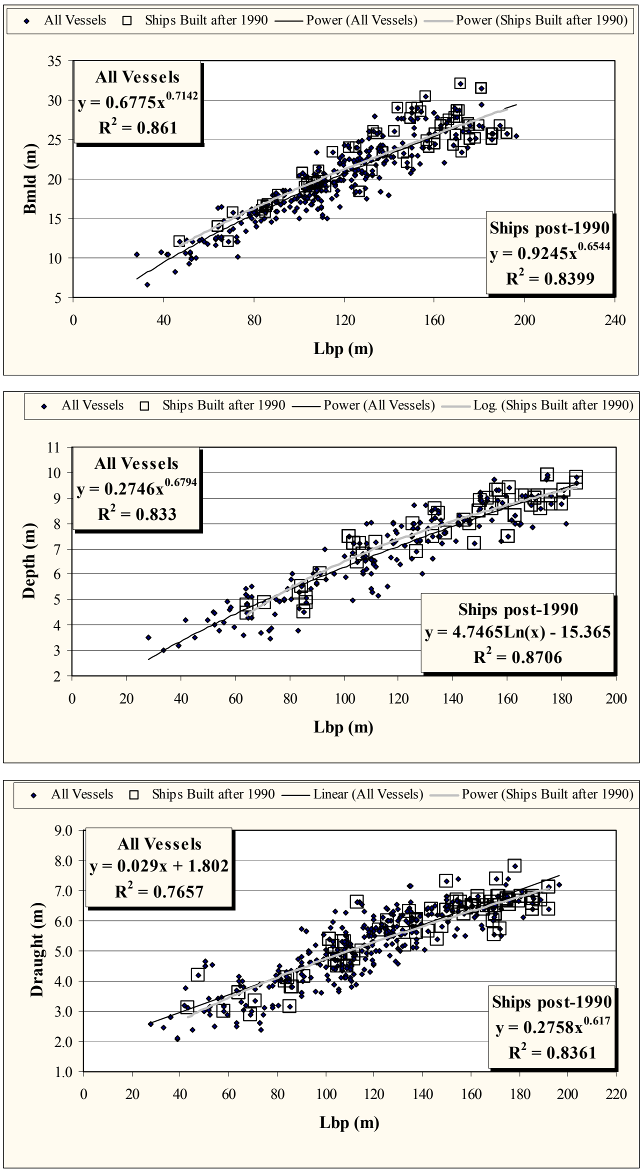

Figure 10: Main Dimensions vs. Lbp

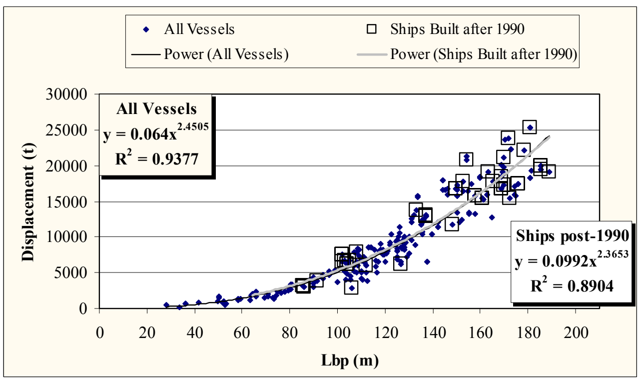

Figure 11: Displacement vs. Lbp

3.4 DISTRIBUTION OF WEIGHTS

Lightship Weight & DWT: For given main dimensions, a vessel built pre-1990 appears to have greater weight of lightship compared to the newer ones. Focusing to the post-1990 ships, lightship is increasing for post-1997 in comparison to ships built in 1990-1996, *Figure 12*.

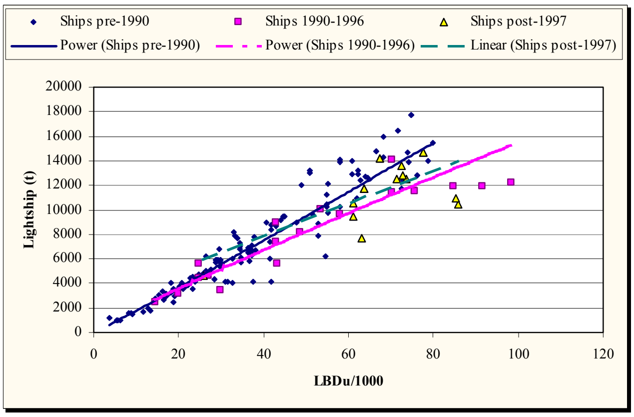

Figure 12: Lightship vs. LBDu/1000

From another point of view, the required compartmentation to meet higher stability standards, leads to an increase of lightship weight due to the additional structural weight, proportional to the number of fitted bulkheads, Papanikolaou et al (2000), *Figure 13*.

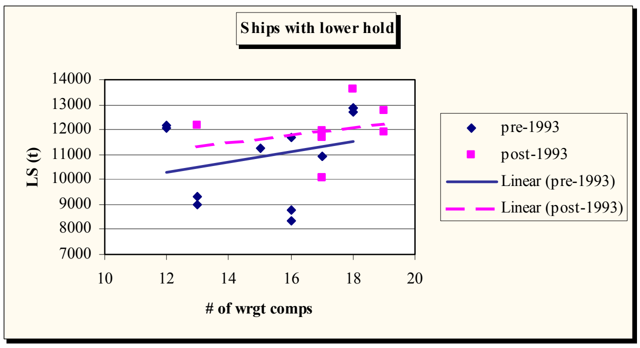

Figure 13: Lightship vs. # of basic transverse watertight compartments

Taking into account the fact that the speed of the vessels continuously increased, DWT/Δ ratios based on speed are presented in *Figure 14*.

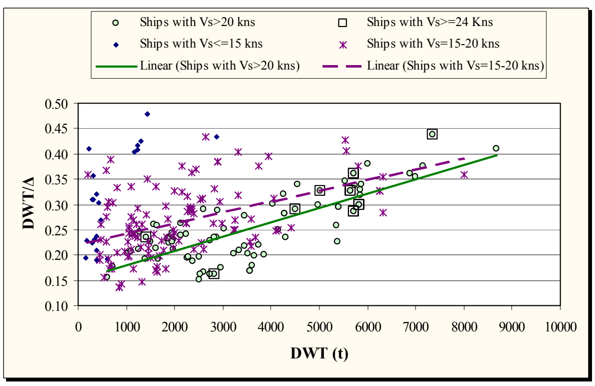

Figure 14: DWT/Displacement vs. DWT

3.5 PAYLOAD

Lanes' length/Lbp ratio: The ratio of the car Lanes' Length/Lbp has significantly increased for the newer ships, indicating the higher efficiency of modern designs. Vessels built before the year 1990 have an average ratio of 7.3, whereas those built after 1990 have a 60% higher ratio of 11.6.
For a given deck waterplane area, ships post-1990 can accommodate a larger number of lane meters than the older ones, *Figure 15*.

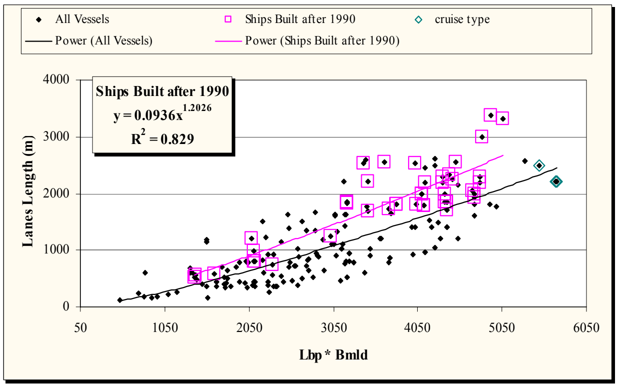

Figure 15: Lanes Length vs. Lbp * Bmld

In domestic voyages, service speeds have been kept at normal levels because it is either impossible by environmental conditions or non-economical to take full advantage of the higher service speeds, *Figure 16*.

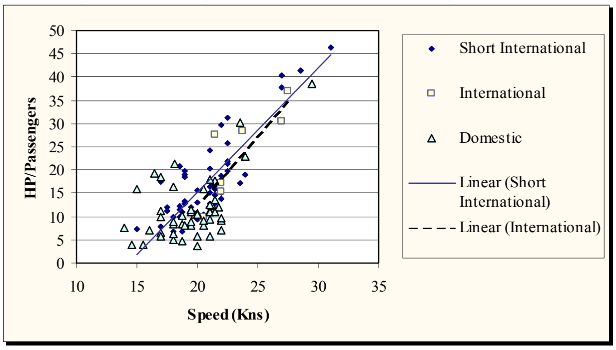

Figure 16: HP/Passengers vs. Speed, per voyage type

3.6 COMPARTMENTATION BELOW MAIN CAR DECK

The introduction of the longitudinal bulkhead concept inside B/5 line has changed the philosophy of design of the internal compartmentation below the main car deck. As a result the considerable floodable volumes have been reduced. The majority of older ships have only transverse bulkheads (TB), as a standard subdivision, to the greater extent of their length, though in newer ships the combination of transverse and longitudinal bulkheads (LB&TB) is a common feature, except for the relatively small ships, *Figure 17*.

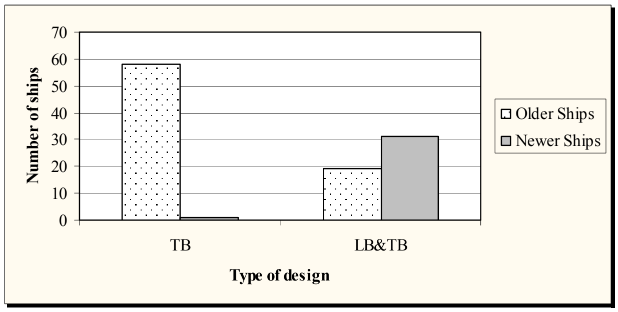

Figure 17: Distribution of type of internal compartmentation below main car deck

The length of primary transverse watertight compartments has been reduced for the newbuildings (and accordingly the number of WT compartments increased) to meet the higher damage stability standards, F*igure 18*.

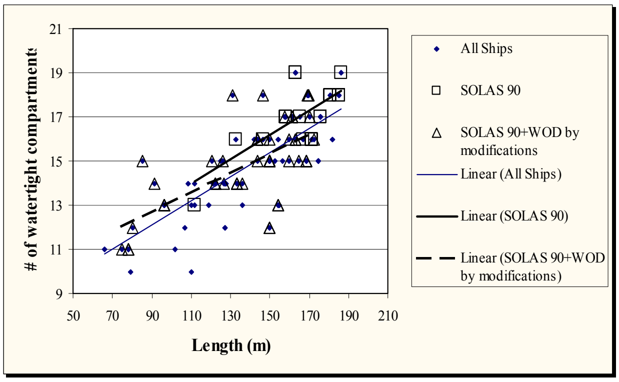

Figure 18: # of watertight compartment vs. Length

In order to utilise the space below the main car deck, as this space cannot be used for accommodation purposes by the latest SOLAS regulations, large lower hold decks inside B/5 line are adopted in new concepts, that in some cases might be exceeding even 50% of ship's length, *Figure 19*.

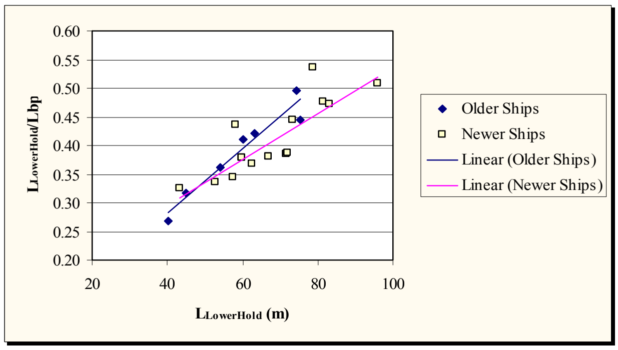

Figure 19: Lower hold Length/Lbp vs. Lower hold Length

Although these large unified spaces are considered intact in typical SOLAS damage conditions, there might be the cause of serious stability problems in cases of actual penetration beyond B/5, if not properly arranged.

The length of engine room appears to become shorter, for given installed power, *Figure 20*. This is attributed to the consideration of alternative machinery arrangements and the use of more compact machinery units.

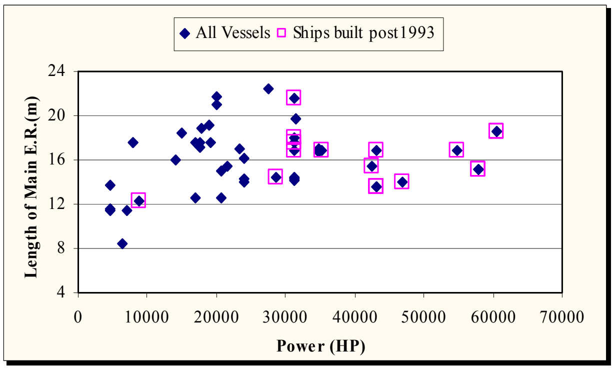

Figure 20: Length of Engine Room vs. installed power

3.7 OUTFITTING

3.7 (a) Stern Ramps

Dimensions of ramps influence their structural design but also ship's operation and efficiency with respect to cargo handling speed.
Normally length varies between 5-12m. Longer ramps of about 20m can also be fitted but are foldable, *Figure 21*.

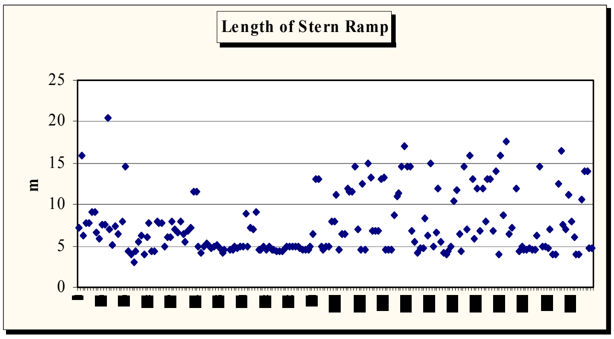

Figure 21: Length of stern ramps

Very wide ramps have been detected at newer ships reaching in some cases 90% of ship's breadth, *Figure 22*.

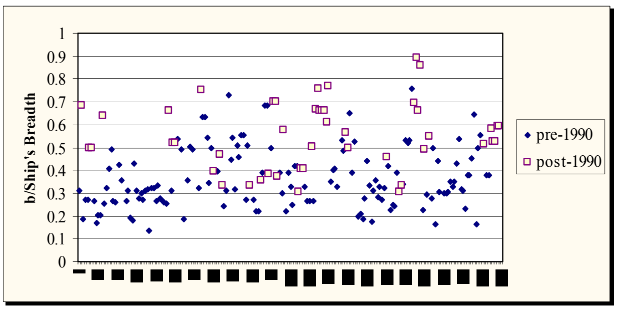

Figure 22: Total breadth of stern ramps/Ship's Breadth ratio

The water ingress through the stern opening might be a problem with poorly maintained stern doors in cases when the seawater level is quite close to the down edge of the ramp. Although newer ships have greater freeboard, it must be noted that in some cases, a roll angle of 9-10 degrees can immerse the down edge of ramps, *Figure 23*.

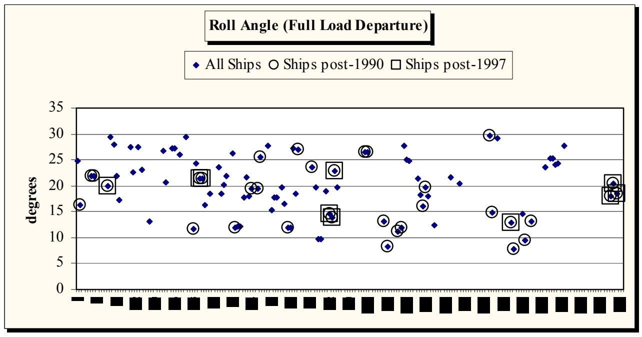

Figure 23: Angle of immersion of down edge

3.7 (b) Thrusters

Bow and even stern thrusters are, nowadays, standard devices for European Ro-Ro Passenger Ferries. Regarding post-1990 ships, the 4% not having fitted thrusters concern small ships of Loa under 70m, *Figure 24*.

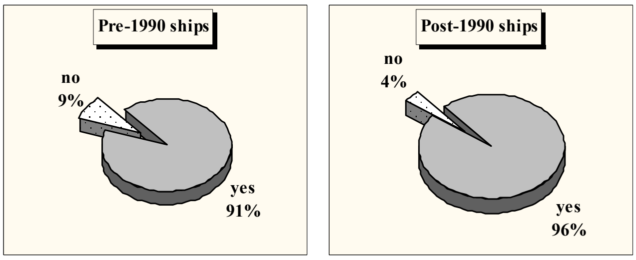

Figure 24: Distribution of existence of thrusters

A significant parameter is also the increased thrusters' power that improves the maneuverability of ships, *Figure 25*.

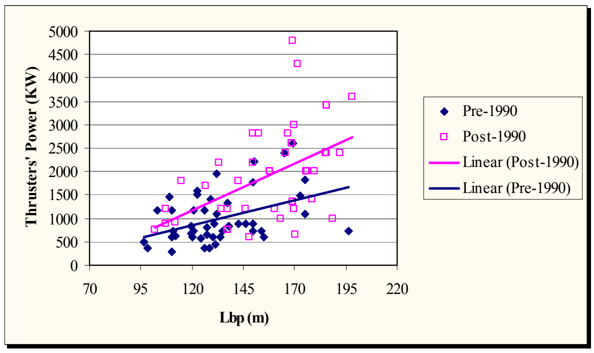

Figure 25: Thrusters' power vs. Lbp

3.8 INTACT STABILITY

Freeboard is an essential parameter affecting the stability and safety of ships both in intact and damage condition. A comparison of the intact freeboards between vessels of different stability standard shows that SOLAS 90 2-compartment standard and A.265 ships dispose comparable and in general larger intact freeboard heights, *Figure 26*.

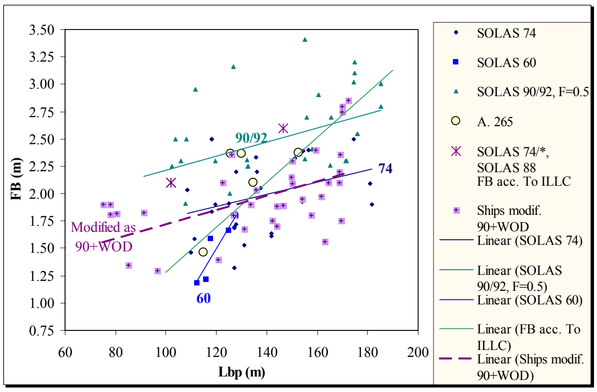

Figure 26: Intact Freeboard vs. Lbp

Note that intact freeboards for the larger new ships are close to and over 2.5 m, what clearly calls for the provision of new docking facilities in some European ports, currently adjusted to freeboards in the range of 1.5 to 2.0m.

Enhanced stability standard clearly requires greater GM values, *Figure 27*. This should generally affect ship's sea kindness, as ships become stiffer in roll and passengers might experience higher transverse accelerations. However, this negative effect of GMt on seakeeping is commonly counteracted by the employment of stabilising fins and of antirolling tanks.

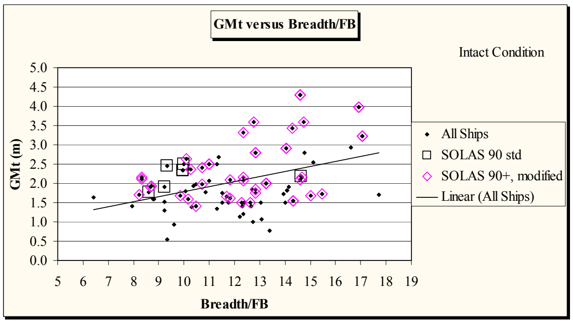

Figure 27: Intact GM vs. Breadth/Intact Freeboard

3.9 DAMAGE STABILITY

Newer vessels have improved damage stability characteristics due to their compliance with enhanced damage stability criteria, *Figure 28*.

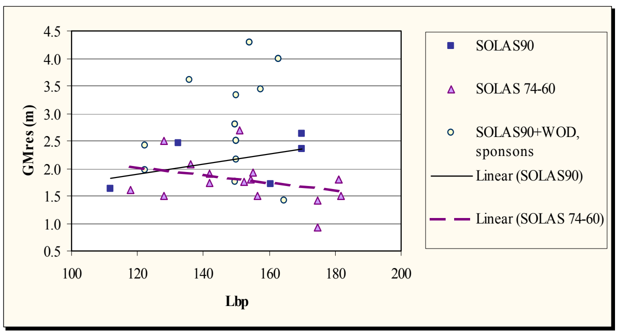

Figure 28: Distribution of residual values of GM

4 CONCLUSIONS

Decisions in the early ship design stage strongly depend on the designer's expertise and knowledge from the past, but also on the knowledge of 'state of the art' technological developments.

Technical ship data to the extent collected herein in a systematic manner are rare, though considered essential in the conceptual-preliminary design stage, that is the stage in which major technical and economic ship characteristics are determined following the owner's requirements and statement of work.

The collected data can be not only exploited in the conceptual design stage, but also for the crosschecking the data of individual designs under consideration. Also, the derived regression formulae might be useful in the set-up of a computer-aided optimisation procedure, as planned in WP3 of the ROROPROB project. Note, however, that in this latter case, special attention should be paid in the careless use of specifically suggested regression formulae, especially in those cases for which the extent of the sample appears small and/or the spread of the collected data large (low R^2 regression values).

5 ACKNOWLEDGES

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