Damage Stability of Ro-Pax Ships with Water-on-Deck

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ABSTRACT

Currently European ro-ro passenger ships constructed after 1 January 2009 must comply with both the new SOLAS2009 probabilistic damage stability requirements and the Stockholm Agreement allowing for water accumulation on the vehicle deck (WOD). Doubts in some European states over whether SOLAS2009 makes sufficient provision for WOD led to the EU decision to retain Stockholm; this was partially reinforced by results from three new research projects, completed in 2009, which revealed potential weaknesses in the probabilistic regulations, particularly for smaller ro-pax ships and those with long lower holds. This paper gives some historical background and outlines some of the steps being taken to rectify the current regulatory situation.

KEYWORDS

Ro-Ro; Damage Stability; SOLAS; IMO.

INTRODUCTION

This paper aims to supply some background to the current situation at IMO with respect to the safety of new ro-ro passenger ships constructed after 1st January 2009 following the introduction of the SOLAS2009 amendments. It includes a brief historical background and goes on to highlight some of the issues which have led to the current regulatory situation in which new ro-ro passenger ships operating in European waters must continue to comply with the Stockholm Agreement as well as with SOLAS2009.

There follows a short section on the ongoing work of the IMO SDS Correspondence Group in trying to address the technical issues underlying three research projects completed in 2009 which examined new ro-ro ship designs compliant with SOLAS 2009. These results, which revealed some weaknesses in the new regulations particularly for smaller vessels and those fitted with long lower holds, have led to the initiation of further research projects which are currently in progress. It is hoped that the results emerging from these new projects will eventually assist IMO in producing satisfactory updates to the SOLAS2009 regulations and accompanying explanatory notes.

Since the task of harmonizing damage stability regulations based on probabilistic methods was initiated more than 15 years ago there have been immense improvements in the computer hardware and software tools available to investigate ship safety. It is hoped that these developments will be fully utilized in the latest research projects to increase our knowledge of the complex issues surrounding the survivability of ro-ro passenger ships. As an approving Authority, however, the MCA has some concern as to how to keep abreast of these developments especially if, in future, direct calculation methods are used to produce radical new designs which will require approval. Perhaps as an industry we need to consider further benchmarking procedures to increase our confidence in the results from, for example, the various numerical techniques currently being developed and used by different organisations.

The main objective of this paper is therefore to encourage dialogue between IMO and the research teams working on the latest ro-ro damage stability projects so that members of the SLF correspondence group and working group, many of whom represent approving Authorities, can be kept fully informed of the latest developments.

HISTORICAL BACKGROUND

The SOLAS regulations are subject to almost continuous review and updating to reflect changes in ship size, type and design and to meet demands for increased safety. Regrettably the regulations have had to be amended on occasions in the wake of a major disaster, indeed the origins of SOLAS can be traced back to the loss of the Titanic in 1912. The losses which particularly affected the regulatory regime for ro-ro passenger ships were the "HERALD OF FREE ENTERPRISE" in 1987 and the "ESTONIA" in 1994. The former led to the early implementation of the planned revisions known as SOLAS90 and the latter to the Stockholm Agreement, which was at the time applicable only to ro-pax vessels operating in N.W. European waters under a SOLAS dispensation allowing local regional agreements to be applied in sea areas considered to be particularly dangerous, whether for congestion or weather conditions.

The disquieting thing about ro-ro passenger ships is the suddenness of the loss following ingress of water onto the open vehicle deck area. The time from the initiating incident to ultimate loss can be so short (a matter of minutes) as to preclude the possibility of anyone being rescued by LSA, with only the fittest (and luckiest) standing any chance of survival. The measures taken in the 1990's to upgrade the existing ro-ro fleet to comply with the Stockholm Agreement and the recognition in new ships that the "water on deck" problem could best be addressed by increasing the residual freeboard after damage seems to have led to a reduction in ro-ro casualties, at least in European waters, but continual vigilance on both the design and operational fronts is necessary.

The collision damage scenarios envisaged by the SOLAS regulations and the Stockholm Agreement – namely side damage to 1 or 2 compartments with a maximum penetration depth of B/5 metres – were not the principal cause of the loss of either the "HERALD" or the "ESTONIA". More recently the loss of the "AL-SALAM BOCCACCIO 98" was attributable to water accumulation on the car deck during fire-fighting operations rather than to collision damage. The common feature of all these tragedies is water accumulation on the vehicle deck. The survivability of a ship complying with the SOLAS90 regulations has not been fully tested in a severe real-life collision. To our knowledge, there has yet to be an incident involving major penetration past the B/5 limit on a ro-pax ship in EU waters - a limit which the accident statistics indicate has historically been exceeded in around 45% of side damage cases.

Concerns that the deterministic regulations only covered limited damage scenarios encouraged development of a new approach to try to deal more comprehensively and scientifically with the problem of damage stability after collision. Originally introduced in 1973 in IMO Res. A265(VIII), then in the 1992 dry cargo ship rules (SOLAS Chapter II-1, Part B-1, Regulations 25-1 to 25-9), the probabilistic approach aimed to remove the limitations of compliance with pre-determined damage scenarios, "outmoded" concepts such as 1 and 2 compartment damage, B/5, floodable lengths and margin line. Instead, formulae and a methodology encompassing a much wider range of damage scenarios derived from an updated and larger database of accident statistics was introduced. The "harmonized" regulations (which in one move replaced deterministic SOLAS90 for passenger ships, the probabilistic dry cargo ship regulations in SOLAS90 Part B-1 and IMO Res A.265) were brought into force in 1st January 2009 as the SOLAS2009 amendments.

To comply with these new regulations, a proposed design must achieve a required index, “R” based on a formula including ship length and the number of persons carried. In general the more passengers carried and the greater the length, the higher “R” becomes. “R” was established using regression techniques on existing ships to try to give, on average, an overall safety level equivalent to that of the preceding deterministic SOLAS90 regulations (excluding, it is now widely believed, the Stockholm Agreement for ro-pax ships). The new design is analysed through subjection to a large number of damage stability cases, determined from damage probability distribution curves derived from the accident database, at 3 pre-determined draughts. Each damage case which survives to a degree determined by the so-called “s”-factor formula based on heel angle, residual GZ and range, then contributes towards a summated attained index, “A”, weighted according to draught, which must be equal to or exceed the “R” index for the design to be approved.

Perhaps because of the UK’s particular anxiety to avoid a repetition of the loss of the HERALD with its unhappy consequences, the MCA initiated a design study into the safety of several different ship types which would be required to comply with SOLAS 2009 [Ref. MCA project RP 552]. The conclusion was that there could be a particular problem with ro-ro passenger ships. Crucially, due to the nature of the probabilistic approach, SOLAS 2009 permits designs in which individual simple, feasible damage scenarios can result in the rapid capsize of a ro-ro passenger ship in spite of the inclusion of a regulation (8) to prevent minor damages from having major consequences. Under the SOLAS90 deterministic regulations such scenarios would have so severely constrained operability (in terms of draught, floodable lengths and/or limiting KG/GM) that design changes would usually have been enforced. The UK also believed that insufficient attention was paid before the introduction of SOLAS2009 to designing new ships exclusively to meet the new requirements which involved a step-change from previous methods. Some work on testing new designs was carried out within the HARDER project, but the regulations for ro-ro ships were later changed considerably during adoption at IMO (for example by removal of the SEM).

These and some other concerns were raised at successive meetings of COSS in Brussels. Eventually the EC and EU member states, having been alerted to some worrying results emerging from a new research project (RP592), funded jointly by the UK and NL, in which two new ro-ro ships were optimized to meet SOLAS2009, submitted a paper (ref. MSC 84/12/12) to IMO MSC asking for the issue of ro-ro damage stability to be re-opened for discussion at SLF. In the meantime, as a temporary precautionary measure, the EC decided that new post-1/1/2009 ro-ro ships should continue to comply with the Stockholm Agreement as well as SOLAS2009.

DEVELOPMENTS AT IMO

At IMO in July 2008 the SLF 51 sub-committee responded to MSC 84/12/12 by tasking the SDS correspondence group with assessing the various technical issues raised by new ro-pax research projects then underway and due to complete in 2009. The CG submitted a report (ref. SLF 52/11/1) which concluded that some amendments to SOLAS2009 for ro-pax ships may be necessary and these should be based on further research in particular on smaller ships with fewer passengers and on ships with long lower holds especially those fitted with B/10 longitudinal bulkheads.

At the SLF 52 meeting in January 2010, the sub-Committee asked the correspondence group to continue the work of assessing the results of further new research projects investigating ro-ro passenger ship damage stability. These projects, notably GOALDS (the subject of another paper at this meeting) and a follow-up design project initiated by EMSA are not expected to conclude until

2011/12. It is hoped that the leaders of these projects will keep IMO regularly informed as to the progress being made.

SOME DISCUSSION POINTS

As this is a workshop, a few points and questions follow which it is hoped may provoke further debate on some of the unresolved issues still surrounding ro-ro damage stability.

(1) Why Focus on Ro-Ro Passenger Ships?

In the UK our concern was always that the loss mechanism for ro-ro passenger ships is quite different from that of conventional passenger ships. The latter can technically capsize (however that is defined) but stay afloat for a lengthy period thanks to the reserve buoyancy provided by the superstructure and the relatively slow speed of progressive flooding allowing more time for evacuation. A ro-pax ship in contrast can capsize and sink in a matter of seconds once sufficient water builds up on the large open car deck leading to potentially much higher casualty rates. The focus of our attention was therefore to seek assurance that the SOLAS2009 regulations are at least as effective in providing for the dangerous WOD effect in ro-pax ships as SOLAS90 and the Stockholm Agreement, imperfect as the latter combination may have been.

(2) Loss Mechanism for LLH Ro-Pax Ships

There are two main designs of ro-pax ship – one which is entirely transversely sub-divided below the car deck (usually employed on short crossings with rapid turnaround times) and one which combines longitudinal and transverse subdivision forming a long, lower hold (LLH). The loss mechanism for a LLH ro-pax ship may be quite different from one which is only transversely sub-divided below the vehicle deck. An unpublished UK study (RP 564) carried out on an existing LLH ro-pax ship compliant with IMO Res A.265 showed that damaging the LLH, one wing compartment and the vehicle deck results in margin line immersion as the LLH slowly fills and then sudden loss as water rapidly spreads over the car deck. The vessel sank in less than 20 minutes (real time) in almost calm conditions, the primary cause being the immersion of the margin line quickly followed by complete loss of reserve buoyancy.

At least two of the studies carried out in 2009 showed it is possible to design new SOLAS2009 LLH ro-ro ships which also sink rapidly in calm seas following penetration of the LLH, which raises the question of whether this possibility was considered when the SOLAS2009 regulations were being developed. Attention seems to have been focused on the residual GZ curve but if the vessel simply sinks without reaching equilibrium then no such curve exists ($s = 0$). At present within SOLAS2009 there is no penalty for $s = 0$ in individual damage cases as long as $A>=R$ and the minor damage regulation 8 is complied with. Whilst some of the $s = 0$ cases may be associated with relatively gradual loss of stability, others could be due to rapid sinkage or capsize due to WOD with high casualties and should therefore not be lightly dismissed. The issue of whether SOLAS2009 has taken sinkage in calm conditions into account is to be examined in more detail in a new MCA-sponsored research project (RP 625) which should be completed by the end of 2010.

(3) Transversely Subdivided Ro-Pax Ships

In contrast, the loss mechanism for a transversely sub-divided ro-pax may not necessarily involve margin line immersion at equilibrium in calm seas but usually arises from a low residual freeboard due to a combination of sinkage, trim and heel followed by gradual water accumulation onto the car deck through the damage opening due to wave action. Here there is some relationship between significant wave height, residual freeboard, residual GZ (dependent on initial KG and the extent of damage) and the amount of water accumulation. The simplified calculations in the Stockholm Agreement allow for these relationships whereas using the alternative model test approach it is considered satisfactory if the vessel survives all 5 test runs for a particular worst damage case for a period of 30 minutes real time in the appropriate sea-state. This loss mechanism was originally to be accounted for in SOLAS2009 by the SEM (static equivalent method) or a method based on residual freeboard but these were both dropped at SLF 47 in favour of the so-called GZ approach advocated by Sigmund Rusaas as discussed below.

(4) The s- factor – development of equation

The key paper, "*Review of WOD and the GZ Approach*", which led to the adoption of the current equation for sfinal,i in SOLAS2009 Reg. 7-2.3

$$s_{\text{final,i}} = K \cdot \left[\frac{GZ_{\max}}{0.12} \cdot \frac{Range}{16} \right]^{\frac{1}{4}}$$

was presented by S.Rusaas to an SLF inter-sessional meeting in Malmo in December 2003. The graphs shown in fig. 1 and 2 of this paper show the relationship between residual GZ and critical wave height leading to capsize (Hs) for ro-ro and conventional passenger ships.

Given the following statement in an earlier HARDER paper incorporated into SLF 45/3/3 p.24 there seem to be some justifiable doubts as to its correctness:-

"Alternatively [for ro-pax ships] the traditional GZ based formulation can be used as a correlation to the probability of survival from the model tests. A format similar to the current proposal in the harmonised regulations is possible:

$$s = [(GZmax/TGZmax)*(Range/TRange)]^{1/4}$$

Where, TGZmax = 0.25m and GZmax not to exceed TGZmax

TRange = 16 degrees and Range not to exceed Trange"

This question was investigated further in the jointly-funded UK/NL project RP592 in which it was shown that increasing TGZmax from 0.12 to 0.25 m for the two new S2009 ro-ro ships designed in the study would result in a reduction of only around 1% in the Attained Index A - a figure apparently correctly predicted in Rusaas' paper. In fact RP592 showed that the relative insensitivity of A to the TGZmax terms in the s-factor equation is attributable more to the fact that a large proportion of damage cases either have s = 0 or s = 1. Only the relatively few cases where 0<s<1 would be influenced by changing TGZmax from 0.12 to 0.25m. It was argued in the report for RP592 that this could vary from ship to ship and that it would be more correct and conservative to use a TGZmax of 0.25 m.

Rusaas argued that 90% of the collisions in the accident database occurred in sea states with SWH < 2 m and virtually none with SWH > 4 m. Fig. 2 of the paper shows that the maximum difference in the s factor between a conventional and a ro-ro passenger ship (which is assumed to be attributable to the WOD effect) is around 10% and this is most pronounced when the GZmax for each type of ship is around 0.1 metres - equivalent to a critical sea state leading to capsize (Hs) of around 1.8 metres for a ro-ro ship and 3 metres for a conventional passenger ship. Where the GZmax is 0.05 m or less (Hs = 1 m for both types) or 0.3 m and above (Hs = 3.9 m for ro-ro's and Hs > 12 m for conventional passenger ships) the s factors are almost the same for both ship types. As both vessel types have equally low survivability at residual GZmax of 0.05 m and there are virtually no instances of collision damages occurring in high sea states such as 3.9 metres SWH and above (sea states in which there would be a pronounced difference between ro-ro and conventional passenger ship survivability), the paper concludes that outside a range of GZmax values between 0.05m and 0.20 m, there is virtually no difference in the s-factor between ro-pax and conventional ships and the WOD effect can therefore safely be neglected.

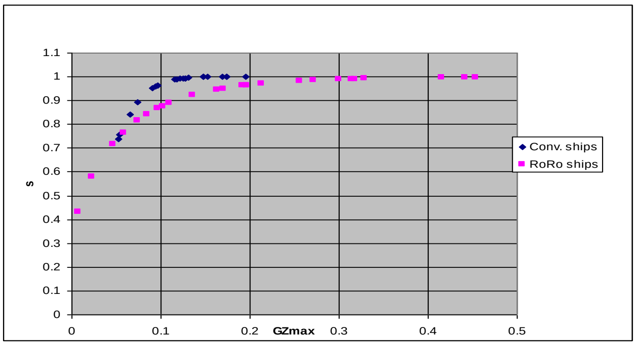


Fig. 1: From S. Rusaas' paper "Review of WOD and the GZ approach" Dec. 2003 fig.2; s- factors for trendlines of Hs.

Rusaas' paper, quoted in IMO SLF 47/3/9, persuaded the majority of member states at SLF to accept the adoption of the GZ approach using a value of GZmax of 0.12 in the above equation covering both ship types. The implication is that there is no evidence for any significant difference between the overall survivability of ro-pax ships and conventional passenger ships within a probabilistic framework and that the WOD can therefore be safely ignored.

The link, established in Stockholm, between residual freeboard and ro-ro survivability (the greater the residual freeboard and the lower the sea state, the less chance of water accumulation on the car deck) is not explicitly expressed in the adopted equation for s-factor.

(5) The s- factor – based on limited data

One major concern with Rusaas' paper is that the conclusions have necessarily been drawn from a rather small set of data. Fig. 2 shows that 68% of the points are taken from model test results for one ro-pax ship (PRR-01). PRR-01 is a transversely sub-divided ro-pax (for full details and a GA see HARDER paper 3-31-D-2001-01-0) and was model tested for one asymmetrical damage case (midships, standard SOLAS extents) for 3 different draughts and trims and 4 different initial KG values. Dividing the data used to produce Fig. 2 into separate ships and fitting individual regression lines gives a truer picture of the variability of the relationship between Hs and GZmax.

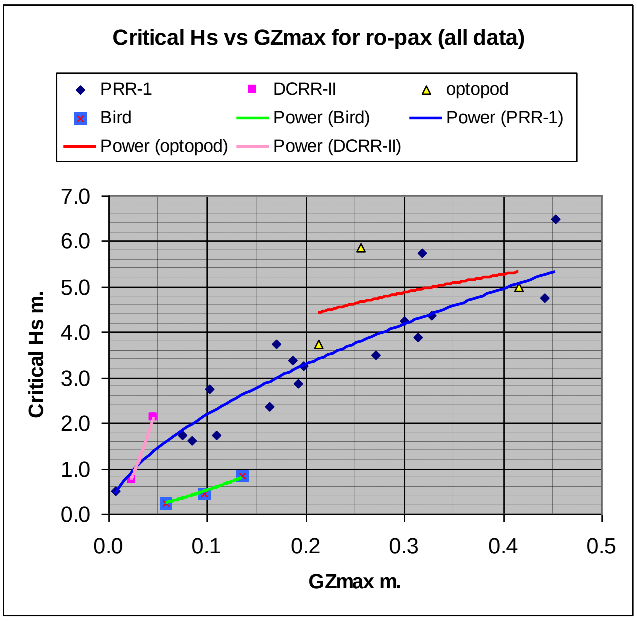


Fig. 2: From S. Rusaas' paper "Review of WOD and the GZ approach" Dec. 2003 fig. 1. Re-drawn to show that 68% of points are for one ship (PRR-01) only tested for 1 midships damage case with penetration depth < B/5

This can be seen more clearly in Fig. 3 which presents curves of Hs against initial KG for PRR-01 for the 3 tested draughts and clearly shows the easily anticipated trend for decreasing survivability with increasing draught and initial KGf for the particular damage case in question.

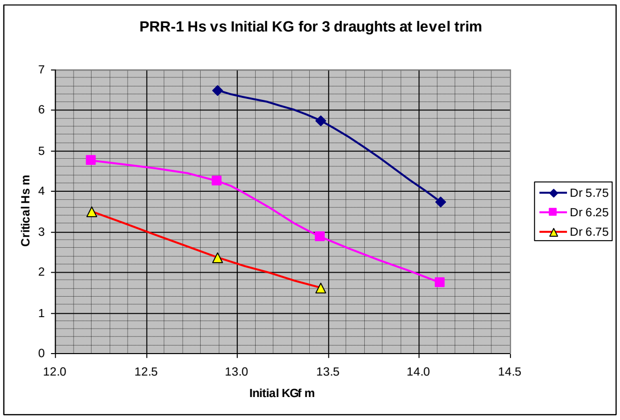
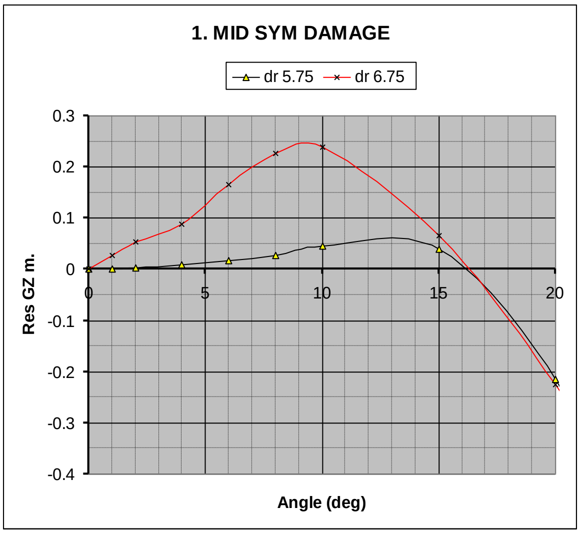


Fig. 3: PRR-01 data re-analysed to show relationship between initial draught, KG and Hs for the midships damage case.

(6) The s- factor – residual range ensures large GZmax?

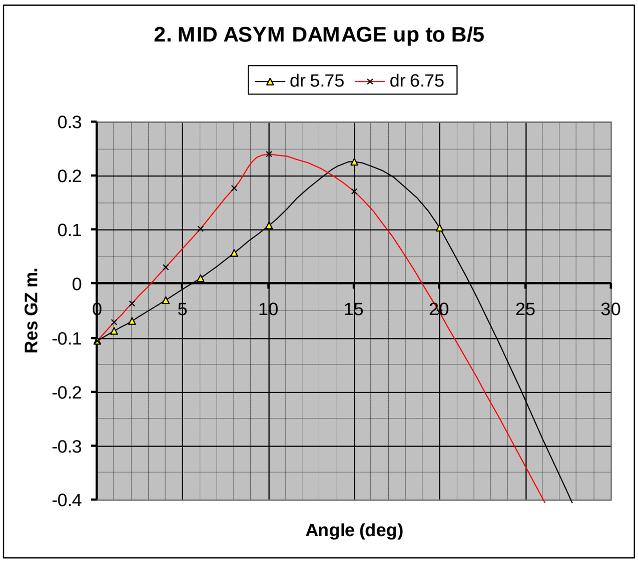
Rusaas also argues that residual range and GZmax are strongly linked (see fig. 3 in his paper) and that if a ro-pax has a residual range of 16 degrees, the GZmax is likely to be around 0.3 metres implying a critical wave height for capsize of around 4 metres. As virtually no collisions have ever occurred in such high sea states the conclusion is drawn that the residual range term within the s-factor can be relied upon to predict the critical wave height for capsize for a ro-pax with acceptable accuracy.

Our concern is, however, that the assumed general relationship between residual GZmax and range is based on data from only one damage case – at amidships, asymmetrical with penetration depth of B/5 – on a ship with mainly transverse subdivision below the car deck (PRR-01). To test whether the assumed 16 degrees / 0.3 metres relationship between residual range and GZmax is more widely applicable, we created 2 simple box-shaped computer models having the same principal dimensions as PRR-01. The first was purely transversely sub-divided so that a midships damage resulted in symmetrical flooding between transverse bulkheads; the second had a long lower hold 40% of LBP in length with B/5 longitudinal boundaries. The second model was subjected firstly to a B/5 asymmetrical damage to the wing tank then to a deeper damage penetrating into the LLH. In all cases the vehicle deck was damaged with 90% permeability. These damages were applied at a light draught of 5.75 m and a deep draught of 6.75 m and the resulting damage GZ curves (figs 4-6 below) were adjusted to give a residual range of approximately 16 degrees by varying the initial KGf to determine the corresponding GZmax.



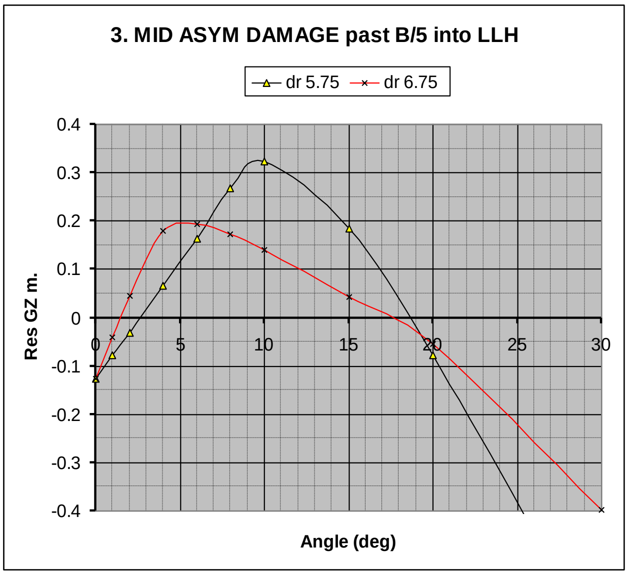
Draught	GZmax for 16 deg range	Hs m.	Initial KGf m
5.75	0.06	1.5	13.6
6.75	0.25	3.8	11.1

Fig. 4: Transversely subdivided box-shaped vessel – amidships symmetrical damage



Draught	GZmax for 16 deg range	Hs m.	Initial KGf m
5.75	0.225	3.5	12.85
6.75	0.240	3.7	10.85

Fig. 5 LLH Box-shaped vessel – amidships asymmetrical damage up to B/5



Draught	GZmax for 16 deg range	Hs m.	Initial KGf m
5.75	0.323	4.3	10.75
6.75	0.193	3.2	7.7

Fig. 6 LLH Box-shaped vessel – amidships asymmetrical damage past B/5 into LLH

This brief exercise appears to show that the GZmax/Residual Range relationship of 0.3 / 16 used to confirm that the equation for s-factor in the SOLAS 2009 Regulation 7-2.3 is equally applicable to ro-pax and conventional passenger ships, may well be valid only for the specific amidships asymmetrical damage case tested for PRR-01 in the HARDER project (corresponding approximately to case 2 in the above study). It therefore seems that a much wider spread of data involving more extensive damages to different ro-ro designs is needed. Perhaps basing the s-factor only on heel, MaxGZ and residual range is too simplistic especially as all these parameters are primarily dependent on initial draught, KG and the damage extent.

These problems may have been compounded by the possible neglect of sinkage as a loss mechanism in SOLAS 2009 - something clearly demonstrated in two of the ro-pax research studies completed in 2009. In our opinion, these uncertainties regarding the s-factor fully justify the extra research work now being undertaken.

CONCLUSIONS

It is hoped that the new research projects - EMSA2, GOALDS, RP625 and FLOODSTAND - using the latest analytical tools will shed more light on some of the issues raised in this paper and eventually inform further discussions at IMO as we seek to ensure that the SOLAS2009 regulations for ro-ro passenger ships are fit for purpose.

Ro-ro vessels are fundamentally important to the economic activity of many countries and yet can remain a relatively vulnerable mode of transport if due precautions are not taken in their design and operation.

The common aim is that we all want to be convinced that new generations of post-2009 ro-ro passenger ships will be able to fully utilize the flexibility of design offered by the probabilistic approach or alternative methods and yet be safer for the travelling public than those built in preceding generations.

REFERENCES

Rusaas, "Review of WOD and the GZ Approach", presented to an SLF inter-sessional meeting in Malmo in December 2003.

Jasionowski, Investigation into the Safety of Ro-Ro Passenger Ships fitted with Long Lower Holds – Phase II. MCA RP592, March 2009.

The above papers and many others relevant to this issue can be readily accessed from the following MCA web-site:-
http://m3net.mcga.gov.uk/c4mca/imosdscg.htm

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