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Theoretical Investigations on the Container Loss of MV Pacific Adventurer off Cape Morton, Queensland

Prepared for: Bundesstelle für Seeunfalluntersuchung, Hamburg

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1. Scope of the Investigation

Several Accidents with German flagged container vessels in ballast condition resulted in heavily injured or even killed crew members on the bridge. These accidents were investigated by the German BSU (see BSU- reports 391-09 and 510-08). All accidents were characterized by extremely violent roll motions and all accidents happened in head or bow quartering seas. Transversal accelerations of 1.2g and more have been computed in the accident situations. As all accidents happened in ballast or close to ballast conditions, it was suspected that the very large GM- values were the main cause of these accidents and that it should be a reasonable option to avoid such kind of accidents by introducing upper limits of stability. However, detailed analyses of the accidents have shown that the accident cause was not related to excessive stability only, but they were governed by large direct wave moments which were introduced into the ship by the seastate. Therefore, none of the phenomana dealt with by IMO currently (parametric rolling, synchronous rolling etc.) can explain the accident reasons, and consequently, counter measures are not developed at present.

A a consequence of these accidents, a diploma thesis was carried out at TUHH to answer the following questions:

- Are all Container Vessels in Ballast (or close to Ballast condition) vulnerable to such kinds of accidents?

- Can technical possibilities be identified to avoid such kind of accidents?

The analysis showed that more or less **all** container ships are affected by this problem. It did further show that the reason of the violent roll motion is large direct roll moment introduced into the ship by the (short crested, irregular) seastate. The analysis showed that the accelerations did not depend strongly on the stability if once a critical stability threshold value was exceeded. If the stability was further significantly increased, the accelarations were then reduced. But it was also shown that the stability could not be reduced (or significantly increased) for operational reasons. And it was also shown that no simple rule of thumb exists at present which allows to predict such kind of accidents (except for detailed numerical simulations with appropriate methods). Therefore, the German BSU is interested in any accident of a Container vessel which may have the same accident cause. This is the reason for the present analysis: To figure out whether the accident reported by the **Australian Transport Safety Bureau** in their report 263 MO 2009-002 has comparable accident causes as the German accidents and to better understand the relevant physical phenomena.

Besides this general aim, the PACIFIC ADVENTURER accident has some interesting details which may help to clarify some conclusions that were drawn from our accidents: After the CHICAGO EXPRESS accident (BSU report 510- 08) we had suggested as one possible option to use partly filled tanks with large free surfaces to improve the situation. Not to reduce the stability but to generate additional roll damping by these partly filled tanks. During the accident investigations of CCNI GUAYAS and FRISIA LISSBON we had analyzed the effect of partly filled tanks on the roll motion but found that the influence is extremely small if double bottom tanks are used (because the free surface moment breaks down immediately when the water sloshes against the top of the tank). During the PACIFIC ADVENTURER accident, free surfaces played an important role, as the crew must have tried to reduce the stability of the ship by massive use of partly filled double bottom tanks, as the accident showed, without success. Therefore the accident is a good opportunity to continue the analysis concerning the free surface influence.

Therefore the present analysis should be seen as a theoretical addendum to the BSU investigations 510-08 and 391- 09, which aims on the better theoretical understanding of these accidents to develop better guidelines to avoid such kind of accidents.

2. Statement of Facts

All relevant facts are presented in the ATSB- report No. 263 MO 2009-002, and we will summarize only those facts which are relevant for our investigations.

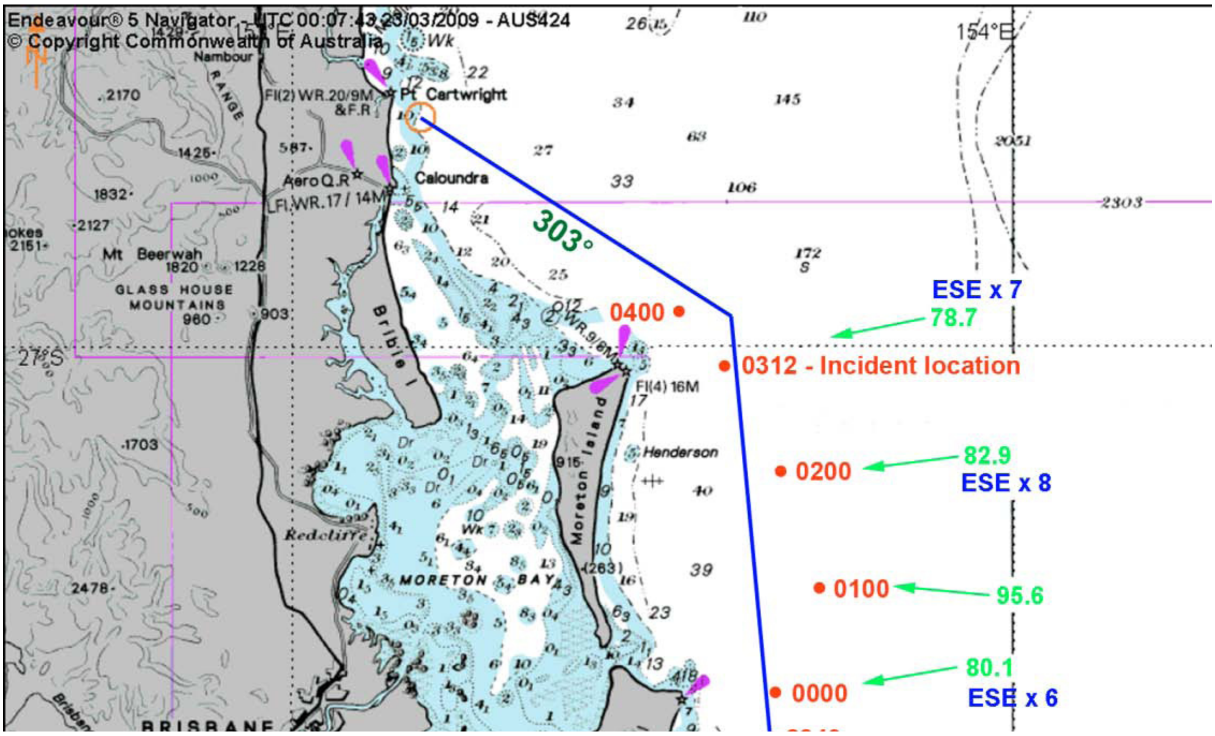

Fig. 1. Circumstances of the accident. Source: ATSB- Report No. 263 MO 2009-002, P. 27, Fig. 16

During the accident, the PACIFIC ADVENTURER was steering a course of approx. 355 Degree at a speed of abt. 9 knots. The ship encountered heavy seas from approx. 80- 100 Degree and was rolling heavily. The significant wave height was recorded to be abt. 4.7m, the significant period about 9-10s. In this respect, the accident is not directly comparable to our accidents, as the PACIFIC ADVENTURERER encountered beam seas, whereas our accidents happened in head seas or bow quartering seas. The weather conditions are exactly the same as for our accidents, where significant periods of 9-10 s and significant wave heights of 5- 7.5 m occurred. The FRISIA LISSABON accident happened at an encounter angle of about 120 degree (if 0 degree denotes following seas) and is therefore the accident which seems to best comparable with the PACIFIC ADVENTURER accident. Like the German accidents the PACIFIC ADVENTURER accident happened in a partly loaded condition which was characterized by a high (solid) value of GM.

In the accident situation, violent rolling was observed, the roll angles reported by the crew were about 40 degree (based on observations of the bridge inclinometer, which is not a reliable device to record dynamic rolling angles, refer to BSU report 510-08). However, the rolling must have been violent, which caused some containers to go overboard after the lashing has collapsed.

3. Ship and Stability Condition

The PACIFIC ADVENTURER is a multi purpose Container vessel built by Minami Shipyard, Japan, in 1991 as yard No. M 615. The main dimensions of the ship are the following:

Length over all: 184.90 m
Length between perpendiculars: 176m
Moulded breadth: 27.60m
Draft (design) 10.07 m
Depth: 14.70 m

The body plan of the ship was handed over to us by BSU/ATSB which allowed us to generate a numerical model for all stability/seakeeping computations. The body plan is shown in Fig. 2 where also the floating waterline in the accident condition is shown.

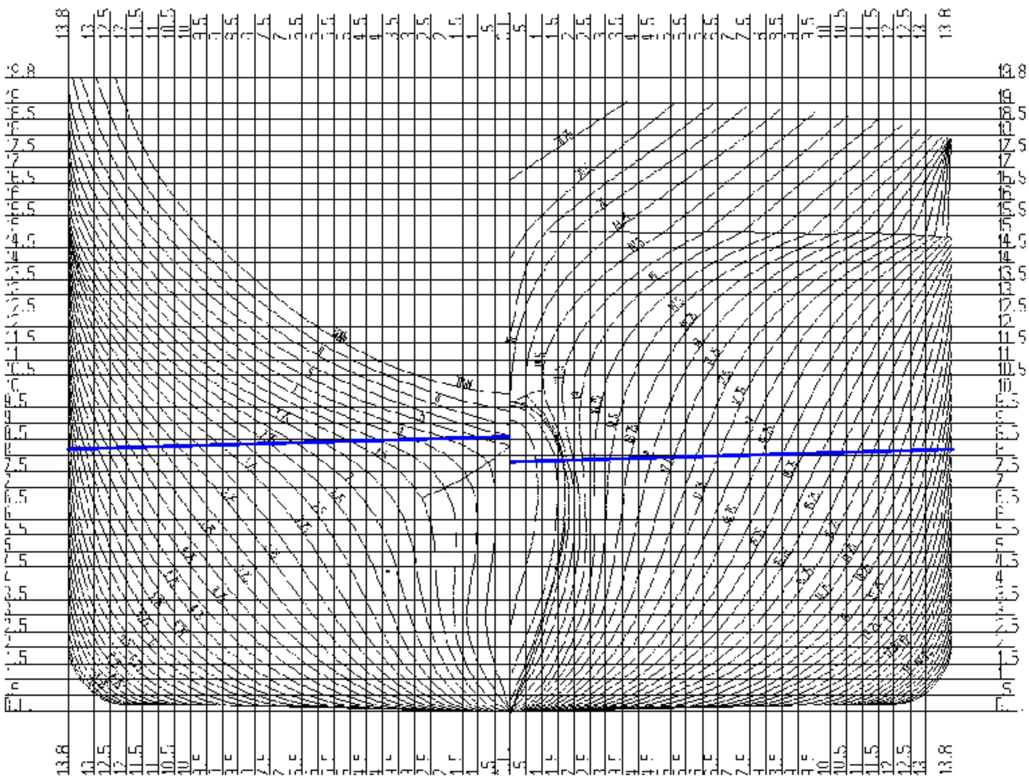

Fig. 2: Body Plan of PACIFIC ADVENTURER and floating condition during accident.

In the ATSB- report No. 263 MO 2009-002, the loading condition of the ship during the accident condition is given by the printout of the loading computes system. The ship had the following floating condition:

- Total Mass: 25690.9 t
- Draft at A.P. : 8.615 m
- Draft mean : 8.197 m
- Draft at F. P.: 7.779 m
- VCG (solid) : 7.385 m a. BL
- GM (solid) : 4.441 m
- GM (fluid) : 2.685 m

The (solid) values show that the ship had a very high GM- value (solid). The German accidents all happened with GM- values of 4.50-7.72 m, therefore the GM- value of PACIFIC ADVENTURER is comparable to the FRISIA LISSABON accident.
What makes the PACIFIC ADVENTURER accident interesting from stability point of view is the fact that large free surfaces had been present. This is very unusual and we see such large free surface corrections for the very first time. The effect of these free surface on the stability and the roll motion will be discussed below in detail. At present it is sufficient that for good reasons we have always disregarded the free surface effect the stability when performing roll motion computations (exept those free surfaces which have explicitly been designed as roll damping devices). These "good" reasons are the following:

- Dynamically, the free surface is sloshing in the tank when the ship rolls, and in best case it provides some additional damping. There is practically no influence of the free surfaces on the rolling period at larger rolling angles (except for tanks which have explicitly been designed as anti rolling devices).

- Because even hydrostatically the free surface computations are invalid for larger roll (and heeling angles). This effect will be studied in detail below.

We have computed the stability for both conditions (solid GM of 4.441m) and (invalid) fluid GM of 2.685m (for comparison purposes) and found reasonable agreement between our computation (which is on free trimming basis) and the values of the loading computer (which are probably fixed trim).

The comparison between the stability computed for both GM- values are plotted in the following figure, showing the large (but incorrect) influence of the free surfaces. Fig. 4 shows the hydrostatic model we have used for our computations.

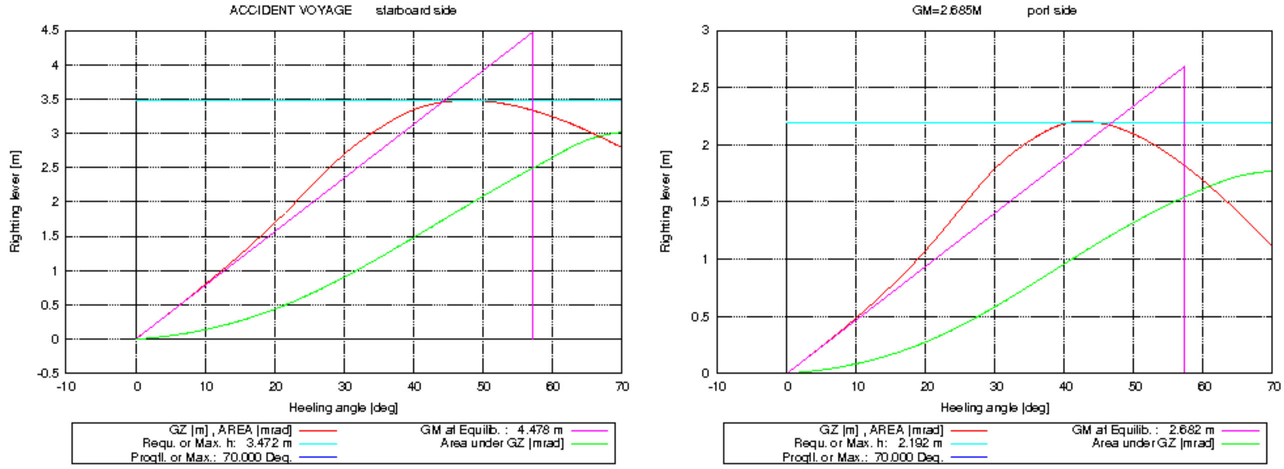

Fig. 3: Stability computed for the GMsolid (left) and the (incorrect) GM fluid. Note the large difference (note also that the diagrams have a different scale).

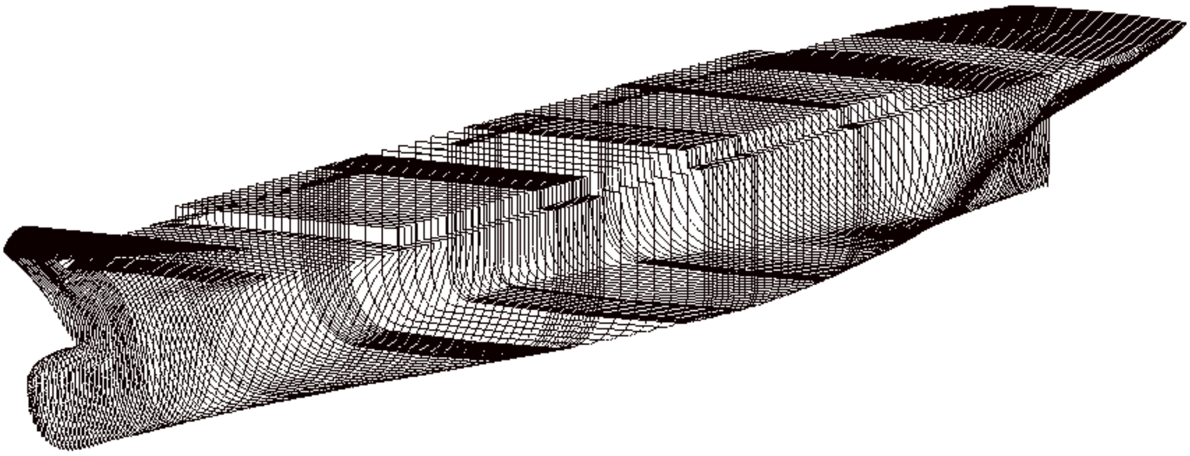

Fig. 4: Hydrostatic model used for our computations

4. Results of the roll motion computation

Using the E4ROLLS motion simulation program, the roll motions were simulated for the accident condition taking into account the solid GM of 4.441m. In a first step, a polar diagram is computed which shows the required limiting significant wave height for a maximum roll angle of 35 degree. The period is set to 9.5 s. For each node in the polar 5 computations of 20000 s each were performed and the significant wave height was adjusted in such a way that 35 degree or more as roll angle were recorded. The results are shown in Fig 5.

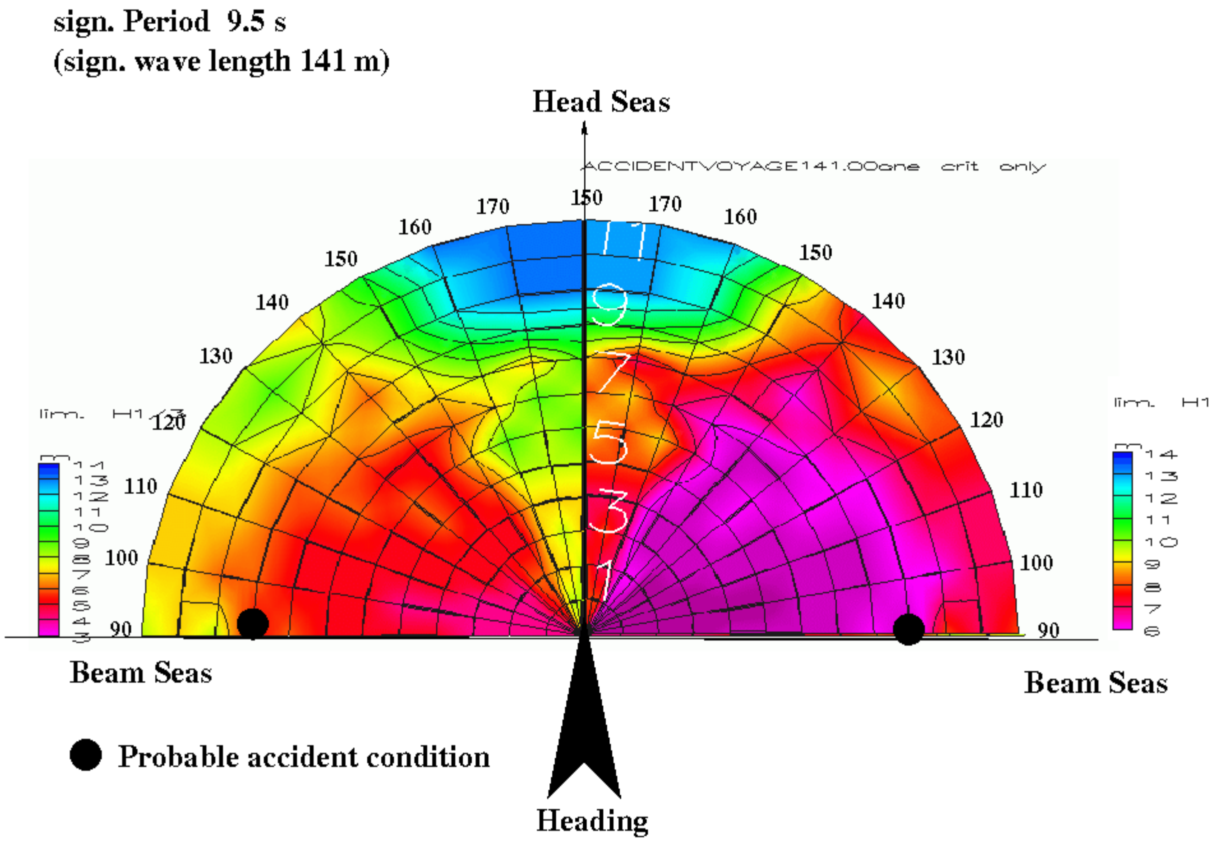

Fig. 5: Polar Plot for 35 Degree maximum roll angle in 9.5 s irregular seastate. The radial rings show the ship speed, the ship sails in north direction. Solid GM of 4.441m is used for the computations. The left polar is scaled according to the actual accident conditions, the right polar is scaled for comparison purposes with our accidents.

Fig. 5 show the same computed polar diagram in different scales. The left polar is scaled from limiting significant wave height 3-14 m to evaluate the PACIFIC ADVENTURER accident, where the significant wave height was about 4.7 m. The right polar uses the same scale (from 6-14m) as we have used for the BSU accident investigations for reasons of comparison. From the left polar it becomes obvious that 35 Degree roll angle are reached in the accident condition if the significant wave heigt amounts to 5-6 m. This is in line with the observations on board. The left polar does also show that the crew had had a theoretical chance to avoid the accident if they had managed to keep the ship directly against the waves at a minimum speed of about 5-6 knots. However, from the findings of the BSU accidents we know that it is practically not possible to keep the ship exactly against the waves, and as soon as a bow quartering scenario is met the ship rolls again heavily. Our computations have shown that in a beam sea condition, heavy rolling occurs below a speed of about 9 knots if the significant wave height amounts to 5-6m. If the speed of the ship is increased to e.g. 11 knots, then about 7 m significant wave height are required for a 35 degree roll angle. These computations are in line with the observations on board: The ship was rolling all the time significantly, and sailing below a certain minimum speed (or a group of higher waves, or both) caused the violent roll. As the ship speed has little influence on the encounter period, the effect of increasing the speed on the roll motion is that the roll damping is increased.

This is exactly what happened to the three German ships, while these have taken the sea more from head or bow quartering. FRISIA LISSABON had comparable weather conditions with higher wave height, and she took the waves from 120 Degree. The polar shows that also under these conditions it is most likely that the PACIFIC ADVENTUERER would have experienced heavy rolling. This makes it a litte doubtful whether the dominating effect is actually synchronous rolling, as the polar does not show any distinct encounter period where rolling is most severe. The ship rolls heavily in all possible beam or bow quartering conditions below a critical speed. This makes a single accident cause not plausible.

Now the right polar plot shows the same computations as the left polar, but it is plotted in the same scale that we have used during the accident conditions fore the German BSU. In this scale, the polar is exactly comparable to all the polars we have computed during our BSU investigations. It shows that the accident would definitively also happened in all head sea and bow quartering sea scenarios if the significant wave height had been slightly higher. Based on these calculations we come to the conclusion that the accident as such is also related to the BSU investiated accidents, namely excessive direct wave moments below a critical speed. What makes this case interesting in addition to our previous findings is that such kind of accident seems also to happen in seas more from the beam. A fact we did not experience before.

Due to the fact that a change in ship speed in pure beam seas does not alter the encounter frequency, the only effect of changing the ship speed can be a change of the roll damping. This is the explanation we give for the computed results that the roll motion decreases when ship speed is increased beyond a certain threshold value. This is in line with the findings from the accident investigations of the BSU investigated vessels.

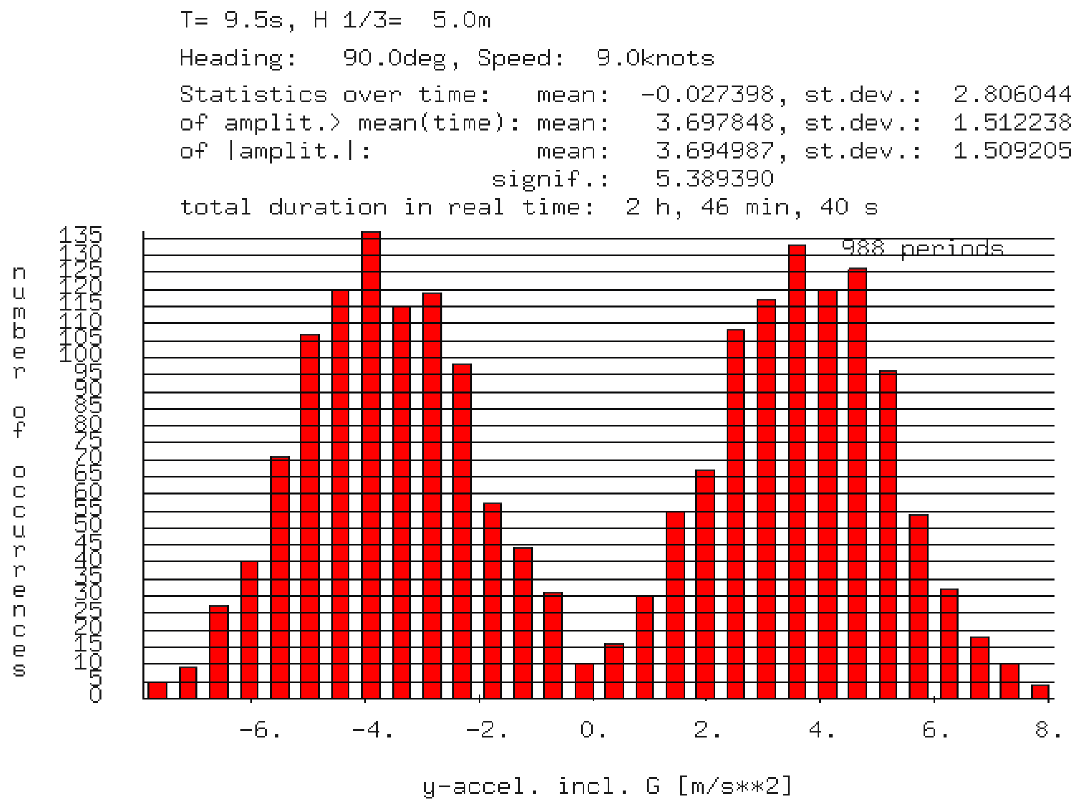

Fig. 6: Accelerations on the bridge in 9.5 s irregular seastate. Solid GM of 4.441m is used for the computations.

Fig. 6 shows the computed accelerations on the bridge deck level. A maximum value of 0.82g (to port side) is computed. These values are smaller compared to the accidents we have investigated, and this may be due to the following reasons:

- As PACIFIC ADVENTURER is not a full container vessel, the bridge deck is lower as the ship was not designed to carry more than four tiers on deck

- The significant wave height was lower compared to our accidents.

Nevertheless the acceleration values computed on the bridge deck level are significantly larger to those values accepted for the cargo and lashing equipment.

In so far, the PACIFIC ADVENTURER accident can according to our computations consistently be explained. The ship in general behaves like the vessels we have investigated for the German BSU.

It is also interesting to see how the ship reacts if the stability is altered. Therefore we have assumed for a moment that the virtually reduced stability due to the free surface correction would have been correct and we have performed the same calculations again, but now for a GM (solid) of 2.86m. The results are shown in Fig. 7.

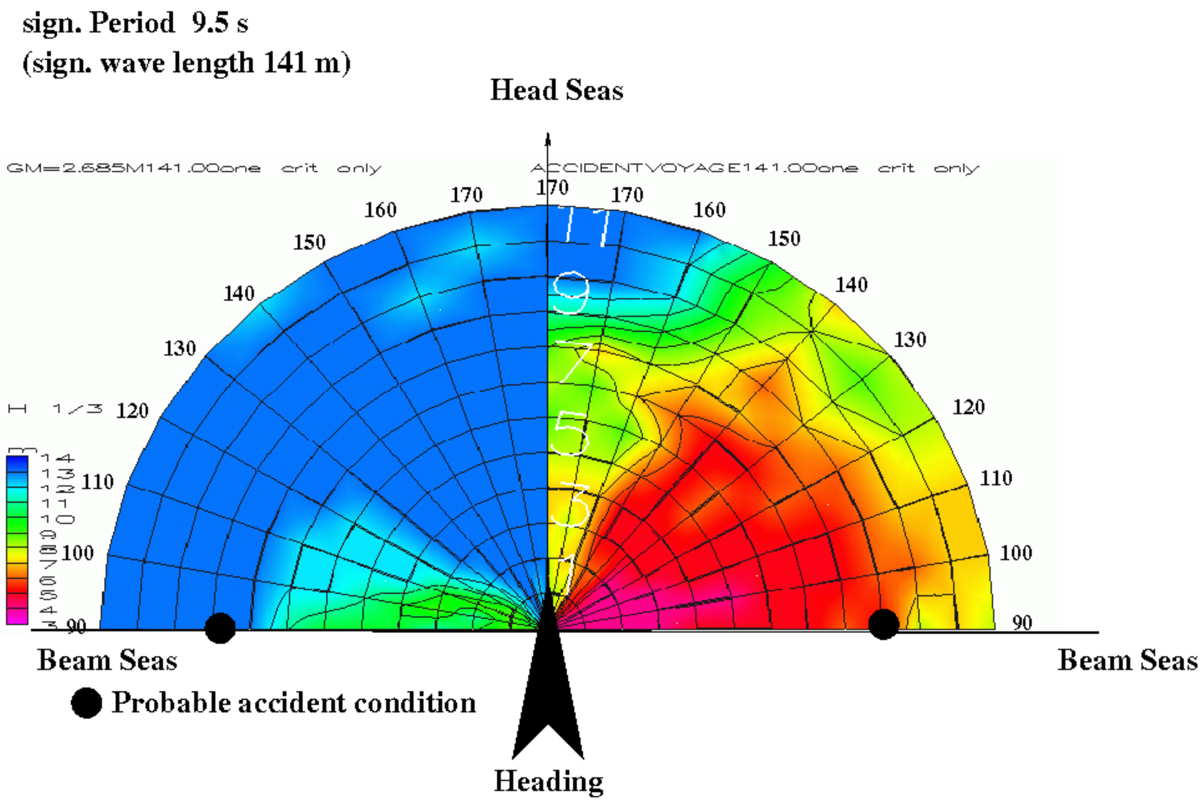

Fig. 7: Polar Plot for 35 Degree maximum roll angle in 9.5 s irregular seastate. The radial rings show the ship speed, the ship sails in north direction. Solid GM of 4.441m (right side) and solid GM of 2.86m (left side).

Fig. 7 shows that for the reduced stability, the problem has disappeared. The roll motion is drastically reduced, and (significant) wave heights of 14m or more (our calculation stops if 14m significant wave height are reached). This result is at the first glance quite astonishing, as we found for the German accidents that stability alterations did not seem to have a significant influence on the problem. On the other hand, the results obtained by Rox [3] showed that there exists a lower threshold stabity value below which severe rolling did not occur, and it is possible that for the present case, such threshold value has been found around the GM of 2.86m. However, the problem remains if this reduction of stability could have practically been achieved. Because the assumed free surface effect does not affect the stability in the supposed way, which was also expressed in the ATSB investigation report. Because if the stability had actually been reduced to that value, the accident would have been avoided according to our computations.

Concluded, from the time domain simulations obtained in irregular seastate, the accident root can be associated to direct wave moments combined with insufficient damping. And the accident would have been avoided if the stability would have actually be reduced to the value wich was (wrongly) indicated by the loading instrument. This aspect of the accident has not been discovered in conjunction with the accidents analyzed, but was found by theoretical investigations. Therefore it is useful to go into a deeper theoretical analysis of the PACIFIC ADVENTURER accident.

5. Some considerations with respect to synchronous rolling

As the PACIFIC ADVENTURER accident happened in beam seas where one stability condition resulted in large rolling motions and the other ond did not, it may help to go into a deeper theoretical analysis for this behavior of the ship. We have computed the natural roll period of the ship to be 10.51 s if the stability equals 4.441m and 12.43s if the stability equals 2.86m. The ecounter period was abt. 9.5s and independent from the ship speed, as the ship was travelling in beam seas. Both natural roll periods are too far away from the exciting frequency to be close to a resonance, and the polar plot for the GM of 4.44m does not show a clear resonance phenomenon. This makes it doubtful to assume resonance effects (and to assume a synchronous rolling scenario).

When trying to find a reason for the fact why one stability situation resulted in an accident and the other one proved to be safe, we made an interesting observation:

While performing some elementary analyses in regular waves (which is typically useless as the real seastate is never regular and the ship normally behaves completely different in an irregular seastate) we found out that also the regular wave computation resulted in large heeling angles for the case with GM=4.44 m, whereas the computation for GM equaling 2.86m difd not show significant rolling. This is a very interesting fact (from academic point of view, for the practical results it is irrelevant).

As a matter of fact, this was clearly not the case for all the German accidents we have analyzed: Because all computation in regular waves did not show any significant rolling (after we detected this for the PACIFIC ADVENTURER, we have recomputed our accidents). This shows that for the PACIFIC ADVENTURER accident, a simplified computational model can also give an answer to the accident problem, which was not possible for our accidents. This may be taken as a hint that the accident cause of the PACIFIC adventurer is dominated by other physical effects than our accidents, and these effects can be decribed by a much simpler computational model. However, the grade of simplicity of the computational model has no impact on the real physics, but it results in the fact that a simpler answer can be given to excplain the problem (this does not mean that recommendations can be given to avoid the problem).

This finding is underlined in Fig. 8. The ship is in both stability cases exposed to a regular wave of 5 m height and 9.5s period. The start roll angle was selected as -25 Degree and it was selected is such a way the the intial phase shift is opposite of the final one. One can immediately see two interesting aspects:

- For the left picture (stability 4.441m) the resulting final amplitude is much larger compared to the situation with GM=2.86m.

- For the left situation, it takes only 2-3 cycles until the final solution is obtained, whereas for the right situation it takes about 15 cycles to reach the converged situation.

- The right situation has a smaller final phase shift between excitation and response. For the maximum roll angle this means that due to the phase shift, the exciting moment is much larger (see snapshots below) which results in a significantly larger amplitude.

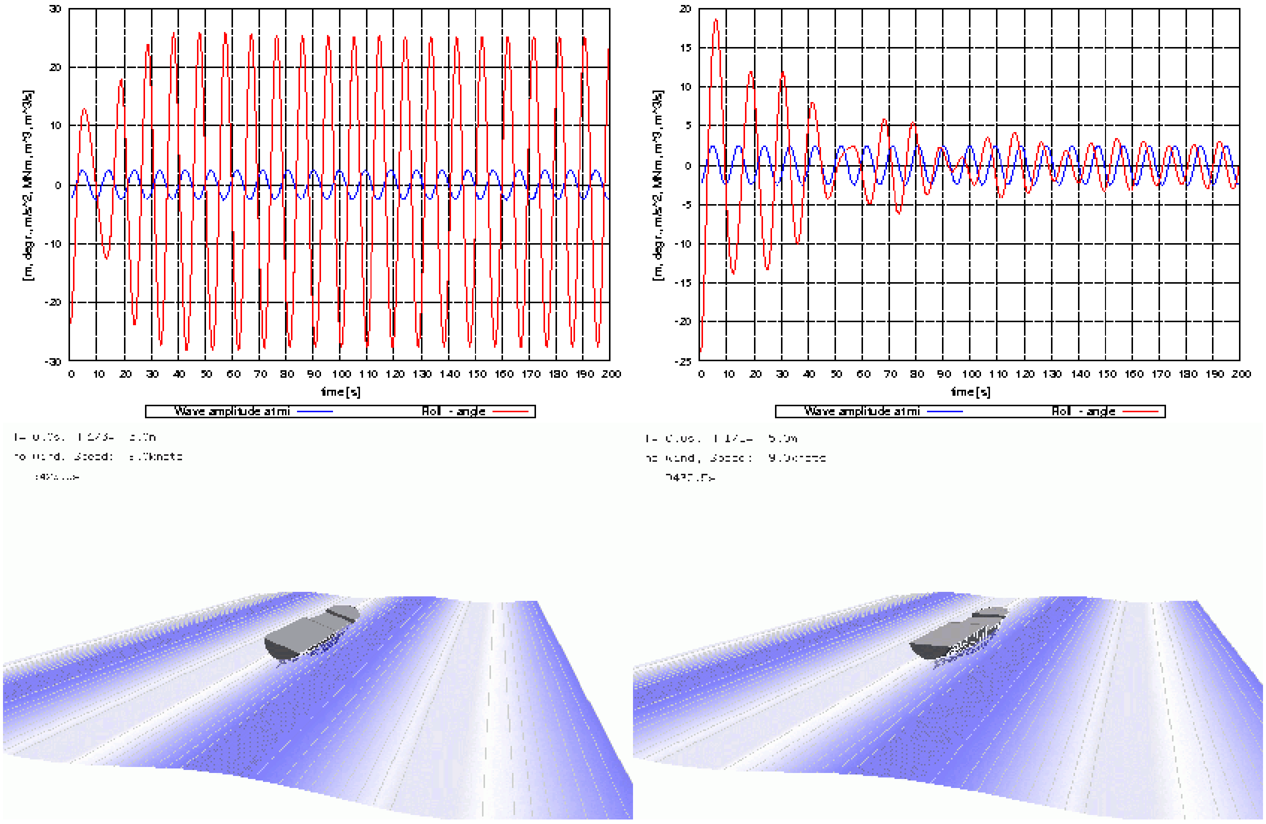

Fig. 8: Computations in reglar beam waves of 9.5s for a GM of 4.441m (left side) and solid GM of 2.86m (right side), ship speed speed 9 knots The red curve shows the roll response, the blue curve the wave elevation at CL. The two snapshots below show the situation at maximum roll angle.

As the motion is a forced motion, the period is exactly the encounter period of 9.5s. The natural roll period of the left picture is 10.5 s, the natural roll period of the right picture is 12.4s. Obviously the phase shift for the left condition is sufficient to build up a large heeling moment to get the roll motion started, although the situation is still far away from the resonance. We have repeated the numerical experiment with an encounter frequency of 10.5 s and found roll amplitudes of more than 43 degree, which is a consequence of moving towards the 1:1 resonance in beam seas.

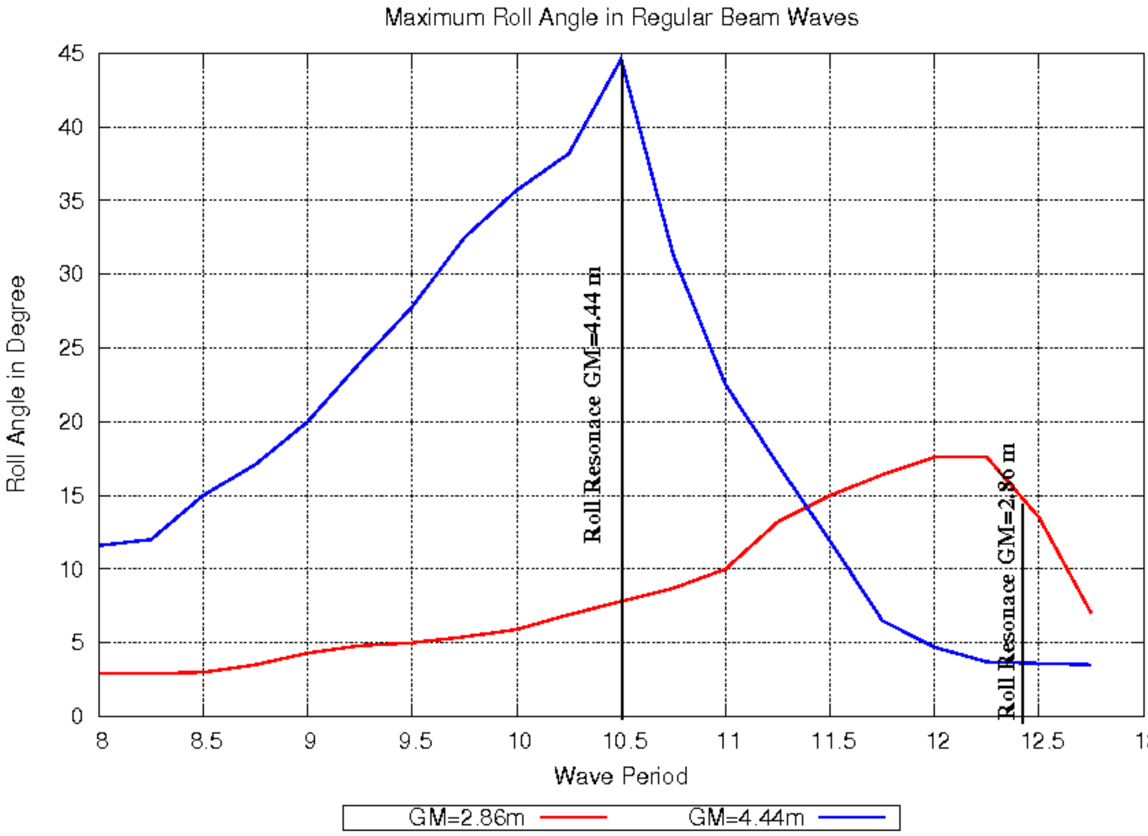

Fig. 8: Computations in reglar beam waves of 9.5s for a GM of 4.441m (blue curve) and solid GM of 2.86m (red curve), speed 9 knots. The curves show the maximum roll angles obtained from the simulation in regular waved as function of the wave period, which equals encounter period.

These findings can (from academic point of view) in principle be transferred to an irregular sea state. Because in the accident condition the ship adapts itself quickly to a converged situation if a group of higher waves with rougly the same period hits the ship. If these wave belong to a group having a shligtly larger period, then the rolling becomes even worse. We have reanalyzed the time plots of our computations in irregular waves with respect to this finding and we observed exactly such kind of wave patterns resulting in large roll motions.

In this respect, the PACIFIC ADVENTURER accident may (from academic point of view) be explained by the dominating phenomenon synchronous rolling in beam seas, and this accident explanation seems to differ from the cases previously investigated by the German BSU.

But from practical point of view, the situation is a little different as the question remains which operational measures the crew could have undertaken to avoid the accident. If we consider for a moment synchronus rolling as the dominating failure mode, the option would have been to avoid sailing close to the critical resonance (increasing the ship speed would have not been disvovered by this simplified failure mode, because the speed has no influence on the encounter period in beam seas). As a matter of fact, the ship was sailing quite far away from the resonance (from theoretical point of view) and the practical question is: How far away is far enough? This question is hard to answer by a simplified approach, because "far enough" depends on the magnitude of the wave moment introduced into the ship. The latter depends on (besides the frequency ratio):

- steepness of the wave
- hull form
- phase shift at large roll angles

The polar plot computed by the full theory does also show that the crew had limited chance to select an alternative course or speed because the ship rolls in all bow quartering scenarios, and had they selected a head sea secario, they would have run into comparable problems as investigated for our accidents. **Therfore this accident is an excellent proof for the fact that seakeeping problems can not be devided into subproblems which simplified computational procedures can handle.**

Nevertheless, the findings of the PACIFIC ADVENTURER accident show that it is useful to reevaluate a recommendation we gave as a result of the CHICAGO EXPRESS accident: There we have recommended to let the ship drift against the waves with zero speed instead of slowly steaming against the waves as a possible operational measure. This action (if it would have been possible with respect to possible leeway) might have prevented that accident. Now the PACIFIC ADVENTURER accident showed that also in beam seas extreme rolling motion is possible, which we never had observed before. We have then computed the 0 kn beam sea condition fror the case with GM=4.441m and fond large roll amplitudes of about 38 Degree. The accelerations on the bridge deck were computed as 1.0 g for a bridge deck level of 30 m above base line and 1.2g for a bridge deck height of 40m above base line. These accelerations take the same order of magnitude compared to the values that occurred during the accidents investigated by the German BSU, and this is in fact a new experience.

Because we have always considered our calculation method to be conservative for zero speed beam sea problems, as we do not take into account the non linear coupling of the drifting motion with the roll motion (in fact the method was developed for following sea capsizing problems), and we have performed model tests which proved that the roll motion in beam seas at zero speed was overprediced (at higher speeds the problem in beam seas disappears as the influence of the drifting motion decreases).

The PACIFIC ADVENTURER accident shows that this general assumption needs to be reinvestigated, as well as the proposal of drifting in beam seas.

6. Some Aspects of the free surface influence on the rolling motion

From the loading condition data available, a large influence of free surfaces is indicated. In fact, the crew has started the voyage with more or less all double bottom tanks partly filled. The stability information of the loading instrument shows a solid GM of 4.441m and a free surface correction of 1.756m, which is extremely large. This free surface correction is due to a partly filled condition of all double bottom tanks. The main contribution to this extremely large surface comes from double bottom tank No. 5 centre (16194 m^4 at 98% filling) and from double bottom tank No. 2 (13350 m^4 at 70% filling). It is immediately obvious (and this was also stated in the ATSB accident report) that the fluid in No. 5 double bottom tank can not really shift as the tank is filled to a level of 98%. This is a due formal prodedure (we should better call it an incorrectness) in the IMO intact stability code: Because beyond a filling level of 98% a tank is assumed as formally filled and the free surface is automatically assumed as zero (due to the prescribed calculation procedure). Therefore, the largest free surface that can be (formally) computed for No. 5 double bottom tank is the free surface which belongs to a filling level of slightly below 98%.
The same situation occurs for No. 2 doble bottom tank: Above the tank top level, No. 2 center tank consists of also of two two wing tanks. The compartment model of this tank is shown in Fig. 9.

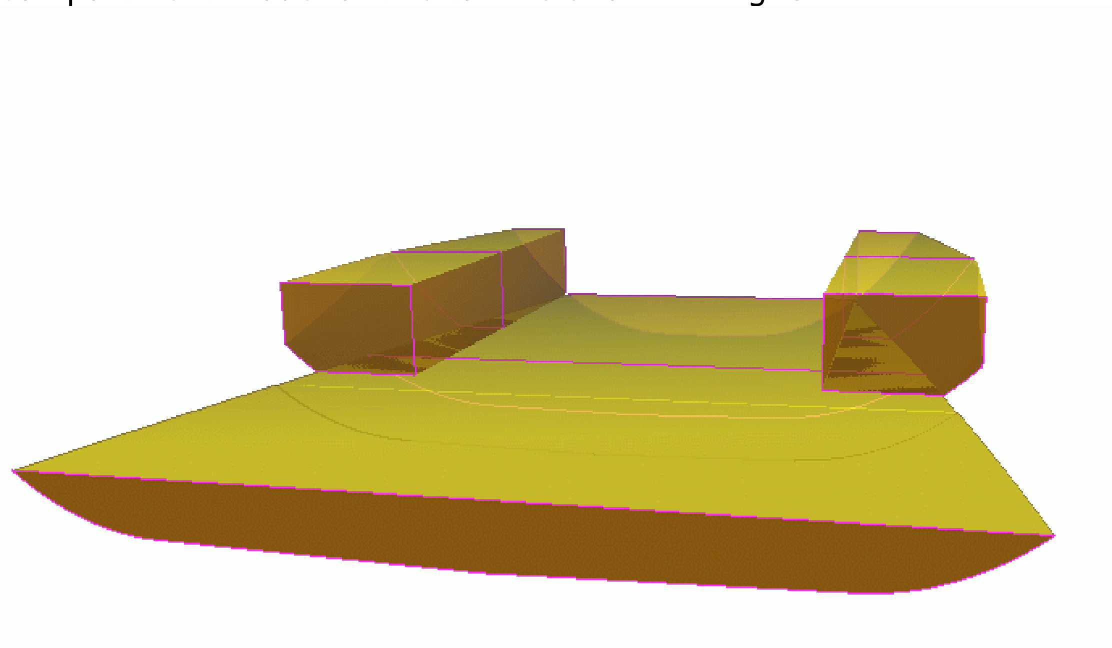

Fig. 9: Geometry of WB Tank No. 2 centre

We have now computed the maximum possible free surface for this tank exactly for a 70% filling condition when the fluid level is infinitesimally below the tank top level. If the filling level is slightly increased, the free surface is drastically reduced as it then consists only of the contribution of the (two) wing tanks. This has lead us to the hypothesis that the crew might have tried to fill all ballast water tanks in such a way that the loading instrument indicates the largest possible free surface reduction (due to the foirmal application of the free surface computation procedure). We have checked this hypothesis for all the other involved tanks and found more or less the same result: Each tank was filled with such a filling level the the free surface computed by the loading instrument was the largest one that could be obtained from the loading instrument´s calculation procedure. As a result, the GM correction due to the free surfaces amounts to 1.756m (according to the calculation procedure of the loading instruemt which follows the guidelines of the actual IS- code). We assume that the crew might have tried to reduce their large (solid) stability by filling all double bottom tanks to exactly that filling level which belongs to the largest free surface correction (according to the IMO- calculation procedure).

But the ATSB noted in their investigation report that at least for the double bottom tank No. 5 (98% filling level) this is clearly wrong, as the fluid can not shift (the tank is practically full). The same holds for No. 2 centre tank. More or less all double bottom tanks have free surfaces that are valid for extremely small heeling angles only, as the following example shows: The tank top height amounts to approx. 1600 mm. Half the beam of the ship amounts to 276000/2 mm = 13800 mm. If the filling level of the tank is about 50%, then the filling height is about 800 mm (with 800 mm to the top of the tank). It is clear that if the heeling angle amounts to arc tan(800/13600) = 3.37 Degree, then the fluid in this tank will hit the top of the tank and the free surface will more or less vanish. Therefore, the computed free surface effect of the loading instrument is valid for extremely small heeling angles only, and, as these are practically not relevant, the computed free surfaces are practically invalid. (It should be noted that this is not a problem of the loading instrument, but of the prescribed IS- calculation procedure). To demonstrate this, we have computed the static stability of the ship in the given loading condition using correct fluid shifting moments for each individual tank (e. g. as prescribed in the German Navy Standard BV 1030) and the results are plotted in the following figure:

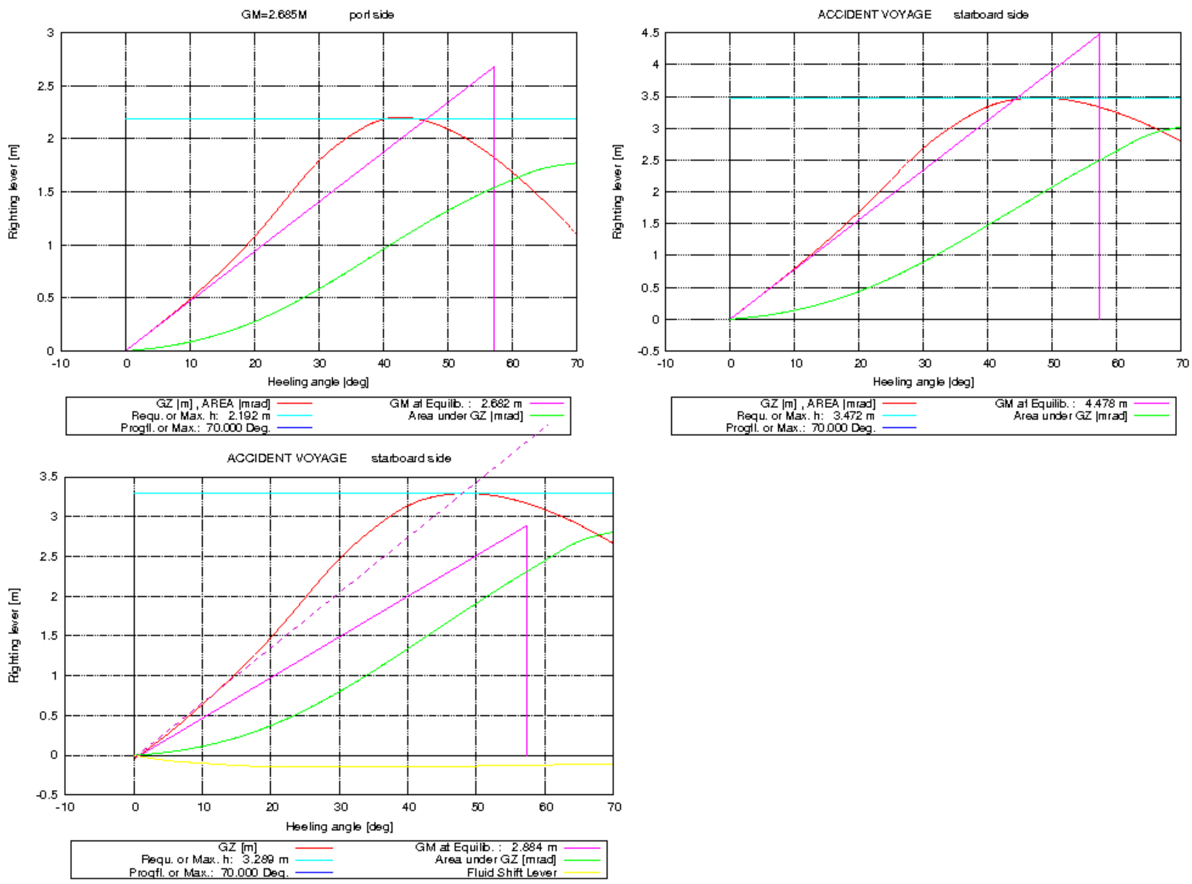

Fig. 10: Righting levers of PACIFIC ADVENTURER in accident loading condition according to different calculation procedures. Top left: How the on board loading instrument computed the stability, Top right: Computation without free surfaces (soild GM only), bottom left: Including all free surfaces, but correct calculation method using fluid shifting moments. (Note that the scale of the diagrams is different).

Fig. 10, top left, shows the righting levers computed in the same way as it was done by the loading instrument. Fig. 10, top right, shows the same computation, but without any free surface correction. Fig. 10, bottom left shows the correct calculation of the free surfaces according to the fluid shifting method.

It can clearly be seen that the correct computation of the free surfaces results in a righting lever curve which is quite close to the solid GM curve when a heeling angle about 5 Degree is reached. The curve shows also that the GM (computed including the free surfaces) is valid for extremely small heeling angles only, which are practically irrelevant. We have also plotted the solid GM into this picture (broken line) and one can see that this is a much better representation of the righting lever curve compared to the GM computed with the free surface correction (for small angles). This leads us immediately to the conclusion that the free surface correction (for small angles as proposed by the IS- code) is clearly wrong in this case if applied to larger heeling angles.

However, from stability point of view it can be argued that although the calculation procedure is clearly wrong, it underestimates the stability and it is therefore conservative. From stability point of view this is correct and acceptable. The problem which occurred during this accident is that the stability information obtained from the simplified calculation procedure can not be used to make any statement on the roll period. Because the roll period we are interested in is related (or should be related) to large heeling angles (if we want to predict critical resonances of large amplitude roll motions), and for this purpose, the simplified free surface calculation procedure is clearly misleading: Because the crew might have thought to have reduced their stability (and increased the roll period), which was clearly not the case. This has been found out during the dynamic simulations because

- the simulations carried out for the solid GM could clearly explain the accident
- the simulations with the reduced GM have shown that the ship would not have experienced large roll angles

Therefore we think it is important to underline the fact that whenever roll periods are computed from stability informations, only the <u>solid</u> GM- values must be taken into account. Otherwise, this leads to completely wrong results, as this case shows. An exception might be the use of tanks which have been explicitly designed as anti roll devices.

Until now, we have only performed hydrostatical calculations for the free surface effect which showed that the virtually large influence of the free surfaces on GM is practically not existent. From dynamic point of view, we have shown in the accident investigations for the German BSU that partly filled double bottom tanks have only marginal influence on the resulting roll angle (BSU report No. 391-09) due to the same reasons metioned above: The limited tank height does not allow to built up large roll damping moments. And the water is sloshing in the tanks without notable roll damping. Therefore, we have not performed such kind of calculation for this accident, as we could demonstrate that all relevant effects could be obtained from a solid GM solution of the problem, and this is in line with all seekeeping computations we have carried out before: The free surfaces should be completely disregarded for such kind of calculations (except for devices which have actually been designed as roll damping devices).

7. Summary and Conclusions

The numerical simulations of the accident have shown that the main root of the accident can be clearly explained. Although the accident type is not directly comparable to the BSU investigated accidents, there are some interesting aspects that complement the findings of the BSU accidents and may lead to additional safety recommendations, which are according to our computations the following:

- The accident showed that also in irregular, short crested beam seas, large rolling angles can actually occur, even at zero speed. Therefore, our pervious recommendation to drift in beam seas in heavy weather should be revised in such a way that this can not be generally be recommended without having prepared reliable information for the crew based on appropriate computations.

- Although the accident happened in beam seas, our calculations have shown that the accident would have also happened if the crew had decided to change the course against the sea. If the crew would have decided to do so, then we would have come to the conclusion that the accident would have had the same root as the German BSU investigated accidents. This is a clear proof for the fact that the actual developments at IMO which tend to separate the different phenomena in heavy weather and to treat them indepently from each other will not lead to a consistent safety regime in the future for stability problems in heavy weather.

- The accident has also shown that the treatment of free surfaces in the current IS code should be subject to a revision. Because the procedure is valid for small heeling angles only. However, from a stability point of view this might be acceptable, provided that such kind of information is definitively not used to make any statement on dynamic effects (such as roll periods).

- Whenever roll periods from static stability information are computed, only the solid GM should be used. Special anti heeling devices must be treated separately.

- The accident has clearly shown that partly filled double bottom tanks of typical size have no or only marginal effect on the roll period of partly loaded container vessels in heavy weather. This is in line with our findings published in the BSU report 391- 09.