EXPERT REPORT

PREPARED BY

DR. NEVILLE ANTHONY ARMSTRONG

Expert Witness appointed by the Commission of Inquiry
into the Collision of Vessels
near Lamma Island on 1 October 2012

3 January 2013

Dr. Neville Anthony Armstrong

Naval Architect of Fastships (Australia) Pty Ltd, Coogee, Western Australia

Specialist Field	:	Ship Hydrodynamics, Aluminium Ship Construction and Ship Safety Regulation, as further detailed in Appendix I.
Appointed on behalf of	:	The Commission of Inquiry into the Collision of Vessels near Lamma Island on 1 October 2012 (the "**Commission**")
Prepared for	:	The Commission
On instructions of	:	Messrs. Lo & Lo, solicitors for the Commission ("**Lo & Lo**")
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings.
Documents reviewed	:	See Appendix II
Documents referred to in this Report	:	See Appendix III
Sketches, Photographs and Diagrams integral to this Report by the Author	:	See Appendix IV
Date of Inspection of the two vessels involved in the collision (*Lamma IV* and *Sea Smooth*)	:	11 December 2012

The Terms of Reference of the Commission are as follows:

Inquire into the facts and circumstances leading to and surrounding the collision of the two vessels that took place near Lamma Island, Hong Kong on 1 October 2012:

(a) ascertain the causes of the incident and make appropriate findings thereof;

(b) consider and evaluate the general conditions of maritime safety concerning passenger vessels in Hong Kong and the adequacy or otherwise of the present system of control; and

(c) make recommendations on measures, if any, required for the prevention of the recurrence of similar incidents in the future.

Instructions

I have been instructed to give my opinion on the matters under the Terms of Reference and this Expert Report represents **Part 1** of my opinion which seeks to address the causes of the incident, with the view to assisting the Commission in making appropriate findings (Item (a) of the Terms of Reference).

In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

1. Identify why the *Lamma IV* sank following the collision.
2. Identify why the *Lamma IV* sank very rapidly.
3. Determine why so many of the seats provided for passengers became detached from the deck during the sinking process.
4. Identify whether the vessels were designed and constructed in accordance with the Regulations in force at the time of manufacture.
5. Comment on whether the lifesaving appliances on board *Lamma IV* were appropriate.
6. Comment on the horn as fitted to *Lamma IV*.
7. Review and examine the available forensic evidence to assess whether it is consistent with the available factual evidence.

Introduction

1. I, Dr Neville A. Armstrong, consultant naval architect of Fremantle, Western Australia, have been appointed as the Commission's expert to assist the Commission in determining the matters under the Terms of Reference. In this Report, I seek to address only the causes of the incident (Item (a) in the Terms of Reference). The causes of the collision are, under its Terms of Reference, a matter for the Commission after hearing all of the evidence. The opinion and conclusions which are set out in this Report were formed on the basis of the evidence that I have seen. I appear as an independent expert for the Commission unrelated to any other work.

2. A collision between a high speed passenger ferry *Sea Smooth* and a company passenger launch *Lamma IV* resulted in the death of 39 passengers travelling on the launch. The Commission was set up on 22 October 2012 and is now inquiring into the facts leading up to the collision. The first part of the Inquiry requires the Commission to ascertain the causes of the incident and make appropriate findings.

Background of the Incident

3. At about 20:20 hrs on 1 October 2012 off Shek Kok Tsui, northwest of Lamma Island, a ferry *Sea Smooth* (owned by Islands Ferry Company Limited, a subsidiary of Hong Kong & Kowloon Ferry Holdings Limited) carrying 4 crew and at least 62 passengers on passage from Central to Yung Shue Wan, Lamma Island collided with *Lamma IV*, a launch owned and operated by The Hongkong Electric Company Limited. The latter vessel was carrying 127 passengers and 3 crew members, and was leaving Lamma Island and heading towards the Victoria Harbour in order to watch the National Day firework display. Passengers were to disembark at Central. After the collision, the ferry *Sea Smooth* remained afloat while the launch *Lamma IV* sank stern first within a few minutes. The vessel came to rest almost vertically with its stern on the sea bed and its bow and forward section protruding above the water. Many persons on board *Lamma IV* fell into the sea or were trapped inside the vessel.

Description of the Vessels

Sea Smooth

4. *Sea Smooth*[1] is a high-speed passenger catamaran restricted by her licence[2] to "ply within the waters of Hong Kong".

Class	1
Type	Ferry Vessel
Length	28.02 metres
Breadth	8.00 metres
Depth	3.10 metres
Tonnage	274 gross tons
Material of hull	G.R.P.
Minimum crew	4
No. of passengers permitted to carry	381

Lamma IV

5. *Lamma IV*[3] is a passenger launch restricted by her licence[4] to "ply within the waters of Hong Kong".

Class	1
Type	Launch
Length	27.21 metres
Breadth	6.81 metres
Depth	2.08 metres
Tonnage	184.07 gross tons
Material of hull	Aluminium
Minimum crew	4
No. of passengers permitted to carry	224

My investigation

6. I was in Hong Kong from 10th – 16th December 2012 at the offices of Lo & Lo for the purposes of reading all of the available evidence and to examine all of the relevant plans and documentation for *Lamma IV*, as detailed in Appendix II. A meeting was held with Mr Sam WC Wong, Senior Surveyor of Ships at the Hong Kong Marine Department in the presence of Mr WF Leung, General Manager at the Marine Department, accompanied by representatives of the Department of Justice and Lo &

[1] General Arrangement of *Sea Smooth*
[2] Vessel Licence of *Sea Smooth* (validity from 02.12.2011 to 30.11.2012)
[3] General Arrangement of *Lamma IV*
[4] Vessel Licence of *Lamma IV* (validity from 08.07.2012 to 07.07.2013)

Lo on 11th December 2012 to clarify certain issues; to understand the difference between a Ferry and Launch and the different application of the Regulations to the two types of craft; to inquire as to what Instructions and Regulations had applied to the construction of Lamma IV, as later discussed in this report; and to understand why design stability documents relevant to the incident had only been marked as "seen", rather than "approved". *Lamma IV* and *Sea Smooth* were both inspected on 11th December 2012. *Lamma IV* was closely examined, but because *Sea Smooth* was afloat and difficult to examine from the outside it was a limited examination. Additional documentation was requested from the Owners of *Lamma IV* and from the Marine Department as a result of my examination.

<u>Explanation for the extent of structural damage on *Lamma IV*</u>

7. In order to understand the sinking process it was necessary to identify the structural damage to the vessel. The wreckage of *Lamma IV* was inspected on the hard-standing at the Hong Kong Government Dockyard during the morning of 11th December 2012, in the presence of Senior Inspector C.M. Tang of the Hong Kong Marine Police. The manner in which the structure had deformed at the point of impact was assessed, and measurements of the damaged area were taken, as reproduced in Appendix IV item 8. The alignment of the individual parts of the damaged structure was also noted as a means to determine the direction in which distorting forces had been applied. Deep scratches in the hull plating in way of the damage was also noted.

8. The broken-off remnants of the bow structure of *Sea Smooth* which had been removed from the hull of *Lamma IV* at the Government Dockyard on 14th November 2012 were also examined separately. Of particular interest were the pieces corresponding to the stem bar of *Sea Smooth*, which had been removed from *Lamma IV* and had been aligned in their correct relative positions[5]. *Sea Smooth* was also visually examined from a small boat, and from the inside of the vessel, although no measurements were taken as *Sea Smooth* was afloat.

9. Reference was also taken of the extensive series of photographs taken by the police of the debris removal[6].

[5] Photographs of Sea Smooth
[6] Police Album IX (taken on 14.11.12)

10. Detail of the structure of *Lamma IV* was provided by the following documents:

Title	**Drg No**	**Date of Marine Department approval**
Shell Expansion[7]	NC-391-7	17 May 1995
Midship Section[8]	NC-391-3	17 May 1995
Profile and Deck[9]	NC-391-4	3 May 1995
Sections and Bulkheads[10]	NC-391-5 sht1	3 May 1995
GA showing additional fender[11]	-	Marked as "seen", 4th Apr 1997

11. The draught at the bow of *Sea Smooth* at the time of the accident was calculated using standard naval architecture procedures based on the technical information related to *Sea Smooth* provided in documents from the Hong Kong Marine Department[12]. Lacking any other evidence for the condition of *Sea Smooth* at the time of the incident, the deadweight of the vessel was assumed to include fuel and fresh water at 50% capacity. The number of persons on-board was taken as 62 passengers and 3 crew members, and a weight for each person was assumed to be 70kg. Passengers were assumed to be equally distributed throughout the available passenger decks. In calculating the draught at the bow of *Sea Smooth* at the exact time of impact, an allowance was also added to include hydrodynamic effects created by the relatively high speed of the vessel and also for the relatively shallow depth of water. The passage of a hull through the water generates pressure around the hull, and at high speeds the pressure distribution will be such as to lift the vessel higher in the water, called sinkage, and to cause it to change trim. The exact changes to trim and sinkage have not been calculated for *Sea Smooth* hull shape *per se*, rather use has been made of empirical formulae which have been derived from very many similar craft. These formulae are based on the concept of Froude Number which provides a standard non-dimensional means to compare pressure effects around a vessel, and depend on the depth of water and vessel speed. According to information supplied by the Department of Justice[13] the depth of water at the location and time of the incident was 13.44 metres. This means that the *Sea Smooth* was subject to exceptional trim and sinkage effects when operated at speeds between 22 and 24

[7] Submission of construction plans fm CLS to MD
[8] Submission of construction plans fm CLS to MD
[9] Submission of construction plans fm CLS to MD
[10] Submission of construction plans fm CLS to MD
[11] Drawing of proposed new fender arrangement
[12] Stability booklet submitted by CLS to MD
[13] DoJ letter dated 13 December 2012, with Chart showing water depths from Hydrographic Office of Hong Kong Marine Department, Drawing H09052

knots, because the Speed-Depth relationship which is independent of vessel shape or size shows a dramatic peak in trim and sinkage effects at this depth and range of speeds, as well as producing a very large wake.

12. The draught of *Lamma IV* at the location of the damage was also calculated using standard naval architecture procedures based on the technical information relating to *Lamma IV* provided in documents from the Hong Kong Police[14]. Lacking any other evidence for the condition of *Lamma IV* at the time of the incident, the deadweight of the vessel was assumed to include 3900 litres of fuel taken from statements by the engineer[15] and coxswain[16] and fresh water at 75% capacity. The number of persons on-board was taken as 127 passengers and 3 crew members, and a weight for each person was assumed as 70kg. Passengers were assumed to be distributed throughout the available passenger decks in the numbers corresponding to those reported by the coxswain on commencement of the voyage.

13. It was assumed that *Lamma IV* was not heeling as a result of possibly turning at the time of impact, which is deemed to be a reasonable assumption because according to a copy of the stability booklet held by the Marine Department[17], the vessel would not have heeled sufficiently far at an assumed speed of 12 knots and with the estimated ship loading to have made any appreciable difference to the draught at the ship side.

14. A diagram showing the estimated relative vertical locations of the two craft at the time of impact is illustrated in Appendix IV Item 4. This diagram shows close correlation with the extent of damage to the bow of *Sea Smooth*[18] and to the sequence of structural failure on *Lamma IV* as further explained.

15. My opinion of the sequence of structural failure events, from inspection of *Lamma IV*, is illustrated in Appendix IV Items 2, 3, 4 and 5. The structural member at the bow of *Sea Smooth* known as the stem bar first struck the fender at the main deck level of *Lamma IV* immediately in front of an additional sloped fender[19]. The stem bar penetrated through the horizontal deck fender and cut through the main deck

[14] Inclining Experiment & Stability Calculations
[15] Translation of Notes of Interview (Leung Pui Sang)
[16] Translation of Notes of Interview and Questionnaire (Chow Chi Wai)
[17] Inclining Experiment & Stability Calculation
[18] Extent of Bow Damage to *Sea Smooth* (taken on 09.11.12)
[19] Drawings of additional fendering

plating[20] at a measured angle of 28°. To assist the Inquiry in determining the factual speed and headings of the two vessels at the exact time of the collision, the measured angle of the cut through the deck of 28° gives a geometric solution to the speeds of the two craft and the relative angle at the time of the collision, which is reproduced in the following Table for a range of craft speeds:

Lamma IV speed	Sea Smooth speed	heading angle at collision
5 knots	24 knots	33.6 °
5 knots	22 knots	34.1 °
9 knots	24 knots	38.1 °
9 knots	22 knots	39.1 °
11 knots	24 knots	40.4 °
11 knots	22 knots	41.6 °

A nominal value of 40° was assumed for all further calculations

16. As the bow of *Sea Smooth* penetrated into the side of *Lamma IV*, the stem bar cut down through the plating owing to its sloping or raked shape. However the presence of the angled fender on *Lamma IV* presented an extremely strong structure and the stem bar did not penetrate this. As the stem bar of *Sea Smooth* entered *Lamma IV* it effectively travelled downwards, and probably twisted as it was constrained by the sloping fender. On meeting the strong Frame 6 it most likely broke into pieces, but the remaining stem bar continued to enter the side of *Lamma IV*. The displaced side plating was pushed down and to one side below the fender, as shown at Location A in the sketches in Appendix IV Item 3-2 and in photographs[21]. On clearing the fender, the stem bar also probably relieved the stress that had built up by breaking further and then continued to remove the plating below the fender until it met the relative strong frame 5, where the stem bar again broke into several pieces. All of these pieces were found within *Lamma IV*. The stem bar of *Sea Smooth* at the forefoot continuously curves around to become a keelson of the same material and size[22]. This keelson continued to penetrate into *Lamma IV* creating a horizontal almost rectangular opening until such time as the keelson met the very strong watertight Bulkhead 4. Judging from the local damage, the local marks and deep scratches, at this point the keelson was broken off. The side forces also broke off a substantial portion of the bow outer side plating of *Sea Smooth*, leaving it embedded within *Lamma IV*.

[20] Cut through the deck (taken on 02.11.12)
[21] Photo of displaced structure *Lamma IV*, below fender
[22] Appendix IV Item 1, modified version of photograph of bow of *Sea Smooth*

17. The stem bar and the keelson are very strong components of many ship designs, and may be thought of as the backbone of a vessel (See Appendix IV item 1). On *Sea Smooth* they were manufactured from hardwood, 220 x 50 mm in size[23], covered with several layers of laminate and thus embedded into the surrounding hull structure. I do not consider it surprising that a hardwood and glass fibre structure could so easily penetrate an aluminium structure, owing to the kinetic energy of *Sea Smooth* at the time of impact (about 5.7 MJ at 22½ knots) resulting from the high speed of the craft.

18. Despite the forces from the keelson on impact, the watertight bulkhead 4 structure remained intact, although distorted, with some small fractures. At this point of time in the collision sequence the momentum of *Sea Smooth* was sufficient to keep it moving towards *Lamma IV*. Eventually the keelson again penetrated the side plating of *Lamma IV*, this time making a roughly rectangular hole into the tank room[24]. It is this second hole which allowed the flooding of the tank compartment and was a major factor contributing to the loss of the vessel. After travelling aft on *Lamma IV* a distance of approximately 700 mm, the keelson broke off once more and the remaining intact structure of *Sea Smooth*, which by now had travelled sufficiently far to reach the extremely strong collision bulkhead with no remaining structure in front of it in the way of *Lamma IV*, caused it to glance off the side of *Lamma IV* and disengage, leaving parts of the bow outer port-side plating and stem bar within *Lamma IV*.

19. Kinetic energy is a function of the square of the speed. If *Sea Smooth* had been travelling at a lesser speed of say 15 knots, the kinetic energy would have been reduced to about 2.5 MJ (less than half of the value at 22½ knots), and with lesser energy I consider it likely that *Sea Smooth* may not have penetrated the hull a second time and caused such catastrophic damage to the Tank Compartment.

20. As well as the bow structure of *Sea Smooth* previously described, the starboard bow of the craft is also fitted with what appears to be a stainless steel stem plate on the outside of the bow in the area known as the forefoot[25]. Such stainless steel plates are commonly fitted for the purpose of dissipating loads resulting from striking floating debris during normal operation, and it appears reasonable to assume that a similar

[23] Construction details of upper deck, as submitted CLS to MD
[24] Photo of hole in side shell in way of the Tank Room (taken on 15.10.12)
[25] Steel stem plate on *Sea Smooth*

stainless steel plate was fitted to the destroyed port bow. This stainless steel plate is of itself a very strong structure, closely fitted to the vessel forefoot by screws. Whether this stainless steel plate played any part in the damage resulting from the collision is not known, as I have not seen any part of this structure. It is not evident in any of the pictures of the debris removal, and it may have become detached and lost at the scene of the accident. My conclusion from examination of the size and shape of the hole is that it played little or no part in the overall damage scenario.

21. The time duration of the collision was very short. By measurement of the extent of the damage and knowing the relative speeds of the two craft it is calculated that the time from the first penetration of the hull to the cessation of damage to the hull of *Lamma IV* between the two craft was about 1.1 seconds.

22. In my opinion the *Sea Smooth* and the *Lamma IV* were never truly "joined" together during the collision. All of the structure of *Sea Smooth* that penetrated the hull of *Lamma IV* and caused severe damage quickly broke up within the hull of *Lamma IV* as it travelled aft, and broke off from *Sea Smooth* when the collision bulkhead struck the side of *Lamma IV*. There remained no volume of the main body of *Sea Smooth* blocking the holes in *Lamma IV's* hull, only individual "flat" shell plates and remnants of the shattered structure. The upper structure of *Sea Smooth* did enter the passenger cabin and remained there for at least two seconds as it moved aft creating damage, until it finally came to rest, but from that time on it is not clear what happened. I consider it possible that *Lamma IV* could have extracted itself quite quickly and without mechanical power from *Sea Smooth* because it was by this stage moving in an astern direction at about 3½ knots owing to the transfer of momentum from *Sea Smooth*, and there was little to hold the upper part of *Sea Smooth* within the confines of *Lamma IV* passenger cabin. However, it is equally possible that *Sea Smooth* remained within *Lamma IV* for a short time and was mechanically reversed out. If this was the case, then the passengers within the cabin would be unaware that there was no bow part of the hull of *Sea Smooth* below their deck, even though the upper part of the bow was obviously within their cabin, and neither could they be aware that the reversing of *Sea Smooth* would make no difference to the inflow of water into the hull. If *Sea Smooth* was reversed out it must have happened within about ten seconds, as *Lamma IV* was by now quickly sinking.

Comment on the general structural condition of *Lamma IV*.

23. During the inspection of damage to *Lamma IV*, the opportunity was taken to make a general survey of the condition of the structure of the vessel. I found that it was generally of sound construction, with little evidence of corrosion or weakening of the plating or stiffening components. Brackets were generally well aligned without obvious buckling from excessive sea loads.

24. There were two locations where there had been very-localised severe corrosion, in the aftermost corners of the main deck where a stainless steel pillar supported the deck above. The deck immediately under each pillar has corroded completely through[26] creating a small hole about 100 mm^2. However at some stage in the past it has been sealed with a filling compound and the pillar put back in place to cover it. I consider that the corrosion was caused by the electrolytic action of the two different metals at this point, namely aluminium and the stainless steel of unknown properties. This hole played no part in the sinking of *Lamma IV* and is only noted as part of the general condition of the ship.

25. On two separate occasions the plating thickness of the side plating of *Lamma IV* has been checked by ultrasound. This was done at the request of the Hong Kong Marine Department as a condition of survey[27] in June 2005 and again[28] in May 2011. The survey results show an average thickness of the side plating as 4.5 mm in July 2005, with a slight decrease to 4.4 mm average in May 2011. From my inspection of the plating, which is protected by paint on both sides and in good condition, I am of the opinion that there was no measurable reduction of thickness over the past 6 years; rather the 0.1 mm discrepancy was more likely caused by differences in the accuracy of the instrumentation and the measurement process used at the time. The drawings approved by the Hong Kong Marine Department[29] show that the side plating should have been 5.0 mm thickness. Given the protective paint scheme on both the outside and inside of *Lamma IV* hull plates, I am of the opinion that it is most likely that the vessel was constructed with side plating of 4.5 mm thickness, as measured in June 2005, despite the drawings showing 5.0 mm thickness. The thinner plating size on *Lamma IV* may have contributed to the extent of the damage that was experienced,

[26] Localised corrosion in the aft deck (taken on 02.11.12)
[27] Plate thickness from Survey & Test Report at 2005 annual survey Lamma IV
[28] Plate thickness from Survey & Test Report at 2011 annual survey Lamma IV
[29] Approved construction drawings of shell expansion showing thickness of side plate

as plating of a greater thickness would have reduced the damaged hole size, which in turn might have provided marginally more time for escape before the vessel sank.

26. The hull construction for *Lamma IV* was sub-contracted to Wuzhou shipyard in Guangxi, China, and the hull survey was conducted by China Classification Society, under an arrangement with the Hong Kong Marine Department[30]. The survey report makes no specific reference to the thickness of materials that were used.

27. The bottom plating thickness also appears to be undersized, although this played no part in the sinking. According to the ultrasound results at survey in 2005[31], the bottom plating thickness was 5.5mm with some variation in the 2011 measurements[32] of up to 5.8 mm. The drawings approved by the Hong Kong Marine Department[33] show a minimum thickness of 6 mm.

28. It is further noted that according to the "Instructions for the Survey of Class I and Class II Launches and Ferry Vessels" (1995)[34] Chapter II regulation 3.2, the minimum thickness of side plating for a launch of less than 30 metres in length is specified as 5.0 mm. This dimension is for a hull built of steel with a stiffener spacing of 600mm. It is permitted to adjust the allowable thickness for other frame spacings, and *Lamma IV* was designed with a frame spacing of 350mm. However, *Lamma IV* was built from aluminium, not steel, and my opinion is that a stiffener spacing of 350 mm for aluminium plate is approximately equivalent to 600mm stiffener spacing for steel, for a similar bending strength. My conclusion is that the side plating in aluminium should have been 5.0 mm in accordance with the instructions, and this is reflected on the drawings approved by the Marine Department. The side plating as built, in my opinion, was 0.5 mm undersized. The Instructions for the Survey of Class I and Class II Launches and Ferry vessels (1995) permit lesser thickness of side plating if the vessel is classed with a recognised Classification Society[35]. However these instructions also makes clear that if it is not maintained in Class with the Classification Society, then the operating licence will be withdrawn and the requirements of the minimum thickness in the Instructions shall be complied with in full. *Lamma IV* had been designed to the Rules of a recognised

[30] Hull survey certificate from China Classification Society
[31] Plate thickness from Survey & Test Report at 2005 annual survey Lamma IV
[32] Plate thickness from Survey & Test Report at 2011 annual survey Lamma IV
[33] Approved construction drawing of shell expansion showing thickness of bottom plate
[34] Instructions for Survey of Class I and Class II (1995), ChII, 3.2
[35] Instructions for Survey of Class I and Class II (1995), ChI, 4

Classification Society, but it had never been classed by them, and so should have complied in full with the thickness requirements given in the 1995 Instructions.

Opinion on why *Lamma IV* sank

29. A vessel floats because it has watertight integrity. The watertight integrity of *Lamma IV* was breached by the collision, and water started filling the vessel immediately through two holes below the waterline. A vessel can survive collision damage if it has internal watertight transverse bulkheads, and these are designated by Regulation. Five such bulkheads were fitted to *Lamma IV*, being located at the bow to protect against collision, at either end of the engine room, and at the after end to form a space called an aft peak (it contains the steering gear for the craft). An additional bulkhead was also fitted forward to comply with a requirement that any one space should have a maximum length of 40% of the length of the ship.

30. The Regulations that were applicable at the time of the collision[36] required that the vessel be capable of surviving a collision that resulted in the flooding of any one compartment. This scenario was examined by the builder and the calculations and results formally submitted to the Marine Department at the time of completion of the craft construction[37]. Following subsequent modifications to the craft to change the location of the solid lead ballast, another set of calculations were submitted to the Marine Department[38] on 10th October 1998 and marked as "Seen" on 13th January 1999[39]. After further modifications were made to the ballast, a new calculation was submitted[40] on 21st September 2005, and which represents *Lamma IV* as it was at the time of the collision. All of the above documents entitled "Damaged Stability Information" show that the vessel could survive a breach of watertight integrity into any one compartment, and thus complied with the Regulation. They also included an examination of the stability of the vessel in the damaged condition with one compartment open to the sea. I am advised by Marine Department that is not a requirement of licensing or certification that damaged stability is approved, which is presumably why the booklet is only stamped by the Marine Department as "seen" rather than "approved". In this case the Builder appears to have done additional calculations to ensure safety.

[36] Fax from Marine Department dated 1 August 1994 with attached regulations for local ferries for stability and watertight subdivision
[37] Watertight subdivision calculations as originally submitted by CLS to MD 10 Mar 98
[38] Watertight subdivision calculations as submitted by CLS to MD 21 Oct 98
[39] Acknowledgement letter for watertight subdivision calculations 1998
[40] Submission of most recent Watertight subdivision calculations, 2005

31. The regulations only required investigation of the effects of flooding one compartment, but the collision between *Lamma IV* and *Sea Smooth* resulted in holes in two compartments, the Engine Room and the Tank Room. This scenario was not examined by the builder as there was no requirement to do so.

32. During my inspection of the structure inside *Lamma IV* after the collision it was noted that the watertight bulkhead between the Aft Peak and the Tank Room contained a large access opening, and that there was no watertight door fitted to this opening[41]. The effect of this "missing door" was that there were three compartments flooded at the after end of the ship, as there was no impediment to the flow of water from the Tank Room into the Aft Peak. Three flooded compartments is a considerably worse scenario than was assumed by the Regulations to which *Lamma IV* was constructed.

33. The draughts of *Lamma IV* at the time immediately before the collision was estimated from the ship's stability book with the stated number of passengers and crew on board distributed as indicated by the coxswain at the start of the voyage a few minutes earlier and with the fuel and fresh water as itemised in paragraph 12 of this Report. This permitted the weight distribution of *Lamma IV* to be estimated within an acceptable accuracy (within 500 kgs). This information was used to define a static model using the software *Maxsurf*, and the associated software *Hydromax* was then used to calculate the static attitude of a damaged craft with selected damaged compartments. The output from this software should be similar to that produced by the builder in the Damage Stability book, and shows the waterline taken on by the vessel after damage. The visual output from the software is reproduced in Appendix IV Item 6.1 and shows that the vessel could have easily survived the regulatory "one-compartment damage" standard to the Tank Compartment, as also indicated by the builders damage stability booklet[42]. The software was then used to examine an assumed two-compartment damage scenario, namely the Tank Compartment and the Engine Room, corresponding to the damage experienced by *Lamma IV*. The results of this analysis, reproduced in Appendix IV item 6.2 shows that the vessel should have finally floated at an inclined waterline which was approaching deck level at the after end of the vessel, although not flooding over it.

[41] Photo of access opening in "watertight" bulkhead at Frame ½
[42] Watertight subdivision, Tank space flooded, from final stability book

This shows that the vessel could have achieved a "two-compartment standard" if the access opening into the aft peak (the steering gear compartment) has been watertight. Finally the computation was run with three compartments flooded, namely the Engine Room, the Tank Compartment and the Aft Peak. In this case the vessel assumed an almost vertical attitude as shown in Appendix IV Item 6.3, although it should be noted that the software is only capable of calculating up to angles of 75°. Nevertheless the vessel was clearly lost at this attitude.

My opinion on why *Lamma IV* sank so quickly

34. It has been reported from many sources that *Lamma IV* sank very quickly. I was asked to examine why this could have been the case.

35. *Maxsurf* and *Hydromax* together only give the final static solution, and cannot reproduce the dynamic situation that would indicate the time to sink. To solve this problem a numerical model was generated based on the detailed information contained in the original design drawings, particularly the exact hull shape and the locations of the watertight decks and bulkheads. The results from *Maxsurf* and *Hydromax* were useful to compare the output from the dynamic simulation model in terms of the final vessel attitude, and a comparison of the two predictions where the vessel remained afloat is given in Appendix IV item 7. The comparisons are considered to be within the range of anticipated accuracy, particularly as the numerical model used the same Hydrostatic particulars as were taken from the vessel stability book and submitted to the Marine Department, whereas *Hydromax* used some slightly different values that were calculated as an integral part of that software. There are also some differences in how the permeability of the flooded spaces was treated. The *Hydromax* values are probably the most accurate, but the small difference in values would not noticeably alter the predicted time to sink.

36. The size and location of the holes in the hull of *Lamma IV* were carefully measured during an inspection on 11th December 2012, and are shown in Appendix IV Item 8. For the purposes of the numerical calculation, the hole into the Engine Room was considered as if it were two holes, one being the hole caused by the keelson and located at the bottom part of the side plating and roughly rectangular in shape, and the second hole being the diagonal penetration caused by the stem bar which had a roughly constant width of opening and extending from the top to the bottom of the

side plating. Knowing the depth of water above each of the assumed three holes, on both the inside and outside surface of the hole, together with the area and shape of the holes themselves, it was possible to calculate the rate of inflow of water into the ship using the commonly-used Bernoulli equation for each of the holes. Different formulations were used to calculate the inflow of water to reflect the different shapes of hole and local flow conditions. This provided a method to calculate the amount of water entering the ship every second, and at the same time to calculate from the design information the response of the craft to the additional internal weight of the flooding water and its exact location at that time. The craft's response to the weight of water entering the craft, namely, increasing stern trim and increasing draught was calculated, and then also the effects of the resulting water running aft inside the vessel in response to the increasing trim. The internal depth of water in way of each of the three holes at the end of the time interval was also calculated, as this had a direct influence on the rate of water entry. This changing scenario was repeated and recalculated at regular one second intervals with the appropriate amount of water coming aboard until the vessel either came to rest with a compartment flooded, or eventually sank.

37. The calculation allowed for the additional buoyancy provided by the internal structure and fittings as the water flooded the inside of the vessel, including the volume of the main engines, the fuel tank, the fresh water tank, the generator and switchboard and the multitude of pipes and other mechanical equipment and outfit.

38. The dynamic numerical flooding simulation was carried out for three scenarios:

1. With the Tank Compartment flooded (<u>one-compartment damage</u>). This was intended to replicate the same flooded condition in the Builder's damage stability book, and thereby check that the numerical model was working satisfactorily. The result showed that the vessel remained afloat with this single compartment damaged and with close agreement on the waterline position, as shown in Appendix IV item 7.

2. With the Tank Compartment and the Engine Room flooded (<u>two-compartment damage</u>). This replicated the damage to the craft, **but assumed that a watertight door had been fitted to the aft peak bulkhead**. The vessel eventually became stable after about 165 seconds (1¾ minutes) from the time of collision. The inflow rate of water varied considerably between 0.4~1.4 tonnes/

second. The flow rate constantly changes because the water level inside changes as the craft trims and the outside water level also changes with both trim and sinkage.

3. With the Tank Compartment, Engine Room and the Aft Peak flooded (three-compartment damage). **This replicated the actual damage to the craft** without a watertight door in the aft peak bulkhead. The results of the numerical simulation suggested that the craft would sink at a faster rate than the second simulation, with the main deck at the stern sinking below the water level about 87 seconds from the time of the collision. The inflow rate remained the same as in scenario 2 above, but once it had overflowed the sill of the access opening in Bulkhead ½, the water became centred further aft, causing worse trim aft.

39. It can be seen from the various photographs[43] [44] that there was a considerable amount of debris remaining in the hole into the engine room of *Lamma IV*, mainly being the bow structure of *Sea Smooth*. This debris appears to have been firmly embedded, as the photographs[45] show a crane being used to pull it out. This embedded structure would have severely restricted the flow of water into the engine room, and an allowance was made for this in the numerical modelling. The hole into the tank compartment does not appear from the photographs taken immediately after recovery to have been similarly choked. Various choking factors were applied to the calculations of the inlet flow rate into the Engine Room in order to estimate the effects. If the holes are choked, then the flooding will clearly be at a slower rate. The finally selected values were 0.2 for the Engine room hole (diagonal slot), 0.4 for the rectangular hole into the engine room near the aft bulkhead, and 0.80 for the rectangular hole into the Tank Compartment. The timeline of the vessel trim as it settled in the water for various conditions and choke factors is illustrated in Appendix IV item 9-1.

40. Having simulated the flooding process, a second numerical model was made to simulate the sinking process, based on the output from the flooding model. This was necessary because of the different physics involved in the flow of water within and around the Lamma IV. The sinking simulation illustrated in Appendix IV item 9-2 indicated that the vessel would continue to increase trim by the stern until such time

[43] Debris from Sea Smooth within hull breach of Lamma IV
[44] Debris from Sea Smooth within hull breach of Lamma IV
[45] Removal of debris from hull breach of Lamma IV

as the transom, rudders and propellers hit the sea bed, at which time the vessel would have an approximate attitude of 70 degrees to the horizontal, with the forward part of the vessel remaining above the water as a result of the buoyancy of the forward hull compartments. This is illustrated in Appendix IV Item 9-3. According to the sinking simulation model the time to reach this position was 102 seconds after the initial collision, and it probably remained at this attitude for some time, say 10~20 minutes. There is a photograph of the vessel in this condition published by the media, before the incoming tide and local currents appear to have allowed the craft to assume a more vertical attitude (90°) as the water became deeper, and eventually to have allowed the craft to "turn over" to an angle of about 110°, which was photographed and circulated by the media.

41. In summary, Lamma IV sank rapidly because of the number of large holes in the hull combined with the lack of a watertight bulkhead at Frame ½. According to the simulation and using reasonable estimates of the amount of choking from debris, the estimate of time from collision until irretrievably lost and taking on a substantial trim would appear to be about 90 seconds. Even assuming that the holes into the Engine room were almost fully choked with debris would only change the estimated survival time to 100 seconds. I considered these to be extremely short times in which to organise effective passenger escape.

Seat failures

42. Following flooding, *Lamma IV* assumed a severe stern trim. This attitude caused the failure of all of the fastenings connecting the seats to the upper deck, with the reported exception of one seat. From inspection, the seats appear to have been screwed to the deck using a variety of different sized screws of various types[46]. There were many screws left lying on the deck when the vessel was recovered.

43. The upper deck was manufactured as a glass fibre composite structure[47], which was made up of three components as follows:

- 2.1 mm thickness of woven rovings and chopped strand mat
- 25 mm thickness of foam
- 2.1 mm thickness of woven rovings and chopped strand mat

[46] Photos of various self-tapping screws attaching the seats
[47] Laminate structural design of deckhouse and submission Ltr fm CLS to MD

This type of construction is typical for a vessel deck, where the foam is essentially used to separate the two outer skins to provide good bending strength. The foam at the core can provide excellent compressibility but is considerably less capable in tension. To ensure that the foam adheres to the outer skins of woven rovings, it is normal practice to introduce some chopped strand mat material, and also to introduce some shear webs. It is the woven rovings that provide almost all of the strength of the deck, held in position by the foam and the chopped strand mat. However, woven rovings are a flat arrangement of glass fibres in a resin matrix which has strength in two dimensions only, corresponding with the direction along the deck or across the deck. It has limited strength perpendicular to the deck and is therefore quite unsuited to the use of screws to attach seats.

44. The actual deck construction is illustrated in Appendix IV item 10, which is a photograph of a hole through the deck structure for a ventilation fitting which was displaced during the collision. The skins and foam construction can be clearly seen. A sketch of the arrangement in way of the seats is illustrated in Appendix IV item 11.

45. Most of the self-tapping screws which were used to attach the seats are 25 mm long, but were only embedded into woven rovings of 2.1 mm thickness. The remaining 20.9 mm of the screws were embedded in the soft foam core and the vinyl floor tiles, which provided no strength to the self-tapping screws. It is an engineering "rule of thumb" that self-tapping screws <u>in metal</u> should be sized such that the thickness of material equals at least two-and-a-half threads of a screw. The majority of screws used on *Lamma IV* did not even have one full thread of the screw engaged with the woven rovings, which would have needed to be at least 5 mm thick to comply with the 2½ times "rule of thumb". In any case, fibreglass construction cannot take a large screw load because it is not a homogeneous material and resin will not hold for a large load. Furthermore, screw holes in a fibreglass deck permit water on the deck to penetrate to the foam at the core which causes it to deteriorate with age, and which may have further contributed in a small way to the seat foundation failure.

46. The seat connections on the upper deck should have been through-bolted, meaning a bolt should have been used that had a nut under the deck with a washer sufficiently large to spread the load so as not to crush the foam. The seat foundations on the lower deck did not fail, because all of them were screwed through the aluminium

metal deck, with about 2½ threads engaged. Viewed from below, as shown in Appendix IV item 12, the screws have remained undisturbed.

47. The "Instructions for the Survey of Class I and Class II Launches and Ferry vessels (1995) Chapter III section 4.1"[48] state "Where seats are provided for passengers, their form, design and attachments to the deck should be adequate for the intended service". In an interview with Wong WC, Senior Surveyor of Ships at the Hong Kong Marine Department referred to in Paragraph 6, I inquired as to what was considered an adequate seat connection. The response was that this was up to the experience of the individual inspector or surveyor.

48. It is noted from the annual survey items that the seats generally appear to have performed adequately since 1995. There is evidence that some of the seat foundations became loose in service[49], and photographs taken after the accident of one seat foundation[50] suggest that at one stage some of the seat screws have pulled out and could not be replaced, and consequently a small steel plate was connected to the deck with four new screws and to which the seat was then attached. In other examples the screws appear to have pulled out at some stage and have been put back very close to the previous hole[51]. It was only in the abnormal condition where the vessel had excessive stern trim and the weight of the seated person generated an abnormal tipping force that the foundations finally failed. Nevertheless the arrangement of screwing seats into GRP foam sandwich in my opinion could not be considered as adequate.

Applicable Regulations at the time of construction of *Lamma IV*

49. *Lamma IV* was constructed in 1995. According to the evidence available to me[52], the keel was laid on 30th June 1995, and it is the date of keel-laying that is used in Hong Kong, as elsewhere, for the purposes of defining the application of Regulations.

[48] Instructions for Survey of Class I and Class II (1995)
[49] Translation of Notes of Interview (Leung Pui Sang)
[50] Modified seat foundation after previous failure (taken on 09.11.12)
[51] Seat foundation screws re-positioned (taken on 02.11.12) (p.357)
[52] China Classification Society signed survey form for hull construction

50. The Hong Kong Marine Department surveyors and inspectors used Guidance documents published by the Director of Marine for the purposes of survey. The document[53] titled "Instructions for the Survey of Class I and Class II Launches and Ferry Vessels (1995)" contain survey requirements for "new vessels" where new vessels are defined as, *inter alia*, "(a) a vessel the keel of which is laid…….**on or after 1st January 1995**"[54]. My conclusion is that these instructions were the correct ones to be used for *Lamma IV*, for which the keel had been laid in June 1995.

51. Prior to 1995, there were Guidance documents[55] titled "Instructions for the Survey of launches and ferry Vessels", originally issued by the Director of Marine in or about 1989. These particular instructions were commonly referred to as "the blue book". At the time of construction of *Lamma IV* there appears to be some confusion as to which of the two books of Instructions were applicable, probably because the surveyors and inspectors were familiar with the blue book, but the new Instructions were less familiar. At that time there would also have been craft building to both sets of instructions because their respective dates of keel-laying fell either side of 1 January 1995.

52. The previous surveyors and inspectors in their respective Reports of Interviews are divided as to which Instructions were in use for *Lamma IV*
    - Ho KT[56] believes the 1995 instructions were used.
    - Leung KC[57] believes that the 1989 instructions were used, except for subdivision calculations which were in the 1995 instructions.
    - Fung WM[58] believes that it was the 1989 instructions (the blue book).
    - Wong CK[59] held a senior position within the Marine Department and believes that both sets of instructions were in use at the time.
    - Yu KC[60] believes that the 1989 instructions were in use.
    - Chau TY[61] believes that both the 1995 instructions and the 1989 Instructions were used for assessing damage stability.

[53] Instructions for Survey of Class I and Class II (1995)
[54] Definition of a new vessel in Instructions for Survey of Class I and Class II (1995)
[55] Instructions for Survey of Launches and Ferry Vessels (1989)
[56] Translation of Notes of Interview (Ho Kai Tak)
[57] Translation of Notes of Interview (Leung Kwong Chow)
[58] Translation of Notes of Interview (Fung Wai Man)
[59] Translation of Notes of Interview of Wong Chi Kin
[60] Translation of Notes of Interview of Yu Kick Chuen Philip

53. Essentially it does not matter too much as to which were the correct regulations, because it is clear that both sets of Instructions were guidance documents for the surveyor and were not mandatory, with much being left up to the discretion of the surveyor or inspector. (For example, see Notes of Interview of Wong CK[62]). Also, both sets of instructions are reasonably similar.

54. The main requirements of the instructions on items relative to the loss of *Lamma IV*, are:

	1995 Instructions		**1989 Instructions (Blue Book)**
ChI 2(i)	*Applicable regulation:* Merchant Ship (Launches & Ferry Vessels) Regulations….	ChI 2	*Applicable regulation:* Merchant Ship (Launches & Ferry Vessels) Regulations….
ChI 4.4	..that the vessel is built in accordance with the approved plans	ChII 9	…to ensure that the approved plans are adhered to....and no material departure from the approved plans will be allowed....
ChII 3.2	Minimum thickness of shell plating > 5.0 mm		*No requirement*
ChII 5.1-5.3	W/T collision bulkhead forward W/T bulkheads at each end of engine room Peak bulkheads at both ends Maximum distance between W/T bulkheads is 40% ship length	ChII 12	(i) W/T collision bulkhead forward (ii) W/T bulkheads at each end of engine room. (iv) Peak bulkheads at both ends (iii) Maximum distance between W/T bulkheads is 40% ship length
ChII 5.4	Any access opening in a watertight bulkhead is to have an efficient watertight closing appliance	ChII 12 (v)	Any access opening in a watertight bulkhead is to have an efficient watertight closing appliance
ChII 8	All vessels carrying more than 100 passengers shall comply with the watertight requirements as stipulated in Regulation 6 of the Merchant Shipping (Safety)(Passenger Ship Construction and Survey)(Ships Built On or After 1 September 1984) Regulations 1991, as amended	ChII 15	All new launches designed to carry more than 100 passengers must comply with the watertight subdivision requirements. Regulation 5 of the Merchant Shipping (Passenger Ship Construction and Survey) Regulations 1984 refers.
ChII 9.4.1	…stability information booklets … shall be submitted for approval		*No requirement for approval*

[61] Translation of Notes of Interview of Chau To-yui
[62] Translation of Notes of Interview of Wong Chi Kin

ChII 9.4.2	The approved stability booklet … should be placed on board the vessel		*No requirement for a copy onboard*
ChIII 4.1	Where seats are provided for passengers, their…. attachments to the deck should be adequate for their intended service	ChIII 26	Seats should always be properly secured

55. It is difficult to identify exactly what issues are deemed to be important in both sets of instructions. The common parlance today in merchant shipping regulation is that the verb "shall" implies a mandatory requirement, and the verb "should" implies guidance. Both sets of Instructions predate this convention.

56. Of particular relevance is the fact that both sets of Instructions refer to the watertight subdivision requirements of the Merchant Shipping (Safety) (Passenger Ship Construction and Survey)(Ships Built On or After 1 September 1984) Regulations 1991 as amended (CAP 369), although one refers to Regulation 5 and the other to Regulation 6. Despite this difference, the intention is clear that watertight subdivision should be addressed in accordance with Schedule 1 of the Regulations, which are essentially very similar if not the same as those for ships as defined in SOLAS at that time. (IMO Assembly Resolution A.265(VIII) is quoted in Regulation 5). The referenced regulations are the same as those used for ocean-going passenger ships and contain complex mathematical procedures that were beyond the capabilities of many ship designers in 1995, and have today been replaced by computer software. These ocean-going regulations might be considered to be inappropriate for Hong Kong local craft, and in my opinion the Director of Marine may have exempted any local craft from the need to comply with these regulations, on the basis that they were extremely difficult to carry out and extremely difficult for surveyors to check. Under Regulation 2, the Director of Marine is empowered to make decision to exempt any ships of Class II(A) (not on an international voyage) of any requirement if it remains within 20 miles of land.

57. My speculation about exemption is supported by documents received from the Department of Justice on 12 December 2012 containing a copy of a letter from the Marine Department to a Ship Designer enquiring about the stability requirements

for ferry vessels[63]. This was not for *Lamma IV*, but it gives a good indication of the stability requirements at about that time. It contains an extract from a document headed L.N. 325 of 1991 and also L.S. No 2 to Gazette No 31/1991. This document appears to me to be identical to Schedule 1 of CAP. 369 Merchant Shipping (Safety) (Passenger Ship Construction and Survey)(Ships Built On or After 1 September 1984) Regulations 1991. Of particular relevance here is that Schedule 3 Section 3 (a) has been struck out and replaced with a typed comment "**one-compartment flooding**". As "one-compartment floodability" is a term in common usage amongst naval architects, I am of the opinion that this requires that the vessel be designed such that the watertight bulkheads are located so that if any one individual compartment is damaged between bulkheads then the vessels will survive and not capsize.

58. The builder of *Lamma IV* carried out the necessary calculations to determine where the vessel would float without capsizing on the assumption that any one compartment would be flooded, and originally submitted these calculations and their results in a booklet entitled "Damage Stability Information" (*sic*) to the Marine Department for approval on 6th March 1996. Further copies were issued as the design progressed or the vessel was changed as follows:

Issue	**File copy**	**Marked "Seen" by Mardep**
Final	Booklet[64]	26 July 1996
Revised B	Booklet[65]	25 March 1998
Final (with ballast)	Booklet[66]	13 January 1999
Final with revised ballast	Booklet[67]	6 January 2005

59. "One-compartment floodability" is a standard in common usage throughout the world for small craft operating close to shore. It is therefore my opinion that it is a suitable standard against which to judge the flooding of small passenger craft. However, with large passenger numbers (say greater than 100) there becomes a need to consider the risk imposed by "one-compartment floodability" on such a large number of persons.

60. I note that there have been statements made by witnesses[68] [69] [70] [71] concerning the validity of including compartments with a length less than 10% of the ship length in

[63] Fax from Marine Department dated 1 August 1994 with attached regulations for local ferries for stability and watertight subdivision
[64] Watertight subdivision original submission 1996
[65] Watertight subdivision second submission 1998
[66] Watertight subdivision third submission 1999
[67] Watertight subdivision fourth submission 2005

the flooding calculations, in response to questions from the Marine Accident Investigation Section. This issue may be relevant because the aft peak space (the steering gear compartment) on *Lamma IV* had a length of less than 10% L.

The derivation of a compartment with a length less than 10%L comes from SOLAS, and is included in CAP. 369AM Merchant Shipping (Safety) (Passenger Ship Construction and Survey)(Ships Built On or After 1 September 1984) Regulations 1991, which states in Schedule 3, paragraph 1(3):

(3) The extent of damage shall be assumed to be as follows-

(a) longitudinal extent: 3 metres plus 3% of the length of the ship, or 11.0 metres, **or 10% of the length of the ship**, whichever is the least.

This requirement, as stated previously, is re-created in a document headed L.N. 325 of 1991 and also L.S. No 2 to Gazette No 31/1991 provided by the Marine Department as being the regulations that were used in 1995. However this whole paragraph has been struck through and replaced by the words "(one-compartment flooding)". The consequence of this deletion and replacement was that small compartments with a length of less than 10%L were considered like any other compartment, and were so treated in the so-called damage stability information booklet[72]. The reason for the original requirement for 10%L minimum length of damage was that the original legislators considered that a vessel should withstand flooding from a reasonably-sized hole, and less than 10%L would be too small when considering the safety of a ship carrying more than 100 passengers. The effect of this is that if the collision were to occur in the region of the tank room on *Lamma IV*, then only one compartment would be damaged and the situation illustrated in the damaged stability book[73] is correct. In this situation the integrity of the aft peak bulkhead is essential, meaning that any access opening would require a watertight door. If the collision were to occur in the region of the steering gear compartment then the 10%L hole would be sufficiently large that TWO compartments would be damaged, namely the steering gear compartment and also the tank room. In this case the presence of the watertight

[68] Translation of Notes of Interview (Ho Kai Tak)
[69] Translation of Notes of Interview (Leung Kwong Chow)
[70] Translation of Notes of Interview of Leung Wai Hok
[71] Translation of Notes of Interview of TY Chau
[72] Watertight subdivision of Lamma IV
[73] Watertight subdivision of Lamma IV – tank compartment

door in the aft peak bulkhead would not be effective, as the 10%L hole covers the compartments on either side of the watertight door. The situation as illustrated in the damaged stability book[74] Marine Bundle 3, Tab 84, Page 479 would be incorrect, as both the steering gear AND the tank room should be investigated as being flooded. However, the requirement for the minimum extent of damage to be 10%L was deleted and superseded, which in my opinion added to the confusion on the requirements for watertight subdivision. It is incorrect to suggest that a compartment with a length of less than 10%L can be ignored, as it is the position of the watertight bulkheads that is important, and they affect the compartments both in front of and behind any small compartment of less than 10%L.

61. It should be noted that the damage for *Lamma IV* was not in the steering gear compartment, and the above explanations are only given to indicate the importance of the 10% requirement that was deleted for whatever reason and that the length of the steering gear compartment is as equally important as the bulkhead watertightness. This will be further considered under Part 2 of my opinion.

<u>Openings in the aft peak bulkhead</u>

62. The drawings provided by the shipbuilder showing the ships structure for *Lamma IV* were originally submitted to the Hong Kong Marine Department by letter of 5 January 1995[75]. There were four structural drawings, which have dates in December 1994 and each showing drawing numbers related to the *Lamma IV* project. Two of these drawings were relevant to the aft peak bulkhead (Frame ½):

- Drawing NC-391-4[76] shows four views of the proposed structure. The top view (side shell profile) shows the words "W.T. BHD" at Frame ½. The second view (centreline profile) shows the words "CORRUGATED W.T. BHD" at Frame ½, and the bottom view (bottom plan) shows "W.T. BHD" at Frame ½. The appropriate line representing the bulkhead is also shown on all four views. The term W.T. is generally understood to mean "Water Tight". It is obvious that the bulkhead at Frame ½ was intended to be watertight, as was required by the Regulations and Instructions (see also my comments in the last part of paragraph 64).

[74] Watertight subdivision of Lamma IV – aft peak only
[75] Initial structural drawings for Lamma IV – Submission Ltr fm CLS to MD
[76] Initial structural drawings for Lamma IV – Profile & Decks

- Drawing NC-391-5 sht-1[77] shows a section at Frame ½. It is a solid corrugated bulkhead with an opening located 650 mm to port of the centreline and marked "ACCESS OPENING 1200 X 600 W/50R AT CORNER (PORT ONLY)". To those knowledgeable in the art, this means that there is an opening in the otherwise solid bulkhead, located on the port side of the vessel, with a size of 1200 mm high and with a width of 600 mm. The corners of the opening are rounded with a 50 mm radius. Dimensions are also given for the exact location of this opening both vertically and horizontally. Someone at some stage has marked both of the above structural drawings as "superseded".

63. On 10 March 1995, the shipbuilder sent a letter[78] to the Hong Kong Marine Department seeking expedited approval of the drawings sent on 5 January 1995, and in an effort to speed up approval also enclosed copies of the drawings for a sister ship which had been built in China some 3 years previously. Because the sister ship had a different cabin layout, the structure was noticeably different, for example the passenger cabin came to the side of the hull and there was no walkway around the outside of the cabin. The structural drawing titled "Profile and Decks"[79] shows the words "W.T. BHD" at Frame ½ on all four views. The sectional view at Frame ½, shown on the drawing called Sections and Bulkheads[80] shows the same opening details as the previous submitted drawing[81] but the words "ACCESS OPENING" have been replaced with the words "W.T. DOOR". All of these drawings for the sister ship have been marked as "FOR RECORD PURPOSES ONLY" and there is no evidence that I can see that they were used for approval purposes for *Lamma IV*.

64. On 21 March 1995, the Builder submitted a new set of drawings[82] with the comment that they have discovered and corrected some minor errors. These are the drawings which were used for approval, and the file copies are accordingly marked as "approved".

- Drawing NC-391-7[83] shows a shell expansion with Frame½ marked as "W.T. BHD"

[77] Initial structural drawings for Lamma IV – Sections & Bulkheads
[78] Letter from CLS with approved drawings for similar ship
[79] Sister ship structural drawings – Profile & Decks
[80] Sister ship structural drawings – Sections & Bulkheads
[81] Initial structural drawings for Lamma IV – Sections & Bulkheads
[82] Submission of finalised construction drawings from CLS to MD
[83] Final structural drawings for Lamma IV – Shell Expansion

- Drawing NC-391-4[84] Profile and Decks shows four views of the proposed structure. The top view (side shell profile) shows the words "W.T. BHD" at Frame ½. The second view (centreline profile) shows the words "CORRUGATED W.T. BHD" at Frame ½, and the bottom view (bottom plan) shows "W.T. BHD" at Frame ½. The appropriate line representing the bulkhead is also shown on all four views.

- Drawing NC-391-5 sht-1[85] shows a section at Frame ½. It is a solid corrugated bulkhead with an opening located 650 mm to port of the centreline and marked "ACCESS OPENING 1200 X 600 W/50R AT CORNER (PORT ONLY)". This indicates that there is an opening in the otherwise solid bulkhead, located on the port side of the vessel, with a size of 1200 mm high and with a width of 600 mm. The corners of the opening are rounded with a 50 mm radius. Dimensions are also given for the exact location of this opening both vertically and horizontally. This drawing is marked as approved.

  The use of the words "ACCESS OPENING" is not helpful, as it does not signify the presence or absence of a watertight door. It is noted that the Instructions for Survey[86] states "where any **access opening** is fitted in a watertight bulkhead, it is to have an efficient closing appliance". This would suggest to me that the use of the term "**access opening**" on a structural drawing of a watertight bulkhead is valid terminology, at least with regard to use with the Instructions to which it was being built. Under those same Instructions it still needs to have an efficient watertight closing appliance.

65. I examined the access opening at Frame ½ on *Lamma IV* very carefully, and could find no evidence of the opening ever having been fitted with a door. Specifically I looked for evidence of hinges and where these would have been attached to the bulkhead and coaming around the door. The bulkhead was smooth throughout the region of the opening and there were no marks suggestive of welded brackets for the hinges, nor evidence of grinding to remove such brackets. I also looked for evidence of wedges on the coaming. All hinged watertight doors operate on the principal of cleats on the door being operated against wedges on the bullhead to create tightness of the rubber seal contained in the periphery of the door. I could find no such evidence of wedges ever having been fitted. I noted that the bulkhead construction

[84] Final structural drawings for Lamma IV – Profile & Decks
[85] Final structural drawings for Lamma IV – Sections & Bulkheads
[86] Instructions for Survey of Class I and Class II (1995)

was corrugated, as indicated on the drawing, with the edges of the door being approximately centralised on the forward face of the corrugations. As a consequence of this, the after face of the corrugations at the centre on the opening, above and below the door, were very close to the door coaming. Consequently there was insufficient room for a door to be fitted that could make an effective seal against the existing coaming. My conclusion is that a door has never been fitted to the existing access opening at any time, and I know of no door that could be fitted to the present arrangement and be effective. If the opening has been modified at some stage, I can see no evidence of this.

66. It is possible that the access opening and door could have been moved at some stage, although there is no obvious evidence of this. Nevertheless I note that the opening is currently physically located at 1400 mm off the centreline, whereas on the drawing[87] it is shown as being 650 mm off the centreline.

67. In summary, the aft peak bulkhead should have been watertight in accordance with the drawing and with all Regulations and with the Instructions. There is no evidence that I can identify that a watertight door was ever fitted at this location.

Horn/ Whistle

68. On inspecting the vessel I also examined the wheelhouse and control console. I noted a push-button clearly marked "HORN" on the right-hand side of the console immediately in front of the helmsman. On investigation I noted that the connections of the electrical cables to the push-button were corroded, as were many of the other connections to other equipment on the console. With a 24-Volt connection it is generally important to keep the connections clean to ensure satisfactory operation. The connections to the horn push-button are shown in Appendix IV Item 13. It was noted that there is a second button marked "horn" and a third button marked "siren". These additional buttons are part of the control panel for the loudhailer. The loud-hailer control panel is on the port side of the helmsman, and the first-mentioned horn push-button is to the starboard side of the helmsman. It is not known which button is claimed to have been pressed by the coxswain immediately prior to the incident. It might reasonably be assumed that the *Horn* and *Siren* buttons on the Loudhailer panel would not operate if the loudhailer was switched off, and there is no requirement that I am aware of for it to be switched on during normal operation.

[87] Final structural drawings for Lamma IV – Sections & Bulkheads

Lifejackets

69. I was invited to comment on the ease of donning lifejackets as fitted to *Lamma IV*. I sat in a seat on the main deck of *Lamma IV*. It was obvious to me that a lifejacket was under the seat, because it was clearly visible[88] in a yellow carrier marked "lifejacket" in English together with some Chinese characters. I was conscious that it was daylight, whereas the accident happened at night-time. Removing the lifejacket from its carrier was a simple process and putting it on was also obvious to me. I knew that it was important to restrain the lifejackets from riding up and choking the wearer when in the water, and that it needed restraining in some way, but the method of tying the relatively long tapes which were attached to the lifejacket was not obvious. Eventually I worked out that they needed passing around the body and tying together. I have donned similar lifejackets on several occasions in the past during evacuation trials, and accept that it would not be obvious to someone who was not familiar with the various lifejackets. It is standard practice in many other countries to have a demonstration at the start of any voyage on how to don a lifejacket. I was subsequently invited to comment on the effects of the long tapes of the lifejackets, and I am of the opinion that the length of the tapes would have represented a significant safety hazard to anyone donning a lifejacket in a hurry, because of the large number of open seat legs which would have entangled the tapes. A demonstration of how to put on the lifejackets would not have solved this problem.

Stability and Ballast

70. The stability of a ship is generally understood by those skilled in the art of ship design to mean the ability of the craft to return to the upright position when disturbed in a transverse direction, (i.e. rolling or heeling). Stability does not generally involve the trimming effects evident in the sinking of *Lamma IV*. I have examined the stability details[89] of *Lamma IV* and I am of the opinion that the transverse stability was adequate for the craft operation, and that adequate transverse stability remained throughout the sinking process.

71. Solid ballast is sometimes added to a craft to improve the intact transverse stability by lowering the centre of gravity. If ballast is added for this reason, then it can have serious outcomes if it is removed or re-located. On *Lamma IV*, 8.25 tonnes of solid

[88] Photo of lifejackets under seats
[89] Final Inclining Experiment & Stability Calculation booklet

lead ballast was added to the craft in October 1998 (and subsequently repositioned on 21 September 2005). According to the submission letter, the ballast was added to improve the running trim of the vessel[90]. Because the stability book indicates that Lamma IV had adequate stability characteristics before the ballast was added, and because it was added as far aft as possible, I am of the opinion that the solid ballast was added to improve the trim and not added to improve the transverse stability. Consequently I am of the opinion that the ballast played no part in the sinking process, although it is noted that a small amount of it did shift when the vessel became steeply inclined, but by that time the craft had become effectively, and unrecoverably, sunken. A visual check of the solid ballast in Lamma IV indicated to me that all of the nominated ballast was in position at the time of the collision. As was required by the Marine Department, a new stability book and a new damage stability book were recalculated and submitted for approval when the ballast was added and when it was shifted.

Summary

A brief summary of the salient points is given in the following paragraphs. More detailed technical information is contained in Appendix IV.

72. *Lamma IV* sank quickly because of the extent of damage to the hull caused by the collision with *Sea Smooth*. Water was admitted at such a rate that the stern of the craft sank under water in about 90 seconds. Thereafter for another 12 seconds the stern continued to sink until it rested on the sea bed, at an angle of approximately 70°, with the bow supported by the buoyancy of the forward compartments of the hull. These characteristics are confirmed by a numerical simulation of the flooding and sinking process.

73. *Lamma IV* was well-constructed and in good structural condition at the time of the accident. There is some question as to whether the hull plating was built with adequate thickness in accordance with the Regulations, and whether this may have contributed in some way to the extent of damage and the rapid sinking time.

74. *Lamma IV* was designed in accordance with stability regulations in force at that time to meet a capability to float in a stable condition with any one watertight compartment flooded below decks. There were five such watertight compartments,

[90] Notification to HKMD of ballast to be added to Lamma IV

and calculations confirming compliance with the Regulations were submitted to the Marine Department. My calculations show that in reality Lamma IV was capable of survival with two compartments flooded, and therefore it was theoretically capable of meeting a higher standard than was required.

75. The watertight bulkhead indicated on the design drawings at Frame ½ and forming a boundary between the Aft Peak space and the Tank Compartment was not constructed as watertight, as it contained a large access opening. The regulations required a watertight door to be fitted, but I am of the opinion that it never was fitted, and the omission was not noticed during survey. The effect of this missing door would not have been catastrophic if only one compartment on *Lamma IV* had been damaged as postulated by the regulations.

76. The collision with *Sea Smooth* resulted in two compartments being flooded very rapidly, and because there was no watertight door at Frame ½ the water also rapidly filled the Aft Peak space resulting in three compartments flooded, which was beyond the capability of the design.

77. The length of time during which the structure of *Sea Smooth* penetrated into the hull of *Lamma IV* was very short, less than 1 second, and *Sea Smooth* clearly exited the hull of *Lamma IV* through natural forces when its collision bulkhead contacted the hull of *Lamma IV*. The upper part of the bow of *Sea Smooth* penetrated the cabin of *Lamma IV* above the main deck, creating a trail of damage until *Sea Smooth* stopped with its bow located at the aft toilet block of *Lamma IV*. Whether *Sea Smooth* was deliberately operated astern at this point is not known, but I believe that the two craft would have separated on their own almost immediately without mechanical reversing, and in any case the hull of *Sea Smooth* was no longer penetrating the hull of *Lamma IV* as the damage had already been done and it would have made no difference to the rapid flooding time.

78. The passenger seats on *Lamma IV* collapsed because they were insufficiently attached to the plastic deck to withstand the abnormal load, being only screwed to the deck structure without apparent consideration of the make-up of the internal structure of the deck.

79. The vessels met at a relative heading of close to 40°, clearly measurable in the damage trail on *Lamma IV*. This is a greater angle than indicated by the radar history, and suggests that one or other (or both) of the two vessels could have been turning with the rudder hard over at the time of the impact. The radar echoes are incapable of providing exact headings at a given time, especially when the speed is rapidly changing.

Expert's Declaration

I, DR NEVILLE ANTHONY ARMSTRONG, DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.

2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.

3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.

4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.

5. I have been shown the sources of all information I have used in Appendix II.

6. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.

7. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

8. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.

9. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.

10. I understand that:

(a) my report will form the evidence to be given under oath or affirmation;

(b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;

(c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

Dr Neville A Armstrong
3 January 2013

CURRICULUM VITAE OF NEVILLE A ARMSTRONG

NEVILLE A. (Tony) ARMSTRONG

Fellow of the Royal Institution of Naval Architects

Fellow of the Institution of Engineers Australia

PERSONAL DETAILS

Date of birth:	24 February 1947
Nationality:	Australian
Qualifications:	PhD, University of New South Wales on the topic of hydrodynamics of high-speed craft, 2000. B.Sc, (Naval Architecture), University of Newcastle-upon-Tyne, UK, 1970. F.R.I.N.A., and F.I.E.Aust.
Awards:	Awarded the AGM Michell Medal of the College of Mechanical Engineering of the Institution of Engineers Australia in 2009 for outstanding contribution to Engineering. Nominated as one of Australia's most influential 100 Engineers by BRW magazine and Engineers Australia in 2007
Professional interests:	Ship Hydrodynamics, Ship Structural Design in aluminium, High-Speed Ship Design, Ship Safety Regulations.
Other (voluntary) positions:	Vice Chairman, Australian Division of the Royal Institution of Naval Architects (**RINA)** (2011-current). Member of Council, Australian Division, RINA (1994-2002, 2009-current). Member of the high-speed vessel committee of RINA (1999-current) Chairman, WA section of RINA (1999-2001) Chairman of the Technical Committee of the Australian Shipbuilders Association (1994-2010). Member of the Board of Management of the Centre for Marine Science and Technology, Curtin University, 2000-current). Member of the Board of St Jerome's Primary school,

Munster, WA (700+ pupils), (2007-current) and Chairman 2009-2011.
Technical advisor to the Australian Government on draft new commercial ship regulations (2000-current)

Publications: 37 patents, 2 books, 3 journals, 23 Conference papers, 265 technical reports, 11 organisations of Conferences, 16 invited presentations including Eminent Speaker tour of Australia for IEAust, 2009

PART-TIME EMPLOYMENT 2012 – PRESENT

FASTSHIPS (Australia) Pty Ltd

2012 - Present

- Panel member for assessment of University Courses for IEAust.
- Series of lectures on seakeeping, on behalf of Curtin University.
- Panel member of the Australian Research Council assessing University research grants.

FULL TIME EMPLOYMENT

AUSTAL SHIPS 1998 – 2012

Chief Scientist, responsible for management of all Research and Development projects across the Austal Group of Companies (Austal Ships, Austal Philippines, Austal USA), and responsible to the Chief Executive Officer.

Main responsibilities involved:

- Management of dedicated research programmes in accordance with a business plan.
- All hydrodynamic aspects of hull forms and associated hull fittings, specifically the optimization of resistance, ship motions, manoeuvrability and minimum wash height.
- External testing programmes, including all model testing, and dissemination of the knowledge from such programmes throughout the Group.
- Exploration of novel hull concepts for the future, offering reduced power and ship motions, reduced environmental impact and rapid turn-around
- Exploitation of lifting control surfaces.
- Exploration of novel propulsion systems and sources of power.
- Exploration of alternative materials for hull construction and methods of fabrication, manufacture and assembly, including non-metallic materials.

- Exploration of novel methods to identify ship structural loads and optimize structure.
- Identification and optimization of ship manufacturing and design processes.
- Working closely with Regulatory Authorities, including Classification Societies and Maritime Safety Authorities, to develop new and relevant regulations for novel vessels
- Management of a team of dedicated R&D researchers.
- Technical support of sales activities of the Austal Group.
- Support of Shipbuilding Contracts, specifically technical risk assessment and problem solving.
- Management of Government Research Grants and research tax initiatives, and various Government and University-funded projects.
- Use of computational tools such as CFD, and other numerical tools developed in-house.

I pioneered the concept and development of the world's first high-speed trimaran ferry, a unique three-hulled solution to the need for high speed combined with a high degree of passenger comfort. A four-year programme of Research and Development led to the construction of the $100 million *mv Benchijigua Express*, a 400 ft long 40-knot ferry carrying over 1000 passengers and 400 cars.

This successful project led to a joint bid with General Dynamics to design and build the next generation of US warship, the LCS *USS Independence*, using a similar concept with three hulls. Following successful trials, several further orders for the same class have now been awarded.

ARMSTRONG MARINE R&D Pty Ltd **1996 – 2000**

Managing Director of my own Consultancy Company

- Design of the Keka-class patrol Boat, as built by Australian Submarine Corporation for the Royal Thai navy and for the Hong Kong Police
- Design of a 35 knot 80-passenger Dive Boat in Aluminium.
- Provision of Expert services to the Australian Research Council
- Technical Advisor to the Australian Government delegation attending IMO on high-speed craft Safety Regulations (Drafting of the HSC Code)

AUSTRALIAN MARITIME ENGINEERING COOPERATIVE RESEARCH CENTRE 1995 – 1996

Regional Manager for New South Wales
Management of maritime engineering research activities by various industry and academic partners at the University of New South Wales.

INTERNATIONAL CATAMARAN DESIGNS (Incat Designs) 1989 – 1995

As **Managing Director**, formally **Director of Design**, I was responsible for the concept design and marketing of many high-speed passenger craft, including:

- The world's first large car-carrying passenger high-speed catamarans (eg *mv Hoverspeed Great Britain*).
- The design of three high-speed catamarans which subsequently were awarded the Hales Trophy for the fastest crossing of the Atlantic.
- The design of the largest passenger-only high-speed catamaran (*mv Condor 9*).
- The design of the largest diesel-powered passenger and car-ferry catamaran (120m length) at that time.
- The design of a rescue catamaran for Kai Tak airport, Hong Kong.

CARRINGTON SLIPWAYS 1988

As **Business Development Manager** I was responsible for winning the contract for a 35 m harbour cruise vessel for Sydney harbour *mv John Cadman III* and also the 95-metre long Antarctic Research vessel *mv Aurora Australis*, for which I was also the principal designer. I was also responsible for the design of a 147-m RoRo craft *mv Searoad Tamar*.

M.J.DOHERTY & COMPANY Pty Ltd 1980 – 1987
also 1975 - 1977

I became **Managing Director** of this company before selling it in 1987, having worked my way through the company from employment as a naval architect.

Examples of my achievements were the successful design of:

- a series of 110 m bulk coal carriers built in The Philippines as part of overseas aid programme by the Australian Government. This contract also included the provision of construction assistance to the shipbuilders.
- several bulk carriers, including 143m cement carrier *mv Goliath*, 108 limestone carrier *Accolade II*, 100m soda-ash carrier *mv Sandra Marie*.
- a novel sidecasting dredger, *mv April Hamer*.
- several offshore supply craft, including one built by Chung Wah Shipbuilding and Engineering in Hong Kong, *mv Lady Penelope*.
- several tugs of various sizes, eg *mv Hauraki* for Auckland Harbour Board, New Zealand.

MARINE DEPARTMENT, HONG KONG GOVERNMENT 1977 – 1980

As a **ship surveyor** I was involved in overseeing the construction of several vessels and other marine structures ordered by the Hong Kong Government, including several Police Launches, Marine Department launches and PWD structures. I was also responsible for the Survey and Certification of a vessel built in Rostok, East Germany (at that time) for Hong Kong Registry, and also for a vessel built in Hong Kong on behalf of the UK Department of Trade for UK registration *mv Salvageman*.

VICKERS SHIPBUILDERS AND ENGINEERS 1965 – 1974

As a **Commissioning and Testing Engineer** I was responsible for the setting to work and testing of hull structures and fittings on a number of warships and submarines, specifically *HMS Sheffield* and *HMS Invincible*. I was originally a Student Apprentice attending University and then became a research engineer working on novel minehunter development using fibreglass construction.

EDUCATION

Wrekin College, UK 1960 - 1965

DOCUMENTS PROVIDED TO DR. ARMSTRONG (for the purpose of this report)

1. An index of the documents the Commission has received from the Hong Kong Police ("HKPF"), the Marine Department ("MarDep") and the Fire Services Department ("FSD") since 9 November 2012 until 12 December 2012.

2. A list of the relevant persons involved in the incident (prepared by Lo & Lo).

3. Soft copies of selected documents provided by HKPF and Mardep to the Commission since 9 November 2012 until 28 December 2012.

4. Hard copy of documents relevant to the scope of the expert engagement:
   (a) Translation of various statements provided by the HKPF,
   (b) Translation of various notes of interviews provided by HKMD,
   (c) Information on the 2 vessels (*Lamma IV* and *Sea Smooth*),
   (d) Photographs relating to *Lamma IV* and *Sea Smooth* after the collision, supplied by Mardep and by HKPF,
   (e) Chart of HK Hydrographic Office HK 09052 showing depths of water, and
   (f) All documents in Marine Bundles 1~8 and Police Bundles P & H.

5. Instructions for the Survey of Launches and Ferry Vessels issued by the Marine Department (1989 Version).

6. Instructions for the Survey of Launches and Ferry Vessels issued by the Marine Department (1995 Version).

7. Fax from HKMD stating the applicable watertight subdivision standard in 1995.

8. Hong Kong Laws, specifically Merchant Shipping Ordinances and Regulations.

APPENDIX III

Documents referred to in this Report

Footnote		Bundle Reference
1.	General Arrangement of *Sea Smooth* approved by Mardep on 10.07.2008	Police H p.1320+
2.	Vessel Licence of *Sea Smooth* (validity from 02.12.2011 to 30.11.2012)	Police H pp.1312-1315
3.	General Arrangement of *Lamma IV* approved by Mardep on 08.05.1995	Police H p.1322
4.	Vessel Licence of *Lamma IV* (validity from 08.07.2012 to 07.07.2013)	Police H pp.1316-1319
5.	Photograph of Sea Smooth	Marine Bundle 8 p. 1981
6.	Police Album IX (taken on 14.11.12)	Police Photo Album IX pp.427+
7.	Submission of construction plans fm CLS to MD (p.202)	Marine Bundle2 p.202
8.	Submission of construction plans fm CLS to MD (p.203)	Marine Bundle2 p.203
9.	Submission of construction plans fm CLS to MD (p.204)	Marine Bundle2 p.204
10.	Submission of construction plans fm CLS to MD (p.205)	Marine Bundle2 p.205
11.	Drawing of proposed new fender arrangement	Police P pp. 4947-4952
12.	Stability booklet submitted by CLS to MD on 26.12.2001	Marine Bundle 6 pp.1351+
13.	Dept of Justice letter dated 13 December 2012, with Chart showing water depths from Hydrographic Office of Hong Kong Marine Department and Drawing No. H109052	Marine Bundle 10 pp.3224-3225 and pp.3281-3282
14.	Inclining Experiment & Stability Calculation (marked as “seen” on 13.01.1999)	Police P pp.4917+
15.	Translation of Note of Interview (Leung Pui Sang)	Marine Bundle 1 p.39-5
16.	Translation of Note of Interview and Questionnaire (Chow Chi Wai)	Marine Bundle 1 pp.89-1 & 89-24
17.	Inclining Experiment & Stability Calculation (marked as “seem” on 13.01.1999)	Police P pp.4917+
18.	Extent of Bow damage to *Sea Smooth* (taken on 09.11.12)	Police Photo Album VIII p.397
19.	Drawings of additional fendering	Police P pp. 4947-4952
20.	Cut through the deck (taken on 02.11.12)	Police Photo Album VII p.381
21.	Photo of displaced structure *Lamma IV*, below fender	Police Photo Album IX p.506
22.	Appendix IV, amended version MB8 p.1975	Marine Bundle 8 p.1975
23.	Construction details of upper deck, as submitted CLS to MD	Marine Bundle 5 p.876
24.	Photo of hole in side shell in way of the Tank Room (taken on 15.10.12)	Police Photo Album V p.267 Photo 12
25.	Steel Stem plate on *Sea Smooth*	Marine Bundle 8 p.1979 photo 29
26.	Localised corrosion in the aft deck (taken on 02.11.12)	Police Photo Album VII p.370, photo 21
27.	Plate thickness from Survey & Test Report at 2005 annual survey *Lamma IV*	Marine Bundle 4 p.654

28.	Plate thickness from Survey & Test Report at 2011 annual survey *Lamma IV*	Police P p.4870
29.	Approved construction drawings of shell expansion showing thickness of side plate (approved by Mardep on 17.05.1995)	Marine Bundle 2 p.202
30.	Hull survey certificate (06.09.1995) from China Classification Society	Marine Bundle 2 pp.265+
31.	Plate thickness from Survey & Test Report at 2005 annual survey Lamma IV	Marine Bundle 4 p.654
32.	Plate thickness from Survey & Test Report at 2011 annual survey Lamma IV	Police P p.4870
33.	Approved construction drawing of shell expansion showing thickness of bottom plate (approved by Mardep on 17.05.1995)(MB2, p.202)	Marine Bundle 2 p.202
34.	Instructions for Survey of Class I and Class II (1995)(ChII, 3.2)	Marine Bundle 8 pp.1820-1821
35.	Instructions for Survey of Class I and Class II (1995)(ChI, 4)	Marine Bundle 8 p.1818
36.	Fax from Marine Department dated 1 August 1994 attached with regulations for local ferries for stability and watertight subdivision	Marine Bundle 8 pp 2081-2085
37.	Watertight subdivision calculations as originally submitted by CLS to MD (10 Mar 1998)	Marine Bundle 3 pp 442-448
38.	Watertight subdivision calculations as submitted by CLS to MD (10 Oct 1998)	Marine Bundle 3 pp.472-479
39.	Acknowledgement letter for watertight subdivision calculations 1998 (marked as “seen” on 13.01.1999)	Police P pp.4933+
40.	Submission of most recent Watertight subdivision calculations 2005 (by CLS to MD on 21.02.2005)	Marine Bundle 3 pp.667+
41.	Photo of access opening in “watertight” bulkhead at Fr½ (taken on 02.11.12)	Police Photo Album VII p.367 photo 18
42.	Watertight subdivision, Tank space flooded, from final stability book (21.07.2005)	Marine Bundle 4 pp.698-699
43.	Debris from *Sea Smooth* within hull breach of *Lamma IV* (taken on 14.11.12)	Police Photo Album IX pp.438-504
44.	Debris from *Sea Smooth* within hull breach of *Lamma IV*	Marine Bundle 1 p.127
45.	Removal of debris from hull breach of *Lamma IV* (taken on 14.11.12)	Police Photo album IX p.441 photo 8
46.	Photos of various self-tapping screws attaching the seats	Marine Bundle 1 p.136
47.	Laminate structural design of deckhouse and submission Letter fm CLS to MD	Marine Bundle 2 pp.210 to 210-1
48.	Instructions for Survey of Class I and Class II (1995)	Marine Bundle 8 p.1835
49.	Translation of Notes of Interview (Leung Pui Sang)	Marine Bundle 1 p.39-3
50.	Modified seat foundation after previous failure (taken on 09.11.12)	Police Photo Album VIII p.421
51.	Seat foundation screws re-positioned (taken on 02.11.12)	Police Photo Album VII p.357
52.	China Classification Society signed survey form for hull construction dated 02.09.1995	Marine Bundle 2 p.266
53.	Instructions for Survey of Class I and Class II (1995)	Marine Bundle 8 pp.1810+
54.	Definition of “new vessel” in “Instructions for Survey of Class I and Class II (1995)”	Marine Bundle 8 p. 1817
55.	Instructions for Survey of Launches and Ferry Vessels (1989)	Marine Bundle 8 p. 1761
56.	Translation of Notes of Interview (Ho Kai Tak)	Marine Bundle 1 pp.34-43

57.	Translation of Notes of Interview (Leung Kwong Chow)	Marine Bundle 1 pp.34-52+
58.	Translation of Notes of Interview (Fung Wai Man)	Marine Bundle 1 pp.34-61+
59.	Translation of Notes of Interview of Wong Chi Kin	Marine Bundle 8 pp.1933-1+
60.	Translation of Notes of Interview of Yu Kick Chuen Philip	Marine Bundle 8 pp.1955-1+
61.	Translation of Notes of Interview of Chau To-yui	Marine Bundle 8 pp.1948-1+
62.	Translation of Notes of Interview of Wong Chi Kin	Marine Bundle 8 p.1933-2 section 3
63.	Fax from Marine Department dated 1 August 1994 with attached regulations for local ferries for stability and watertight subdivision	Marine Bundle 8 pp 2081-2085
64.	Watertight subdivision first submission 1996	Marine Bundle 2 pp.337+
65.	Watertight subdivision second submission 1998	Marine Bundle 3 pp.442-448
66.	Watertight subdivision third submission 1999	Marine Bundle 3 pp.472+
67.	Watertight subdivision fourth submission 2005	Marine Bundle 4 pp.695-707
68.	Translation of Notes of Interview (Ho Kai Tak)	Marine Bundle 1 p.34-45 para [19]
69.	Translation of Notes of Interview (Leung Kwong Chow)	Marine Bundle 1 p.34-55 para [16]
70.	Translation of Notes of Interview of Leung Wai Hok	Marine Bundle 8 pp.1941-2 para [8]
71.	Translation of Notes of Interview of TY Chau	Marine Bundle 8 p.1948-3 para [7]
72.	Watertight subdivision of *Lamma IV* (submitted by CLS to MD on 10.03.1998)	Marine Bundle 3 p.479
73.	Watertight subdivision of *Lamma IV* – tank room (submitted by CLS to MD on 10.03.1998)	Marine Bundle 3 p.478
74.	Watertight subdivision of Lamma IV – aft peak only (submitted by CLS to MD on 10.03.1998)	Marine Bundle 3 p.479
75.	Structural drawings for *Lamma IV* – Submission Letter dated 05.01.1995 from CLS to MD	Marine Bundle 2 pp.175+
76.	Structural drawings for *Lamma IV* (submitted by CLS to MD on 05.01.1995) - Drawing NC-391-4 (Profile and Deck)	Marine Bundle 2 p.192
77.	Structural drawings for *Lamma IV* (submitted by CLS to MD on 05.01.1995) - Drawing NC-391-5 sht-1 (Sections & Bulkheads)	Marine Bundle 2 p.193
78.	Letter from CLS to MD dated 10.03.1995 with approved drawings for sister ship	Marine Bundle 2 pp.195+
79.	Sister ship structural drawings – Profile & Decks	Marine Bundle 2 p.197
80.	Sister ship structural drawings – Sections & Bulkheads	Marine Bundle 2 p.198
81.	Initial structural drawings for *Lamma IV* – Sections & Bulkheads	Marine Bundle 2 p.193
82.	Submission of finalised construction drawings from CLS to MD (21.03.1995)	Marine Bundle 2 pp.201+
83.	Final structural drawings for *Lamma IV* – Shell Expansion	Marine Bundle 2 p.202
84.	Final structural drawings for *Lamma IV* – Profile & Decks	Marine Bundle 2 p.204
85.	Final structural drawings for *Lamma IV* – Sections & Bulkheads	Marine Bundle 2 p.205
86.	Instructions for Survey of Class I and Class II (1995)	Marine Bundle 8 p.1822 [ChII, 5.4]
87.	Final structural drawings for *Lamma IV* – Sections & Bulkheads	Marine Bundle 2

		p.205
88.	Photo of lifejackets under seats (taken on 15.10.12)	Police Photo album V p.322
89.	Final Inclining Experiment & Stability Calculation booklet (1998)	Police P p.4917+
90.	Notification to HKMD of ballast to be added to *Lamma IV*	Marine Bundle 3 p. 428

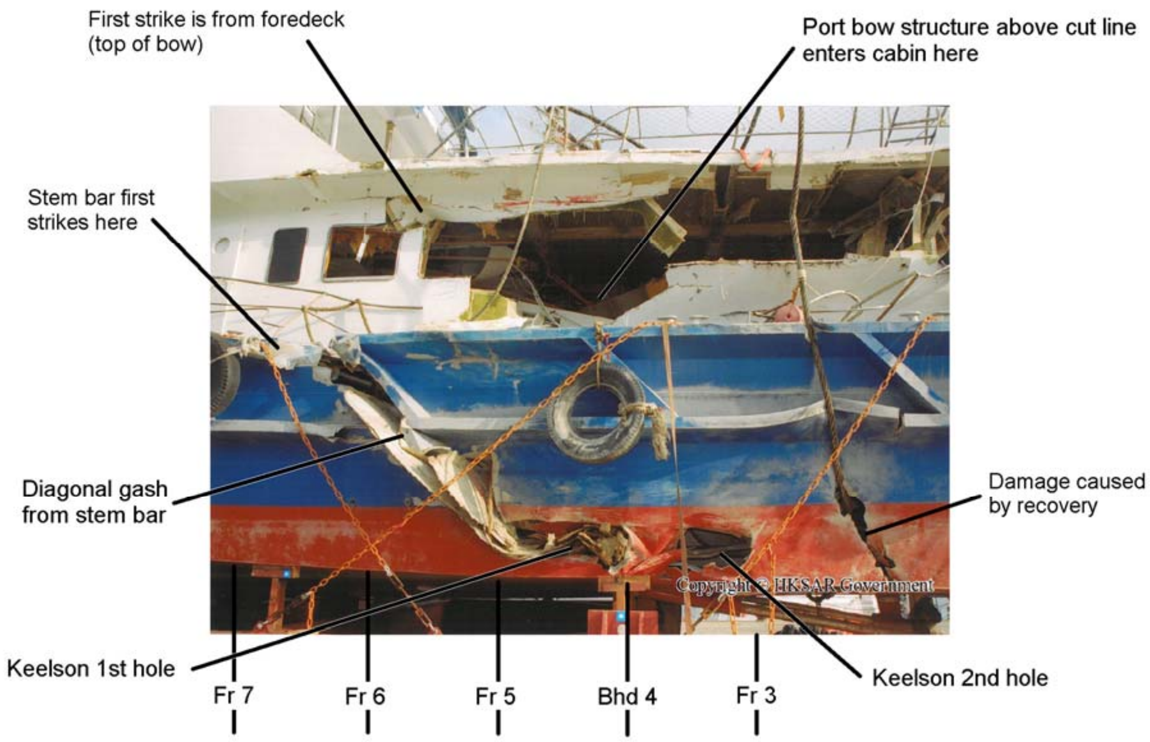
APPENDIX IV

Photographs taken and sketches by Dr NEVILLE A ARMSTRONG, and referenced in this Report

App IV - 1. Stem Bar and Keelson

Illustration of how the stem bar and keelson form the bow structure of the *Sea Smooth*, superimposed on picture Police Photo Album VIII p. 397. These two items are the same material and the same size, and were responsible for most of the damage to the hull of *Lamma IV*.

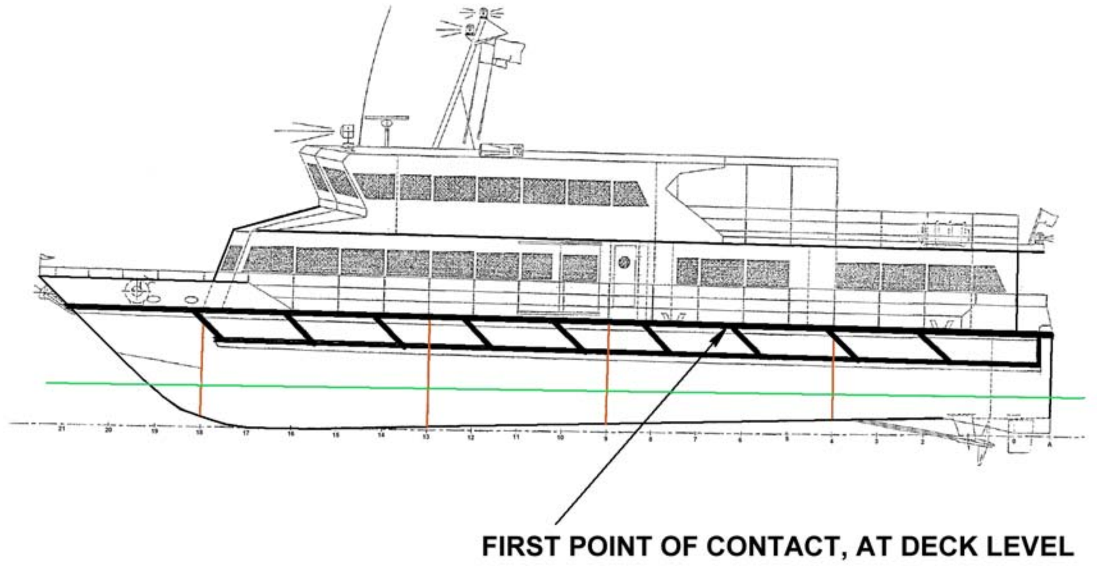
App IV - 2. Principal damage to Lamma IV watertight integrity



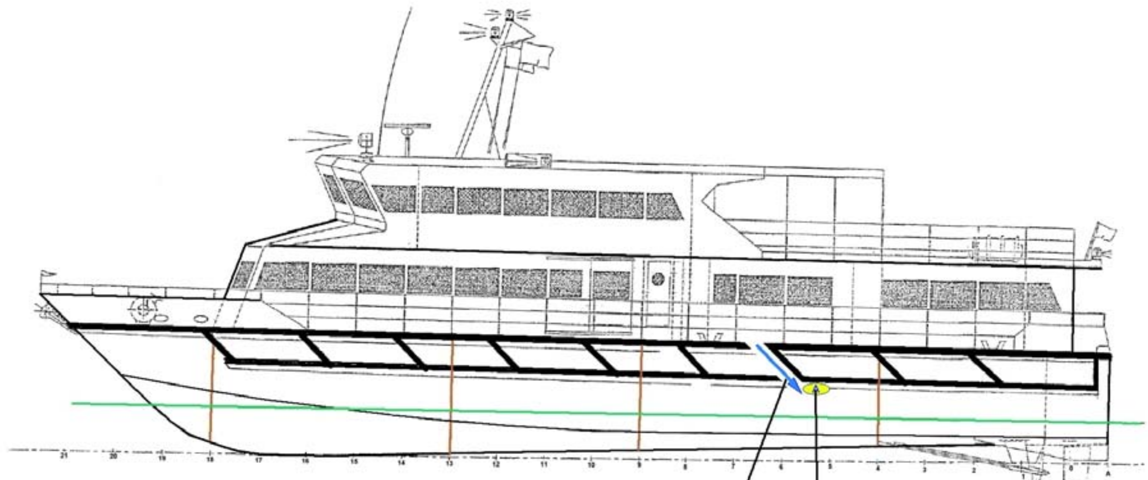
Annotations on Photograph in Police Photo Album VIII, Page 415

App IV-3. Explanation of the hull damage sequence to Lamma IV.

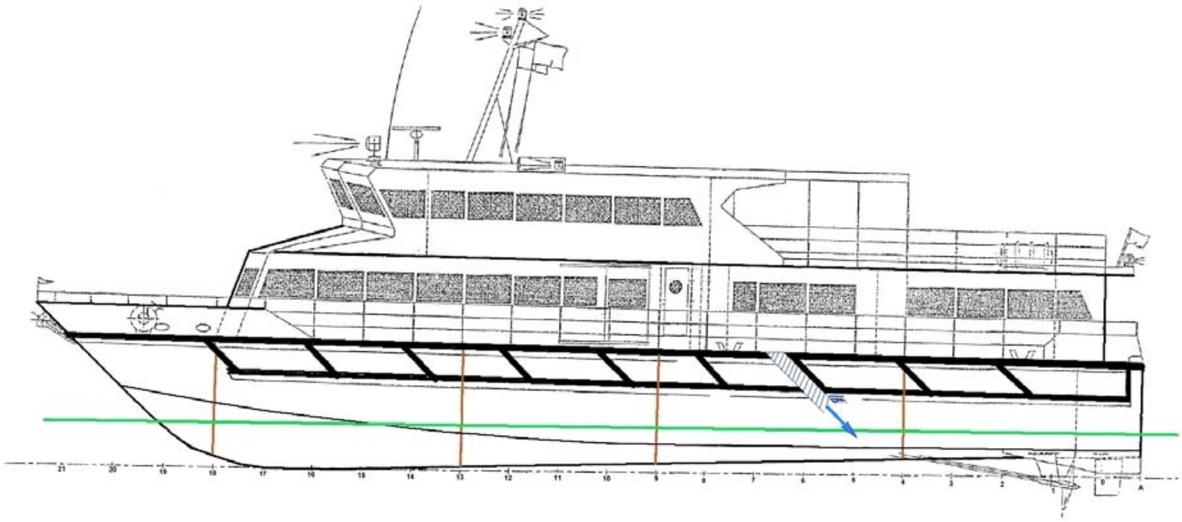
Sketch AppIV-3.1: Stem bar of *Sea Smooth* strikes deck of *Lamma IV* forward of a strong sloping fender.



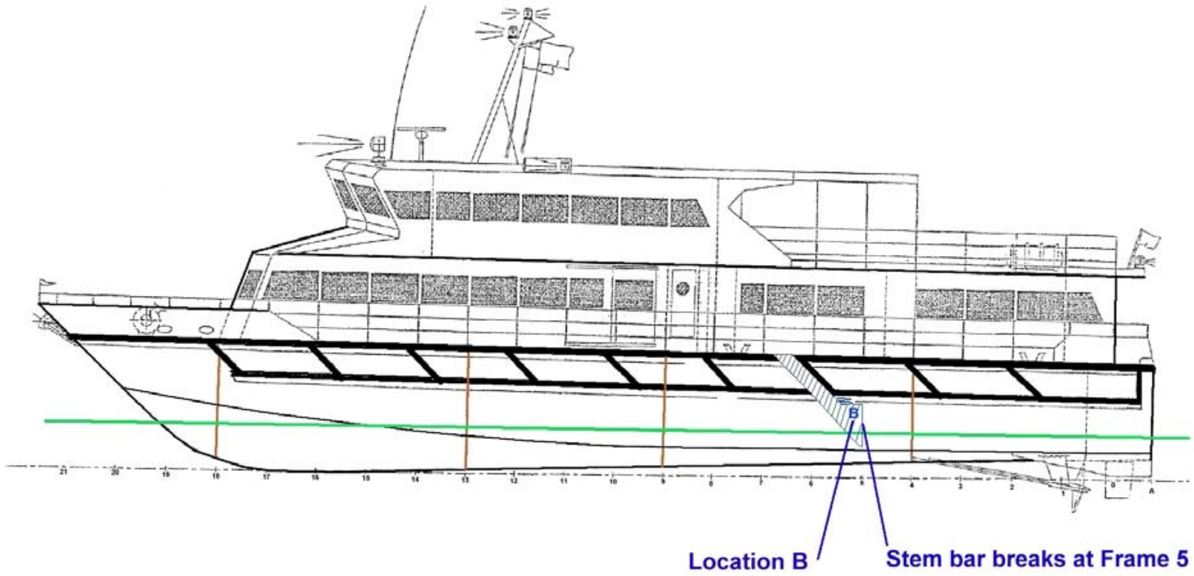
Sketch AppIV-3.2: Stem bar penetrates into *Lamma IV*, and travels downwards relative to the shell. It displaces *Lamma IV* plating which finally ends up below the sloping fender at Location A. The stem bar is twisted by the combination of the presence of the sloping fender and the relative motions of the two vessels, and strikes the strong Frame 6, which further stresses it.



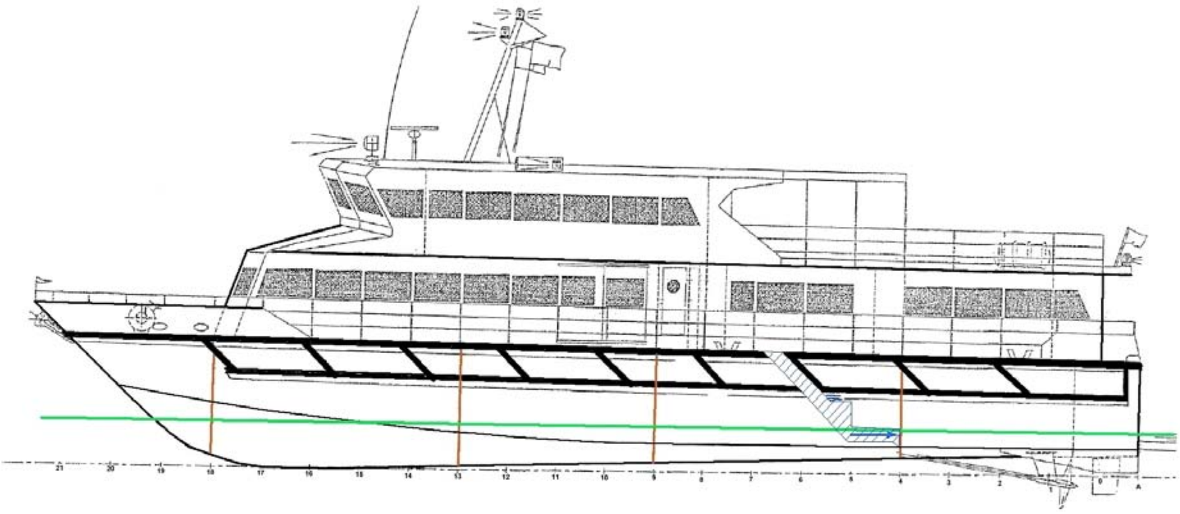
Sketch AppIV-3.3: The stem bar travels down, clears the fender and possibly relieves stress by breaking at the lower fender level.



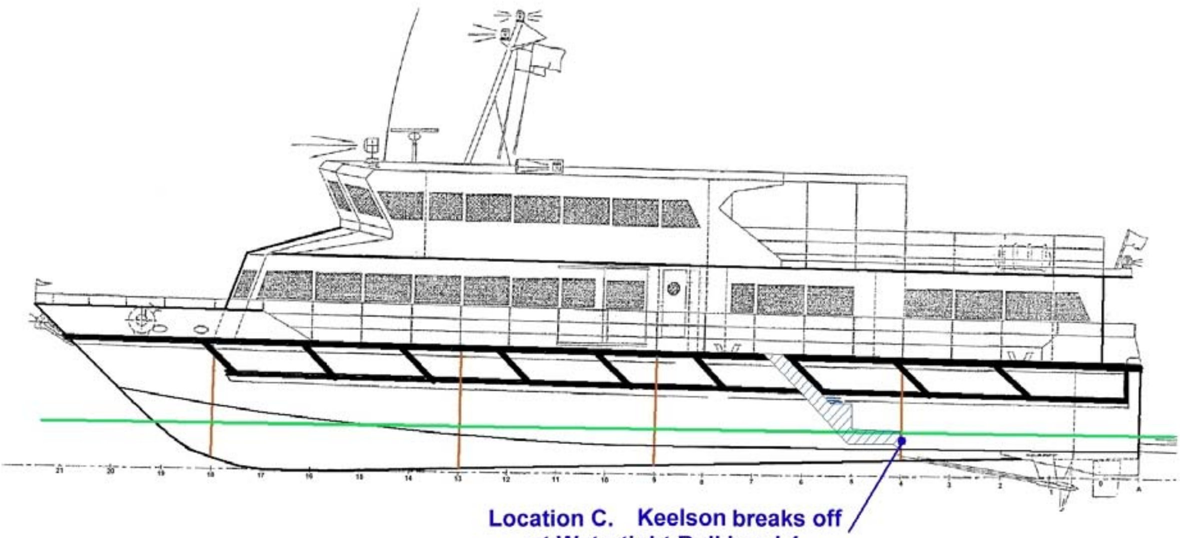
Sketch AppIV-3.4: The remaining stem bar removes plating from *Lamma IV* (Location B) until it strikes the strong frame 5, where it again breaks off.



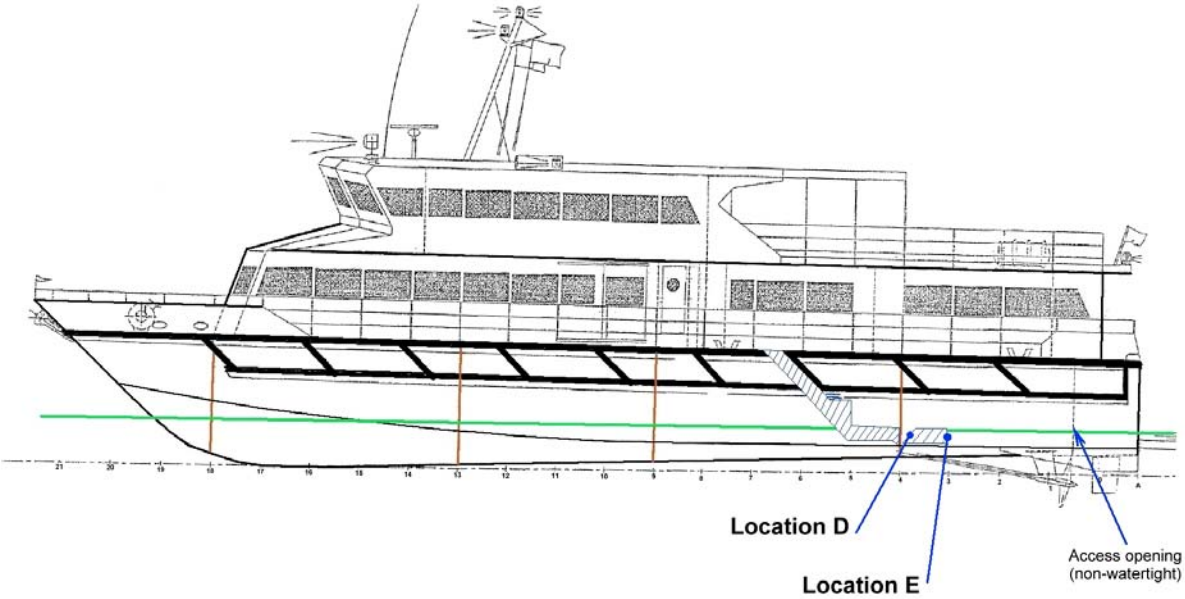
Sketch AppIV-3.5: the stem bar has broken off inside *Lamma IV*, but the keelson continues to enter the shell and removes more plating up to the Watertight Bulkhead 4.



Sketch AppIV-3.6: The keelson breaks off at Watertight Bulkhead 4.

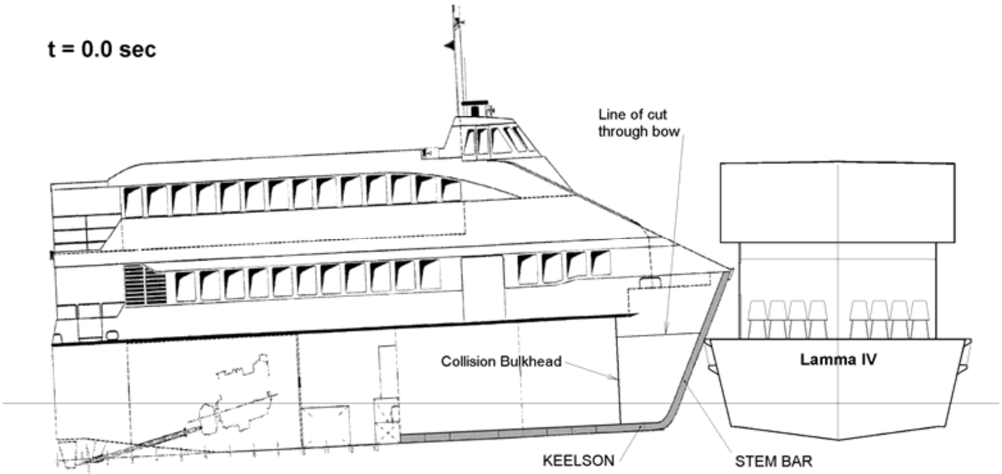


Sketch AppIV-3.7: Owing to the continuing forward motion of *Sea Smooth*, the keelson again penetrates the shell plate of *Lamma IV* (at location D) until it meets Frame 3 at Location E and again breaks off. At this point the collision bulkhead of *Sea Smooth* meets the side of *Lamma IV*, and the surfaces in contact are now large enough for the motion of *Sea Smooth* to be arrested, causing no further hull damage.



App IV - 4. Relative positions of *Lamma IV* and *Sea Smooth*

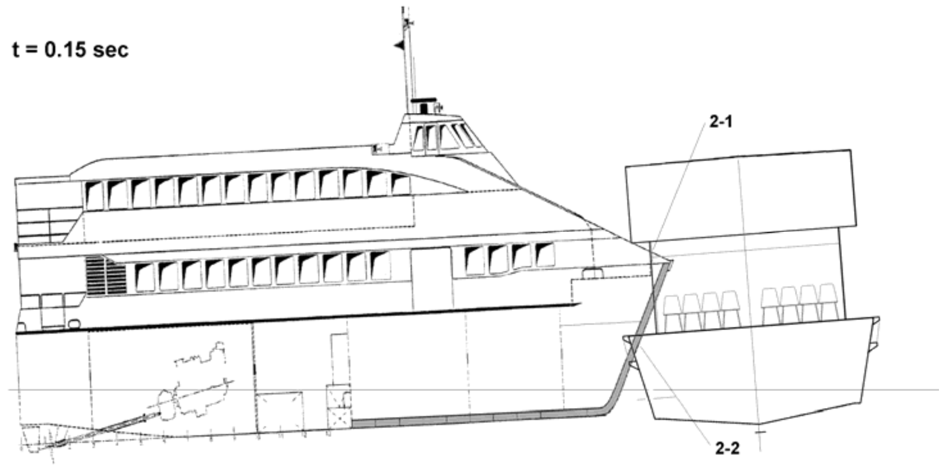
Based on the estimated loading of the two vessels, using the data within the stability books, the draughts at the forward and after end can be calculated. *Sea Smooth* was travelling at speed which would have produced substantial stern trim, which has been calculated for a vessel at 22.5 knots and in the depth of water of 13.44 m. The positions of the two craft correlate well with the measured extent of damage.



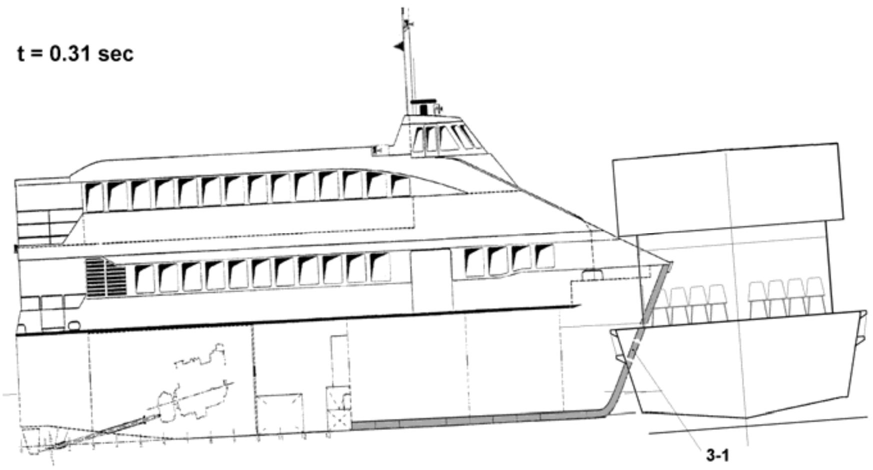
Sea Smooth appears to be foreshortened here because it was at an angle of approximately 40° to Lamma IV. (See paragraph 15 of the main Report for justification of the 40° angle).

Note the line of cut through the bow of *Sea Smooth*, coinciding with the deck level of *Lamma IV*. The stem bar of *Sea Smooth* first strikes the fender of *Lamma IV* very close to Frame 7.

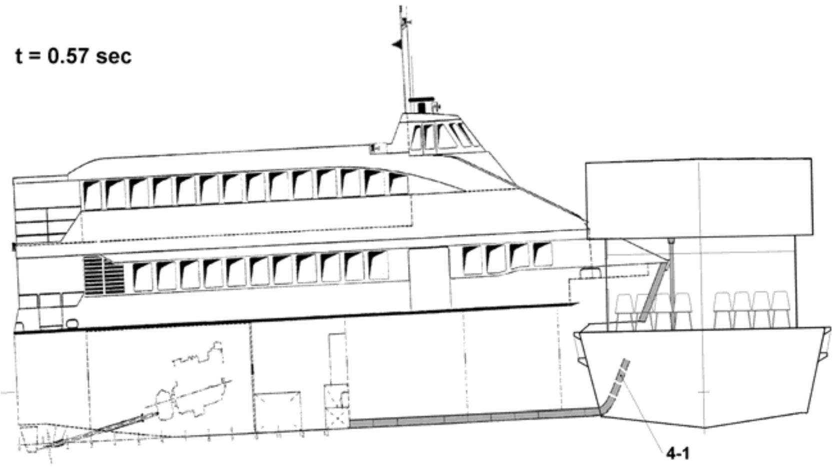
The following series of diagrams illustrate the relative position of the two craft at various time intervals during the collision:



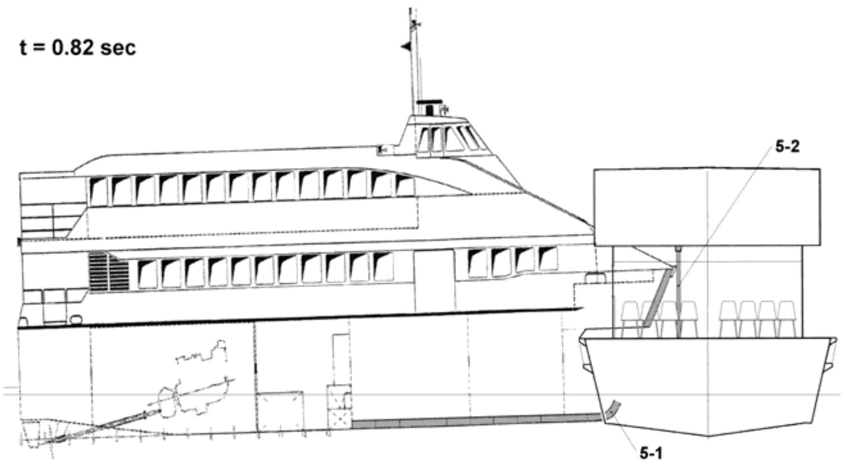
Sketch AppIV-4-2-1 The foredeck of *Sea Smooth* strikes the deckhouse of *Lamma IV* just above the window level, as can be seen the annotated photograph in App IV Item 2.
Sketch AppIV-4-2-2 The stem bar of *Sea Smooth* cuts through the deck and side structure of *Lamma IV*.



Sketch AppIV- 4-3-1 The diagonal gash in the side of *Lamma IV* is caused by the stem bar entering at an angle and the forward motion of *Lamma IV*. Constrained in its path by the sloping fender, the stem bar twists and breaks in way of the deck.

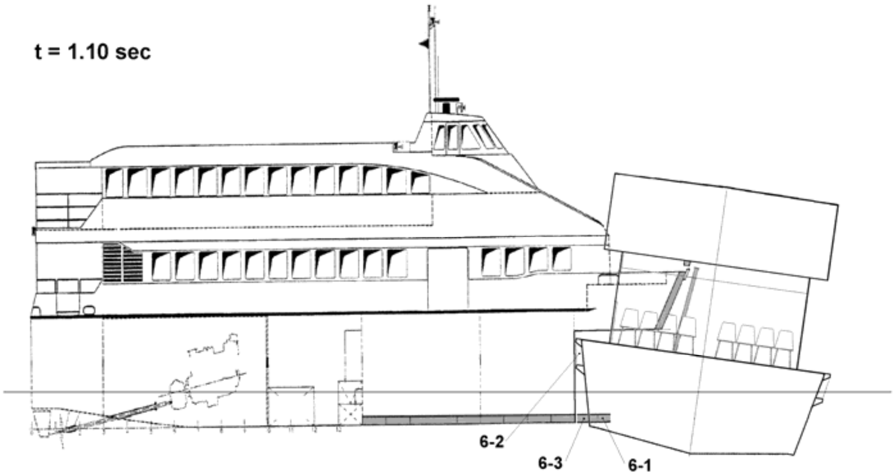


Sketch AppIV-4-4-1 The lower part of the stem bar strikes a strong point of the structure of *Lamma IV*, Frame 5, and breaks into pieces below decks, leaving the keelson within *Lamma IV*, which continues to make a rectangular hole through the shell plating.



Sketch AppIV-4-5-1 The keelson strikes Bulkhead 4 in its travels down the length of *Lamma IV*, and breaks off.

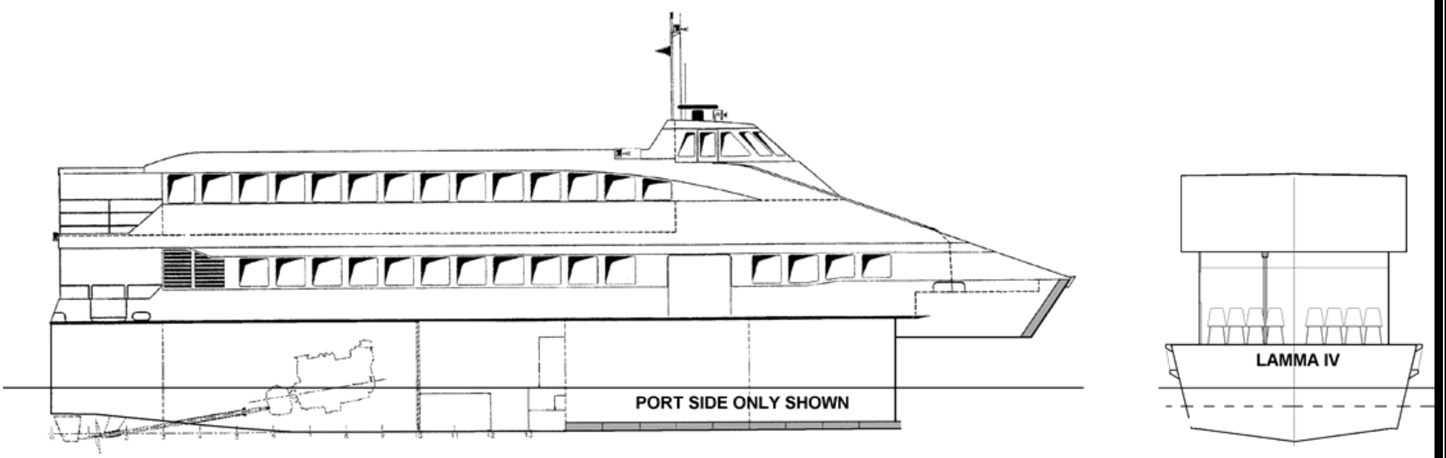
Sketch AppIV-4-5-2 the foredeck of Sea Smooth makes contact with a supporting pillar within the cabin and displaces it to an angle of about 10°.



Sketch AppIV-4-6-1 Shortly after breaking off at Bulkhead 4, the stem bar re-enters the hull of *Lamma IV* causing a hole into the Tank Compartment.

Sketch AppIV-4-6-2 the "forward" motion of *Sea Smooth* is effectively halted by the very strong collision bulkhead (port side hull) meeting the hull of *Lamma IV*.

Sketch AppIV-4-6-3 At this stage both vessels are moving together through the water at about 3½ knots , with Lamma IV going backwards but rotating relative to *Sea Smooth*, causing the keelson to break off *Sea Smooth* near the collision bulkhead, and further intrusion into the hull of *Lamma IV* ceases at this point.

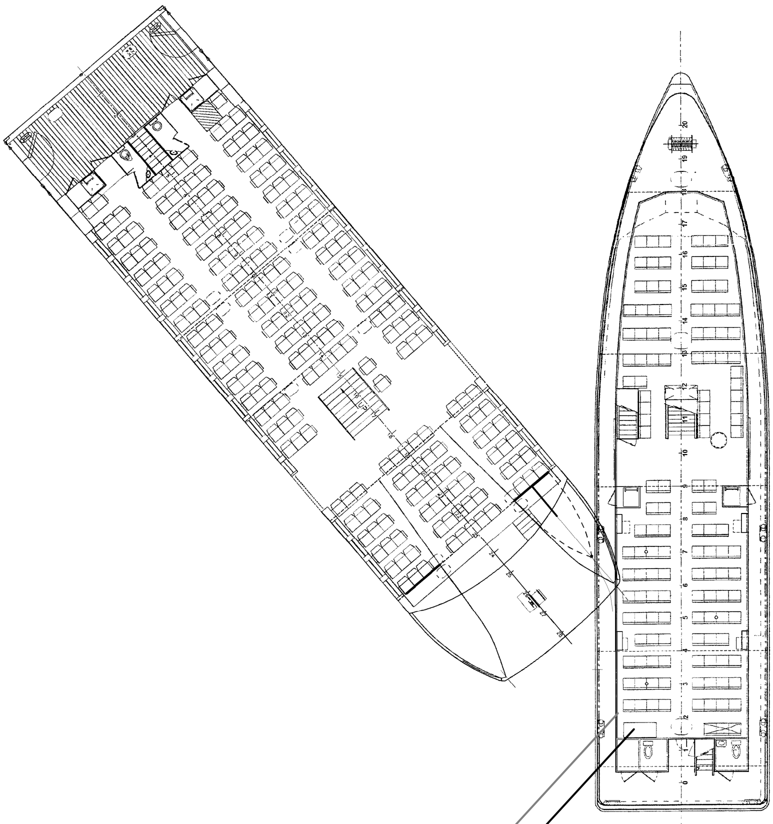


Sketch AppIV-4-7 Sea Smooth separated from Lamma IV after the collision

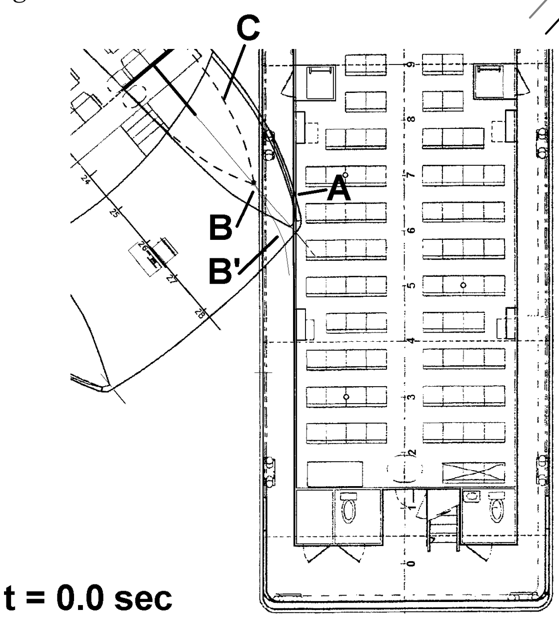
<u>App IV - 5. Sketches in plan view showing the relative positions of *Sea Smooth* and *Lamma IV* during stages of the collision</u>

Time = 0 secs

Lamma IV at 11.5 kn, Sea Smooth at 22.5 kn, relative heading 40°



In greater detail:



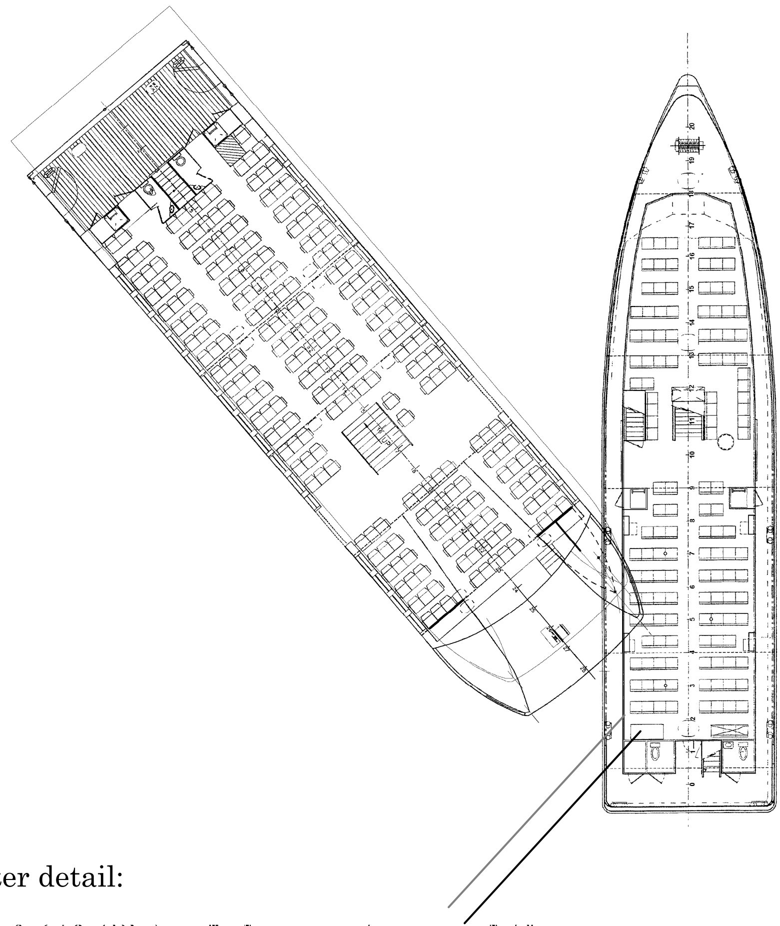
A. First contact, see App IV Item 2

B. Stem bar strikes fender.

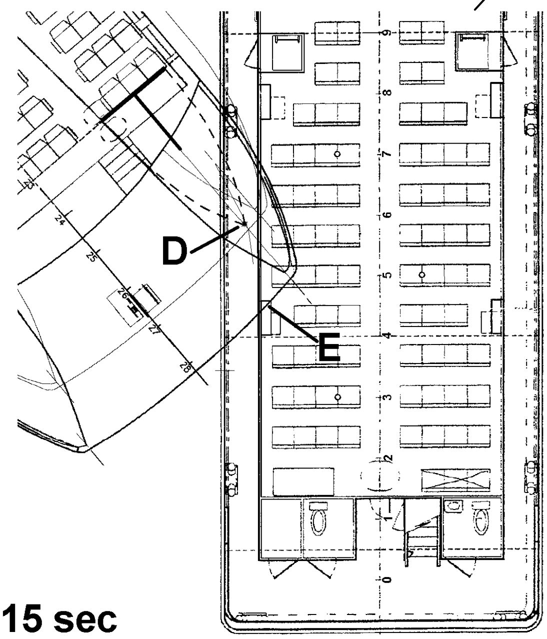
B'. Cut line of stem bar through deck, as measured.

C. Shape of bow at deck level of Lamma IV.

Time = 0.15 secs



In greater detail:

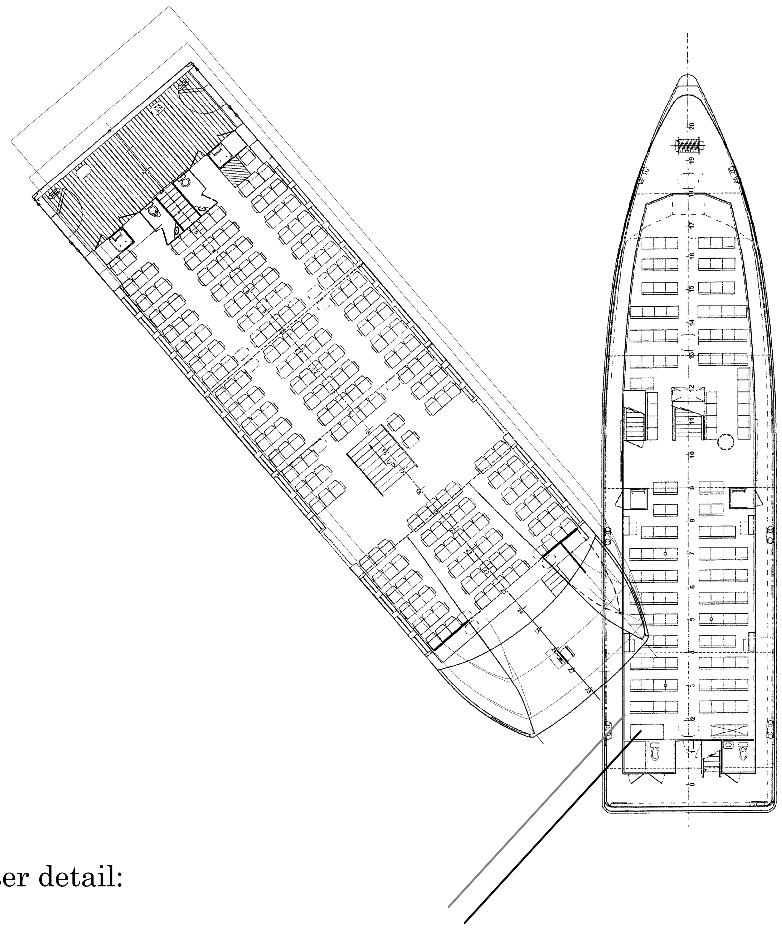


t = 0.15 sec

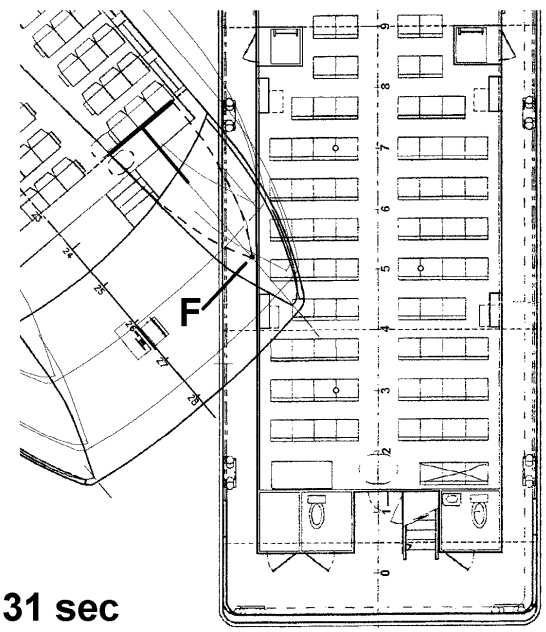
D. Stem bar following cut line in deck.

E. Foredeck strikes vent trunking causing visible marks on the bow of Sea Smooth

Time = 0.31 secs



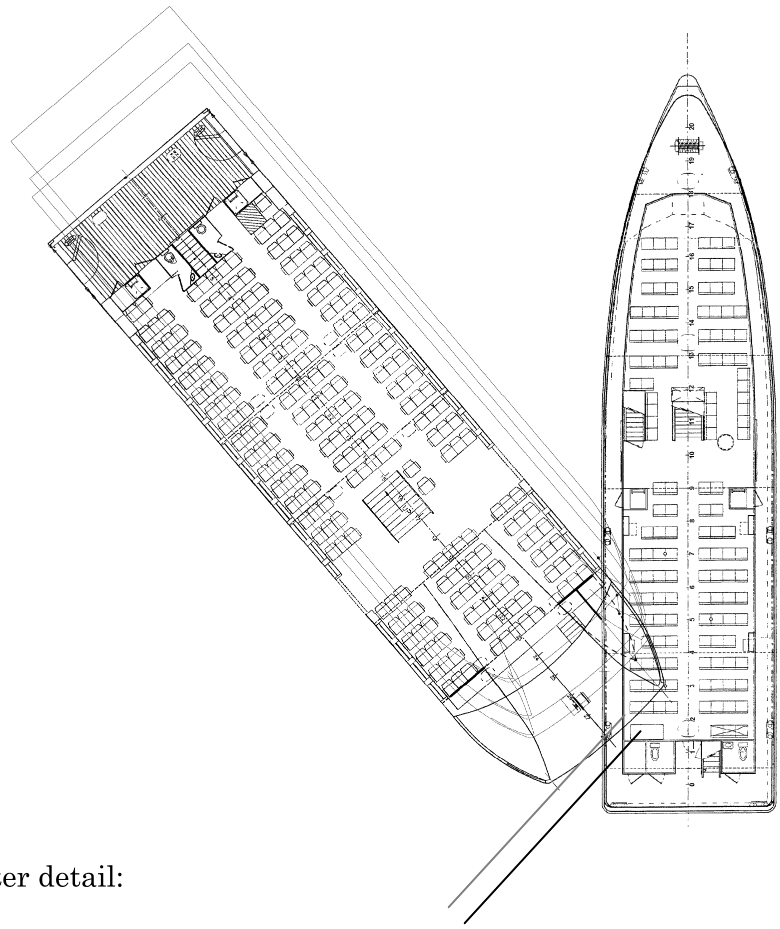
In greater detail:



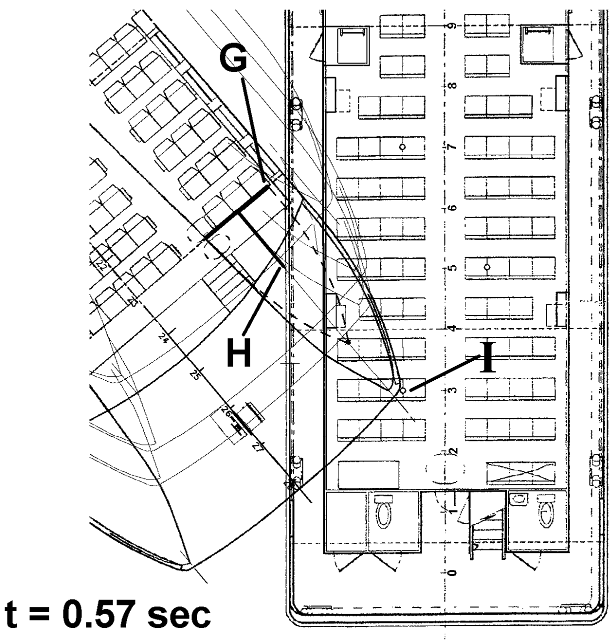
F: Stem bar meets Frame 5 and breaks at deck level and below.

t = 0.31 sec

Time = 0.57 secs



In greater detail:

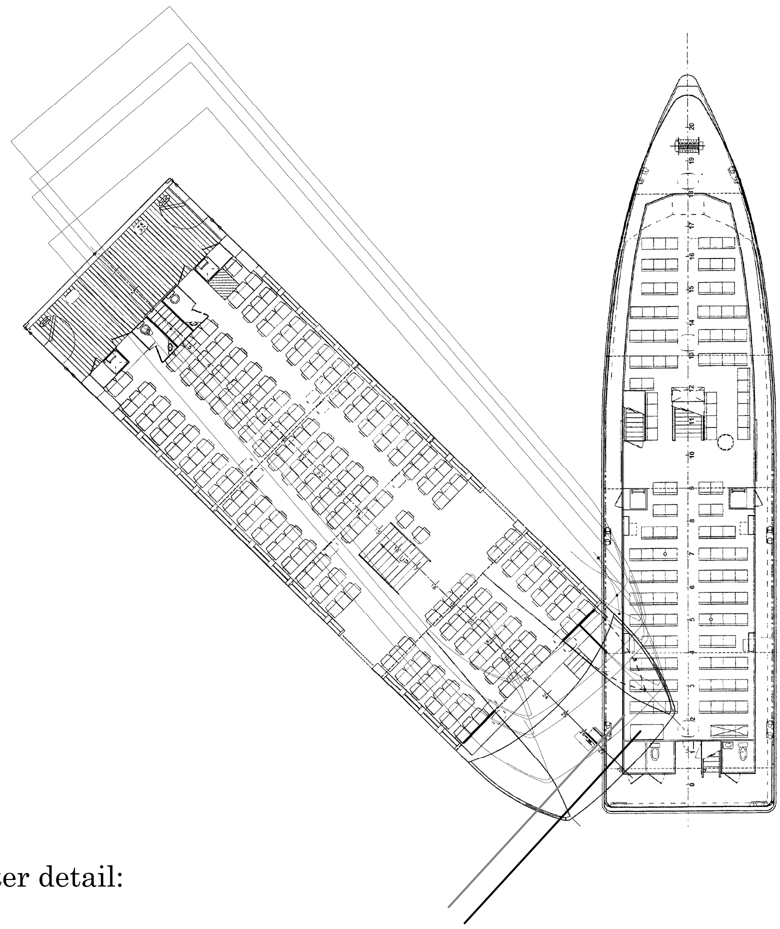


G: Collision bulkhead contacts hull of *Lamma IV*. Forces result in turning of *Sea Smooth* and heel of *Lamma IV*

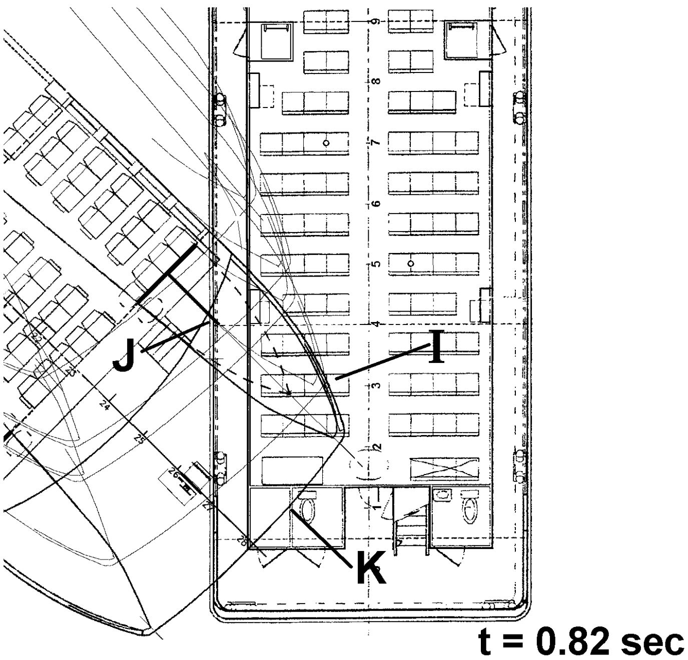
H. Keelson first enters hull

I. Pillar within cabin is struck and displaced.

Time = 0.82 secs



In greater detail:

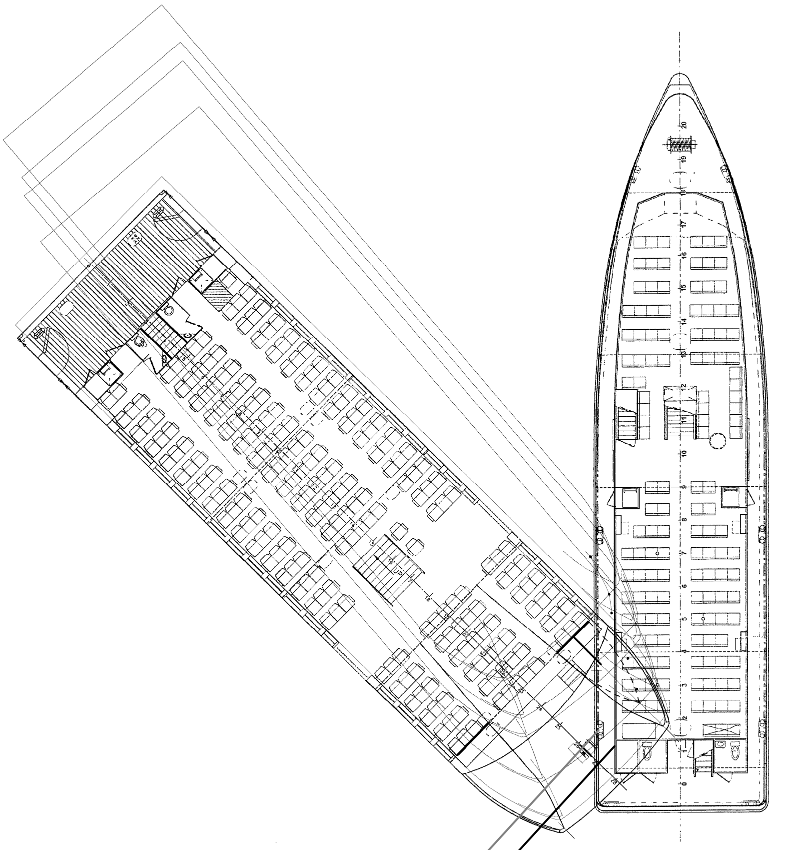


J: Keelson breaks on Bulkhead 4, and then re-penetrates the hull on the after-side of the bulkhead.

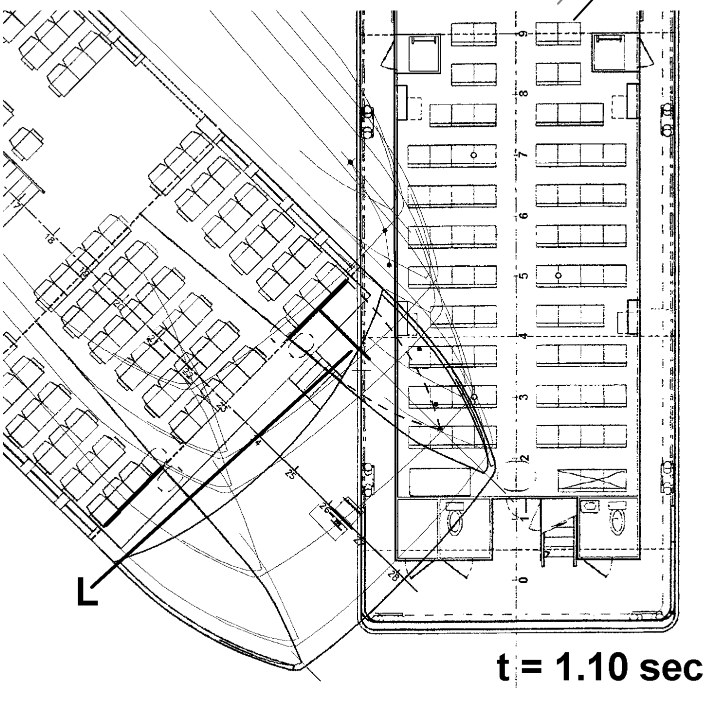
K. Forward wet deck of Sea Smooth cuts through the structure of *Lamma IV* under the upper deck, removing the support structure and tops of the bulkheads around the toilet and stores block.

Time = 1.10 secs

Momentum of *Sea Smooth* has been substantially reduced, and some converted to rotational energy



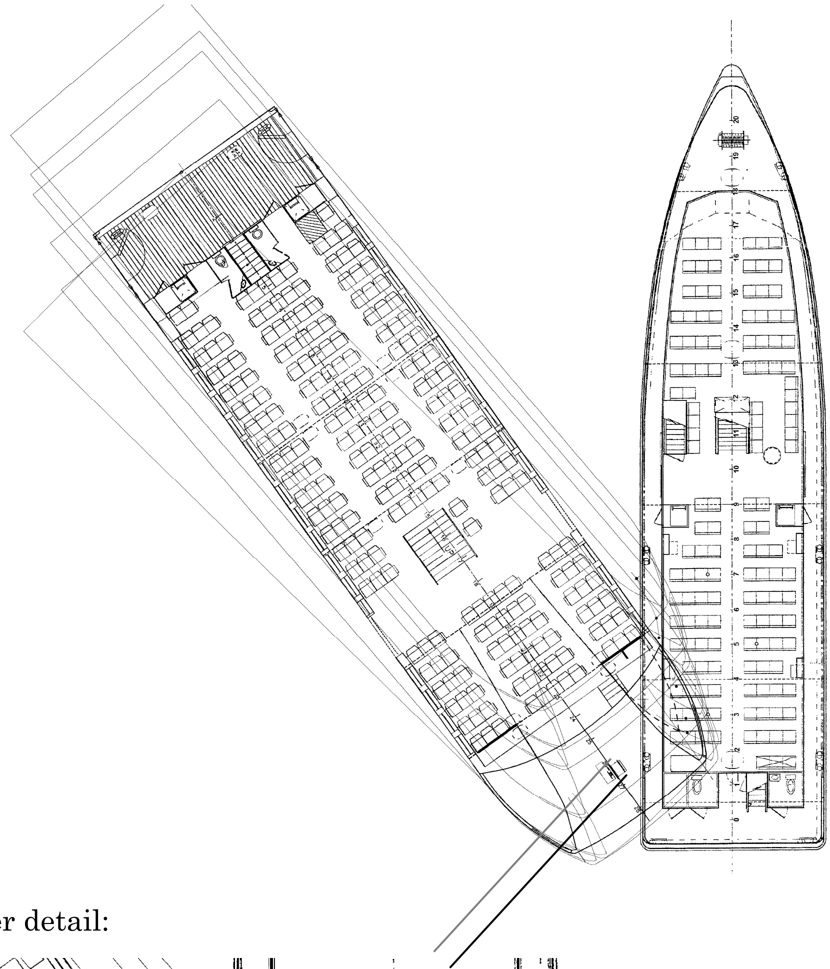
In greater detail:



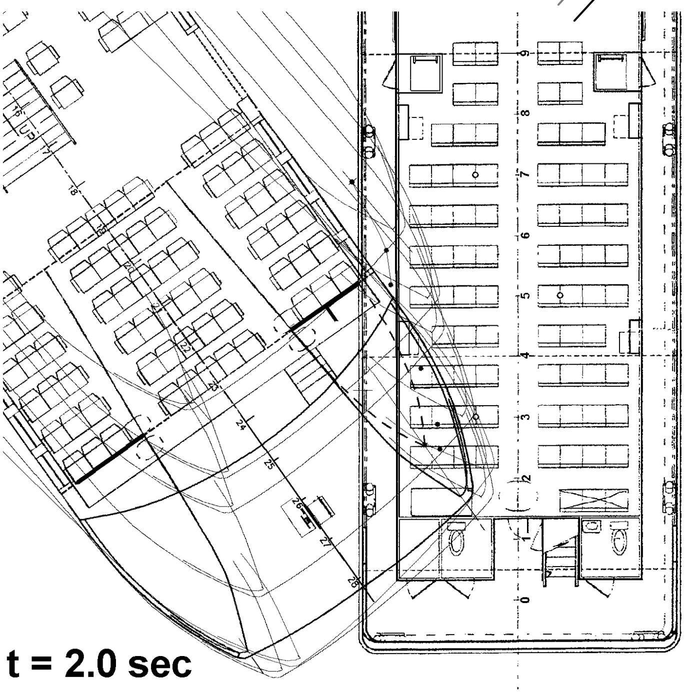
L: Keelson breaks before Frame 3, with no further hull penetration.

Time = 2.0 secs

Forward speed of Sea Smooth halted. Lamma IV rotates relative to Sea Smooth, reducing the angle between them. Both craft moving together at about 3½ knots (Lamma IV moving astern)



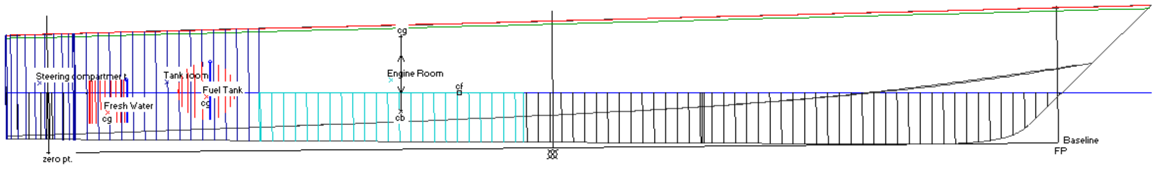
In greater detail:



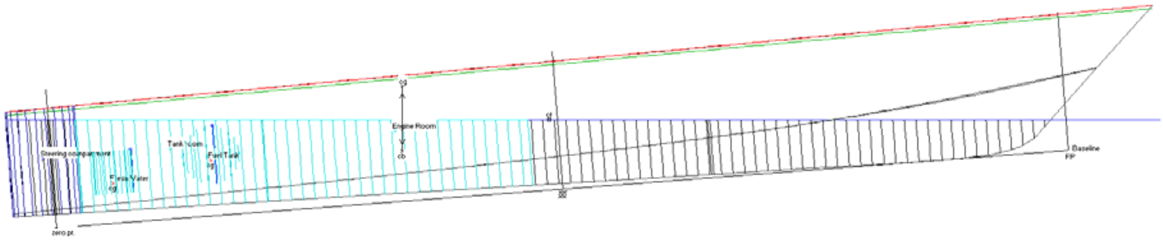
This is the furthest penetration into the cabin of Lamma IV. Lamma IV possibly continues to move astern leaving Sea Smooth behind.

t = 2.0 sec

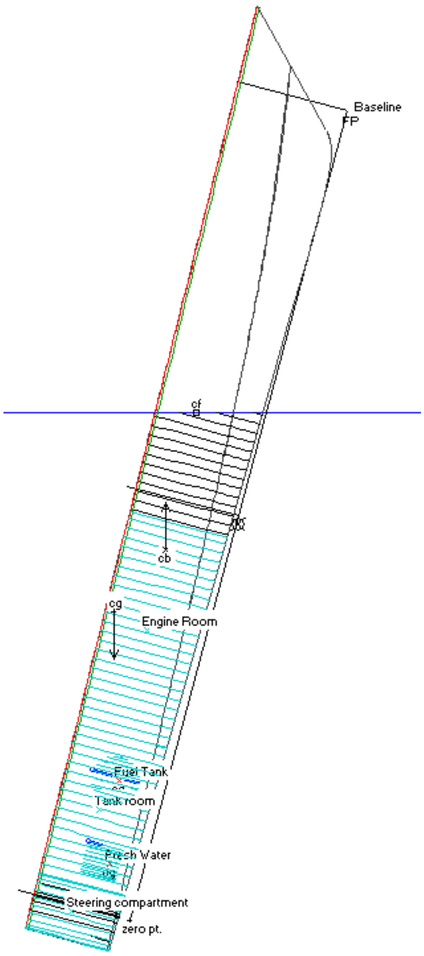
App IV - 6. Output from the software *Hydromax*, showing flooded waterlines for three vessel conditions:



App IV - 6.1 One-compartment damage – Engine Room



App IV - 6.2 Two-compartment damage – Engine Room & Tank Compartment
Note that the stern is almost submerged, but the vessel remains afloat.



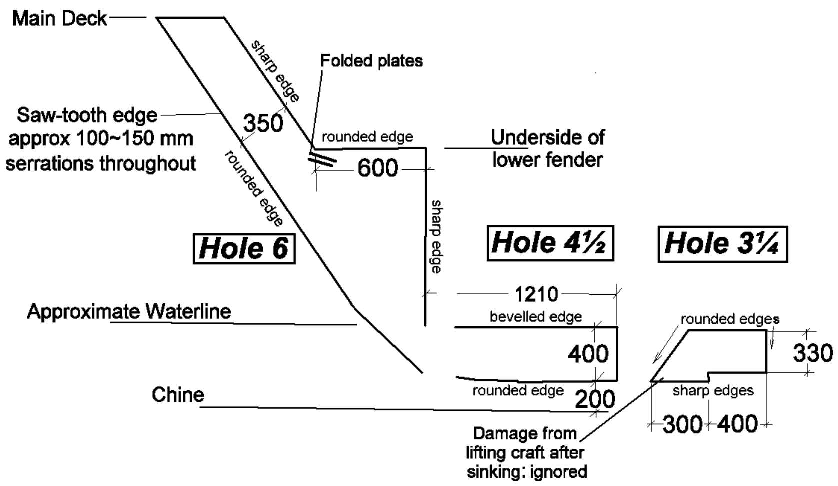
App IV - 6.3 Three-compartment damage – Engine Room, Tank Compartment and Aft Peak

App IV – 7. Comparison of the output from two different calculations of flooded waterline position.

Condition		Draught Aft	Draught Fwd
Engine Room only		**1 compartment**	
Hydromax software		1.44 m	1.21 m
Numerical Simulation model		1.47 m	1.27 m
Stability Book (2005)		1.51 m	1.29 m
Engine Room & Tank Room		**2 compartment**	
Hydromax software		2.55 m	0.72 m
Numerical Simulation model		2.81 m	0.72 m

App IV – 8. Information on the holes in the shell plating Lamma IV

Measurements were taken on 11 December 2012 to assist with setting up a numerical model and calculating the area of the holes which influence the inlet flow velocity.



App IV – 9. Plot of Trim Attitude for the damaged craft against Elapsed Time

A dynamic numerical model of the flooding of Lamma IV was prepared to simulate the flooding process and to examine the reason for the apparent rapid sinking and excessive stern trim of *Lamma IV*. The prediction from the simulation is illustrated against elapsed time in the following diagram for a vessel with an access opening located in the bulkhead at Fr½. The vessel becomes unrecoverably sunk when the transom disappears below the waterline, in about 87 seconds from first breach of the hull.

The same simulation was also run with a watertight door on the open access at Bulkhead ½. In this scenario the vessel floated with equilibrium despite the damage.

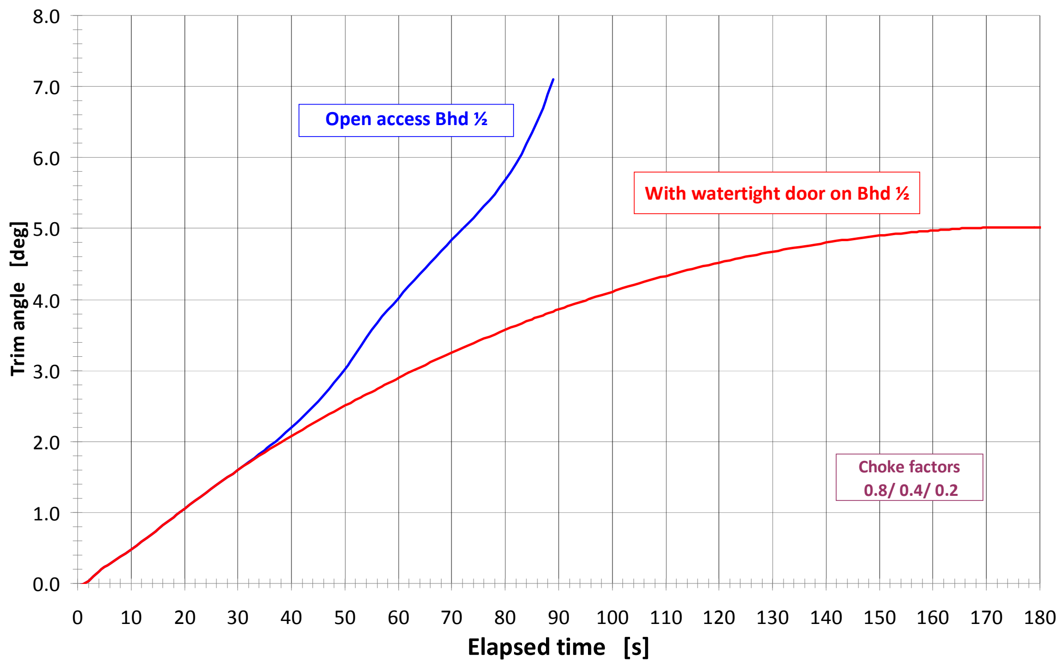


Diagram App IV:-9-1

The above simulation only calculated the flooding of the vessel and not the sinking. The output from the simulation was used as a starting point for a further simplified mathematical model which predicted the attitude of the vessel as it sank to the sea bed. The timeline of this second simulation is illustrated below:

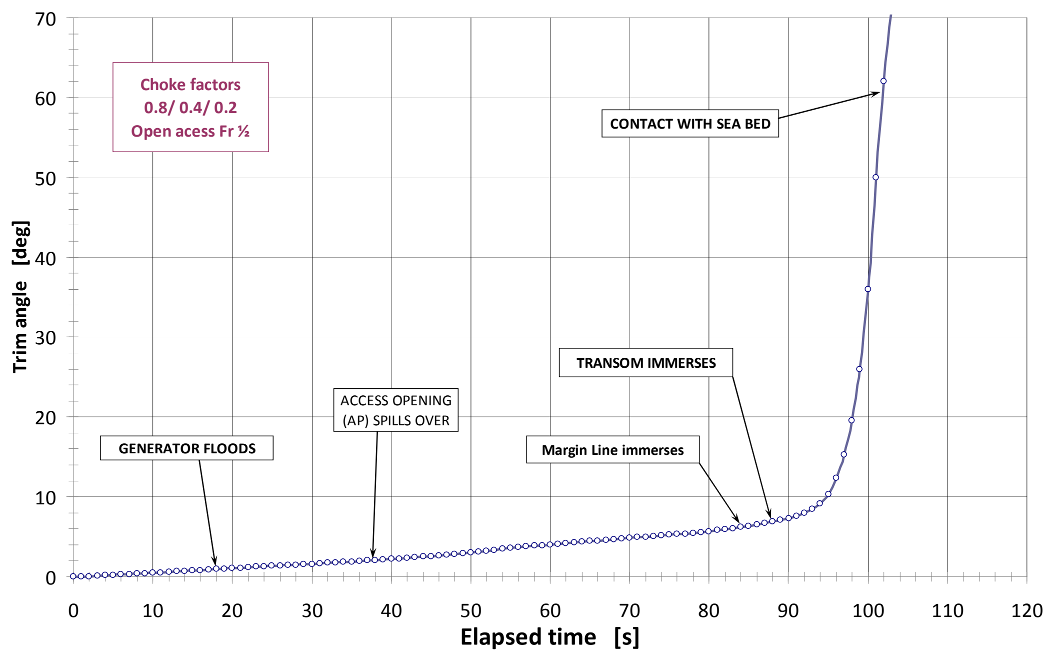
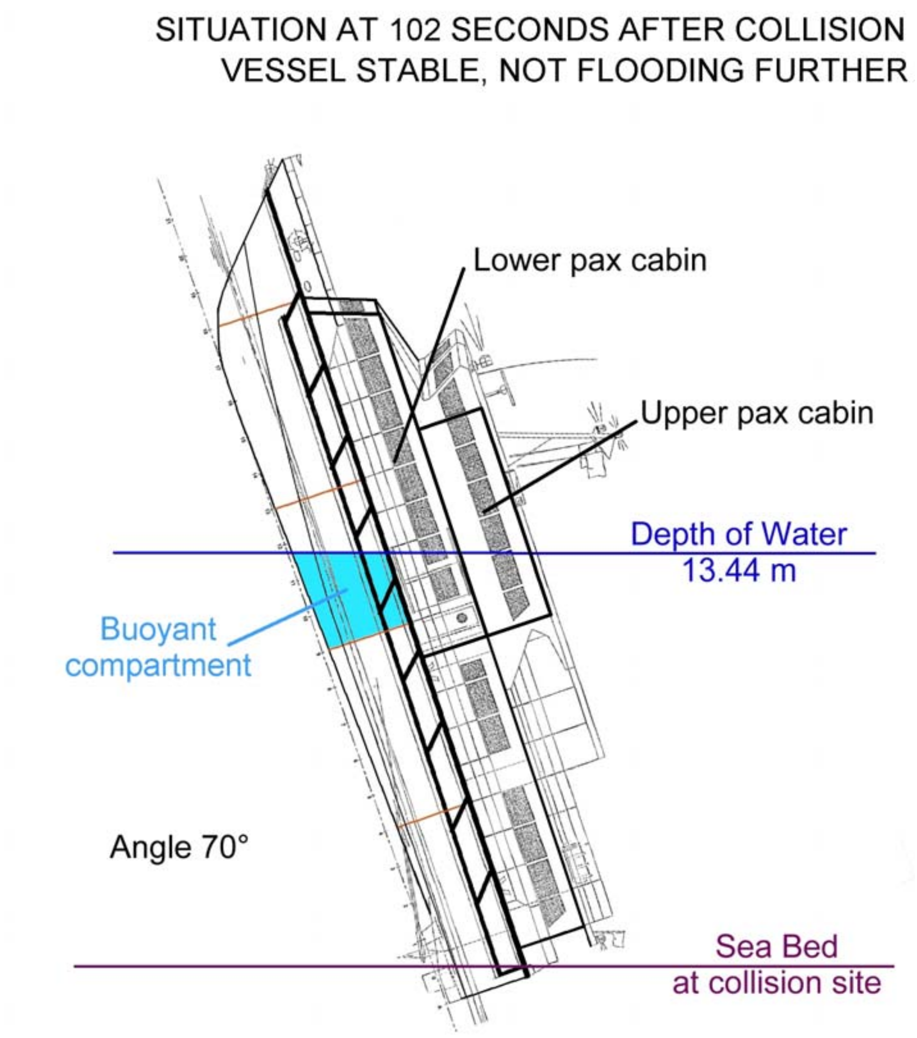


Diagram App IV-9-2

The attitude of the vessel taken from the numerical simulation after 102 seconds from the first contact between the two vessels is illustrated below:



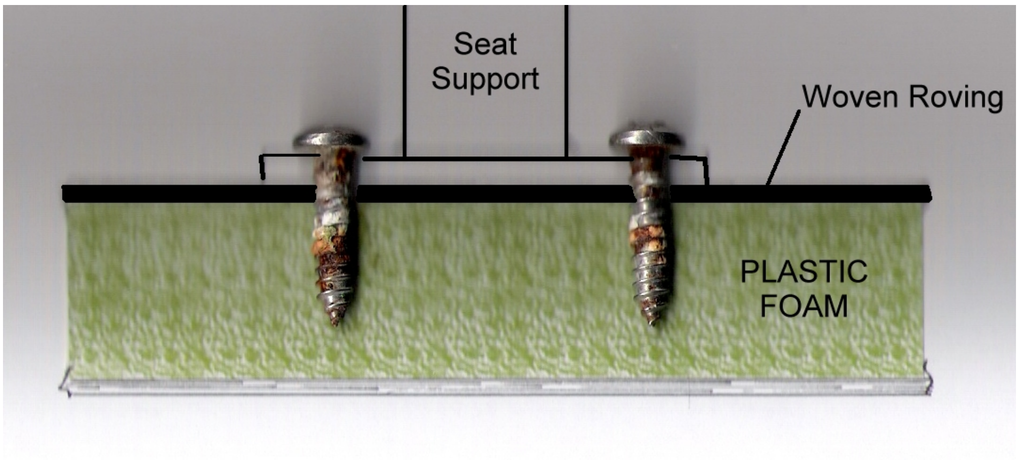
This compares closely with a photograph taken during the initial rescue process.

App IV - 10. Detail of the upper deck GRP (fiberglass) laminate construction

The following photograph was taken by Dr. Armstrong during an inspection of *Lamma IV* on 11 December 2012, which shows the deck construction in way of a ventilation trunk which became displaced during the accident. According to the construction drawings the laminate at this location is the same as at all other locations where there were seats.

App IV - 11. Sketch of the seat foundation arrangement on the upper deck

This sketch is drawn to scale from the construction drawings, using two of the actual screws remaining on the upper deck.



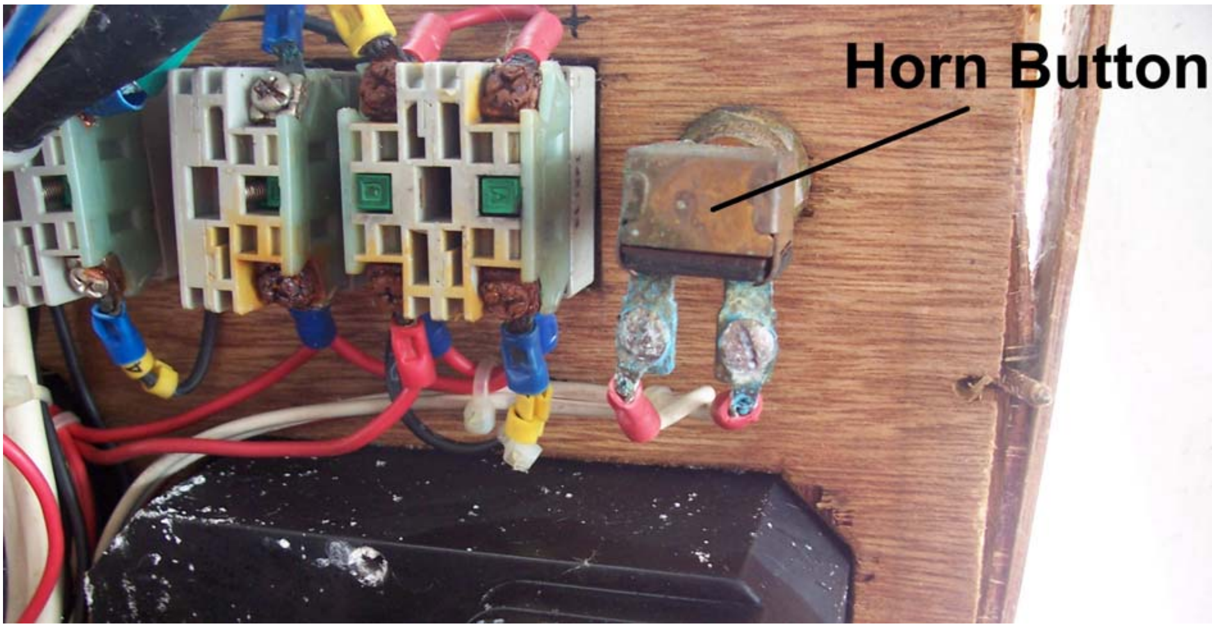
Only the black part marked as "Woven Roving" makes a structural connection with the screws, the plastic foam having no strength to resist "pull-out".

App IV - 12. Seat foundation screws in the aluminium main deck

Photograph taken from underneath the aluminium main deck, showing undisturbed seat screws encased in paint. As far as I could see this was typical of them all, without cracked paint.

App IV - 13. Horn Whistle

The following photographs were taken in the wheelhouse of Lamma IV, and show the corroded connections of the wiring to the Horn button, as well as two alternative horn buttons in the lower picture.




Also marked
Horn Button ?
Main
Horn Button ?
UNWY
ANCH
STOP
AGND
SAIL
SIREN
TOW
HORN
IC 1
IC 2
PA
FWD
BOTH
AFT
IC
PA
Also marked
Horn Button ?
11/12/2012
11/12/2012