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Ship Structure Committee Case Study

This case study has been prepared by the Ship Structure Committee (SSC) as an educational tool to advance the study of ship structures. The SSC is a maritime industry and allied agency partnership that supports, the active pursuit of research and development to identify gaps in knowledge for marine structures. The Committee was formed in 1943 to study Liberty Ship structural failures and now is comprised of 8 Principal Member Agencies. The Committee has established itself as a world recognized leader in marine structures with hundreds of technical reports, a global membership of over 900 volunteer subject matter experts, and a dynamic website to disseminate past, current, and future work of the Committee. We encourage you to review other case studies, reports, and material on ship structures available to the public online at **www.shipistructure.org**.

RMS TITANIC: ALTERNATIVE THEORY: Complete Hull Failure Following Collision with Iceberg

Summary: The wreck of RMS Titanic is arguably the most famous marine casualty of modern times. On 14 April 1912 during her maiden voyage, RMS Titanic struck an iceberg southeast of Newfoundland, Canada. She floated for approximately two hours, eventually assuming an extreme trim by the bow and breaking in half.

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Vessel Particulars

LOA: 882 ft 9 in
Breadth: 92 ft 6 in
Depth: 64 ft 3 in
Draft: 34 ft 7 in
Gross Tonnage: 46,328 GT
Displacement: 52,310 LT
Passengers & Crew: 3,547
Design Speed: 21 knots
Builder: Harland and Wolff, Belfast, Ireland
Year Built: 1912
Flag: United Kingdom
Registered Owner: White Star Line
Vessel Type: Passenger Liner
Hull Material: Riveted Steel

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Background

Previous Theories

705 people survived the loss of RMS Titanic, so there was no shortage of eyewitnesses. Unfortunately accounts differ greatly, with some survivors claiming that the vessel plunged intact and some that her stern rose out of the water and then broke off, both pieces ultimately sinking. Until Robert Ballard located the wreck in 1985, the prevailing theory was that the vessel sank intact. With the discovery of two large pieces almost 2,000 ft apart facing in opposite directions, the theory became that she fractured on the surface and the bow and stern sank separately.

There is no debate that the primary cause of the demise of the Titanic was the collision with ice. It is the contributing factors that caused this “unsinkable” ship to plunge after only two hours, claiming 1,517 lives that will continue to be the fascination of engineers. Popular theories hold that the watertight bulkheads were not continued high enough in the ship, allowing flooding over the top; brittle fracture occurred due to poor quality steel and or low temperatures; and that the stern rose out of the water to as much as 40 degrees of trim prior to braking apart. SNAME’s Marine Forensic Panel has devoted substantial resources to investigating the Titanic and has published several of the most scientific papers on the topic. [1,2]

In the summer of 2005, a team of divers, scientists, and engineers launched a trip to Titanic using manned submersibles. The expedition was sponsored and documented by the History Channel and was publicized in their program “Titanic’s Last Moments”[3] and led by Richie Kohler and Jon Chatterton. Roger Long was the naval architecture consultant on the project and has carefully studied two large previously undocumented sections of Titanic’s bottom structure that were found during the trip.

Case Study

Since the time of her loss, much engineering has been devoted to RMS Titanic. This case study follows a recent analysis examining a previously unstudied theory.

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Detailed Description of Structural Failure

Hypothesis

Beginning with eyewitness testimony and continuing today, there have always been whisperings of a theory of shallow angle failure substantiated by various pieces of evidence. Historically, this has been disregarded in favor of the higher angle scenario. The discovery of the two bottom sections added further credence to the shallow angle theory. Close examination of the steel in the bottom portions shows that the tanktop failed in tension and the bottom in compression. This could only happen if the hull above broke gradually, causing the double bottom to act as the primary hull girder.

The debris field shows two large bow and stern sections, the "new" bottom pieces and a large amount of fragmented debris. The fragmented debris accounts for an inverted V-shaped portion of the hull that is otherwise missing from the larger pieces. Mr. Long's theory is that the vessel commenced to fracture at the aft expansion joint. As the fracture traveled through the side shell, seawater poured into the stern portion, causing stress to be reduced, permitting the bottom structure to take the load for a short time. As reduced forces induced a sagging moment, the bottom was pulled free, while the upper hull was forced back together, causing the splintering of the missing V portion. See Figure 1.

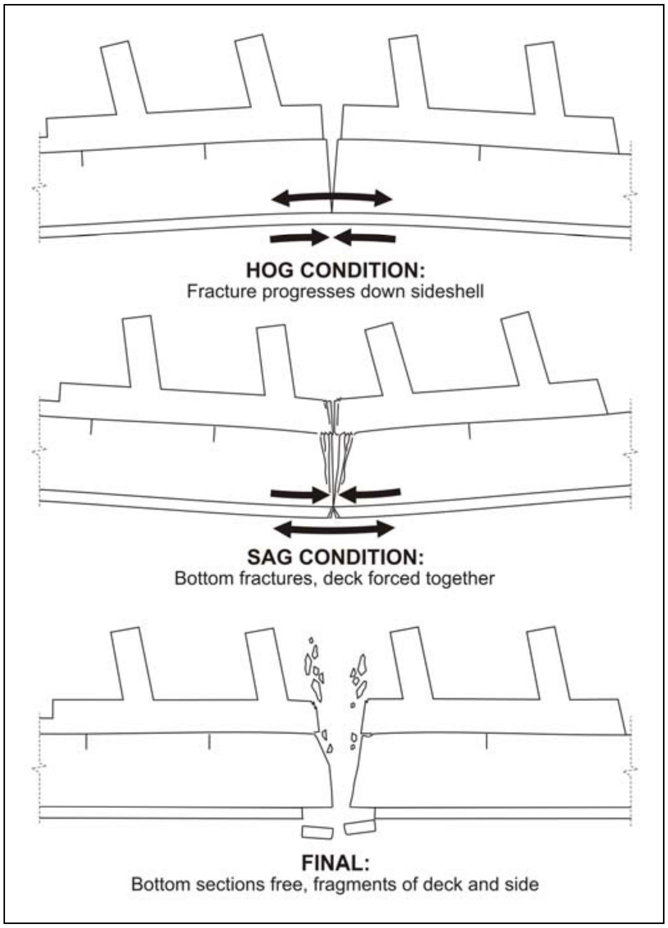

Figure 1. Mechanics of Long's Theory

The shallower angle hypothesized is not substantially more than would be expected pitching in heavy seas. While engineering at the time was capable of predicting and designing for loads on a ship's structure, Titanic was so much larger than other vessels of the time that she may have been near the threshold of this capability. Economic forces also may have driven a minimal design that was perhaps too weak.

As part of continued research sponsored by History, Mr. Long asked JMS Naval Architects to perform forensic analysis to calculate the loads on the ship in both intact and damaged conditions.

Modeling

JMS developed a HECSALV digital hull model of the TITANIC's hull suitable for calculation of hydrostatics, stability, hull bending moments, and shear force. This included main and secondary watertight compartments in the forward half of the vessel for determination of damaged compartment volumes, flooded weight and free surface. Hull and structural modeling were based on vessel plans. Figures 2 through 4 show the hull model and watertight subdivision.

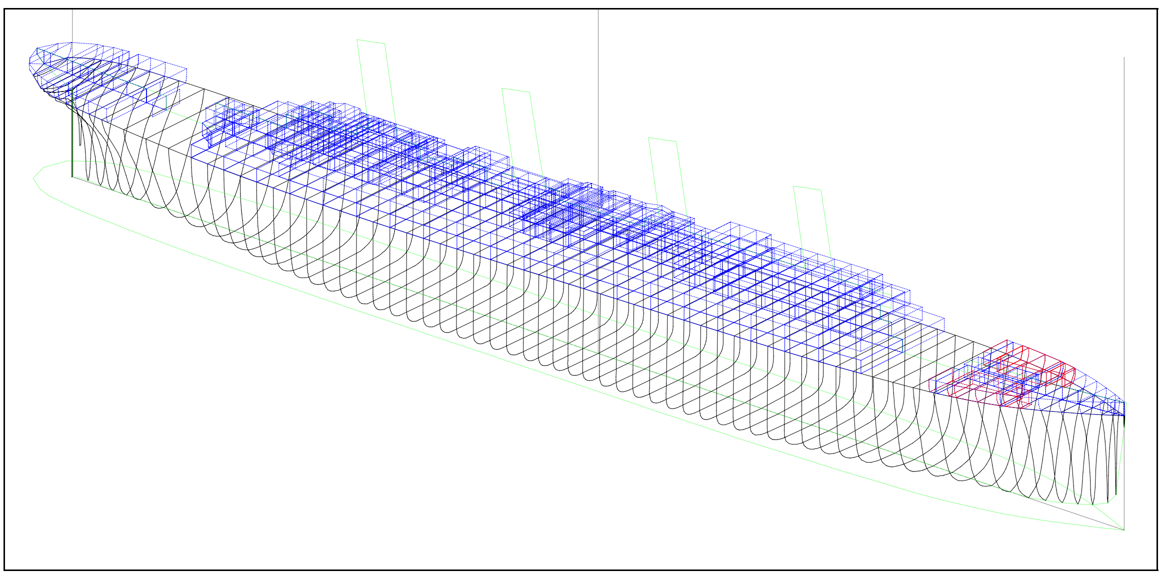

Figure 2. HECSALV Hull Model

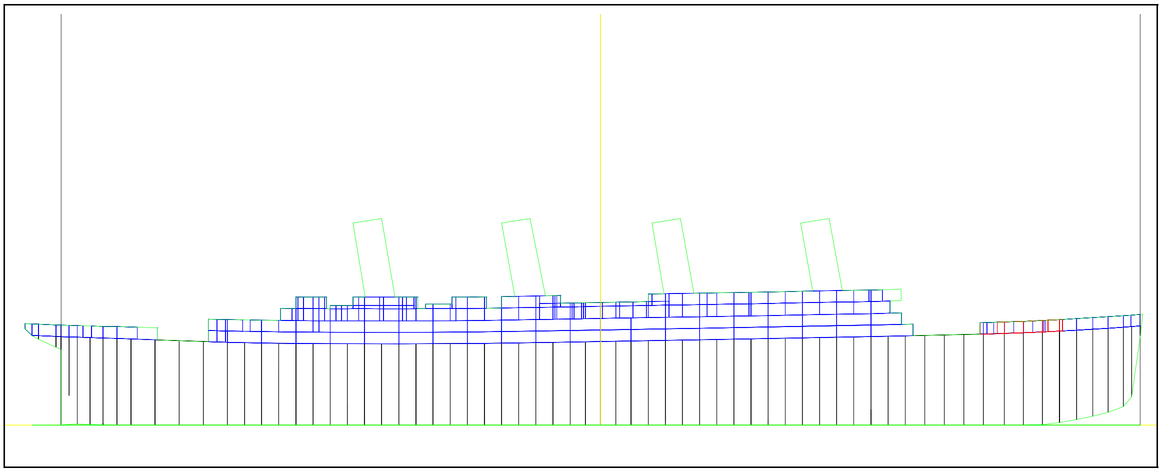

Figure 3. HECSALV Hull Model – Profile

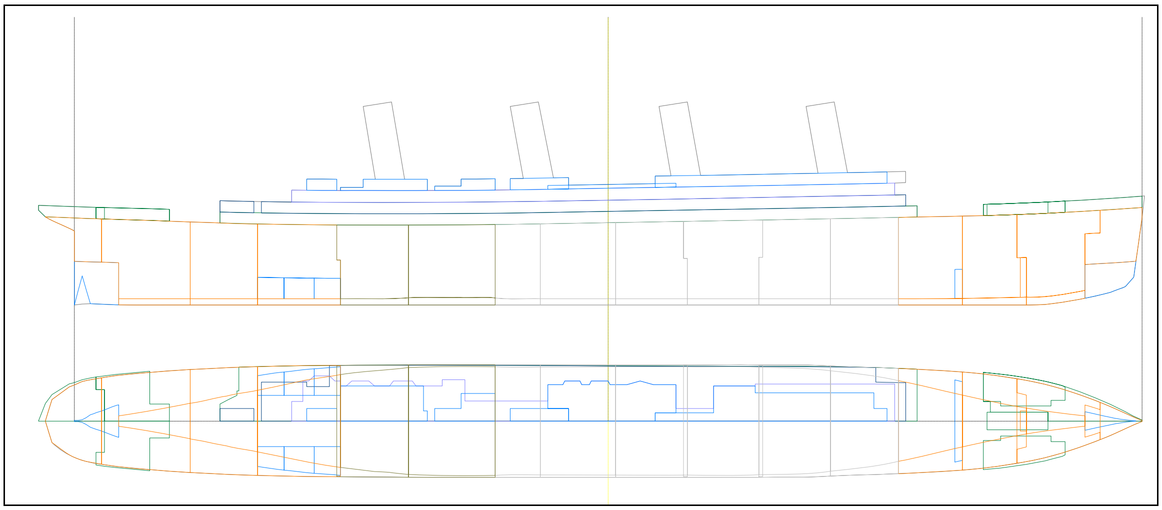

Figure 4. HECSALV Model - Watertight Subdivision

<u>Analysis</u>

It was assumed that the intact loading condition (just prior to collision with the iceberg) resulted in a displacement of 50,220 LT. The resulting drafts are 30 feet at the forward perpendicular and 35 feet 7 inches at the aft perpendicular. The weight curve shown in Figure 5 was developed based upon general naval architecture assumptions as summarized in Table 1.

Table 1. Weight Distribution

ITEM	WEIGHT (LT)	LCG (FT-MS)
Hull (Steel/Outfit/Machinery/Margin)	42,740.00	23.31 A
Coal/Bunkers	3,890.00	80.00 F
Cargo/Dunnage	609.00	332.00 A
Stores	149.00	255.00 A
Baggage	87.00	314.00 F

Passengers/Crew	113.00	299.11 A
Ballast	1,150.77	103.16 F
Fresh Water	591.63	242.08 A
Feed Water	843.08	124.40 A
Corrector Weight	47.36	117.66 F

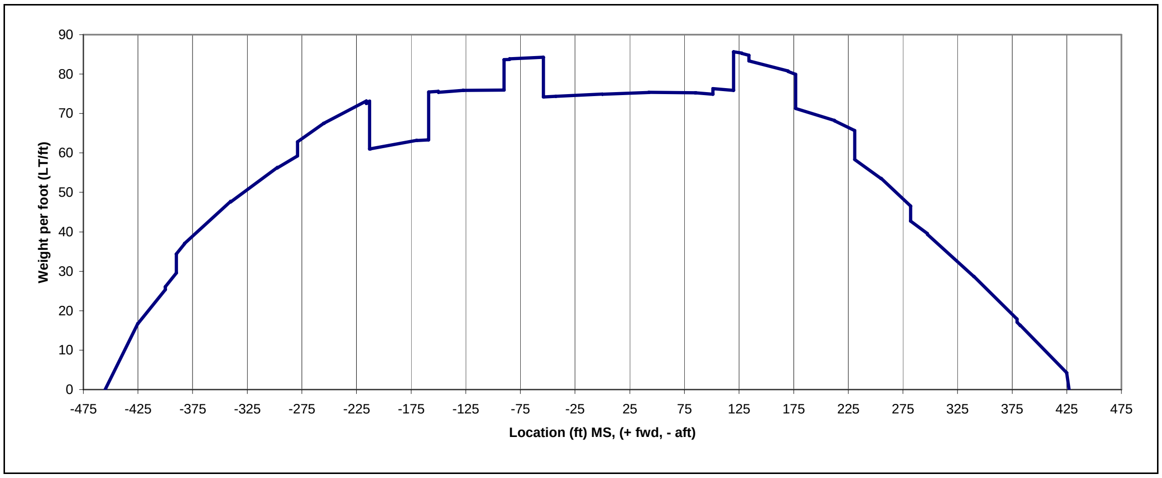

Figure 5. Weight Distribution Curve

In addition to the intact loading, Titanic would have been designed to withstand a theoretical “quasi-static” wave. The “quasi-static” wave modifies the buoyancy distribution along the hull based on the wave height, length and location relative to the ship, but it does not take into account the vessel motions or any other dynamic loading. A variety of wave lengths were analyzed with the height assumed to be 1/7 of the length. For each wave, three locations were considered: crest forward, crest aft, and crest amidship. For the hypothetical maximum wave, only two positions were analyzed because the length of the wave was equal to the length of the ship: crest at midship and trough at midship.

To approximate the casualty, progressive flooding was considered beginning at the forepeak tank. As shown in Figure 6, the final flooding condition analyzed experienced 10 degrees of trim by the bow, and included flooding to the Forepeak Tank and Stores, Holds 1-3, Double Bottoms 1-3, Boiler Rooms 4-6 and Decks A, B, and C.

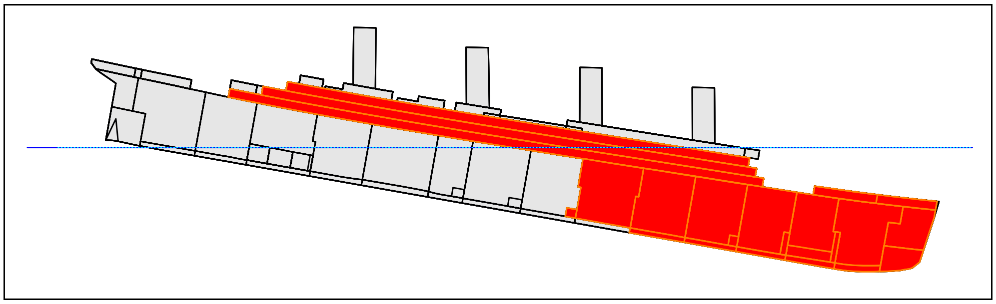

Figure 6. 10 degree Trim Flooding Condition

The “design” bending moment and actual flooded bending moment were then compared. A great deal of time and effort was spent to resolve differences between flooding conditions based on various historical research. JMS also examined transverse and longitudinal reserve stability at the 10 degrees trim under all the progressive flooding scenarios. Under all these scenarios JMS determined the point at which the vessel lost longitudinal stability.

The following conditions were evaluated.

1. Intact - still water.
2. Intact - 20’x140’ wave, crest located amidships.
3. Intact - 20’x140’ wave, crest located at forward perpendicular.
4. Intact - 20’x140’ wave, crest located at aft perpendicular.
5. Intact - 30’x210’ wave, crest located amidships.
6. Intact - 30’x210’ wave, crest located at forward perpendicular.
7. Intact - 30’x210’ wave, crest located at aft perpendicular.
8. Intact - 40’x280’ wave, crest located amidships.
9. Intact - 40’x280’ wave, crest located at forward perpendicular.
10. Intact - 40’x280’ wave, crest located at aft perpendicular.
11. Intact - L/20 Wave (42.5’x297.5’), crest located at forward perpendicular.
12. Intact - L/20 Wave (42.5’x297.5’), crest located amidships.
13. Intact - L/20 Wave (42.5’x297.5’), trough located amidships.
14. Intact - Hypothetical Wave (121’x850’), trough amidships.
15. Intact - Hypothetical Wave (121’x850’), crest amidships.
16. Free Flooding - Fore Peak Tank Flooded.
17. Free Flooding - Load Case 16, Plus Hold No. 1 Flooded.
18. Free Flooding - Load Case 17, Plus Hold No. 2 Flooded.
19. Free Flooding - Load Case 18, Plus Hold No. 3 Flooded.
20. Free Flooding - Load Case 19, Plus Boiler Room No. 6 Flooded.
21. Free Flooding - Load Case 20, Plus Boiler Room No. 5 Flooded.
22. Free Flooding - 10 Deg Trim by the bow. Fore Peak Tank, Fore Peak Stores, Hold No. 1-3, Double Bottom in Hold No. 1-3 & Boiler Room No. 4-6, Decks C, B, A.

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End Result

Figures 8 and 9 compare the shear and bending moments over Titanic's length for each flooding condition against a theoretical design condition. The "Design" bending moment was taken to be the maximum bending moment calculated from load cases 1-13, the "Design" bending moment was determined to be 661,768 ft-LT in Hog and 151,840 ft-LT in Sag. The calculated flooded bending moment with enough flooding to create 10 degrees of trim (load case 22) was determined to be 1,538,892 ft-LT in Hog. The analysis shows that the bending moment resulting from the assumed flooding scenario far exceeds the "Design" bending moment.

Similarly, the peak shear stress calculated from load cases 1-13, was determined to be 4,285 LT, 216 ft aft amidships (frame 72 aft amidships). The calculated flooded peak shear stress with enough flooding to create 10 degrees of trim (load case 22) was determined to be 7,847 LT, 63 ft forward amidships (frame 22 forward amidships).

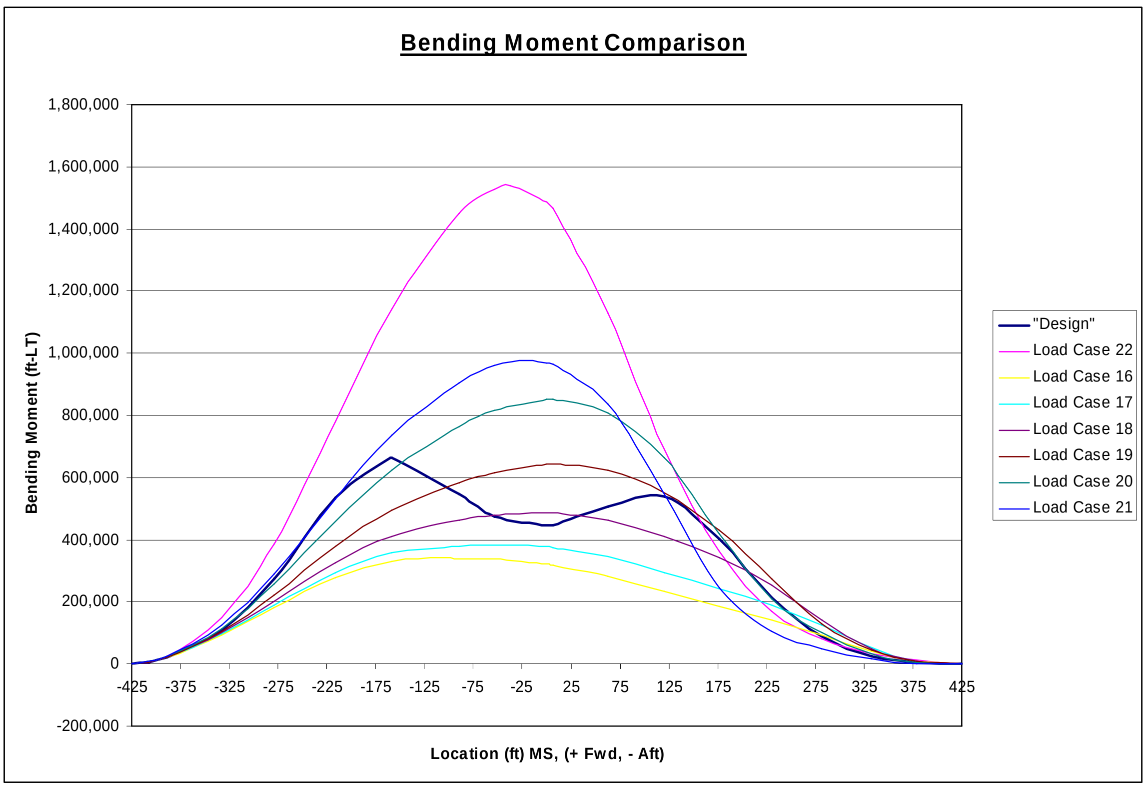

Figure 7. Bending Moment Comparison

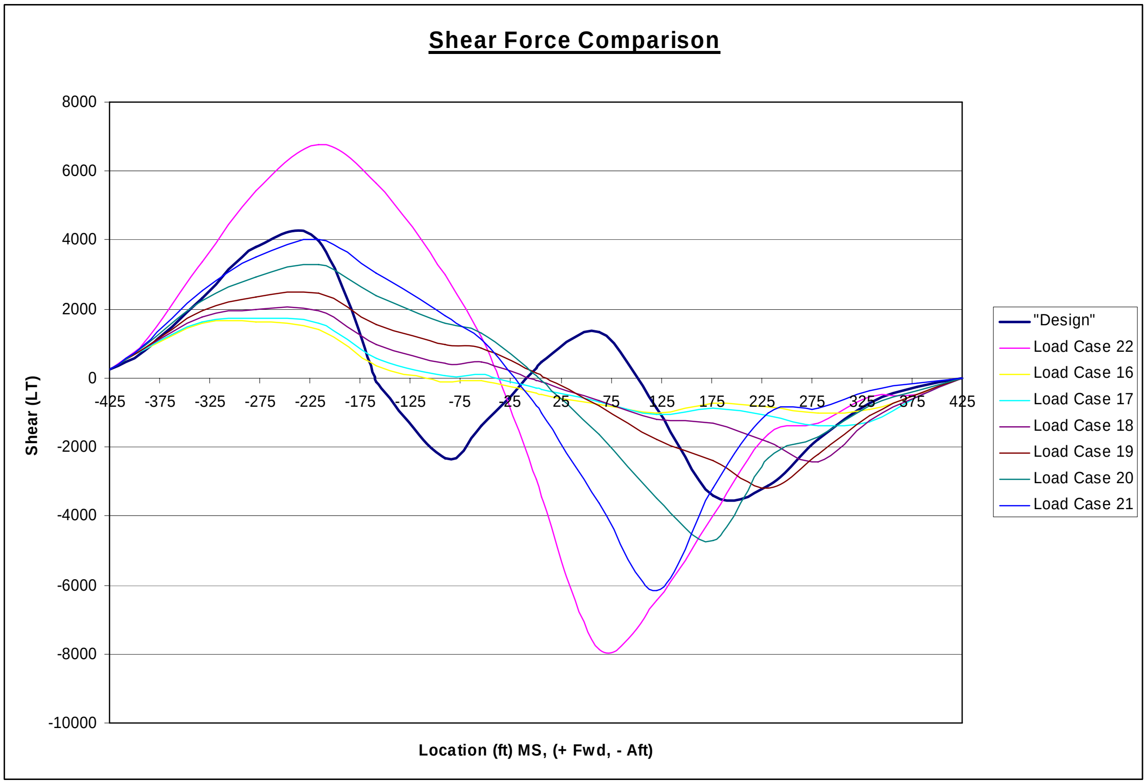

Figure 8. Shear Force Comparison

It was found that the predicted flooded bending moments exceeded the predicted "design" bending moments in excess of two times. If damage to the hull girder occurred as a result of the flooding condition and associated bending moment, this would not necessarily indicate the vessel was insufficiently designed, disproving that portion of the hypothesis. The analysis does confirm high bending moments at only 10 degrees of trim, lending credence to the shallow angle fracture theory. In addition, longitudinal stability is lost at much shallower angles than the 40 degrees widely believed to be Titanic's final intact attitude.

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Acknowledgements

References:

[1] "The Titanic and Lusitania, A Final Forensic Analysis", Garzke, Brown, Sandiford, Hsu and Woodward, Marine Technology, SNAME, October 1996.
[2] "Titanic, The Anatomy of a Disaster: A Report from the Marine Forensic Panel (SD-7)", Garzke, Brown, Matthias, Cullimore, Wood, Livingstone, Leighly, Foecke, and Sandiford, Transactions, SNAME, January 1997.
[3] "Titanic's Achilles Heel", Video Production of Lone Wolf Documentaries, 2006.

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