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The Consequences of Extreme Loadings on Ship Structures

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This paper examines the casualty data generated by 1,104 vessels during the calendar year 1978; 935 ship-years of experience are represented. The data is reviewed with regard to the areas of the vessels that were subject to damage and to the causes of damage. Statistics regarding frequency of damage, cost of repair and time lost to repair are presented, and some conclusions are drawn regarding possible areas for future research.

INTRODUCTION

If one considers an analogy between the life of a ship's hull and that of a human being, one could say that conception is the design concept that may someday become a ship, that gestation is the thousands of man-hours of design and analysis that make that concept feasible, that birth is the construction of the vessel, and that life is the years of service during which the vessel carries out its mission and hopefully makes a profit for its owner. Every year, much important literature is presented regarding the conception and gestation of ships, and in these last few years the midwifery by which paper becomes steel also seems to be getting more, well deserved attention. This presentation, however, will deal with the lives of vessels, the mishaps which vessels face, and hopefully some insights for would-be parents and godparents.

At the danger of stretching this analogy beyond the elastic limit, a ship's hull also serves, in some respects like the skin, skeleton, and muscle of a human body, and it suffers every imaginable form of cut, abrasion, fracture, and wound while doing so. In ministering to the results of these mishaps, ship owners, ship repairers and surveyors meet to examine the damage and agree to the four basic issues of cause of damage, nature and extent of damage, method of repair, and cost of the repair. These pathological deliberations are normally brief, since usually a basic objective is to put the vessel back to work as quickly as possible, and they are normally separate from the owner's efforts to maintain the vessel's good health against encroaching old age, and normal wear and tear.

Since the reports of these findings are sometimes voluminous, the compilation and analysis of data pertaining to ship damages is no small task; consequently, a relatively small amount of such data has been compiled. The discussion which follows is based upon the experience of 1,104 vessels during the calendar year 1978; since all of the vessels were not under consideration for the entire year, a total of some 935 ship-years of experience are represented. The vessels were of many different flags and in many different trades; the vessels roughly divide into 36% carrying general cargo by some mode, 21% carrying liquid bulk cargoes, and 42% carrying dry bulk cargoes.

The data presented must be considered with a fair dose of suspicion since the sample size, sample distribution, and sample period are not designed to render a statistical picture of the world merchant fleet. Also, the process by which the information is gathered and compiled involves many different people and is, by nature, imprecise; the causes of damage, and sometimes even the extent of damages are often obscure and subject to differing interpretation. The data relating to costs of repairs should be treated most suspiciously since not only do costs vary greatly between different geographical areas and change significantly during a single year, but costs vary due to the magnitude of the repair job to be done, due to the type of facilities available, due to the skill and experience of the labor available, and sometimes due to the magnitude of the owner's distress. In fact, one could make a case that the cost of ship

TABLE 1
FREQUENCY OF DAMAGE AND AVERAGE REPAIR
COST BY VESSEL TYPE

Vessel Type	No. of Vessels Reporting Casualties	No. of Casualties	Average Repair Cost Index
Break Bulk-General Cargo	216	217	33.0
Break Bulk/Container	44	44	24.1
Full Container	88	89	50.7
Barge Carrier	65	66	69.9
RO/RO	39	40	45.4
Refrigerated Cargo	18	18	18.7
Passenger	4	5	91.6
Dry Bulk	287	287	27.1
Dry Bulk-Self Unloading	29	31	26.5
Ore/Oil	46	48	31.5
Tanker, 0-110 KDWT	177	180	63.9
Tanker, 110-210 KDWT	10	10	154.5
Tanker, over 210 KDWT	23	23	72.1
Tanker - Liquid Gas	5	5	65.9
Bulk Chemical	6	6	27.3
Total	1,057	1,069	41.9

repair is as volatile a topic in marine circles as the cost of health care seems to be in the general public.

Because of the uncertainties associated with representations of cost data, it was felt that average repair costs should be shown by an arbitrary index which would not reference any specific currency. The average repair cost index used herein, while suitable for comparisons between categories, avoids potentially unpleasant surprises which could result if actual cost figures were used in economic calculations.

VESSEL TYPE

Table 1 presents the data by vessel type, and also shows the average repair cost index for each vessel type. It is interesting to note that while relatively few vessels reported more than one casualty during the sample period, some 95.7% of the vessels for which data were compiled reported at least one casualty. This illustrates the point that casualties are not rare events, and that damage should be expected as a consequence of the environment in which any ship must function.

Severe casualties, however, are relatively rare events, and the resulting repair costs can unduly influence average cost data. Bearing this in mind, we can see that tankers, barge carriers, passenger vessels, and liquid gas carriers all have average repair costs significantly greater than the overall average. In spite of the small sample sizes in the latter two categories, the high costs for these types of vessels can probably be partly attributed to the expense of dealing with the extensive outfitting of passenger staterooms and cryogenic cargo systems respectively. With respect to tankships, it is interesting to note that all three size categories experienced above average repairs costs; however, the average cost of repairing tankers of between 110,000 DWT and 210,000 DWT probably reflects one or more extraordinarily severe casualties.

AFFECTED AREAS

Table 2 portrays the frequency, average repair cost, and average repair time for various areas or elements of the vessels reporting damage. Since some casualties affect several areas or elements of a vessel's hull, machinery, and outfit, the costs and time required to effect repairs have been apportioned between the various areas involved. A detailed presentation is given only for the structural elements of a vessel, and totals are given for machinery and other elements. Total losses have been excluded from these data.

As expected, either structural or machinery elements were affected in the bulk of the casualties reported. They were affected in nearly equal proportions, structural damage appearing in 43.2% of the reports, and machinery damage in 41.5% of the reports. Structural and machinery repairs also clearly represent the bulk of costs and time expended. The fact that average structural repair costs were slightly greater than those for machinery elements probably reflects the additional costs of drydocking which would be required to complete structural repairs more often than machinery repairs.

Table 3, which ranks the ten most frequently affected areas, surprisingly reveals that these ten areas reflect nearly half of all reports. To characterize this table, one would say that areas of the vessel exposed to

TABLE 2
VESSEL AREAS AFFECTED BY CASUALTIES

Area Affected	No. of Reports	Avg. Repair Cost Index	Avg. Repair Time (days)
Structural:			
Shell, Bottom, General	16	231.0	23.6
Shell, Bottom, Forward	57	39.5	7.9
Shell, Forward, as in collision	25	73.7	12.3
Shell, Bottom, Amidships	11	28.4	4.7
Shell, Bottom, Aft	12	39.6	7.7
Shell, Side, General, Below Sheer	15	45.3	9.0
Shell, Side, Forward, Below Sheer	123	22.1	6.6
Shell, Side, Midships, Below Sheer	49	16.8	6.2
Shell, Side, Aft, Below Sheer	81	18.8	6.5
Sheer Strake, Side,Forward	23	15.2	5.6
Sheer Strake, Side, Aft	15	16.2	5.3
Deck plating	14	26.3	9.8
Bulwarks, Forward	8	6.7	5.0
Plating, Forecastle Deck	11	11.1	6.9
Plating, Deck House	12	15.0	8.5
Hatch Covers	19	11.7	6.7
Tanks, Integral	5	86.6	28.6
Framing, Transverse	14	30.7	10.0
Framing, Longitudinal	5	12.2	11.0
Plating, Tank Top	6	8.7	5.0
Bilge, Keel	16	6.0	2.8
Stern Frame, Skeg, Struts	2	23.4	14.5
Other Structural	69	3.5	3.9
Total Structural	608	28.2	7.3
Total Machinery	583	25.6	10.0
Total Other	215	7.5	4.1
Grand Total	1,406	24.0	8.0

TABLE 3
AFFECTED AREAS RANKED BY FREQUENCY

Affected Area	No. of Reports	% of Total
1. Shell, Side, Forward, Below Sheer	123	8.75
2. Propeller, Solid Type	97	6.90
3. Machinery, Auxiliary	91	6.47
4. Shell, Side, Aft, Below Sheer	81	5.76
5. Machinery, Propulsion, Diesel	61	4.34
6. Shell, Bottom, Forward	57	4.05
7. Rudder	50	3.56
8. Shell, Side, Amidships, Below Sheer	49	3.49
9. Tail Shaft	46	3.27
10. Boilers and Components	40	2.84
Total	695	49.43

TABLE 4
AFFECTED AREAS RANKED BY AVERAGE REPAIR COST

Affected Area	Avg. Repair Cost Index	No. of Reports
1. Shell, Bottom, General	231.0	16
2. Machinery, Propulsion, Electric Motor	109.1	5
3. Tanks, Integral	86.6	5
4. Gears, Main Reduction	84.2	19
5. Shell, Forward, as in collision	73.7	25
6. Boilers and Components	52.9	40
7. Shell, Side, General, Below Sheer	45.3	15
8. Shell, Bottom, Aft	39.6	12
9. Piping, Cargo, Interior	39.6	2
10. Shell, Bottom, Forward	39.5	57
Total	70.0	196

TABLE 5
CAUSES OF DAMAGE

Cause	No. of Reports	Avg. Repair Cost Index	Avg. Repair Time (Days)
Contact with Structure	161	24.1	6.9
Collision with Vessel	139	33.5	9.4
Grounding/Stranding	112	84.9	12.1
Cause Unknown	107	47.3	2.5
Heavy Weather	105	25.8	11.2
Crew Negligence	96	33.6	14.2
Struck Submerged Object	49	45.2	7.8
Shipbuilder's or Shiprepairer's Negligence	32	65.2	14.1
Surging at Dock or Pier	19	43.7	10.0
Stevedore Damage	19	5.0	5.0
Fire	17	49.7	28.1
Design Fault	16	213.6	49.9
Encounter with Ice	16	40.1	9.9
Propeller Damage	14	22.8	6.7
Electrical Failure	10	19.2	13.0
Latent Defect	9	42.0	9.7
Explosion	8	69.3	45.0
Contamination of Machinery	8	52.6	17.1
Struck Floating Object	6	39.2	7.3
Freezing Damage	3	19.5	13.0
Automation Control Failure	2	16.1	7.0
Overpressurization of Tanks	1	63.2	17.0
All Others	120	28.5	11.6
Total	1,069	41.9	10.6

TABLE 6
CAUSE OF DAMAGE RANKED BY AVERAGE
REPAIR COST INDEX

Cause	Avg. Repair Cost Index	No. of Reports
Design Fault	213.6	16
Grounding/Stranding	84.9	112
Explosion	69.3	8
Shipbuilder's or Shiprepairer's Negligence	65.2	32
Overpressurization of Tanks	63.2	1
Contamination of Machinery	52.6	8
Fire	49.7	17
Cause Unknown	47.3	107
Struck Submerged Object	45.2	49
Surging at Dock or Pier	43.7	19
Total	67.8	369

the sea and adjacent vessels and structures apparently receive the most punishment. The remainder of the misforturnate "top ten" are generally complex mechanisms. The shell plating between the sheer and the bilge and along the forward third of the bottom figure prominently in this characterization. In fact, the shell plating, including the sheer strake, is involved in more than 30% of the reports available.

Table 4 presents a ranking of areas affected by average cost of repair, and the characterizations of exposure and complexity seem to apply somewhat to this presentation as well; however, only two of the affected areas shown in the previous table, boilers and components and forward bottom shell plating, appear in Table 4. As stated previously, severe damages are normally rare events. For example, general damage to bottom shell plating, which would result from a serious grounding or similar catastrophe, represents only slightly more than 1% of the total frequency, but had an average cost more than 100% greater than the next element in the ranking. General bottom shell plating damage also required an average repair time of almost 24 days, which from a shipowner's point of view could be more expensive than the shipyard invoice at the completion of repairs.

CAUSES OF DAMAGE

The tables described in the foregoing paragraphs discuss only the consequences, and not the causes, of casualties. The causes, as determined at the time of survey to be the primary cause of damage rather than causes of consequential damage, are shown in Table 5 ranked by frequency. Examination of the ten most frequent causes readily indicates that seven of the categories result in extreme loads being applied due to contact with the sea, the sea bottom, or some vessel, object, or structure. These seven categories account for 56.5% of all the casualties reported in this sample.

Such a finding, in itself, is not necessarily significant, since many of these mishaps may require only "band-aid" cures. Table 6 ranks the top ten causes by average repair cost index, and Table 7 ranks the top ten by time required to effect repairs. The true cost of damage to the shipowner would be some weighted combination of repair cost and lost time, but since insurance arrangements and daily worth of vessels vary so widely, no such portrayal is possible here. Table 6 indicates that at least five of the ten highest cost categories involve contact. It is interesting to note that two of the top five high cost categories involve ship designers or shipyards. As one would expect, a great deal of commonality exists between Tables 6 and 7; seven of the causes appear in both the repair cost and the repair time rankings. These causes therefore represent high costs both to shipowners and marine underwriters. Significantly, 112 reports of groundings and strandings are reflected in both rankings.

Another cause of damage which incurs both high repair costs and a great deal of time lost to repair is explosion; however, only eight reports of explosion damage are included among 1,069 casualties considered in these data. Explosions, while certainly serious, represent only 1.2% of the total amount of repair costs expended, and only 3.2% of total time lost to repair; the point is that even minor casualties, if frequent, can result in significant portions of the total repair bill. An examination of the total amounts of money and time expended to repair the damages resulting from the various causes is given respectively by Tables 8 and 9.

Table 8, shows the percentage of the total repair bill attributable to the ten most expensive categories, which account for nearly 84% of the total expenditure. Of these ten items, five causes can be directly related to extreme loadings on a vessel's hull as a consequence of contact. Groundings and strandings alone account for more than one fifth of this total, and, when considered together with all types of strikings and contact, amount to at least one-half of the total repair cost. A similar situation prevails when considering the portion of total repair time expended. Table 9 shows that the causes ranked in the top ten account for more than three-quarters of the total repair time, and that almost one-half of the total time is expended in repairs resulting from some type of contact with the vessel's hull.

CONCLUSIONS

It appears from the foregoing that the most severe and the most frequent punishment is administered to the external structure of vessels by virtue of contact, with other vessels, fixed structures, objects in the water, the sea bottom, and the sea itself. While

TABLE 7
CAUSE OF DAMAGE RANKED BY
TIME TO REPAIR

Cause	Avg. Time to Repair	No. of Reports
Design Fault	49.9	16
Explosion	45.0	8
Fire	28.1	17
Contamination of Machinery	17.1	8
Overpressurization of Tanks	17.0	1
Crew Negligence	14.2	96
Shipbuilder's or Shiprepairer's Negligence	14.1	32
Electrical Failure	13.0	10
Freezing Damage	13.0	2
Grounding/Stranding	12.1	112
Total	16.9	302

TABLE 8
PERCENTAGE OF TOTAL REPAIR COSTS
EXPENDED BY CAUSE

Cause	Percentage
Grounding/Stranding	21.2
Cause Unknown	11.3
Collision with Vessel	10.4
Contact with Structure	8.7
Design Fault	7.6
Crew Negligence	7.2
Heavy Weather	6.0
Struck Submerged Object	4.9
Shipbuilder's or Shiprepairer's Negligence	4.7
Fire	1.9
Total	83.9

TABLE 9
PERCENTAGE OF TOTAL REPAIR TIME
EXPENDED BY CAUSE

Cause	Percentage
Crew Negligence	12.0
Grounding/Stranding	12.0
Collision with Vessel	11.5
Heavy Weather	10.4
Contact with Structure	9.8
Design Fault	7.0
Fire	4.2
Shipbuilder's or Shiprepairer's Negligence	4.0
Struck Submerged Object	3.4
Explosion	3.2
Total	77.5

much has been done in the past and should be done in the future to prevent such contact from occuring, this type of damage must be regarded as being a fact of life. With regard to groundings and strandings, for example, the increased size and draft of vessels today as compared with twenty years ago would seem to be a reason to expect such casualties to continue to occur unless the operability of the vessels is enhanced by improved navigational equipment and other innovations. The frequency of contact-type damages, many of which are not of great magnitude, points to ship operation and operability as a fruitful area to pursue.

But not all future research should be directed at ship operation; design faults, while fortunately not a frequent cause of damage, are shown to be very expensive in terms of repair cost and lost time. The nature of these faults cannot be easily characterized; some are the results of applying new, untested technology; some are the result of comprises made with respect to construction methods; and some can be identified as errors. Most often, these faults seem to occur at a relatively detailed level of design. The recent work in the area of ship structural details would seem to be useful in this regard, and is a good example of the type of feedback to the designers and builders of ships that makes effective changes in design possible.

Whenever the phrase "design change" is uttered, the next thought in most minds concerns the cost of the change. Unfortunately, the cost information contained within these data is not suitable for comparisons with that from other sources, nor is it useful for design economic studies; however, one point that should be made is that a considerable portion of the total cost to repair damage is involved in the time of repair, during which the service of the vessel is lost to the owner. While a significant portion of the shipyard repair bill may be refunded to the owner by his underwriters, the cost of lost service may be borne largely by the owner. Since the shipowner also bears the cost of design and construction of the vessel, the decision is one of choosing the investment in hopefully effective design measures which will reduce the extent of this damage, or rather choosing to bear the expenses of future repairs.

Before such decisions can be offered to shipowners, the alternatives, their costs, and their potential effectiveness must be studied, and such study requires the cooperation of shipowners regarding the performance of their ships. An interesting and possibly enlightening study of this type would be to trace the casualty history of a class of vessels, and to analyze the design features of the vessels that were effective or ineffective in countering the damaging forces to which the vessels were subjected. Such a study would necessarily be long in preparation, and would require the cooperation of designers, builders, classification societies, and possibly others, but the results, which hopefully could give a realistic economic picture of the costs of damage, would be interesting.