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BULK CARRIERS - THE SAFETY ISSUES

J. C. ADAM, J. M. FERGUSON, D. W. ROBINSON
LLOYD'S REGISTER OF SHIPPING, ENGLAND

INTRODUCTION

Lloyd's Register has for many years conducted a program of defect monitoring for its classed fleet. The systems used for this purpose have evolved from edge punched cards sorted by inserting needles through holes, via 80 column punched cards sorted mechanically, into a fully computerised hierarchical database system which is currently being transferred to a modern relational database.

At present the system holds the 'basic' and 'defect' data for some 17,000 ships built since 1960 to Lloyd's Register class or which have been classed with the Society for some period of their service lives.

Over half this number are currently in LR class.

The database can be regarded as a crystal ball into which we look for answers to many and varied questions. Crystal balls often give a misty picture and interpretation of the answers requires considerable depth of knowledge of both the system and its limitations, and of ship structures and their machinery.

Bulk carriers are of course included in the ships covered by the database and their special features taken into account.

DATA ACQUISITION

The main source of data is our survey reports. Other sources can be useful, particularly owners when, for example, an incident occurs at a location remote from LR surveyors. In the case of a loss at sea, our surveyors will not have the opportunity to report the circumstances or details and we must rely on the data reported by the owner, the press or the national authorities.

Terminology and detail given in the reports are very variable, and whilst a degree of consistency is achieved by giving training, guidance and supervision to our surveyors, it must be recognised that the writer's mother tongue may not be English and drafting sometimes takes place under unfavourable or stressful conditions.

We can only record what is reported, though we do make interpretations of the reported facts. For example when 'date and cause' are reported as 'unknown' but it is clear from the description of the damage that its cause was an external contact rather than a structural or other 'non-contact' reason, we record it as a 'contact-type damage'. If the date is not reported we record the date of survey.

Our surveyors are encouraged to forward sketches, photographs and plans to amplify their reports wherever possible, as these can be more informative than pages of text.

The text of the reports is transmitted electronically to our mainframe computer from most of the outports, and for those outports not linked to the system, entered by Headquarters upon receipt.

Having been processed by the classification surveyors and any administrative work such as the issue of certificates completed, they are consigned to an historical file for longterm storage. At this point a printed copy is passed to the database group. These are sorted to remove those which do not report defects or damages before being microfilmed and passed to specialist surveyors, hull and machinery, who read them and give instructions to the recorders on the extent of coding needed. They also look into any case of particular note which might need further investigation. By this means they gain an overview of what is occurring by way of defects to the entire classed fleet from which to identify trends.

The microfiches are a valuable record; being the source of all the defects recorded on the system, they provide a concise defect history for each classed ship. The microfiches also contain sketches, photos and a copy of the basic ship data which is thus immediately available for reference when reading the reports.

DEFECT DATA RECORDING

Reported defects are translated into code and entered into the system. The reason for using code is to facilitate retrieval of the data and to allow its efficient analysis.

The coding system used until now has been numeric, one or two digit codes being assigned a meaning dependent upon their location in an 80 column line. This method required a great deal of reference to the code dictionaries, and the learning curve was slow. It was fairly easy to make errors and keying using a numeric pad was a further source of errors. Internal validation did inhibit the use of invalid codes, but it was all too easy to make a mistake which still satisfied the validation criteria.

The new system codes are alphabetic and thus have a resemblance to their decodes: it is intended that this will speed up the process of recording defects. The system will also permit online coding which will display the full decodes to the recorder before being committed to the database. This will eliminate many of the sources of error inherent in the previous system.

For each reported INCIDENT the following details are held:

LR number
Report Number
Date of Incident
Incident Cause
Severity
Secondary Cause
Load State
Ship Location
Ship Operation
Environmental Pollution

And for each DEFECT associated with that incident:

Longitudinal Section
Number of Spaces affected
Location 1 - Space or Structure
Location 2 - Component
Location 3 - Item
Location 4 - Sub-item
Detail
Defect Type
Repair
Microfiche Index

Location 1 spaces of particular use for bulk carriers include:

Topside tanks
Hopper tanks
Bulkhead stools top and bottom
Duct keels and pipe funnels
Hatch coamings

ANALYSIS OF THE DATA

Analyses may be instigated for a variety of reasons and are carried out routinely or at the request of another department and sometimes for external clients.

To identify and separate populations of ships for analysis we use the basic data held by the system eg to identify sisters or ship types, or to restrict the study to ships within certain dimension limits.

We as a classification society are particularly interested in defects which have no evident external explanation. When such a situation arises we will first look at the record of the ship concerned and then any sister ships to see if there has been a previous occurrence and extend the search to similar sized ships of the same type. Studies are also carried out to establish changing trends in operational aspects, eg contact damages from cargo handling machinery.

When a trend is identified which merit further investigation a more wide ranging search is carried out to identify the ships at risk.

Statistical methods are sometimes of use to highlight the importance of a perceived problem area. They can also be used to evaluate historical trends and the relevance of age. The effect or rule changes can be monitored by comparing defect rates for ships built prior to the change with those built to the revised requirement. Looking at age related defect rates enables us to establish 'mean time to first failure' which is particularly relevant to fatigue life studies.

Routine programs are also available which take each of the defects recorded in a given period and compare them with those previously recorded on that ship or its sister ships thus highlighting any common trend which may be taking place unobserved.

DISSEMINATION OF RESULTS

When we have detected a trend taking place there are several actions that can be taken:

If there is a perceived possible deficiency in the structural or machinery rules we will advise those concerned with the research and development behind the rule revision process. This in turn often stimulates further enquiries and review of the source data held on the microfiche system.

In some circumstances when the consequences of an occurrence of a defect are considered serious enough to warrant it, the owners or their managers will be advised direct.

When a problem concerns a specific ship or group of ships, and needs to be addressed by the field

surveyors during surveys, they are advised by circular letter of where to check and the preferred remedial action. This action effectively completes the loop which started with the field surveyor reporting the initial defect.
It will be appreciated that all the defect information held on our database is ship specific and therefore treated as confidential. Access to the system is controlled and care is taken to preserve the confidentiality of the data.
No identifiable information is released to third parties without the owner's consent. In most cases we can present the data statistically to preserve its anonymity.

The Challenge

INTRODUCTION

During the year 1990, twelve ships carrying dry bulk cargoes, where structural failure may have been a factor, were lost with a consequent loss of life of a reported 200 seamen. Of the ships concerned eight were bulk carriers, two were ore carriers and two were ore or oil carriers. For ease of reference the structural cross section for each type is shown in Figure 1. A number of major structural failures to the primary hull girder members on bulk carriers which did not result in the loss of the ships also occurred during this period.
In the cases of the ships that were lost and also in the cases where major structural damage occurred without loss the ships concerned were generally carrying iron ore.
This year to date some six ships with bulk carrier structural configuration have already gone missing with additional loss of life. These ships were again all carrying iron ore.
The purpose of this paper is to give an awareness of what LR has done, or is doing at this time with regard to addressing the situation regarding bulk carrier incidents as well as taking the opportunity to discuss the matter as a whole. Other aspects such as the greater usage of higher tensile steels in recently constructed ships also make this a time for deliberation with regard to this ship type.
It has become increasingly apparent that dry bulk carriers are the heavy workhorses of the world fleet and because of their cargoes could inadvertently experience loadings not normally catered for in their design. The growth in size of these ships and the proposals for the use of higher yield steels has necessitated that a more or less continual review of their scantlings takes place, taking account of both service experience and findings from theoretical investigations. Recent events, however, in the form of major damage to a number of bulk carriers some of which were constructed in the last decade led Lloyds' Register's Chief Ship Surveyor to giving priority to a study with a view to determining the probable causes of incidents to this ship type.
A brief chronology of events which illustrate Lloyd's Register's recent concern with regard to bulk carriers is given as follows:

February '89 - LR special instruction to surveyors on survey of topside tanks and holds.

November '90 - Commencement of bulk carrier investigation.

November '90 -	LR special instructions to surveyors on survey of holds and in particularly main frames and brackets.
December '90 -	Additional guidance to surveyors on survey of bulk carriers.
January '91 -	Additional guidance to surveyors on survey of bulk carriers.
January '91 -	Letter to bulk carrier operators/owners portraying concern and requesting information.
February '91 -	Further letter to owners of bulk carriers drawing attention to untypically high rate of casualties and advising of LR policy.
April '91	Close up inspection requested on sample of bulk carriers as part of LR investigations.

These actions can be summarised as both providing guidance to LR surveyors and being a vehicle to provide the shipping community with an awareness of potential problems with this ship type. The letter to the shipowners dated January '91 as well as indicating LR's concern also constituted a questionnaire. This was sent out to a large sample of bulk carrier owners and many have responded positively with information. In addition to this a more general letter was also sent out to bulk carrier owners worldwide during February advising them of the study being carried out. This letter also requested any information considered relevant to be forwarded to LR's Technical Planning Department in the Ship Division.
In investigating the various levels of the problem, from design to operation, it appears than many operators believe that cracking in the structure of these ships is inevitable, possibly as a result of poor design, and more probably as a result of operational procedures.
This is the challenge that Lloyd's Register is addressing with a view to making the occurrence of cracking and unacceptable levels of structural depreciation a rare event and thereby improving reliability of the ships concerned. To do this it is

recognised that a better appreciation of the operators operational pressures is fundamental, together with a reappraisal of structural arrangements and survey requirements.
Aspects which can influence the life of bulk carriers are shown in Figure 2 and include structural design, ship operation, cargo handling aspects, types of cargo and maintenance and repair policies. These topics are generally addressed in this presentation although not necessarily under these specific headings.
A summary of aspects addresses is given as follows:
i)What is a bulk carrier, its cargoes and its environment.
ii)Age structure of the fleet
iii)Statistics of losses
iv)Focal points of damage
v)Development of damage
vi)Actions

WHAT IS A BULK CARRIER, ITS CARGOES AND ITS ENVIRONMENT?

The most widely recognised structural concept identified with a bulk carrier is a single deck ship with a double bottom, hopper tanks, single transversely framed side shell, topside tanks and deck hatchways. This concept, as described, dates back to the early nineteen sixties when deadweights of up to about 20,000 tons were introduced. During the period until the early nineteen seventies this design configuration was extended to ships of about 170,000 tons deadweight. During the mid sixties the utility of the ship type was further developed when the O.B.O. (Ore, bulk, Oil) ship was conceived. This development in operational capabilities came after considerable investigation which concluded that this ship type could carry liquid oil cargoes without destroying basic simple structural concept. An outline structure arrangement for the cargo area of a bulk carrier is shown as Figure 3.
Cargoes carried by these ships are numerous, however, for the purpose of this paper, discussion will be on the carriage of ores and coals.
In a practical sense the shipowner endeavours to minimise the empty ballast voyage legs of the operational cycle with these ships. With regard to the carriage of coal the major exporters and major consumers dictate the trade plied by bulk carriers. Mayor producers of coal for seaborne export include Australia, United States and South Africa and the total coal carried in ships is over 300 million tonnes per year. Major importers of coal are Japan and Europe as well as other industrial nations such as Korea and Taiwan. A typical voyage route for a ship upon leaving Europe could be a ballast a trip to the United States for loading of a particular coal cargo, followed possibly by loading of another parcel of coal in South Africa and a voyage to Japan. After discharge in Japan the ship could then proceed to Australia for a cargo of coal or even ore for delivery to Europe. During this service a wide variety of coal cargoes, sea and environmental conditions as well as port operational procedures will be experienced.
In the carriage of ore, which is the most severe cargo carried in terms of loading on the ship, the ships ply between the major exporters e.g. Brazil, Australia, India, South Africa and Canada, and the major consumers e.g. Japan, Europe, Korea, etc. Due to its high weight per unit volume, ore is normally carried in alternate holds within the ship. In general the holds loaded are the odd numbers i.e. nos. 1, 3, 5, 7, etc. The purpose of this alternate loading is to increase the height of the ships centre of gravity above the base so as to make the ship less stiff. i.e. the ships roll motions are more moderate. Even with the ore cargoes carried in alternate holds the cargo quantity does not occupy, on many occasions, a large proportion of the hold space.
In addition to commercial pressures dictating the growth in the ship size for the carriage of ore and coal they have also dictated that the cargoes can be loaded and unloaded from the ships holds as quickly as possible. In order that this can be attained ports have developed more efficient facilities in terms of grab size for discharge and conveyor systems for loading. In this respect grab sizes have greatly increased in capacity and in unloaded weight. Indeed it is now common for unloaded grabs to weigh as much as 35 tons. Examples of typical weights for unladen grabs are given as follows with their respective ports.

	Iron Ore	Coal
Emo Maasvlakte	20/36	18/28 (Tons)
Redcar	10/15	20 (Tons)
Nagoya	20/30	20/30 (Tons)
Kure	20	20 (Tons)
Taiwan	19.4/19.9	19.4/19.9 (M.T.)

Equipment to free coal or even ore from the ship structure can constitute hydraulic hammers fitted to the extending arms of tractors within the holds. In addition, the gathering of coal or ore in the holds can be the job of bulldozers which are, to say the least, ship unfriendly. A fundamental question to be addressed is; "can a ship be designed to withstand the repeated energy from 35 ton grabs or bulldozers when used with enthusiasm?" ... If traditional shipbuilding standards are to be employed

probably not.
It would be wrong and unfair to isolate the primary problem to the factor of stevedoring. Other aspects such as the corrosive nature of the cargo or even the environment can have a great effect on structural reliability and performance. In this respect certain coal cargoes can have a high sulphur content and this in association with the "sweating" of the steelwork, due to the environmental conditions experienced, can lead to very concentrated corrosion of the hull internal steelwork. This phenomena, together with heavy sea conditions can lead to extremely rapid break down in the integrity of the structural components.
Other aspects, such as how the quantity of ore in each hold can be ascertained during loading are also fundamental consideration in terms of the hull girder loading. Cargo temperatures in the carriage of certain pelletised ores and also coal, while being less common is an aspect of load which cannot be ignored. In a paper to the Tasmanina Branch of the National Institute during 1988 Captain Davies, a marine surveyor, assumed the hypothesis that the loading and carriage of high temperature iron ore pellets excessively degrades ship structures. In this paper he commented that ores were being loaded at well above the recommended temperatures of 65 degrees centigrade, with temperatures of over 150 degrees centigrade being recorded. Ref. 1.

AGE STRUCTURE OF THE FLEET

The age structure of the bulk carrier fleet is shown in Figure 4. From this figure it will be noted that the fleet is a reasonably balanced fleet in terms of size, up to about 100,000 t dwt, for ships built between the early seventies and mid eighties. During the early eighties there appears to be an upswing in newbuildings for ships above 125,000 t dwt.
By far the majority of the ships which form the bulk carrier fleet are the handy sized ships ranging in age up to over 30 years.

STATISTICS OF LOSSES

Figures 5, 6 and 7 illustrate the loss of dry bulk carrying ships, where such losses can be attributed to structural failure, from the end of 1979 to date, i.e. ships which have had reported hull leakages or have simply gone missing. The ship types include single hull and double hull bulk carriers as well as ships with an ore carrier structural configuration. Over this time period the average rate per year is about 6 ships with the highest level being 12 ships during the year 1990.
Ships which have been lost or have known to have suffered significant damage during the period from the beginning of 1990 to the time of writing are shown in Figures 8 and 9. From this information it can be deduced that the average age of the 18 ships which were lost was about 19 years, with the majority being over 20 years of age. The average age being influenced by the loss of the 'Mineral Diamond' which was only 9 years old. From this information it will also be noted that 14 of the ships were carrying iron ore. In nearly all of the cases (13 ships), except those where the ships have simply 'gone missing', it is understood that the loss was preceeded by water being taken in one or more hold spaces.
From the information available for the handy sized ships it is evident that the rate of sinkings increases with age. i.e. less than 1% for ships in the 5 to 9 age group ranging to 4% for the 20 to 24 year group. In the case of larger ships there are indications that this trend is still applicable with the 50,000 to 75,000 t dwt group being up to about 7.5% when the ships are in the 20 to 254 year age group. With regard to ships in the 100,000 to 125,000 t dwt the very much smaller sample is relatively consistent in performance at about 7%. It required to be appreciated when considering these magnitudes that as the sample group sizes vary to such a large degree that the actual percentages are not comparable in ship number terms. These percentages do, however, indicate a trend for the various deadweight ranges.
In view of the difficulty in establishing probable causes for ship losses, information available with regard to bulk carriers with significant damages within the same time frame have also been included in these statistics. The information available indicates that cracking of the main frames and their brackets is a consistent occurrence. In certain cases this cracking has led to a reduction in support for the side shell which in turn has resulted in cracking occurring in the side shell plating itself. In at least two prominent cases this phenomena actually led to the loss of the side shell plating over the affected hold lengths.
These statistics used also seem to indicate that there are two distinct problem areas. i.e. one with the older ships and the other on a smaller scale with middle aged tonnage.

FOCAL POINTS FOR STRUCTURAL DEFECTS

In a sense the particular ship configuration and service dictate the location and extent of damages on ships. In the case of bulk carriers the cargo containment space is bounded by the port and starboard side shells, the ships inner bottom and is normally subdivided along its length by corrugated transverse bulkheads which have supporting stools top and bottom. The presence of large hatchway openings over the cargo area also creates a hull with a reduced torsional resistance, as well as focal points for stress concentration at the corners of the hatchways. While seemingly not obvious the structural arrangements employed for transverse bulkheads can also create, under certain loading conditions, concentrations of load in the deck structure and in particular the cross deck strips between the hatchways. In addition to these aspects the handling of cargo can damage certain areas of the structure more than others by virtue of grab damage or even that created by bulldozers or hydraulic hammers. The cargoes themselves by virtue of their temperatures or their corrosive properties can also be fast acting and ruinous to the structure. Other aspects, such as structural discontinuities, can of course also be focal points for cracking.

A brief summary of types of defects and the locations where these can be found is given as follows;

- i) Cracking at hatch corners.
- ii) Plate panel buckling of cross deck strips and stiffening structure.
- iii) Cracking of hatch coamings.
- v) Cracking at the intersection of the inner bottom plating and the hopper plating.
- vi) Grab and bulldozer damage to the main frames lower brackets.
- vii) Grab damage to the inner bottom platings, hopper and lower stool platings.
- viii) Cracking at main frame bracket toes.
- ix) Both general and localised corrosion of main frames and brackets.
- x) Cracking at fore and aft extremities of topside tank structures.
- xi) Corrosion within topside tanks.

While the above listed damages are typical of those found on bulk carriers they are not inevitable. Evidence would seem to indicate that even with sister ships significant differences in occurrence and extent do exist. This would seem to indicate that in addition to the importance of structural strength to the importance of structural strength and detail design, that other factors, such as operational controls, come into play.

An aspect considered relevant with regard to loadings is the procedure and the number of loading passes made by the loaders on the individual holds of the ships. Again for commercial reasons it is in the ship operators' and port operators' interests the number of passes be kept to the minimum. In considering a group of very similar ships carrying very similar cargoes it becomes apparent that great variations in structural performance do occur. With the ships which incur minimum damage it would appear that the operators are particularly cautious with regard to loading ore cargoes and employ a large number of loading passes which will reduce the likelihood of overloading individual holds.

For the purpose of this paper it is not intended to discuss all of the items listed beforehand but to address only those aspects which are more likely to cause hold leakage and possible flooding. i.e. items (vi), (viii) and (ix).

The remaining aspects have been, or are being, dealt with and will be reflected in rule reviews in the near future.

GRAB AND BULLDOZER DAMAGE TO MAIN-FRAME LOWER BRACKETS

As previously indicated it is normally expected that the lower region of the main frames at some time receive some level of damage during the unloading of the ship. This can involve damage ranging from localised deformation of the frame bracket face plates to large physical deformations of a number of frames.

In the case of single hull bulk carriers the ships side main frames are individual pieces of structure which, if rendered ineffective, will place additional load on the adjacent main frame or frames. Progressive failure by the domino effect is therefore a reality.

CRACKING OF MAIN FRAME BRACKET TOES

This type of cracking is initially created by detail discontinuities in the bracket toe regions. The type of bracket configuration used will to a large extent dictate the location and extent of cracking. Where separate brackets are employed the cracking location is more normally at the bracket toe position on the frames whereas with integral brackets the crack location is at the toe location on the hopper and topside tank. See Figures 10 and 11 respectively. Turning to the latter case first, i.e., the contiguous bracket design, the cracking has been found to be almost self limiting with a very small propagation rate after the initial occurrence. In the case where separate brackets are fitted experience has shown that the fracture, once it has occurred, propagates very quickly to the side shell.

These experience-based conclusions have been confirmed by experimental and theoretical studies, carried out by Japanese shipbuilders, to determine the fatigue characteristics of various configurations of frame bracket. Ref. 2.

Loadings on the main frames and their brackets are complex and are generated by hydrostatic load and the rotation of the hopper and topside tanks. Cyclic loadings are induced from these load sources by the passage of waves and the motion of the ship in a seaway. See Figure 12.

REPAIR OF DEFECTS AND DAMAGE

Inspection of the ship by shipowners after cargo discharge on many occasions will reveal some level of damage. In many of the ports where unloading takes place there are no facilities for repair and therefore the owner can be faced with a decision as to whether to accept the damages as (i) being only a blemish, (ii) to carry out temporary repair and carry out permanent repairs later on (iii) to sail to a repair facility. It is emphasised that any significant damage should be advised to the classification society concerned. Commercial pressures will have inevitably influenced in the decisions taken in the past.

A fundamental question is: how can the internal structure of the holds be effectively examined in any case? The lower frame bracket areas can be accessed by means of ladders but how can the upper reaches of the cargo holds be accessed? To enable effective examination so as to assess corrosion or even cargo handling damage means to permit close up examination are fundamental, i.e. by the use of 'cherry picker' type equipment.

BOTH GENERAL AND LOCALISED CORROSION OF MAIN FRAMES AND BRACKETS

The marine environment in association with the characteristics of certain cargoes can create a very severe situation in terms of corrosion. This has been very adequately demonstrated over recent years by the loss of ballast tank side shell structure on oil tankers due to differential temperatures between cargoes and the environment.

In the case of single hull bulk, or 'ore bulk oil' carriers the environment created within the hold spaces by a cargo, such as coal which is carried at temperatures of up to 38 degrees centigrade, can create, in association with the colder sea water outside, significant sweating at the interface of the side shell and topside tanks. In addition to this certain coal cargoes possess a high sulphur content which adds to the corrosive effect. By virtue of gravity the condensation is limited to the outboard portion of the main frame webs and the lower bracket connection to the hopper to which it gravitates.

It is not unusual therefore to find that bulk carrier main frames have suffered from highly localised corrosion on their webs adjacent to the side shell. In addition the bracket web connection to the hopper is similarly effected.

This corrosion, with some typical structure arrangements, would seem to be the trigger for fracturing which either propagates from the lower bracket toe outboard or up the web connection to the side shell (leaving the bracket intact).

DEVELOPMENT OF DAMAGE

In the case where integral brackets are employed experience has shown that, in the absence of corrosion, any fatigue cracking will be contained in very localised areas at bracket toes. It has also been shown that where localised corrosion has occurred in association with localised fatigue cracking that this cracking propagated to the side shell along the bracket connection. In the absence of significant mechanical damage to the main frames this cracking, by virtue of its location, will be difficult to detect. In addition due to the consistency of structural arrangements, loads and the environment it is probable that the other frames in the same hold will be in a similar condition. If this situation goes unnoticed it is only a matter of time before the side shell cracks and tears thus permitting sea water into the hold space.

An obvious question to address would be: why does this damage more often occur when the ships are carrying ore as the evidence suggests? The obvious answer to this is that when carrying ore, particularly in the alternate hold loading condition, both the local components, such as the frames, and the hull girder are more highly stressed. In addition, because of the low fill rates of the ore cargoes the side frame deflection amplitudes and panting are not restricted. Also the ship's very stiff rolling motions in the ore conditions can only exacerbate the loading situation.

ACTIONS

If this portrayal of the situation is correct it would seem that there is a need to introduce a greater degree of structural reserve so as to improve the robustness of the hull thus making an allowance for the latterday increased severity of operational procedures. This is particularly true with regard to the side framing members.

There is a need for an awareness in the ship operating community with regard to the possible consequence of damage to main frames, whether this is caused by cracking and corrosion or by the act of unloading the ships.

There is a need to prevent corrosion occurring in these critical locations.

Bearing in mind the age statistics of the ships concerned it would seem logical to require an increase in survey requirements, for hold areas.

It would also seem logical to look to the future and ensure that new designs being constructed of higher tensile steels reflect the experience gained.

While more a long term objective it would seem that positive means should be developed to gauge more accurately the ore filling levels and also to announce the ingress of water into hold spaces.

It is considered that the lower frame brackets require to be increased in thickness because of their working environment. In addition it would also seem logical to consider the use of additional structure to provide an alternative load flowpath in the event of local failure.

In conclusion, I consider that the challenge for the classification societies is relatively clear but the effort of their actions will only be significant if an awareness of the consequences of damage is reflected in action by industry.

Ref. 1 *Arctic Carrier*, 1985 - A contributory cause of loss? - Captain Davies, 1988

Ref. 2 *Study on the fatigue strength of local parts ships structures*
2nd report - Strength of side frame ends of Bulk Carriers - I H I, 1978

APPENDIX 1

LOSSES OF BULK CARRIERS DURING 1990

In the course of 1990, Lloyds' Register noted with increasing concern the untypically high rate of bulk carrier casualties which were sustained during the year due to unknown causes or the consequences of structural failure.

In this context, 'casualty' means that the ships sank or were damaged to an extent which cause them to be at a particular risk while at sea. The great majority of bulk carriers that became casualties were built in the early 1970s, and many different owners, flag states and classification societies were associated with them. The list of casualties comprises 23 ships, 12 of which sank and 11 were seriously damaged.

In November 1990 LR commenced both a thorough review of the published data on the casualties and a major research project to determine causes and remedies. Further data is now needed to progress this work.

Certain tentative inferences can already be drawn from the available data.

Firstly, the loss of side shell plating in the cargo holds is common to many of the ships in question.

Secondly, the types of cargo carried by the ships prior to, and at the time of, the casualty appear to be significant. The carriage of coal followed by iron ore is prevalent in the casualty sample and the carriage of iron ore in alternate holds predominates. The manner in which the ships were discharged could also be significant.

Thirdly, the rates of corrosion of the lower side framing and its connection to the hopper side plating appear to have been high and to have accelerated with age.

Pending the results of this research, LR has issued instructions to its surveyors to reduce the amount of corrosion permitted in this area of the structure at the special surveys, and to be especially vigilant during the annual surveys of these regions.

LR will collaborate with other classification societies to confirm the validity of its research in order, if humanly possible, to reduce the current unacceptable casualty rate of these ships.

The Technical Planning and Development Department of LR seeks information from any informed party to assist the research.

The Bulk Carrier Research project

BACKGROUND

The uncharacteristically high loss and serious damage incidents to bulk carriers in 1990, in particular, focussed our attention and efforts to provide, at the earliest possible moment, recommendations for improving their safety.

To put this work into perspective, it must be realised that improvements to Class Rules are being made continually on the basis of service experience through the reporting procedure described previously. In fact, several aspects now incorporated within the overall scope of the research project, such as hatchway openings, cross deck strips inner bottom plating and transverse bulkhead stools were already being addressed under a long term rule improvement project.

INITIAL WORK

In the first instance, a seven point plan was devised in order to produce a rational and measured short-term responde to the main problem, if it could be identified. This plan, was also to define possible areas of work which, when completed, could have a positive effect on structural and operational safety of bulk carriers.

Seven point plan:

- Casualty and damage investigation.
- Relevant information from operators.
- Visits to ships during unloading/loading process.
- Definition of research topics.
- Interim response to initial findings.
- Preparation of initial Rule proposals.
- Commencement of relevant full scale measurements.

The first three points were essentially information gathering and were extremely important. The discussions with a limited number of extremely helpful operators and associated visits to their ships, particularly during the unloading process, were used to concentrate out thoughts and define the areas for further study.

It soon became clear that, whilst there are many factors which affect a bulk carriers' structural or operational capability, they are a well tried design and will perform satisfactorily provided the structure does not significantly deteriorate locally due to corrosion, physical damage or overloading.

CASUALTY AND DAMAGE INVESTIGATION

The investigation started with seven of the twenty three ships listed in the press release of January 1991. The seven ships were either to LR class or Ex LR so that classification survey reports were readily available. A summary of the particulars and findings for the seven ships are given in Table 1.

The casualty and damage investigation pointed in the first instance to the side structure being an important and common feature of the majority of serious damage or casualty cases and this aspect received immediate attention. The importance of this topic was also highlighted by discussions and information from operators and by considering casualty reports, where available, on bulk carrier losses and serious damage cases for ships over 20,000 tonnes deadweight going back to 1980.

A common feature of the statistics was the prevalence of ore in alternate holds when damage occurred. In damaged ships which were not lost, severe localised corrosion of the side frames and bottom bracket was a very common feature.

TOPICS FOR STUDY

Ships side structure

The first topic for detailed study, identified as a 'problem' by all of the information gathering stages was the side structure.

Three-dimensional finite element analyses (3-D FE) were carried to confirm levels of operating stress and possible mechanism of failure and these confirmed their adequacy, provided the scantlings stayed within permissible limits.

Other dramatic evidence also showed that the side structure rapidly loses its capability if high levels of local corrosion are present or where physical damage to the frames and their brackets existed.

On the basis of the initial work, recommendations are currently being prepared. These are aimed at increasing the robustness of the structure to match the severity of today's loading and unloading procedures and increasing the frequency of surveys to cover new and existing ships respectively. Recommendations will cover:

- Minimum thickness requirement for main frames.
- Increase of arm length of top and bottom frame brackets.
- Requirement for fabricated 'T' section for higher tensile frames and for large span mild steel frames.
- Recommendations regarding detailed design of brackets.
- Requirements for supporting structure in hopper and topside tanks.
- Inertia and depth requirements for frames.
- Requirement for two or three lines of tripping diaphragms dependent on frame span.
- Increase in thickness of one shell strake adjacent to top of hopper tank with a possible increase in steel grade.
- Protective coating recommendations.
- Survey requirements.

DEFINITION OF FURTHER WORK

Keeping an open mind and realising that the loss of a limited amount of the side shell would not necessarily cause a bulk carrier to sink, other areas were singled out for further investigation. The list of general topics was almost intuitively obvious and covers:

Transverse bulkheads including stools
Topside and hopper tank structure
Cross deck strips
Hatchway openings, coamings supports and covers
Scarphing at fore and after ends of cargo holds
Global loading of the hull girder
Inner bottom plating
Double bottom details.

Some overlap between the two phases is evident and intentional enabling changes to our initial recommendations to be made if subsequent work can indicate any improvements.

STATUS OF PROJECT

All items shown in the initial short-term phase are being finalised with the exception of the full scale measurements which are on-going into the second phase of the project.

In particular:

Damage investigation - summarised previously but has been extended to a larger number of ships to check on any other areas of statistical significante.

Side frame analysis - some of the work illustrated previously. Additional work on bracket design was carrried out and confirmed finding of some earlier Japanese stress concentration studies. This work supports the recommendations for bracket design.

Strength evaluation

The two items of cross deck strips and transverse bulkheads were included in the initial phase, as both were being reviewed prior to the commencement of the project.

In the case of the cross deck strips, a direct calculation procedure has been produced which ensures strength adequacy for deck strips of unusual dimension without recourse to a complete 3D FE model.

Rule and survey procedures review

For the initial phase, the items being reviewed relating to the side structure and holds are described above. Other items will undoubtably arise from the second phase of the project.

Full scale measurements

Measurements are being carried out on two ships at present with considerable cooperation and interest from the owners. In both cases, the measurement programme was initiated some time before the current research project started.

On one ship, the IRONBRIDGE, operated by Furness Withy for British Steel, we are measuring both local stresses on a transverse bulkhead and stool using foil gauges and global hull bending loads using long base strain gauges on the deck. Several so called static tests have been carried out for a number of unloading/loading and loading/unloading sequences and dynamic measurements on voyages from South America have also been recorded.

On a second ship, the M.V. ORMOND, operated by P & O Bulk Shipping, a dedicated recording system has been attached to an existing hull surveillance system which includes four long base strain gauges along the upper deck and a forward accelerometer. This system is primarily to investigate the ships global response and is capable of recording any high frequency vibratory response if it is present. The system records on five channels continuously for half an hour each watch, and changes to a fully continuous mode if dynamic stresses exceed 50% of the Rule permissible values.

The static measurements for the IRONBRIDGE are now being processed, and the global response on both ships will be processed periodically or after sequences of high bending stress.

OTHER ASPECTS

In association with the ship measurements, a relatively large 3D FE model, covering three holds of a bulk carrier is being carried out to investigate the behaviour of a ballast hold transverse bulkhead and stool arrangements in the circumstance of a partially flooded hold which creates sloshing in heavy weather. The full-scale measurements will be used to calibrate the F.E. model.

The second phase of the project is now underway where it is intended to investigate the performance of other structural components in more detail, and review the need for definitive Rule changes.

One aspect that is currently before our Technical Committee is an increase in inner bottom plating to lessen the effect of grab damage.

Alternative modes of overall failure will be considered in phase two and some aspects of the initial phase such as finite element analyses and measurements will be both expanded and linked to consider the interaction of all the individual components.

INTERIM CONCLUSIONS

Bulk carriers are hard working ships where every component or design feature is working near its design limit at one point or another during its working life.

A detailed and on-going investigation following accelerated damages and losses of ships in 1990 indicates that a prime cause of a high percentage of the damages is 'failure' of the side structure due to a combination of corrosion, physical damage sustained during an operation and design.

Immediate changes to survey procedures have been taken to spot ships at risk and recommendations are being made and implemented to improve the robustness of the side structure to take account of today's loading and unloading procedures.

Although the Lloyd's Register project is concentrating on the structural aspects, operation procedures such as unloading and loading, hold cleaning, periodic maintenance and even ship handling can have a considerable influence on the frequency of damage. Recommendations will be made on such topics.

Many other features of bulk carriers are now being investigated and if the work highlights further areas where our requirements can be improved then changes will be made.

The purpose of presenting our interim findings and giving an insight into what is still being addressed, is to give interested parties the opportunity to advise us on the adequacy of the scpe of our work. In this way it is hoped that a full and lasting solution can be found to the problems which face bulk carriers today.

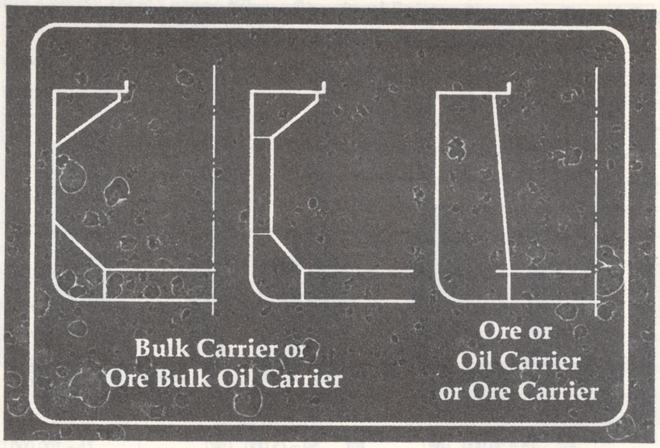
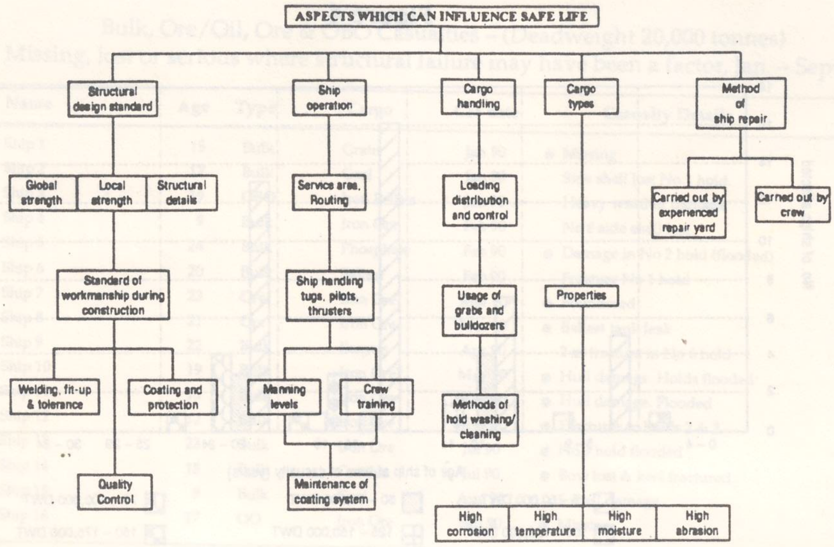


Figure 1



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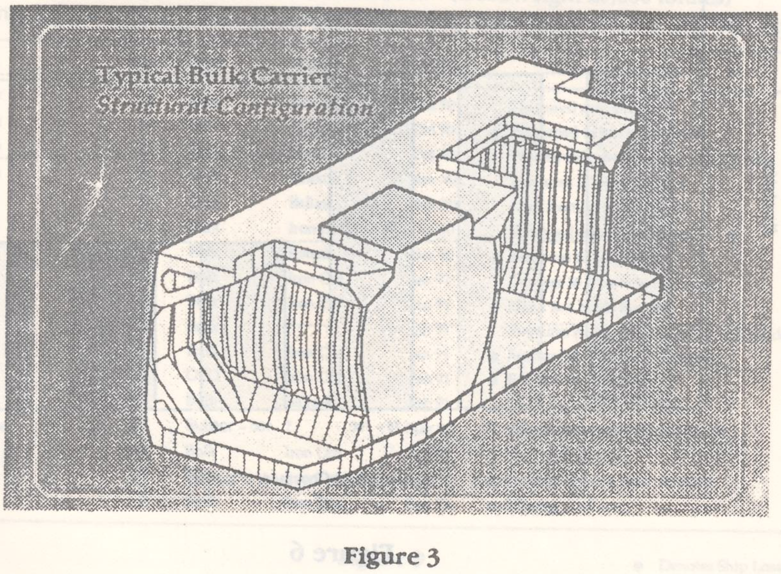

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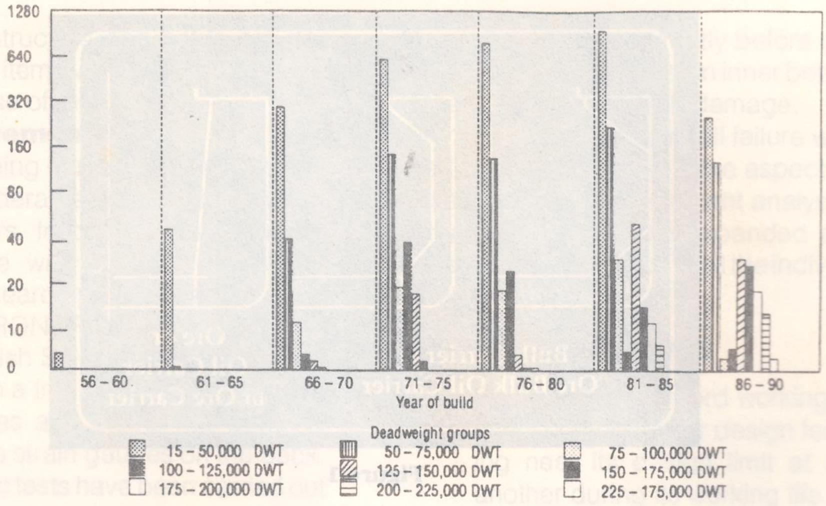

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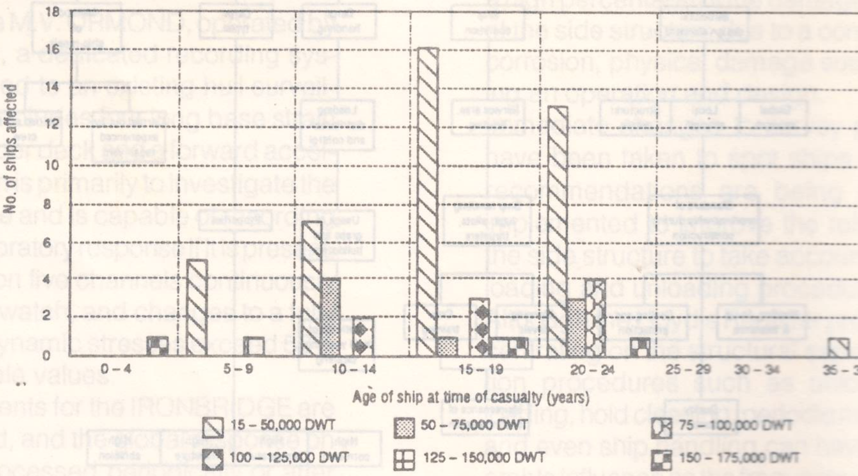

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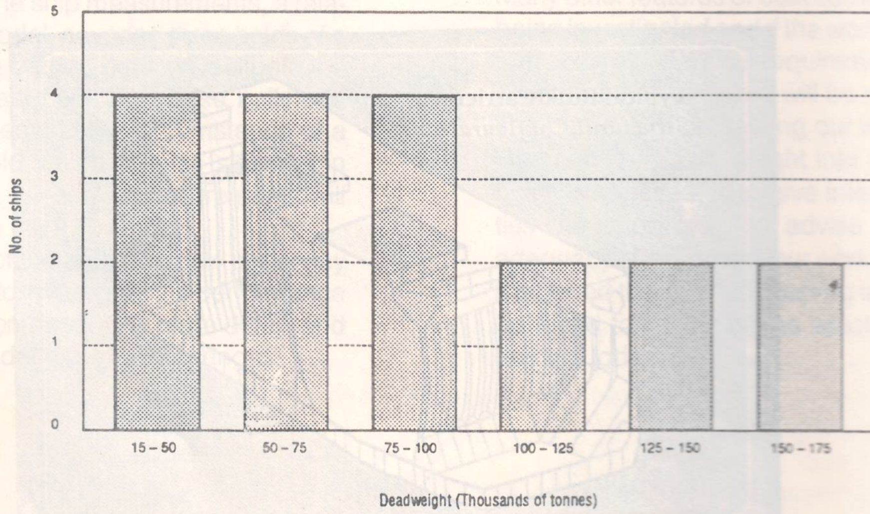


Figure 6

Bulk Carrier Total Losses Where Structural Failure May Have Been A Factor (1980 – 1991) 15,000 T. DWT Upwards

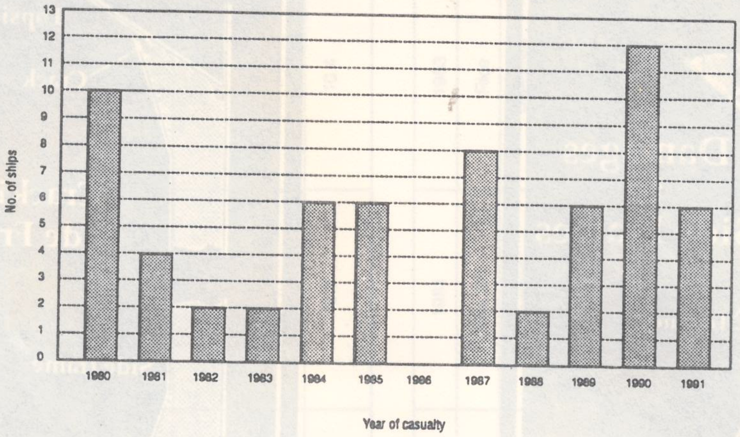


Figure 7

Bulk, Ore/Oil, Ore & OBO Casualties – (Deadweight 20,000 tonnes)
Missing, lost or serious where structural failure may have been a factor, Jan. – Sept. '90

Name	Age	Type	Cargo	Cas date	Casualty Details
Ship 1	15	Bulk	Grain	Jan 90	● Missing
Ship 2	17	Bulk	Coal	Jan 90	Side shell lost No 1 hold.
Ship 3	19	OBO	Iron Pellets	Jan 90	Heavy weather damage
Ship 4	9	Bulk	Iron Ore	Feb 90	No 8 side shell lost
Ship 5	24	Bulk	Phosphate	Feb 90	● Damage in No 2 hold (flooded)
Ship 6	20	Bulk	Ballast	Feb 90	Fracture No 1 hold
Ship 7	23	Ore	Iron Ore	Mar 90	● Foundered
Ship 8	21	Ore	Iron Ore	Mar 90	● Ballast tank leak
Ship 9	22	Bulk	Barytes	Apr 90	2 m fracture in No 6 hold
Ship 10	19	Bulk	Iron Ore?	May 90	● Hull damage. Holds flooded
Ship 11	13	Bulk	Iron Ore	May 90	● Hull damage. Flooded
Ship 12	12	Bulk	Iron Ore	May 90	● Fractures in holds 2 & 3
Ship 13	23	Bulk	Iron Ore	Jul 90	● No 3 hold flooded
Ship 14	18	Bulk	Cement	Jul 90	● Bow lost & keel fractured
Ship 15	9	Bulk	Coal	Aug 90	S shell damage
Ship 16	17	OO	Iron Ore	Sep 90	● Missing

Figure 8

● Denotes Ship Loss

Bulk, Ore/Oil, Ore & OBO Casualties – (Deadweight 20,000 tonnes)
Missing, lost or serious where structural failure may have been a factor, Oct '90 – Apr '91

Name	Age	Type	Cargo	Cas date	Casualty Details
Ship 17	24	Bulk	Iron Ore	Oct 90	Fractured side shell
Ship 18	19	OO	Iron Ore	Oct 90	● Presumed to have foundered
Ship 19	17	Bulk	Iron Ore	Oct 90	Wasted side shell framing in No 3 hold
Ship 20	21	Bulk	Bauxite	Nov 90	Fractures in holds 2, 3 & 6
Ship 21	19	Bulk	Ballast	Nov 90	12 m fracture in No 5 hold
Ship 22	18	Bulk	Iron Ore?	Dec 90	Bulkhead frames loosened
Ship 23	17	Bulk	Potash	Dec 90	● Fractures in No 2 hold
Ship 24	18	Bulk	Iron Ore	Jan 91	Damage to frames in No 1 hold
Ship 25	24	Bulk	Iron Ore	Jan 91	● Nos 2 & 4 holds flooded
Ship 26	19	Bulk	?	Jan 91	Fractures & detached frames in two holds
Ship 27	24	Bulk	Iron Ore	Jan 91	● Fracture in No 5 hold. Flooded
Ship 28	21	OBO	Iron Ore	Feb 91	● Fracture in No 1 hold
Ship 29	14	Bulk	Ballast	Feb 91	Fractures in no 3 WB hold
Ship 30	17	Bulk	?	Mar 91	frames detached from No 6 hold
Ship 31	24	Bulk	Iron Ore	Apr 91	● No 1 hold flooded
Ship 32	21	Bulk	Iron Ore	Apr 91	● Fracture in No 4 hold. Flooded
Ship 33	9	Bulk	Iron Ore	Apr 91	● Missing

Figure 9

● Denotes Ship Loss

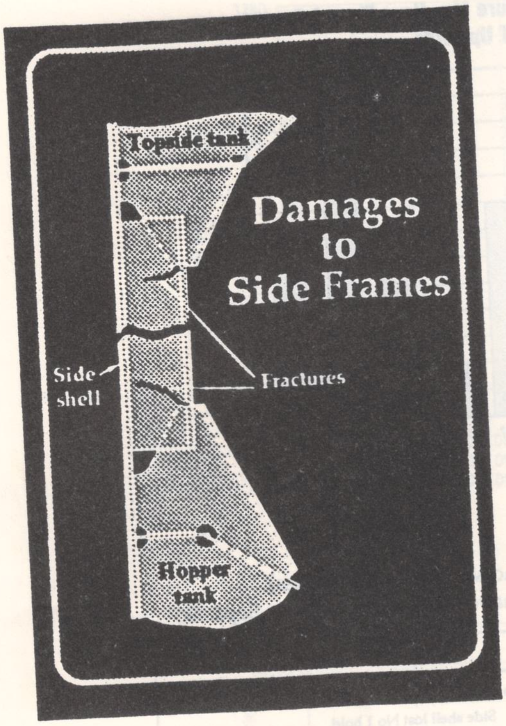


Figure 10

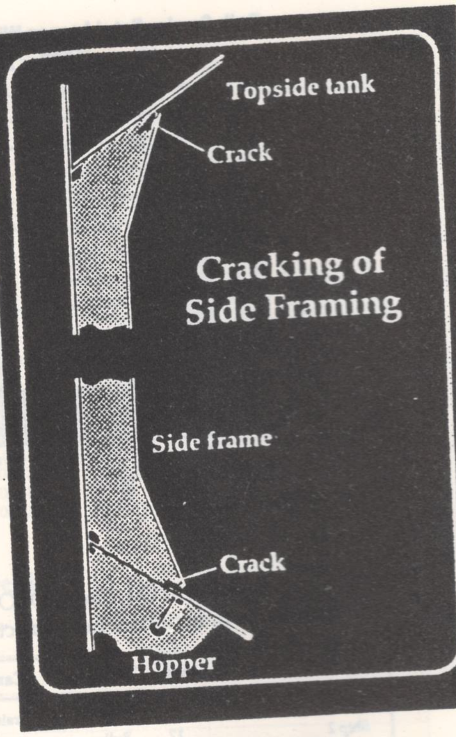
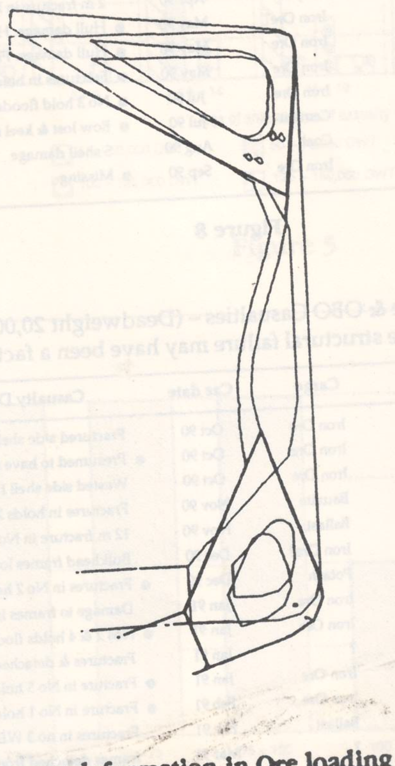


Figure 11



Frame/hopper deformation in Ore loading condition

Figure 12

Table 1: Seven Damaged/Sunk Bulk Carriers (LR & Ex-LR)

ITEM	SHIP NUMBER						
	1	2	3	4 (Ex-LR)	5	6	7
Principal Dimensions							
Lpp (metres)	235.9	223.9	247.0	259.9	254.2	259.4	170.8
DWT (tonnes)	80,580	66,350	120,143	122,734	127,907	140,832	26,400
Mld Breadth (metres)	32.2	32.0	40.6	39.0	40.8	42.9	22.7
Mld Depth (metres)	20.1	18.2	22.5	22.0	22.8	27.8	14.4
Max Draught (metres)	14.6	13.3	16.5	16.1	16.7	16.7	10.4
Other Particulars							
Year of Build	1967	1973	1973	1977	1981	1981	1983
Cargo Carried	Iron Ore	Coal	Iron Ore	Iron Ore	Iron Ore	Iron Ore	Rice
Current Status	Grounded & Sank	Awaiting Repair	Repaired	Abandoned & foundered	Repaired	Repaired	Repaired
Nature of Damage and Weather Condition	No 3 hold flooded due to damaged/lost hatch covers. A length of side shell had been torn away. *Heavy weather.*	Engine room and No 2 hold flooded via weld fracture in duct keel. *Heavy weather.*	Sprank leak in Nos 2 & 3 holds. Wasted side shell framing and detached brackets to hopper in No 3 hold. *Heavy weather.*	Sustained hull damage and holds flooded. *Heavy weather.*	Hold flooded and side shell torn off. *Heavy weather.*	Side shell heavily set in Nos 5 & 7 holds, framing wasted and detached from hopper. *Heavy weather.*	No 5 hold flooded. Starboard shell plate fractured. *Heavy weather.*
Summary of Surveyor's Reports	Localised corrosion found in side frames in way of No 1 hold. Previous history of damage repairs were identified in Nos 1 & 2 tank side tanks and Nos 3,5,& 7 bulkheads. Localised corrosion in topside tanks were also reported.	Fractures and localised corrosion were found in all hatch openings. Fracture found in No 1 DB tank sloped tanktop plating weld connection to side shell. Incidents of fractures reported in topside tanks.	Localised corrosion found in Nos 2, 3, 5 & 7 holds side frames & brackets. Damage to holds No 1, 4 and 8 side structures were reported and attributed to mooring contact, heavy weather and grabs impact.	Previous damage reported and stated to have occured during cargo discharging. History of fractures and localised corrosion on hatch coaming, openings, corners & supports. Conditions of side shell & frames unknown since disclassed.	Localised corrosion & fractures found in hatch no 1-4, 6& 9. Localised corrosion at all main frames lower connections to hopper tank. Some plates were found distorted in hold nos 2,3,4, & 5.	Main frames in no 5 & 7 holds found buckled & fractured. Localised corrosion of internal frames & brackets found in no 1, 2, 3, 5, 7, 8, 9 holds. Localised corrosion also found in no 5 topside tank.	A crack developed at no 5 hold shell plating in way of upper part of hold frames and associated connecting brackets. Damages to side shell sustained, stated as a result of contact.