Trends of Recent Hull Damage and Countermeasures

by Tomoo Mizukami, Ichiro Ishikawa** and Michifumi Yuasa****

1. Introduction

It is important for those responsible for ship surveys/inspections and ship maintenance to make themselves cognizant with the progress of corrosion and wastage of structural hull members and the occurrence of hull damage. Recognizing the recent chain of marine casualties caused by corrosion and wastage of structural hull members and the reported occurrence of fatigue cracks in the side longitudinals of second generation VLCCs, the classification societies have decided to take the necessary steps and countermeasures.

This paper reports on marine casualty statistics prepared by responsible organizations including those for the points above, and the occurrence of these marine casualties, and gives explanatory notes on the statistical trends of general hull failure , examples of hull damage, and proposed damage repairs and countermeasures.

2. Marine Casualty Statistics and Hull Damage Statistics

2.1 Marine Casualty Statistics

The Marine Accidents Inquiry Agency investigates marine casualties in territorial waters of Japan and those of Japanese ships outside territorial waters and publishes marine casualty statistics. According to paper[1], the total number of marine casualties reported during 1991 was 10,290. The number of marine casualties is the number of accidents covered by damage reports submitted, which include slight cases of damage. Table 1 shows a breakdown of marine casualties classified by type of accident. Collisions, contacts, groundings and ship-wrecks are the major marine casualties. Many accidents are considered to have resulted from the common practice of shipping companies of submitting damage reports to recover losses and damages from hull underwriters.

It must, however, be borne in mind that the marine casualty statistics suggest that the frequency of encountering perils at sea is extremely high, although we admit that the statistics include very minor accidents.

From among marine casualties, decisions are taken by the Marine Accident Inquiry Agency on those judged to be serious on the basis of the cause, extent and nature of damage. Table 2 shows a breakdown of marine casualties, which are classified by cause, subjected to decisions by the Marine Accident Inquiry Agency during 1991.

Most of the accidents were reportedly caused by simple human errors in ship operation committed by crew members; those related to maintenance, inspection and handling of main engines and auxiliaries account for 7.5%, and accidents connected to the construction, materials and repairs of hull, machinery and installation, 1.0%.

The number of ships that requested rescue services from the Maritime Safety Agency during 1992 was 2,371, of which 441 ships were marine casualties caused by typhoons and foul weather[2]. Breakdown of 1,930 ships excluding those damaged by typhoons and foul weather, classified by service shows that fishing

Table 1 The items of marine casualties in Japan by kinds of casualty (1991)

Kinds of casualty	Percent
Collision	13.8
Contact	18.2
Stranded *	17.5
Wrecked **	32.2
Machinery damage	8.9
Capsized	0.9
Fire	0.9
Foundered	0.4
Others	7.2

* including contact of bottom
** including contact with floating obstacles
Total number of marine casualties : 10,290

* ex-Yokohama branch
** Lecturer
*** Research Institute

Table 2 The items of marine casualties in Japan by causes of casualty (1991)

Causes of casualty	Percent
Insufficient watch	21.4
Nonobservant navigation	19.0
Nonobservant routine/expedient work by crew	12.1
Nonblowing of signal	6.6
Nonconfirmation of ship's position	6.6
Poor adjustment, inspection & handling of main engine	6.2
Dozing	4.5
Improper command & supervision	3.3
Improper handling of ship	2.3
Insufficient examination of sailing directions	2.2
Poor checking & handling of fuel & lubrication oil	1.8
The others	14.0

vessels and pleasure boats account for 71.2% and merchant ships for 29.8%. When assessed by cause, the marine casualty statistics also show that many were caused by human errors as in the case of data by the Marine Accident Inquiry Agency, and the percentage share of those caused by defective materials and construction, poor hull and machinery maintenance reaches 8.3%. It is also noteworthy that accidents connected to inadequate machinery handling account for 12.5%.

Fig. 1 shows the number of ships that were total losses among the world merchant fleet after 1979 extracted from the marine casualty statistics[3]. The number of total losses peaked at 473 in 1978, then continued to decrease up to 1990. We must pay attention to the fact that the trend took an upturn in 1991.

Ships covered by the casualty statistics are those with a gross tonnage of 100 *tons* and over engaged in international voyages, and merchant ships and fishing vessels with a gross tonnage of 1,000 *tons* and over not engaged in international voyages. Table 3 shows a breakdown of total loss accidents after 1985 classified by type. In the breakdown of 258 total losses in

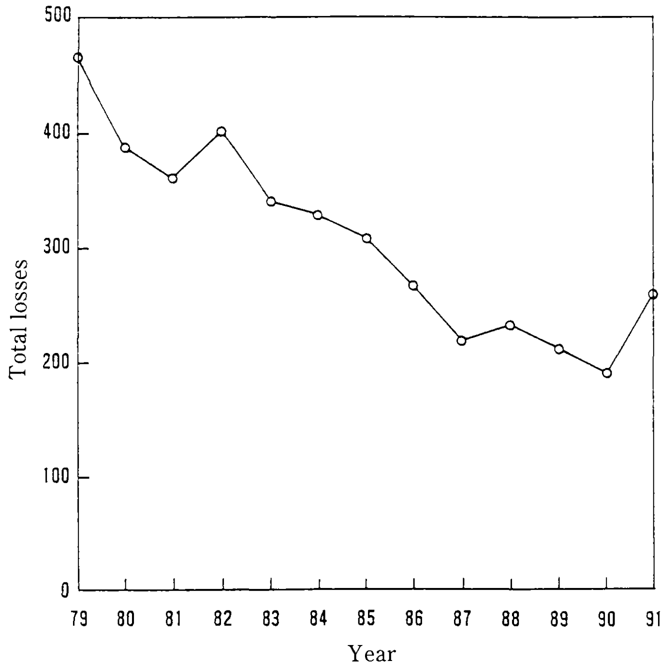


Fig. 1 Change by year of number of total loss ships in the world

Table 3 Change by year of number of total loss ships in the world (by kinds of accident)

Casualty Categories	'85	'86	'87	'88	'89	'90	'91
Foundered	108	99	101	105	101	72	111
Missing	2	7	4	2	3	6	3
Collision	35	21	24	20	29	21	36
Contact	10	5	7	9	8	9	13
Fire/Explosion	48	47	27	31	27	32	37
Stranded	74	51	43	53	38	44	45
Others	30	35	13	11	5	4	13
Total losses	307	265	219	231	211	188	258

1991, approximately three-quarters of the total loss tonnage is occupied by bulk carriers, ore/bulk/oil carriers and oil tankers. Furthermore, the breakdown by percent share of accidents (tonnage ratio) of all total losses during 1991 by flag shows that Korean, Italian and Maltese ships are high, while Japanese ships are low, and it may be fair to mention that the accident ratio of ships classed by NK is low from a global outlook[4].

2.2 General Hull Failure Statistics

Failures caused under ordinary ship operating conditions other than those due to marine casualties are defined here to be general failures, of which corrosion and wastage of structural hull members not associated with failures are excluded. In other words, the number of ships, in which abnormalities such as cracks, deformations (buckling, bending, etc.) and fractures are generated in structural hull members, and the number of members are statistically processed and presented. When failures are generated in both plate members and frame/girder members, they are counted individually.

Table 4 shows the rate of occurrence of general failures during 1991 (ratio by number of ships)[5]. The ratio of occurrence of cracking failures is three times that of deformation failures. The trend in ratios of occurrences of failures in the last decade is shown in Fig. 2.

The ratios of occurrences of both cracking failures and deformation failures have largely decreased in the last decade. However, the ratio of failures per ship followed a decreasing trend after 1982, but it took an upturn after 1990. The reasons for the increasing number of failures might be attributable to the ageing of ships built during the 1970s under a mass production system, but we should refrain from making any hasty conclusions. Table 5 shows the ratios of occurrence of failures by ship type in 1991.

General failures during 1991 are broken down by type of failure into 78% for cracking and 22% for deformation. The cracking failures occurred in oil tankers and bulk carriers account for 54% of the total cases. A breakdown of the causes of failures excluding corrosion and wastage is shown in Table 6. The causes of failures are, in descending order, design, vibrations, erroneous handling, defective workmanship, waves, loading and slamming.

Fig. 3 shows indexes of ratios of occurrences of failures (the value for ships aged 15 to 19 = 1) by ship age.

Table 7 shows the number of failures of structural hull members *per year* classified by ship type and member obtained from the results of a five-year investigation up to 1990[6].

Structural hull members ranked among the six worst members are shown for each ship type, in which the numbers of failures of hold frames in bulk carriers and lumber carriers are extremely large. Recently, the

Table 4 Rate of general damage by shapes of damage

Shapes of general damage	Rate per year (%)
Crack damage	3.3
Deformation damage	1.1
Crack & deformation damage	3.5

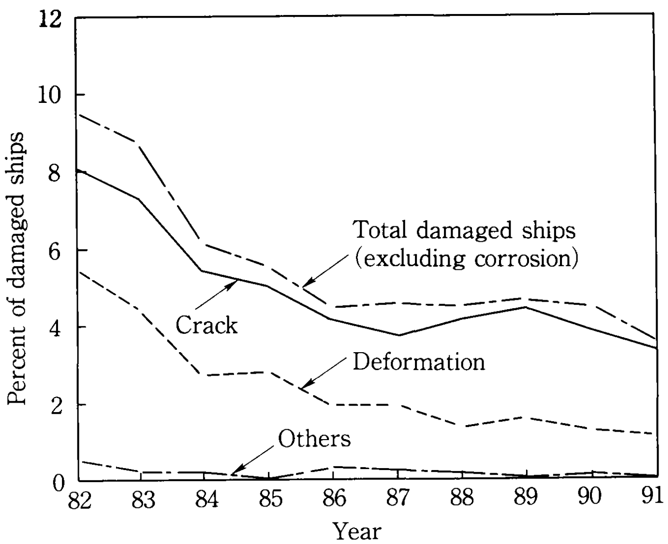


Fig. 2 Change by year of rate of general damage by shape of damage

Table 5 Rate of general damage by kinds of ship

Kinds of ship	No. of classed ships (1991E)	Rate per year (%)
Granular cargo carriers	1,197	6.98
Oil tankers	1,152	4.54
Gas tankers	278	2.44
Typical cargo carriers *	1,482	0.70
General cargo carriers **	625	5.60
Others ***	1,293	1.62

* container carriers and car carriers etc.
** including lumber carriers
*** Fishing ships, special-purpose ships, offshore structures, yachts and leisure boats etc.

Table 6 The items of general damage by causes (excluding corrosion and wastage)

Causes of general damage	Percent
Design	23.7
Vibration	14.9
Mishandling	13.2
Workmanship	7.4
Wave	4.8
Loading	3.5
Slamming	2.5
Others *	31.5

* including Unknown

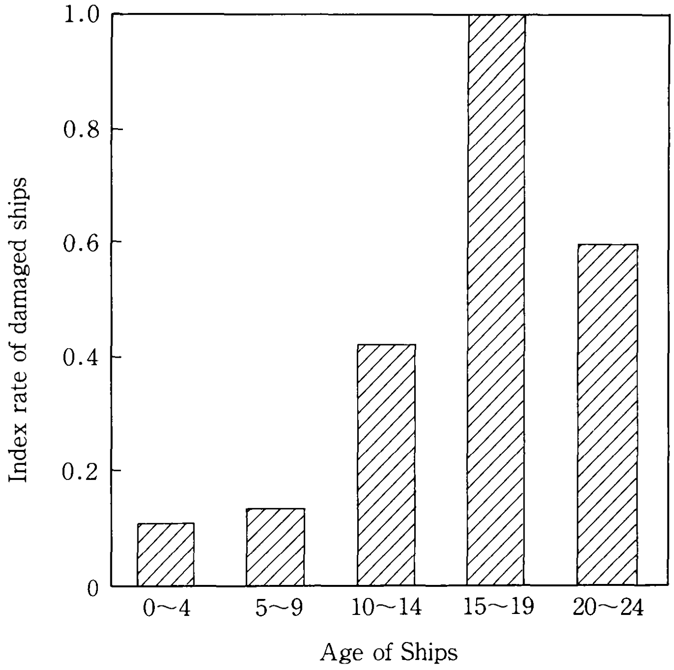


Fig. 3 Index rate of damage by ship's age

Table 7 Number of damage per ship-year by kinds of ship and structural members (worst 6 members)

Kind of ship	Structural members	Number of damage per ship-year
Oil tankers	Stiff. on L.Bhd in COT	0.08
	Side longi. in COT	0.06
	Stiff. on T.Bhd in WBT	0.06
	Bottom trans. in COT	0.06
	Stiff. on L.Bhd in WBT	0.05
	Side trans. in WBT	0.05
Bulk carriers	Hold frame	0.79
	Bulwark	0.17
	Hatch coaming	0.16
	Stiff. on bottom in DB	0.13
	Stiff. on side girder	0.12
	Stiff. on bottom in TST	0.11
Lumber carriers	Hold frame	1.07
	Hatch coaming	0.25
	Bulwark	0.14
	Stiff. on T.Bhd in CH	0.08
	Web frame in CH	0.06
	Floor in DB	0.04
Car carriers	Partial Bhd in CH	0.04
	Floor in WBT	0.04
	T.Bhd in CH	0.04
	Floor in FPT/APT	0.03
	Hold frame	0.02
	Stiff. on bottom in DT	0.02
General cargo carriers	Hold frame	0.21
	Hatch coaming	0.03
	Bulwark	0.02
	T.Bhd in CH	0.01
	Top plate of DB	0.01
	Stiff. on T.Bhd in CH	0.01
Bulk/Lumber carriers	Hatch coaming	0.08
	Bulwark	0.07
	Hold frame	0.04
	Non-tight floor in DB	0.02
	Side trans. in TST	0.02
	Stiff. on bottom in TST	0.02

numbers of failures of side longitudinals and longitudinal stiffeners on the longitudinal bulkhead in cargo oil tanks of oil tankers has been increasing.

3. Corrosion/Wastage of Hull and Failures

The failure statistics show that approximately 70% of failures of structural hull members are caused by corrosion and wastage, and the prime cause of serious marine casualties of bulk carriers and ore carriers such as sinking and flooding is, in many cases, assumed to be corrosion and wastage of structural hull members.

Although the significance of the need to protect the structural hull members of ships from corrosion due to sea water and cargo carried is well recognized, the seriousness of the phenomena surfaces seven or eight years after the ship is put into service. Moreover, the progress of corrosion and wastage is slow at the beginning, and this tends to result in the delayed detection of corrosion and wastage until a problematic stage is reached in terms of degraded structural hull strength. Stress levels also rise in association with the progress of corrosion and wastage, and the progress of wastage is accelerated. In addition to the surveyors of classification societies, all of those responsible for hull maintenance management should sufficiently realize the actual conditions of corrosion and wastage[7].

3.1 Progress of Wastage

Frequency distribution of measured data obtained from the summary results of plate thickness gaugings carried out for principal structural hull members is shown in Fig. 4[8]. In this figure, the values obtained by dividing the measured plate thickness reduction by ship's age are shown as the annual rate of wastage.

Table 8 compares ten percent probabilities of exceedance and mean values by ship type on the greatest annual rate of wastage and mean wastage. In the statistics, data on shell plating and upper deck plating occupy a large share, but data on internal members is also included.

Normally, the exterior surfaces of shell plating and upper deck plating are effectively protected against corrosion, and the shell plating, in particular, is subjected to regular maintenance each time a ship is in drydock. As a result, the rate of wear of these members is smaller than that of internal members. The corrosion and wastage conditions of internal members of real ships are considered to be represented by the maximum annual rates of wastage. In the cargo holds of lumber carriers and bulk carriers, oily paints are often coated. In this case, long-lasting corrosion control effects cannot be expected in ambient conditions with high temperatures and high humidities. The results summarizing the wastage of webs and face plates of frames in the cargo holds of bulk carriers

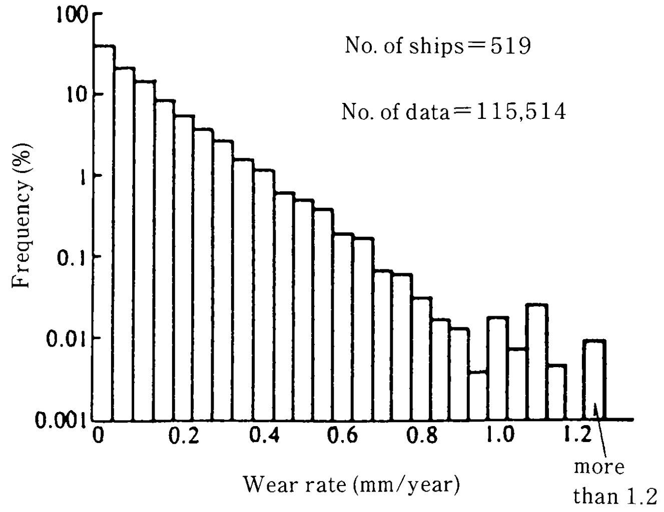


Fig. 4 Frequency distribution of plate thickness data by measurements.

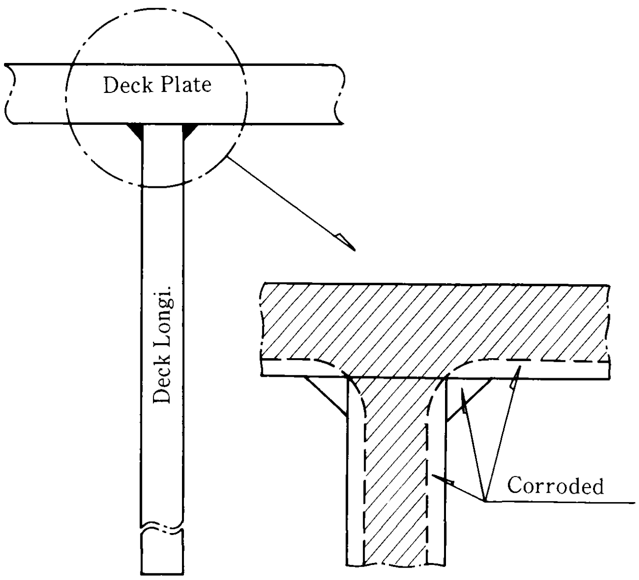


Fig. 5 An example of wasted deck longitudinal

Table 8 Rate of wastage per year by kinds of ship

Kind of ship	average per ship (mm/year)		maximum per ship (mm/year)	
	mean value	exceeding prob. of 10%	mean value	exceeding prob. of 10%
Oil tankers	0.10	0.22	0.40	0.63
Ore carriers	0.12	0.27	0.46	0.76
Bulk carriers	0.17	0.27	0.49	0.84
General cargo	0.09	0.20	0.29	0.48
Lumber carriers	0.20	0.37	0.55	0.90
Whole total	0.10	0.25	0.34	0.61

classified by painting specification[9] show that corrosion and wastage are intense if the surfaces are left unpainted or are coated with oily paints than in the case of coating with tar-epoxy paints.

3.2 Serious Failures due to Corrosion and Wastage

(1) Buckling of deck plating due to detachment of upper deck longitudinals

When an oil tanker ages, it is common for wastage of the deckhead of the upper deck in cargo oil tanks and ballast tanks to have developed to a considerable extent. Although sufficient attention tends to be given to the wastage of structural members such as deck transverses and deck longitudinals, wastage of fillet welds tends to be overlooked. We have often experienced failures involving several metres of longitudinals which have detached due to a reduction of the effective throat thickness of fillet welds of upper deck longitudinals (see Fig. 5).

With an aged, large oil tanker, we have experienced a serious hull failure involving the buckling of the upper deck plating amidships with consequent bending of the hull, which was partly due to improper loading, while proceeding under ballast on a relatively calm sea.

(2) Failures of side shell plating due to worn hold frames

The recent chain reaction of serious marine casualties of large bulk carriers involving sinking and flooding has given warnings of the need for inspections and maintenance management of aged ships.

Paper[9] shows that 40 more ships worldwide sank, were flooded or became missing in the period from January to August 1990. The particulars of ship type and outline of ships and damage are shown in Table 9.

Failures are concentrated on bulk carriers, and failures of the side shell plating, in many cases, occurred in plating in way of cargo holds, while they were at sea laden with iron ore. In some cases, part of side shell plating with side longitudinals became detached and fell off. Fig. 6 shows the condition of a 14 years old large bulk carrier whose side shell plating had fallen off.

(3) Compartments and structural hull members where corrosion and wastage are particularly significant

It is well known that ambient temperatures and humidities have large effects on the corrosion and the wastage of steel members. Experimental results show that the mass of corrosion doubles with every 10°C rise of

Table 9 Outline of accident and damage of large bulk carriers

Kind of ship		Loading condition	
Bulk carrier	31	Iron ore	22
Ore/Oil carrier	3	Ballast	3
Ore/Bulk/Oil carrier	3	Coal	2
Ore carrier	1	Grain	2
		Others	5
		Unknown	4
Outline of accidents and damage			
Damage of cargo hold			32
(Flooding into cargo hold		14)	
(Flooding into WBT (Ore carrier)		2)	
(Crack & Buckling of upper deck		3)	
(Damage of side shell		16)	
(Damage of trans. bulkhead		1)	
Flooding into engine room			2
Tearing off of bow structure			1
Unknown			6

temperature. It is also known that the temperature of empty top side tanks of bulk carriers becomes 40°C or thereabouts in summer, and it sometimes exceeds 45°C depending on sailing route and season. Accordingly, wastage of internal members can be three to five times greater than internal members in other compartments.

Triggered by the serious failures of large ships, the painting range in water ballast tanks was prescribed in rules and regulations, and guidance in 1970. For top side tanks, it was required to apply paint coats to one-third of the tank depth from the deckhead. However, failures of uncoated surfaces are increasing as a ship ages, because zinc anodes cannot provide sufficient corrosion control. New ships built after 1980 have ballast tanks totally coated with tar-epoxy paints and fewer problems of corrosion and wastage now occur.

In compartments adjacent to fuel oil tanks with heating coils, additional precautions are necessary as the corrosive environment deteriorates under the effects of high temperatures. Care must be taken in this regard[10) With the transverse bulkhead within the top side tank bounding the fuel oil tank, we have experienced a fracture opening created when the ship was aged 10 with the thickness of the surrounding plates reduced to less than 50% of the original thickness over an extensive area. If such

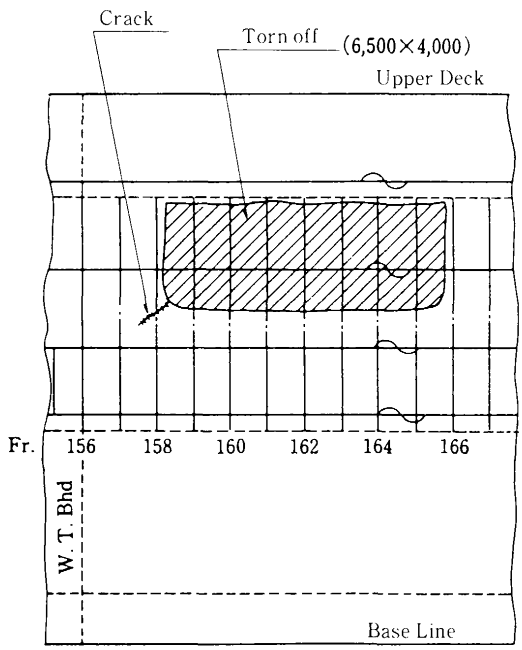


Fig. 6 Damage of side shell of cargo hold (bulk carrier)

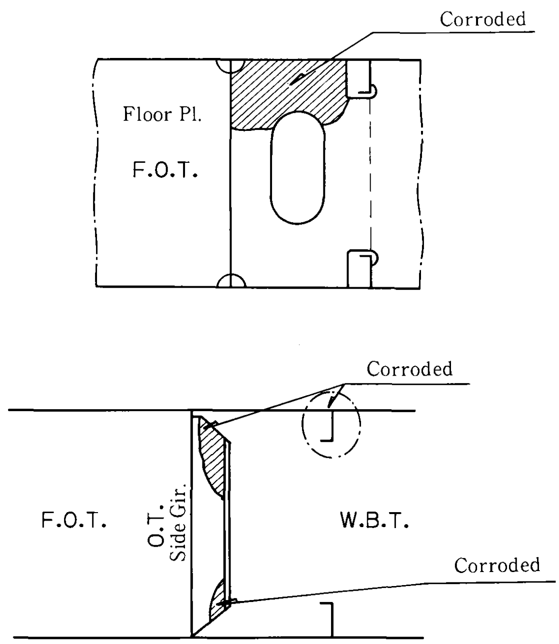


Fig. 7 Corrosion and wastage in the vicinity of side girders in double bottom (boundary wall of FOT and WBT)

conditions of wastage are left unnoticed, fracture openings and crackings are produced resulting in oil spill accidents, hence, early detection and maintenance are necessary. Similar problems can occur with double bottom ballast tanks, and corrosion and wastage often occur particularly in the double bottom tank of a general cargo ship. Fig. 7 shows examples of failure shown above.

In an oil tanker carrying highly viscose crude oil, the cargo oil tank is heated, and corrosion and wastage of the internal members in the adjacent ballast tanks are sharply accelerated as in the case shown above. In an afra-max type tanker, the ratios of wastage are 42-63% for upper deck transverse girders and deck longitudinals, and 26-35% for longitudinal bulkheads, 50-58% for side longitudinals, and 57-67% for longitudinal stiffeners on the longitudinal bulkheads within 10 *years* of service.

(4) Failures due to corrosion and wastage of shell plating

According to failure statistics, the rate of occurrence of serious failures involving cracking or fracture openings of shell plating had moved at or around 0.8 - 0.9%, but it increased to 1.5% in 1991. Many of these failures are due to corrosion and wastage, and their proportion in 1991 was 77%. For example, some were induced by corrosion and wastage of hold frames as in (2) above, some others were caused by grooving corrosion developing along frame lines due to corrosion fatigue under the reduced strength of worn shell plating and wave loads, with cracking and/or fracture openings eventually occurring in many cases. Fig. 8 shows an example of such failures.

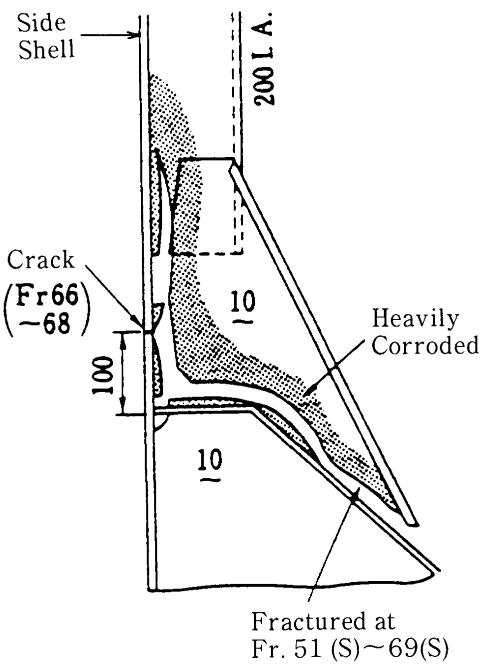


Fig. 8 Crack damage of side shell due to wastage and fracture of lower end brackets of hold frames

(5) Abnormal corrosion due to cargoes carried

It has conventionally been known that the tanktop plating of molasses tanks of molasses carriers, cargo hold top and deckhead members of coal carriers suffer from intense corrosion and wastage. In molasses carriers, the temperatures of molasses tanks become high due to continuing heating at loading, and it is also pointed out that the alcoholic vapour given off by molasses has some adverse effects. Sulfide ore carriers tend to have abnormal corrosion in the longitudinal bulkheads and transverse bulkhead at the lower levels of cargo holds. The corrosive residue produced by the reaction between the sulfur content of sulfide ore and moisture in cargo holds acting on these structural members, in many cases, cause local wastage.

4. Fatigue Failures of Structural Hull Members

4.1 Cracks in Side Longitudinals of Large Oil Tankers etc.

In first generation VLCCs built in a huge tonnage during the period from the second half of the 1960's to the 1970's, many cracks were generated in transverses and stiffeners on the transverse bulkheads of cargo oil tanks and water ballast tanks at relatively early periods of their services. Examples of typical failures are shown in Fig. 9.

Most of these failures were identified as cracks in the peripheral areas of slots in girder webs and cracks in the connected parts between flat bars on web plates and longitudinals. Concerning cracks in connections to longitudinals, cracking in the longitudinals themselves was rare. The results of an investigation on failures of structural hull members in large oil tankers from 1973 to 1979 show that failures were predominant in bottom transverses, girders on transverse bulkheads, girders on longitudinal bulkheads and side transverses, but there were not many failures of side longitudinals.

In second-generation VLCCs, use of high tensile steels greatly increased so they were used even for side longitudinals. As a result, the number of ships suffering from cracking of side longitudinals in the three to four years after delivery increased. Fig. 10 shows the typical examples of cracking failures.

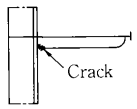
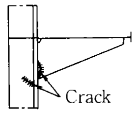
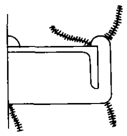
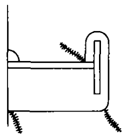
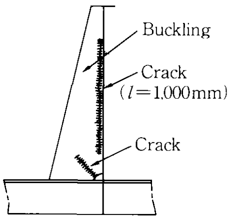
Patterns of Damage	Number of Cracks: Side Trans.	L. Bhd Trans.	Bottom Trans. W	Bottom Trans. C
	127	107	12	26
	10	20	1	
	41	23	1	0
				
			0	1

Fig.9 An example of crack damage frequently occured in large oil tankers of 1970's

Many cracks were found in the collars of transverse bulkheads or heels of flat bars or bracket on web plates where side longitudinals penetrate transverse bulkheads or side transverses. Based on the results of a meeting to assess high tensile steel structures provided for studying countermeasures[11)], the locations of failures are shown in Fig. 11.

The failures are characterized by:

○ Failures are more significant on the starboard

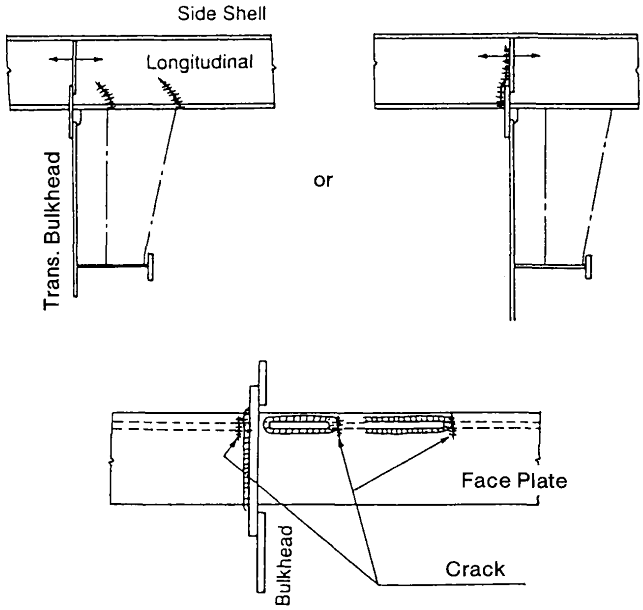


Fig. 10 Examples of crack damage of side longitudinals

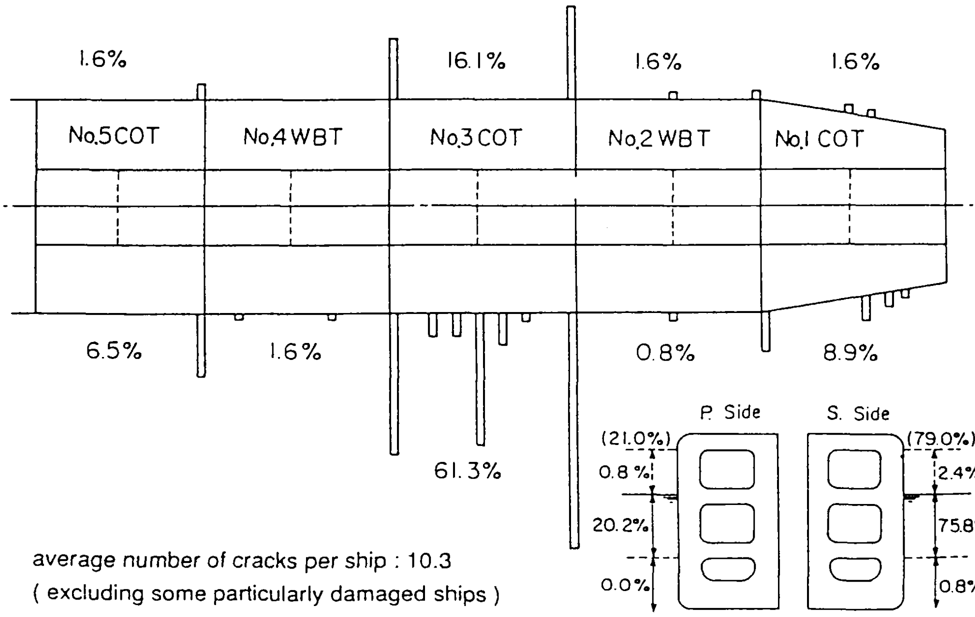


Fig. 11 Distribution of damage in VLCC's of second generation

side.

- Failures are most significant in No. 3 C.O.T., which is close amidships.
- Failures are more significant in transverse bulkheads afore or abaft tanks.
- Depthwise distribution of the locations of failures shows they heavily concentrate in the area from the water line to seven metres therebelow.

Detailed reports on probable causes of failures and countermeasures are given in paper[11]. Many first-generation VLCCs are old, and the results of a detailed investigation on failures in second-generation VLCCs indicate that cracks in side longitudinals due to corrosion and wastage sometimes found in ships aged 15 to 20, and care must be taken.

4.2 Cracks in Shell Plating

Among cracks in shell plating during 1991, approximately 23% were due to causes other than corrosion and wastage. Vibrations, insufficient local design strength of internal members and poor workmanship are the major causes in the broad classification.

(1) Cracks in shell plating due to vibrations

Due to impacts of propeller-induced vortex wake, the shell plating in the aft part of a ship:

i) undergoes panel vibrations with consequent cracks running along the fitting lines of frames or floors. Many were found in container carriers and pure car carriers with a wide and flat stern construction. Examples of cracks are shown in Fig. 12[12].

ii) specifically, shell plate panels with insufficient stiffness undergo resonant vibrations due to propeller-excited forces and diesel engine-excited forces with consequent cracking. As in the case of i), many were found in relatively high-speed ships.

iii) undergoes resonant vibrations of floors and longitudinal girders of the stern construction with consequent cracking in the internal members propagating to the shell plating.

(2) Cracking of internal members propagating to shell plating

In general cargo ships and bulk carriers, the ratios of occurrences of fatigue cracks due to stress concentration are high in the balance bracket at the fwd end corners in No. 1 cargo hold or the fwd end brackets of side longitudinal web penetrating the side frames, and the lower end brackets of hold frames, and these cracks often propagate to the shell plating. Examples of failures of balance brackets caused by defective geometric shapes are shown in Fig. 13[13].

There are many failures due to inadequate fabrication of slant plates on brackets. Cracks propagated from similar members to the shell plating at the corners of common cargo/ballast holds of bulk carriers and chip carriers are not few. The stress levels at connections between hold frames and lower end brackets are high with a high stress concentration caused by their geometry, and fatigue cracks in them are relatively frequent. Examples of fatigue cracks are shown in Fig. 14.

Ships carrying cargoes with a large specific gravity, in particular, have short rolling

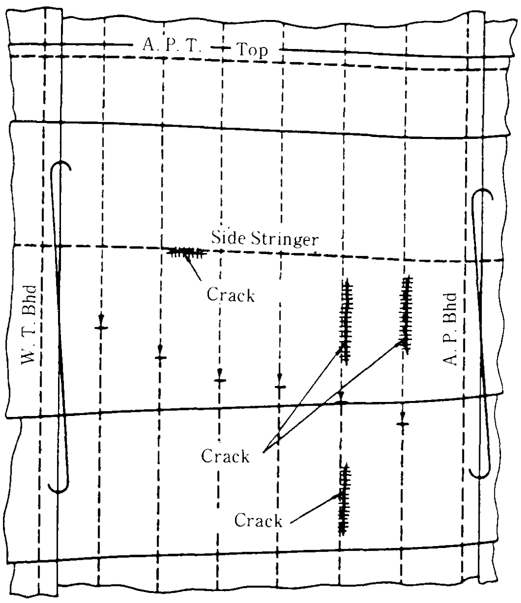


Fig. 12 An example of crack damage of shell plate due to vibration

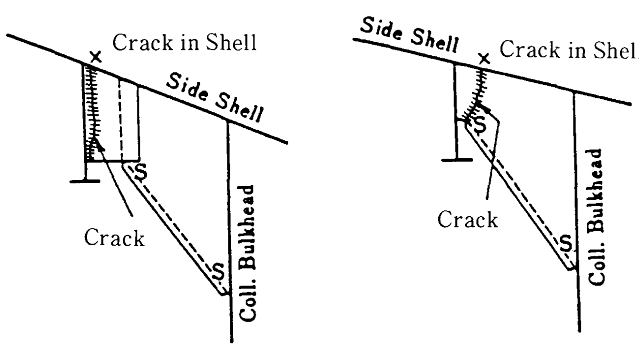


Fig. 13 Crack damage of fore end balancing bracket of cargo hold

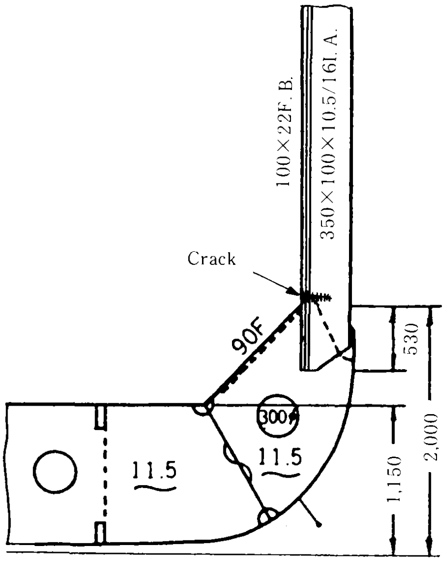


Fig. 14 Crack damage of lower end bracket of hold frame

Table 10 Rate of crack damage of shell plates by types of crack

Types of crack in shell plate	Rate of damage per ship-year
due to wastage & fracture at ends of hold frame	10.3 x10⁻⁴
along hold frame & internal member	7.5
due to fracture of bracket on collision bulkhead	1.6
due to wastage and fracture of internal tank member	1.2
due to fracture of other internal member (excluding wastage)	1.2
due to fracture at ends of hold frame (excluding wastage)	1.0
through slot part of internal tank member	1.0
the others	2.0
Total	25.8 x10⁻⁴

periods associated with high fluctuating water pressure, and the risk of cracks generating increases.

Table 10 shows the results of the investigation on ratios of cracking failures of shell plating from 1971 to 1987[14]. Compared with cracking failures of shell plating due to wastage and fracture of hold frames, the ratio of occurrence of cracking failures due to causes other than wastage is remarkably low, but overlooking them can lead to their propagation to shell plating, and care must be taken.

(3) Cracking failures of shell plating due to inadequate fabrication

Although sufficient precautions are taken for butt welding of longitudinal members, in particular, of internal structural hull members,

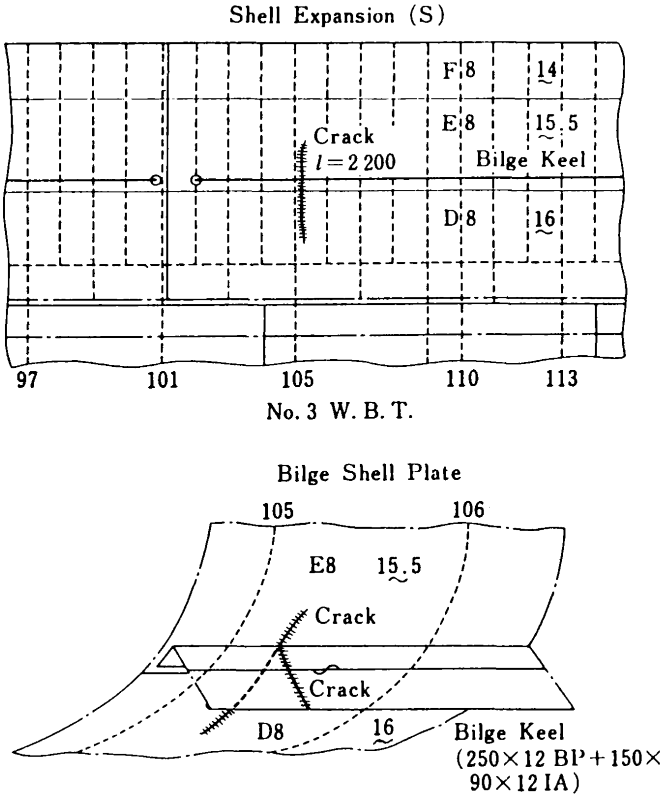


Fig. 15 Crack damage of shell plate through joint of bilge keel

which are directly fitted to the shell plating, the same precautions must be taken for butt welds of secondary members and bilge keels. Fig. 15 shows a case of a 2.2 *metre*-long crack generated in the shell plating because of a poorly welded bilge keel during replacement work, which was bent as the consequence of a marine casualty[14].

4.3 Cracks in Upper Deck and Hatch Coaming

Depending upon the geometric shapes of cargo hatches and other openings, there are many areas of stress concentration with resultant fatigue cracks, although not very frequent.

(1) Cracks at hatch corners

Design consideration is given to mitigating stress concentrations at hatch corners. For container carriers, bulk carriers and chip carriers, however, large hatch openings are provided, and the problem of torsional strength must also be taken into account. Torsional moments are added if oblique waves are encountered, and in such a case, the corners of the upper deck hatch openings, and particularly those in cargo hatches close to the bow or stern, in which the effects of torsion are significant, require additional strength consideration. Fig. 16 shows examples of failures at

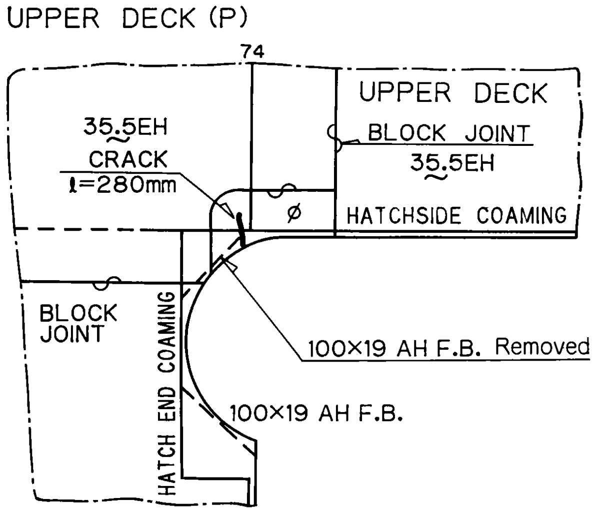


Fig. 16 Crack damage at hatch corner (container carrier)

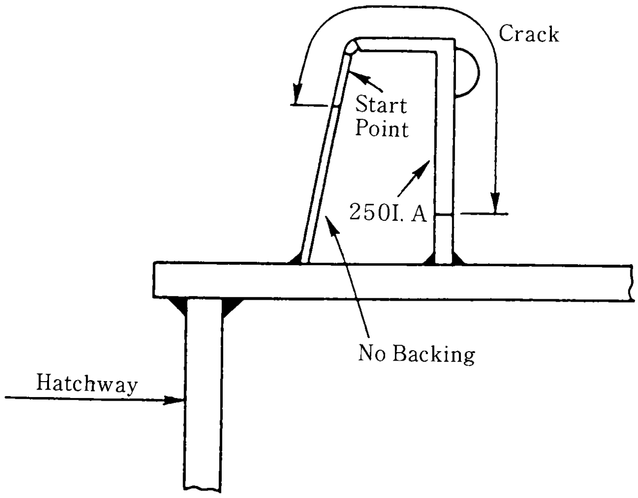


Fig. 18 An example of brittle fracture by hatchside coaming top

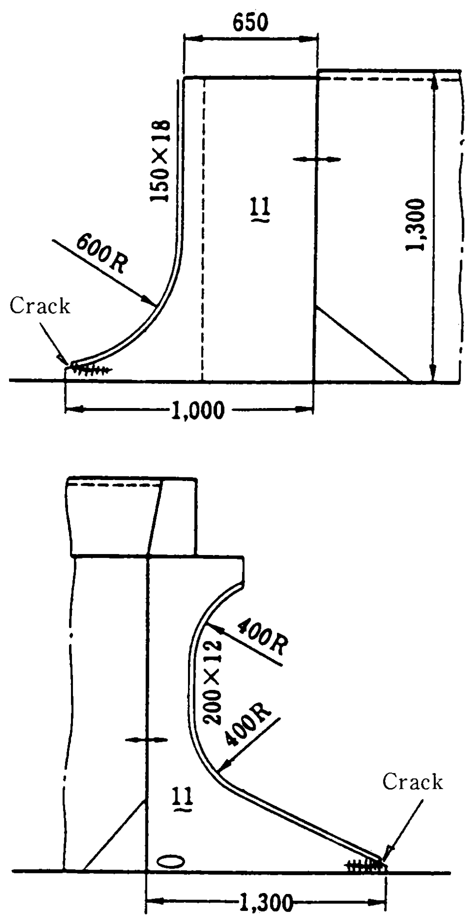


Fig. 17 Crack damage of end bracket toe of hatchside coaming

hatch corners of a container carrier[15]. The origin of the crack is located at the end of a flat bar for preventing buckling provided at the corner. In the absence of a danger of buckling at the corner, the flat bar in question was removed during repair work. In one case, cracks were generated due to an internal welding defect in a slant plate at the hatch corner.

(2) Cracks in hatch side coamings

Hatch side coamings of a continuous construction are used in container carriers. As a result, high levels of stress are created in the coamings due to longitudinal bending of the hull. On the other hand, bulk carriers use hatch coamings that are independent of individual cargo hatches, but the stress levels due to longitudinal bending are normally quite high even if the coaming ends have an arc geometry. Fig. 17 shows examples of failures of hatch side coaming ends[13].

The rails for operating hatch covers provided on the top plates have structural discontinuities and cracks were often found in these areas. Fig. 18 shows examples of failures, in which cracks originating from welding defects in the top coaming developed into brittle fractures of the upper deck[15]. In this case, the abutting area of the closing plate for the top coaming was found to have been welded without applying a backing strip.

4.4 Cracks in Internal Structural Hull Members

(1) In cargo/ballast holds of bulk carriers, chip carriers etc.

(a) Failures in the lower part of stools for transverse bulkheads

It is reported that cracks were found in the transverse bulkheads provided afore and abaft cargo/ballast holds, specifically in the connections between the slant plate of stools and the inner bottom plating of a

double bottom due to the effects of ballast loads and ship motions. Typical examples of failures are shown in Fig. 19.
In this case, cracks were generated along a line of fillet welds at the connections between the slant plate and the inner bottom plating, covering the crossings with girders of the inner bottom plating, fillets between floors/girders and the inner bottom plating. In ships of this type, fuel oil tanks, in many cases, are located on the inboard side of the double bottom and such cracks have serious effects upon the problem of oil pollution and ship operations.

(b) Failures in vertical webs on the transverse bulkheads of chip carriers
In chip carriers with a large depth provided because of the smaller specific gravity of cargoes, loads acting on the transverse bulkheads located afore and abaft cargo/ballast holds are large, and the dynamic impacts of water ballast is also significant. Failures of structural hull members of chip carriers are significant with girders on the transverse bulkheads and side girders in cargo/ballast holds. The transverse bulkheads of chip carriers often have a corrugated construction, and there are some reports on cracks generated in the inner bottom plating at the ends of such corrugated bulkheads as shown in Fig. 20[16].
The cause of such cracking failures is considered to be attributable to misalignments of floors and carlings in the double bottom space, which are provided at the crests and troughs of the corrugated bulkhead plate.

(2) Failures of transverse bulkheads in pure car carriers
Under the requirements for the intended service, the area of transverse bulkheads in a pure car carrier is largely reduced in design. As a result, there is a trend in which failures of the transverse bulkheads due to racking deformations of the cross sectional area of the

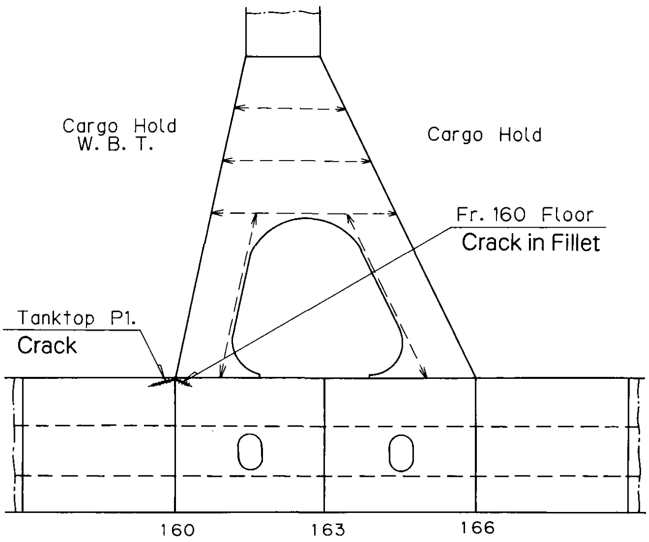


Fig. 19 Crack damage of lower part of trans. bulkhead stool (bulk carrier)

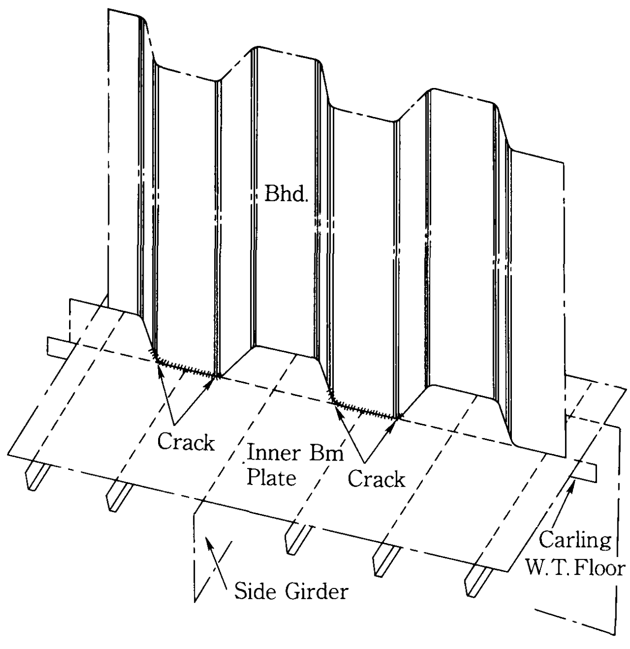


Fig. 20 Crack damage of lower part of corrugated trans. bulkhead (chip carrier)

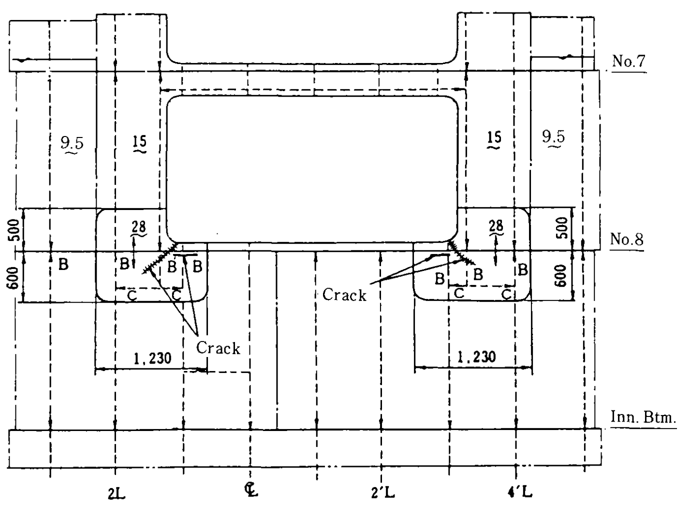


Fig. 21 Crack damage at corners of trans. bulkhead opening (car carrier)

hull are frequent. Shown in Fig. 21 are examples of cracking failures generated at the corners of large openings provided in the transverse bulkheads for the passage of cars[15].

The countermeasure was to increase the plate thickness at the corners of the openings. Furthermore, the connected parts of the ship side partial bulkheads and the transverse beams on car decks and the area of partial bulkheads where changes in stiffness are involved had frequent cracking failures due to racking deformations[12].

(3) Failures in cargo oil/ballast tanks of large oil tankers etc.

In large oil tankers etc., built in the second half of the 1980's, frequent cracking failures at slots in webs through which longitudinals pass and cracks in flat bar stiffeners decreased. However, high tensile steels are used for girders of these ships, and it, therefore, is necessary to keep them under careful observation in the future, as well as fatigue cracks in side longitudinals.

Many of the failures in the statistics were generated in ageing first-generation VLCCs. In the example shown in Fig. 22, cracks in the connected part between longitudinal bottom centre girder and the transverse bulkhead at the boundary between No. 3 W.B.T.(C) and No. 4 C.O.T.(C) were found just before fracturing. It is considered in this way that fatigue cracking had developed due to cycled high stresses under the joint effects of longitudinal bending stress, longitudinal shearing stress and local bending stress caused by ballast. In

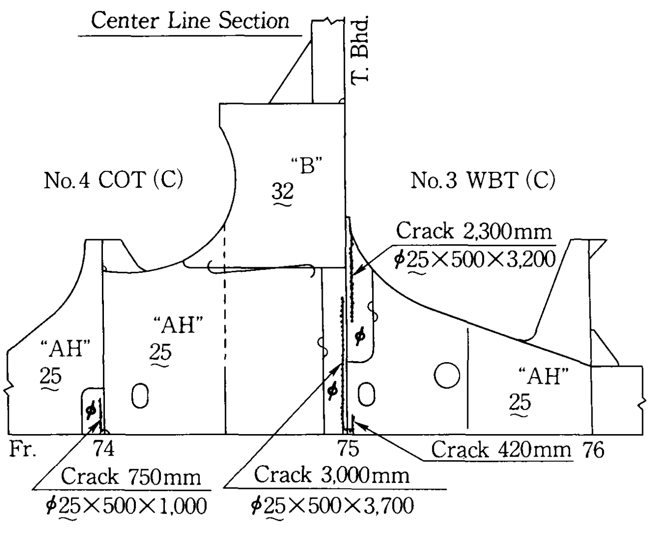


Fig. 22 Crack damage of bottom center-line girder (oil tanker)

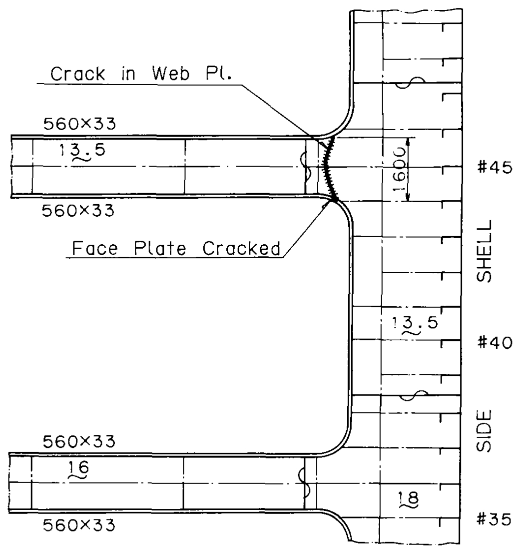


Fig. 23 Crack damage of cross tie of trans. girders (oil tanker)

the example shown in Fig. 23, the cracks in the upper cross ties on the shell side were found in four transverse rings of No. 3 C. O. T. (S) in a condition just before being fractured.

5. Deformation Failures

5.1 Failures due to waves

(1) Bottom forward failures

Failure statistics of the 1970's show that bottom forward failures due to slamming occurred frequently, and the annual rate of occurrence of such failures accounted for 3 to 4%. Failures within this category have been decreased by the revised rules and regulations and greater precautions taken for shiphandling. The hull failure statistics in the last decade show that the annual rate of occurrence of failures due to slamming is approximately 0.15%. Although it is considered to be feasible to forestall bottom forward failures in ships by maintaining the draught forward in ballasted voyages at recommended levels, slow steaming when navigating in foul weather and greater shiphandling precautions. This type of failure in refrigerated cargo carriers of ever-increasing ship speeds has not decreased.

(2) Side forward failures

In high-speed container carriers with large flares at the bow, failures are experienced in the sides forward caused by wave impacts. Most of such failures are concentrated in the upper space of F.P.T. and side structures located aft of it. The extents of failure range from a slight dent in the shell panel to buckling

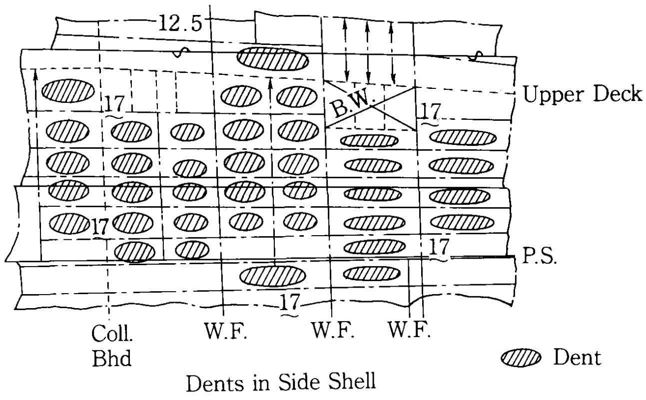


Fig. 24 Deformation damage of fore side shell (container carrier)

of web plates of strong frame , and bending of frames. Fig. 24 shows the examples of failures in container carriers[17].

From experience of failures, reinforcing plans are employed for new ships, and the rate of occurrence of such failures has decreased. On the other hand, side forward failures due to wave impacts have been reported in association with the recent advent of high-speed refrigerated cargo carriers and large high-speed car ferries.

5.2 Deformation Failures in Bulk Carriers etc.

(1) Buckling of upper deck crossdecks

Many bulk carriers or ore carriers of the early design are provided with the longitudinal beam type crossdeck, and buckling failures were generated frequently. Failures decreased later with the introduction of the transverse beam type crossdeck, but failures were sometimes generated even with this design. Typical examples of failures generated in the longitudinal beam type crossdeck are shown in Fig. 25. In the top side tank fully filled with water, the entire tank undergoes a rotative displacement and the crossdeck is compressed in the direction of its breadth.

In the case of ore carriers, the crossdeck assumes the same state due to the relationship between the load of ore and the buoyancy of the ballast tank.

(2) Buckling of web plates of transverses in bilge hopper tanks

Buckling failures are sometimes generated in the web plates of transverses in a bilge hopper tank and these are caused by shearing buckling due to the load of ballast in the cargo/ballast hold acting on an empty tank. Web plates located at the upper part of the transverse ring

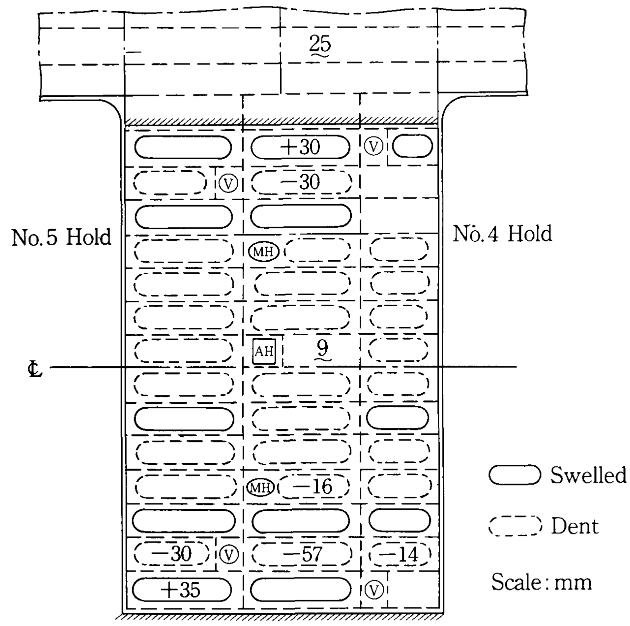


Fig. 25 Buckling damage of upper cross deck (bulk carrier)

in the same tank sometimes show failures due to compressive buckling, and care must be taken in arranging stiffeners for web panels.

(3) Buckling of web plates of transverses in topside tanks

In the ballasted conditions of cargo/ballast holds, compression and shearing forces act on the web plates of transverses in an empty topside tank. Although static loads are more or less the same as with the topside tank filled with water, the free-surface effects of water ballast caused by ship motions are greater in the former case. For this reason, buckling failures tend to occur if the arrangement of stiffeners on web panels is inadequate. Examples of typical failures are shown in Fig. 26[13]. Cases of collapsed transverses due to buckling while proceeding in foul weather associated with fractures and detachments of face plates from web plates have been reported.

(4) Buckling of balance brackets in topside tanks

Balance brackets are provided at the upper ends of hold frames in topside tanks, and they sometimes fail due to buckling. Therefore, attention should be given to the required stiffening arrangements. These members constrain rotative displacements at the upper ends of hold frames, and the upper ends on the side of face plates are subjected to compression in ordinary cargo holds, and are subject to tension in cargo/ballast holds.

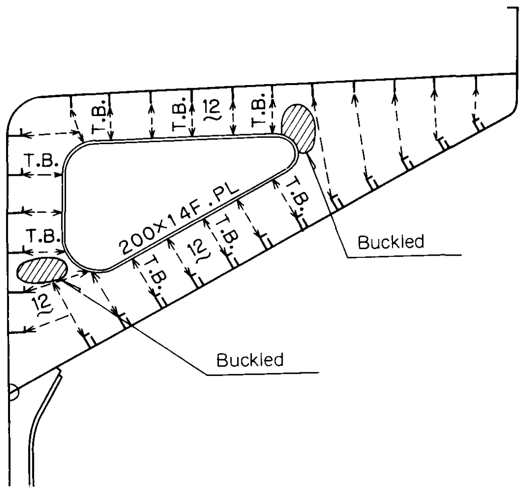


Fig. 26 Buckling damage of trans. girder in top side tank

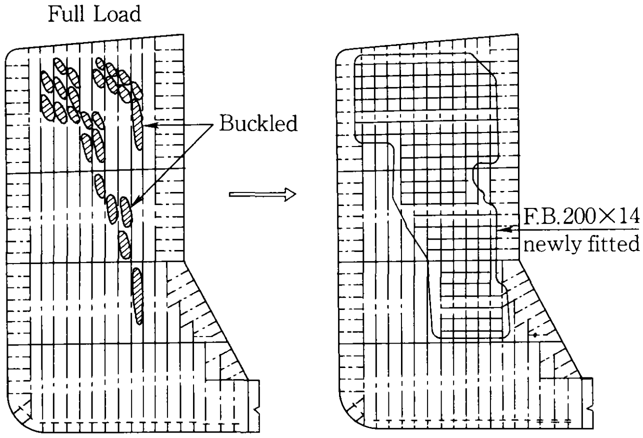


Fig. 27 Buckling damage of trans. bulkhead in wing tank (ore carrier)

5.3 Deformation Failures in Tanks of Large Oil Tankers etc.

In large oil tankers and ore carriers built in the 1970's, buckling failures occurred frequently soon after delivery due to a lack of shearing strength at the corners of transverses and web plates in the vicinity of the roots of cross ties in wing tanks. Additional problems arose involving shearing deformations of wing tanks resulting from increased ship tonnage and longer tanks, shearing buckling of the transverse bulkhead panels in wing tanks and buckling of the longitudinal bulkhead panels due to longitudinal bending of the hull.

Attempts were made to counter these problems by revising classification rules and regulations with a view to feed back information to design, whereby the rate of occurrence of failures decreased. On the other hand, large oil tankers built in the second half of the 1980's have been operated without serious buckling failures. Examples of failures of the transverse bulkhead in the wing tanks of an ore carrier caused by shearing buckling are shown in Fig. 27. This buckling reportedly expands in a ship under a full load.

There is a sign of failures related to the basic hull strength as ships get older, and we must be cautious.

5.4 Deformation Failures due to Overloading

Although rare, failures occur due to cargoes exceeding the design cargo load. In the event that cargoes with a large specific gravity are loaded in tweendeck spaces, in particular, serious failures can occur unless cargo stowage is made strictly in accordance with design conditions. We have a report stating that sagging failures of the tween deck were caused by loading cargoes of three times the design load.

6. Repairs to Failures/Countermeasures

6.1 Damage Repairs

(1) Ascertaining the extent of damage
Extent of hull damage due to marine casualties varies: from indents of shell plating between frames to a large fracture opening developing into sinking of a ship. External loads due to contact between solid objects caused by marine casualties are very large, and the concentrated load often involves unexpected damage to internal members in the form of deformation or fracture, not to mention the shell plating. It is therefore necessary to carefully inspect the internal structural members when carrying out damage repairs. Web plates of transverses in wing tanks of oil tankers and ore carriers, in particular, are vulnerable to buckling or deformation when they are corroded and worn. Overlooking damage to the internal members is a seed of serious strength problems later, and care must be taken.

(2) Repair method

a) Extent of dents requiring repairs (shell plates and deck plates)
To justify repairs of dents in shell plates and deck plates caused by marine casualties, the data given in Table 11 are normally referred to as general criteria. Even if renewal of a shell plate is not required, the damaged internal members, if any, must be repaired. If the dents are located at critical areas where large longitudinal stresses and shearing stresses are created, fitting of carlings might be required depending on circumstances.

b) Selecting of materials

Table 11 Repair standard for dents of shell and deck plates

Forms of dent	Area of dent to be repaired
Local dent (dent of plate between the stiffeners)	dent greater than 2 times of plate thickness or 25mm
Large bend (dent with the stiffeners)	dent greater than 4 times of plate thickness or 50mm
Minimum length of new plate : longer than 1.5 m Minimum breadth of new plate : breadth of base plate or wider than 800mm	

Materials used for damage repairs should, in principle, be of the class or the grade specified in the relevant plans at construction in accordance with the requirements of the classification society or other recognized organizations concerned. In an urgent case of damage repairs, timely procurement of materials meeting the grade or class requirements might be impossible. If the steel is of the same type of material, it can be used for damage repairs, providing it is subjected to charpy tests for each material group to prove that it has a high energy-absorbing value as specified in the classification rules and regulations. High tensile steels have recently been in widespread use, but substituting high tensile steel with ordinary mild steel is not generally permitted in repairs for proper hull maintenance. In an unavoidable situation, to cope with a sudden need for damage repairs, substitute use of high tensile steel by mild steel is accepted under the following conditions, namely:
If the stress levels of the material under the loading conditions specified in the rules are within the permissible range for mild steel, repairs using mild steel of structural hull members with increased scantlings are accepted as permanent repairs only in the case of substitution for 32K class high tensile steel. It must be noted, however, that in repairs to strength decks, deck longitudinals, sheer strakes and side longitudinals on sheer strakes, the longitudinal members located within the specified distance from strength decks, bottom shell plates or ship's bottom, longitudinal members on strength decks, hatch coaming members and their horizontal stiffeners, equivalent high tensile steels should be used.

c) Shell and deck plates replacement criteria
The minimum length and the minimum width of plates when shell and deck plates are cropped and partly renewed are given in Table 11 as reference criteria. In the case of local dents, plates may be cropped and partly renewed without regard to seams and butts. In this case, a sufficient corner radius (300 *mm* or over) should be provided with particular attention paid to the welding sequence.

d) Welding sequence for replacement plates
Plate replacement work is carried out by spigot welding, and care must be taken for the welding sequence[15] When a plate covering two different compartments is cropped and renewed, welders possibly carry out welding individually without due regard paid to the overall welding sequence. Welding under constraining conditions due to an inadequate welding sequence can lead to cracking generated in the course of repairs.

(3) Temporary repairs
In the case of marine casualties occurring accidentally, immediate repairs to damaged members are often impractical. As a result, permanent repairs are carried out later after temporary repairs or temporary reinforcement, or after an appropriate time required for ship operations without making any repairs. The procedures for temporary repairs and temporary reinforcements are determined from the locational relationship between the damaged area and the load line, importance in strength consideration, service of damaged compartment, trade area, type of cargo and the time allowance before permanent repairs are made, etc.

a) Fracture openings in shell plates
The fracture openings in the shell plating should be covered and watertight. If the location is above the water line, doublers are applied externally, but such a repair method is limited to small fractures between frames. In the case of larger fracture openings, temporary repairs must be arranged taking the stiffness of the doubling plate into account. If doublers are applied, permanent repairs can, in many cases, be postponed until drydocking. In the event of fracture openings in the shell plating below the water line, flooding is normally checked by applying a cement box. Reinforcements should be made as necessary. In such a case, a voyage may be

allowed to the nearest port for repairs or discharge, but permanent repairs at the earliest opportunity are required.

b) Dents in shell plates without fracture openings
In the case of minor dents in shell plates alone or associated with slight deformations of internal structural members, permanent repairs to such minor damage may be postponed until next drydocking, but depending on circumstances the fitting of stiffeners may be called for considering the structural importance of internal members.

6.2 Measures for Ordinary Failures of Structural Hull Members

6.2.1 Measures for cracking failures

(1) Measures for cracking failures of side longitudinals in second generation VLCCs
Frequent cracking failures in side longitudinals using high tensile steel were reported as mentioned. It has been concluded that such frequent cracking failures were ascribable to insufficient design consideration to mitigate stress concentrations where longitudinals penetrate transverse bulkhead and crossings between side longitudinals and side transverses, and consequent fatigue cracking. The Society has drawn up and implemented an interim policy to prevent cracking failures of this nature.

(2) Measures for typical cracking failures
Structural hull members suffer from diverse failures due to a variety of causes as already mentioned. In the case of contact damage to a ship with a wharf structure, the cause is explicit, and the requirements for damage repairs are simply to restore the original state of the hull. In ordinary failures, however, the same failures recur unless adequate measures for the cause(s) are taken. Although the causes of failures and specific procedures for structural improvement differ from ship to ship, explanatory notes are given here on the common procedures for repairs to redress failures and countermeasures.

a) Cracking failures in girders
Fig. 28 shows typical cracking failures occurring in girders, which are major supporting members of the hull, and countermeasures are proposed.
① shows a cracking failure at slots in the web plates of main girders, in which high bending and shearing stress levels, stress concentrations due to the slot geometry and corner radius at corners are relevant. Recurrence of cracking failures can be prevented by cropping and renewing web plates and fitting collar plates. In deep bottom girders in oil tankers, the off-the-plane deformation of web plates can be relevant. In this case, recurrence is prevented by installing additional tripping brackets.
② and ③show cracking failures at the roots of flat bars on web plates of girders. In bottom transverses of oil tankers and ore carriers, high stresses are created in this area due to off-the-plane deformation of web plates, and bending stresses are also created in flat bars. To counter the failures, it is effective to fit small brackets to the side on which cracks are generated. In the case of deep girders, follow the procedure shown in ①.
④ shows a cracking failure at the cross joints between face plates of girders, and

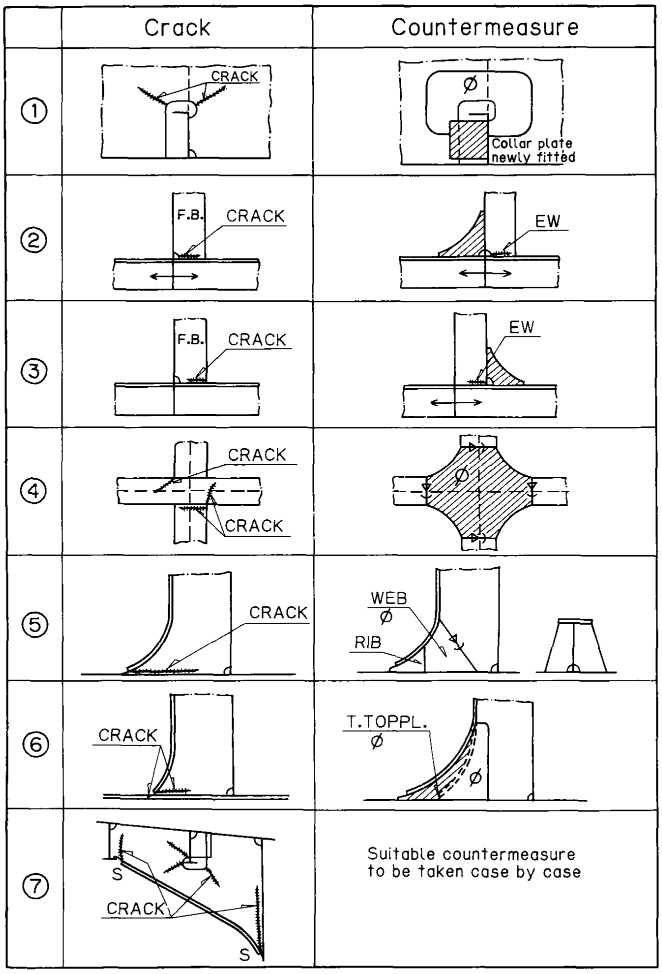


Fig. 28 Typical crack damage of girders and the countermeasure

frequently found in aft tanks. Cracking failures of this type are mainly caused by vibrations in geometrical stress concentration areas. Replacement with rounded gusset plates or fitting small ribs are considered to be effective. To counter the problem of vibrations, anti-resonance measures by increasing stiffness might be required.

⑤ shows cracking failures in web plates at the ends of girders, which are frequently found at the roots of girders or web frames on the transverse bulkhead in cargo/ballast holds of chip carriers and bulk carriers, the risers of bottom transverses in the centre tank of oil tankers, and connecting points with longitudinal bulkheads. Countermeasures are taken by cropping and renewing web plates, but fitting ribs is effective for preventing off-the-plane deformation of the girder ends in deep girders.

⑥ is the same as ⑤, in which frequent cracking failures were found in the counterparts (e.g., the inner bottom plating for vertical girders) due to the stiff geometry at ends. It is effective, in this case, if the end geometry is changed to a softer one by gradually extending the end portions.

⑦ shows cracking failures that were frequently found at the ends of side longitudinals and fwd end corner brackets in No. 1 cargo hold of bulk carriers. These members are designed to ease the transition of stiffness from the panting arrangement of F.P.T., but are liable to suffer from extensive off-the-plane deformation due to wave impacts at their sides. Causes vary, and a package of complex countermeasures such as improving bracket geometry and softening the ends of face plates at edges, and additional installation of web stiffeners etc. is necessary.

b) Cracking failures in plates

The typical cracking failures of the plate members forming hull structure are shown in Fig. 29

① shows the cracking failures running along stiffeners or frames, and if those caused by vibrations are excluded, many are caused by worn plate members. In dealing with cracking failures due to wastage, extensive plate renewal is necessary, and when caused by vibrations, it is necessary to reinforce the panel by fitting carlings.

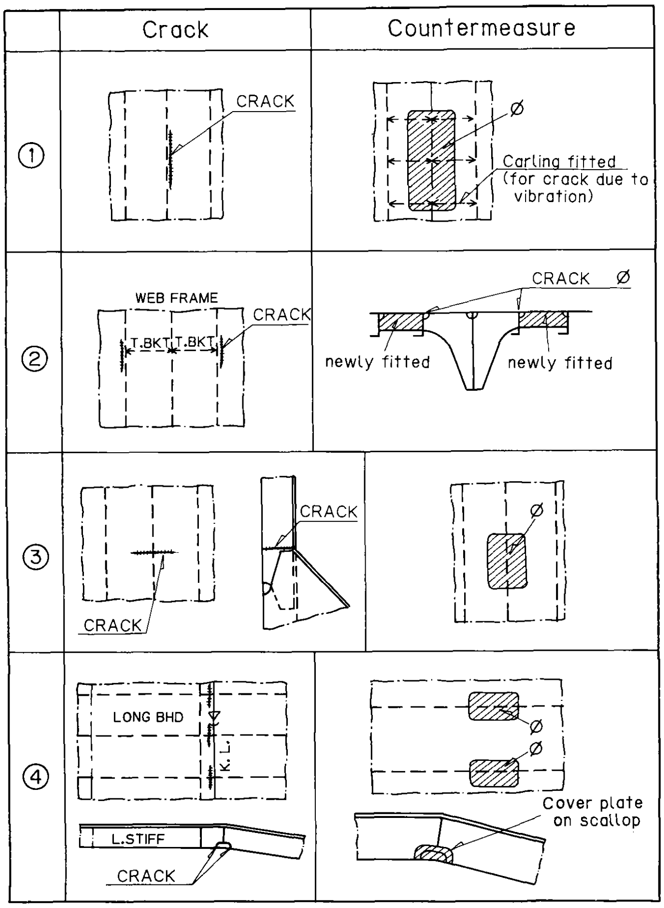


Fig. 29 Typical crack damage of plates and the countermeasure

② shows those running along ribs, but caused by the structures of the internal members, and in one case cracking failures were generated in the shell plating at the fitted positions of tripping brackets of the web frames of cargo holds in a chip carrier. Because ship side deformation is constrained at the bracket positions, fitting of carlings is the suggested countermeasure.

③ shows an example of cracking failures created in the direction normal to the stiffener line, and generally propagated to the plate members from the internal members. Measures to counter cracking failures in the internal members must be taken. They were, in many cases, caused by wastage of stiffeners, and the plates must be renewed. Separate measures are necessary for cracking failures caused by vibrations.

④ shows cracking failures generating

when scallops are provided in the internal longitudinal members at the fwd knuckled part of the longitudinal bulkhead in oil tankers and ore carriers. It is necessary to close the scallops.

6.2.2 Measures against deformation failures

What is required in repairs to structural hull members damaged as a consequence of solid contacts in marine casualties is to restore the hull to its original state, but in repairs of deformation failures of members due to other causes, a judgement must be made according to multiple factors involved, i.e., the importance of the specific member, dynamic causes of failures, whether only repairs are required or reinforcements are necessary. It is important to identify whether deformations were caused by welding distortion at construction or were created in operations after delivery, and also identify the mode of deformation (compressive buckling, shearing buckling or bending failures due to off-the-plane deformation).

(1) Deformation failures due to off-the-plane loads

a) In the case of deformation failures caused by wave impact loads in the form of off-the-plane load (failures due to blue waves, slamming etc.), a lack of shiphandling precautions is, in many cases, the cause. Reinforcements are normally arranged recognizing the fact of occurrence of failures. Indented shell plates or deck plates may be repaired as guided by the reference criteria given in 6.1. However, if the internal structural members are deformed, cropping and renewal or fitting of stiffeners are necessary. If the damage caused by slamming extends beyond the bottom fwd reinforced area, additional reinforcements should be arranged for non-reinforced areas as well, for the sake of safety.

b) In the case of deformation failures as a consequence of being struck or contacted by falling cargo during cargo operations, the criteria given in a) above are considered to be reasonably applied.

c) If the bulkhead plating is dented due to impact loads of moving liquids in tanks, applicable criteria for repairs differ according to the importance of individual bulkheads. In the case of the transverse bulkheads in wing tanks of large oil tankers and ore carriers, reinforcements may be required for dents deeper than the plate thickness, but for others, the criteria given in a) above are considered to be reasonably applied.

(2) Deformation failures affecting the whole strength of the hull

a) Compressive buckling due to longitudinal bending of the hull
Buckling failures of the upper deck panel or the bottom shell panel are rarely seen these days, but if there is a sign of buckling in ships applying the transverse framing or beam system due to wastage, carlings should be fitted as soon as possible when the buckling deflection exceeds the plate thickness to improve the critical buckling strength. The pitch for fitting carlings should be approximately two in terms of aspect ratio. The same principle applies to buckling caused by longitudinal shearing of the hull.

b) Shearing buckling due to torsion of the hull or compressive buckling of the upper deck caused by relative deformations of wing tanks
Buckling of the crossdecks of bulk carriers and ore carriers is within this category. For buckling of this nature, it is necessary for ships applying the longitudinal beam system to fit carlings in the direction of ship's breadth as in a) above.

c) Buckling associated with the shearing deformation of the hull within the cross-sectional area
Buckling of the transverse bulkheads and swash bulkheads in wing tank of large oil tankers and ore carriers is within this category. It is necessary to fit carlings as soon as possible where buckling deflection exceeds the plate thickness.

(3) Buckling failures of girders
Compressive buckling and shearing buckling are the buckling of web plates of girders. In either case, reinforcements are to be arranged by applying carlings if buckling deflection exceeds the plate thickness. Examples of reinforcement are shown in Fig. 30.
It is effective if carlings are fitted in the direction normal to the working direction of buckling, but they may be fitted as shown in (A) if structural features so require. It generally holds that when buckling deflection is within 20 *mm* or thereabouts, reconditioning through fairing coupled with fitting of carlings is feasible, but in some cases, cropping and renewal of web plates may be called for. Tripping of face plates is seen, although it is rare. In such a case, fit ribs as shown in (B) of the figure.

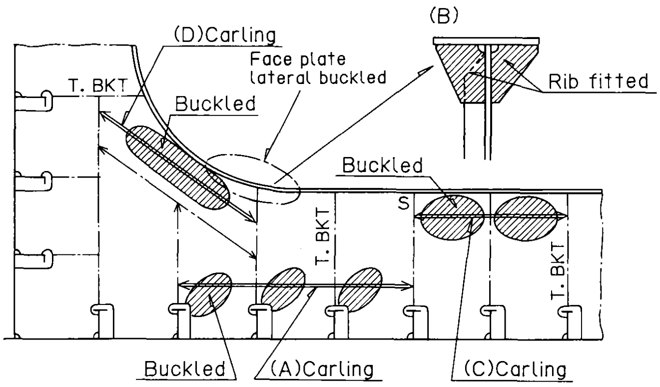


Fig. 30 An example of reinforcement for buckled girder

6.3 Measures for Failures due to Corrosion and Wastage

(1) Measures for new ships

The most drastic measure is to protect the structural hull members from corrosion and wastage. Due to recent improvements in the quality of paints, it is now possible to select suitable paints for a corrosive environment. For compartments conventionally been fitted with zinc anodes for galvanic corrosion control or those coated with oily paints of limited durability can be effectively protected against corrosion and wastage by adequately applying more durable paints in corrosive environments. Under the quick-return attitude in the economy predominant in the past, corrosion control through the proposed means has not been employed to any appreciable extent. However, if the significance of this corrosion control system is viewed from the standpoint of a ship's life, employment of an effective corrosion control system at construction is considered to be very advantageous. The Society has established new classification rules on corrosion control measures, and some of them have been applied and implemented. The scope of application will be expanded in the future.

(2) Measures for existing ships

a) Correct grasp of the current conditions of corrosion and wastage

Hull compartments of a ship are subjected to Special Surveys, and as age increases they also undergo Intermediate Surveys for internal examinations. As the size of ships has increased, close inspections of structural members at an elevation have become difficult. Surveys and inspections under these circumstances are carried out by erecting special scaffoldings or using a rubber boat in the tank, but due to a lack of understanding of the significance of internal examinations and insufficient time for preparations, implementation of surveys/inspections often encountered difficulties.

The conventional inspection method remains valid for young ships, but a correct understanding of the current state of structural members cannot be achieved unless thick layers of rust and corrosion are removed. The IACS's unified rules were introduced to revise the rules and regulations of the Society on the basis of conclusions, which recognized that occurrence of serious failures of structural hull members due to corrosion and wastage cannot be forestalled if the conventional inspection procedures and the system of preparations remain unchanged.

b) Application of criteria for wastage of structural hull members

The limits for wastage of structural hull members are actually judged by the attending Surveyors, also considering the results of plate thickness gaugings and visual progress of wastage in peripheral members etc. As a rule of thumb, rough guidance for ship owners and ship operators is shown in numerical references as "Guidance to class maintenance for owners/operators (for hull)[18]" but these numerical criteria are reasonable produced by accumulation of extensive experience in the past. It is indispensable in hull maintenance to properly observe the criteria.

Concluding Remarks

Marine casualty statistics and the results of investigations on ordinary hull failures including damage and failure examples have been quoted above. Detailed explanatory notes have also been given on typical cases of hull failures, repairs and countermeasures. In the wake of the increasing frequency of marine casualties involving large bulk carriers and oil tankers worldwide, the reduced reliability of surveys carried out by the classification societies has been pointed out by hull underwriters. Furthermore, structural defects in ships and equipment have increasingly been pointed out as a consequence of Port State Control. These are problems common to all classification societies. In response, an assessment is being done at IACS for the introduction of unified classification rules.

Once a large marine casualty takes place, not only are human lives and property lost, but also serious marine pollution results. The global demand for safe ships is considered to grow still further. The Society has been actively implementing various projects. Good hull maintenance, particularly the hull maintenance through thoughtful corrosion control techniques is necessary. In this context, understanding and cooperation of ship owners and ship maintenance companies are indispensable.

References

1) Marine Accidents Inquiry Board: Present State of Marine Accidents Inquiries, 1991
2) Maritime Safety Agency: Present State of Maritime Safety Activities, 1992
3) Lloyd's List
4) Ichiro Ishikawa, Serious Hull Damage, In-house Reference Material
5) Survey Department of NK: Hull Damage Statistics in 1992, Transactions of Nippon Kaiji Kyokai, No. 221, 1992
6) Survey Department of NK: Hull Damage Statistics in 1991, Transactions of Nippon Kaiji Kyokai, No. 217, 1991
7) Mitsuo Abe, Damage to Ships classed by NK and Countermeasures, Transactions of Nippon Kaiji Kyokai, No. 175, 1981
8) Masahiro Ohyagi, What should We Learn from Past Damage? Transactions of Nippon Kaiji Kyokai, No. 202, 1988
9) Survey Department of NK: An Investigation of Large, Aged Bulk Carriers, Transactions of Nippon Kaiji Kyokai, No. 219, 1992
10) Ichiro Ishikawa, Hull Corrosion in High-temperature Environment, Transactions of Nippon Kaiji Kyokai, No. 202, 1988
11) High-tensile Steel Structure Study Group: Damage to Side Longitudinals of VLCCs (from the Report of the High-tensile Steel Structure Study Group), Transactions of Nippon Kaiji Kyokai, No. 218, 1992
12) Classification Department of NK: Damage to Pure Car Carriers and Countermeasures (Part 2), Transactions of Nippon Kaiji Kyokai, No. 162, 1977
13) Hitoshi Ikeda et al., Damage to Bulk Carriers, Transactions of Nippon Kaiji Kyokai, No. 191, 1985
14) Kenji Yasuda et al., Cracking Damage to Upper Deck and Shell Plating, Transactions of Nippon Kaiji Kyokai, No. 206, 1989
15) Fumihiko Imai, Typical Cases of Hull Damage and Countermeasures, Transactions of Nippon Kaiji Kyokai, No. 210, 1990
16) Classification Department of NK: Damage to Chip Carriers, Transactions of Nippon Kaiji Kyokai, No. 166, 1979
17) Kenji Murai, Damage to Bow Shell Plating of Container Carriers, Transactions of Nippon Kaiji Kyokai, No. 150, 1975
18) Nippon Kaiji Kyokai: Guidance to Class Maintenance for Owners/Operators (for Hull), 1993