Tanker Structure and Hull Failure Strength

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Contents;

1-1. Large-scale oil spill accident by tankers

year	ship name	flag state	volume (10^3 kL)	causes
1967	"Torrey Canyon"	Liberia	119	grounding
1972	"Sea Star"	Korea	120	collision & fire
1976	"Urquiola"	Spain	100	grounding
1977	**"Hawaiian Patriot"**	**Liberia**	**95**	**foundered at 12yrs**
1978	"Amoco Cadiz"	Liberia	223	grounding
1979	"Atlantic Empress"	Greece	287	collision & fire
1979	"Independenta"	Rumania	95	collision & fire
1983	"Castillo de Bellver"	Spain	252	fire
1988	**"Odyssey"**	**Greece**	**132**	**foundered at 17yrs**
1989	"Exxon Valdez"	USA.	37	grounding
1991	"ABT Summer"	Liberia	260	Fire
1993	"Braer"	Liberia	85	grounding
1996	"Sea Empress"	Liberia	72	grounding
1997	**"Nakhodka"**	**Russia**	**6.2**	**foundered at 26yrs**
1999	**"Erika"**	**Malta**	**10 + α**	**foundered at 25yrs**
2001	"Baltic Carrier"	Marshall Is.	2.5	collision & fire
2002	**"Prestige"**	**Bahama**	**(4)??**	**foundered at 26yrs**

1-2. IMO rule movement on tanker structure
History in VLCC structural changes (1)

1st generation VLCC;
Mass-transportation

- About 700 VLCCs built during 1966-1979.
  Idemitsu Maru (209kDWT) in 1966.
- Gigantic tankers & Mammoth docks.

↓

2nd generation VLCC;
Environment friendly and energy-saving era

- *Torrey canyon* casualty accompanied MARPOL 73/78.
- SBT, limited tank volume, protective location, IGS/COW
- Automatized machines and tools, maintenance-free, turbine to diesel conversion, long-stroke diesel, increase of HT-steels use.

↓

3rd generation VLCC;
Life-cycle cost, economical & safety oriented

- *Exxon Valdez* brought about Double-hull tanker.
- Structural safety against oil leakage, ESP, access for inspection, re-cycling & scrapping.

1-2. IMO rule movement on tanker structure
History in VLCC structural changes (2)

Tanker structural regulation by IMO

1954: OILPOL adopted　(海洋汚濁防止条約)

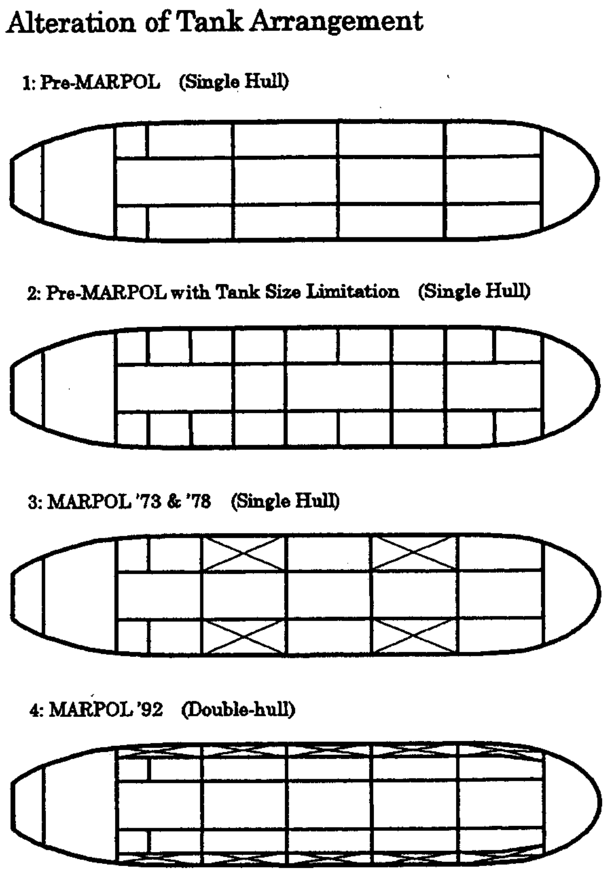
1969: Load on top (LOT) system

1971: Tank size limitation

1973: Segregated ballast tank (SBT)
　　Damage stability

1978: MARPOL 73/78 13E. SBT protective location (PL)
　　IGS / COW requirement

1992: MARPOL 73/78 13F. Double-hull tanker for new ship
　　ditto　13G.　Existing ship phase out schedule

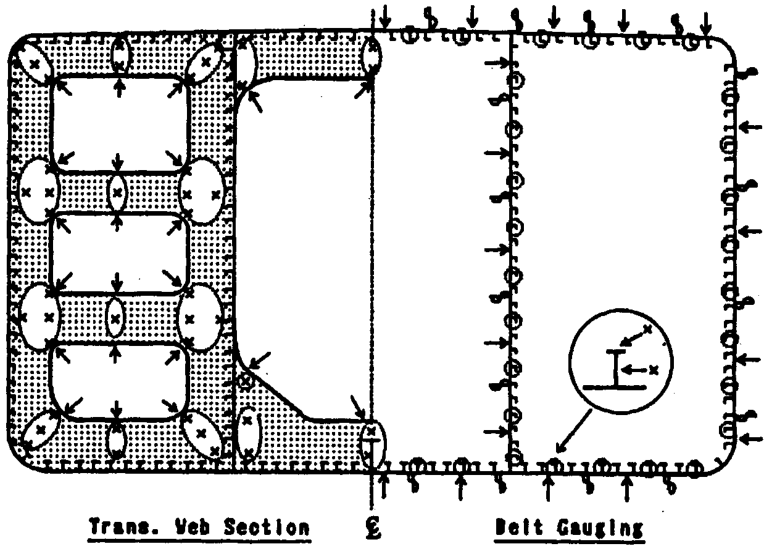


1-2. IMO rule movement on tanker structure
Enhanced Survey Program on tanker structure

<u>Guideline on "Enhanced Survey Program"</u>

IMO resolution A.744 (18)
SOLAS chapter XI, regulation 2

1) Survey program worked out in advance
2) Dry-dock survey
3) Overall survey
4) Close-up survey
5) Thickness measurement
incl. belt gauging →→→
6) Corrosion preventive system (coating)
7) survey report file on board



1-2. IMO rule movement on tanker structure
Phase out of single hull tankers

MEPC46 revision to MARPOL regulation 13G.

Category of tanker (crude and dirty oil)	New phase out schedule
Category-1 Non-double hull (Pre-PL/SBT) oil tankers Built before 1982 20,000 DWT and above	Withdrawn between 2003 - 2007 Beyond 2005, CAS requirement
Category-2 Non-double hull (PL/SBT) oil tankers Built during 1982 ~ 1996 20,000 DWT and above	Withdrawn between 2003 - 2015 by arriving at 25 years of age Final use 2015 Beyond 2010, CAS requirement
Category-3 Non-double hull oil tankers 5,000〜20,000 DWT	Withdrawn between 2003 - 2015 Final use 2015

(Note) CAS; Condition Assessment Scheme

2. Aging effect on ship hull

2-1. Typical strength degradation by aging

(1) Corrosion
  a. Corrosion in frame member
  b. Corrosion in plating
  c. Local corrosion

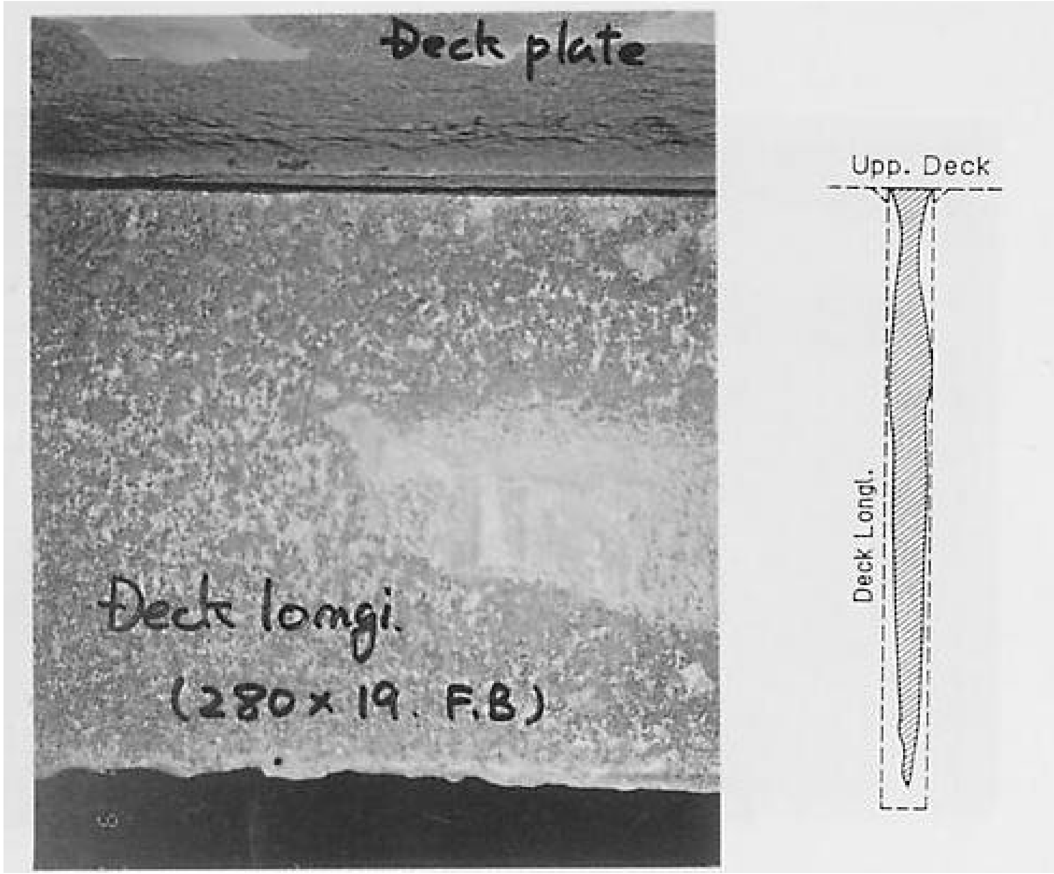
(2) Fatigue crack

(3) Degradation of paint coating

2-1. Typical strength degradation by aging(1)

(1) Corrosion
- **a. Frame corrosion**
- **b. Plating corrosion**
- **c. Local corrosion**

(2) Fatigue crack
(3) Coating degradation

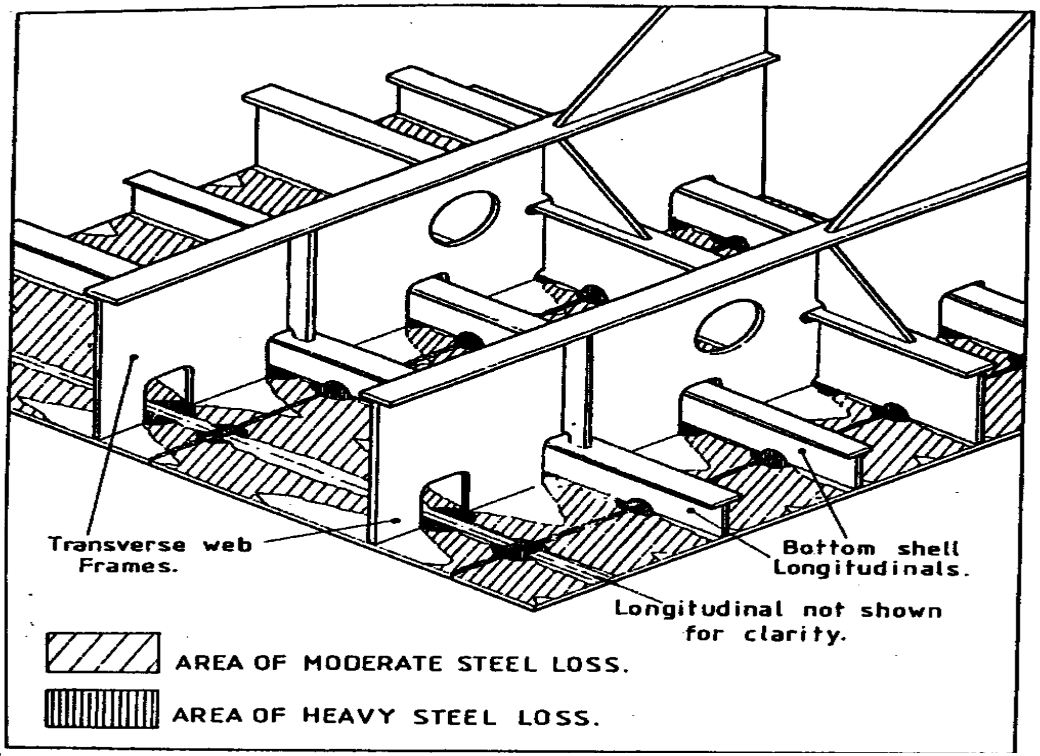


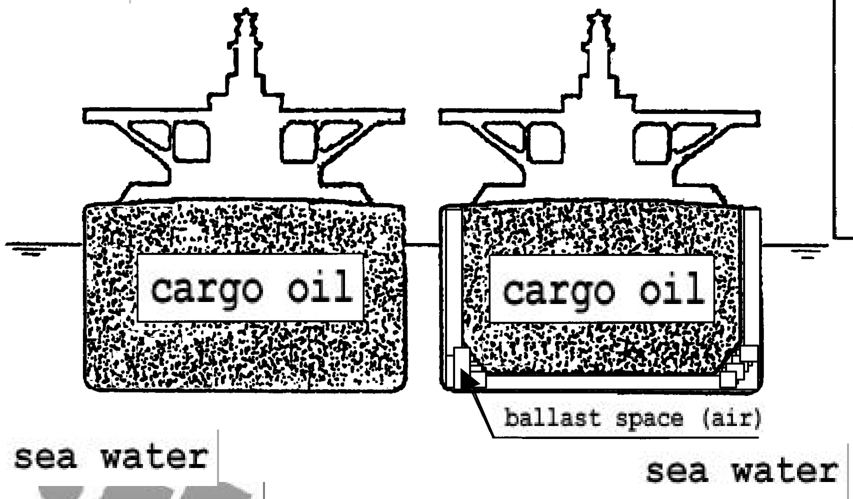
Corrosion wastage in deck longitudinal of WBT, with poor fillet weld and sharp edge at depth end. (aged 15 years)

2-1. Typical strength degradation by aging(2)

(1) Corrosion
- **a. Frame corrosion**
- **<u>b. Plating corrosion</u>**
- **c. Local corrosion**

(2) Fatigue crack
(3) Coating degradation





Corrosion in bottom plating ;
1) **horizontal / vertical plating**
2) **splashed zone or not**
3) **effect of fluid velocity**
4) **effect of high temperature, etc**

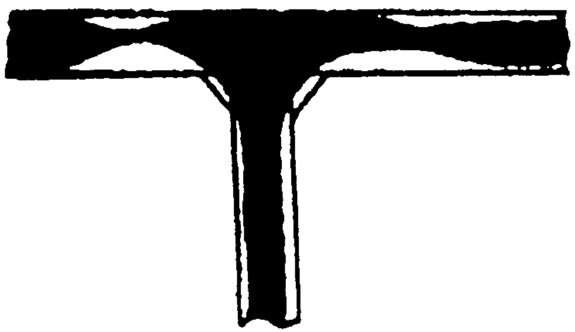
2-1. Typical strength degradation by aging(3)

(1) Corrosion
- **a. Frame corrosion**
- **b. Plating corrosion**
- **c. Local corrosion**

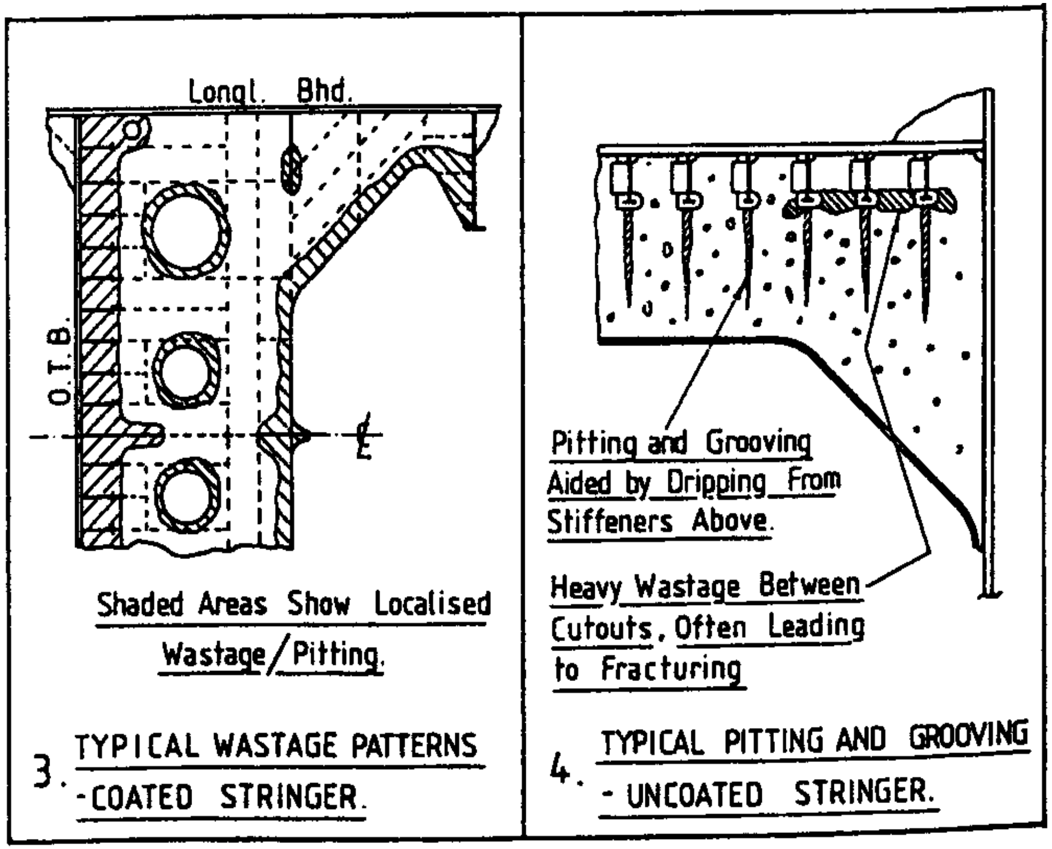
(2) Fatigue crack
(3) Coating degradation

＊ pitting corrosion
＊ raised by high stresses
＊ grooving corrosion , etc.

Typical local corrosion on stringer: below



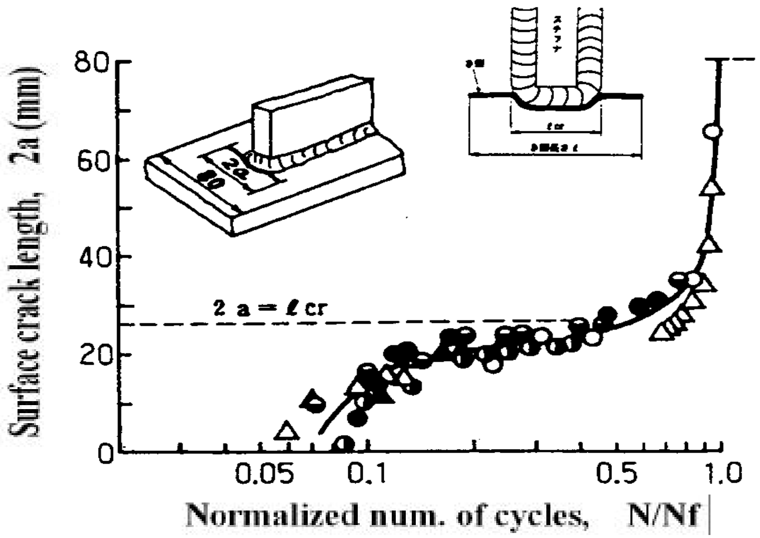
grooving corrosion along fillet weld of deck longl.



2-1. Typical strength degradation by aging(4)

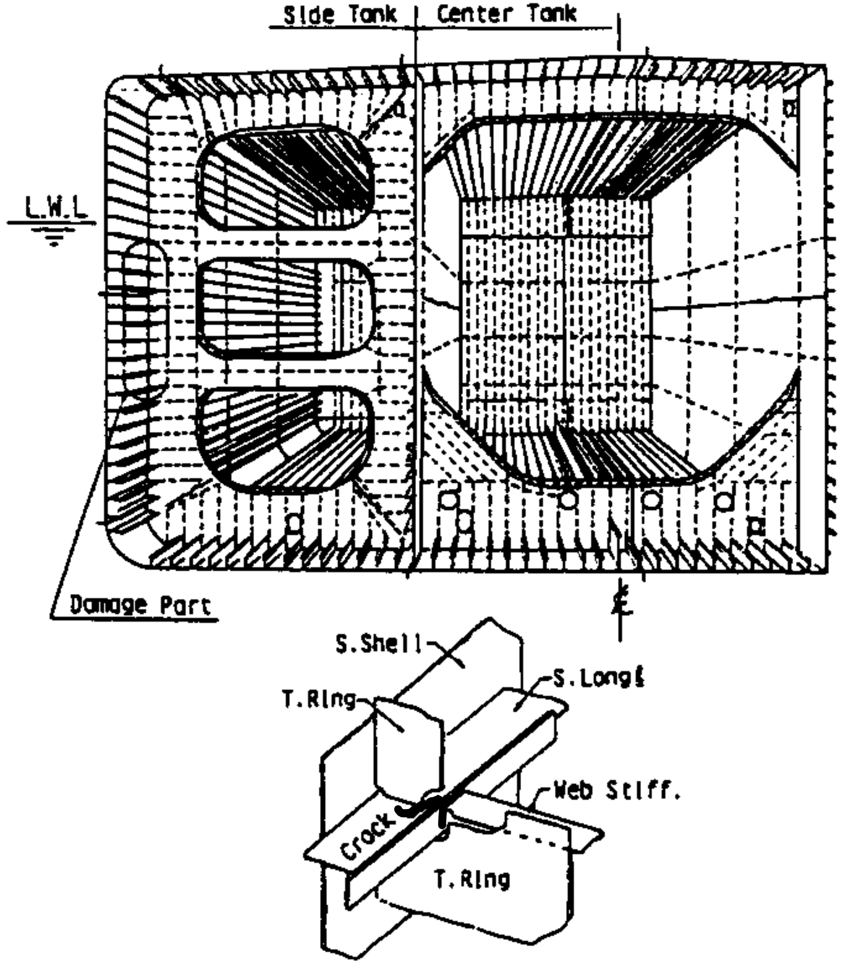
(1) Corrosion
- **a. Frame corrosion**
- **b. Plating corrosion**
- **c. Local corrosion**

(2) Fatigue crack
(3) Coating degradation



Fatigue crack growth at fillet welded corner.

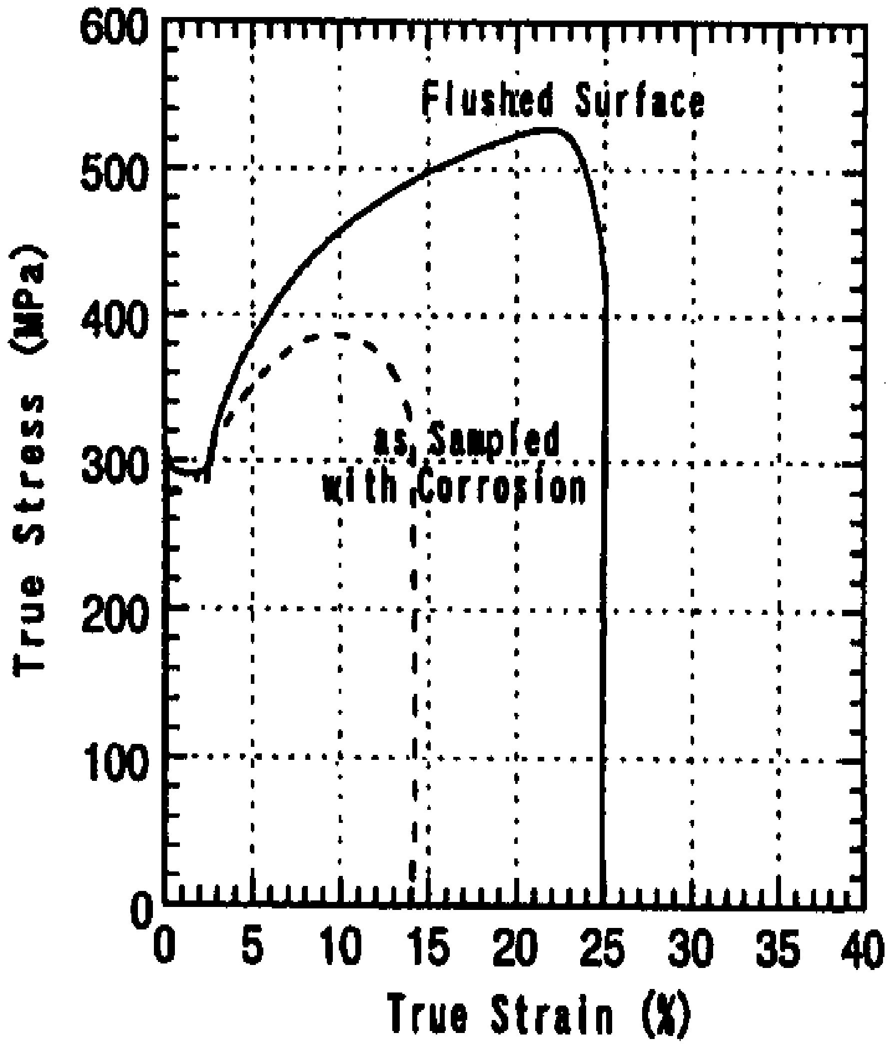
Fatigue crack at side longitudinal, in 2nd generation VLCC damages.



2-1. Typical strength degradation by aging(5)

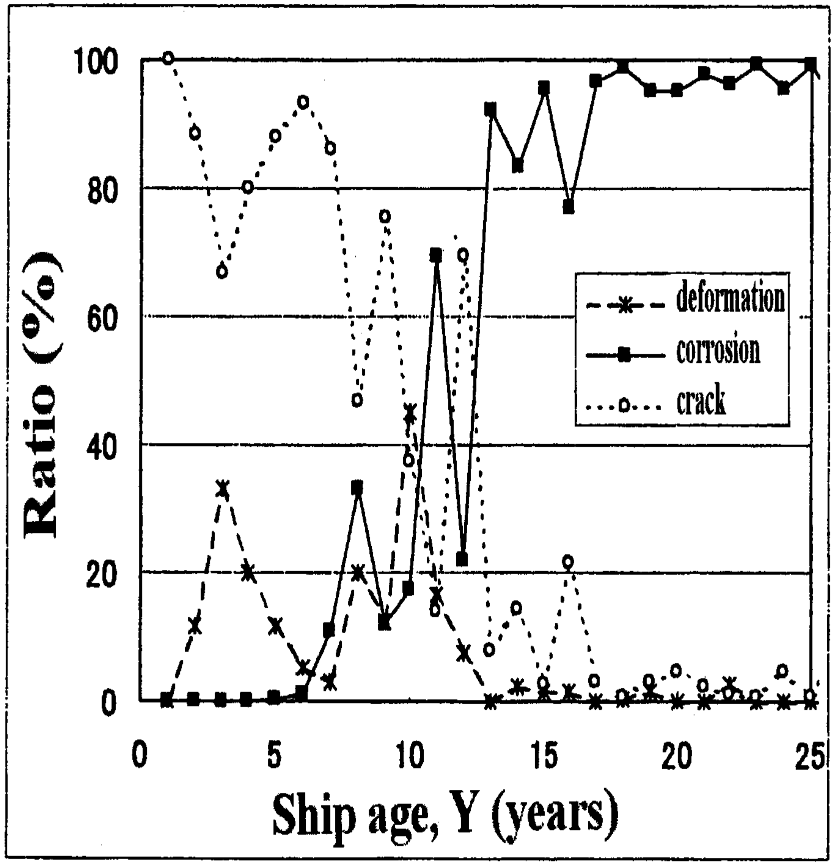
Stress vs. strain curve of aging plate;

- **a) Cut-out and flushed specimen shows no less ability to virgin plate.**
- **b) Apparent drop in S-S curve for aging plate is by surface roughness due to corrosion.**

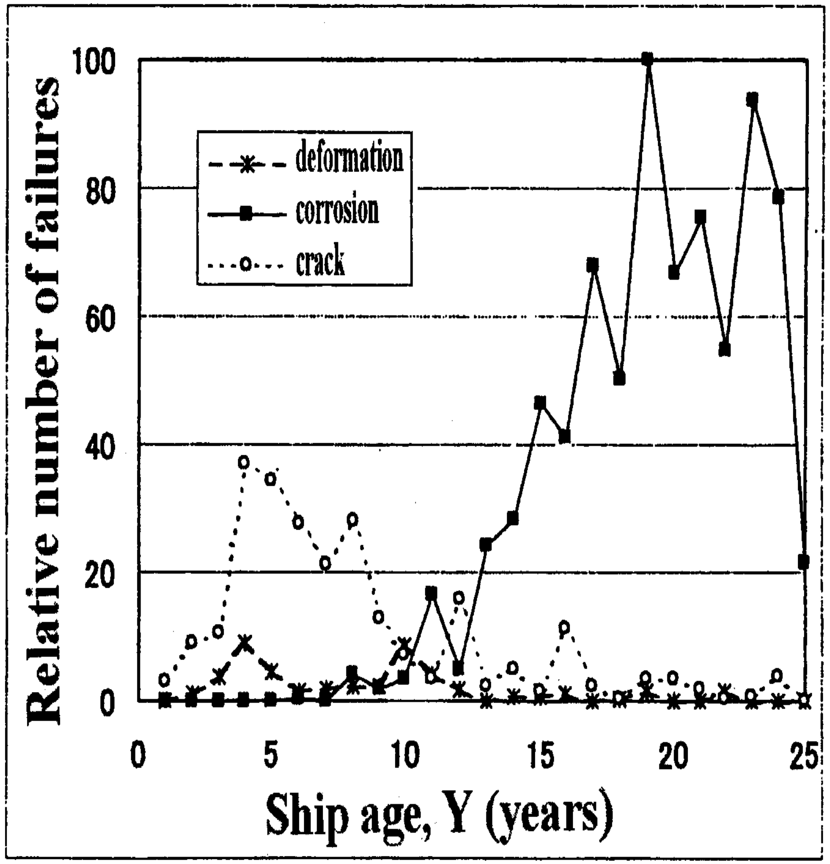


2-1. Typical strength degradation by aging

Degradation tendency with increase of ship age



(a) Trend in degradation mode



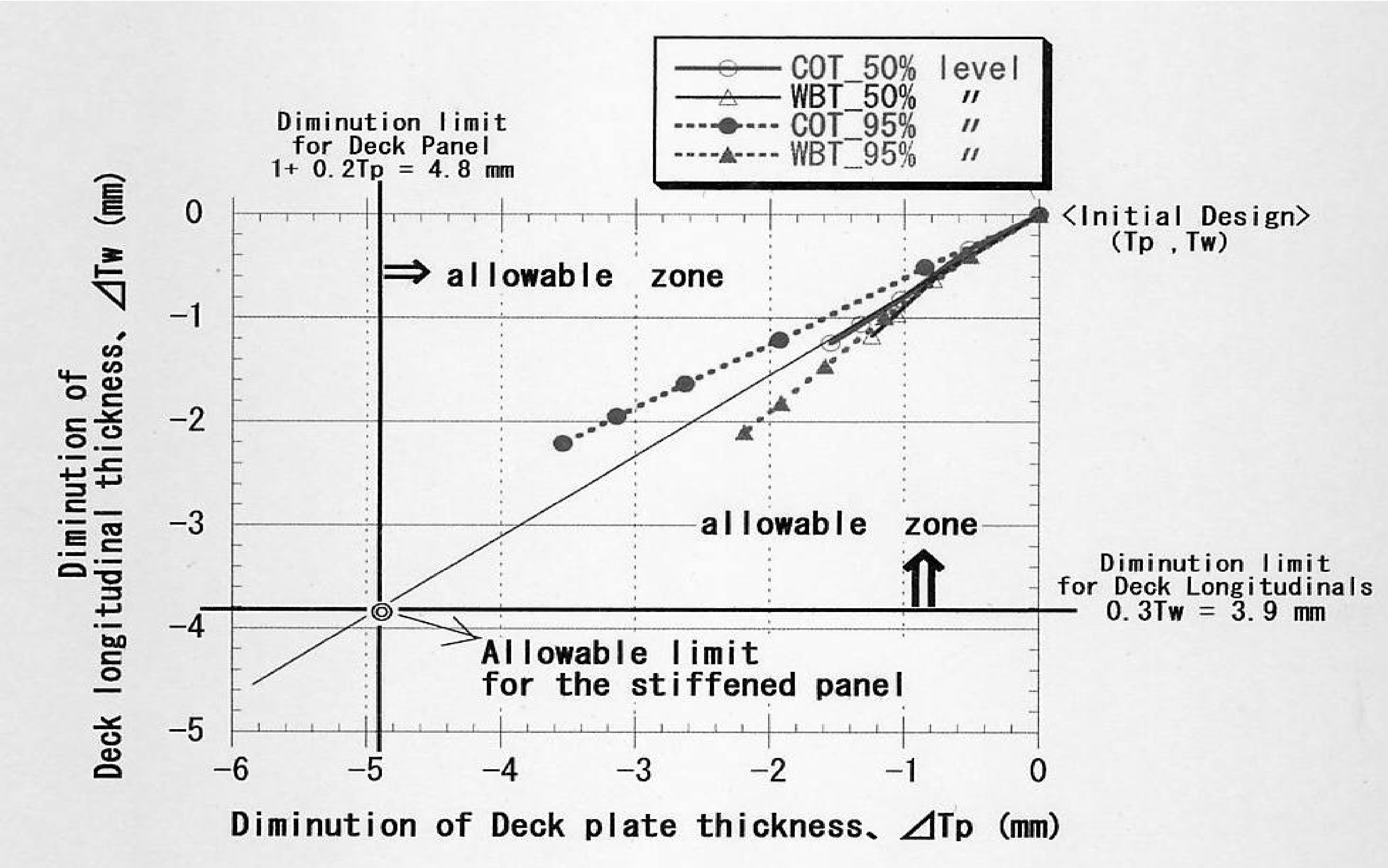
(b) Trend in number of failures

2. Aging effect of ship hull
2-2. Hull plate corrosion data properties

Corrosion rate analysis by using class NK database

Structural Member			50% level				95% level			
		Tk.	5yrs.	10yrs.	15yrs.	20yrs.	5yrs.	10yrs.	15yrs.	20yrs.
Upper Deck Plate		COT	0.00	0.52	1.03	1.33	0.82	1.93	2.63	3.14
〃		WBT	0.00	0.00	0.79	1.06	0.51	1.15	1.59	1.92
Deck Longitudinals		COT	0.00	0.34	0.82	1.06	0.51	1.21	1.64	1.95
〃		WBT	0.00	0.00	0.63	0.96	0.00	0.99	1.46	1.82
Bottom Plate		COT	0.00	0.74	1.16	1.43	1.02	2.11	2.78	3.27
〃		WBT	0.00	0.00	0.88	1.28	0.30	1.53	2.35	2.96
Bottom Longl.	Web	COT	0.00	0.00	0.68	1.00	0.27	1.04	1.50	1.85
〃	〃	WBT	0.00	0.00	0.68	1.00	0.00	1.03	1.50	1.85
〃	Flange	COT	0.00	0.00	0.77	1.01	0.59	1.24	1.64	1.94
〃	〃	WBT	0.00	0.00	0.53	0.91	0.00	0.93	1.40	1.77
Side Shell Plate		COT	0.00	0.00	0.78	1.03	0.44	1.16	1.60	1.92
〃		WBT	0.00	0.00	0.69	1.20	0.00	1.11	1.66	2.09
Side Longl.	Web	COT	0.00	0.00	0.59	0.94	0.29	1.02	1.46	1.81
〃	〃	WBT	0.00	0.00	0.44	0.87	0.00	0.97	1.41	1.76
〃	Flange	COT	0.00	0.00	0.58	0.94	0.00	0.98	1.44	1.80
〃	〃	WBT	0.00	0.00	0.48	0.89	0.00	0.92	1.39	1.75
Longitudinal Bhd.Plate		COT	0.00	0.00	0.84	1.10	0.55	1.19	1.63	1.96
〃		WBT	0.00	0.33	0.81	1.04	0.56	1.24	1.65	1.95
Longi.Bhd.Longl.	Web	COT	0.00	0.00	0.54	0.92	0.27	1.01	1.45	1.79
〃	〃	WBT	0.00	0.00	0.54	0.92	0.25	1.01	1.44	1.79
〃	Flange	COT	0.00	0.00	0.62	0.96	0.34	1.04	1.48	1.82
〃	〃	WBT	0.00	0.00	0.44	0.94	0.00	0.97	1.75	2.45

2-2. Hull plate corrosion data properties (2)
—example for deck structure—



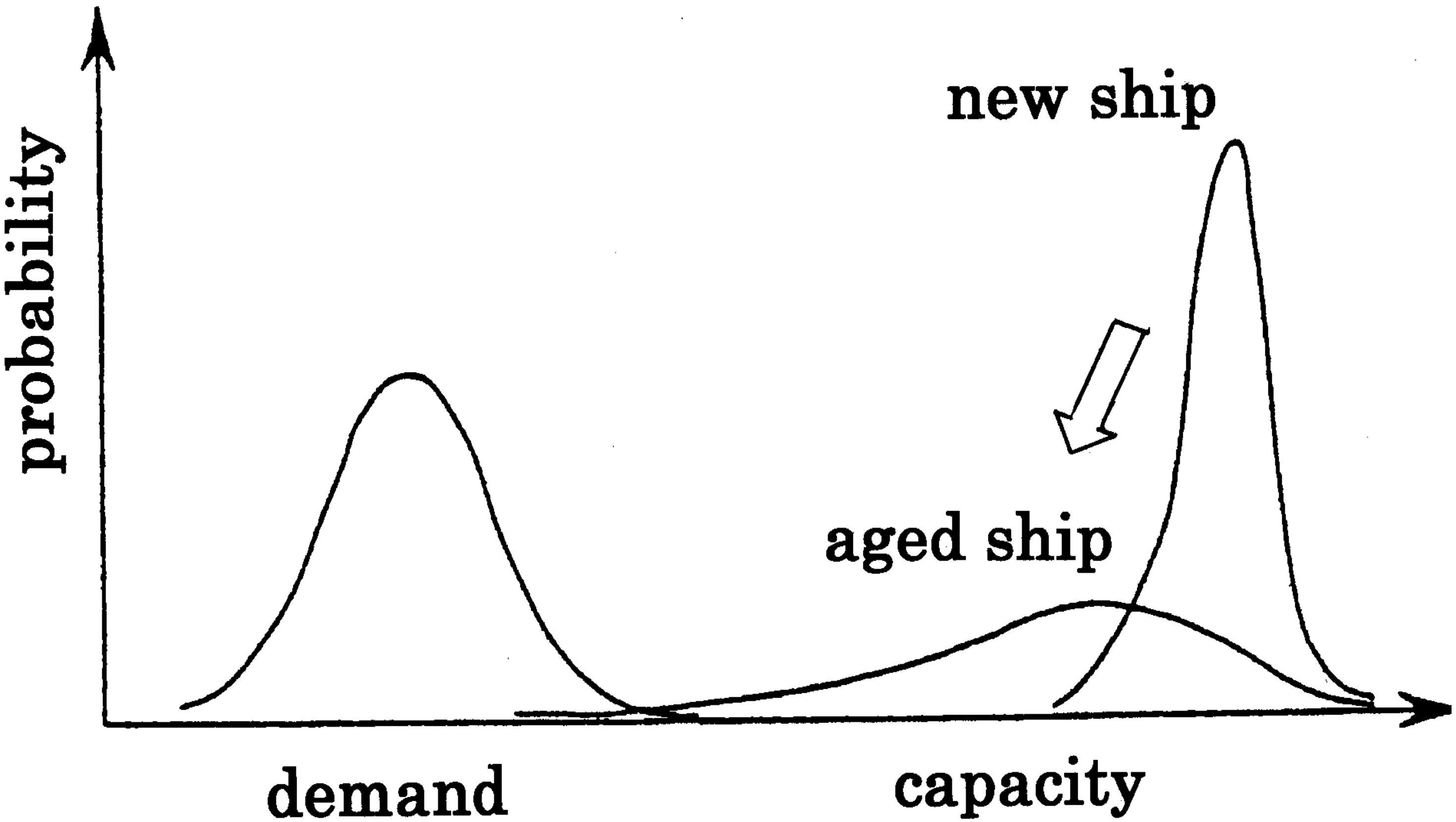
Allowable diminution Level by Class Society spec.

Allowable diminution level for uniform corrosion

Structural Member	Allowable Diminution Level
-Shell plates -Strength deck plates -Slab longls on shear strake and stringer plate of strength deck -Tight bulkheads in deep tanks -Inner bottom plates	20% of original thickness + 1 mm
-Floors and girders in double bottom -Primary members (web & face) -Web, face and bracket of hold frames -Watertight bulkhead plates	25% of original thickness
-Web, face and bracket of frames (excluding hold frames), longitudinal beams and stiffeners -Effective deck plates -Hatch cover and hatch beam	30% of original thickness

2-2. Hull plate corrosion data properties

Schematic diagram on aging ship strength



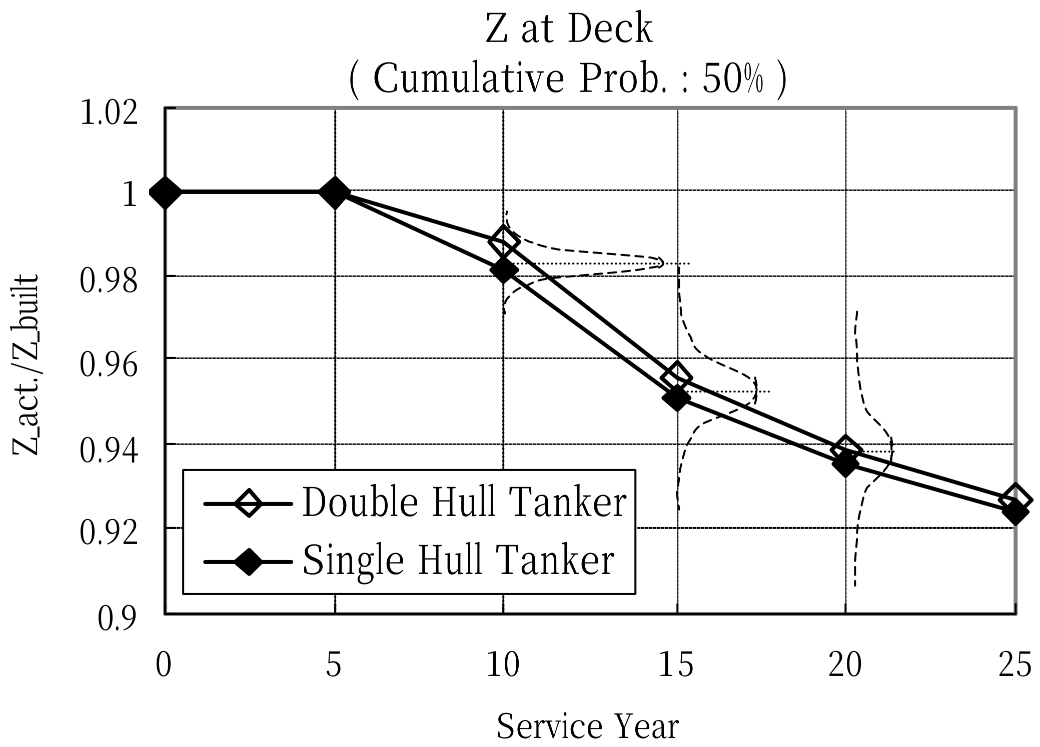
2. Aging effect of ship hull
2-3. Reduction in mid-ship section modulus

Estimated results on average tendency of the VLCC mid-ship section modulus;

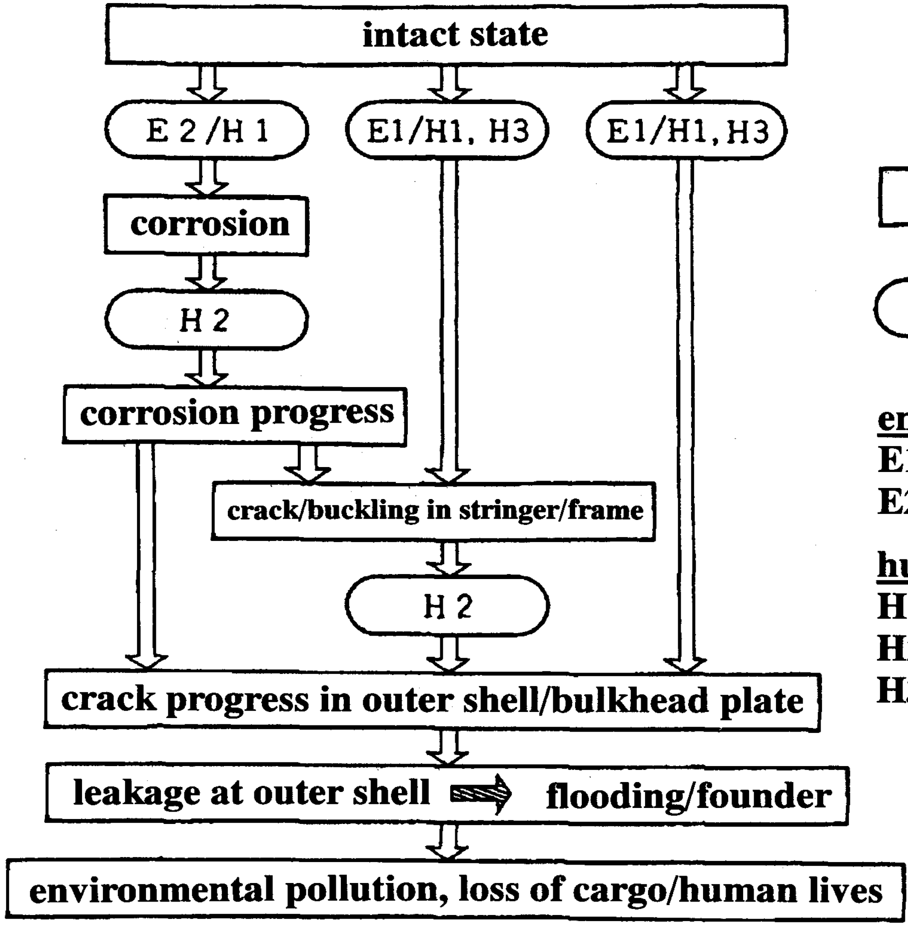
(1) IMO requirement :
within 10% loss of Z

(2) Average corrosion damage is within IMO requirement.

Note:
◆◇ analyzed
---- imaginary scatter



3. Failure strength of aging tanker hull
3-1. Basic mechanism of large-scale hull failure



failure or sequential event

factor making failure occur or propagate

environment factor
E1 : excessive load/impact load
E2 : corrosive circumstance

human factor
H1 : insufficient strength or defects
H2 : poor maintenance
H3 : miss-operation

3-1. Basic mechanism of large-scale hull failure
As to hull break-up mode

Trigger element for tanker hull break-up；

(1) Buckling/collapse at Deck structure in Sagging →◎

(2) Crack propagation at Bottom structure in Sagging

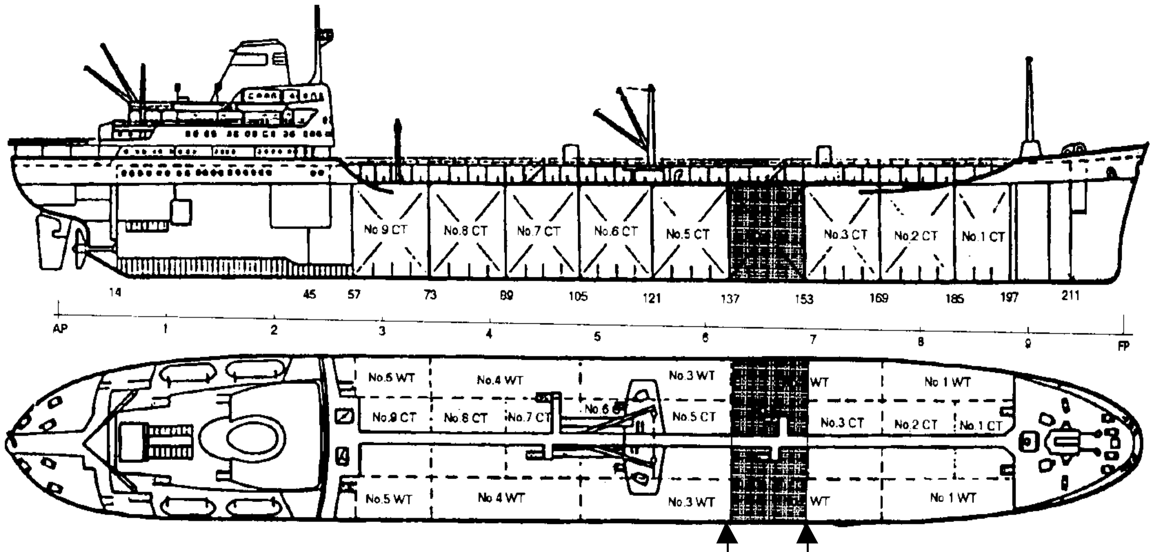
(3) Crack propagation at Deck structure in Hogging →○
(multi-site damage)

(4) Buckling/collapse at Bottom structure in Hogging

∵ i) break-up occurs in high wave；Sagging M.> Hogging M.
ii) deck back surface is the most severe corrosive space in hull circumstances, and so forth.

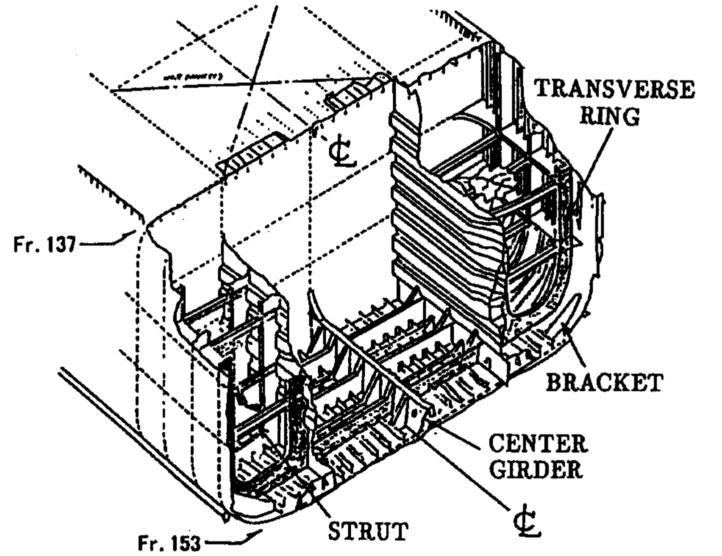
3-2. Case study
Outline of the Nakhodka casualty

Date: 1977.1.02, 02:40am
Location: Okino-shima NNE 106km
wave condition: $H_{1/3}$ 8m, T_{ave} 9 sec



General Arrangement of the MS Nakhodka

Fr.137 Fr.153
Failed and broke in two

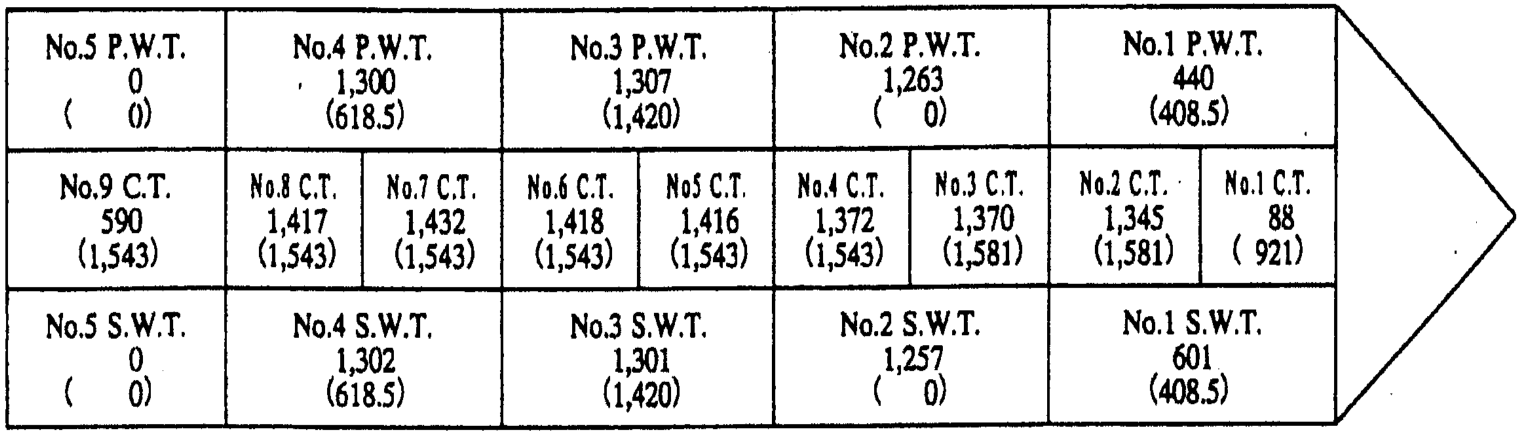


Fractured cross-section of hull girder at sea bottom

3-2. Case study

Loading pattern at the Nakhodka casualty

Loading pattern at the casualty ;
excess to a standard loading pattern



Loading Patterns

values : Load (in kl) at the casualty
() indicates a standard condition.

3-2. Case study

Corrosion wastage at the Nakhodka casualty

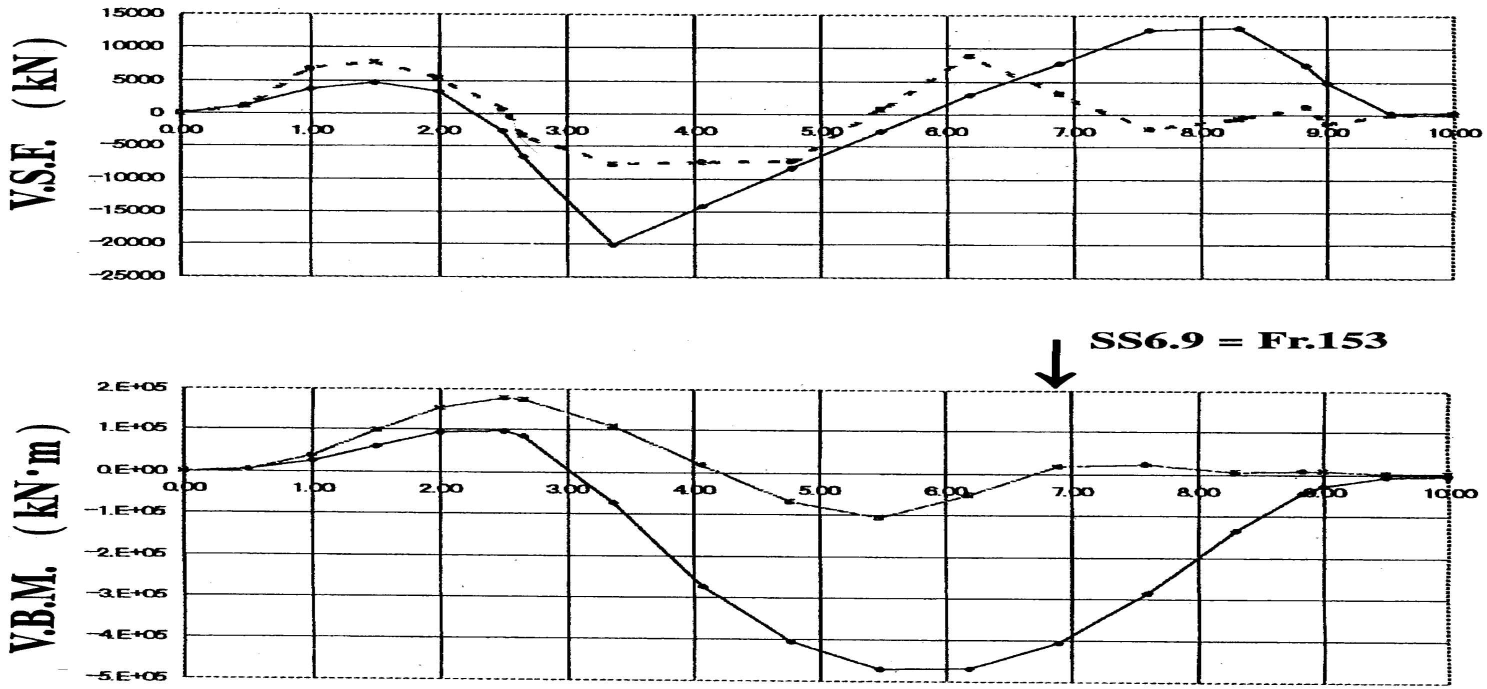
Measurement result ;
20-35% of plate thickness reduced due to corrosion

Structural member	Original thickness	Thickness reduction	Remarks
Bottom plate	20 mm	6 mm	based on the average of measured data around Fr. 157
Side shell	17 mm	6 mm	measured data are limited, and considered to br the same as bottom plating
Deck plate of center tank	20-24 mm	4 mm	based on the measured data in 1993
Deck plate of side tank	20-24 mm	7.5 mm	based on the average of measured data
Deck longitudinal	14 mm	5.5 mm	based on the average of measured data
Other members	11-14 mm	3 mm	measured data are scattering between 2 mm and 4 mm

3-2. Case study

Applied force at the Nakhodka casualty

VBM and VSF were obtained by using non-linear ship motion and response simulation software.



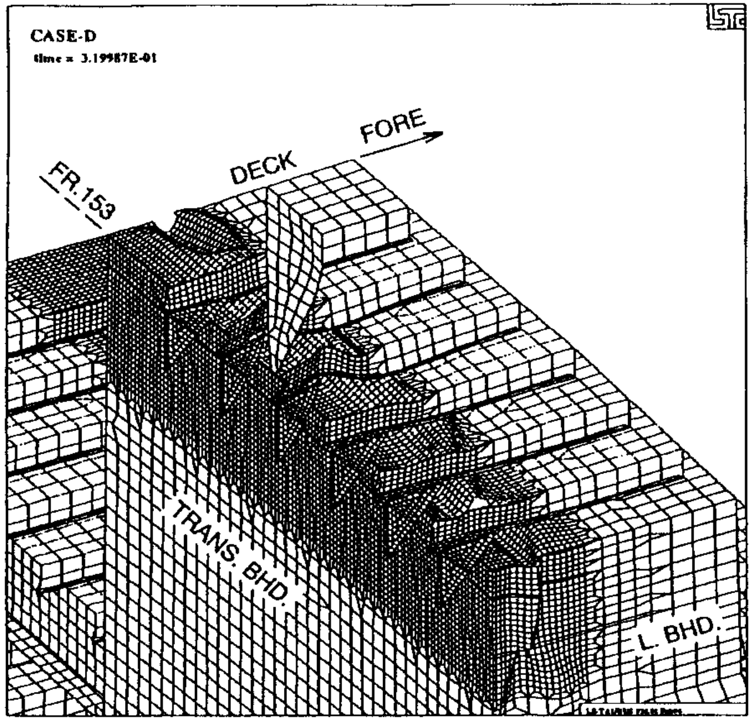
Still water shearing force and bending moment for the Nakhodka

(solid line : at the accident, dotted line : standard condition)

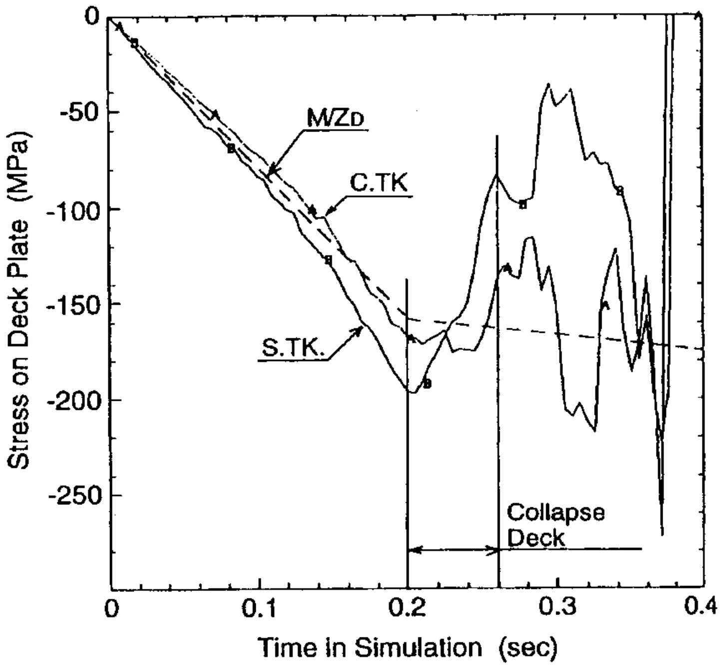
3-2. Case study

Simulation cal. on ultimate collapse of Nakhodka

Simulation result showed ;
the break-up started at the deck structure on about Fr.153.

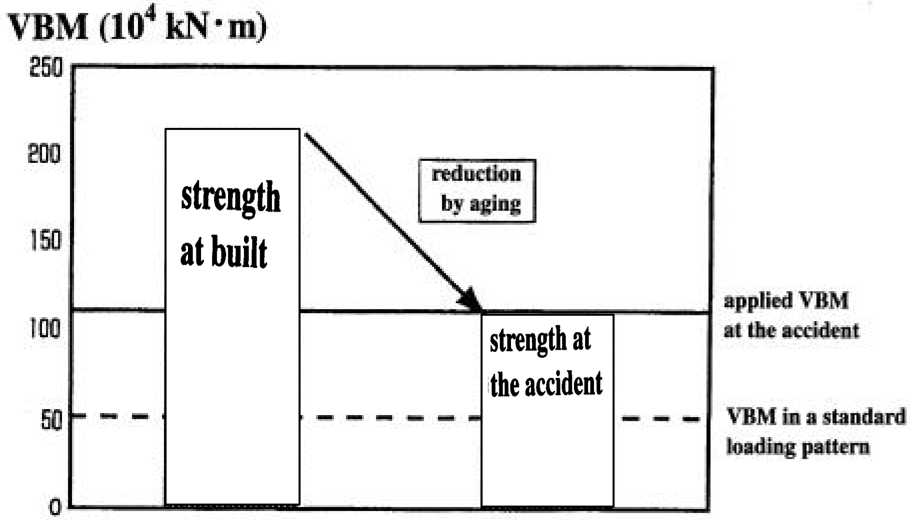


(a) collapse mode at deck



(b) stress at deck vs. time in simulation

3-2. Case study
Estimated results on load and strength



Section Modulus at the accident

Location	Section modulus at the time of accident	
	SS 6.2	SS 6.9
Deck	80,000 cm^2m	67,800 cm^2m
Bottom	67,000 cm^2m	68,500 cm^2m

Causes of the Nakhodka casualty;

(1) *Excessive corrosion* made the Nakhodka's vertical bending strength about one half to that of as built.

(2) So, the most *severe wave load* in a year at Japan sea, let her broke up.

(3) In addition to the above, the *non-standard loading pattern* at the accident had enlarged the wave load.

4. Conclusions

(1) Large-scale oil spill from tankers were not yet exterminated. And one critical factor must be hull excessive corrosion that might be overlooked, so that it should be strongly required strict implementation of the ESP and excluding sub-standard tankers.

(2) From the analysis of corrosion measurement data at the classNK inspections, not only average wastage rate but also increase of standard deviation of the rate are key factors to understand the ship ageing and the influence.

(3) As to hull breaking up, it seems that excessive corrosion and severe wave condition are two main players and a possible trigger failure might be a buckling/collapse of deck structure at the time of high wave of sagging.

In anyway more actions are necessitated, not only to prevent casualties but also to mitigate the oil outflow and the damage of the ocean, to keep our global environment clean.