Final Report
of Committee on Large Container Ship Safety

(*English version*)

In March 2015

Issued by

Committee on Large Container Ship Safety

JAPAN

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Preamble

The Bahamian flagged large container ship (8,000 TEU class) "MOL COMFORT" (herein referred to as "The Ship") experienced a fracture of midship part while transiting the Indian Ocean from Singapore to Jeddah (Saudi Arabia) on 17 June 2013. Following this, The Ship split into two halves, which were adrift before sinking. Thanks to the swift rescue efforts of ships navigating the area and Indian disaster relief authorities, no loss of life occurred in this accident. We express our gratitude to those involved in this rescue.

As The Ship's builder, operator and classification society (a third-party organization that carries out such activities as surveys on hull construction) are all located in Japan and are able to closely share information and discuss safety measures, the Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) established the Committee on Large Container Ship Safety (the Committee) composed of members from the maritime industry, experts with relevant knowledge and experience, and the related research institution staffs, and issued the interim report of the Committee in December 2013. This final report includes the results of considerations of further actions, which are shown in the interim report, and safety measures based on these results.

While this final report is intended to inform the industry of the safety measures discussed by the Committee, through the preparation of this English translation, it is also meant to provide information to The Ship's flag State, which is tasked with investigating the accident, as well as to the International Association of Classification Societies (IACS), in charge of international standards for hull construction, and the International Maritime Organization (IMO).

Summary

Results of investigation

It was inferred that the hull fracture originated from the bottom shell plates in the midship part of The Ship. About 20mm buckling deformation was detected in the bottom shell plates during safety inspections of The Sister Ships (large container ships of the same design as “The Ship”). For reproduction of the hull fracture, the Committee conducted simulation of acting loads on The Ship from the data of weather and sea condition at the time of accident. And the ship structural strength (hull girder ultimate strength) simulated by modeling midship part of The Ship was compared with the acting loads.

In the simulation for ship structural strength, lateral loads were also included in addition to vertical bending moment, taking into account actual phenomenon. This value of ship structural strength was lower than that calculated by the case without considering lateral loads. Simulation of acting loads was conducted, taking into account whipping loads (loads of vibration of ships induced by slamming), which had not been explicitly considered in the current structural requirements. The acting loads increased with growing wave height and/or ship speed. Also, the analysis was conducted in consideration of deviation of container weight (gap between declared weight and actual weight), uncertainly in actual sea and deviation of yield stress of steel.

Consequently it was found, by simulation, that The Ship had the possibility of fracture at the time of the accident. Also, it was found, by simulation, that buckling deformation detected in bottom shell plates of The Sister Ships could occur by provision of slightly lower loads than ship structural strength and that the amount of deformation could increase by repeated loads.

With regard to the safety of large container ships, the Committee considered the requirements based on the result of simulations. Consequently, it was found that the requirements should consider the effect of lateral loads in evaluation of ship structural strength (hull girder ultimate strength). It was also found that the requirements for longitudinal strength should consider the effect of whipping response against ship structural strength, based on the knowledge accumulated for the development of the requirements. Furthermore the technical backgrounds of the requirements for the vertical bending strength, including sea condition, should be considered so that they could be available as reference taking into account that acting loads for hull girder could be changed depending on wave height, ship's speed and so on.

With regard to the large container ships of ClassNK with different design from The Ship, no similar deformations of bottom shell plates were found through the safety inspections and sufficient structural margins were found comparing with The Ship as the results of the simulations. It can be considered that the similar confirmations, such as inspection of bottom shell plates, are effective for other large container

ships.

Recommendations of requirements for large container ship (8,000 TEU class or over)

It is recommended that the classification requirements for large container ship structural strength, including Class NK requirements and IACS Unified Requirements, should be amended or considered in the following way at the early stage in order to implement the safety measures internationally.

.1 The effect of the lateral loads which induce bi-axial stresses of bottom shell plates should be considered in the requirements of the hull girder ultimate strength taking into account the close relationship of the lateral loads and the hull girder ultimate strength.

.2 Effects of whipping responses should be explicitly considered in the requirements of the vertical bending strength.

.3 Representation of technical backgrounds of the requirements for vertical bending strength such as sea states etc. should be considered.

1 Information regarding the accident and buckling deformations in the bottom shell plates of The Sister Ships

1.1 Outline of container ship MOL COMFORT

The Bahamian flagged container ship “MOL COMFORT”, operated by Mitsui O.S.K. Lines, was designed and built by the Mitsubishi Heavy Industries, Ltd., Nagasaki Shipyard & Machinery Works. The Ship was the sixth in a series of large container ships that were delivered starting in 2007. The Ship was built using YP47 steel (yield stress: 460 N/mm^2) in the hatch coaming to mitigate toughness degradation that could occur when using extremely thick plates. All fuel oil tanks were protectively designed in side structural areas such as double hull construction to prevent environmental pollution.

The main engine was an electronically controlled diesel engine of Mitsubishi-Sulzer 11RT-flex 96C with a service speed of 25.25 knots. The Ship had seven cargo holds in front of the engine room and two cargo holds aft of the engine room with a maximum capacity of 8,110 TEU.

1.2 Conformity with Rules/Survey Conditions

Application for classification and statutory services during construction was made to Nippon Kaiji Kyokai*, as the representative authority of the Government of the Bahamas, and it was confirmed that The Ship’s plans and hull structure conformed with the relevant requirements of the Rules for the Survey and Construction of Steel Ships, Guidance for the Survey and Construction of Steel Ships, during plan approval, as well as during classification surveys during her construction.

As part of the approval based on the rules mentioned above, direct strength calculations for the evaluation of transverse strength, torsional strength and fatigue strength were implemented. All these were confirmed to be satisfied with the requirements. In addition to the above, conformity with IACS Unified Requirements related to ship structural strength was also verified.

1.3 State and Conditions at the Time of the Accident

According to the operator of The Ship, a crack occurred midship part at about 07h45 (GMT + 5 hours) on 17 June 2013, while crossing the Indian Ocean on a voyage from Singapore to Jeddah in Saudi Arabia. The Ship was sailing at a speed of approximately 17 knots with the engine running at 79 rpm. The significant wave height at the time of the accident was 5.5 m with a south-westerly wind of Beaufort force 7. As a result of water ingress into the cargo hold, The Ship was unable to operate under its own power. The 26 crew members escaped by lifeboat and were rescued. Subsequently, The Ship’s hull split into two which then drifted apart, and subsequently sank in the open sea (3,000 to 4,000m in depth). Records on board, such as Voyage Data Recorder, Ship Log Book, and Ballast Log Book Record among others, were lost when The Ship sank.

Water ingress was first detected by the water ingress alarm in the Duct Keel located near the center line of the double bottom of The Ship. Approximately two minutes later, further water ingress was detected in No.6 Cargo Hold located on the double bottom midship part. From the enlarged view in Fig. 1.3.1, the crack progression ran upwards from the bottom of The Ship, at No.6 Cargo Hold. From this, it was assumed that the crack which triggered the fracture had originated in the bottom shell plates below No.6 Cargo Hold midship part.

Fig 1.3.1 Condition of The Ship at the time of the accident
(Direction of the crack progression (photo by Mitsui O.S.K. Lines, Ltd))

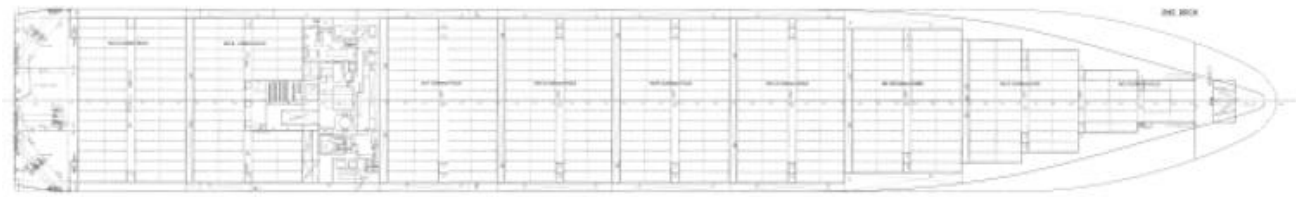


Fig 1.3.2 2nd Deck Arrangement

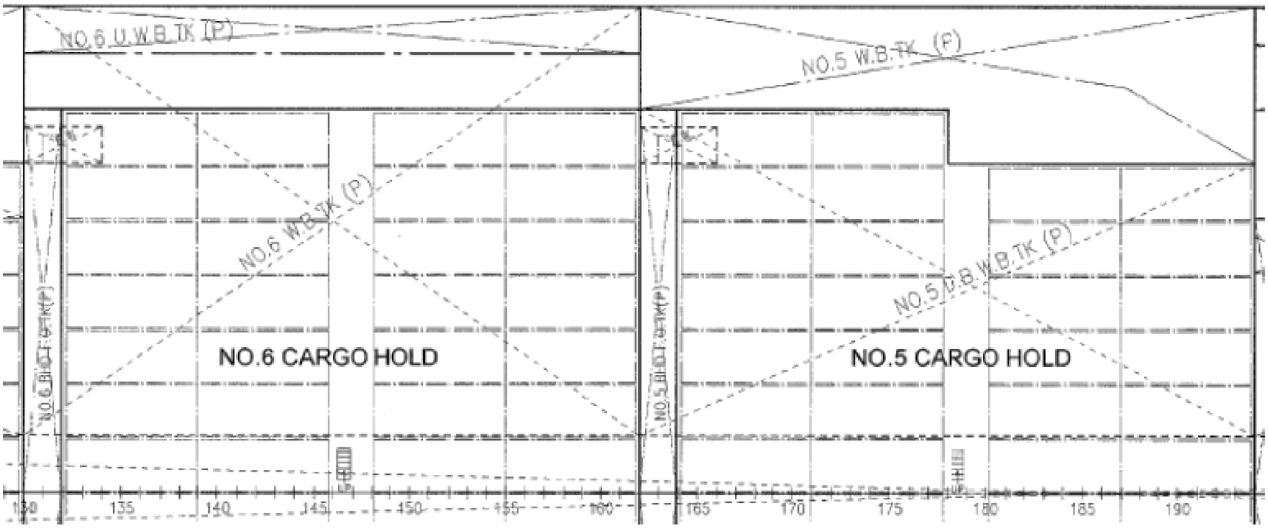


Fig 1.3.3 Tank Top Arrangement of No.5 & No.6 Cargo Holds (Port Side)

1.4 Safety Inspections of The Sister Ships

As the conditions of the hull damage and the cargo loading could not be verified due to the sinking of The Ship with on-board records, safety inspections of their bottom shell plates were conducted on The Sister Ships to collect any information relevant to the accident. Upon results of the safety inspections carried out on The Sister Ships, buckling deformations (concave and convex deformation of the bottom shell pates) of up to a maximum of 20mm in height were observed near the center line of the transverse section of the bottom shell plates in midship part. As a preventative safety measure for these Sister Ships, significant reinforcements of the double bottom structure to increase hull girder strength had been carried out successively for each ship. Inspections of 6 The Sister Ships and four other ships similar in design to The Ship were carried out with the cooperation of each operator in line with the Committee's objectives. As these ships were not Japanese flagged ships, no information about these ships will be disclosed excluding information mentioned in this report. Although differences were observed in their shape and frequency, deformations of the bottom shell plates, including minor deformations, were found in five of The Sister Ships operated by the same operator of The Ship, and found in one of the other four similar ships. No deformations were found on the remaining one operated by the same operator of The Ship just delivered in 2013.

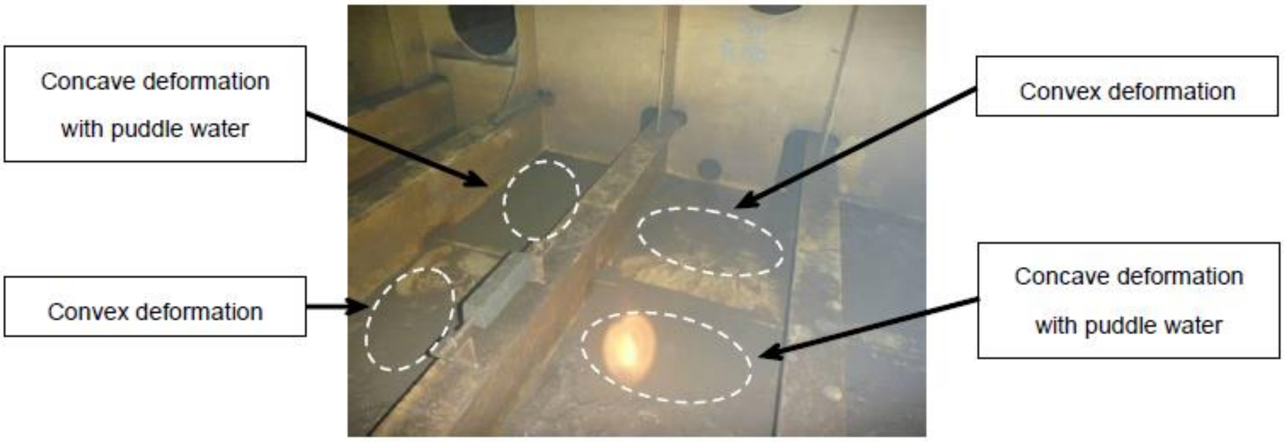


Fig 1.4.1 Example of buckling deformations observed in the bottom shell plates in double bottom midship part found on The Sister Ship operated by the same operator of The Ship (photo by Mitsui O.S.K. Lines, Ltd.)

Fig. 1.4.1 shows an example of deformation observed in The Sister Ship operated by the same operator of The Ship. The concave and convex buckling deformation of the bottom shell plates were observed between the bottom longitudinal stiffeners which were not deformed.

The maintenance records, as a part of Safety Management System, of The Ship were investigated. No deformation was recorded in the bottom shell plates under No.6 Cargo Hold midship part, assumed to be the part where the fracture originated, but showed buckling deformations in bottom shell plates on both the port and starboard sides near the butt joint in the vicinity of Fr.182 under No.5 Cargo Hold locating one-hold forward. Some similar deformations were recorded after 4 January 2010. Since no repairs were recorded, such deformations may exist in The Ship. In addition, there are no records regarding buckling deformations in the bottom shell plates during the periodic dry-docking surveys by the classification society.

The detailed information in this section should be referred to the Interim Report (Sections 2 to 4).

2 Reproduction of The Ship fracture and buckling deformations in the bottom shell plates by Simulation Calculations

2.1 Method of simulation calculations

In order to reproduce The Ship fracture by simulation calculation, acting loads were calculated by estimating the sea condition from the data of weather and sea at the accident. At the same time, the elasto-plastic assessment of the midship part of The Ship was conducted and ship structural strength was estimated. The Committee verified the possibility of the accident by comparing acting loads with ship structural strength.

In simulation of acting loads by calculation, whipping loads, which have not been explicitly considered in current structural requirements, were taken into account. The deviation of the sea condition in the accident was also considered, taking into account the weather and sea conditions data. Besides, the effect of deviation of container weight (gap between declared weight and actual weight) on the still water vertical bending moment was considered. The calculated acting loads were increased or decreased depending on sea condition and/or ship speed[1].

On the other hand, ship structural strength was estimated by the elasto-plastic assessment of the midship part of The Ship. In this assessment, the effect of lateral loads such as pressure on bottom hull and container weight, which induce bi-axial stress on the bottom plating, was considered as well as vertical bending moment.(refer to Annex 2). The Committee also considered the following; the effects of deviation of yielding point of steel plate constituting ship structure, the effect of welding residual stress of bottom longitudinal and the effect of buckling deformations of the bottom shell plates, as observed in The Sister Ships. The ship structural strength by the simulation calculation is increased or decreased by those effects[2].

2.2 Verification of possibility of The Ship fracture

The Interim report has indicated the necessity of consideration of the effect of uncertainty factors in the simulations for acting loads and ship structure strength, as the cause of the accident has not yet fully been clarified quantitatively. Responding to the Interim report, ClassNK, one of the Committee members, considered the possibility of the accident, taking into account the uncertainty factors, and informed of the following report to this Committee;

.1 With regard to the possibility of the fracture accident, it considered comparison between acting loads and ship structural strength, taking into account the deviation of uncertainty factors such as yield stress of steel data, sea condition at the accident and the gap of declared container weight and actual weight.

.2 The result indicated that there was actually possibility, although quite low, that ship

[1] The method of simulation for calculation of acting loads (NMRIW) includes consideration of non-linearity of wave height by estimation of various hydrodynamic forces by time steps. The detail of this method can be found in paragraph 6.2.2 in the Interim report.

[2] The method of simulation for calculation of the hull girder ultimate strength (LS-Dyna) and the considered uncertainty factors can be found in Section 3 in NK report.

fracture occurred where the load of the vertical bending moment exceeded the hull girder ultimate strength at the time of the accident.

In order to verify the possibility of the accident, the simulation of acting loads was conducted by changing the condition of ship speed, significant wave height and mean wave period, taking into account deviation of the weather and sea conditions. And the result of this simulation was compared with ship structural strength simulated by calculation. In this simulation, ship speed and sea conditions (significant wave height, mean wave period and wave direction) were changed except for the wave direction in order to confirm that the condition, set in NK report which indicated the possibility of the accident, does not lead to peculiar results. Consequently, it was verified that it is actually possible that ship fracture happened where the load of the vertical bending moment exceeded the ship structural strength at the time of the accident as shown in Table 2.2.1 and Figure 2.2.1.

Table 2.2.1 Consideration for possibility of the accident

	Interim report	NK report	Present simulation
Ship speed	17 knot	17 knot	15 knot
Significant wave height	5.5 m	7.5 m	8 m
Mean wave period	10.3 sec	15 sec	12.5 sec
Wave direction	Oblique sea from bow and port side	Head sea	Head sea
Deviation of hull girder ultimate strength	-	Included (refer to paragraph 3.3 in NK report)	Included (refer to paragraph 3.3 in NK report)
Loading condition for calculation of strength	At the accident	At the accident (Section 3 in NK report)	1 Bay Empty
Result	No fracture	Ship fracture is possible	Ship fracture is possible

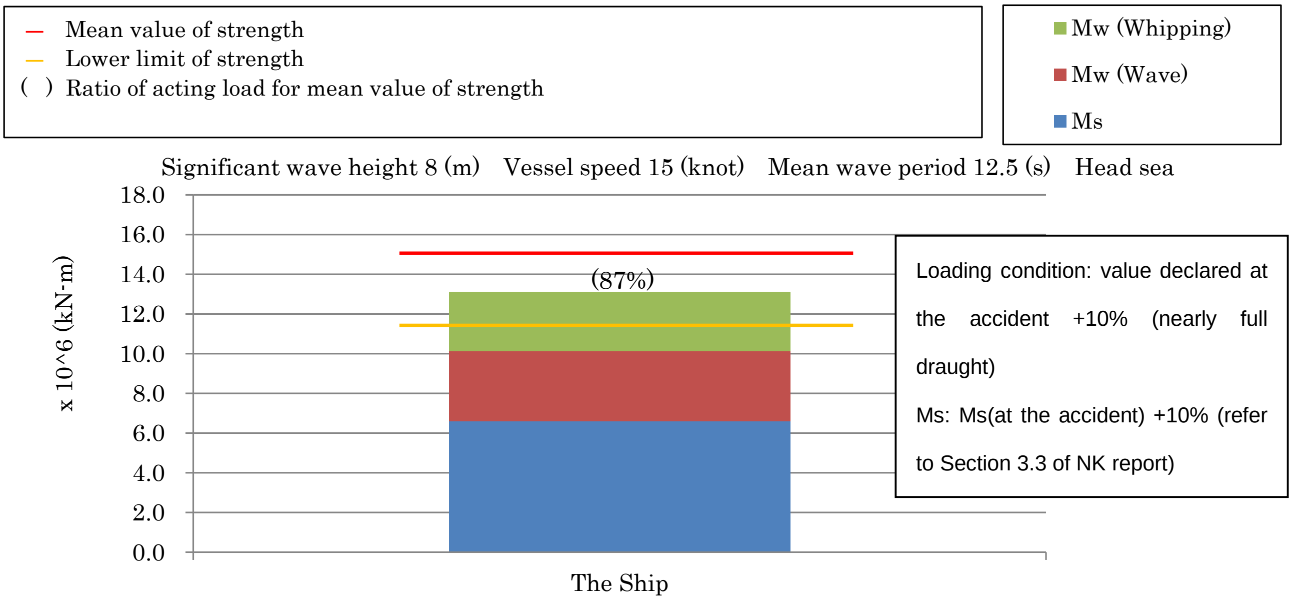
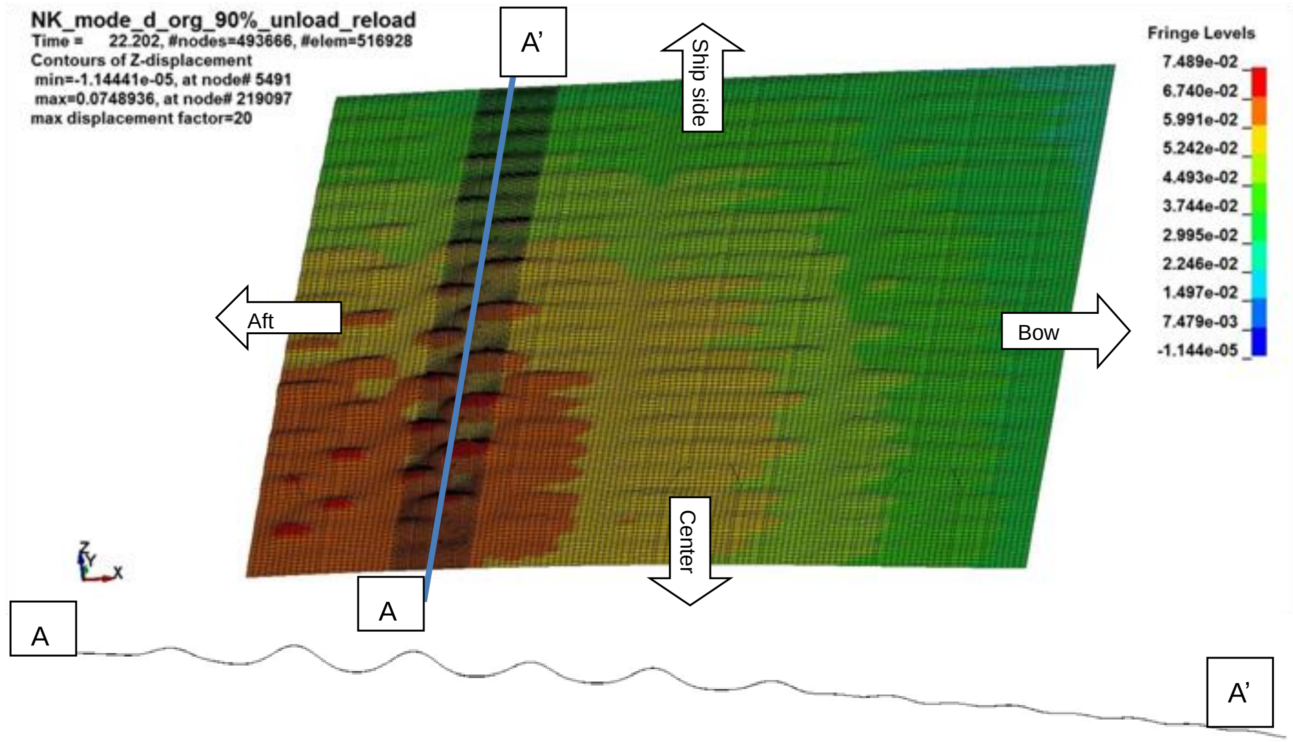


Figure 2.2.1 Consideration for possibility of the accident

2.3 Reproduction of buckling deformations of the bottom shell plates

The buckling deformations of about 20mm height have been found in the bottom shell plates during safety inspection of the Sister Ships. In order to reproduce those phenomena, the simulation of structural strength of The Ship was conducted by applying slightly lower loads than the ship structural strength calculated under the condition of mean values of material strength and the assumption of possible small initial shape imperfection of construction in the bottom shell plates. Consequently, it was found that buckling deformations of the bottom shell plates might occur and then increase under subsequent repeated loads. The loads were applied in the following manner: when the load was, for example, a maximum of 90% of the mean value of the ship structural strength (95.2% of ultimate hull girder strength in case of the initial deformation given in Annex 3), the 90% of the mean value of the ship structural strength was applied first after providing the initial deflection of Annex 3 and kept in a certain period of time and unloaded to the value of still water bending moment (Ms). The loading/unloading were repeated between Ms and the 90% of the mean value of the ship structural strength. The reproduction of buckling deformations of the bottom shell plates was verified by the simulation of residual deformation after unloaded to Ms. The deformation was accumulated under such repeated loads and height of deformation was increased. It should be noted that the estimated value of the deformation tends to be large due to the characteristics of solution method of simulation. (refer to Figure 2.3.1 and Annex 3)



Maximum deformation 17.01 mm (double amplitude quantitative, deformation between longitudinal stiffeners would be about half of this double amplitude)

Figure 2.3.1 Sample of Simulation for Reproduction of buckling deformations on bottom shell plates (At Fourth unloading after repeatedly providing 90% of mean value of strength (95.2% of hull girder ultimate strength in case initial deformation (Annex 3) was provided))

As mentioned in paragraph 2.1, the values of the estimated hull girder ultimate strength of each The Sister Ship have the deviation. Therefore, the value of loads, which caused the buckling deformation, could not be definitely specified. However, it was found that buckling deformation of the bottom shell plates might occur in The Sister Ships although hull girder fracture did not occur.

3 Safety of Large container ships (other than The Sister Ships)

3.1 Safety inspection of bottom shell plates

As the results of safety inspection for existing large container ships (in general, more than 45m in breadth and 8,000 TEU in capacity), recommended in Section 9 of the Interim report, it was reported that any large container ships, whose design is different from that of The Ship, have no buckling deformation.

3.2 Comparison between Ship structural strength and Acting loads by Simulation calculations

In order to consider the safety of large container ships with different design from The Ship, the

Committee estimated the ship structural strength of those ships by elasto-plastic assessment and conducted the simulation of acting loads with variety of sea condition and ship speed. After that, the Committee compared the ship structural strength with the acting loads. Besides, in the simulation of acting loads, direction of wave was set out as head sea and loading condition as full draught. Large container ships used in this simulation are shown in Table 3.3.1, because The Ship was 8,000 class container ship so that the comparisons were mainly of interest for 8,000 TEU class container ships. This simulation did not consider the effect of deformations in the bottom shell plates in those ships because the safety inspection indicated no deformation in the bottom shell plates.

Table 3.3.1 Large container ships used in comparison between ship structural strength and acting loads

	ship(1) (The Ship)	ship(2)	ship(3)	ship(4)
Number of container	8,110TEU	8,600TEU	8,100TEU	6,000TEU
Figure 4.3 in NK report	A	C	D	-

The results of the comparison between ship structural strength and acting loads are shown in Figure 3.3.1, which should be contrasted to Figure 2.2.1. It can be found that the large container ships except for The Ship (accident ship) had enough margins for ship structural strength compared to The Ship (refer to Figure 2.2.1).

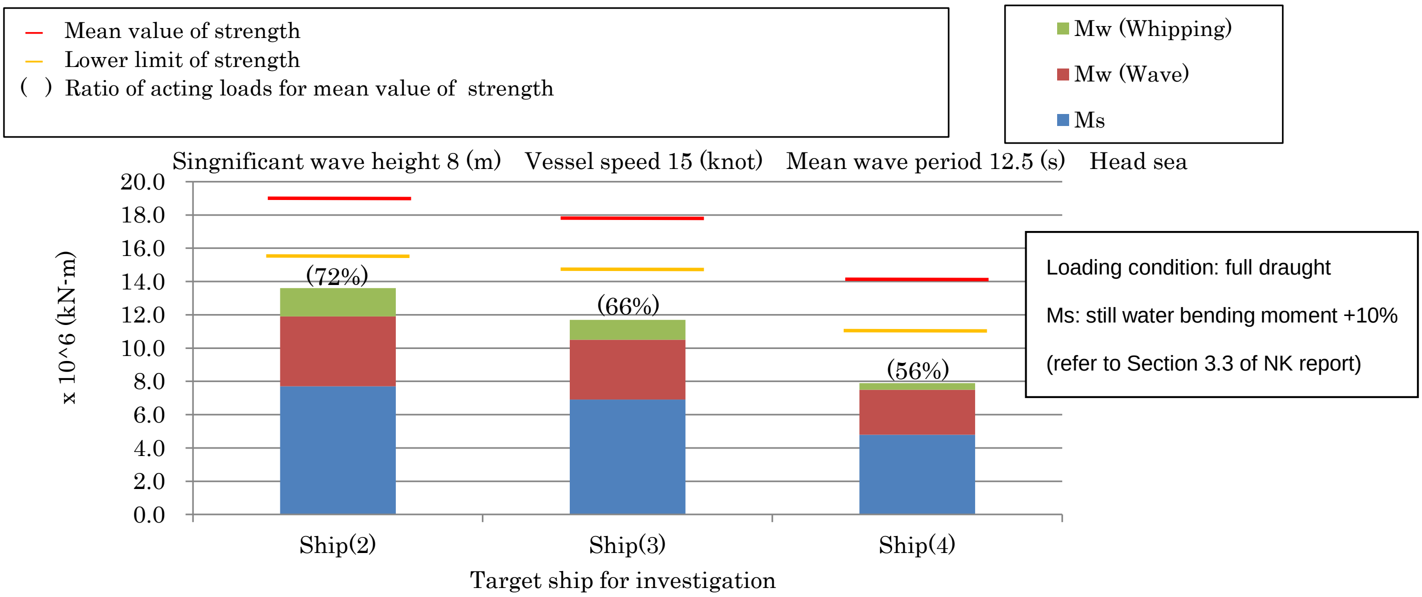


Figure 3.3.1 Ship structural strength and acting loads for large container ships (other than The Sister Ships)

With regard to the large container ships of ClassNK with different design from The Ship, no similar deformations of bottom shell plates were found through the safety inspections, and in contrast to The Ship, sufficient structural margins were found as the results of the simulations. NK report also describes the investigation of margin of ship structure strength through the evaluation of hull girder ultimate strength taking into account the effect of lateral load and the evaluation of the buckling collapse strength of stiffened bottom panel. (refer to Section 4.3.3 in NK report) It can be considered that the similar confirmations such as inspection of bottom shell plates are effective for other large container ships.

4 Findings by simulation calculations and consideration of requirements for large container ships

With regard to the safety requirements of large container ships having high-speed, the calculation results of acting loads and ship structural strength are considered in Sections 4.1 to 4.3.

4.1 Requirements of Classification Societies

According to SOLAS Chapter II-1 regulation 3-1, large container ships shall be designed, constructed and maintained in compliance with the structural requirements of a classification society which is recognized by the Administration. IACS, consisted of major classification societies (including ClassNK), has established the Unified Requirements which cover various areas such as ship structure, and ClassNK Rules have incorporated the IACS Unified Requirements (refer to paragraph 2.2 of the Interim report). Therefore, the consideration for the requirements of classification societies applied to IACS Unified Requirements as well as ClassNK Rules.

4.2 Ship structural strength

Ship structural strength (hull girder ultimate strength) should be considered, taking into account the decrease of The Ship structural strength by the effect of lateral loads, which induce bi-axial stress on the bottom shell plates. In order to prevent local buckling deformations detected in the bottom shell plates of The Sister Ships, sufficient safety margin should be considered in ship design from such a view point that the biaxial stress states induced by both the vertical bending stress and the lateral loads fall within the interaction curve of the buckling collapse strength of stiffened bottom panels (refer to Section 4.6 in NK report).

Figure 4.2.1 Decrease of structural strength by the effect of lateral loads (developed by Figure 4.4 NK report)

The effect of lateral loads on ship structural strength could be actually indicated by the method of this simulation (3 Hold FE Model). The transverse strength of double bottom construction against the lateral loads such as bottom sea pressure and container loads has close relationship to the ship structural strength (the hull girder ultimate strength). (refer to paragraph 4.2.3 in NK report)

Thus, the requirements for ship structural strength (hull girder ultimate strength) should consider the effect of lateral loads, which induce bi-axial stress on the bottom shell plates.

4.3 Acting loads

Acting loads should consider the following points;

.1 Whipping loads

An example of the effect of whipping response in the simulation for acting loads is shown in Annex 4. It is possible that large acting loads may occur by the effect of whipping response. Such phenomenon has been recognized, but experience-based rule has not explicitly considered such phenomenon, so that the quantitative assessment of the effect of whipping response has not been implemented in international requirements.

With regard to acting loads, it is necessary that the effect of whipping response, which has not been explicitly considered in current structural requirements, should be considered. Longitudinal Strength Standard (S11) of IACS Unified Requirements does not explicitly consider effect of whipping response.

Therefore, the effect of whipping loads should be explicitly considered in the requirements for longitudinal strength, based on the knowledge accumulated for developments of the requirements.

.2 Increase of acting loads with wave height or ship speed

An example of the effect of wave height on acting loads in simulation is shown in Figure 4.3.1 (ship speed is constant). An example of the effect of ship speed on acting loads is shown in Figure 4.3.2 (wave height is constant).

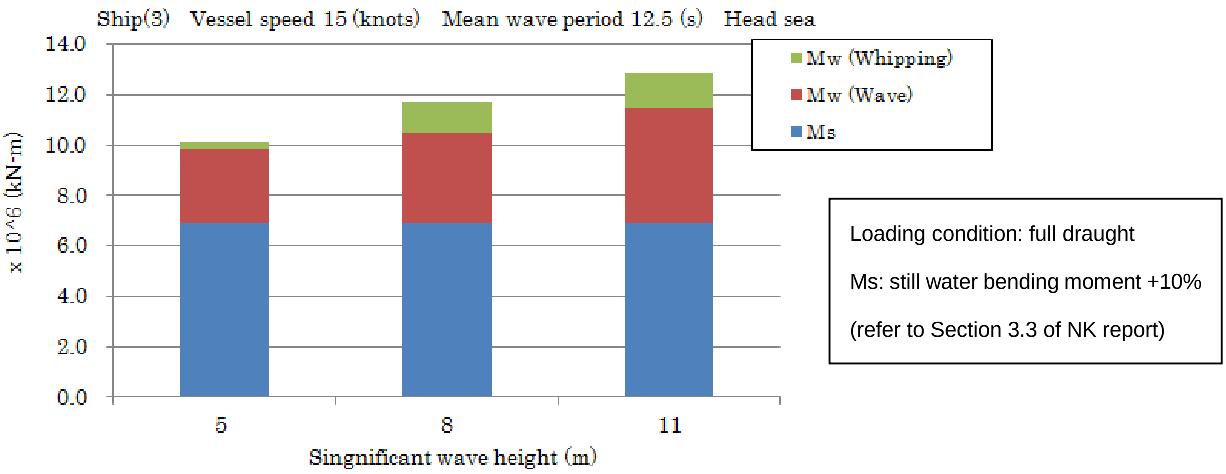


Figure 4.3.1 Example of the effect of acting loads (ship speed is constant)

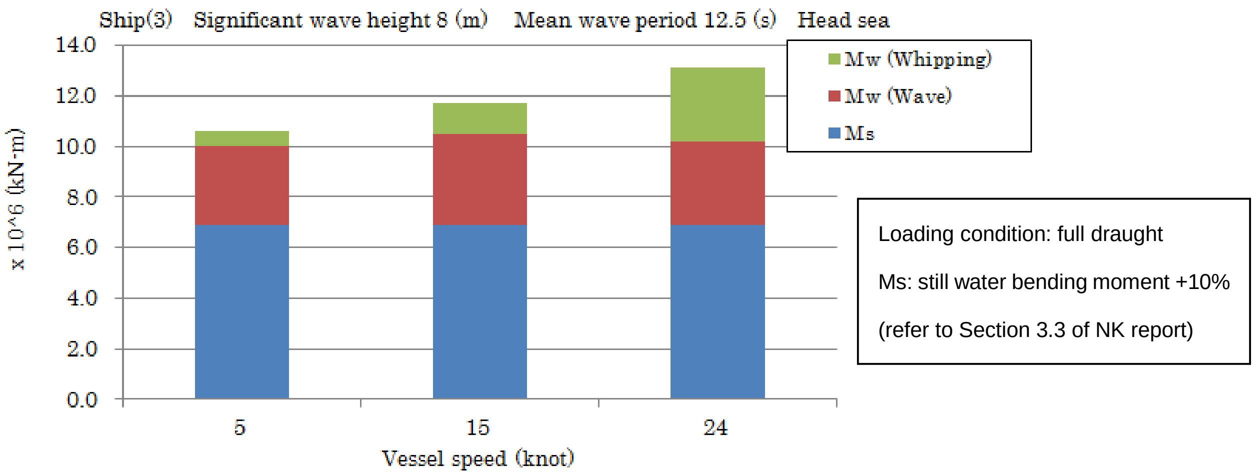


Figure 4.3.2 Example of the effect of ship speed (wave height is constant)

The acting loads may increase or decrease by sea condition and ship speed. On the other hand, wave-induced vertical bending moment in Longitudinal Strength Standard (S11) of IACS Unified Requirements is based on past operational results such as damage experiences, considering the effects operation such as rough sea avoidance, but it does not explicitly take into account wave height, wave period and ship speed (refer to figure 4.3.3).

Therefore, the representation of the technical backgrounds of requirements of longitudinal strength such as sea conditions, should be considered.

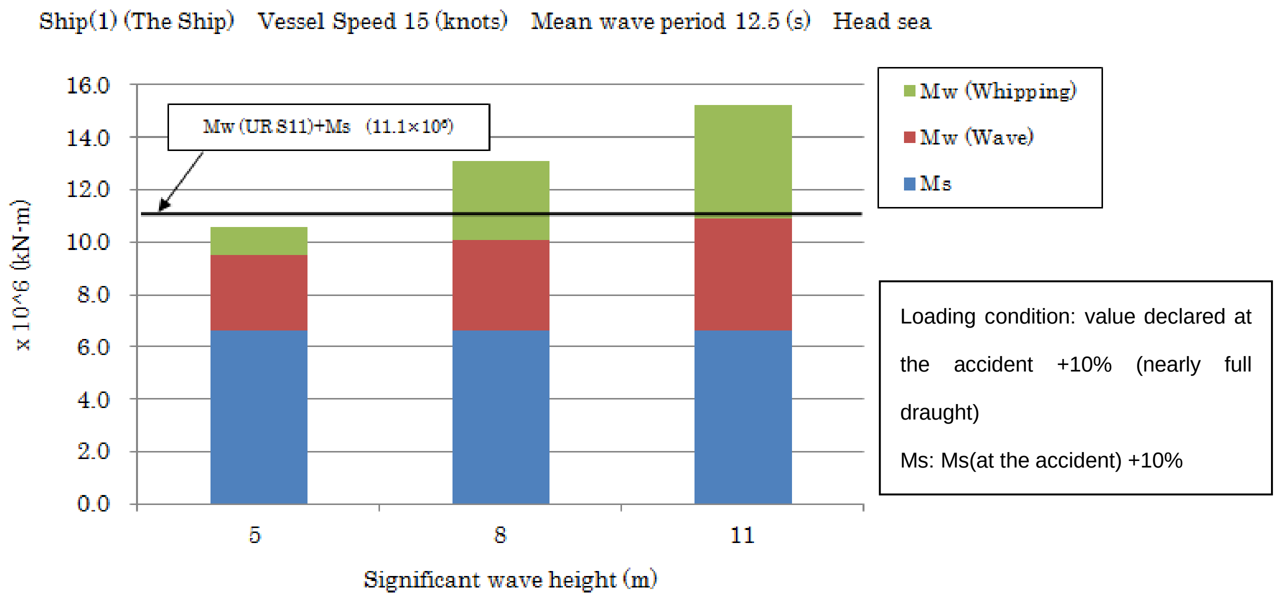


Figure 4.3.3 Relation to acting loads in IACS Unified Requirements (Mw(URS11))

5 Conclusions and recommendations

With regard to the large container ships of ClassNK with different design from The Ship, no similar deformations of bottom shell plates were found through the safety inspections and sufficient structural margins were found comparing with The Ship as the results of the simulations. It can be considered that the similar confirmations such as inspection of bottom shell plates are effective for other large container ships. (Refer to Section 3)

<u>Recommendations of requirements for large container ships (8,000 TEU class or over)</u>

(Refer to Section 4)

It is recommended that the classification requirements for large container ship structural strength, including Class NK requirements and IACS Unified Requirements, should be amended or considered in the following way at the early stage in order to implement the safety measures internationally.

.1 The effect of the lateral loads which induce bi-axial stresses of bottom shell plates should be considered in the requirements of the hull girder ultimate strength, taking into account the close relationship of the lateral loads and the hull girder ultimate strength.

.2 Effects of whipping responses should be explicitly considered in the requirements of the vertical bending strength.

.3 Representation of technical backgrounds of the requirements for vertical bending strength such as sea states etc. should be considered.

Annex 1

Committee on Large Container Ship Safety
Member List

Chair Person

Professor Emeritus, Dr. Eng, Yoichi SUMI	Yokohama National University

Members (Alphabetical order)

Professor, Dr. Eng, Masahiko FUJIKUBO	Osaka University
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Mr. Yoshikazu KAWAGOE	Executive Officer, Mitsui O.S.K. Lines, Ltd.
Mr. Mitsuhiko KIDOGAWA	Operating Officer, General Manager of Hull Department NIPPON KAIJI KYOKAI (ClassNK)
Mr. Kazuya KOBAYASHI	Associate Officer, General Manager, Engineering Division, Ship & Offshore Structure Company Kawasaki Heavy Industries, Ltd.
Mr. Toyohisa NAKANO	General Manager, Technical Group KAWASAKI KISEN KAISHA, LTD.
Mr. Junichi IWANO	General Manager, Technical Group, Nippon Yusen Kabushiki Kaisha
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Secretary

Safety Policy Division, Maritime Bureau,
Ministry of Land, Infrastructure, Transport and Tourism

Annex 2

Loads acting on the Double Bottom Construction of Container Ships (according to Appendix 9 in NK report)(related to Section 2.1)

In general, hogging is a major condition of vertical bending in container ships. The tension load acts at the deck side, and the compressive load acts at the bottom side almost all the time in service. The tendency is remarkable particularly in container ships of up to 10,000TEU class with the engine room and the deckhouse located semi-aft.

Bottom sea pressure, container load and the weight of ballast water and fuel oil in double bottom construction are listed as the load acting on the double bottom construction. The upward load due to bottom sea pressure is a major load as the lateral load acting on the double bottom construction because the cargo weight is relatively smaller than the load due to bottom sea pressure. The bottom sea pressure comprises hydrostatic pressure corresponding to the draught and wave-induced pressure. This upward load due to bottom sea pressure is relaxed when ballast or fuel oil is loaded in double bottom construction because the load due to them is downward, i.e., the effect due to ballast is larger than that of fuel oil because of the specific gravity.

And the compressive load due to sea pressure acting on side shell is generated in the transverse direction. Hence, it can be said that the following 3 loads almost always act on the double bottom construction as shown in Fig. A2-1;

① Compressive load due to vertical bending
② Upward load due to bottom sea pressure
③ Transverse compressive load due to side sea pressure

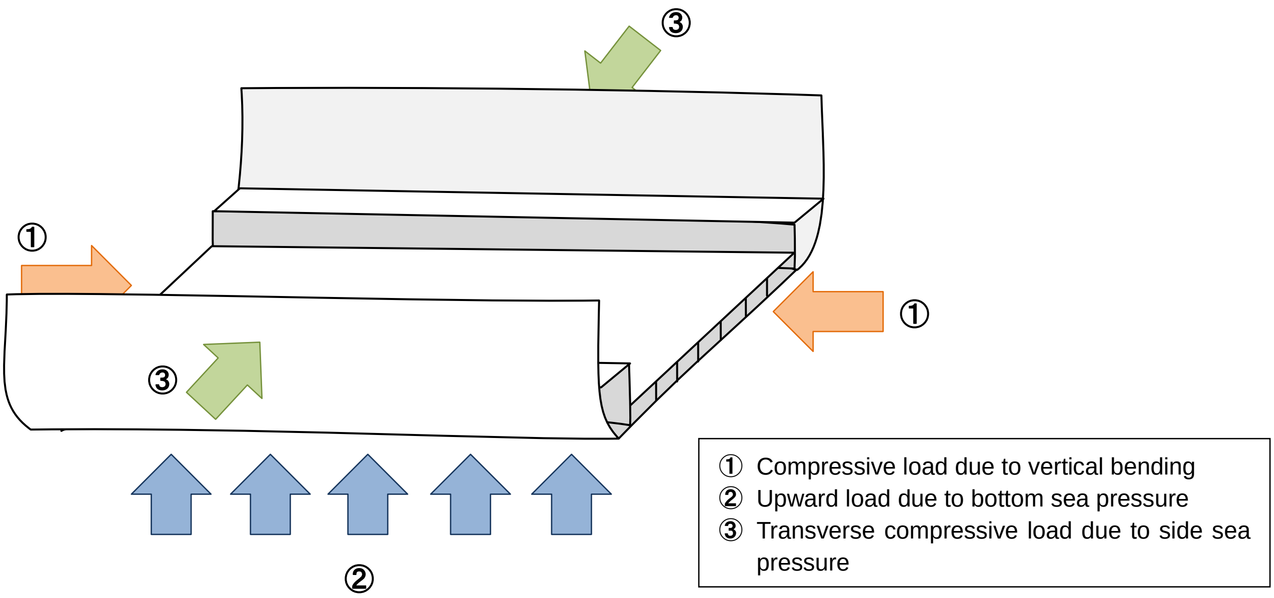

Figure A2-1 Load acting on Double Bottom Construction of Container Ships

The compressive load due to vertical bending shown in ① causes longitudinal compressive stress to the bottom shell plates. And the transverse compressive load due to ③ causes transverse compressive stress to the bottom shell plates.
On the other hand, the upward load due to bottom sea pressure shown in ② makes convex deformation as shown in Fig. A2-2 on the double bottom construction consisting of bottom shell plates with bottom longitudinal, inner bottom shell plates with inner bottom longitudinal, girder and floor. As the result, transverse compressive stress on the bottom shell plates is generated near the center line. The deformation of the double bottom construction is maximized near the partial bulkhead within the longitudinal direction and therefore longitudinal compressive stress is generated in the bottom shell plates around the partial bulkhead.

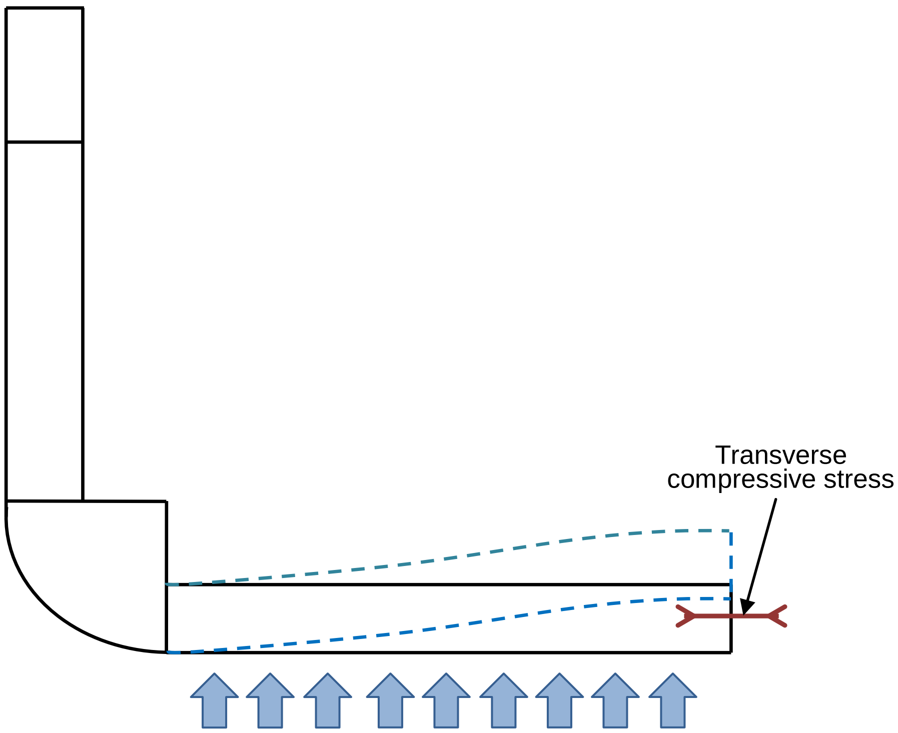

Fig. A2-2　Stress generated in the Bottom Shell Plate due to Bottom Sea Pressure

Consequently, in the bottom shell plates at the center of the hold, i.e., near the center line and near the partial bulkhead, compressive stress due to ① (compressive load due to vertical bending) and due to ② (upward load from bottom sea pressure) are superimposed in the longitudinal direction, and compressive stress due to ② (upward load due to bottom sea pressure) and due to ③ (compressive load due to side sea pressure) are superimposed in the transverse direction.

Annex 3 Reproduction of buckling deformations in bottom shell plates (related to Section 2.3)

The elasto-plastic analysis of the midship part of The Ship (see Section 2.1) was conducted. The loading condition was set out as One-bay empty condition without ballast in double bottom.

<u>Small initial deformation in bottom shell plates</u>

Magnitude of deformation: A small initial deformation (sum of the one half-wave to five half-wave sinusoidal deflection components with the amplitude of 1/50 of plate thickness each) was provided to the bottom shell plates (long side of 3,600mm) in the longitudinal direction.

Each deflection component was provided equally in magnitude because several buckling deformations could occur depending on the bi-axial stress ratio. The shape of the initial deformation is shown in Figure A3-1.

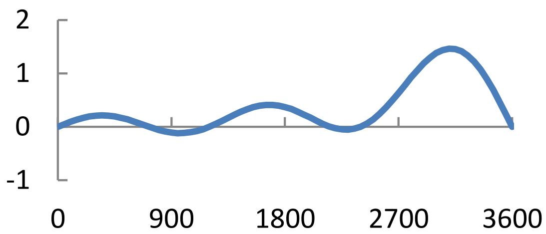

Figure A3-1 Cross section surface of initial minor deformation (cross section surface: mm)

<u>Example for repetition of acting loads</u>

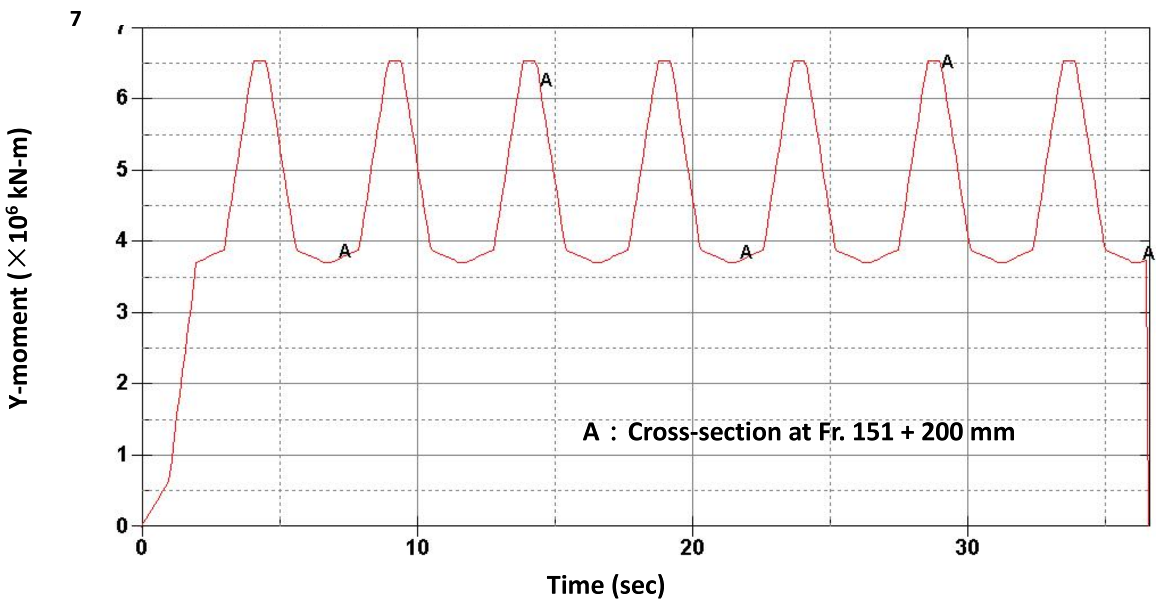

Figure A3-2 Example for repetition of acting loads (Vertical bending moment for side hull)

Reproduction of buckling deformations in bottom shell plates and increase of deformation height

Table A3-1 Buckling deformation in bottom shell plates (setting out the loads on the simulation not relating to the sea condition)

Loads provided repeatedly against mean value of strength	92.5%	91.5%	90.0%
Corresponding loads from hull girder ultimate strength of initial deformation (figure A3-1)	97.8%	96.8%	95.2%
Maximum deformation (double amplitude)	21.2mm (First time at unloaded as Ms)	17.3mm (First time unloaded as Ms)	14.6mm (First time unloaded as Ms)
History of growing deformation	↑	18.7mm (Second time unloaded as Ms)	17.6mm (Fourth time unloaded as Ms)
Period of times larger than 20mm	↑	20.2mm (Third time unloaded as Ms)	20.3mm (Ninth time unloaded as Ms)

In addition, it should be noted that the estimated height value of deformation tends to be large due to the characteristics of solution method of simulation (explicitly method of Annex 3 in Interim report).

Annex 4 Consideration of whipping loads (related to Section 4.3.1)

An example of the effect of whipping response in simulation of acting loads is shown in Figures A4-1 and A4-2. Large acting loads by the effect of whipping response could occur.

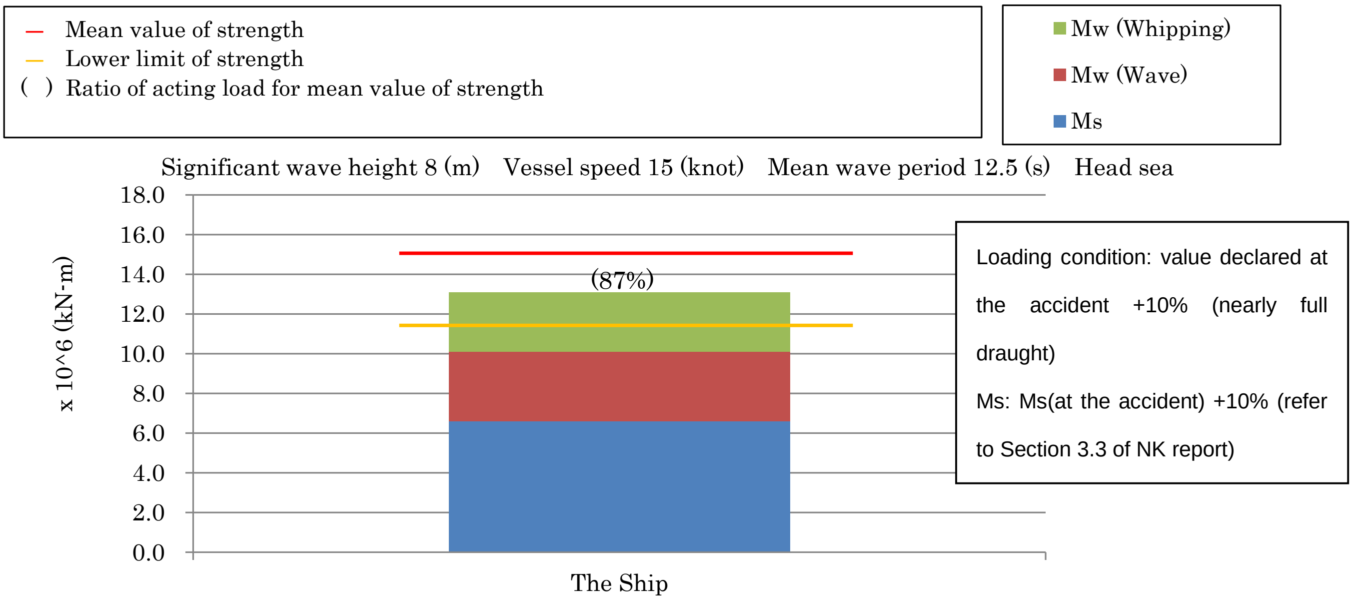

Figure A4-1 Same as Figure 2.2.1

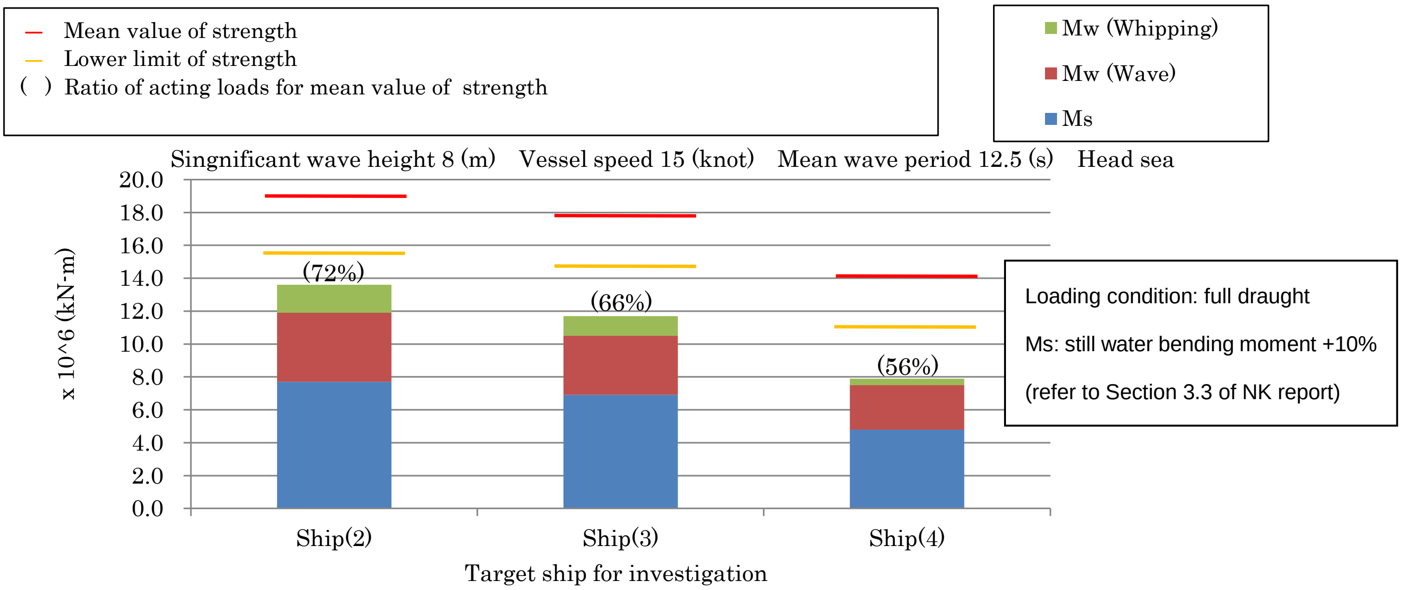

Figure A4-2 Same as Figure 3.3.1

With regard to whipping loads, which have not been explicitly considered in current structural requirements, examples for comparison between the method used in this simulation (NMRIW) and the other method are shown in Figure A4-3. This example was under the condition of ship speed of 17 knot, head sea, a mean wave period of 12.5 second and loading condition as value declared at the accident of Ship (1) (The Ship). Even if ship speed was the same, the sum of wave-induced bending moment and whipping loads increased with growing significant wave height. By methods of analysis, composition ratio and value of whipping loads are different.

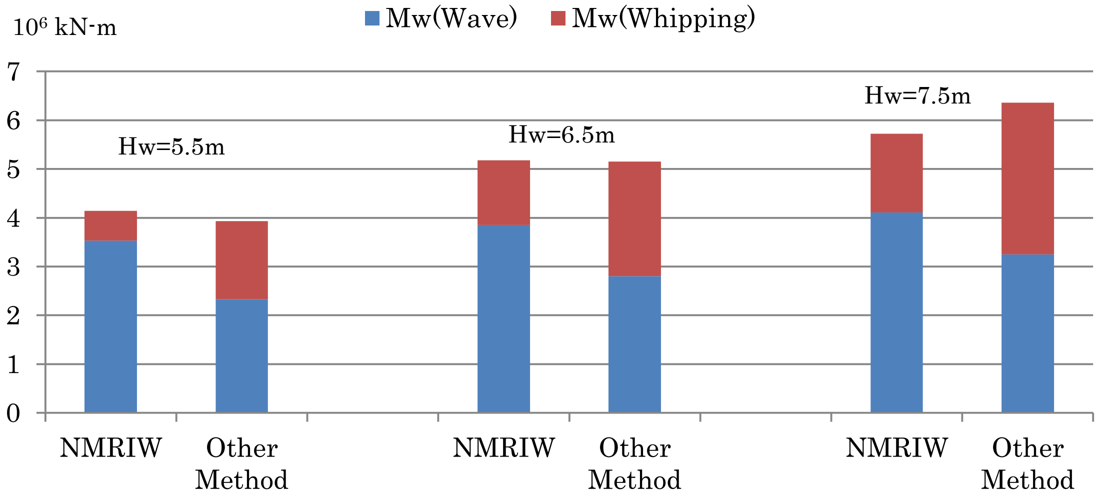

Figure A4-3 Comparison with the methods of analysis for consideration of whipping loads (Ship speed of 17 knot, head sea, a mean wave period of 12.5 second and loading condition as value declared at the accident of ship (The Ship))

In comparison between acting loads and ship structural strength, the effect of whipping loads has not been explicitly considered in current structural requirements. Therefore, it is technically informative to collect the data by on-board full scale measurements.

Thus, on-board full scale measurements for three large container ships (8,100 TEU, 8,200 TEU and 9,600 TEU) have started by the Committee members. An example of the data analysis (now on-going) is shown in Figures A4-4 and A4-5. This analysis needs to collect the data in full year sea condition and will be completed by the end of 2015 or the beginning of 2016. The future analysis may highlight the followings;

.1 understanding composition ratio and value of whipping loads in wave vertical bending moment;

.2 understanding the relation between whipping loads, sea condition, and ship speed;

.3 as the future action, organizing the data as time series in order to understand the relation between limited energy of whipping loads and hull collapse (refer to section 8.3 in the

Interim report)[3]

In this analysis of on-board full scale measurements, the data have been collected by setting some stress and acceleration measuring equipment in the bottom shell plates, etc. An example of measured data by stress measuring equipment (bi-axial stress) in May 2014 is shown in Figures A4-4 and A4-5. Blue line corresponds to Mw (Wave), while Green line corresponds to Mw (Whipping). Data of both lines are obtained by processing raw data through low and high pass filters, respectively.

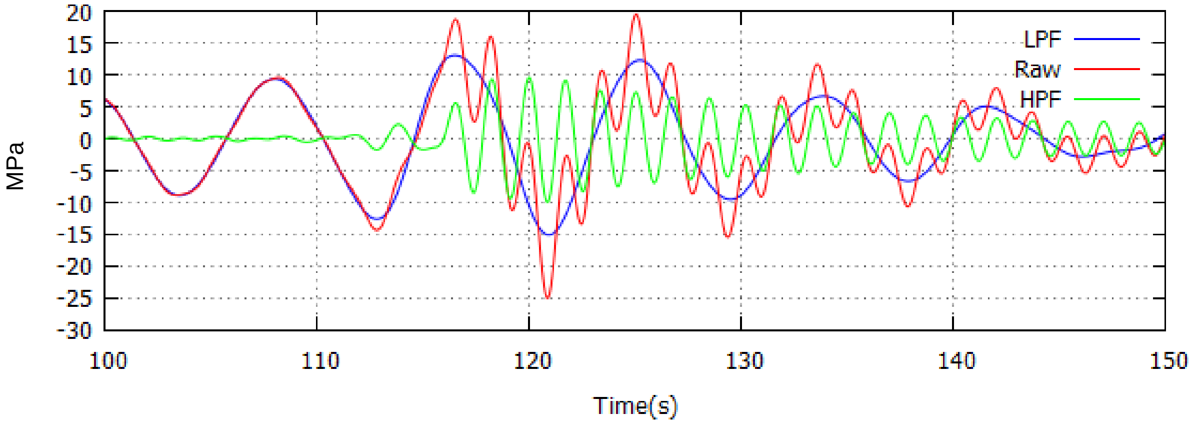

Figure A4-4 Longitudinal direction stress on the bottom shell plates

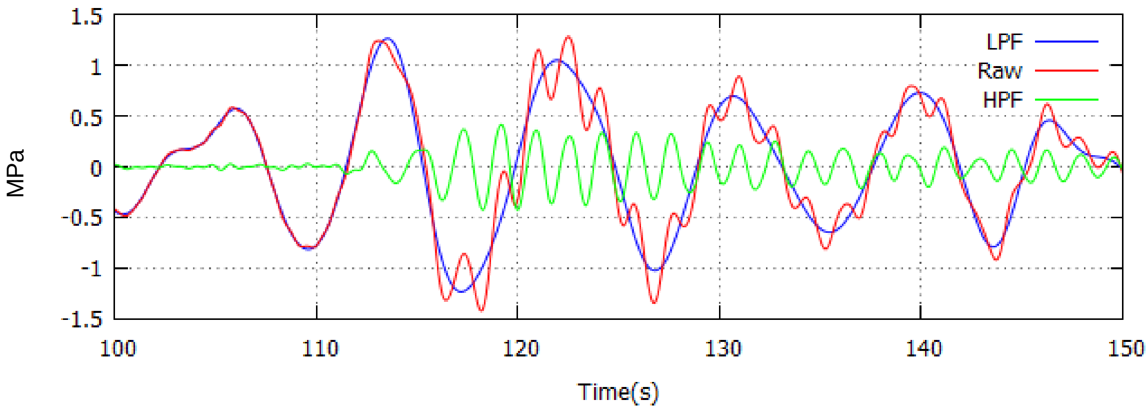

Figure A4-5 Transverse direction stress on the bottom shell plates

Reference:

As mentioned in paragraph 4.3.2, the simulation indicated that the acting loads varied widely depending on the sea condition that a large container ship encountered and on her speed. “The Revised Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions”

[3] Component of whipping loads, constituted acting loads, might be changed in the time period including the difference of duration by each component, as shown in Figures A4-4 and A4-5. The analysis of this effect in consideration for ship fracture is fruitful for further consideration of the safety of ship structure. Committee members are starting this basic analysis.

(MSC.1/Circ.1228, issued at 11 January 2007) does not consider the effect of head sea wave but only considers ensuring the stability under the condition of following or quartering sea. As reference information, commonality for operation of large container ships can be mentioned as follows;

.1 Large container ships are commonly operated with energy saving and routed based on weather information for rough sea avoidance.

.2 Rough sea avoidance maneuvers by container ships mainly intend to prevent shifting and losing any container and the bottom emergence from sea surface.

.3 The power of main engines of large container ships are much higher than those of tankers or bulk carriers so that the tendency of the natural reduction of speed in rough seas is not so significant.

Appendix　Definition of terms in this report

Classification society:
a third party that establishes and maintains technical standards for the construction and operation of ships and their equipment.

Nippon Kaiji Kyokai:
Nippon Kaiji Kyokai, known as ClassNK or NK, is a ship classification society, located in Japan. Around 20 % of the world merchant fleet has registered in the society at the end of November 2014. This is a non-governmental organization.

International Association of Classification Societies (IACS):
International Association of Classification Societies that consists of 12 classification society members including ClassNK. The secretariat is located in London.

Interim Report: "Interim Report of Committee on Large Container Ship Safety" issued in Dec. 2013, Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan (http://www.mlit.go.jp/en/report/press/kaiji06_hh_000000.html)

NK Report: "Investigation Report on Structural Safety of Large Container Ships" issued by Class NK in Sep.2014 (30 September 2014 of "http://www.classnk.or.jp/hp/en/press_release.aspx")

Significant wave height (Hw):
Ocean wave consists of combination of irregular wave heights. This is the average height (trough to crest) of the higher third of the waves valid for the indicated period. Wave height by visual observation is said to be close to significant wave height and thus, "wave height" generally indicates "significant wave height".

Acting Load (Unit: N-m): In this report, this is defined as vertical bending moment acting on midship section, consists of following three parts;

Still water bending moment:
This is a bending moment occurring in still water by light weight, cargo weight, fuel oil, ballast water and buoyant force. It is shown "Ms" as symbol.

Wave-induced bending moment:
This is a bending moment changed by period of wave occurring in hull by inertial force and difference in water pressure between wave and still water, and is not including "Whipping loads". It is shown "Mw(Wave)" as symbol.

Whipping loads:
This is a bending moment occurring by vibration of ships caused by slamming. It is also called

“Whipping moment”. It is shown “Mw(Whipping)” as symbol.

Wave-induced bending moment of longitudinal strength standard:

This is a wave-induced bending moment, described IACS Unified Requirements, S11: Longitudinal Strength Standard. It is shown “Mw(UR S11)” as symbol in Figure 4.3.3.

Ship Structural Strength (Unit: N-m):

This is structural strength for vertical bending moment in midship section in this report. Its representative values are considered as the followings. This is also explained as “hull girder ultimate strength” in this report by contexts.

Mean value of strength: This is calculated by using a mean value of yield stress of steels used in construction. This is also strength, not including the effects of deviation of yield stress of steel used in construction and welding residual stress. (refer to Appendix 8 in NK report)

Lower limit of strength: This is calculated by using a minimum value (the specified minimum yield stress in NK report) of deviation of yield stress of steels used in construction. And this is strength including the effects of welding residual stress. The structural strength of The Ship is considered to be reduced at maximum 4% by deformations of the bottom shell plate. (refer to Section 3.3 in NK report)

Slamming: This is a phenomenon caused by the impact of bottom hull or fore flare part onto the sea surface sailing in heavy weather. This may cause whipping vibration.