# Interim Report
# of Committee on Large Container Ship Safety

(*English Excerpted version*)

In December 2013

Issued by

Committee on Large Container Ship Safety

Japan

*This report is the provisional English translation and the full text of the report (final English version) will be posted at web site of the Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport and Tourism at a later date*.

*This is an abridged version of the report containing only the following underlined items*.

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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 amidships 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 this interim report of the Committee.

While this interim 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), which are responsible for international standards for hull construction, and the International Maritime Organization (IMO).

## Overview

Results of Investigation

The Ship experienced hogging (convex deformations in the longitudinal direction), causing the ship’s midship to fracture. According to observation of the progression following the outbreak of the accident, the upper deck area was the last part to fracture. From this, it can be assumed that the crack which trigged the fracture began below the waterline in the bottom part of the ship’s hull and then progressed upwards along the side of the ship. The fracture is believed to have originated in the bottom shell plates of No. 6 Cargo Hold.

Safety inspections of The Ship's sister ships (large container ships of the same design as “The Ship”) have found buckling deformations (for example, measuring approximately 20mm in height) on the bottom shell plates.

An investigation of The Ship's maintenance and inspections records also found buckling deformations on the bottom shell plates of the No. 5 Cargo Hold forward of the presumed fracture point.

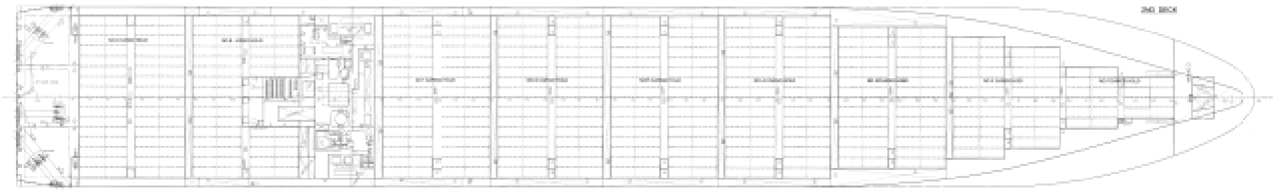
Structural analyses (simulations) were carried out using 3 hold FE model representing the midship part in order to simulate the fracture of The Ship. Meanwhile wave-load analyses under the sea state condition at the time of the accident were also carried out.

As a result, the hull strength of The Ship was calculated to be 14.0 x $10^6$ kN-m. On the other hand, the estimated load acting on the hull was found to be 9.4 x $10^6$ kN-m. This indicates that the estimated load equated to only approximately 67% of the hull strength.

Structural simulations were also conducted to simulate the buckling deformations (approx. 20mm) found on the bottom shell plates during the safety inspections of the sister ships, but such buckling deformations did not occur even when applying loads near the ultimate hull girder strength.

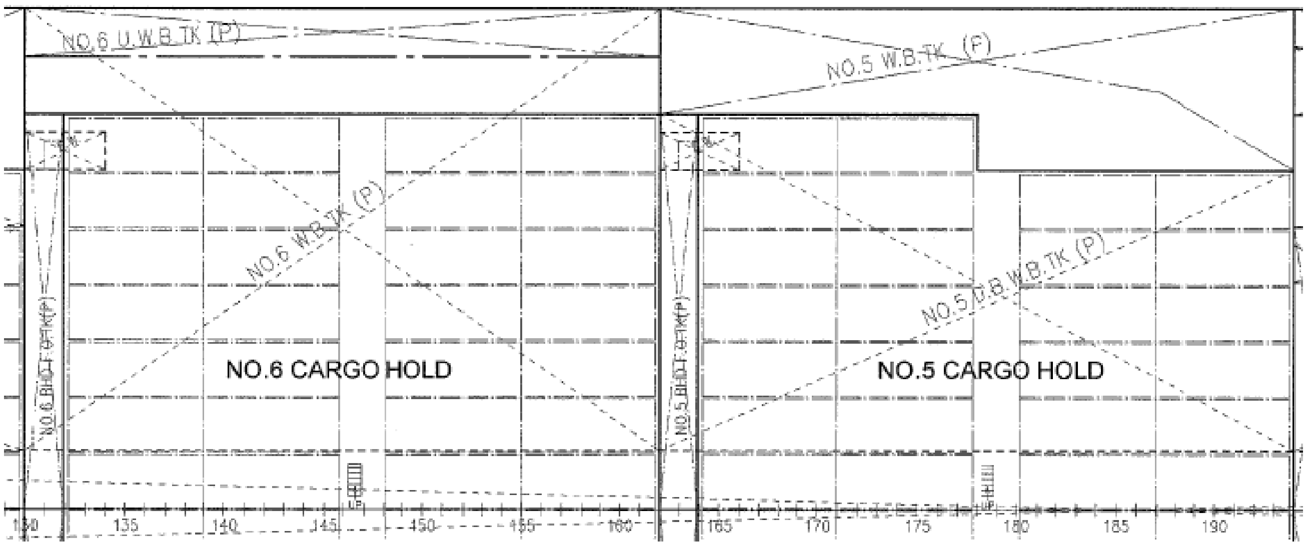
Uncertain factors, in the estimation of structural strength such as the possible presence of residual deformations approximately 20mm in height on the bottom shell plates along the butt joint of the ship bottom (the welded areas between the blocks in which the hull was built) were quantitatively assessed. Furthermore, the cargo loading effect on the simulations of acting loads were quantitatively assessed. However, the conditions for fracture were not able to be simulated.

2nd Deck Arrangements



↑ ↑

No.6 Cargo Hold No.5 Cargo Hold




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

Assessment of Investigation Results

The load acting on the ship under the sea state at the time of the accident is estimated to be 9.4 x $10^6$ kN-m by the Committee. However, according to the navigation records, the ship had encountered sea states in which it withstood a load of approximately 10.0 x $10^6$ kN-m around three and a half years prior to the accident, and no such fracturing accident had occurred in that instance. Since fracturing accident occurred after this event, three possibilities are hypothesized that:

(1) the real loads acting on the hull at the time of the accident exceeded the estimation;

(2) The Ship's hull strength had been reduced due to possible presence of residual buckling deformations on the bottom shell plates or any other reasons; or

(3) both of the above elements were combined.

For this reason, it is necessary to conduct further verification of both load and strength related simulations, including consideration of the effect of the uncertain factors in the simulations.

Furthermore, with regards to the fact that deformations of approximately 20mm were found on the bottom shell plates during the safety inspections of the sister ships, given that the deformations could not be simulated even when loads very close to the ultimate hull girder strength were applied, and that some buckling deformations of the bottom shell plates of The Ship had been found even though she is presumed not have encountered loads close to her hull strength, it is necessary to clarify the mechanism of these buckling deformations by both full-scale stress measurements of actual ships and numerical simulations.

## Further Actions

Further investigations including numerical simulations of the wave loads and the hull structure strength as well as full-scale stress measurements of sister ships will be carried out to clarify the cause of the accident and to establish safety measures to prevent the occurrence of similar accidents.

Furthermore, in order to determine the scope of ships for safety measures, numerical simulations of hull strength and acting loads, as well as full-scale stress measurements of actual ships will be carried out on large container ships with designs other than The Ship.

## Temporary Safety Measures

As stated above, while the Committee is still in the process of extrapolating the cause of the accident scenario and developing upon safety measures, the Committee recommends that the following actions be taken as temporary safety measures for existing container ships with loading capacities similar to or greater than 8,000 TEU class.

A safety inspection on the bottom shell plates to the extent possible should be conducted in order to verify the presence of buckling deformations. If such deformations are found during this inspection, consult a classification society regarding the proper measures to be taken.

In accordance with the deliberations at the IMO related to the enforcement of container weight verification prior to loading, verification of the actual weight of container cargoes provided by the shipper is recommended in order to reduce uncertainty related to the still water bending moments of large container ships.

## 8. Results of the Investigation and Future Tasks

Based on the consideration of the estimation of the acting load based on conditions at the time of the accident, the evaluation of the hull strength based on safety inspections of The Ship's sister ships, and the consideration of accident occurrence scenarios, the results and future tasks are presented in the following sections.

### 8.1 Weight Distribution and Still Water Bending Moment

Investigation Results

Since it was difficult to make an estimation of the weight distribution based on certain assumptions with respect to the presence of cargo in excess of its manifested weight and uneven weight distribution, simulations for acting loads were conducted by using the declared weights for the cargo loading. In this case, the still water bending moment would be equal to Ms=$6.0\text{x}10^6$ kN-m.

Future Tasks

With regards to the proper management of cargo weight on the hull for large container ships in the 8,000 TEU class and over in particular, cargo loading planning for actual voyages could be frequently reached to the maximum permissible still water vertical bending moment (hogging condition). In accordance with the deliberations at the IMO related to the enforcement of container weight verification prior to loading, verification of the actual weight of container cargoes provided by the shipper is recommended as a safety measure for large container ships.

(see Sections 6.2 and 6.3)

### 8.2 Sea State Conditions at the time of the Accident and Wave Bending Moment

Investigation Results

Based on the estimation in the long crested irregular waves under the sea conditions at the time of the accident (significant wave height: 5.5m, mean wave period: 10.3 seconds), the maximum load at the time of the accident was $M_w=2.0\text{x}10^6$ kN-m (wave), and $M_{whip}=1.4\text{x}10^6$ kN-m (whipping), $M_w+M_{whip}=3.4\text{x}10^6$ kN-m in total. Therefore the estimated bending moment is $M_s+M_w+M_{whip}=9.4\text{x}10^6$ kN-m in total, by combining the still water bending moment with the wave induced vertical bending moment.

Future Tasks

Even though The Ship encountered sea states that generated loads of approximately $10.0\text{x}10^6$ kN-m three and a half years prior to this accident, no such fracturing occurred in that instance. This means that (1) the possibility of loads acting on the hull exceeding the estimated values at the time of the accident, (2) the possibility of the weakening of the hull strength due to the extent of buckling deformation on the bottom shell plates and/or any other reasons, and (3) both (1) and (2) may be taken into consideration, so that further investigations are necessary to verify the effects of uncertainties involved in the strength and acting load simulations.

Moreover, the following uncertain factors and technical challenges may exist in the simulations and it is important to upgrade the technology of evaluation and to calibrate it by full-scale stress measurements of ships;

・Accuracy of estimation of whipping effect on wave loads in the simulation
・The variation of estimated wave loads due to the difference of the phase angle of each component waves in the time domain analysis
・The difference of wave directional spectrum between short crested irregular waves (real sea state) and long crested irregular waves (in simulation and model tests)
・Development of the method for estimating load under multi-directional waves and for simulating structural strength in that wave condition.

(see Sections 6.2 and 6.3)

### 8.3 Whipping Effect on Bending Moment

Investigation Results

Even in cases where wave height is not considerably high, superposition of the load due to ship motion and hull girder vibration (whipping load) may be substantial depending on the wave period. While conventional rules for hull structure do not consider the effect of whipping on vertical bending moments explicitly, the effect of whipping accounted for 70% of the wave induced vertical bending moment in the present case.

Future Tasks

Effect of the load due to hull girder vibration (whipping load) superposed on the load from ship motions shall be evaluated from the view point of hull structure rules as well as through the full-scale stress measurements of ships.

For example, the load simulation only takes into account long crested and single-directional long crested waves. However, as observed in Annex 6 with regard to whipping effect, actual ships also encounter short crested and multi-directional waves.

Furthermore, technical knowledge with regards to the behavior of hull collapse caused by whipping loads with limited energy of this kind is very restricted at the present, and should be clarified in the near future along with the development of a reasonable method of evaluating strength. (If some confirmative findings are gained from full-scale stress measurements of sister ships, this could be a possible explanation as a mechanism for generating the buckling deformation detected in the bottom shell plate of the sister ships.)

(see Section 6.2)

### 8.4 Ultimate Hull Girder Strength

Investigation Results

The ultimate hull girder strength simulations with the following four initial shape imperfection cases were carried out on a three-hold model, which showed ultimate strength range of $M_{ult}$=14.0~15.0x $10^6$ kN-m.

Case 1: No initial shape imperfection

Case 2: Initial shape imperfection with 4mm amplitude in plate buckling mode

Case 3: Initial shape imperfection in “hungry-horse” mode of plate with standard amplitude level specified in JSQS (Japanese Shipbuilding Quality Standard: the acceptable range of construction accuracy used by Japanese shipbuilders)

Case 4: Initial shape imperfection taking into account the concave/convex deformation observed in the inspection of sister ships

With regards to the buckling deformations detected on the bottom shell plate during the inspections of the sister ships, as only very minimal deformation was calculated in the simulations of hull girder strength at loads close to the ultimate strength, the residual deformations were not reproduced by the simulations.

Further, in the case where a local wavy deflection in a circular shape with 30mm amplitude across butt joint was assumed in full breadth on the bottom shell plate, the ultimate strength was weaken down to 13.4x$10^6$ kN-m.

Future Tasks

Although buckling residual deformation on the bottom shell plate was not simulated, deformations were actually observed even though The Ship was not thought to have encountered loads close to the hull girder strength (ultimate strength). Therefore, it is necessary to clarify the mechanisms for generating buckling residual deformation on the bottom shell based on full-scale stress measurements on ship and simulations. Investigations are necessary for the out-of-plane deformation regarding the cause of its generation and the resulting effects (possibly by comparing the aspect ratio of plating).

In order to evaluate reduction of hull girder strength due to initial deformation, it is necessary to conduct verification using three hold model for double bottom structure along with the sensitivity screening of deformation shapes. Potential causes for generating such residual deformation should also be investigated from the view points of both structural strength and acting loads.

## 8.5 Uncertainty Factors involved in the Evaluation of Ultimate Hull Girder Strength and Required Rule Values

Investigation Results

In the present investigation, acting loads based on the non-linear strip method were estimated at $M_s+M_w+M_{whip}=9.4x10^6$ kN-m, while the ultimate hull girder strength based on the three hold model analysis (simulation) was calculated as $M_{ult}=14.0\sim15.0x10^6$ kN-m, so that the fracturing conditions were not met. The estimated ultimate strength of The Ship was found to be around 126% of the strength required by the classification rules (a surplus margin of 26%).

Future Tasks

With regards to the following uncertain factors and the not fully established quantitative measures involved, the appropriateness of the safety margins, which current classification rule requirements ensure, should be reviewed as to whether the margin is satisfactory, and also comparisons of large container ships with designs other than The Ship should be carried out.

・The whipping effect on wave bending moment
・Surplus margin of wave bending moment required by classification rules for whipping component
・The uncertainty in still water bending moment due to the uncertainty of container weight distribution
・Ultimate strength taking into account of transverse load (bottom and side water pressure, container load, in particular, the asymmetrical water pressure distribution due to oblique waves and two-directional waves), etc.
・Variability of the material properties and effect of welding residual stress

## 9. Recommended Safety Measures

Further Actions

As the cause of this accident has not yet fully been clarified quantitatively, measurements of acting loads on The Ship's sister ships will be carried out in order to verify the investigation results as well as the acting load and strength simulations including uncertain factors, more accurately reproduce the accident conditions, and develop safety measures to prevent the occurrence of similar accidents.

(see Section 8.5)

Furthermore, in order to determine the range of ship scale for which these safety measures should be applied, simulations of hull strength and acting loads, as well as full-scale stress measurements of actual ships will be carried out on large container ships with designs other than The Ship.

(see Section 8.5)

Temporary Safety Measures (Ships in service)

While the Committee is still in the process of extrapolating the accident scenario and developing upon safety measures, the Committee recommends that the following actions be carried out on ships with loading capacities similar to or greater than 8,000 TEU class as temporary safety measures.

- A visual safety inspections on the bottom shell plates to the extent possible should be conducted on large container ships which do not require ballast water to maintain stability (primarily ships over 45m breadth, carrying 8000 TEU or greater) to confirm the presence of buckling deformations. Where the deformations are found, consult with a classification society regarding the proper measures to be taken. (see Section 8.4)

- With regards to the proper management of cargo weight on the hull for large container ships in the 8,000 TEU class and over in particular, cargo loading planning for actual voyages could be frequently reached to the maximum permissible still water bending moment (hogging condition). In accordance with the deliberations at the IMO related to the enforcement of container weight verification prior to loading, verification of the actual weight of container cargoes provided by the shipper is recommended as a safety measure for large container ships. (see Section 8.1)

- Other general items for caution include rough sea avoidance maneuvers such as speed reduction. (see Section 6.2.4)

Annex 7

# Committee on Large Container Ship Safety
# Members List

Chair Person

| | |
|---|---|
| Professor, Dr. Eng, Yoichi SUMI | Yokohama National University |

Members (Alphabetical order)

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|---|---|
| Professor, Dr. Eng, Masahiko FUJIKUBO | Osaka University |
| Mr. Yoshikazu KAWAGOE | Executive Officer, Mitsui O.S.K. Lines, Ltd. |
| Mr. Mitsuhiko KIDOGAWA | Operating Officer,<br>General Manager of Hull Department<br>NIPPON KAIJI KYOKAI (ClassNK) |
| Mr. Kazuya KOBAYASHI | Associate Officer, General Manager, Engineering Division, Ship & Offshore Structure Company<br>Kawasaki Heavy Industries, Ltd. |
| Mr. Yoshiyuki NAKAJIMA | General Manager of Planning & Development Department<br>Japan Marine United Corporation |
| Mr. Toyohisa NAKANO | General Manager, Technical Group<br>KAWASAKI KISEN KAISHA, LTD. |
| Mr. Mitsuhiko SUNOUCHI | General Manager, Technical Group,<br>Nippon Yusen Kabushiki Kaisha |
| Dr. Eng, Kenkichi TAMURA | National Maritime Research Institute |
| Mr. Naoki UEDA | Senior General Manager<br>Ship & Ocean Engineering Department<br>Shipbuilding & Ocean Development Division<br>Commercial Aviation & Transportation Systems<br>Mitsubishi Heavy Industries, Ltd. |

Secretary

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