Ship Stability Calculation for Cause Analysis of No. 501 Oryong Sinking Accident

† Sang-Gab Lee · Jae-Seok Lee* · Jee-Hun Kim**

*, † Division of Naval Archit. and Ocean Systems Eng, Korea Maritime & Ocean University, Marine Safety Technology, Busan, Korea
**Department of Stability & Load Line, Korea Ship Safety Technology Authority, Sejong-Si, Korea

Abstract: Deep-sea fishing vessel No. 501 Oryong was fully flooded through the openings and was sunk down to the bottom of sea due to the very rough sea weather on the way of evasion after fishing operation in the Bering Sea with many crews dead and/or missed. In this study, calculation of ship stability was carried out using KST-SHIP (ship calculation system of KST), considering the effect of flow fluid and fish catch arrangement according to the progress of its sinking accident, and damage stability was analyzed. For this study, intact stability calculation of its accident ship under the full load departure condition and its calculation result were verified by comparing with each other, and intact stability according to displacement from the departure of accident ship just before the accident was calculated and analyzed. Damage stability was calculated according to the progress during sinking accident and also analyzed.

Key words: Deep-Sea Fishing Vessel No. 501 Oryong, Cause Analysis of Sinking Accident, Ship Stability Calculation, KST-SHIP (ship calculation system of KST), Intact Stability, Damage Stability.
1. Introduction

- Two steps of flooding and sinking simulation scenarios
  - Case 1: Case of much seawater inflow into the inboard during dropping fish catch due to excessive fishing activities and deteriorating weather conditions, and inclination occurrence to the starboard side due to port transverse wave
  - Case 1-0a: Case of a voyage under waves of stern angle 44° of starboard side with an incomplete shutdown hatch cover, after opening hatch cover of fish binusar following hauling on neat and much seawater inflow during dropping fish catch
  - Case 1-0b: Another case of a voyage under waves of stern angle 20° of starboard side in Case 1-0a
  - Case 1-1: Case of a continuous seawater inflow during avoidance under waves of stern angle 20° of port side, turning to Navarone, 270° direction, following Case 1-0a
  - Case 1-2: Case of inclination until around 20° to the starboard side and much seawater inflow into the steering gear room under a lot of continuous seawater inflow, with wooden partition broken and inflow of fish catch and seawater into processing & working space under waves of stern angle 20° of port side, following Case 1-1

- Full-scale ship flooding and sinking simulation

1. Introduction

- Two steps of flooding and sinking simulation scenarios
  - Case 2-0a: Case of a little bit inclination to the starboard side by a continuous seawater inflow through a sewage outlet in Case 2-0a, keeping a temporary balance for a while
  - Case 2-1: Case of inclination until around 5°-10° to the port side under waves of stern angle 25.5° of starboard side, after counter clockwise turning from Case 2-0
  - Case 2-2: Case of inclination until around 30°-35° to the port side and sinking of the stern with a continuous seawater inflow, following Case 2-1
  - Case 2-3: Case of a continuous inclination over about 45°-50° to the port side and large sinking of the stern with a continuous seawater inflow, following Case 2-2
  - Case 2-4: Case of inclination over 60° to the port side and great sinking of the stern with a lot of seawater inflow, following Case 2-3
  - Case 2-5: Case of inclination until around 90° to the port side and fully complete sinking of the whole ship with more large seawater inflow, following Case 2-4

- Full-scale ship flooding and sinking simulation

1. Introduction

- Two steps of flooding and sinking simulation scenarios
  - Case 3-0a: Case of a voyage under waves of stern angle 44° of starboard side with an incomplete shutdown hatch cover, after opening hatch cover of fish binusar following hauling on neat and much seawater inflow during dropping fish catch
  - Case 3-0b: Another case of a voyage under waves of stern angle 20° of starboard side in Case 3-0a
  - Case 3-1: Case of a continuous seawater inflow during avoidance under waves of stern angle 20° of port side, turning to Navarone, 270° direction, following Case 3-0a
  - Case 3-2: Case of inclination until around 20° to the starboard side and much seawater inflow into the steering gear room under a lot of continuous seawater inflow, with wooden partition broken and inflow of fish catch and seawater into processing & working space under waves of stern angle 20° of port side, following Case 3-1

- Full-scale ship flooding and sinking simulation
1. Introduction

- Full-scale ship flooding and sinking simulation
  
  Seawater inflow flooding amount and ratio of exterior inflow openings according to simulation scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Seawater Inflow</th>
<th>Inflow Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>250</td>
<td>0.5</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>500</td>
<td>0.7</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>750</td>
<td>0.9</td>
</tr>
</tbody>
</table>

1. Introduction

- Calculation of ship stability was carried out using KST-SHIP (ship calculation system of KST), considering the effect of flow fluid and fish catch arrangement according to the progress of its sinking accident, and damage stability was analyzed.
  - intact stability calculation of its accident ship under the full load departure condition and its calculation result were verified by comparing with each other
  - intact stability according to displacement from the departure of accident ship to the just before the accident was calculated and analyzed
  - damage stability was calculated according to the progress during sinking accident and also analyzed as follows:
    - Case 1: Case of much seawater inflow into the inboard during dropping fish catch into the fish bunker due to excessive fishing activities and deteriorating weather conditions, and inclination occurrence to the starboard side due to port transverse wave
    - Case 1-10): much seawater inflow during dropping fish catch through fish bunker and flooding condition

1. Introduction

- Considerations of full-scale ship flooding - sinking simulation
  - As the ship headed to the port or starboard side, a lot of seawater flowed into the processing & working space and even engine room and fish holds with lower location than the center of gravity, and then its stem part with an already stem trim was sunk under the surface according to the increasing stem draft more and more. If seawater flowed just into the processing & working space above the center of gravity, it could be thought that the stem draft or subsideance of stem part would not be increased so greatly, and that ship stability would be worsened more rapidly in accordance with the further advancement of its heel.
  - It could be confirmed that the accident ship was sunk down from the simulation response behaviors with different situation from the capsizal and sinking due to the simple loss of stability, in that the stem part subsided under the surface with the center of gravity descended a little bit down due to the seawater inflow in the engine room and fish holds, and with continued large angle of heel at the same time of submerged stem part under the surface even though its heel was progressed greatly.

1. Introduction

- Case 1-3(25°): Case of a continuous seawater inflow through an incomplete shutdown hatch cover and sewage outlet with broken cover after disable steering gear, and inclination until around 25° to the starboard side, following Case 1-2
  - Case 1-4(30°): Case of inclination until around 30° to the starboard side with a continuous seawater inflow, following Case 1-3
  - Case 2: Case of counter clockwise turning the ship from a temporary balance by moving the fish catch and fuel oil to the port side and discharging some of seawater using drain pumps, and rapid inclination to the port side and sinking down under starboard transverse wave.
  - Case 2-0(0°): Case of a temporary balance
  - Case 2-20(0°): Case of inclination until about 20° to the port side with a continuous seawater inflow
  - Case 2-3(45°): Case of a continuous inclination until about 45° to the port side with a continuous seawater inflow

1. Introduction

- Intact stability standard
  - Stability standard for wave and wind follows:
    - area B must be above the area A in righting arm curve
    - rolling angle $\theta = KV \cdot V^2 / r_2$ (degree)
  - Damage stability standard
    - calculation of righting arm (GZ) under flooding state and after flooding of rolling angle and deck line according to the process of sinking accident using KST-SHIP applied by the Lost Buoyancy Method
    - analysis of damage stability, applying intact stability standard to the state after flooding because of no damage stability standard in the case of fishing boat
    - It could be considered that this could more objectively analyze the damage simulation results from the stability side, and that this would be the best way for the investigation of accident cause and prediction of simulation results.
2. Verification of Intact Stability Calculation Result of KST-SHIP

- Stability calculation sheet under the full load departure condition was compared with each other.
- For the verification of intact stability calculation results of accident ship using KST-SHIP.
- Tables 1 & 2: the comparison of hydrostatic characteristics and volume according to compartment, such as fuel oil tank (F.O.T.), lubrication oil tank (L.O.T.), fresh water tank (F.W.T.), etc., between the stability calculation sheet of accident ship and calculation by KST-SHIP.
- It could be found that there is very small in their errors.
2. Verification of Intact Stability Calculation Result of KST-SHIP

- Hydrostatic characteristics and calculation result of righting arm (GZ) and its curve under full load departure condition
- KST-SHIP calculation would be generally agreed with stability calculation sheet

Table 5 Comparison of stability criteria between stability calculation and KST-SHIP calculation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Stability calculation</th>
<th>KST-SHIP calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre of Gravity</td>
<td>10.2 m</td>
<td>10.3 m</td>
</tr>
<tr>
<td>Centre of Gravity (G)</td>
<td>2.5 m</td>
<td>2.6 m</td>
</tr>
<tr>
<td>Centre of Buoyancy (B)</td>
<td>9.3 m</td>
<td>9.5 m</td>
</tr>
<tr>
<td>Centre of Lateral Resistance (C)</td>
<td>1.8 m</td>
<td>1.9 m</td>
</tr>
<tr>
<td>Centre of Metacentre (GZ)</td>
<td>0.7 m</td>
<td>0.8 m</td>
</tr>
<tr>
<td>Centre of Mass (GZ)</td>
<td>0.6 m</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Angle of Max. BC at 20% dist. of GZ</td>
<td>10°</td>
<td>11°</td>
</tr>
<tr>
<td>Angle of Max. BC at 50% dist. of GZ</td>
<td>20°</td>
<td>22°</td>
</tr>
<tr>
<td>Angle of Max. BC at 80% dist. of GZ</td>
<td>30°</td>
<td>33°</td>
</tr>
</tbody>
</table>

3. Intact Stability Calculation according to Displacement

- Intact stability calculation and analysis in the case of seawater inflow opening at the damage of sewage outlet cover
- Hydrostatic characteristics of each weight according to weight distribution and of total ship in the intact stability calculation sheet, righting arm (GZ) according to hawling angle, and righting arm curves were obtained under the departure from the port on 7.10, under the fishing on 8.14, in the morning and right before the accident on the accident date 12.1.
- their intact stability criteria were summarized in Table 8.
  - it could be found that intact stability criteria were satisfied under the departure from port on 7.10, and the fishing on 8.14.
  - in the case in the morning and right before the accident on the accident date 12.1, stability criteria were partially below the standard, and area ratios by the severe wave and wind were also very small compared to the departure from the port on 7.10 and under the fishing on 8.14.

Table 7 Displacement and draft according to loading condition at each fishing date on voyage

<table>
<thead>
<tr>
<th>Date</th>
<th>Total Displacement</th>
<th>Total Load</th>
<th>Draft</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.10</td>
<td>1250 m^3</td>
<td>1000 m^3</td>
<td>4.5 m</td>
</tr>
<tr>
<td>8.14</td>
<td>1300 m^3</td>
<td>1100 m^3</td>
<td>5.0 m</td>
</tr>
<tr>
<td>12.1</td>
<td>1400 m^3</td>
<td>1200 m^3</td>
<td>5.5 m</td>
</tr>
</tbody>
</table>

3. Intact Stability Calculation according to Displacement

- Intact stability calculation and analysis in the case of seawater inflow opening at the damage of sewage outlet cover
- Even though the decreasing trend of righting arm (GZ) according to large displacement order could be confirmed, stability during fishing on 8.14 was relatively good due to the low gravity center since fish catch was filled in the fish holds.
- It could be found that stability criteria in the morning and right before the accident on 12.1 were below the standard, and area ratios by the severe wave and wind were also very small compared to the departure from the port on 7.10, and the fishing on 8.14.
  - This might be the result of the great reduction of seawater inlet angle due to the transition of seawater inflow opening from the low of chimney to sewage outlet since its cover was broken in 2014.9. Sinking accident could be predicted that this would be due to the flooding of continuous seawater inflow since restoration was not easy after the ship list.

Table 9 Comparison of stability criteria according to displacement from 7.10 – 12.1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>7.10</th>
<th>8.14</th>
<th>12.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre of Gravity</td>
<td>10.2 m</td>
<td>10.3 m</td>
<td>10.4 m</td>
</tr>
<tr>
<td>Centre of Gravity (G)</td>
<td>2.5 m</td>
<td>2.6 m</td>
<td>2.6 m</td>
</tr>
<tr>
<td>Centre of Buoyancy (B)</td>
<td>9.3 m</td>
<td>9.5 m</td>
<td>9.6 m</td>
</tr>
<tr>
<td>Centre of Lateral Resistance (C)</td>
<td>1.8 m</td>
<td>1.9 m</td>
<td>1.9 m</td>
</tr>
<tr>
<td>Centre of Metacentre (GZ)</td>
<td>0.7 m</td>
<td>0.8 m</td>
<td>0.8 m</td>
</tr>
<tr>
<td>Centre of Mass (GZ)</td>
<td>0.6 m</td>
<td>0.7 m</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Angle of Max. BC at 20% dist. of GZ</td>
<td>10°</td>
<td>11°</td>
<td>11°</td>
</tr>
<tr>
<td>Angle of Max. BC at 50% dist. of GZ</td>
<td>20°</td>
<td>22°</td>
<td>23°</td>
</tr>
<tr>
<td>Angle of Max. BC at 80% dist. of GZ</td>
<td>30°</td>
<td>33°</td>
<td>34°</td>
</tr>
</tbody>
</table>

252
3. Intact Stability Calculation according to Displacement

- Comparison of righting arm curve and stability criteria in the case of seawater inflow opening between at the damage of sewage outlet cover and at the bottom of chimney

Fig. 5 Comparison of righting arm (G) curve according to seawater inflow opening in the morning and right before accident on 12.1.

<table>
<thead>
<tr>
<th>Stability criteria</th>
<th>0%</th>
<th>12%</th>
<th>24%</th>
<th>36%</th>
<th>48%</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2 Curve vs. join (deg)</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
</tr>
<tr>
<td>D2 Curve vs. join (deg)</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
</tr>
<tr>
<td>D2 Curve vs. join (deg)</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
</tr>
<tr>
<td>D2 Curve vs. join (deg)</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
</tr>
<tr>
<td>D2 Curve vs. join (deg)</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
<td>13.7</td>
</tr>
</tbody>
</table>

4. Damage Stability Calculation and Analysis in Accident

- Since the processing and working space of accident fishing vessel is located above the center of gravity of ship, it could be confirmed from the simulation results using FSI (Fluid-Structure Interaction) analysis technique that damage stability would have a remarkably dropping and worsening trend as the seawater inflow into the processing and working space.

- In this study, damage stability scenarios were set up and calculation was carried out according to seawater flooding situation into the compartment from the simulation results.

- As confirmed from the flooding - sinking simulation results, whereas there was no seawater inflow into the engine room since engine room was closed and seawater of the engine room entrance was drained when ship was inclined around 35° to the starboard, partial seawater flowed in the fish hold when fish catch was moved to the port side, and a lot of seawater flowed into the engine room and fish hold when the ship was inclined around 30° and 45° to the port side.

4. Damage Stability Calculation and Analysis in Accident

- Damage stability calculation was performed step by step according to the seawater inflow into the engine room and fish hold as well as the processing and working space, for 2 cases largely according to the progress situation of accident ship sinking accident.

- As Figure 2 shows, the first and second fish holds were changed according to the sinking accident progress.

4. Damage Stability Calculation and Analysis in Accident

- Case 1 (inclination to the stbd. side due to port transverse wave)

- damage stability calculation was carried out and analyzed for the seawater inflow into the fish holds as well as processing and working space by stages in 3 detailed cases, Case 1-1(10°), Case 1-3(starboard 25°) and Case 1-4(starboard 35°).

- As Figure 3 shows, the first and second fish holds were changed according to the sinking accident progress.

- As Figure 4 shows, the first and second fish holds were changed according to the sinking accident progress.

4. Damage Stability Calculation and Analysis in Accident

- Case 1

Table 11 Permeability according to flooding damage compartment in Case 1

<table>
<thead>
<tr>
<th>Damage Compartment</th>
<th>Case 1-1(10°)</th>
<th>Case 1-3(25°)</th>
<th>Case 1-4(35°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heli Deck Hold</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Engine Room</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Processing Room</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Fish Hold</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 6 Fish hold condition according to sinking accident progress

Fig. 7 Flooding damage compartment situation in Case 1

Fig. 8 Righting arm (G) curve in Case 1
4. Damage Stability Calculation and Analysis in Accident

**Case 1**
- Table 13: Righting arm (GZ) and area ratio in Case 1
- Table 13: Damage stability criteria in Case 1
- Table 14: Permeability according to flooding damage compartment in Case 2

**Case 2**
- Damage stability calculation was carried out and analyzed for the seawater inflow into the fish holds as well as processing and working space by stages in 3 detailed cases, Case 2-0(0°), Case 2-2-0 port 30°, and Case 2-2-0 port 45°.

Fig. 9 Flooding damage compartment situation in Case 2

Fig. 10 Righting arm (GZ) curve in Case 2

**Case 2**
- It could be found that the stability criteria was satisfied and area ratio by severe wave and strong wind was also favorable in Case 1-0(0°), and that all stability criteria were not satisfied except GoM and area ratio, also unsatisfied in Cases 1-3(25°) and 1-4(35°).
- This means there was no enough stability and dynamic stability energy since stability occurred after 25° and 35° due to the flooding damage list.

4. Damage Stability Calculation and Analysis in Accident

- **Case 2**
  - All criteria for the dynamic stability were not satisfied except GoM and area ratio, also unsatisfied in Cases 2-2(30°) and 2-3(45°). As expected, the situation was more worsened in Case 2-3(45°) than Case 2-2(30°).
  - From this damage stability calculation in Case 2, it could be predicted that the accident ship would be sunk down with more gradually flooding from the stern part, as flooding in fish holds and engine room would be progressing with continuous seawater inflow through the hatch cover and sewage outlet after proceeding list by the severe wave and strong wind.

5. Considerations & Conclusions

- As the analysis result of intact stability, seawater inlet angle was greatly decreased due to the damage of sewage outlet cover, and accident ship could not easily restored after heeling due to the restoration energy reduction due to the inflow seawater through low seawater inlet angle according to the heeling of accident ship by the severe wave and wind.
- Stability calculation according to inflow progress state was analyzed for the damage stability. Since analysis result of damage stability was also not satisfied with area ratio by severe wave and wind pressure and standard related to the dynamic stability due to the incompletely sealed hatch cover and damage of sewage outlet cover, it could be predicted that seawater continuously flowed in with gradually severe heeling angle due to very hard restoration during list and that the accident ship was sunk due to the first flooding from the stern through the several analyses.

5. Considerations & Conclusions

- It could be considered that this would be very important basis for the cause investigation of sinking accident by showing the coincidence in the large part of heeling angle and flooded condition, etc., even compared with flooding and sinking simulation.

Acknowledgement

- This research was performed by the support of Korea Maritime Safety Tribunal. The authors would like to express our appreciation to their supports.
- This paper is a part of the research report including flooding & sinking simulation and stability calculation results, which was basis of the Sinking Accident Safety Investigation Report of Deep-Sea Fishing Vessel No. 501 Oryong by Special Investigation Department of Korea Maritime Safety Tribunal.