Design Development of Corrugated Bulkheads

TSCF 2010 Shipbuilders Meeting
27 October 2010

Nippon Kaiji Kyokai

Topics

- Purpose of corrugated bulkheads
- Structural types of corrugated bulkheads
- Types of damages
- Design development
- Latest rule requirements
- Conclusion
Typical Hull Structure of Tankers

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000 t</td>
<td>20,000 t</td>
<td>30,000 t</td>
</tr>
<tr>
<td>50,000 t</td>
<td>100,000 t</td>
<td>DWT</td>
</tr>
</tbody>
</table>

Purpose of corrugated bulkheads

- Plane surface as cargo tank boundary
- Complete cargo tank washing
- Minimize the cargo residue
- Maximum cargo tank capacity
Purpose of corrugated bulkheads

Structural types of corrugated bulkheads

Types of damages

Design development

Latest rule requirements

Conclusion

### Structural types of corrugated bulkheads

<table>
<thead>
<tr>
<th>Types of cargo tank bulkhead</th>
<th>Vertically Corrugated BHD</th>
<th>Vertically Corrugated BHD</th>
<th>Horizontally Corrugated BHD</th>
<th>Horizontally Corrugated BHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank cleaning</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Tank capacity</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
</tr>
</tbody>
</table>

◎: Very good  ○: Good
Structural types of corrugated bulkheads

Types of Transverse Corrugated Bulkheads

Types of Longitudinal Corrugated Bulkheads

Number of ships (ClassNK) delivered in 1990-2008

Next Topic

- Purpose of corrugated bulkheads
- Structural types of corrugated bulkheads
- Types of damages
- Design development
- Latest rule requirements
- Conclusion
ClassNK

Typical damages of corrugated bulkheads

Stress concentration at toes of fillet welding

Cargo Tank

Corru. BHD

Inner Bottom

Cause of damages

✓ Defects of welding (Overlapping, Undercutting)
✓ Lack of supporting structures
✓ Lack of continuity (misalignment)
Purpose of corrugated bulkheads
- Structural types of corrugated bulkheads
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1. Design of supporting structures

**Stiffeners under corrugation flange**

**Floors and girders under corrugation flange**
**Effectiveness of supporting structure**

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of stiffener / d₀</td>
<td>0.31</td>
<td>0.46</td>
<td>0.62</td>
<td>0.92</td>
<td>2.06</td>
</tr>
</tbody>
</table>

**Outcome:**

- Stress of end connection decreases by deeper supporting structure
- Half of corrugation depth is considered as effective support depth
- Floors/girders are suitable as supporting structure

**Suitable supporting structure under flange plate of corrugated bulkhead gives higher reliability**
Design development

2. Application of full penetration welding

Full penetration welding has been recently applied at the corner of corrugation of lower end connection with weld toe grinder.

Effectiveness of full penetration welding

Comparative stress evaluation
- by bending load and tensile load
- with various gaps
Von-Mises stress caused by bending / tensile load

Bending load

Full penetration  Gap 0mm (Fillet)  Gap 2mm

Tensile load

Von-Mises stress by tensile load

Relative stress at Position A
(Stress of Full Penetration = 1.0)
Experimental test of stainless steel (SUS316L)

Tensile test (as weld)

Tensile test (Grinder)

Weld toe grinding

Tensile test (as weld)

Higher tensile load

(Tensile test (Grinder)

Higher tensile load

(ClassNK Research Institute)

Application of full penetration welding

Outcome;

- Cracks by bending load initiate from weld toe regardless of root gap
- Cracks by tensile load initiate from weld toe or root
- Root gaps lead to higher stress at weld toe and root by tensile load
- Gap control and satisfactory throat thickness are important
- Full penetration welding contributes;
  - to mitigate the risk of gap control
  - to give satisfactory throat thickness
- Grinder or TIG welding which gives more smooth surface further contributes to lower the stress concentration at weld toe

Full penetration welding and smoothed weld toe at corrugation corner gives higher reliability
Design development

3. Verification of designs with gussets and shedder plates

Impact by gusset and shedder plates were investigated

Impact to the design by gusset and shedder plates

1. Reduced stress at critical point

2. Stress concentration at the crossing of shedder plates

3. Extended enclosed space leads to a loss of cargo capacity
Reinforcement by gusset and shedder plate

Outcome;

- Gusset and shedder plates are often used in the design of corrugated bulkheads in bulk carriers and recommended in CSR for tankers.
- Gusset and shedder plates definitely contribute to lower the stress.
- However, following deep considerations are necessary;
  - Manholes and air holes to avoid formation of any gas pocket.
  - Bracketed Stiffener where adjacent shedder plate cross.
  - Careful workmanship of welding in narrow space.
- Extended gusset plate leads to some loss of cargo capacity.

Better to keep just as recommendation instead of mandatory requirement in tanker designs.
**CSR Requirements**

**Prescriptive requirements:**

- Local strength (Plate thickness, Section Modulus)
- Arrangement of supporting structures
- Full penetration welding to lower end of vertical corrugated bulkhead connections

![Diagram](image1)

**Recent practice**

**Requirements of Finite Element Analysis (FEA):**

- Overall stress and buckling analysis by Coarse Mesh
- Detail stress analysis of lower end connection of vertically corrugated bulkhead by Fine Mesh

![Diagram](image2)
Sensitivity of mesh size at corrugation corner

Parametric analysis to know the sensitivity of mesh size

- Coarse Mesh
- Fine Mesh (50mm x 50mm)
- Very Fine Mesh (17mm x 17mm)

Von-Mises stress depending on mesh size

- MR Tanker
- Load Case: B4-1 (Zig-Zag)
- Thickness: 22mm (net)
- S.G. (t/m³) = 0.8, 1.025, 1.3, 1.5, 1.85

- Element stress strongly depends on the mesh size near the corner
- Definition of mesh size is important when detail analysis is required
Impact on scantlings by CSR Fine Mesh

Case studies to investigate the impact of CSR criteria
- MR Tanker
- Transverse Corrugate Bulkhead (Vertical)
- Critical Load Case : B4-5a (Zig-Zag)
- S.G. = 1.025

Ships for study
Ship A : New design vessel which fully complies with CSR
Ship B : Non-CSR ship with successful service experiences without any damage records
Ship C : Non-CSR ships with damage records
Ship C with bracket : After reinforcement of ShipC without any further damage records
Impact on scantlings by CSR Fine Mesh

- CSR contribute to more robust corrugated bulkhead designs

Feedback from Japanese shipyards

- Considerable scantling increase even from designs having demonstrated history of successful service experiences
- Required thickness tends to reach to the maximum allowable thickness for the fabrication of cold-bending
- Modification of corrugation span by fitting upper/lower stools or reduction of design cargo density has been required, which inevitably leads to a loss of cargo capacity and deadweight

Further rule development considering such as edge treatment and anti-fatigue steel is anticipated

Conclusion

- Corrugated bulkheads are essential structure for product / chemical tankers
- Sufficient service records have proved the advantage
- Rules and designs have been improved to cover complexities of fabrications and operations
- However it has been also reported that designers need to modify the initial design to save unacceptable scantling increase due to latest CSR requirements
- Continuous update of rules allowing establishment of new technologies should also be performed, while watching valuable service experiences of existing designs
Thank you for your Attention

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