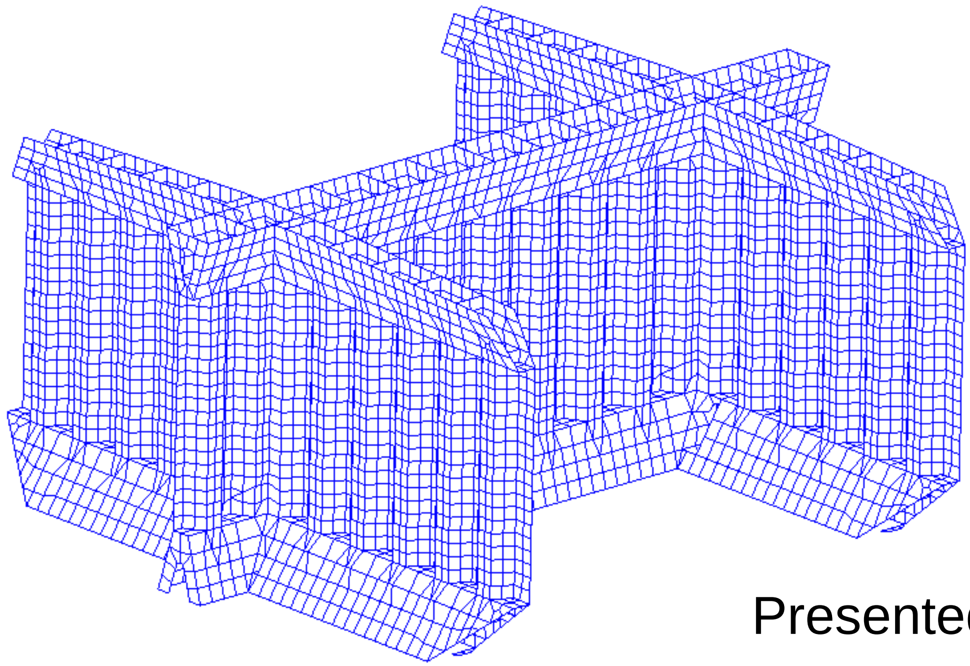
# Comparison Analysis between CSR-OT and CSR-H for Corrugated Bulkhead of Large Product Tanker



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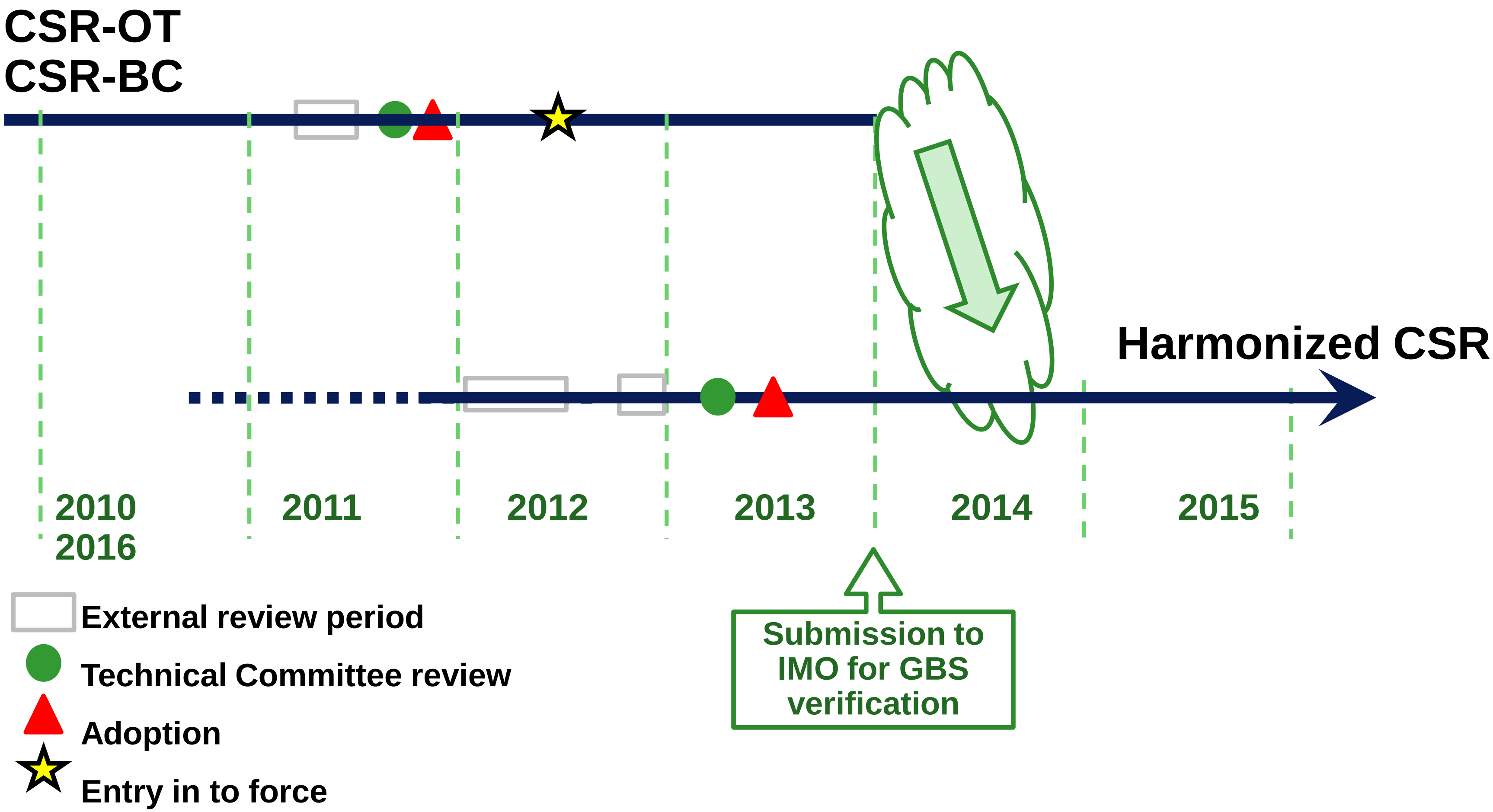
October 23th, 2013, China

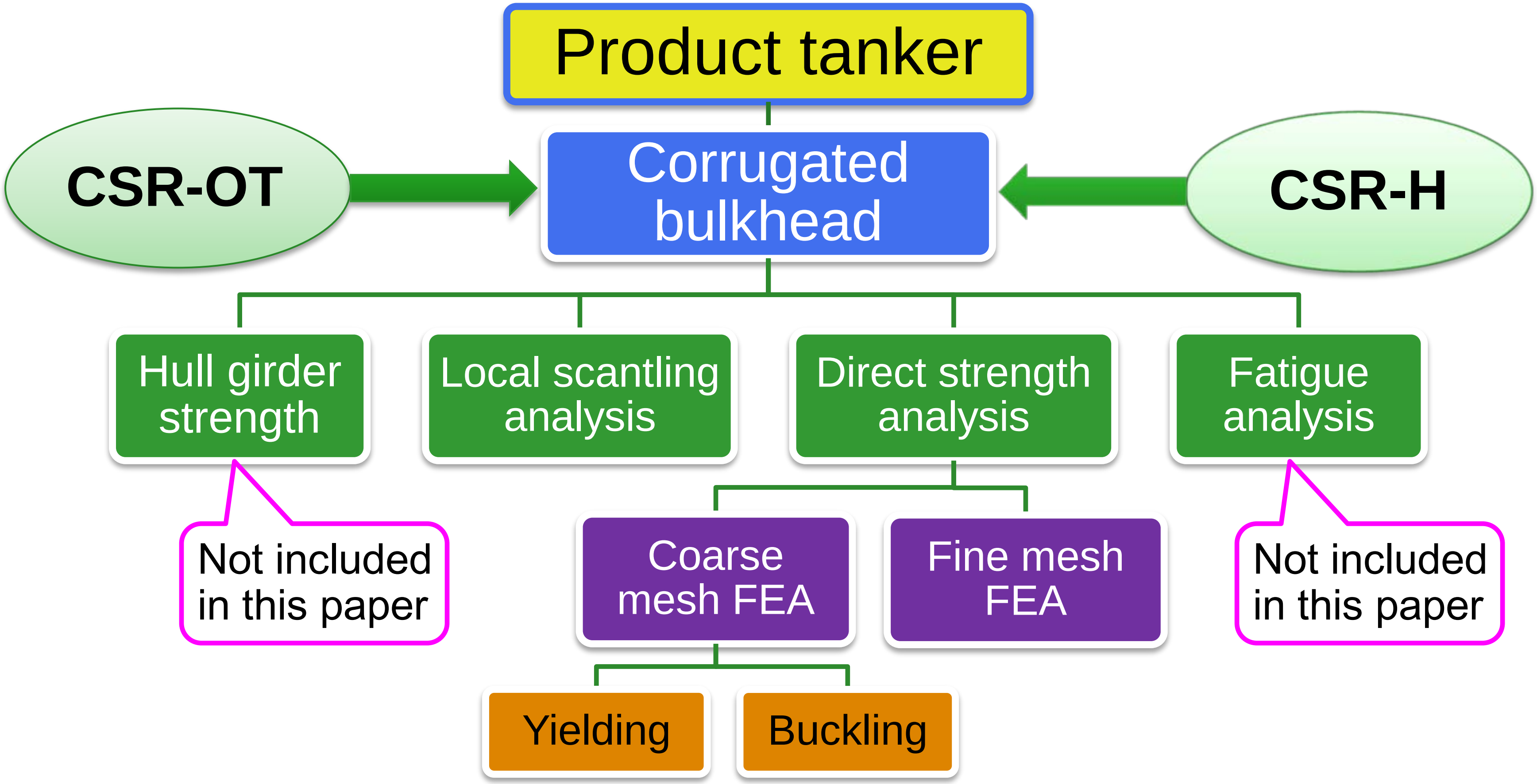
# Agenda

- Introduction
- Rule Comparison
- Local Scantling Analysis
- Direct Strength Analysis with Coarse Mesh
- Local Fine Mesh Analysis
- Conclusion

# Introduction



# Introduction




**Object ship for analysis: 115k DWT product tanker**

# Rule Comparison

- **Local Scantling**

1. **Depth of the corrugation**

**CSR-H:** $$d = \frac{1000\ell_c}{C}$$

For the definition of $l_c$, the bottom of the upper stool is not to be taken more than a distance from the deck at the centre line equal to:

- 3 times the depth of corrugation, in general.
- 2 times the depth of corrugation, for rectangular stool.

Not noted in CSR_OT

2. **Cold and hot formed corrugations**

**CSR-H:** $$t = 0.0158\, b_p \sqrt{\frac{|P|}{C_{CB}\, R_{eH}}}$$

For horizontally corrugated longitudinal bulkheads, without being greater than $C_{CB\text{-}max}$.

$$C_{CB} = \beta_{CB} - \alpha_{CB} \frac{|\sigma_{hg}|}{R_{eH}}$$

…

# Rule Comparison

- **Local Scantling**

**3. Net section modulus over the height**

$$Z_{cg} = \frac{1000 M_{cg}}{C_{s-cg} R_{eH}} \qquad M_{cg} = \frac{C_i |P| s_{cg} \ell_0^2}{12000}$$

Some parameter values are different when calculating $C_i$ between CSR-H and CSR-OT (2010). For example:

$C_i$ value at upper end of $l_{cg}$

| Bulkhead | CSR-OT(2010) | CSR-H |
|---|---|---|
| Transverse bulkhead | $0.80C_{m1}$ | $0.65C_{m1}$ |

**4. Design pressure**

*May be the main factor influencing the results.*

# Rule Comparison

- **Direct Strength Analysis**

**1. Structural modelling (Coarse mesh)**

**(1) CSR-H (Pt1, Ch7, Sec2, 2.4.4) (Not noted in CSR-OT):**

- The mesh on the longitudinal corrugated bulkhead shall follow longitudinal positions of transverse web frames…
- The aspect ratio of the mesh in the corrugation is not to exceed 2 with a minimum of 2 elements for the flange breadth and the web height.
- Dummy rod elements with a cross sectional area of 1 mm2 are to be modelled at the intersection between the flange and the web of corrugation.

**(2) Mesh adjustment between corrugation and stool**

| Adjustment item | Corrugation shape | Stiffeners on stool | Stress correction |
|---|---|---|---|
| CSR-OT | Allowed | Allowed | Allowed |
| CSR-H | Not allowed | Allowed | None |

# Rule Comparison

❍ **Direct Strength Analysis**

**2. Permissible yield utilisation factor (Coarse mesh)**

| CSR-OT | | CSR-H | |
|---|---|---|---|
| Structural component | $\lambda_{yperm}$ | Structural component | $\lambda_{yperm}$ |
| Bulkhead with no lateral pressure | 1.0 (S+D)<br>0.8 (S) | Bulkhead with no lateral pressure, dummy rod of corrugated bulkhead | 1.0 (S+D)<br>0.8 (S) |
| Longitudinal bulkheads (with lower stool) | 0.9 (S+D)<br>0.72 (S) | Vertically corrugated bulkheads (with lower stool), horizontally corrugated bulkhead | 0.9 (S+D)<br>0.72 (S) |
| Transverse bulkheads (with lower stool) | 0.8 (S+D)<br>0.64 (S) | | |
| Longitudinal bulkheads (without lower stool) | 0.81 (S+D)<br>0.648 (S) | Vertically corrugated bulkheads (without lower stool) | 0.81 (S+D)<br>0.65 (S) |
| Transverse bulkheads (without lower stool) | 0.72 (S+D)<br>0.576 (S) | | |

# Rule Comparison

- Direct Strength Analysis

3. Yield utilisation factor (Coarse mesh)

| CSR-OT | CSR-H |
|---|---|
| $\lambda_y = \sigma_{vm} / \sigma_{yd}$ for shell elements<br>$\lambda_y = \sigma_{rod} / \sigma_{yd}$ for rod elements<br>$\sigma_{yd}$: specified minimum yield stress, <=315MPa for S+D in areas of stress concentration. | $\lambda_y = \sigma_{vm} / R_y$ for shell elements<br>$\lambda_y = \lvert\sigma_{axial}\rvert / R_y$ for rod or beam elements<br>$R_y = 235/k$ |

4. Local fine mesh analysis

(1) Corrosion addition

| CSR-OT | CSR-H |
|---|---|
| The specified fine mesh areas: 1.0 tc<br>Other areas: 0.5 tc | 0.5 tc |

# Rule Comparison

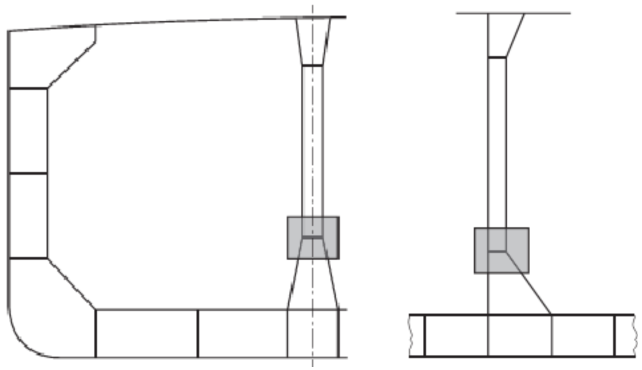
## ❍ Direct Strength Analysis

**4. Local fine mesh analysis**

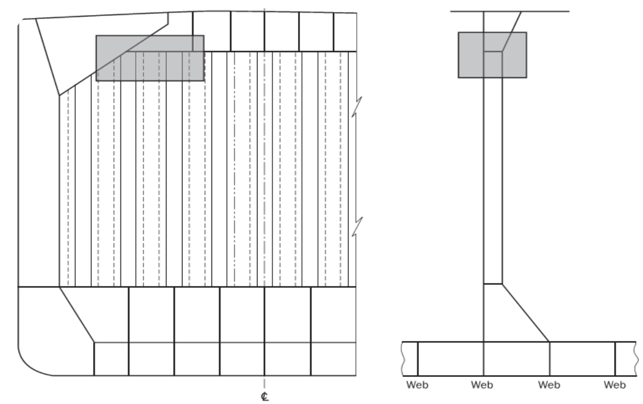
**(2) Mandatory and screening areas**

**CSR-H (Not noted in CSR-OT):**

- Midship cargo tank region:



Mandatory area
(Intersection of long. BHD. & tans. BHD.)




Screening area

- Outside midship cargo tank region (Screening area):

Connections between corrugation and adjoining lower structure

# Rule Comparison

- Direct Strength Analysis

4. Local fine mesh analysis

(3) Screening criteria

CSR-H (Not noted in CSR-OT):

<table>
<tr><th>Type of Details</th><th>Screening factors, $\lambda_{sc}$</th><th colspan="2">Permissible screening factors, $\lambda_{scperm}$</th></tr>
<tr><td>The connection of corrugation and upper supporting structure to upper stool</td><td>$\lambda_y$</td><td colspan="2">0.75 $\lambda_{yperm}$</td></tr>
<tr><td>Connections of corrugation to adjoining structure (Outside midship cargo tank region)</td><td>$\lambda_{sc} = \frac{K_{sc} \cdot \sigma_c}{R_y}$</td><td>1.50 $f_f$ (S+D)</td><td>1.20 $f_f$ (S)</td></tr>
</table>

(4) Fine mesh criteria:

| | CSR-OT | CSR-H |
|---|---|---|
| Yield utilisation factor | $k\sigma_{vm}/235$ (k>=0.78 for S+D) | $\sigma_{vm} / R_y$ |

# Rule Comparison

- **Buckling Assessment**

1. **Buckling criteria**

| CSR-OT | | CSR-H | |
|---|---|---|---|
| Structural component | $\eta_{all}$ | Structural component | $\eta_{all}$ |
| - | - | Bulkhead with no lateral pressure | 1.0 (S+D)<br>0.8 (S) |
| Corrugated bulkheads (with lower stool) | 0.9 (S+D)<br>0.72 (S) | Vertically corrugated bulkheads (with lower stool), horizontally corrugated bulkhead | 0.9 (S+D)<br>0.72 (S) |
| Corrugated bulkheads (without lower stool) | 0.81 (S+D)<br>0.648 (S) | Vertically corrugated bulkheads (without lower stool) | 0.81 (S+D)<br>0.65 (S) |

# Rule Comparison

- **Buckling Assessment**

**2. Buckling requirements for direct strength analysis**

**(1) Local buckling**

| | CSR-OT | CSR-H |
|---|---|---|
| Structural item | Corrugation flange | Corrugation flange and web |
| Stress combination | Uni-axial: only normal stress parallel to the corrugation | Max normal stress parallel to the corrugation + another normal stress + shear stress;<br>Max shear stress + two normal stresses |
| Parameters | $\psi = 1$ | $\alpha = 2$, $\psi = 1$ |

**(2) Reference stress**

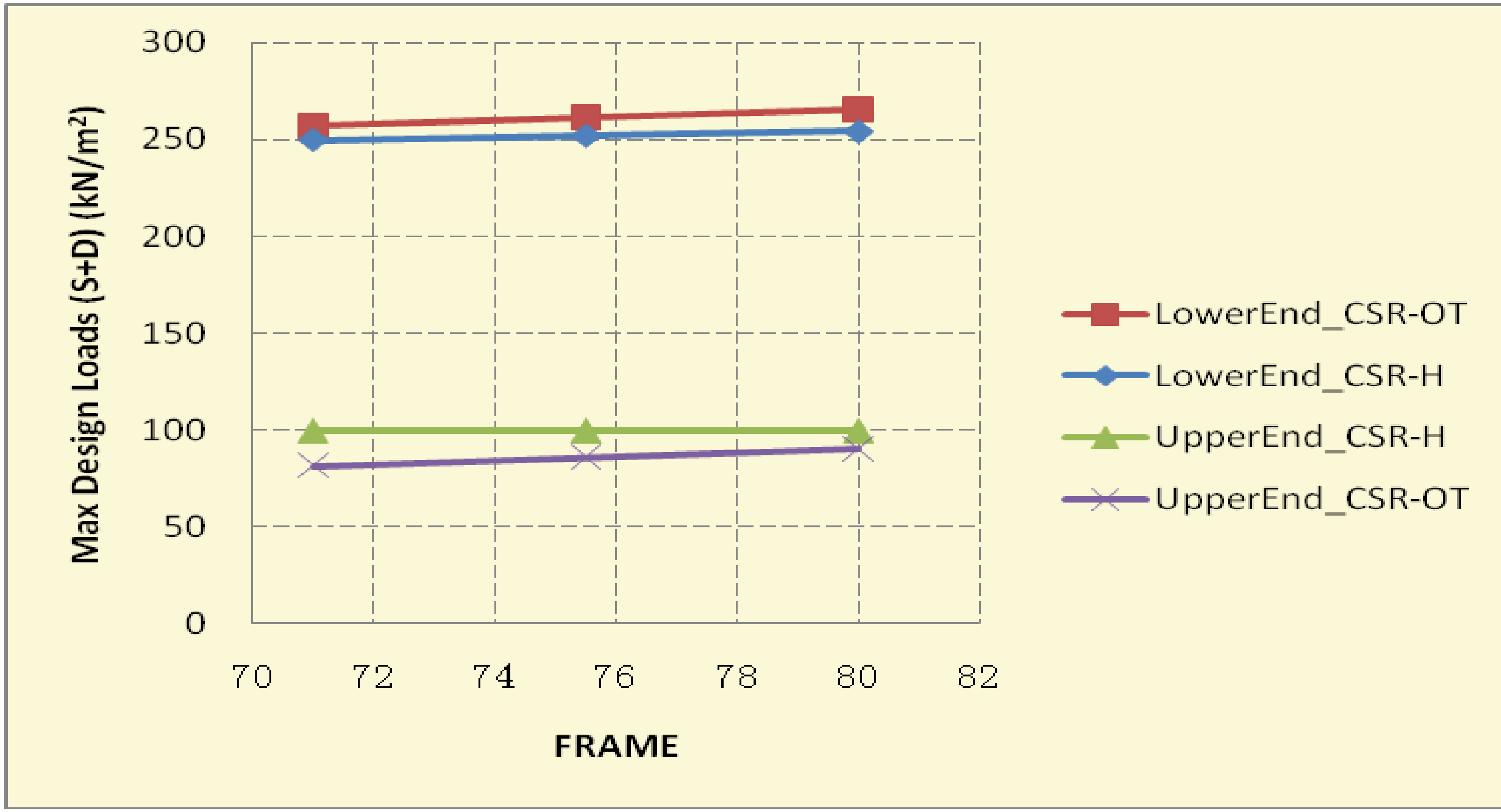
Not noted in CSR-OT.

# Object ship for analysis

| | |
|---|---|
| **Ship type** | Aframax product tanker |
| **Dead weight** | 115,000 DWT |
| **Corrugated bulkhead** | Longitudianl and transverse |
| **Stool fitted** | Lower and upper stool |
| **Corrugation direction** | Vertical corrugation |
| **Corrugation type** | Mainly rolled by line heat forming |

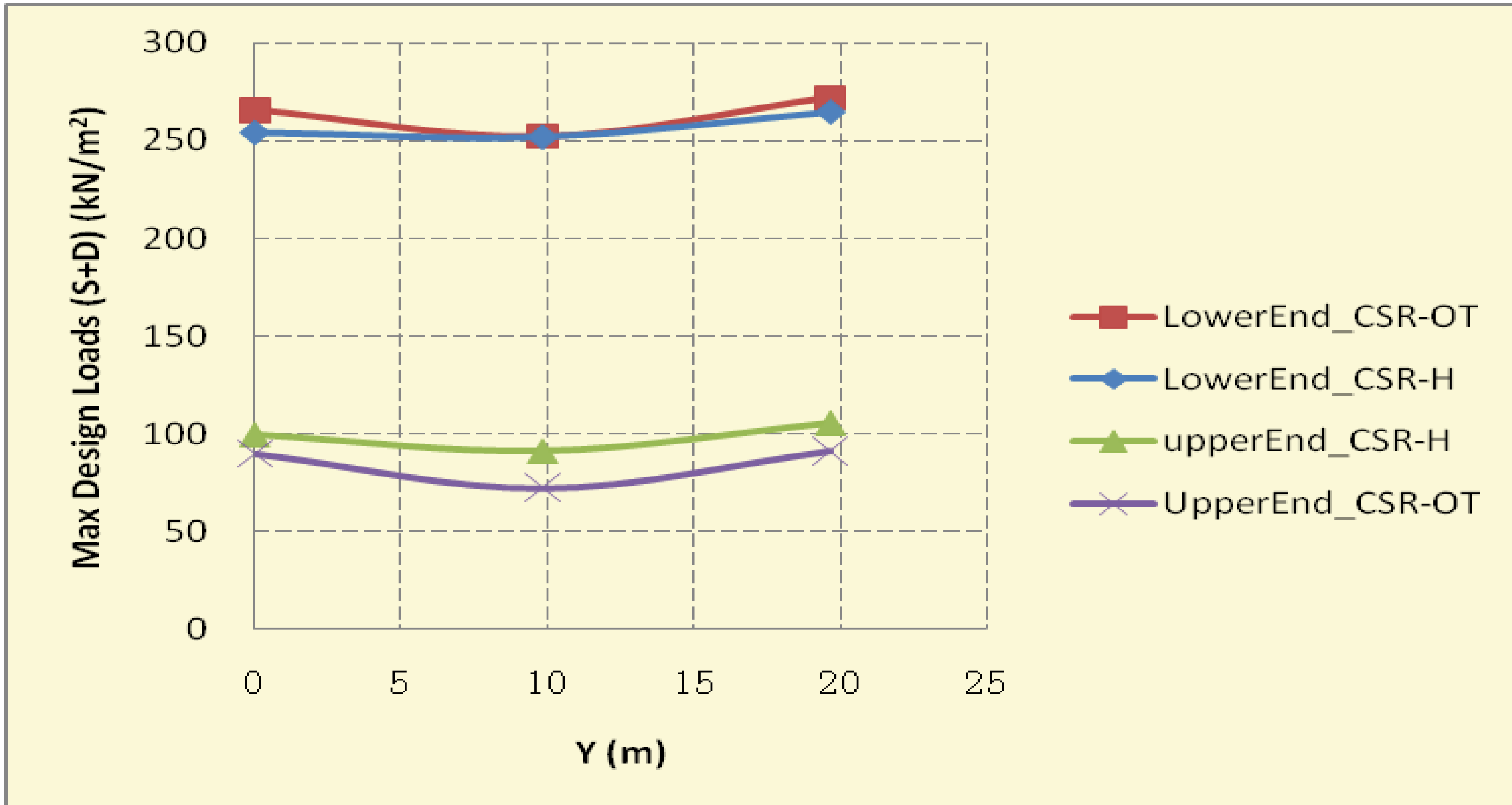
# Local Scantling Analysis

- **Maximum design loads (longitudinal corrugated bulkhead, mid cargo tank)**



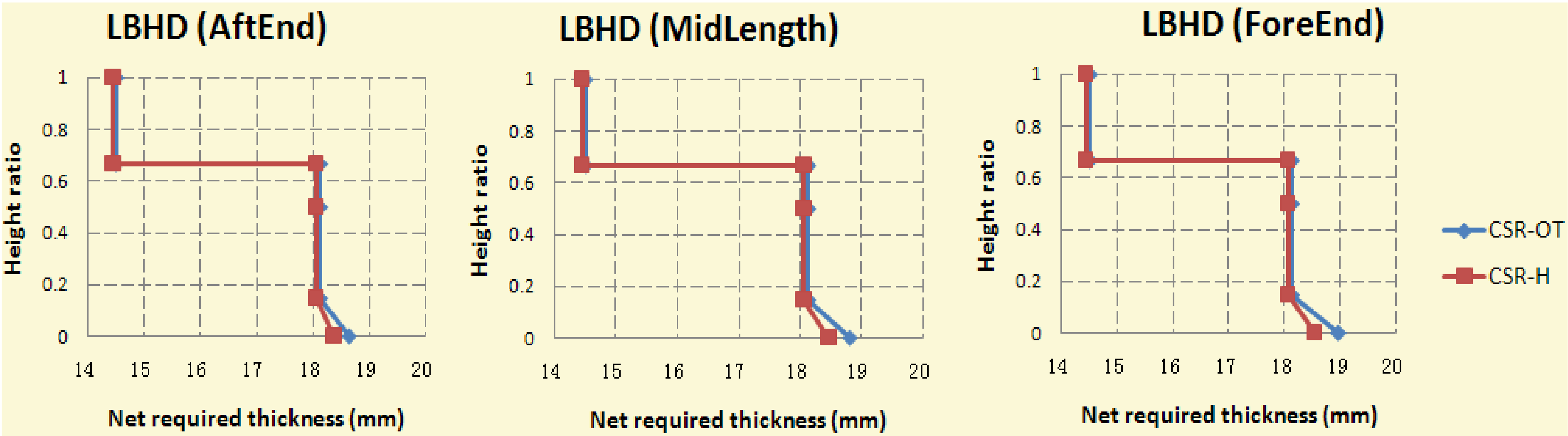
# Local Scantling Analysis

- Maximum design loads (transverse corrugated bulkhead, FR80)



# Local Scantling Analysis

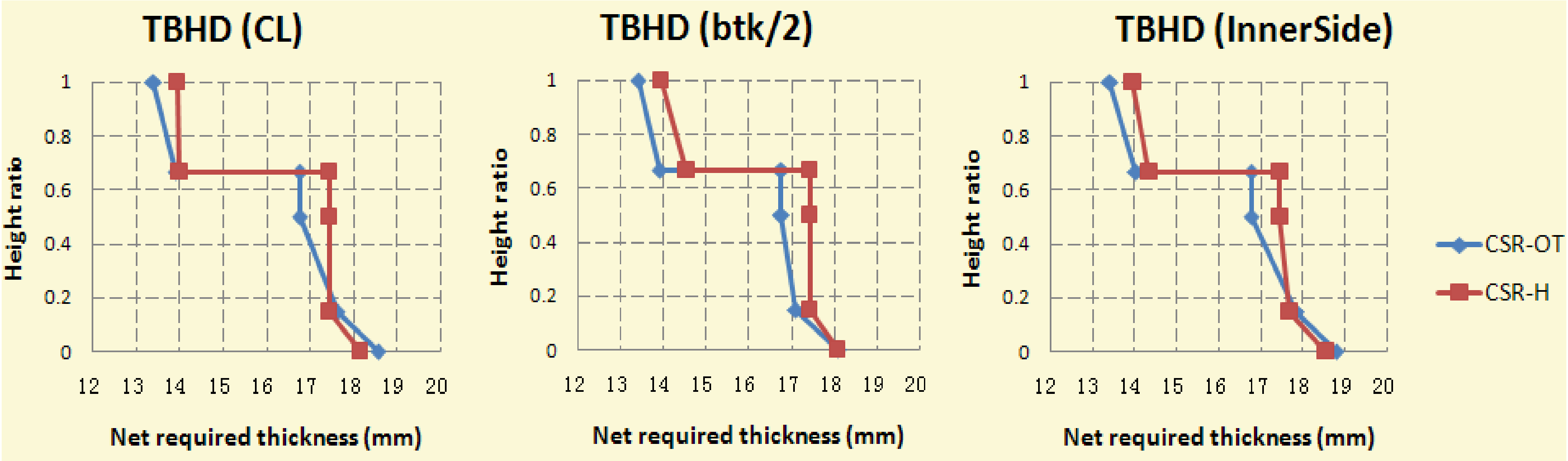
- Results for longitudinal bulkhead




| Vertical position | Main factor |
|---|---|
| Lower part | Design load at the lower end |
| Middle and upper part | average load of lower and upper end at ends of the tank |

# Local Scantling Analysis

- Results for transverse bulkhead

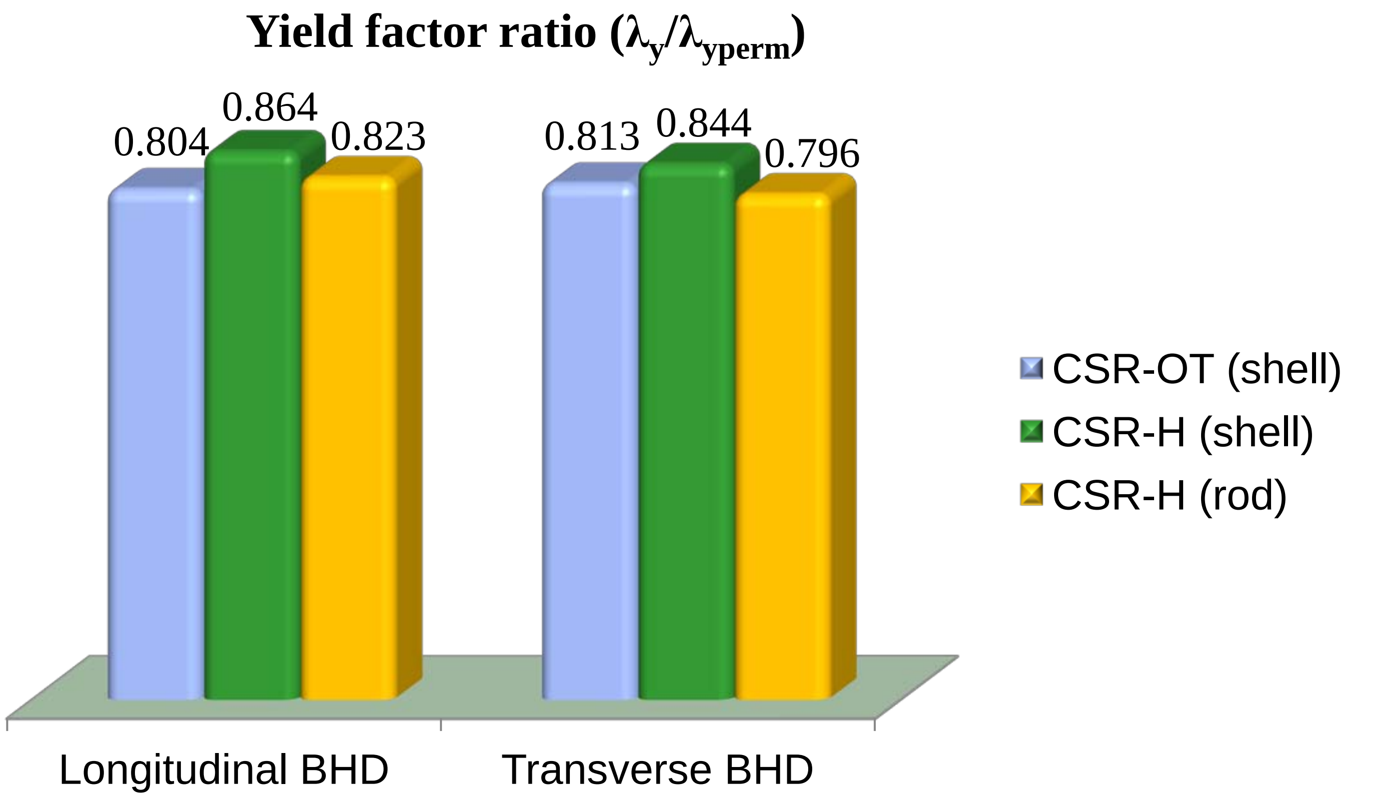



| Vertical position | Main factor |
|---|---|
| Lower part | Design load at the lower end |
| Middle and upper part | average load of lower and upper end at mid of the tank |

# Direct Strength Analysis (Coarse Mesh)

- **Yielding Assessment**

**(1) The most critical yielding assessment results**

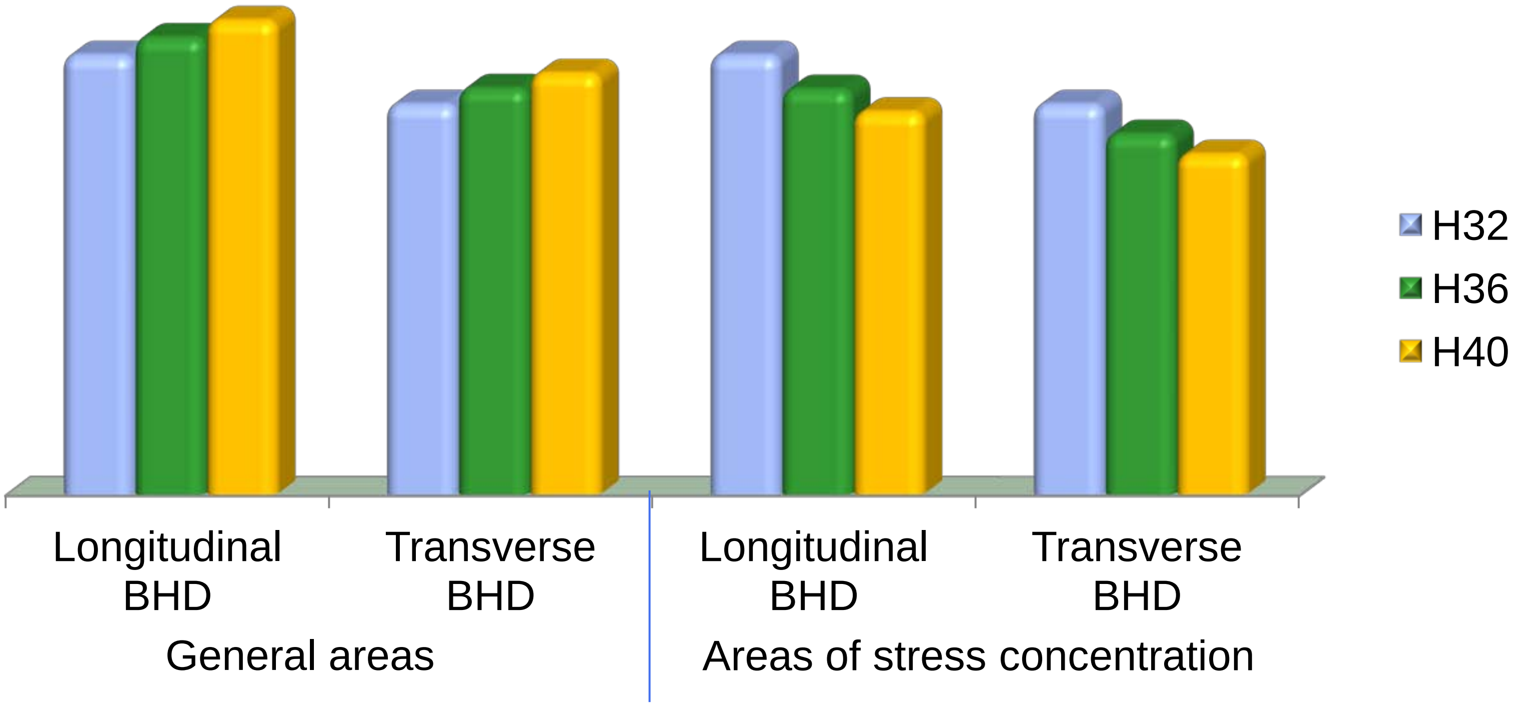


# Direct Strength Analysis (Coarse Mesh)

- **Yielding Assessment**

**(2) Yield criteria analysis (S+D)**

$(\lambda_y/\lambda_{yperm})_{CSR\_H} / (\lambda_y/\lambda_{yperm})_{CSR\_OT}$

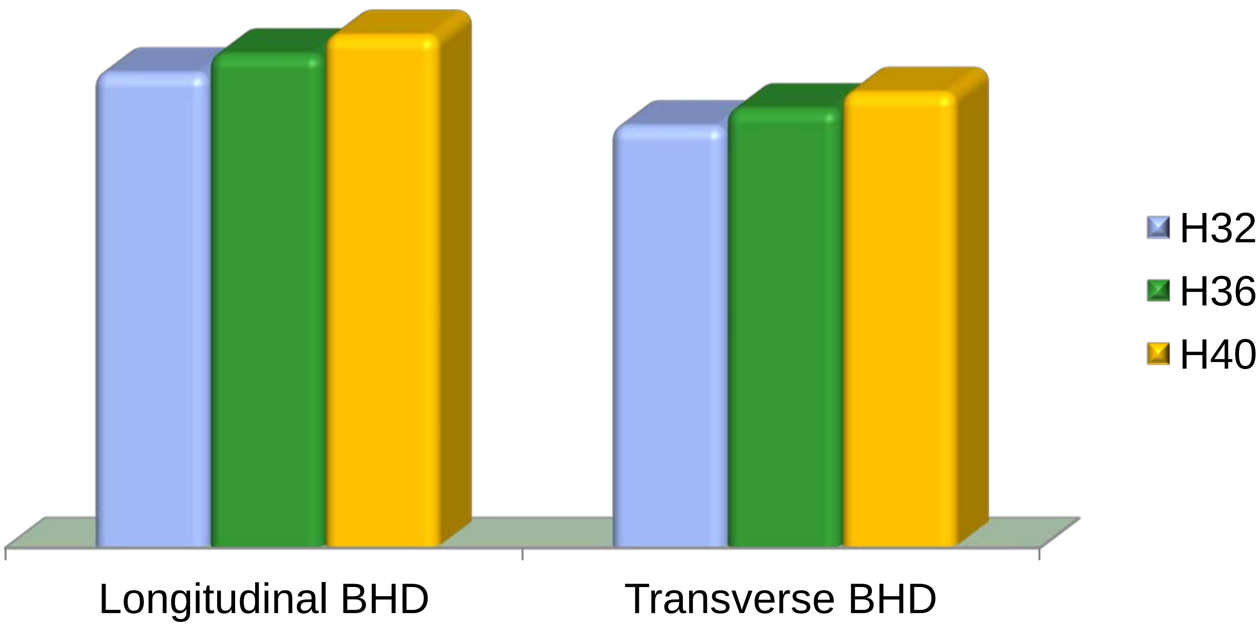


# Direct Strength Analysis (Coarse Mesh)

- **Yielding Assessment**

**(3) Yield criteria analysis (S)**

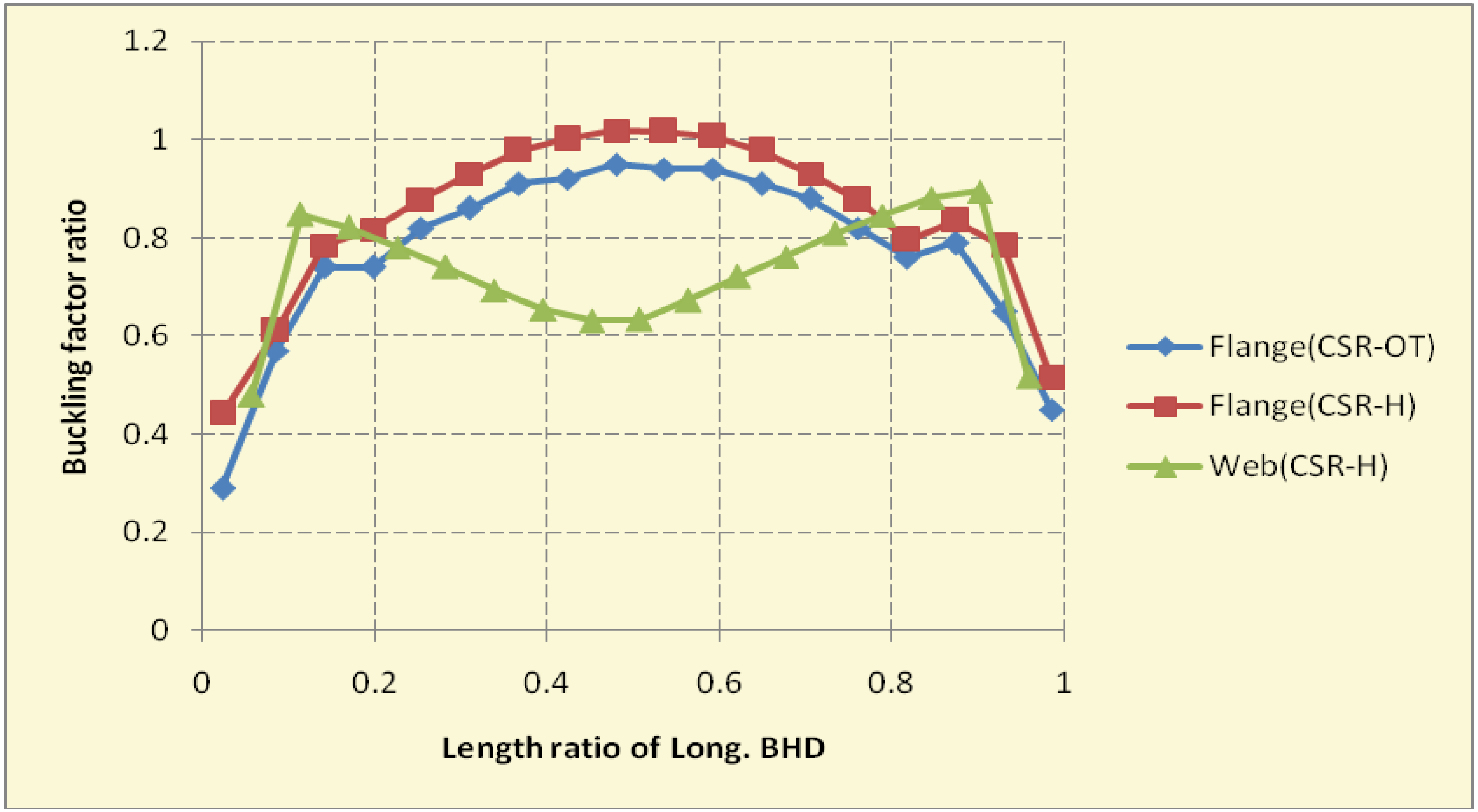
$(\lambda_y/\lambda_{yperm})_{CSR\_H} / (\lambda_y/\lambda_{yperm})_{CSR\_OT}$



# Direct Strength Analysis (Coarse Mesh)

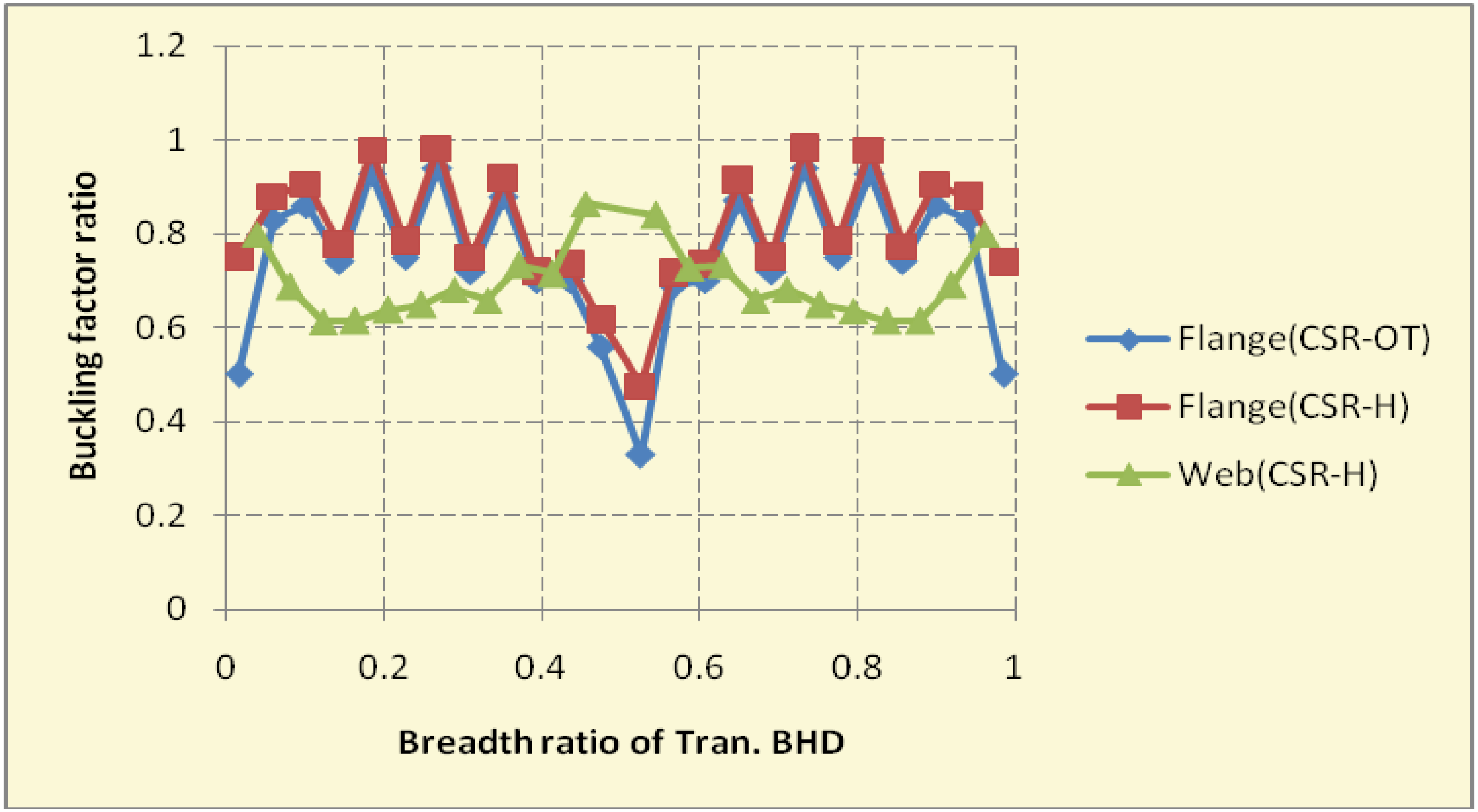
## ❍ Buckling Assessment

**(1) Buckling results of longitudinal corrugated bulkhead**



- **Buckling Assessment**

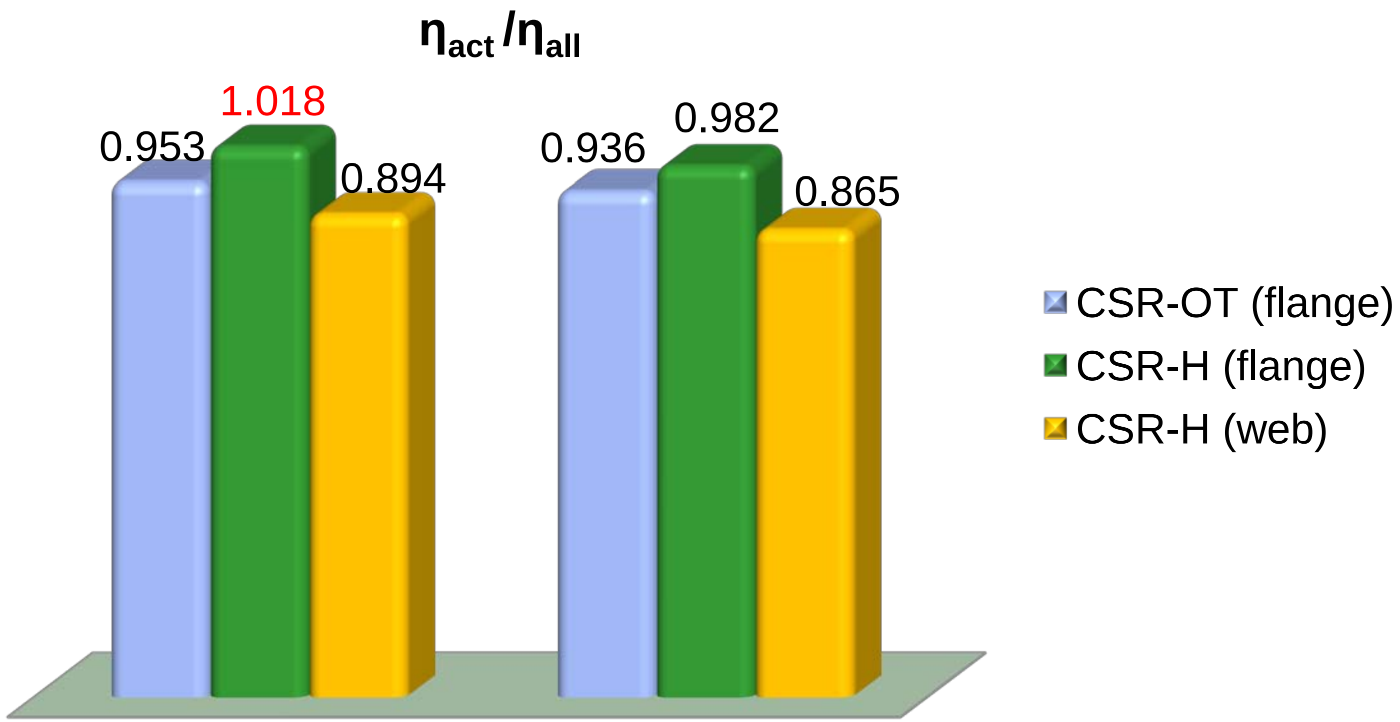
**(2) Buckling results of transverse corrugated bulkhead**



# Direct Strength Analysis (Coarse Mesh)

- **Buckling Assessment**

  **(3) The most critical buckling assessment results**

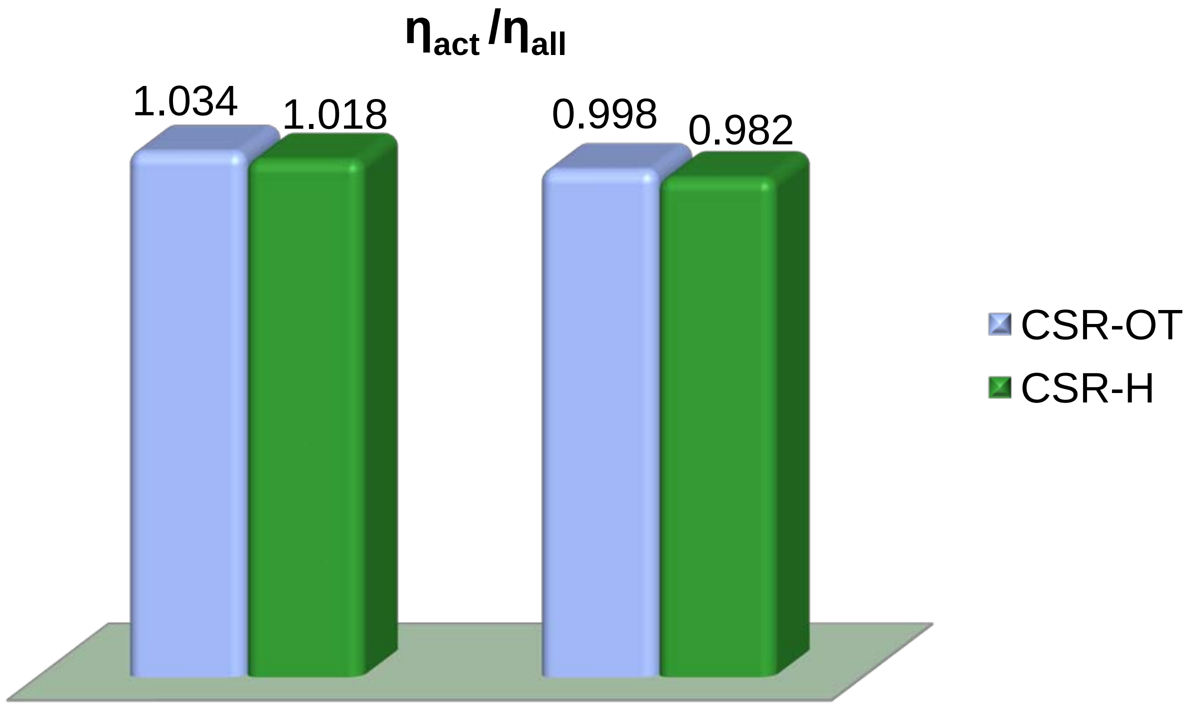


# Direct Strength Analysis (Coarse Mesh)

- **Buckling Assessment**

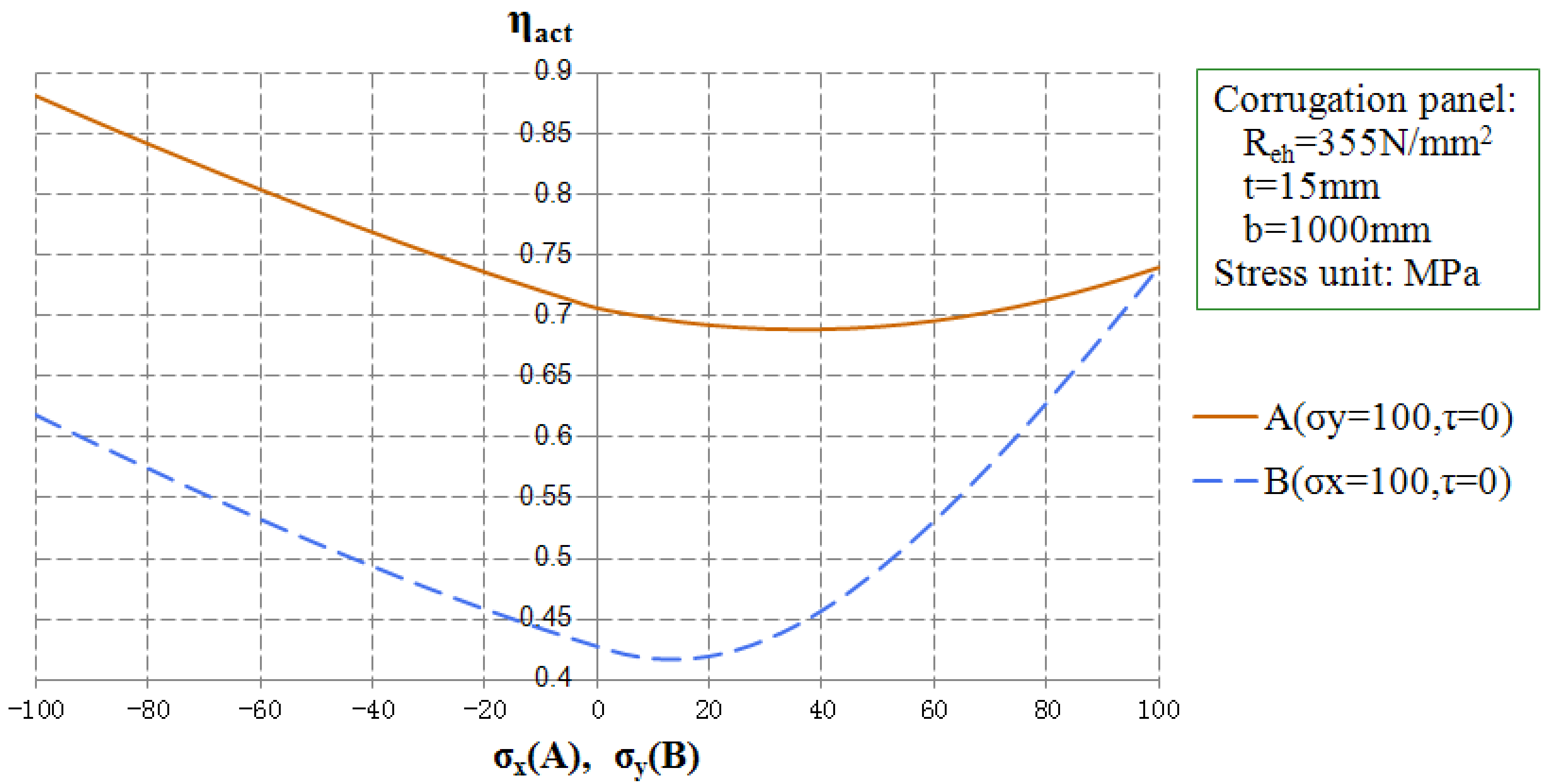
  **(4) Comparison buckling analysis of corrugation flange**

  **(Same stresses for CSR-OT and CST-H)**



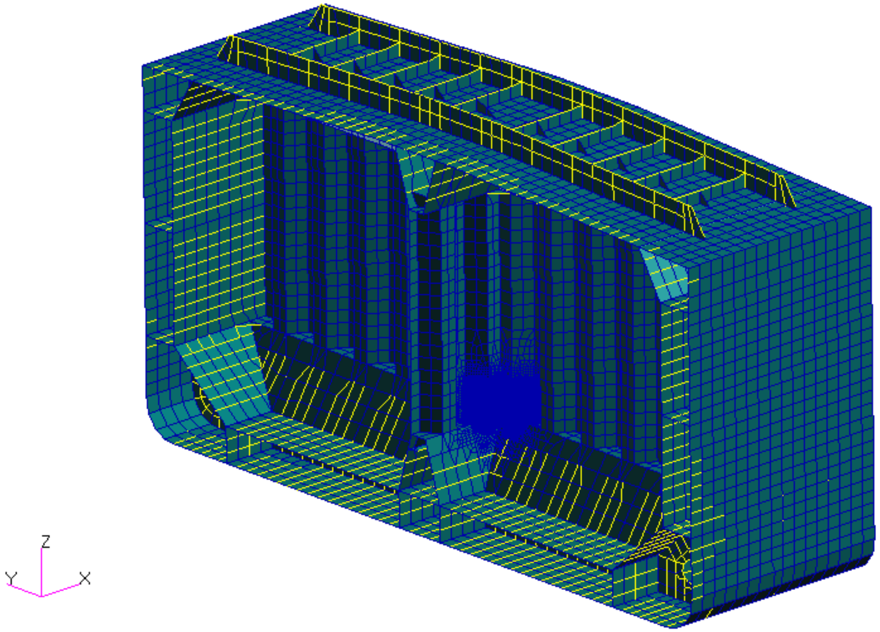
## Buckling Assessment

### (5) Sensitivity analysis for normal stresses



# Local Fine Mesh Analysis

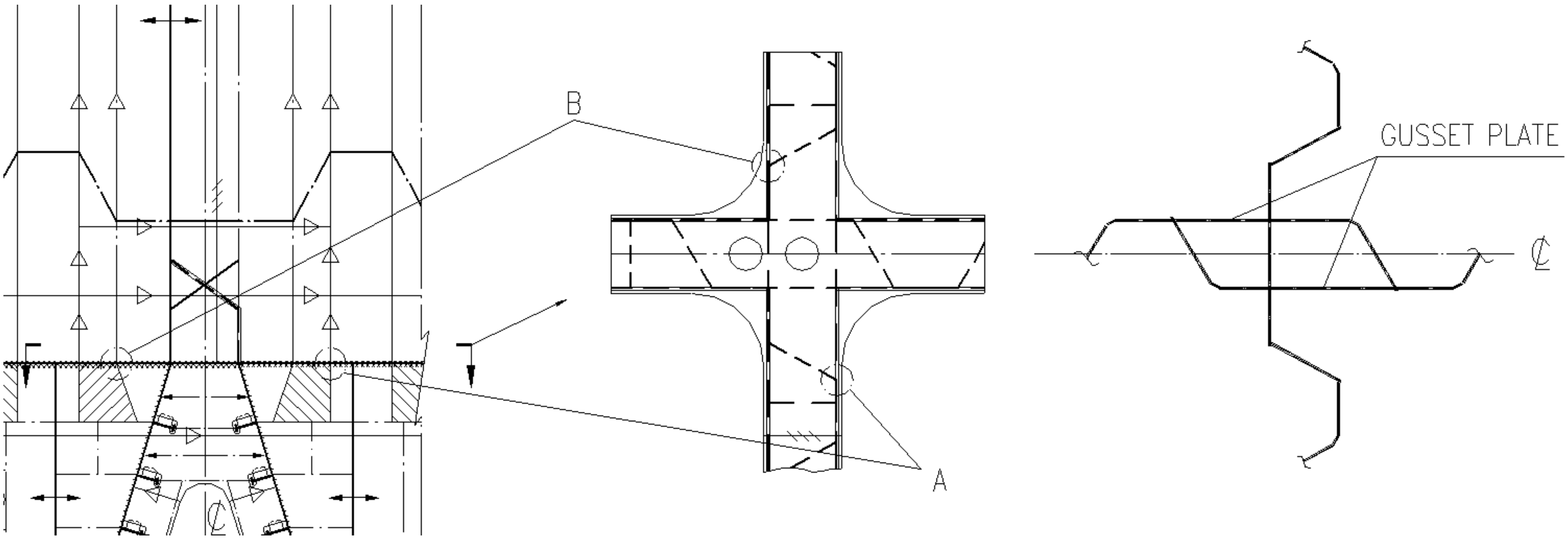
- **Object area:** **Connection between corrugations and supporting structure in way of the lower stool shelf plate at the intersection of longitudinal and transverse corrugated bulkheads.**
- **Method:** **Sub model method.**
- **Model extent:** **Full breadth and depth, ±2 frames.**




***The bigger the model extent is, the more accurate the results are!***

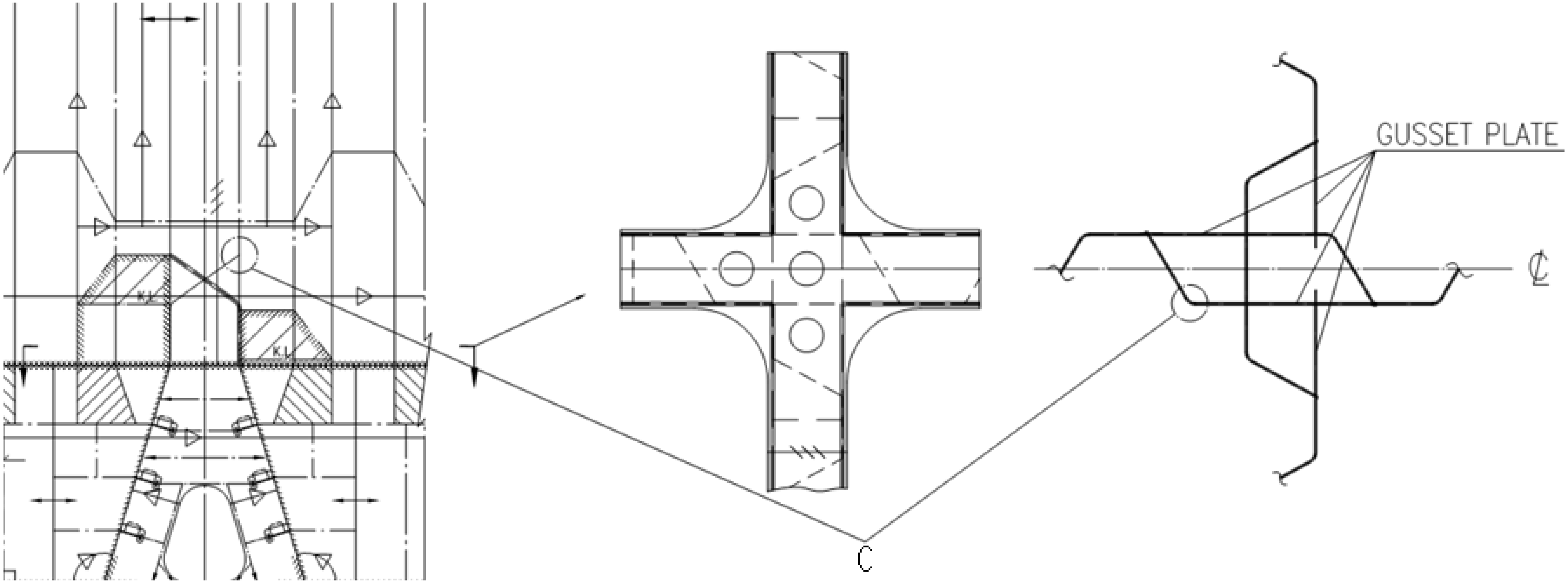
# Local Fine Mesh Analysis

- Original gusset plate arrangement:



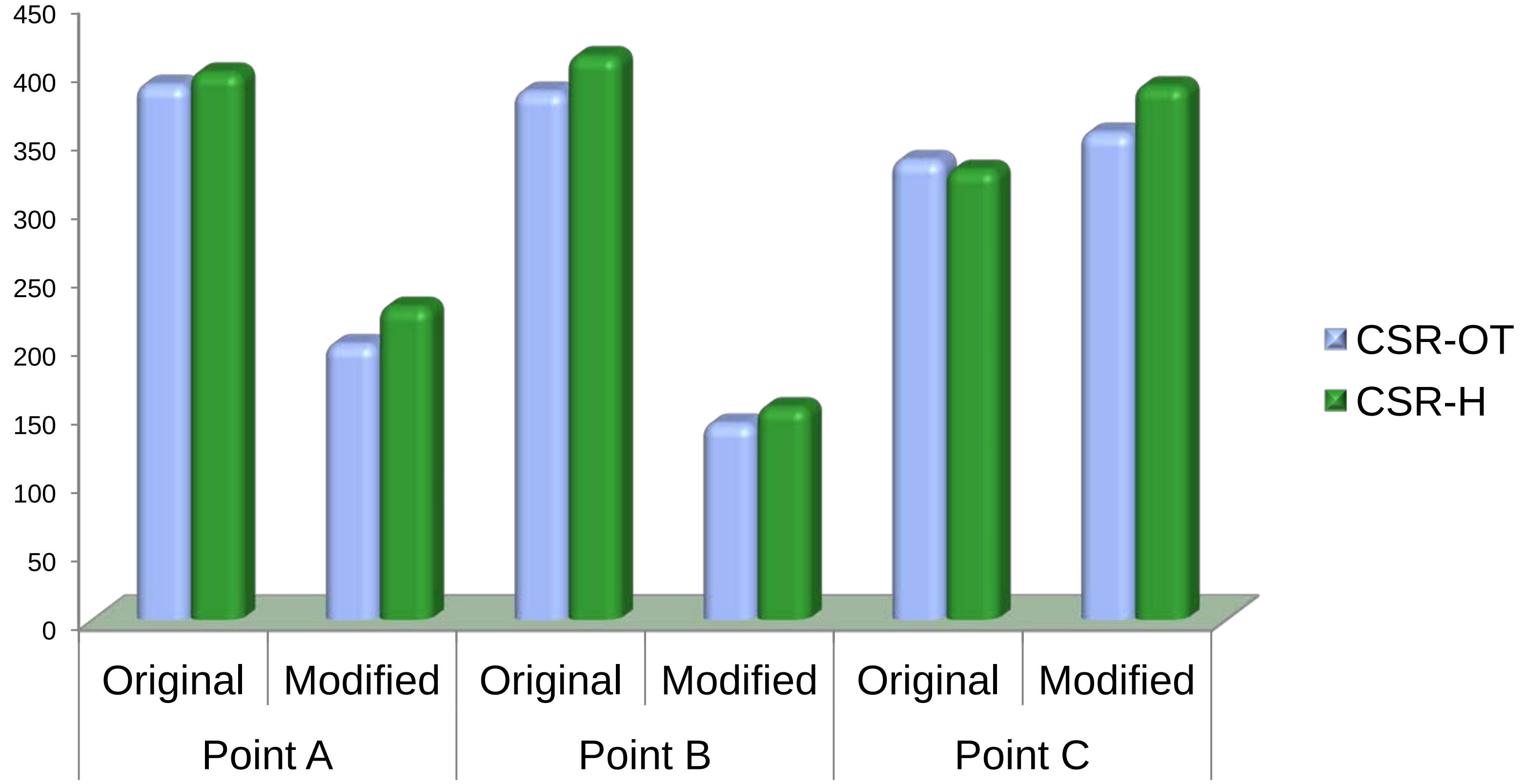
# Local Fine Mesh Analysis

- Modified gusset plate arrangement:



# Local Fine Mesh Analysis

- Maximum stresses(Mpa):



# Conclusion

- **The local scantling requirements are similar between CSR-OT and CSR-H, while the design load is the main factor.**
- **The results of CSR-H are generally a little higher than that of CSR-OT from the direct strength analysis mainly due to the higher design loads.**
- **In coarse mesh analysis, for general areas (not stress concentration), higher strength steel will give more severe yielding results for CSR-H than CSR-OT, but for areas of stress concentration in S+D, it is opposite. There are more advantages for transverse bulkhead than longitudinal bulkhead in the transition of criteria.**

# Conclusion

- The corrugation scantlings in the middle and upper part are normally determined by the buckling assessment results. The buckling assessment results of flange are mainly determined by vertical normal stress, higher in the mid breadth of tank. The buckling assessment results of web are mainly determined by shear stress, higher in the end of tank.

- The scantling requirements of lowest part of corrugation are determined by the local fine mesh results. More attentions shall be paid to the area around the intersection of longitudinal and transverse corrugated bulkheads near lower stool. The way adding proper gusset plate is more effective than increasing thickness.