Rudder Investigation

By

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Where and on What?

- Series of RO RO Vessels designed and constructed by Flensberger Schiffbau Gesselschaft GmbH.

- Rudders independently manufactured by Macor Neptun GmbH.
Why this Analysis?

The appearance of 2 sets of cracks.

- Crack in the Rudder Trunk (1).
- Where the Rudder Stock is joined to the Rudder Plate (2).
- Problem of Structural Strength.
# Ship Particulars

## PRINCIPAL DIMENSIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>RO-RO</td>
</tr>
<tr>
<td>Length (overall)</td>
<td>193.00 m</td>
</tr>
<tr>
<td>Length (between perpendiculars)</td>
<td>182.39 m</td>
</tr>
<tr>
<td>Breadth</td>
<td>26.00 m</td>
</tr>
<tr>
<td>Depth</td>
<td>16.70 m</td>
</tr>
<tr>
<td>Draught (design)</td>
<td>5.70 m</td>
</tr>
<tr>
<td>Draught (summer load)</td>
<td>6.45 m</td>
</tr>
</tbody>
</table>
Rudder Particulars

Height = 4.8m
Breadth = 3.0 m
F.E. Model

- Rudder Stock by 3D Beam Elements.
- Rudder Plate by 3D Shell Elements.
- Rudder Trunk and Rudder Skeg by 3D Shell Elements.
F.E. Model

- Beam Elements to mimic the *Stiff Bearing* Region.

- 3D Spar Elements to mimic the action of the *Rudder Trunk - Rudder Stock* reaction.
Static Analysis

Displacement Boundary Conditions

• Rudder Skeg.

• Rudder Stock.
**Force Boundary Conditions**

- Forces and Torque to be applied is got from Germanischer Lloyd Rule Book.

\[
\]

\[
1181500 \text{ N}
\]

\[
Rudder Torque = Q_R = C_R . r \text{ Nm}
\]

\[
1134240 \text{ Nm}
\]

- The Forces are applied at the nodes where the Ribs and Webs intersect the Rudder Outer Plate.
Force Boundary Conditions

44000 N
39440 N
8342 N
40440 N
3940 N
3940 N
39440 N

Diagram with labeled forces.
von Mises Stresses.

Max von Mises Stress = 78.5MPa
Inferences & Results from Static Analysis

• Stresses far below the allowed limit.

• If Static loads are not the reason then …

  What is the Reason for the Failure?
  – Fatigue?… Failure in new vessels rules out the option.
  – Dynamic Amplification due to Resonance?
Resonance

Rudder in Air

- Same Model for Static Analysis used.

- Model should be representative of Stiffness as well as Inertia.

- The mass distribution should be same.

  Total Mass of Prototype: 15.605 Tonnes
  Total Mass of Model: 15.257 Tonnes
Result for Rudder in Air

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Torsional Mode</th>
<th>Lateral Mode</th>
<th>Longitudinal Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.06</td>
<td>16.19</td>
<td>15.32</td>
</tr>
</tbody>
</table>

- In reality Rudder is in water and hence the question of added mass arises.
Added Mass

Existing Method

• **Quantity** - Prof. Soding’s formula for a rectangular plate.

\[
M^* = \frac{C \times \rho_{sw} \times \pi \times B^2 \times L}{4}
\]

\[
MI^* = \frac{C \times \rho_{sw} \times \pi \times B^4 \times L}{128}
\]

- Mass per node is found out.

- Distributed equally on the nodes on the outer shell of the rudder plate as mass elements with

\[M_x = M_y = M_z = M^* \text{ per node}\]
Value of $C$ from this graph.
**Proposed Method**

- *Quantity* - Prof. Soding’s formula for a rectangular plate.
- Mass and Mass Moment of Inertia per node is found out.
- Analysis done in 2 parts.

**Part 1**

- Distributed equally on the nodes on the outer shell of the rudder plate as mass elements with

\[
M_x = M^* \text{ per node.}
\]
\[
M_y = M^* \text{ per node using "L", the average thickness of the rudder.}
\]
\[
M_z = 0.
\]

- Isolate the Lateral and Longitudinal mode frequencies.
Part 2

• Distributed equally on the nodes on the outer shell of the rudder plate as mass elements with

\[ M_x = M_y = M_z = 0 \]

\[ M_{Iz} = M_{I^*} \]

• Isolate the Torsional mode frequency.
• Propeller Frequency $= 125\text{rpm} \times 4\text{blades} = 8.33 \text{ Hz}$

• Good chance of Resonance from the $2^{\text{nd}}$ mode.

• Propeller can always run at a lesser rpm which can result in the torsional mode getting excited.
Results & Inferences

• 1\textsuperscript{st} crack attributed to resonance with Lateral Mode.

• 2\textsuperscript{nd} crack attributed to resonance with the torsional mode.
  – 45 degree angle is usually due to torsion.
Three Main Modes

- Torsional
- Lateral
- Longitudinal
- Earlier I had assumed the torsional stiffness of the Steering Gear to be infinite. – not fully correct!

- Steering gear can be modeled by using a Torsional Spring connected at the end of the Rudder Stock.
• Knowing the frequency from experiment we can predict the value of the torsional stiffness to be used for the analysis of other rudders.
Water Level at the Rudder as variable.

- To find out the variation of frequencies by varying the water level at the Rudder.
• **Torsional Mode Frequency** doesn’t change with water depth?
  – For torsional mode we don’t require added mass?

• **Longitudinal Mode** dominant at lower water levels than the Lateral Mode
Why is it needed?

- Beam Element formulation of Rudder Stock not sufficient.

- Design *nominal contact pressure* was around 10-20 MPa.

Verifying the veracity of this value.
Nonlinearity arises due to...

- Presence of a gap.
- Varying Gap width.
- Use of materials with big difference in Elastic Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>E (Pa)</th>
<th>G (Pa)</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Steel</td>
<td>2.10E+11</td>
<td>8.08E+10</td>
<td>0.3</td>
</tr>
<tr>
<td>Thordon</td>
<td>4.40E+08</td>
<td>1.51E+08</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Note: Nonlinearity dealt with is only the “Gap type”.
F.E. Model

- 3D Brick Elements for Rudder Stock.
- 3D Brick Elements for Rudder Trunk.
- 3D Shell Elements for the upper part of trunk.
Boundary Conditions

Displacement Boundary Conditions

*Rudder Trunk*

- Topmost Nodes.

- Stiffeners are modeled by BC’s.
Boundary Conditions

Displacement Boundary Conditions

*Rudder Stock.*

- Topmost Nodes.
- Bearing Regions.
- Arresting the Rotation of the Stock.
Boundary Conditions

Force Boundary Conditions

- Force Calculated as per Germanischer Lloyd’s Rule Book.
- Equally distributed among the three nodes in the rudder stock.
Contact Surfaces & Elements

Defining both

- Master Surface.
- Slave Surface.

<table>
<thead>
<tr>
<th>Surface ID</th>
<th>Type</th>
<th>Order</th>
<th>Rev. Flag</th>
<th>Surface type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shell</td>
<td>3</td>
<td>NO</td>
<td>Master Surface</td>
</tr>
<tr>
<td>2</td>
<td>Shell</td>
<td>3</td>
<td>NO</td>
<td>Slave Surface</td>
</tr>
</tbody>
</table>
## Parameters involved & their values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penalty No. in Normal Direction</td>
<td>1e11</td>
</tr>
<tr>
<td>Penalty No. in Tangential Direction</td>
<td>1e9</td>
</tr>
<tr>
<td>No. of Time Steps</td>
<td>15</td>
</tr>
<tr>
<td>Total Duration for the applied force / Event</td>
<td>1 sec</td>
</tr>
</tbody>
</table>
Inferences from the Contact Analysis

- Nominal Contact Pressure = 12.26 MPa

- Well within the design range.
Conclusions

• Cause of Rudder failure attributed to Resonance.

• The New Proposed way of modeling added masses.

• Assuming Torsional Stiffness for the Steering gear gives better results.

• Torsional Mode Natural Frequency doesn’t vary with water depth.
Thank You