UPDATING FAILURE PROBABILITY
OF A WELDED JOINT IN OWT SUBSTRUCTURES

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Motivation

Reduce O&M Costs → RBI → Update Pf (insp.) → Limit State Function
Fatigue Assessment Diagram can be used to update the failure probability of an existing OWT substructure when new information about either loading, structural responses or inspections is available.
Outline

Fatigue Assessment Diagram

Updating Probability of Failure

Results
Outline

Fatigue Assessment Diagram

Updating Probability of Failure

Results
Fatigue Assessment Diagram

Figure: Level 2A Fatigue Assessment Diagram

Fatigue Assessment Diagram

Figure: Level 2A Fatigue Assessment Diagram

\[ L_{r,\text{max}} = \frac{\sigma_Y + \sigma_U}{2\sigma_Y} \]

Fatigue Assessment Diagram

\[ L_r = \frac{\sigma_{ref}}{\sigma_Y}; ~ K_r = \frac{K_I}{K_{mat}} \]

**Figure:** Level 2A Fatigue Assessment Diagram

Fatigue Assessment Diagram

\[
L_r = \frac{\sigma_{\text{ref}}}{\sigma_Y}; \quad K_r = \frac{K_I}{K_{\text{mat}}}
\]

Figure: Level 2A Fatigue Assessment Diagram

Fatigue Assessment Diagram

\[ L_r = \frac{\sigma_{\text{ref}}}{\sigma_Y}; \quad K_r = \frac{K_I}{K_{\text{mat}}} \]

Figure: Level 2A Fatigue Assessment Diagram

Outline

- Fatigue Assessment Diagram
- Updating Probability of Failure
- Results
## Uncertainties

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cycle/year</td>
<td>$1 \times 10^7$</td>
</tr>
<tr>
<td>Steel thickness [mm]</td>
<td>65</td>
</tr>
<tr>
<td>Outer radius [mm]</td>
<td>79.5</td>
</tr>
<tr>
<td>Joint length [mm]</td>
<td>100</td>
</tr>
<tr>
<td>Bend. to memb. ratio</td>
<td>0.81</td>
</tr>
<tr>
<td>Transition SIF range</td>
<td>196</td>
</tr>
<tr>
<td>Paris law, 1\textsuperscript{st} line</td>
<td>5.10</td>
</tr>
<tr>
<td>Paris law, 2\textsuperscript{nd} line</td>
<td>2.88</td>
</tr>
<tr>
<td>C ratio for a and c</td>
<td>0.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Distr.</th>
<th>Mean</th>
<th>CoV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>W</td>
<td>k=0.8</td>
<td>$N(\mu, \sigma)$</td>
</tr>
<tr>
<td>$\sigma_Y$</td>
<td>LN</td>
<td>368.75</td>
<td>0.07</td>
</tr>
<tr>
<td>$\sigma_U$</td>
<td>LN</td>
<td>750</td>
<td>0.04</td>
</tr>
<tr>
<td>$\Delta K_{th}$</td>
<td>LN</td>
<td>160</td>
<td>0.4</td>
</tr>
<tr>
<td>$K_{mat}$</td>
<td>Fracture toughness</td>
<td>3p W</td>
<td>-</td>
</tr>
<tr>
<td>$C_1$</td>
<td>Paris law, 1\textsuperscript{st} line</td>
<td>LN</td>
<td>$4.8 \times 10^{-18}$</td>
</tr>
<tr>
<td>$C_2$</td>
<td>Paris law, 2\textsuperscript{nd} line</td>
<td>LN</td>
<td>$5.86 \times 10^{-13}$</td>
</tr>
<tr>
<td>$a_0$</td>
<td>Initial crack depth</td>
<td>LN</td>
<td>0.15</td>
</tr>
<tr>
<td>$a_0/c_0$</td>
<td>Initial aspect ratio</td>
<td>LN</td>
<td>0.6</td>
</tr>
<tr>
<td>$\sigma_{scf}$</td>
<td>Uncertainty in SCF</td>
<td>LN</td>
<td>1</td>
</tr>
<tr>
<td>$B_{sif}$</td>
<td>Uncertainty in SIF</td>
<td>LN</td>
<td>1</td>
</tr>
</tbody>
</table>
Updating method

Uncertainties
Updating method

<table>
<thead>
<tr>
<th>$a_0, c_0$</th>
<th>SIF</th>
<th>SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_Y$</td>
<td>$\sigma_U$</td>
<td>$\Delta \sigma$</td>
</tr>
<tr>
<td>$K_{mat}$</td>
<td>$\Delta K_{th}$</td>
<td>FM</td>
</tr>
</tbody>
</table>
Updating method

\[
\begin{array}{cccc}
  a_0, c_0 & SIF & SCF \\
  \sigma_Y & \sigma_U & \Delta\sigma \\
  K_{mat} & \Delta K_{th} & FM \\
\end{array}
\]

Limit State Function \[\Rightarrow\] Pf

POD \[\Rightarrow\] Updating Pf

Decisions

Updating method

Limit State Function

Crack Growth Simulation

POD
Decisions

$a_0, c_0$, SIF, SCF
$\sigma_Y$, $\sigma_U$, $\Delta\sigma$
$K_{mat}$, $\Delta K_{th}$, FM

Limit State Function

POD
Decisions
Updating method

Limit State Function

Crack Growth Simulation

Updated Pf

POD

Decisions

$a_0, c_0$ SIF SCF

$\sigma_Y, \sigma_U, \Delta\sigma$

$K_{mat}, \Delta K_{th}, FM$
Crack depth $a$ and crack length $2c$ are coupled during the simulation.

\[
\begin{align*}
\frac{da}{dN} &= C_a (\Delta K_a)^m \quad \Delta K_a \geq \Delta K_{th} \\
\frac{dc}{dN} &= C_c (\Delta K_c)^m \quad \Delta K_c \geq \Delta K_{th}
\end{align*}
\]

(1)

\[
\Delta K_a = SY_a \sqrt{\pi a}
\]

(2)

\[
\Delta K_c = SY_c \sqrt{\pi a}
\]

(3)
Crack Growth Simulation

Figure: Crack growth in combination with inspections
Crack Growth Simulation

Figure: Crack growth in combination with inspections
Crack Growth Simulation

Figure: Crack growth in combination with inspections
Outline

Fatigue Assessment Diagram

Updating Probability of Failure

Results
Results
Crack Propagation

Figure: Crack propagation
Results
No Crack Detected

Figure: Annual POF
Results
Crack Detected & Repaired

Figure: Annual POF
Summary

Fatigue Assessment Diagram can be used to **update the failure probability** of an existing OWT substructure when **new information** about either loading, structural responses or inspections is available.

- **Outlook**
  - Reduction of uncertainty related to stress-ranges given new information about loading and structural response
  - Improved modelling of crack growth after reaching the wall thickness.
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