Structural Design of Offshore Floaters
Day 4 – Fatigue Design

Houston

03 November 2016
<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 9:15</td>
<td>Introduction, expectations</td>
</tr>
<tr>
<td>9:15 – 10:30</td>
<td>Principles of fatigue</td>
</tr>
<tr>
<td>10:30 – 10:45</td>
<td>Break</td>
</tr>
<tr>
<td>10:45 – 12:00</td>
<td>Fatigue assessment methods</td>
</tr>
<tr>
<td>12:00 – 13:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:00 – 14:00</td>
<td>Workshop – simplified fatigue</td>
</tr>
<tr>
<td>14:00 – 14:15</td>
<td>Break</td>
</tr>
<tr>
<td>14:15 – 15:15</td>
<td>Workshop – stochastic fatigue</td>
</tr>
<tr>
<td>15:15 – 15:40</td>
<td>Additional considerations</td>
</tr>
<tr>
<td>15:45 – 16:00</td>
<td>Summing up</td>
</tr>
</tbody>
</table>
Fatigue history in a nutshell

15 October 1842: Fatigue failure of shaft in train at Versailles. 60 killed.

Several Comet crashes in 1950s due to fatigue cracks initiating from corners of square windows.

Testing of shafts: “Wöhler kurver” after 1850.

At 18.30 27 March 1980: Fatigue failure in one of important members of floating platform “Alexander L. Kielland” 123 killed. Worst accident in Norwegian oil industry.
The "Alexander L. Kielland" Accident

D-6 failed
D was lost
The "Alexander L. Kielland" Accident

- Fatigue crack that initiated from the fillet welds
- Hydrophone holder
- Brace
- Section of area by hydrophone fitting and drain hole

Node 3
Node 4
Column C
Column D
Column E
Node 6
Hydrophone
Drainhole
The "Alexander L. Kielland" Accident

Failed Member
Fatigue Crack Growth in Failed Member

- Crack initiation in fillet welds
- Fatigue crack growth around the brace
- Final fracture in storm
Examples of fatigue cracks
In-service Experience on Fatigue Critical Details

- Stiffener end connections
- Root source of cracking
  - Global hull girder bending
  - Local dynamic pressures
  - Relative deflections caused by bending of girder system
  - Stress concentration at stiffener toe and heel
In-service Experience on Fatigue Critical Details

- Knuckles in inner structure (hopper knuckle)
- Root source of cracking:
  - Deflection on main girder system
  - High stress concentration
In-service Experience on Fatigue Critical Details

- Shell plating
- Root source of cracking
  - Local pressure
In-service Experience on Fatigue Critical Details

- Main deck openings and attachments
- Root source of cracking
  - Global hull girder stress
  - Stress due to hull girder deflection and stiff topside lattice construction
  - Stress from topside inertia forces
  - Local stress concentrations
Critical Details on Deck
In-Service Experience on Fatigue Critical Details

Dominating loads:
Hull girder bending, local stress concentration can be high
9 Year Old Double Hull Tanker for Oil

- Cracks found at the intersection between inner side and bulkhead.
- The cracks were found in several cargo tanks.
- First time experienced this type of cracking by DNV.
- Owner has similar experience from similar ships.
Principles of fatigue
Content

- Failure modes
- S-N curves basics
- Nominal, hot-spot and notch stress
- Impact of corrosion
- Fatigue damage accumulation: Palmgren - Miner rule
- Thickness effect
- Fatigue strength of high tensile strength steels
- Mean stress effect
- Effect of stress direction
- Examples of joint classification
- Stress Concentration Factors
- SCF by FEM analysis
Failure Modes Considered in DNV-RP-C203

1. Fatigue crack growth from the weld toe

2. Fatigue crack growth from a notch in the base material

3. Fatigue crack growth from the weld root into the plate below the fillet weld

4. Fatigue crack growth from the weld root through the weld
Definitions

- Low cycle fatigue (LCF): \( N < 10^4 \) cycles
- High cycle fatigue (HCF): \( N \geq 10^4 \) cycles

Number of cycles from waves in one year (mean period: 6 sec):
\[
60 \times 60 \times 24 \times 365 / 6 = 5.25 \times 10^6 \text{ cycles}
\]

- LCF: Based on strain (normally)
- HCF: Based on stress (normally)

Fatigue life: \( N = N_i + N_g \)

- \( N_i \): Number of cycles to initiate a crack (strain based calculation)
- \( N_g \): Number of cycles with crack growth until failure (fracture mechanics)
Fatigue testing
Design S-N Curve from Fatigue Test Data

- **Stress Range**
- **Number of Cycles**

Design S-N curve: Mean – 2 St. Dev.

Characteristic fatigue strength (FAT class)
S-N Curve

- The basic design S-N curve is given as

\[
\log N = \log \bar{a} - m \log \Delta \sigma
\]

or:

\[
N = \bar{a} \cdot (\Delta \sigma)^{-m}
\]

where

- \(N\) = predicted number of cycles to failure for stress range \(\Delta \sigma\)
- \(\Delta \sigma\) = stress range
- \(m\) = negative inverse slope of S-N curve
- \(\log \bar{a}\) = intercept of log N-axis by S-N curve

- Alternatively in air environment, the S-N curve can be defined by the characteristic fatigue strength at \(2 \cdot 10^6\) cycles (FAT class)
S-N Curves in DNV-RP-C203

Designation (FAT-class)
2min buzz group

WHAT AFFECTS CHOICE OF FATIGUE S-N CURVE?
Basic S-N Curve
Illustration of Stress at a Bracket Toe

- Fillet Weld
- Bracket Toe
- Hot Spot Stress
- Nominal Stress

Vector arrows indicate stress directions.
\[ \sigma_{\text{Notch stress}} = K_g K_w \sigma_{\text{Nominal}} \]
Assumptions on fatigue damage:

– Linear
– Cumulative

\[ D = \sum_{i=1}^{k} \frac{n_i}{N_i} = \frac{1}{\bar{a}} \sum_{i=1}^{k} n_i \cdot (\Delta \sigma_i)^m \leq \eta \]

Important conclusion:

– Load sequence does not matter
Example Palmgren - Miner Rule

\[ D = \frac{n_1}{N_1} \]

- \( \Delta \sigma_1 \)
- \( N_1 \)

Stress Range

Number of Cycles
Example Palmgren – Miner Rule

\[ D = \frac{n_1}{N_1} + \frac{n_2}{N_2} \]

Stress Range

Number of Cycles

\( \Delta \sigma_1 \)

\( \Delta \sigma_2 \)

\( N_1 \)

\( N_2 \)
**Thickness Effect**

\[
\sigma_{\text{eq}} = \sigma_{\text{ml}} \left[ 1 + \left( \frac{t}{t_{\text{ref}}} \right)^k \right]
\]

- For tubular joints \( t_{\text{ref}} = 32 \text{ mm} \).
- For bolts \( t_{\text{ref}} = 25 \text{ mm} \).
- \( t_{\text{ref}} = 25 \text{ mm} \) for welded connections.
- \( k: 0 - 0.30 \) for different details.

**Parameters:**

- \( t_{\text{ref}} = \) reference thickness
- \( t = \) thickness through which a crack will most likely grow.
  - \( t = t_{\text{ref}} \) is used for thickness less than \( t_{\text{ref}} \).
- \( k = \) thickness exponent on fatigue strength
Size Effect

**Volume Effect:**
- Increased weld length and increased possibility for defects that can initiate to fatigue cracks.

**Attachment Length:**
- More flow of stress into a long/thick attachment than into a short.

**Thickness of Plate:**
- The notch stress is increased with increasing plate dimensions as the notch radius is not increasing in the same proportion as the other geometry.
Fatigue Strength Versus Tensile Strength

Ultimate tensile strength of steel, MPa

Note for welded structure, the fatigue strength is independent of yield strength!
Mean stress effect (R-ratio)

1. Static stress tension
2. Zero static stress (alternating stress)
3. Static stress compression

\[ R = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \]
Effect of Corrosion / Coating

Unacceptable Damage Zone

Fatigue Level

Bare Steel, Corroding

5 yr. Paint Life

10 yr. Paint Life

15 yr. Paint Life

Fully protected

5 10 15 20 25 30 Years

Effect

Thinning Effect

5 10 15 20 25 30 Years
Principal stress direction – perpendicular to weld toe

\[ \Delta \tau_{//}, \Delta \sigma_{\perp}, \Delta \sigma_{//} \]

Fatigue crack

Section

Weld toe

Principal stress direction

\[ \varphi \]
Principal stress direction – parallel to weld toe

Δτ //, Δσ //, Δσ ⊥, Φ, Fatigue crack, Weld toe, Section
Principal stress direction – choice of S-N curve
Example: Cross Joint S-N curve choice
Hot Spot 1 and 2

From DNV RP-C203 Table A7:

6. Gusset plate welded to the edge of a plate or beam flange.
7. Flange welded to another flange at crossing joints.

6 and 7:
The distance $l$ is governing detail category for the stress direction shown in sketch. For main stress in the other beam the distance $L$ will govern detail category.

<table>
<thead>
<tr>
<th></th>
<th>$l$ conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>$l \leq 150$mm</td>
</tr>
<tr>
<td>W1</td>
<td>$150 &lt; l \leq 300$mm</td>
</tr>
<tr>
<td>W2</td>
<td>$l &gt; 300$mm</td>
</tr>
</tbody>
</table>
### Improved fabrication

**From DNV RP-C-203 Table A7:**

<table>
<thead>
<tr>
<th></th>
<th>5. Gusset plate with a radius welded to the edge of a plate or beam flange.</th>
<th>5. The specified radius to be achieved by grinding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>( \frac{1}{3} \leq \frac{r}{W}, r \geq 150\text{mm} )</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>( \frac{1}{6} \leq \frac{r}{W} &lt; \frac{1}{3} )</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>( \frac{1}{10} \leq \frac{r}{W} &lt; \frac{1}{6} )</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>( \frac{1}{16} \leq \frac{r}{W} &lt; \frac{1}{10} )</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>( \frac{1}{25} \leq \frac{r}{W} &lt; \frac{1}{16} )</td>
<td></td>
</tr>
</tbody>
</table>
From DNV RP-C-203 Table A4:

2. Ends of continuous welds at cope holes.

2.:
- Cope hole not to be filled with weld material.
Stress Concentration Factors
Definition of a Stress Concentration Factor:

- Stress magnification at a structural detail due to the detail itself or due to a fabrication tolerance with the nominal stress as reference value

\[ SCF = \frac{\sigma_{\text{hot spot}}}{\sigma_{\text{nominal}}} \]
Stress Distribution at a Hole

Relative stress vs. Relative distance from centre of hole $x/r$. The graph shows the distribution of stress relative to the distance from the centre of a hole. The line for calculation of stress is highlighted, indicating the method used to determine stress distribution.

The relative stress decreases as the relative distance from the centre of the hole increases, following a specific curve that is typical in stress analysis around circular holes in materials.
Fatigue Life?

SCFs multiply !!!
SCF_{total} = SCF_1 \times SCF_2 \times \ldots
Fatigue Life?

Crack in main deck

Soft transitions, avoid stress concentrations
Example - SCF due to eccentricity

Static system:

Deflected shape:

Bending moment:

Axial + bending stress:

$$\sigma_{\text{nominal}}$$

$$\sigma_{\text{nominal}} \left(1 + 3 \frac{\delta}{t}\right)$$
Example - SCF due to thickness transition

\[
SCF = 1 + \frac{6(\delta_m + \delta_t - \delta_0)}{t \left[ 1 + \frac{t^{1.5}}{T^{1.5}} \right]}
\]

where

\( \delta_m \) = maximum misalignment

\( \delta_t \) = \( \frac{1}{2} (T - t) \) eccentricity due to change in thickness

\( \delta_0 \) = 0.1t is misalignment inherent in the S-N data for butt welds

\( T \) = thickness of thicker plate

\( t \) = thickness of thinner plate
Example - SCFs for Welded Penetrations

The diagram illustrates the stress concentration factors (SCFs) for welded penetrations. The graphs show the SCFs as a function of the ratio of penetration thickness to plate thickness ($t_p$) for different ratios of penetration radius to penetration thickness ($r/t_p$). The graphs are divided into two sections: one for $t/t_p$ in the range of 0 to 2 and another for $t/t_p$ in the range of 0 to 20. The SCFs are represented by lines of varying slopes, with each line corresponding to a specific $r/t_p$ value.
Example - SCFs for Scallops

- SCF = 2.4 at point A (misalignment not included)
- SCF = 1.27 at point B

- SCF = 1.27 at point A (misalignment not included)
- SCF = 1.27 at point B

- SCF = 1.17 at point A (misalignment not included)
- SCF = 1.27 at point B
Example - SCF due to skew bending effect

Un-symmetrical stiffeners on laterally loaded panels, $K_n$

Example:
• L340x12+150x15 -> Life = 15 years
• T340x12+150x15 -> Life = 24 years

$\sigma_{\text{nominal}}$

Neutral axis

$K_{n1\sigma_{\text{nominal}}}$

$K_{n2\sigma_{\text{nominal}}}$

$K_{n3\sigma_{\text{nominal}}}$
Example - Tubular Joint Hot Spot Locations

SCF_{brace}: SCF from axial force at crown
SCF_{AS}: SCF from axial force at saddle
SCF_{MIP}: SCF from in-plane bending moment
SCF_{MOP}: SCF from out-of-plane bending moment
### Where to find SCFs?

#### RECOMMENDED PRACTICE

**DNVGL-RP-C203**
Edition April 2016

**Fatigue design of offshore steel structures**

<table>
<thead>
<tr>
<th>Category</th>
<th>Construction Details</th>
<th>Description</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1. Parent material adjacent to the loss of full penetration welded bolter joints.</td>
<td>1. The design should be based on the hot spot stress.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2. Welded rungs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3. Gusseted connections made with full penetration welds.</td>
<td>3. The design stress must include the stress concentration factor due to the overall form of the joint.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4. Gusseted connections made with fillet welds.</td>
<td>4. The design stress must include the stress concentration factor due to the overall form of the joint.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5. Parent material at the toe of a weld attaching a diaphragm to a tubular member.</td>
<td>The nominal design stress for the inside may be determined from section 2.3.8.</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>E ≤ 25 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>E &gt; 25 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>E to G, see Table A-7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6. Parent material of the stressed member adjacent to the loss of a bevel butt or fillet welded attachments in region of stress concentration.</td>
<td>6. Class depends on attachment length (see Table A-7) but stress must include the stress concentration factor due to the overall shape of adjoining structure.</td>
<td></td>
</tr>
</tbody>
</table>
Fatigue – evaluation methods
Content

- Phases of fatigue control (design analysis, in-service follow-up)
- Simplified fatigue analysis
  - Weibull distribution
  - Allowable stress range – simplified fatigue design curves

WORKSHOP: Simplified fatigue of topside to deck connection on FPSO

- Component stochastic fatigue analysis
- Full stochastic fatigue analysis

WORKSHOP: Stochastic fatigue analysis of the FPSO
Phases of Fatigue Control

Concept | Design | Construction | Operations | Life Extension

- Structural design requirements
- Newbuilding inspection

**FATIGUE ANALYSIS**

- In-service inspection
- Maintenance
- Re-analysis
- Repairs
Phases of Fatigue Analysis

Phase III
- Full Ship FE Analysis
- Full Stochastic Fatigue Analysis On Local FE Models
- Hydrodynamic Analysis Using Full Ship FE Model As Mass Model

Phase II
- Cargo Hold FE Analysis
- Component Stochastic Fatigue Screening Analysis
- Hydrodynamic Analysis - Refined Mass Model

Phase I
- Main Scantlings
- Simplified Fatigue
- Preliminary Hydrodynamic
Palmgren Miner Rule – Damage Summation

\[ D = \frac{n_1}{N_1} + \frac{n_2}{N_2} \]
Damage Calculations

Two main types of fatigue damage calculations

- Stochastic: use direct input and stress spectrum
- Simplified: use Weibull distribution

Stochastic

Simplified

Stress spectrum

SN curve

Scatter diagram
Weibull Distribution

\[ Q(\Delta \sigma) = \exp\left[ -\left( \frac{\Delta \sigma}{q} \right)^h \right] \]

where

- \( Q \) = probability for exceedance of the stress range \( \Delta \sigma \)
- \( h \) = Weibull shape parameter
- \( q \) = Weibull scale parameter is defined from the stress range level, \( \Delta \sigma_0 \), as

\[ q = \frac{\Delta \sigma_0}{(\ln n_0)^{1/h}} \]

\( \Delta \sigma_0 \) is the largest stress range out of \( n_0 \) cycles.
Example $h = 0.70$

$$\Delta \sigma = \Delta \sigma_{20} \left(1 - \frac{\text{Log } n}{\text{Log } n_{20}}\right)^{1/h}$$
Weibull Long Term Stress Range Distribution

\[ Q(\Delta \sigma) = \frac{1}{n_0} \]

- \( h > 1 \)
- \( h < 1 \)
- \( h = 1 \)

Probability of exceedance: \( \frac{1}{n_0} \) to \( 1 \)

Log \( n \): \( n_0 \) to \( Q(\Delta \sigma) \)
Integrated Fatigue Damage

Damage calculated based on One-slope SN curve

\[
D = \frac{v_0 T_d}{a} q^m \Gamma(1 + \frac{m}{h}) \leq \eta
\]  \hspace{1cm} (5.1.3)

where

- \( T_d \) = design life in seconds
- \( h \) = Weibull stress range shape distribution parameter
- \( q \) = Weibull stress range scale distribution parameter
- \( v_0 \) = average zero-crossing frequency
- \( \Gamma(1 + \frac{m}{h}) \) = gamma function. Values of the gamma function are listed in Table 5-1.
Integrated Fatigue Damage

Damage calculated based on Two-slope SN curve

\[
D = \int_{S_1}^{S} \frac{v_0 T_d f(S, \Delta \sigma_0, h)}{N_2(S)} dS + \int_{S_1}^{\Delta \sigma_0} \frac{v_0 T_d f(S, \Delta \sigma_0, h)}{N_1(S)} dS
\]

\[
f(S, \Delta \sigma_0, h) = h \frac{S^{h-1}}{q(\Delta \sigma_0, h)^h} \exp \left( -\left( \frac{S}{q(\Delta \sigma_0, h)} \right)^h \right)
\]

\[
q(\Delta \sigma_0, h) = \frac{\Delta \sigma_0}{(\ln(n_0))^{1/h}}
\]
Allowable Extreme Stress Range During $10^8$ Cycles

![Graph showing allowable extreme stress range vs. Weibull shape parameter h.](image-url)
# Allowable Extreme Stress Range

Allowable extreme stress range in MPa during $10^8$ cycles for components in air

<table>
<thead>
<tr>
<th>S-N curves</th>
<th>$0.50$</th>
<th>$0.60$</th>
<th>$0.70$</th>
<th>$0.80$</th>
<th>$0.90$</th>
<th>$1.00$</th>
<th>$1.10$</th>
<th>$1.20$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1449.3</td>
<td>1092.2</td>
<td>861.2</td>
<td>704.7</td>
<td>594.1</td>
<td>512.9</td>
<td>451.4</td>
<td>403.6</td>
</tr>
<tr>
<td>B2</td>
<td>1268.1</td>
<td>955.7</td>
<td>753.6</td>
<td>616.6</td>
<td>519.7</td>
<td>448.7</td>
<td>394.9</td>
<td>353.1</td>
</tr>
<tr>
<td>C</td>
<td>1319.3</td>
<td>919.6</td>
<td>688.1</td>
<td>542.8</td>
<td>445.5</td>
<td>377.2</td>
<td>326.9</td>
<td>289.0</td>
</tr>
<tr>
<td>C1</td>
<td>1182.0</td>
<td>824.0</td>
<td>616.5</td>
<td>486.2</td>
<td>399.2</td>
<td>337.8</td>
<td>292.9</td>
<td>258.9</td>
</tr>
<tr>
<td>C2</td>
<td>1055.3</td>
<td>735.6</td>
<td>550.3</td>
<td>434.1</td>
<td>356.3</td>
<td>301.6</td>
<td>261.5</td>
<td>231.1</td>
</tr>
<tr>
<td>D and T</td>
<td>949.9</td>
<td>662.1</td>
<td>495.4</td>
<td>390.7</td>
<td>320.8</td>
<td>271.5</td>
<td>235.4</td>
<td>208.1</td>
</tr>
<tr>
<td>E</td>
<td>843.9</td>
<td>588.3</td>
<td>440.2</td>
<td>347.2</td>
<td>284.9</td>
<td>241.2</td>
<td>209.2</td>
<td>184.9</td>
</tr>
<tr>
<td>F</td>
<td>749.2</td>
<td>522.3</td>
<td>390.8</td>
<td>308.2</td>
<td>253.0</td>
<td>214.1</td>
<td>185.6</td>
<td>164.1</td>
</tr>
<tr>
<td>F1</td>
<td>664.8</td>
<td>463.4</td>
<td>346.7</td>
<td>273.5</td>
<td>224.5</td>
<td>190.0</td>
<td>164.7</td>
<td>145.6</td>
</tr>
<tr>
<td>F3</td>
<td>591.1</td>
<td>412.0</td>
<td>308.3</td>
<td>243.2</td>
<td>199.6</td>
<td>169.0</td>
<td>146.5</td>
<td>129.4</td>
</tr>
<tr>
<td>G</td>
<td>527.6</td>
<td>367.8</td>
<td>275.2</td>
<td>217.1</td>
<td>178.2</td>
<td>150.8</td>
<td>130.8</td>
<td>115.6</td>
</tr>
<tr>
<td>W1</td>
<td>475.0</td>
<td>331.0</td>
<td>247.8</td>
<td>195.4</td>
<td>160.4</td>
<td>135.8</td>
<td>117.7</td>
<td>104.0</td>
</tr>
<tr>
<td>W2</td>
<td>422.1</td>
<td>294.1</td>
<td>220.1</td>
<td>173.6</td>
<td>142.5</td>
<td>120.6</td>
<td>104.6</td>
<td>92.5</td>
</tr>
<tr>
<td>W3</td>
<td>379.9</td>
<td>264.8</td>
<td>198.2</td>
<td>156.0</td>
<td>128.2</td>
<td>108.6</td>
<td>94.2</td>
<td>83.2</td>
</tr>
</tbody>
</table>
### Design Charts (Different Design Lives and DFFs)

#### Utilisation factors $\eta$ as function of design life and Design Fatigue Factor

<table>
<thead>
<tr>
<th>DFF</th>
<th>Design life in years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
</tr>
<tr>
<td>3</td>
<td>0.33</td>
</tr>
<tr>
<td>5</td>
<td>0.20</td>
</tr>
<tr>
<td>10</td>
<td>0.10</td>
</tr>
</tbody>
</table>
## Reduction Factor on Stress for Lower Utilization

### Reduction factor on stress to correspond with utilisation factor $\eta$ for C – W3 curves in air environment

<table>
<thead>
<tr>
<th>Fatigue damage utilisation $\eta$</th>
<th>Weibull shape parameter $h$</th>
<th>0.50</th>
<th>0.60</th>
<th>0.70</th>
<th>0.80</th>
<th>0.90</th>
<th>1.00</th>
<th>1.10</th>
<th>1.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td></td>
<td>0.497</td>
<td>0.511</td>
<td>0.526</td>
<td>0.540</td>
<td>0.552</td>
<td>0.563</td>
<td>0.573</td>
<td>0.582</td>
</tr>
<tr>
<td>0.20</td>
<td></td>
<td>0.609</td>
<td>0.620</td>
<td>0.632</td>
<td>0.642</td>
<td>0.652</td>
<td>0.661</td>
<td>0.670</td>
<td>0.677</td>
</tr>
<tr>
<td>0.22</td>
<td></td>
<td>0.627</td>
<td>0.899</td>
<td>0.852</td>
<td>0.822</td>
<td>0.802</td>
<td>0.789</td>
<td>0.781</td>
<td>0.775</td>
</tr>
<tr>
<td>0.27</td>
<td></td>
<td>0.661</td>
<td>0.676</td>
<td>0.686</td>
<td>0.695</td>
<td>0.703</td>
<td>0.711</td>
<td>0.719</td>
<td>0.725</td>
</tr>
<tr>
<td>0.30</td>
<td></td>
<td>0.688</td>
<td>0.697</td>
<td>0.706</td>
<td>0.715</td>
<td>0.723</td>
<td>0.730</td>
<td>0.737</td>
<td>0.743</td>
</tr>
<tr>
<td>0.33</td>
<td></td>
<td>0.708</td>
<td>0.717</td>
<td>0.725</td>
<td>0.733</td>
<td>0.741</td>
<td>0.748</td>
<td>0.754</td>
<td>0.760</td>
</tr>
<tr>
<td>0.40</td>
<td></td>
<td>0.751</td>
<td>0.758</td>
<td>0.765</td>
<td>0.772</td>
<td>0.779</td>
<td>0.785</td>
<td>0.790</td>
<td>0.795</td>
</tr>
<tr>
<td>0.50</td>
<td></td>
<td>0.805</td>
<td>0.810</td>
<td>0.816</td>
<td>0.821</td>
<td>0.826</td>
<td>0.831</td>
<td>0.835</td>
<td>0.839</td>
</tr>
<tr>
<td>0.60</td>
<td></td>
<td>0.852</td>
<td>0.856</td>
<td>0.860</td>
<td>0.864</td>
<td>0.868</td>
<td>0.871</td>
<td>0.875</td>
<td>0.878</td>
</tr>
<tr>
<td>0.67</td>
<td></td>
<td>0.882</td>
<td>0.885</td>
<td>0.888</td>
<td>0.891</td>
<td>0.894</td>
<td>0.897</td>
<td>0.900</td>
<td>0.902</td>
</tr>
<tr>
<td>0.70</td>
<td></td>
<td>0.894</td>
<td>0.897</td>
<td>0.900</td>
<td>0.902</td>
<td>0.905</td>
<td>0.908</td>
<td>0.910</td>
<td>0.912</td>
</tr>
<tr>
<td>0.80</td>
<td></td>
<td>0.932</td>
<td>0.934</td>
<td>0.936</td>
<td>0.938</td>
<td>0.939</td>
<td>0.941</td>
<td>0.942</td>
<td>0.944</td>
</tr>
<tr>
<td>1.00</td>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Workshop 1

Simplified fatigue analysis
Group Work – Simplified Fatigue – FPSO Topside Stool to Deck

Principal stress direction

Force direction

Bracket toe
Welded attachment, $l > 300$ mm:
Table A7.1
Full Penetration weld or fillet weld
S-N curve: F3
Bending Moments at $10^{-8}$ Probability Level

\[
M_{wo,s} = -0.11 \ k_{wm} \ C_w \ L^2 \ B \ (C_B + 0.7) \ \text{(kNm)}
\]

\[
M_{wo,h} = 0.19 \ k_{wm} \ C_w \ L^2 \ B \ C_B \ \text{(kNm)}
\]

\[
\Delta M_{20} = M_{wo,s} - M_{wo,h}
\]

\[
\Delta \sigma_{20} = \frac{\Delta M_{20}}{Z_d}
\]
Example Use of Design Charts

Detail on deck of FPS:
- Design life 25 years
- Deck plate thickness $t = 35 \text{ mm}$
- F3 fatigue curve

Questions:
- Expected fatigue failure mode?
- Expected crack location?
- Select S-N curve
- Is thickness effect applicable?
- What is recommended DFF?
- Calculate Weibull distribution factor (CN 30.7)
- Allowable stress range with/without FMS notation?
Fatigue – evaluation methods

Stochastic methods
Component Stochastic Fatigue Check of FPSO Longitudinals

- The longitudinals and hull girder are normally modelled as a beam model
- Tabulated stress concentration factors
- Fatigue damage
  - Weibull: simplified fatigue
  - Stochastic: component stochastic
- Time efficient method

Stress Concentration Factors

<table>
<thead>
<tr>
<th>Axial stress in the longitudinal direction</th>
<th>Bending due to lateral load</th>
</tr>
</thead>
<tbody>
<tr>
<td>At point A:</td>
<td></td>
</tr>
<tr>
<td>$K_l = 1.33$ $d \leq 150$</td>
<td></td>
</tr>
<tr>
<td>$K_l = 1.40$ $d &gt; 150$</td>
<td></td>
</tr>
<tr>
<td>At point B:</td>
<td></td>
</tr>
<tr>
<td>$K_z = 1.33$ $d \leq 150$</td>
<td></td>
</tr>
<tr>
<td>$K_z = 1.40$ $d &gt; 150$</td>
<td></td>
</tr>
</tbody>
</table>

Beam Model of Longitudinal

$$M = \frac{psI_{eff}^2}{12}$$

Beam Model of Hull Girder
Example, Longitudinal End Connections

- 3.0 < DFF
- 2.5 < DFF < 3.0
- 2.0 < DFF < 2.5
- 1.5 < DFF < 2.0
- 1.0 < DFF < 1.5
- 1.0 > DFF
---

**Full Stochastic Fatigue Assessment**

- **Hydrodynamic analysis**
  - RAO’s
    - External pressure
    - Relative wave elevation
    - Accelerations
    - Full load / intermediate / ballast
    - ->800 complex lc

- **Load transfer**
  - RAO’s
    - External pressure
    - Internal pressure
    - Accelerations
    - Adjusted pressure for intermittent wetted areas

- **Global structural analysis**
  - RAO’s
    - Global stress/deflections
    - Entire global model

- **Deflection transfer to local model**
  - Global deflections as boundary conditions on local model

---

**Hydrodynamic model**

**Global FE-model**

**Global + local FE-model**

**Global stress/deflection**

**Local model boundary conditions**

---
Full Stochastic Fatigue Assessment

Local stress/deflections

Local stress transfer functions

Principal hotspot stress

Stress distribution for each load case

RAO’s
• Local stress/deflections

Stress extrapolation

Input
• Hot spot location

Result
• RAO
• Principal hot spot stress

Fatigue calculations

Input
• Wave scatter diagram
• Wave spectrum
• SN-curve
• Stress RAO

•⇒ Fatigue damage

Scatter diagram

SN data

Notch stress

Geometric stress

Geometric stress at hot spot (Hot spot stress)

Nominal stress

Stress

Hot spot

Geometric stress

Nominal stress

Hot spot (Hot spot stress)
Screening for Critical Locations

Plot of fatigue lives for main deck (full stochastic)

Stool positions
SCF by FEM analysis
SCF by FEM – stress definitions

\[ \sigma_{\text{Notch stress}} = K_g K_w \sigma_{\text{Nominal}} \]
Derivation of Hot Spot Stress

Stress

Extrapolated geometric stress (Method A)

Direct calculated geometric stress (Method B)

Weld toe or intersection line

σ_{t/2}

σ_{3t/2}

t/2

3t/2

Distance
SCF by FEM – what stress to use?

Intersection line

Hot spot

Extrapolated hot spot stress

Gaussian integration point

A

0.5 t

1

2

3

4

B

1.5 t

End of bracket

Main stress direction

8 node shell element

Element for stress extrapolation

Plate
Different Hot Spot Positions
Mesh Size using 4-Node Shell Elements

- Recommended mesh size 0.5t x 0.5t to 2t x 2t.
- Larger mesh sizes at the hot spot region may provide non-conservative results.

- **Method A:**
  Hot spot stress based on linear extrapolation of stresses at 0.5t and 1.5t when linked to D - curve.

- **Method B:**
  Hot spot stress from 0.5t should be linked to E – curve (or stress to be multiplied with 1.12 and D – curve).
Mesh Size using 8-Node Shell Elements

- Recommended mesh size from \( t \times t \) up to \( 2t \times 2t \).
- Smaller and larger mesh sizes at the hot spot region may provide non-conservative results.

**Method A:**
Hot spot stress based on linear extrapolation of stresses \( 0.5t \) and \( 1.5t \) when linked to \( D - curve \).

**Method B:**
Hot spot stress based on read out points \( 0.5t \) when linked to \( E - curve \) (or stress to be multiplied with 1.12 and \( D - curve \))
Stress Extrapolation in a Three-dimensional Model
Mesh Size using Solid Elements

- For 20-node hexahedral elements it is sufficient with one element over the thickness to pick up a linear stress distribution.
- For simple 8-node brick elements at least 4 elements are required for the same purpose.
- Width length ratio within 1:4.
- Modelling of a fillet weld will likely limit the size of the mesh at the hot spot region.
- In order to capture St Venant torsion it is recommended to use several elements for modelling of a bulb section.
Examples of FE models for fatigue
Details Subjected to Local Bending, e.g. Hopper Knuckle

- Initiation point
- Semi-elliptic crack
- Section through beam at weld toe
Crack Growth Analysis of Hopper Knuckle

- Initiation point
- Semi-elliptic crack
- Section through beam at weld toe

Stress top flange
Stress bottom flange

Crack depth (mm)

Normalised Time

- PureMembrane
- SCF=1.8
- Pure Bending
Effective Hot Spot Stress from FE Analysis

- At hot spots with significant plate bending one might derive an effective hot spot stress for fatigue assessment based on the following equation:

\[ \Delta \sigma_{e,spot} = \Delta \sigma_{a,spot} + 0.60 \Delta \sigma_{b,spot} \]

- Only to be used at hot spots with possibility for redistribution of stresses
Limitations of FE Procedure

- Should not be used for single sided butt welds (Nominal S-N curve is W3, F3 or F, G if welded on backing)

- Should not be used for cruciform joints as calculated $K_G = 1.0$ from FEA with shell or 3D analysis model (Nominal S-N curve is E, F)

- Can not be used for fatigue cracking of the root in fillet welds
Workshop 2

Stochastic fatigue analysis using STOFAT

FPSO Hopper Knuckle connection
In-service Experience on Fatigue Critical Details

- Knuckles in inner structure (hopper knuckle)
- Root source of cracking:
  - Deflection on main girder system
  - High stress concentration
Low Cycle Fatigue
### Low Cycle Fatigue vs High Cycle Fatigue

<table>
<thead>
<tr>
<th>Load case</th>
<th>Stress component</th>
<th>Midship section view</th>
<th>Plan view</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1</td>
<td>Full load, $T_L$, $\sigma_{LC1}$</td>
<td><img src="image1" alt="Midship section view" /></td>
<td><img src="image2" alt="Plan view" /></td>
</tr>
<tr>
<td>LC2</td>
<td>Ballast, $T_{ball}$, $\sigma_{LC2}$</td>
<td><img src="image3" alt="Midship section view" /></td>
<td><img src="image4" alt="Plan view" /></td>
</tr>
<tr>
<td>LC3</td>
<td>Alternate 1, $T_{act}$, $\sigma_{LC3}$</td>
<td><img src="image5" alt="Midship section view" /></td>
<td><img src="image6" alt="Plan view" /></td>
</tr>
<tr>
<td>LC4</td>
<td>Alternate 2, $T_{act}$, $\sigma_{LC4}$</td>
<td><img src="image7" alt="Midship section view" /></td>
<td><img src="image8" alt="Plan view" /></td>
</tr>
<tr>
<td>LC5</td>
<td>Alternate 3, $T_{act}$, $\sigma_{LC5}$</td>
<td><img src="image9" alt="Midship section view" /></td>
<td><img src="image10" alt="Plan view" /></td>
</tr>
<tr>
<td>LC6</td>
<td>Alternate 4, $T_{act}$, $\sigma_{LC6}$</td>
<td><img src="image11" alt="Midship section view" /></td>
<td><img src="image12" alt="Plan view" /></td>
</tr>
</tbody>
</table>
Operation: Ballast – Full Last
Operation: Alternating
Combined Fatigue Criteria (LCF + HCF)

\[ D_f = \sqrt{D_{HCF}^2 + \left(\frac{D_{LCF} - 0.25}{0.75}\right)^2} \leq 1.0 \]
Root cracking
Design S-N Curve: W3
Partial Penetration/Fillet Weld

Weld toe failure

Root failure

h

2a_i

t_p

σ

σ
Failure from the Weld Root?

- **Weld toe failure**
- **Root failure**

Graph showing the relationship between $\frac{2a}{t_p}$ and $\frac{h}{t_p}$ for different values of $t_p$ (50 mm, 25 mm, 12 mm, 6 mm). The graph indicates the weld toe and root failure regions.
Uncertainties in fatigue prediction
Question?

WHAT ARE THE UNCERTAINTIES
### Examples of DFFs in fatigue codes

<table>
<thead>
<tr>
<th>Classification of structural components based on damage consequence</th>
<th>Access for inspection and repair</th>
<th>NORSOK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No access or in the splash zone</td>
<td></td>
</tr>
<tr>
<td>Substantial consequences</td>
<td>Accessible</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below splash zone</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Above splash zone or internal</td>
<td>3</td>
</tr>
<tr>
<td>Without substantial consequences</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Structural Elements

<table>
<thead>
<tr>
<th>Structural Elements</th>
<th>Class</th>
<th>FMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal structures, accessible and not welded directly to the submerged part of the shell plate</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Internal structure, accessible and welded directly to the submerged part of the shell plate</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>External structure above lowest inspection waterline, accessible for inspection and repair</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>External structure below lowest inspection waterline, accessible for inspection by divers</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>External structure below lowest inspection waterline, inaccessible for inspection by divers</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

DNVGL-OS-C102 (FPSO)
Design Fatigue Factor (DFF)
Benefits of Increased DFF

**Fatigue analysis**

**Standard DFF**

**Increased DFF**

In-service inspection
Maintenance
Re-analysis
Repairs

UNEXPECTED
# FMS – Fatigue Methodology Specification

## Main Class vs FMS: Principles of Fatigue Analysis

<table>
<thead>
<tr>
<th></th>
<th>Main Class</th>
<th>FMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main focus</strong></td>
<td>Safety</td>
<td>Safety + Economical consequences</td>
</tr>
<tr>
<td><strong>Design Fatigue Factors (DFFs)</strong></td>
<td>1 - 2 - 3</td>
<td>2 - 3 - 10</td>
</tr>
<tr>
<td><strong>Dynamic loads</strong></td>
<td>Rule loads</td>
<td>Direct wave load analysis</td>
</tr>
<tr>
<td><strong>Analysis methods</strong></td>
<td>Simplified fatigue acceptable</td>
<td>Stochastic methods are required</td>
</tr>
<tr>
<td><strong>Uncertainties of fatigue life prediction</strong></td>
<td>May be less accurate due to simplified methods</td>
<td>High confidence of direct analysis methods</td>
</tr>
</tbody>
</table>
Improvements by fabrication
Example of Joints Suitable for Improvements
Example Unsuitable for Improvement
## Improvement on Fatigue Life

<table>
<thead>
<tr>
<th>Improvement method</th>
<th>Minimum specified yield strength</th>
<th>Increase in fatigue life (factor on life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding</td>
<td>Less than 350 MPa</td>
<td>0.01$f_y$</td>
</tr>
<tr>
<td></td>
<td>Higher than 350 MPa</td>
<td>3.5</td>
</tr>
<tr>
<td>TIG dressing</td>
<td>Less than 350 MPa</td>
<td>0.01$f_y$</td>
</tr>
<tr>
<td></td>
<td>Higher than 350 MPa</td>
<td>3.5</td>
</tr>
<tr>
<td>Hammer peening</td>
<td>Less than 350 MPa</td>
<td>0.011$f_y$</td>
</tr>
<tr>
<td></td>
<td>Higher than 350 MPa</td>
<td>4.0</td>
</tr>
</tbody>
</table>
The Weld Toe Burr Grinding Technique

(a) Direction of travel

(b) Stiffener plate

Existing weld

Start toe grind

Grind toe continuously along both sides and around end of stiffener plate

Approximately 4x1

Stress
Grinding of Weld Toe

Grinding depth

Original profile

Minimum throat to be maintained

Root

Ground profile

Original toe

NOT TO SCALE

d = 0.5 below undercut
r/t > 0.25
r/d > 4

Depth gauge

Plate

Depth measurement
Correctly Ground Weld Toe

- Weld metal
- Ground toe
- Parent plate
Incorrectly Ground Weld Toe

Weld metal

Weld toe inadequately ground

Parent plate
Grinding

Depth of grinding should be 0.5mm below bottom of any visible undercut.
TIG Dressing of Welds
Fillet Weld before and after TIG Dressing
Hammer Peening
Hammer Peening Operation

- Bright, shiny surface
- Peening depth 0.5mm
- 60-80° angle
- 75-90° angle

[Diagram of hammer peening operation]
Needle Peening Equipment and Operation
Effect of Additional Weld Leg on Fatigue Life

![Diagram showing the effect of additional weld leg length on fatigue life improvement.](image-url)
Fatigue design codes
Rules (Recommended Practice)

- Norsok N-004 and DNV-RP-C203 developed at the same time (1997). Funded by the industry.
  http://exchange.dnv.com/publishing/Codes/ToC_edition.asp#Recommended Practices
- API RP 2A Recommended practice for planning, designing and constructing fixed offshore platforms.
Next task is to set up a new Wadam FLS run

- Task: Prepare and run the hydrodynamic wave load analysis for the FLS case
  - Set up the required data for environment, models etc.
  - Create load file for the structural FLC analysis

- This is done within the same HydroD workspace, as described in the following pages
  - This time without using the Wizard (which is also possible)
Set-up FLS load transfer analyses

- **Full load FLS**
  - Include the already defined frequency domain environment condition and sea state
  - Switch to load transfer analysis by selecting **Structural Loads**
  - Verify / define the new tolerances made available to the load transfer analysis
Set-up FLS load transfer analyses

- **Full load FLS**
  - The roll damping model is similar to what was done for the first analysis, for long term response. See page 30 for details.
  - Define load transfer options as seen in the menu below
    - Include static load
    - Pressure reduction zone, \( A = 4.275 \)
      (the calculation from Postresp with the updated model gives 4.44)
      - For intermittent wet surfaces in waterline region
    - Specify first load case = 1
Run load transfer analyses for FLS

- Start the analyses from Run analysis or the All Activities Monitor
  - Select the wanted analyses and click Start

- Before exiting from HydroD, check print file, Wadam1.lis, and pressures in Xtract
  - After having started Xtract from HydroD, do as follows
    - Xtract: File – Open with offset.
    - Specify first complex load case as no. 2
    - Select T1.FEM and G1.SIF (by ctrl-click)
    - Focus on not matching elements, i.e. elements not receiving pressure
Goal of workshop
- Learn to use Stofat for local fatigue calculations using both Element fatigue points and Hot spot approach in Stofat.

Input files
- **HopperR10.SIN**
- *(StofatHopp_Inp.jnl)*

Run Stofat interactively to calculate the results.
- Element fatigue check
- Hot spot fatigue check

Display results in Xtract
- Calculated fatigue damage
- Long term stress amplitude
- Long term static+dynmic stress

The interactive commands will be shown in the following pages
In the Local_FLS_Hopper_Knuckle | Stofat_Hotspot_Fatigue application, specify:
- Make sure the Results File from above Sestra activity is selected,
- Do not select any Command Input File
  - The input file is the solution to the tasks you should perform in the workshop

The results file is opened automatically, as seen in the Stofat interface:
Next is to perform File Transfer:

![Transfer Superelement dialog box](image1)

Note the information written in the Stofat window when the file transfer is completed:

![Stofat window](image2)

- The essential wave load information, from the S10.FEM file read by Sestra, is shown, making it possible for Stofat to continue.
- There is also information on the number of elements in the model and available named sets (defined in GeniE).
- The ‘Non Stofat Elements’ listed are typically beam elements.
- The main commands from the input file are shown in the next pages.
Start by **assigning** wave direction probabilities:

- Select the wave direction and type the probability, press Apply
- Repeat for all wanted wave directions
- Sum of probabilities = 1

<table>
<thead>
<tr>
<th>Dir.</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>90.0</td>
<td>0.05</td>
</tr>
<tr>
<td>135.0</td>
<td>0.15</td>
</tr>
<tr>
<td>180.0</td>
<td>0.6</td>
</tr>
<tr>
<td>225.0</td>
<td>0.15</td>
</tr>
<tr>
<td>270.0</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Select the number of elements to be included in the fatigue screening: **Set = HOPHS**

Assign the following properties:
- Select SN curve for default selection of elements: **DNV2010_DNVC-I**
- Stress Type K-factors
Assign continued:

- Wave spectrum shape
  - DNV-WW: PM

- Wave statistics (scatter diagram)
  - DNV-WW for all directions (as for the previous wave direction probabilities)
Create the element fatigue check points to be used in the screening

Use surface points – both sides

We want to include long term stress calculation

Define long term probabilities
Define long term return period
- 100 years only in this case

We want to include static loads from the hydrostatic & gravity load case

Define static load case

Define long term stress components
- Principal stress, Sp1
- Include SCF
- Local reference system
- Include static results
Define output of fatigue results to be printed to a VTF file for Xtract
- File name: HopperFull
- Element fatigue point results
- Usage factors

Not all definitions made are echoed in the Stofat window

To verify some of these definitions, select Print Run Overview

In the below print is selected
- Wave direction data
- Long term probabilities
Run the fatigue check

- A run name must be defined

When the run has finished, main results and other information are printed to the main Stofat window:
We want to present long term results, as well as fatigue results, in Xtract.

Print long term results to VTF:
- Append to old file, HopperFull
- Select Long term response
- Select Probability exponent
  - Select Stress amplitude
  - Apply
- Select Return period
  - Select Max stress
  - Apply

![Print Fatigue Results to VTF File](image)
Assign new Stress Type K-factors

**Assign Stress Type K-factors to Elements**

- **AXIAL Stress K-factors**
  - Geometric stress concentration: 1.0
  - Weld stress concentration: 1.0
  - Eccentricity stress concentration: 1.0
  - Angular mismatch factor: 1.0
  - Lateral panel load factor: 1.0

- **BENDING Stress K-factors**
  - Geometric stress concentration: 0.6
  - Weld stress concentration: 1.0
  - Eccentricity stress concentration: 1.0
  - Angular mismatch factor: 1.0
  - Lateral panel load factor: 1.0

- **SHEAR Stress K-factors**
  - Geometric stress concentration: 1.0
  - Weld stress concentration: 1.0
  - Eccentricity stress concentration: 1.0
  - Angular mismatch factor: 1.0
  - Lateral panel load factor: 1.0

Resulting stress type K-factor = Product of stress type K-factors = K\text{axial} = K_{\text{geometric}} \times K_{\text{weld}} \times K_{\text{eccentricity}} \times K_{\text{angular}} \times K_{\text{lateral}}
Create the fatigue check points to be used in the Hot spot calculation:

- The Hot spot point and the interpolation points are defined by use of coordinates.
- When clicking Only, some feedback is given in the Stofat window.
- The input has to be accepted by Stofat.
- Clicking Show will print the positions of the points to be print window.
- See next page for an outline of the location of the hotspot.
Location of elements used in the hotspot analysis. In the base case the elements 3125 and 3126 are used.

The numbers will of course depend on mesh settings etc.
Run the fatigue check
- A run name must be defined

When the run has finished, main results and other information are printed to the main Stofat window:
Print the Hot spot fatigue point results to the print window (or file).

The results from the hot spot calculation cannot be displayed in Xtract.

Exit from Stofat.
Start Xtract from Sesam Manager and open the HopperFull.vtf file.
- For example by right-clicking the VTF file in the File Overview

This file contains three result cases. Double-click each of them to display the different results
- RUN1_1: Fatigue damage for the element check
- RUN1_2: Long term stress amplitude $10^{-4}$
- RUN1_3: Max stress 100 years return period
Safeguarding life, property, and the environment

www.dnvgl.com

SAFER, SMARTER, GREENER