A new model to estimate fatigue damage accumulated during one ship voyage

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Outline

◆ Measurement data
◆ Preliminary conditions for estimation
◆ Narrow band approximation
◆ A new simple fatigue model
◆ Validation and application of the model
◆ Conclusions and Future work
Measurement data

1. Time series stress (signal) of the whole voyage (left) & one typical sea state (right)

2. Sea states (directional wave spectra) of whole voyage (left) & one sea state (right)
Preliminary conditions for estimation

Rain-flow counting method

The mean stress for all sea states in one voyage

<table>
<thead>
<tr>
<th>Voyage</th>
<th>Whole voyage</th>
<th>Sum of all sea states</th>
<th>Mean stress influence</th>
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</table>

Fatigue damage estimated by different approaches based on rain-flow method

mean stress distribution of one voyage

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Narrow band approximation

- NBA for expected fatigue damage

\[ E[D^{nb}(t)] \approx tf_z (h_s^m / \alpha)^2^{-m/2} \Gamma(1 + m / 2) = 0.47tf_z h_s^3 / \alpha \]

- Response should be available

- \( f_z \) zero crossing response frequency

- \( h_s \) significant response height

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Narrow band approximation

✓ Ship response from hydrodynamic simulation

\[ S_\sigma(w_e \mid U_0, \beta, H_s, T_z) = \int_0^{2\pi} |H_\sigma(w_e \mid U_0, \beta)|^2 \cdot S(w_e, \alpha) d\alpha \]

\[ \lambda_n = \int_0^{\infty} \int_0^{2\pi} \left| w + \left( w^2 U_0 / g \right) \cos \beta \right|^n H^2_\sigma(w \mid U_0, \beta) S(w) f(\alpha) d\alpha dw \]

\[ h_s = 4 \cdot \sqrt{\lambda_0} \quad f_z = 2 \cdot \pi \cdot \sqrt{\frac{\lambda_2}{\lambda_0}} \]

✓ Ship response \( X(t) \) from onboard measurement

\[ h_s = 4\sqrt{\lambda_0} = 4\sqrt{V[X(0)]} \]

\[ f_z \quad \text{zero crossing frequency of } X(0) \]
A new simple fatigue model

1. Significant response height

\[
h_s = 4 \cdot \sqrt{\int_0^\infty H^2 \sigma(w | U_0, \theta) \frac{4\pi^3 H^2_s}{T^4} \exp \left[ - \frac{1}{\pi} \left( \frac{wT_z}{2\pi} \right)^{-4} \right] dw}
\]

Constant \( C_i \): \( C_i = h_{si} / H_{si} \)

Tz distribution \( f(t_i) \) from long term wave statistics: \( C = \sum_{i=1}^{n} C_i f(t_i) \)

2. Zero crossing response frequency

\[
f_z = \frac{1}{T_z} + \frac{2\pi U_0 \cos \theta}{9.81 T_z^2} \quad T_z = 3.5 \cdot \sqrt{H_s}
\]
Validation and application of the model

Voyages for validation

- 7 voyages from Europe to Canada (in 2008)
- 7 voyages from Canada to Europe (in 2008)

Voyages of North Atlantic Crossing in different seasons
Validation and application of the model

Comparison of significant response height

Comparison of zero crossing response frequency

Calculation from time series stress (x-axis) VS our proposed model (y-axis)
Validation and application of the model

Fatigue damage distribution along different voyages
Total damage of different voyages and constant C

7 voyages from Europe to Canada

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Validation and application of the model

HDG distribution of sea states Hs>0

HDG distribution of sea states Hs>5m

Analysis of 3 special voyages from Canada to EU

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Conclusions and Future work

- The fatigue estimation model proposed here works well (comparing with the rain-flow estimation)
- For the fatigue estimation location of above vessel, the constant C is 20 for head sea, and 14 for following sea
- There are some uncertainties of fz in the model…
- Include uncertainties for reliability analysis…
- Whipping influence …(further work)
- Routing tool design….
Thank you!