Sea Loads on Vertical Cylinder Groups induced by JONSWAP Spectra

Diploma Thesis

Part of the DFG-Project „Investigations on Wave Loadings of Cylindrical Marine Structures“

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Background

- Wide field of application of cylindrical structures in offshore constructions.
- Lack of calculation approaches for close-grouped cylinders.
- What is the influence of neighboring cylinders of the wave load on a single cylinder?

Foto: Matthias Ibeler, alpha-ventus.de
Foto: Arndt Hildebrandt, WeserWind
The Large Wave Channel (GWK) of the Coastal Research Centre (FZK)

Length: 310 m
Width: 5 m
Depth: 7 m
Max. water depth: 5 m
Max. wave height: 2.5 m
Test Set-Up
Test Set-Up

Analysed cylinder group configurations

$S_c = \frac{1}{D}$
Test Set-Up

### Jonswap Spectra

<table>
<thead>
<tr>
<th>d = 4.26 m</th>
<th>Significant Wave Height H_s [m]</th>
<th>Peak Period T_p [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.80</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
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<td></td>
<td></td>
<td>8</td>
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<tr>
<td></td>
<td></td>
<td>-</td>
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<tr>
<td></td>
<td>1.00</td>
<td>4</td>
</tr>
<tr>
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<td>1.00</td>
<td>4</td>
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<tr>
<td></td>
<td>1.40</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

### Regular Waves

<table>
<thead>
<tr>
<th>d = 4.26 m</th>
<th>Wave Period T [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 5 6 7 8</td>
</tr>
<tr>
<td></td>
<td>x x x x x</td>
</tr>
<tr>
<td></td>
<td>x x x x x</td>
</tr>
<tr>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
</tr>
</tbody>
</table>

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[Image of test set-up]

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**FORSCUNGSZENTRUM KÜSTE**
 Gemeinsame Zentrale Einrichtung
 der Leibniz Universität Hannover und
er der Technischen Universität Carolo-Wilhelmina zu Braunschweig

**Institut für Land- und Seeverkehr**
Fachgebiet Meerestechnik

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Experimental Procedure

$T = 8 \text{ s and } H = 1,4 \text{ m}$
Analysis

Single cylinder with T=4 s and H=0.8 m, KC = 10.4
Analysis

Single cylinder with $T=8\ s$ and $H=1.5\ m$, $KC = 43$
Pressure Distribution and Vortex Shedding

Notice: The pressure plotted is underpressure.
Analysis

Q2r in comparison to K0 for T=6.4 s and H=0.8 m
Q2r in comparison to K0 for T=4 s and H=0.8 m
Results

Increased loads on the measuring cylinder due to presence of the neighboring cylinders

- $Q_2m$
  - $S_c = 2$
  - $S_k = 2$
  - $+ 30\% \text{ (mean value)}$
  - $+ 59\% \text{ (maximal)}$
  - $+ 6\% \text{ (minimal)}$

- $Q_2r$
  - $S_c = 2$
  - $+ 15\% \text{ (mean value)}$
  - $+ 38\% \text{ (maximal)}$
  - $- 25\% \text{ (minimal)}$

- $Q_4m$
  - $S_c = 4$
  - $S_k = 4$
  - $+ 14\% \text{ (mean value)}$
  - $+ 37\% \text{ (maximal)}$
  - $- 16\% \text{ (minimal)}$

- $Q_4r$
  - $S_c = 4$
  - $+ 11\% \text{ (mean value)}$
  - $+ 34\% \text{ (maximal)}$
  - $- 14\% \text{ (minimal)}$
Results

$C_D$ coefficients calculated with least-square method

![Graph showing $C_D$ vs KC with different markers for K0, Q2m, Q2r, Q4m, and Q4r]
Results

\( C_D \) coefficients calculated with least-square method

![Diagram showing \( C_D \) vs. \( KC \) for different groups and mean values.]

- \( K_0 \)
- \( K_0 \) mean
- \( Q_2m \)
- \( Q_2m \) mean
- \( Q_2r \)
- \( Q_2r \) mean
- \( Q_4m \)
- \( Q_4m \) mean
- \( Q_4r \)
- \( Q_4r \) mean
Results

$C_M$ coefficients calculated with least-square method
Results

$C_M$ coefficients calculated with least-square method
Results

$C_D$ coefficients dependent upon estimation method

**Least-Square Method**

<table>
<thead>
<tr>
<th>$C_D$ mean</th>
<th>K0</th>
<th>Q2m</th>
<th>Q2r</th>
<th>Q4m</th>
<th>Q4r</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_D$ mean</td>
<td>0,90</td>
<td>1,41</td>
<td>1,23</td>
<td>1,15</td>
<td>1,04</td>
</tr>
</tbody>
</table>

**Maximum Value Method**

<table>
<thead>
<tr>
<th>$C_D$ mean</th>
<th>K0</th>
<th>Q2m</th>
<th>Q2r</th>
<th>Q4m</th>
<th>Q4m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_D$ mean</td>
<td>0,79</td>
<td>1,35</td>
<td>1,17</td>
<td>1,03</td>
<td>0,96</td>
</tr>
</tbody>
</table>
Results

C_M coefficients dependent upon estimation method

<table>
<thead>
<tr>
<th>Method</th>
<th>K0</th>
<th>Q2m</th>
<th>Q2r</th>
<th>Q4m</th>
<th>Q4r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least-Square Method</td>
<td>1,44</td>
<td>1,61</td>
<td>1,46</td>
<td>1,33</td>
<td>1,41</td>
</tr>
<tr>
<td>Maximum Value Method</td>
<td>1,58</td>
<td>1,70</td>
<td>1,63</td>
<td>1,57</td>
<td>1,57</td>
</tr>
</tbody>
</table>
Results

\( C_D \) coefficients calculated with least-square method

<table>
<thead>
<tr>
<th>( K_0 )</th>
<th>( Q_{2m} )</th>
<th>( Q_{2r} )</th>
<th>( Q_{4m} )</th>
<th>( Q_{4r} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD mean</td>
<td>0.90</td>
<td>1.41</td>
<td>1.23</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>0.84</td>
<td>1.30</td>
<td>1.13</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Results

$C_M$ coefficients calculated with least-square method

### Jonswap Spectra

<table>
<thead>
<tr>
<th>$K_0$</th>
<th>$Q_{2m}$</th>
<th>$Q_{2r}$</th>
<th>$Q_{4m}$</th>
<th>$Q_{4r}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM mean</td>
<td>1.44</td>
<td>1.61</td>
<td>1.46</td>
<td>1.33</td>
</tr>
</tbody>
</table>

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<table>
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<tr>
<th>$K_0$</th>
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<th>$Q_{2r}$</th>
<th>$Q_{4m}$</th>
<th>$Q_{4r}$</th>
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<td>1.63</td>
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</tr>
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Summary and Conclusion

- Neighboring cylinders induce more intensive vortex shedding.
  - Thereby they induce an increase of load.
- The indicative point for the structurally designation of the piers are the wave crests.
- The maximum increase of load depends on the wave regime.
- Middle cylinders encounter a larger increase of load in comparison with the cylinders having only one flanking cylinder.
- The influence of the neighboring cylinders on the single cylinder decreases with increasing cylinder distance.
- The $C_D$ and $C_M$ coefficients reflect the physical processes.
Outlook

- Video recording of the development of the vortices.
- Investigating more cylinder distances \((S_c < 2 \text{ und } S_c > 5)\).
- Investigating of more cylinder diameters.
- Investigating of more neighboring cylinders.
- Measuring the forces on more than one cylinder.
- Application of other estimation methods for the force coefficients \(C_D\) and \(C_M\).
Thank you for your attention

The provision of the measured data by Oumeraci et al. is gratefully acknowledged.