Rotatorische und oszillatorische Scherversuche zur Ermittlung steifigkeitsrelevanter Kenngrößen von Offshore-Vergussmörteln unter dem Einfluss des Early-age Movement

Rotational and Oscillatory Shear Tests for Determining Time-dependent Properties of Offshore Grouts under the Influence of Early-age Movement

Cotardo, D., Begemann, C., Haist, M., Lohaus, L.
INTRODUCTION

Wave-induced loadings

Relative movements between pile and sleeve during the initial setting of grout

Early-age Movement (EAM)

Effect of EAM on the mechanical properties of grout is unknown

DNVGL-ST-0126, 2018:
Relative movements shall be limited to a maximum of 1 mm, whereby ungrouted connections shall be considered

Jack-up Barge

Jacket

Monopile

Grouted connection

Grout pipeline

Pile

Sleeve

Annulus
### MOTIVATION

DNVGL requirement (1 mm) leads to severe restrictions and additional costs

<table>
<thead>
<tr>
<th><strong>Implications for the installation and design process</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater displacements already occur at relatively calm sea</td>
</tr>
<tr>
<td>Necessity for additional measures in order to secure grouted connections</td>
</tr>
<tr>
<td>Uncertainties in the design process</td>
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</tbody>
</table>

- Expansion of the installation time slot could lead to economic advantages
- Sacrifice of cost-intensive measures (e.g. pile gripper)
- More economical design of offshore support structures and knowledge of lifespan

Benefits for the installation and design process by knowledge of the effects of EAM
The goal was to provide a method for determining time-dependent properties of grout under the influence of Early-age Movement.

Oscillatory rheology in order to simulate wave-induced relative movements

determine the development of grout properties

Rotational rheology for determining material characteristics

Combination of both methods
EXPERIMENTAL PROGRAMME

SAMPLES

Flowability as a function of w/s ratio

A
\( \varnothing_A = 150 \text{ mm} \)
\( \varphi = 10^\circ \)

B
\( \varnothing_B = 300 \text{ mm} \)
\( \varphi = 0^\circ \)
\( \varphi = 1.5^\circ \)

C
\( \varnothing_C = 450 \text{ mm} \)
\( \varphi = 10^\circ \)

Influence of the material properties

Influence of the oscillation angle \( \varphi \)

Representation of the development of grout-stiffness

ROTATIONAL AND OSCILLATORY RHEOLOGY

Influence of the EAM on the development of grout properties

DETERMINATION OF THE COMPRESSIVE STRENGTH

Undisturbed and disturbed

Influence on the strength
**METHODS**

### Implementation of the investigations

- **Viskomat XL**
- **Concrete paddle**
- **Resulting relative displacement depending on the rotation angle $\varphi$ and the geometry of the measuring sensor**

\[ \begin{align*}
\varphi_1 &= 10^\circ, \quad C_1 \approx 21.3 \text{ mm} \\
\varphi_2 &= 1.5^\circ, \quad C_2 \approx 3.2 \text{ mm}
\end{align*} \]
**METHODS**

**Implementation of the investigations**

**Numerical investigations:**
Relative displacement of a monopile substructure depending on the significant wave height

**Resulting relative displacement**
Depending on the rotation angle $\phi$ and the geometry of the measuring sensor

- $\phi_1 = 10^\circ$
- $\phi_2 = 1.5^\circ$
- $C_1 \approx 21.3 \text{ mm}$
- $C_2 \approx 3.2 \text{ mm}$
METHODS

Sequence of the measurement profile

Flow curves generated from a downward step profile

Rheological form

\[ \tau(\dot{\gamma}, t) = \tau_0(t) + \mu(t) \cdot \dot{\gamma} \]

‘BINGHAM model’

Rheometric form

\[ T(\Omega, t) = T_0(t) + \frac{\Delta \Omega}{\Delta T}(t) \cdot \Omega \]
**METHODS**

**PREPARATION OF SPECIMENS**

- **EAM samples**
  - Preparation of undisturbed EAM samples
  - Preparation of disturbed EAM samples
  - Comparison of the compressive strength (tested after 7 days)

- **REF samples**
  - Preparation of specimens
  - Without any kind of shear stress

**Comparison of the compressive strength (tested after 7 days)**

- φ = 10°
- φ = 1.5°
- φ = 0°
## RESULTS AND DISCUSSION

<table>
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<tr>
<th>Results</th>
<th>Discussion</th>
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<tr>
<td>➔ The lower the w/s ratio, the more accelerated an increase in grout properties</td>
<td>➔ Pore spaces can be bridged faster by the growth of early hydration products</td>
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<tr>
<td>➔ A greater oscillation angle $\phi$ causes an accelerated increase in grout properties</td>
<td>➔ Primary structures are formed by the externally applied shear stress</td>
</tr>
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<td></td>
<td>➔ Permanent cyclical movements lead to a process of deaeration</td>
</tr>
<tr>
<td></td>
<td>➔ Due to abrasion of hydration products, the time span of the dormant period is reduced</td>
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</table>
RESULTS AND DISCUSSION

The torque amplitude $T_A$ of the oscillation tests themselves also reflect the described relationships.
RESULTS AND DISCUSSION

Permanent cyclical movements lead to greater compressive strength (disturbed samples)

The higher the initial flowability of the material, the lower the influence of cyclic movements on the compressive strength

Permanent cyclical movements lead to a process of deaeration, which increases the compressive strength

Shear stress could lead to abrasion of hydration products, which acts as precipitation nuclei during the hydration period of hardening
### SUMMARY

<table>
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<tr>
<th>Effect of w/s ratio on the time-dependent grout properties</th>
<th>Effect of oscillation angle $\varphi$ on the time-dependent grout properties</th>
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<td>The lower the w/s ratio the more accelerated the increase in grout properties</td>
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<tr>
<td>→ Pore spaces can be bridged faster</td>
<td>→ Process of deaeration occurs</td>
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<tr>
<td></td>
<td>→ Extrinsic agglomeration occurs</td>
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<tr>
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<td>→ Acceleration period commences earlier</td>
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<td>→ Process of deaeration occurs</td>
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<tr>
<td>→ Colloidal hydration products act as precipitation nuclei during the hydration period of hardening, if the shear rate is high enough</td>
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<td>→ <strong>No impairment due to EAM on strength was observed</strong></td>
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**CONCLUSIONS**

<table>
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<th>Rheological method</th>
<th>Recommendation for the practice</th>
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<tr>
<td>The method for simulating the EAM via oscillation is very promising</td>
<td>The lower the w/s ratio…</td>
</tr>
<tr>
<td>➔ This type of cyclic movements closely resembles wave-induced loads</td>
<td>➔ the lower are segregation phenomena,</td>
</tr>
<tr>
<td>➔ Varying deflections and frequencies can be simulated</td>
<td>➔ the more accelerated the development of grout properties,</td>
</tr>
<tr>
<td></td>
<td>➔ the greater the strength of the hardened grout.</td>
</tr>
<tr>
<td>The combination of rotation and oscillation allows a deep understanding of the</td>
<td>The flowability must be high enough for the material to be pumped!!</td>
</tr>
<tr>
<td>rheological behavior</td>
<td></td>
</tr>
<tr>
<td>Further methods</td>
<td>Goals</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------------</td>
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<tr>
<td>Determination of the air void content of the hardened grout</td>
<td>Verification of the process of deaeration due to cyclical movements</td>
</tr>
<tr>
<td>Conductivity measurements</td>
<td>Verification of abrasion processes due to shear stress</td>
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<tr>
<td>Particle size analysis</td>
<td>Verification of the effect of extrinsic agglomeration</td>
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<tr>
<td>Determination of the material behavior over a period of 24 hours</td>
<td>Representation of a comprehensive property profile of the grout from the liquid to the hardened state</td>
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</table>
ACKNOWLEDGEMENTS

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REFERENCES


Thank you for your attention!

Dipl.-Ing. Dario Cotardo
Research Staff
Institute of Building Materials Science
Appelstraße 9A
30167 Hannover

d.cotardo@baustoff.uni-hannover.de

www.baustoff.uni-hannover.de