3DEC analysis of crosswise tension resistance in masonry structures

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The Crosswise Tension Resistance

The phenomenon:

Its importance:

(Simon & Bagi, 2016)

(Beatini et al, 2018)
Overview of the research

Practical experience:
Bond pattern strongly affects crack formation and hence the load bearing capacity.

Analyzed patterns:

Running bond pattern

Herringbone pattern

Main steps of the analysis of each pattern:

Step 1: Theoretical prediction on the suitably chosen elementary cell of the pattern

Step 2: Run discovery DEM simulations to figure out how different bond patterns fail

Step 3: Check the theoretical derivations with DEM experiments
Theoretical derivations: 1. The straight running bond pattern

\[
\sigma_t \leq \mu \cdot \frac{\alpha \cdot b}{h} \sigma_c
\]
Theoretical derivations: 2. The skew shifted running bond pattern

\[ \sigma_t \leq \mu \cdot \frac{\alpha \cdot b}{h} \sigma_c \]
Theoretical derivations: 3. The herringbone pattern (1/2)

\[ \sigma_t \leq \frac{0.5 + \mu}{4} \cdot \sigma_c \]
Theoretical derivations: 4. The herringbone pattern (1/3)

\[ \sigma_t \leq \frac{2/3 + 2\mu}{6} \cdot \sigma_c \]
DEM simulation to check the predictions: Material, contact, element subdivision

Data of the 3DEC model:

Elements: linearly elastic, density 1428 kg/m³, bulk modulus: $1.10 \cdot 10^{10}$ N/m²,
shear modulus $0.833 \cdot 10^{10}$ N/m²

Joints: frictional, cohesionless, friction angle $38^\circ$,
normal stiffness: $1.0 \cdot 10^{10}$ (N/m²)/m, shear stiffness: $0.70 \cdot 10^{10}$ (N/m²)/m

Convergence analysis on the necessary density of element subdivision:

Brick size: $0.25 \text{ m} \times 0.125 \text{ m} \times 0.065 \text{ m}$

<table>
<thead>
<tr>
<th>Mesh size (m)</th>
<th>Computation time (min)</th>
<th>Limit tensile stress (N/m²)</th>
<th>Deviation from “Very dense meshing”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough meshing</td>
<td>0.03</td>
<td>8</td>
<td>5830</td>
</tr>
<tr>
<td>Medium meshing</td>
<td>0.02</td>
<td>16</td>
<td>5760</td>
</tr>
<tr>
<td>Dense meshing</td>
<td>0.01</td>
<td>171</td>
<td>5730</td>
</tr>
<tr>
<td>Very dense meshing</td>
<td>0.005</td>
<td>2838</td>
<td>5720</td>
</tr>
</tbody>
</table>
DEM simulation to check the predictions: Validation method

Validation method:

First try: Planar walls, BUT: boundary failure
Instead:

1. Apply vertical compressive stresses.
2. Apply gradually increasing outwards surface load on the intrados.
3. Detect failure and compare to the theoretical predictions.
Definition:
If the measured displacement for 1% load increment exceeds ten times the value that was accumulated until the last load step, then this is failure.
DEM to check the predictions: Results

Validation result:

Relation between crosswise tensile resistance and vertical compression
Further plans

Generalize theoretical predictions:

for herringbone pattern:
   extend simulations for 1/4

Application of the results:

domes:  
fan vaults:  

\{  
   by quantifying hoop tension resistance,
   modify the predictions for their critical thickness
\}

barrel vaults:
   bond pattern influences the load bearing capacity,
   and this can be quantified
Thank you for your attention!

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