Verification of pile group

Input data

Project
Description: Pile Group - Example 3
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Date: 28.10.2015

Name: Pile Group - Example 3
Description: Static scheme of Pile Group - Spring method

Settings
(input for current task)
Materials and standards
Concrete structures: EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1: standard

Soil parameters

Silty sand (SM), medium dense
Unit weight: $\gamma = 18,00 \text{ kN/m}^3$
Angle of internal friction: $\varphi_{ef} = 29,00^\circ$
Cohesion of soil: $c_{ef} = 5,00 \text{ kPa}$
Oedometric modulus: $E_{oed} = 13,50 \text{ MPa}$
Saturated unit weight: $\gamma_{sat} = 20,00 \text{ kN/m}^3$

Sand with trace of fines (S-F), medium dense
Unit weight: $\gamma = 17,50 \text{ kN/m}^3$
Angle of internal friction: $\varphi_{ef} = 29,50^\circ$
Cohesion of soil: $c_{ef} = 0,00 \text{ kPa}$
Oedometric modulus: $E_{oed} = 21,00 \text{ MPa}$
Saturated unit weight: $\gamma_{sat} = 19,50 \text{ kN/m}^3$

Low plasticity silt (ML,MI), consistency firm
Unit weight: $\gamma = 20,00 \text{ kN/m}^3$
Angle of internal friction: $\varphi_{ef} = 21,00^\circ$
Cohesion of soil: $c_{ef} = 12,00 \text{ kPa}$
Oedometric modulus: \( E_{oed} = 8.50 \text{ MPa} \)
Saturated unit weight: \( \gamma_{sat} = 22.00 \text{ kN/m}^3 \)

**Construction**

Width of pile cap \( b_x = 15.00 \text{ m} \)
\( b_y = 15.00 \text{ m} \)

Pile diameter \( d = 1.00 \text{ m} \)

Number of piles \( n_x = 5 \)
\( n_y = 4 \)

Spacing of piles \( s_x = 3.00 \text{ m} \)
\( s_y = 4.00 \text{ m} \)

**Geometry**

Depth from ground surface \( h_z = 2.00 \text{ m} \)

Pile head offset \( h = 0.00 \text{ m} \)

Thickness of pile cap \( t = 1.00 \text{ m} \)

Length of piles \( l = 12.00 \text{ m} \)

**Material of structure**

Unit weight \( \gamma = 25.00 \text{ kN/m}^3 \)

Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete: C 20/25

Cylinder compressive strength \( f_{ck} = 20.00 \text{ MPa} \)

Tensile strength \( f_{ctm} = 2.20 \text{ MPa} \)

Elasticity modulus \( E_{cm} = 30000.00 \text{ MPa} \)

Shear modulus \( G = 12500.00 \text{ MPa} \)

Longitudinal steel: B500

Yield strength \( f_{yk} = 500.00 \text{ MPa} \)

**Horizontal modulus of subsoil reaction**

<table>
<thead>
<tr>
<th>Depth [m]</th>
<th>( k_h ) [MN/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>12.00</td>
<td>10.00</td>
</tr>
</tbody>
</table>
Determination of vertical springs

Typical load (for analysis of vertical springs): 4_Q3:G1+G2+W4 (4)

Geological profile and assigned soils

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer [m]</th>
<th>Assigned soil</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,00</td>
<td>Low plasticity silt (ML,MI), consistency firm</td>
<td>🌾 🌾</td>
</tr>
<tr>
<td>2</td>
<td>5,00</td>
<td>Sand with trace of fines (S-F), medium dense</td>
<td>🌾 🌾</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>Silty sand (SM), medium dense</td>
<td>🌾 🌾</td>
</tr>
</tbody>
</table>

Load

<table>
<thead>
<tr>
<th>No.</th>
<th>Load new change</th>
<th>Name</th>
<th>Type</th>
<th>N [kN]</th>
<th>Mx [kNm]</th>
<th>My [kNm]</th>
<th>Hx [kN]</th>
<th>Hy [kN]</th>
<th>Mz [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>1_G1+G2 (1)</td>
<td>Design</td>
<td>17355,00</td>
<td>0,00</td>
<td>1879,25</td>
<td>-0,05</td>
<td>0,08</td>
<td>0,00</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>2_W4:G1+G2 (2)</td>
<td>Design</td>
<td>18600,00</td>
<td>-162,00</td>
<td>1879,25</td>
<td>728,95</td>
<td>0,08</td>
<td>0,00</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>3_Q3:G1+G2 (3)</td>
<td>Design</td>
<td>19250,00</td>
<td>0,00</td>
<td>3499,25</td>
<td>1079,95</td>
<td>0,08</td>
<td>0,00</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>4_Q3:G1+G2* (4)</td>
<td>Design</td>
<td>22500,00</td>
<td>-97,20</td>
<td>3499,25</td>
<td>1517,35</td>
<td>0,08</td>
<td>0,00</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>5_W4:G1+G2* (5)</td>
<td>Design</td>
<td>23700,00</td>
<td>-162,00</td>
<td>3013,25</td>
<td>1484,95</td>
<td>0,08</td>
<td>0,00</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>1_G1+G2 (6)</td>
<td>Service</td>
<td>15165,00</td>
<td>0,00</td>
<td>1392,04</td>
<td>-0,04</td>
<td>0,06</td>
<td>0,00</td>
</tr>
</tbody>
</table>
Ground water table

The ground water table is at a depth of 7.00 m from the original terrain.

Global settings

Analysis type: spring method
Type of pile: floating piles - compute the stiffness of springs from soil parameters
Connection piles / pile cap: fixed
Modulus of subsoil reaction: input by distribution

Analysis of the stage of construction

Design situation: permanent

Analysis results

Maximum internal forces (all load cases)

Maximum compressive force = -2330.20 kN
Minimum compressive force = -431.63 kN
Max. bending moment = 483.39 kNm
Max. shear force = 119.69 kN

Maximum displacements (only service load cases)

Max. settlement = 34.7 mm
Maximum horizontal displacement of pile cap = 4.8 mm
Max. rotation of pile cap = 5.3E-03 °
Verification No. 1

Dimensioning of piles - input data

Analysis carried out with an automatic selection of the most unfavorable LC. Reinforcement designed for all piles in the group.

Dimensioning of reinforcement:

Reinforcement - 20 pc bars 26,0 mm; covering 60,0 mm
Type of structure (reinforcement ratio) : pile

Reinforcement ratio $\rho = 1,352 \% > 0,357 \% = \rho_{\text{min}}$

Load : $N_{\text{Ed}} = -2330,20$ kN (compression); $M_{\text{Ed}} = 483,39$ kNm
Bearing capacity : $N_{\text{Rd}} = -7996,63$ kN; $M_{\text{Rd}} = 1658,86$ kNm

Designed pile reinforcement is SATISFACTORY

Verification of shear reinforcement:

Ultimate shear force: $V_{\text{Rd}} = 544,44$ kN > $119,69$ kN = $V_{\text{Ed}}$
Cross-section is SATISFACTORY.
### Distribution of forces on construction

<table>
<thead>
<tr>
<th>Depth [m]</th>
<th>Normal force $N$ [kN] (tah)</th>
<th>Normal force $N$ [kN] (tlak)</th>
<th>Shear force $Q$ [kN]</th>
<th>Bending moment $M$ [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-431.63</td>
<td>-2330.20</td>
<td>119.69</td>
<td>483.39</td>
</tr>
<tr>
<td>1.20</td>
<td>-451.17</td>
<td>-2312.03</td>
<td>114.48</td>
<td>342.91</td>
</tr>
<tr>
<td>2.40</td>
<td>-466.68</td>
<td>-2252.33</td>
<td>100.06</td>
<td>214.34</td>
</tr>
<tr>
<td>3.60</td>
<td>-477.47</td>
<td>-2144.06</td>
<td>79.02</td>
<td>123.53</td>
</tr>
<tr>
<td>4.80</td>
<td>-479.23</td>
<td>-1943.13</td>
<td>54.54</td>
<td>77.30</td>
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<tr>
<td>6.00</td>
<td>-476.39</td>
<td>-1698.73</td>
<td>29.90</td>
<td>45.39</td>
</tr>
<tr>
<td>7.20</td>
<td>-473.39</td>
<td>-1455.15</td>
<td>15.34</td>
<td>44.73</td>
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<tr>
<td>8.40</td>
<td>-471.85</td>
<td>-1226.51</td>
<td>8.56</td>
<td>43.53</td>
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<tr>
<td>9.60</td>
<td>-475.07</td>
<td>-1045.97</td>
<td>16.00</td>
<td>28.11</td>
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<td>10.80</td>
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<td>13.57</td>
<td>9.25</td>
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<td>12.00</td>
<td>-496.72</td>
<td>-837.58</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

- **Name:** Pile Group - Example 3
- **Description:** Dimensioning - Internal forces
- **Stage - analysis:** 1 - 1

**Construction**

- **Normal force**
  - Maximum compressive force = -2330.20 kN
  - Minimum compressive force = -431.63 kN

- **Shear force**
  - Max. = 119.69 kN

- **Bending moment**
  - Max. = 483.39 kNm