Evaluation of Gravity Retaining Walls from Jet Grouting Piles Installed in Sands

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Abstract

When height of retaining walls is small it is rational to install gravity retaining walls. The jet grouting technology often is used installing piles in the sand. Pile diameter can be varied from 0.50 to 1.20 m using single-phase jet grouting with 30÷40 MPa pressure. This type of piles applied for the installation of retaining walls too. Low retaining wall constructed using jet grouting pile should be treated as gravity walls. Diameter of the jet grouting piles from which are constructed retaining walls depend on the choice of wall height and from internal friction angle in sand. Influence of interaction between the wall surface and soil on stability is from 10% to 35%. Using of jet grouting technology formed gravity walls allow reduce the volume of mining amount and the installation duration.

Keywords: jet grouting, pile; gravity wall, sand, stability.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>distance between the pile centers (m)</td>
</tr>
<tr>
<td>A’</td>
<td>effective area of foundation pad (m²)</td>
</tr>
<tr>
<td>Aσ</td>
<td>active pressure action area on the wall surface (m²)</td>
</tr>
<tr>
<td>B’</td>
<td>effective foundation width (m)</td>
</tr>
<tr>
<td>c</td>
<td>cohesion of the soil (kPa)</td>
</tr>
<tr>
<td>d</td>
<td>embedding depth of the retaining wall (m)</td>
</tr>
<tr>
<td>Ea,h</td>
<td>resultant force of active lateral pressure (kN; kN/m)</td>
</tr>
<tr>
<td>εa</td>
<td>eccentricity of lateral active force action (m)</td>
</tr>
<tr>
<td>εf</td>
<td>eccentricity of interaction force between soil and wall surface action (m)</td>
</tr>
<tr>
<td>εG</td>
<td>eccentricity of wall weight action (m)</td>
</tr>
<tr>
<td>Ft</td>
<td>interaction force between soil and wall surface (kN)</td>
</tr>
<tr>
<td>G</td>
<td>weight of the retaining wall piles (kN; kN/m)</td>
</tr>
<tr>
<td>H</td>
<td>height of retaining wall (m)</td>
</tr>
<tr>
<td>k</td>
<td>stability against overturning</td>
</tr>
<tr>
<td>kσ,b</td>
<td>active earth pressure coefficient</td>
</tr>
<tr>
<td>kσ</td>
<td>coefficient of stability against horizontal translation</td>
</tr>
<tr>
<td>kR</td>
<td>safety factor for bearing capacity of the retaining wall base</td>
</tr>
<tr>
<td>M0</td>
<td>bending moment at foundation pad level (kNm, kNm/m)</td>
</tr>
<tr>
<td>Mr</td>
<td>overturning moment about point A (kNm; kNm/m)</td>
</tr>
</tbody>
</table>

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1. Introduction

Solving the problem of rational build-up area use is often inexpedient to leave the inclined slopes. The same problem is reconstructing roads when increasing roadway width. Retaining wall type depends on many factors [1]: the construction site boundary, size, geotechnical conditions, excavation depth, etc. More and more often are seeking non-traditional installation techniques for support structures [2]. Using the jet grouting technology are formed sheet-pile walls reinforced with a rigid armature or central reinforcing bars [3], [4]. According to soil type and injection parameters it is possible to predict the jet grouting pile diameter [5] and material properties [6], [7]. Material properties can be improved by using micro cement [8]. However, the using of micro cement is not yet widespread, because many things still to be done based on experience, rather than the calculations [9]. When height of retaining walls is small it is rational to install gravity retaining walls. Usually the installation sequence is: excavated soil, installed gravity wall, the space behind the wall is filled with soil using compaction. However, mining volumes and sometimes the construction site boundaries do not allow this type of retaining wall. Then, it may be installed embedded retaining walls using piles. The soil excavation in front wall are doing when wall is in design position, it reduces the volume of excavation and retaining walls installation time. However, embedded wall using piles due to bending moment action must be reinforced. The upper soil layers of the territory of Lithuania formed a retreating ice shield. According to Dundulis [10] naturally formed glacial sand and clay deposits covering 79% of the country’s territory. Fliuvioglacial sands and gravel formations, alluvium, marine and eolian sand reach 30%. The jet grouting technology more often is used installing piles in the sand. This type of piles also applied for the installation of retaining walls. Pile diameter can be varied from 0.50 to 1.20 m using single-phase jet grouting with 30÷40 MPa pressure. Retaining walls from jet grouting piles and with proper height can be treated as a gravity wall. This allows reduce the volume of mining amount and the installation duration.

2. Stability evaluation of the gravity wall from jet grouting piles

All potential soil base and retaining wall structures collapse cases must be appreciate when calculating the retaining walls [11]. The main conditions that must always be considered when ensuring gravity retaining walls stability (see Fig. 1) is:
• the stability against the overturning;
• the stability against the horizontal translation;
• the bearing capacity of gravity wall base.

![Fig. 1. Failure of retaining wall: (a) overturning, (b) horizontal translation, (c) insufficient bearing capacity](image-url)
Analyzed gravity retaining wall formed from jet grouting piles installed in sand wherein: cohesion $c = 0$, the ground surface on both sides of the wall is horizontal, embedding depth of the retaining wall $d = 0.50$ m, weight density of jet grouting piles $\gamma_{JG} = 20$ kN/m$^3$. Embedding depth calculating overturning and horizontal translation stability is not considered.

Values of active and passive pressure coefficient are presented in tables, graphs or are calculating using analytical expression. Values can be determined by different methods [13], [14], [15], [16], [17]. For further analysis we choose often applied Muller-Breslau solution [12]. According to it the active pressure coefficient equal:

$$k_{a,h} = \frac{\cos^2 \varphi}{\left(1 + \frac{\sin(\delta + \varphi) \cdot \sin(\varphi)}{\cos(\delta)}\right)^2}$$

The wall roughness has significant effect on active and passive pressure value [13], [16], [18], [19]. When using jet grouting piles, we don’t take into account roughness because the surface of the pile is very rugged (Fig. 2.). For such surfaces can be proposed that the friction angle between the soil and the retaining wall is equal to the internal friction angle of the soil.

In this case, the active pressure coefficient:

$$k_{a,h} = \frac{\cos^2 \varphi}{\left(1 + \sin(\varphi) \cdot \sqrt{2}\right)^2}$$

The resultant force of active lateral pressure equal:

$$E_{a,h} = 0.5 \cdot H \cdot \sigma_{a,h} \cdot a$$

Shear strain between wall surface and soil equal:

$$\tau_{a,v} = \sigma_{a,h} \cdot \tan(\delta) = \sigma_{a,h} \cdot \tan(\varphi)$$

3. Stability against overturning

It is checking the retaining walls stability against inversion about point A (Fig. 1). The retaining wall will be not overturning if will be meet condition:
Retaining moment about point A consist of two parts:

\[ M_{stb} = M_{stb,G} + M_{stb,Ft} \]  

(6)

\( M_{stb,G} \) retaining moment due weight of the gravity retaining wall action:

\[ M_{stb,G} = G \cdot e_G = \pi \cdot r^3 \cdot H \cdot \gamma_G \cdot r = \pi \cdot r^3 \cdot H \cdot \gamma_G \]  

(7)

where \( e_G \) – eccentricity of wall weight action, \( G \) – the weight of the retaining wall piles.

The retaining moment due of interaction force between soil and wall surface action:

\[ M_{stb,Ft} = F_t \cdot e_{Ft} \]  

(8)

where \( e_{Ft} \) – eccentricity of interaction force between soil and wall surface action. The interaction force between soil and wall surface can be find:

\[ F_t = 0.5 \cdot r \cdot A_s = 0.5 \cdot \sigma_{a,h} \cdot \tan \phi \cdot A_s \]  

(9)

where \( A_s \) – the active pressure action area on the wall surface. When calculating action on arc AB surface (see Fig. 3):

\[ A_s = \pi \cdot r \cdot H \]  

(10)

\[ e_{Ft} = r + \frac{2 \cdot r}{\pi} \]  

(11)

Fig. 3. Pile location in retaining wall: (a) retaining wall with contiguous pile, (b) the wall with spaces between the piles

The overturning moment about point A will be due active pressure action and equal:

\[ M_{dsh} = E_{as,h} \cdot e_{Eas} = E_{as,h} \cdot \frac{H}{3} \]  

(12)

After inserting the retaining and overturning moment’s expressions in Eq. (5) and simplifying similar members we get expression for wall with space between piles:

\[ k = 6 \cdot \pi \cdot r^3 \cdot \gamma + \frac{3 \cdot \tan \phi \cdot r^2 \cdot (\pi + 2)}{H \cdot a} \]  

(13)

for wall with contiguous piles.
The first member evaluate stability before the inversion that warrant jet grouting pile weight, the second – the influence of interaction forces between soil and pile surface. Interaction influence between soil and pile the surface, depending of the soil internal friction angle and diameter given in Fig. 4.

If simplify the scheme and accept that the interaction between the soil and pile surface mobilized on plane CD (see Fig. 3), then calculating the friction force should be adopted the surface area:

\[ A_s = H \cdot a \]  \hspace{1cm} (15)

And eccentricity of interaction force between soil and wall surface action according point A will be equal:

\[ e_{fi} = 2 \cdot r \]  \hspace{1cm} (16)

These changes inserting into Eq. (13) for the wall with spaces between the piles we get:

\[ k = \frac{6 \cdot \pi \cdot r^2 \cdot \gamma}{\sigma_{a,H} \cdot a \cdot H} + \frac{2 \cdot t \cdot \phi \cdot r \cdot (\pi + 2)}{H} \]  \hspace{1cm} (17)

Inserting into Eq. (14) for the wall with contiguous jet grouting pile we get:

\[ k = \frac{6 \cdot \pi \cdot r^2 \cdot \gamma}{\sigma_{a,H} \cdot a \cdot H} + \frac{2 \cdot t \cdot \phi \cdot r}{H} \]  \hspace{1cm} (18)

Comparison the members of the equations Eq. (14) and Eq. (18) that show affect of the interaction between the soil and pile surface, we can see that regardless of the walls geometric dimensions and soil properties will be always more dangerous the contact surface CD (see (a) Fig. 3) for the wall with contiguous jet grouting pile:

\[ 3 \cdot (\pi + 2) > 2 \]  \hspace{1cm} (19)

For the case when the wall is with spaces \( a \) between the piles (see (b) Fig. 3) should also be applied to the same scheme as:
This dependence obtained from equations Eq. (13) and Eq. (17).

\[
a \geq \frac{3 \cdot r \cdot (\pi + 2)}{2} = 7.712 \cdot r
\]  

(20)

The safety factor against overturning (see Fig. 5) always satisfied when the wall formed from jet grouting pile with a radius more than 0.35 m. If the radius is less 0.3 m wall installed in weaker sands ($\varphi < 32^\circ$) will be overturned.

4. Stability against horizontal translation

Retaining wall will be pushed down if stability coefficient less than 1:

\[
k_n = \frac{T}{E_{a,h}}
\]

(21)

where $T$ – force expressing the interaction between the soil and jet grouting pile pad; $E_{a,h}$ – resultant force of active lateral pressure.

By inserting these forces expressions into Eq. (21), we obtain:

\[
k_n = \frac{2 \cdot (G + F_t) \cdot \tan \varphi}{H \cdot \sigma_{a,h} \cdot a} = \frac{2 \cdot G \cdot \tan \varphi}{H \cdot \sigma_{a,h} \cdot a} + \frac{\tan^2 \varphi \cdot A_h}{H \cdot a}
\]

(22)

Fig. 5. Dependences of safety factor against overturning calculating wall with contiguous jet grouting pile when wall height is 3.0 m.

Fig. 6. The retaining wall stability against horizontal translation: (a) for retaining wall formed from 0.8 m diameter jet grouting pile located every 1.0 m. (b) verification of 2.5 m high retaining wall.
Horizontal translation condition for walls higher than 2.0 m satisfied, regardless of the soil internal friction angle (see (a) Fig. 6). When $H = 2.5$, this condition is critical for the walls formed from pile with diameter less than 0.90 m. When the piles diameter is smaller horizontal translation condition depends on the friction angle of sand (see (b) Fig. 6).

5. Evaluation of wall base bearing capacity

The bearing capacity of the wall base must satisfy the condition:

$$V \leq R$$

When retaining wall installed in sand the cohesion $c = 0$. The bearing capacity can be calculated according EN 1997-1:2004 [20]. When calculating effective dimensions of the foundation must be assessed bending moment at the foundation pad level:

$$B' = 2 \cdot r - 2 \cdot e_B = 2 \left( r - \frac{M_0}{V} \right)$$

Embedding depth ($d = 0.5$ m) was evaluated when calculating the bearing capacity of the retaining wall base. The moment acting on the foundation pad level (see Fig. 1) equal:

$$M_0 = E_{a,h} \cdot e_{a,h} - E_{p,h} \cdot e_{p,h} - F_{l} \cdot e_{F_l} = E_{a,h} \cdot \frac{H}{3} - E_{p,h} \cdot \frac{d}{3} - F_{l} \cdot r$$

The condition in Eq. (23) will be the satisfy when safety factor $k_R \geq 1$. This factor can be expressed as the ratio:

$$k_R = \frac{R}{V}$$

![Fig. 7. The dependences of the retaining wall base bearing capacity. (a) for retaining wall formed from 0.8 m diameter jet grouting pile located every 1.0 m. (b) the assessment bearing capacity of 2.0 m high retaining walls depending on the pad diameter](image)

When the wall height less 2.0 m the base resistance always sufficient, regardless of the pile diameter and soil. When the wall height 2.0 m the base bearing capacity sufficient when the pile diameter greater than 0.80 m. The base bearing capacity of piles with smaller diameter is sufficient when the internal friction angle of sand greater than 30°.

6. Conclusion

Diameter of jet grouting piles installed in sands using the single-phase jet grouting technology and 30÷40 MPa pressure can varied from 0.50 to 1.20 m. Low retaining wall constructed using jet grouting pile should be treated as gravity walls. Diameter of the jet grouting piles from which are constructed retaining walls depend on the choice of wall height and the from internal friction angle in sand. Influence of interaction between the wall surface and soil on stability is from 10% to
35% (see Fig. 4). The overturning condition (see Fig. 5) always satisfied when the wall formed from jet grouting piles with a diameter exceeding 0.70 m.

Horizontal translation condition for walls higher than 2.0 m satisfied, regardless of the soil internal friction angle. When $H = 2.5$, this condition is critical for the walls formed from pile with diameter less than 0.90 m. When the pile diameter is smaller horizontal translation condition depends on the friction angle of sand.

When the wall height less 2.0 m the base resistance always sufficient, regardless of the pile diameter and soil. The base bearing capacity for the wall with height 2.0 m is sufficient when the pile diameter greater than 0.80 m, for piles with smaller diameter is sufficient when the internal friction angle of sand greater than 30°.

References