USING OF JET GROUTING PILES REINFORCED WITH CENTRAL BARS FOR LOW RETAINING WALLS

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Abstract. In the retaining geotechnical structures it is important that the structural element must take not only axial forces, but bending moments too. The jet grouting piles are widely used when retaining walls and foundations of the structures are made. In most cases these piles are reinforced with rigid profile without evaluating the piles material strength. Malinin, A.G and Malinin, P.A (2004) proposed a method for the calculation of jet grouting piles reinforced with the central bar and acted by bending moment. The method of the bending moment calculation with more realistic assumption is suggested this article. This method is safer than propose Malinin, A.G and Malinin P.A (2004). Piles diameter and material strength are very important for the bending moment calculation. The reinforcement with central bars requires less metal than reinforcing with rigid profiles. The reinforcement with central bars is sufficient for retaining walls made using jet grouting technology.

Keywords: jet grouting, bending moment, retaining wall, central bar.

Introduction

In Lithuania jet grouting piles begin use from 1997th. Under this technology the water and cement mixture with a very high pressure is injected into the soil. The water and cement mixture is squirted into the soil over 1.8 ... 3.2 mm diameter nozzles. In the turbulent flow which formed in the ground the soil particles mixed with cement/water mixture Massonnet, R. (2009). The soil–water–cement mixture formed and during the chemical reaction hardens over the time. The water – cement mixture, which is used in Jet–grouting technology is a liquid consistency. Usually the water-cement ratio of mass was taken within the range 0.7-1.25. In the soils with a high coefficient of permeability excess water absorbs into the soils which are dislocated under ground water level. The residual water content does not much exceed the quantity needed for chemical reaction and when mixture has hardened excess water leave not much Gomes Correia, A. et al. (2009). The particularly marked absorption of excess water takes place in cases when the water – cement – soil mixture subside very much (Sližytė, D. (1999)). Jet grouting widely used installing retaining walls. In order to withstand the bending moments such retaining walls must be reinforced with steel elements.

The properties of jet grouting piles and their reinforcement with rigid profiles

The jet grouting piles material– we call it "grouting soil" can be described as hardened mixture from cement, water and soil particles, conversely to the production of concrete we cannot choose aggregates when using jet grouting technology.

- Soil type (see Fig.2)
- Cement content
- Cement/water mass ratio (Kutzner, Ch. (1996))
- Hardening time

![Fig.2.](image) Dependence of the grouting soil strength from soil type, cement content and hardening time. 1–5 – cement content 300 kg/m³, 6–7 – cement content 390 kg/m³, 8 – cement content 530 kg/m³, soil type: 1 – gravelly sand, 2 –sand, 3 – silty sand, 4 – sandy silt, 5 –silt, 6 – clayer silt, 7 – silty clay, 8 – clay.

![Fig 3.](image) The view of retaining wall made using jet grouted technology.

The ranges of jet grouting use are very wide – from ground improvement (see Fig 1) till retaining walls. Structures made using jet grouting technology may act not only axial forces but also horizontal forces and bending moment Massonnet, R. (2009). LST EN 12716 (standard approved in Lithuania) regulate the jet grouting execution works. This standard allows reinforcing jet grouting piles. There are more practical to reinforce such piles with rigid profiles or small size reinforcement case. The reinforcement must be to smaller size to fit in the hole formed by monitor. In the middle of the pile at full length formed small diameter core filled by cement and water mixture with a small amount of the soil particles. Away from center the proportion of soil particles increases. Very often jet grouting piles are used in retaining walls which bending moments are acted. There-for jet grouting piles are reinforced with rigid profile (see Fig.3). The bending moment that jet grouting pile sustained can be calculated using equation:

\[
M = \frac{f_y}{W}
\]

were \(f_y\) – steel resistance, \(W\) – the section modulus of the rigid profile.

In this equation does not evaluated the strength of jet grouting piles material The strength of the jet grouting piles installed in sands can be more than 15 MPa (see Fig.4).

![Fig 4.](image) Dependence of the grouting soil strength from cement content and hardening time in sand. (Slizyte, D. 1999)

Calculation of the bearing bending moment, when the pile is reinforced with central bar

![Fig 5.](image) Malinin et al. (2006) proposed calculating scheme

Malinin, A.G and Malinin P.A (2004) and Malinin, A.G. et al. (2008) offers a jet grouting pile reinforcements to calculate using the principles of reinforced concrete. The above-mentioned article accepted assumption that stresses in compression zone is equal to material compressive strength (see Fig 5). In this case, it is overestimated compression stresses Vainiūnas, P. et al. (2004), Bacinškas, D. et al. (2007)

We suggest another calculation assumption. The following assumption is accepted calculating the strength of the pile perpendicular section reinforced with central bars:
• Hypothesis of plane sections is valid.
• Deformation of the tension bars are the same as the deformation of the surrounding grouting.
• Hooke's law is valid for reinforcement and grouting.
• Tension work of the grouting soil is invaluable.
• Reinforcing bar placed in the center of the pile cross section.
• The height of compression zone is less than the radius of pile.

\[ y = \sqrt{r^2 - x^2 - z_i} \]  \hspace{1cm} (5)

there \( z_i \) – distance from the neutral line to the center of the mid-reinforcing:

\[ z_i = r \cdot \cos(\alpha) \]  \hspace{1cm} (6)

Compression normal stresses acting in the grouting soil can be found from similar triangles CDE and CFG:

\[ \sigma_c = \frac{f_c \cdot y}{r - z_i} \]  \hspace{1cm} (7)

\[ \sigma_y = \frac{f_c \cdot y}{r - z_i} \left( \sqrt{r^2 - x^2 - z_i} \right) \]  \hspace{1cm} (8)

Thus, a triangular area equal to

\[ A_{\text{CDE}} = \frac{0.5 \cdot f_c \left( \sqrt{r^2 - x^2 - z_i} \right)^2}{r - z_i} \]  \hspace{1cm} (9)

The resultant force \( F_c \) of the compression normal stresses acting in the grouting soil is equal:

\[ F_c = \int_{0}^{2} \frac{0.5 \cdot f_c \left( \sqrt{r^2 - x^2 - z_i} \right)^2}{r - z_i} \, dx \]  \hspace{1cm} (10)

where:

\[ k = r \cdot \sin(\alpha) \]  \hspace{1cm} (11)

The integration was carried Wolfram Mathematica Online Integrator support.

The resultant force \( F_c \) which equal to volume of cylindrical wedge when \( k < r \) be found:

\[ F_c = \frac{f_c \cdot r^2}{k \left( \frac{k}{r} \cdot z_i - z_i \right)^2} \left( \frac{k}{r} \cdot z_i + r^2 \right) \frac{\sqrt{r^2 - k^2}}{3} \]  \hspace{1cm} (12)

If the expression 6 and 11 insert into equation 12 and simplify the resultant force \( F_c \) will be equal:

\[ F_c = \frac{f_c \cdot r^2}{6(1 - \cos(\alpha))} \left( \sin(2 \cdot \alpha) \cdot \cos(\alpha) - 4 \cdot \sin(\alpha) - 6 \cdot \alpha \cdot \cos(\alpha) \right) \]  \hspace{1cm} (13)
The limit bending moment will be equal:

\[ M_{e} = F_{c} \cdot z_{c} + F_{r} \cdot z_{r} \]  

(14)

\( z_{c} \) – distance from neutral axis to the center of gravity of the cylinder wedge.

Center of gravity of the triangle CDE from neutral axis is located within distance \( y_{c} \):

\[ y_{c} = \frac{2}{3} \cdot y = \frac{2}{3} \left( \sqrt{r^{2} - x^{2}} - z_{c} \right) \]  

(15)

Product of the \( F_{c} \) with \( z_{c} \), we can find integrated product of the triangle ACDE area and distance from the neutral line to the triangle gravity the center \( y_{c} \):

\[ F_{c} \cdot z_{c} = \frac{f_{c}}{r - z_{c}} \int_{0}^{r} \left( \sqrt{r^{2} - x^{2}} - z_{c} \right)^{3} \cdot \frac{2}{3} \left( \sqrt{r^{2} - x^{2}} - z_{c} \right) dx = \]

\[ = \frac{2 \cdot f_{c}}{3 \cdot (r - z_{c})} \left( \sqrt{r^{2} - x^{2}} - z_{c} \right)^{2} dx \]  

(16)

The integration was carried Wolfram Mathematica Online Integrator support.

\[ F_{c} \cdot z_{c} = \frac{2f_{c}}{3(r - z_{c})} \left( \frac{1}{8} \cdot k \cdot \sqrt{r^{2} - k^{2}} \left( 12 \cdot z_{c}^2 + 5 \cdot r^2 - 2 \cdot k^2 \right) + \right. \]

\[ + \frac{3}{8} \cdot r^2 \cdot 4 \cdot z_{c}^2 + r^2 \cdot \text{arctg} \left( \frac{k}{\sqrt{r^{2} - k^{2}}} \right) - \]

\[ - z_{c} \cdot k \cdot (z_{c}^2 + 3 \cdot r^2) + z_{c} \cdot k^3 \]  

(17)

If the expression 6 and 11 insert into equation 17 and simplify we get:

\[ F_{c} \cdot z_{c} = \frac{f_{c} \cdot r^3}{12(1 - \cos(a))} \left( 12 \cdot \alpha \cdot \cos^{3}(\alpha) + 3 \cdot \alpha - \right. \]

\[ - 2 \cdot \cos^{3}(\alpha) \cdot \sin(\alpha) - 6,5 \cdot \sin(2 \cdot \alpha) \]  

(18)

The results of calculation

Malinin, A.G and Malinin P.A (2004) calculated limit bending moment of jet grouting piles with a diameter of 70 cm, compression strength of 10 MPa, the central bar of steel, with yield stress 235 MPa, and bar cross-sectional area of 26.6 cm². Revealed that the pile can withstand 166 kNm limit bending moment.

Meanwhile, an assessment that compression stress in elastic stage is not evenly distributed across the compressive zone (see Fig 6), a limit bending moment will be only 144 kNm. This is 15.2% less than Malinin, A.G and Malinin P.A (2004) got.

Calculating according to the methodology proposed in this article extend jet grouting pile application for installation of the retaining walls. The graphs (see Fig.9) show that bending moment up to 82 kNm can be achieved reinforcing with the S400 class central bar reinforcement when grouting soil strength \( F_{s} \) = 10 MPa, reinforcement diameter 32 mm. Profile, with the section modulus \( W = 348.3 \text{ cm}^{3} \), steel yield stress \( f_{s} = 235 \text{ MPa} \) can withstand the same bending moment. When decrease compressive strength of the grouting soil the bending moment decreases to (see Fig.8), however even at \( f_{s} = 4 \text{ MPa} \) strength can be achieved bending moment over 60 kNm.

Diameter of the jet grouting piles varies from 0.50 m to 1.00 m. The grouting pile diameter according Massonnet, R. (2009) depends by:

- soil type,
- nozzles diameter and its number,
- injection time.

The soil type has greatest influence on piles diameter.
Application of the central reinforcement in retaining walls

The bending moments are acting retaining walls therefore they must be reinforced.

For example: should be reinforcing piles of retaining wall. The retaining wall was installed in the sand with follow properties:

- angle of shear resistance $\varphi = 30^\circ$,
- weight density $\gamma = 18 \text{ kN/m}^3$.

Retaining wall calculation scheme varies depending on its construction stage. In initial construction stage (see scheme a in Fig.11) the maximum bending 32.5 kNm / m (see Fig.13). The maximum bending moment decreased 2.8 times and equal to 11.5 kNm / m (see Fig.12) when basement floor is installed (see scheme b in Fig.11).

The jet grouting pile reinforced with central bar and with material strength 4MPa (see Fig 10) is capable to withstand these bending moments.

![Fig 11. The retaining walls calculation schemes](image)

Whereas bending moment depends very much on the diameter and the compressive strength of the grouting soil must be keep a tight control of the installation works and the grouting parameters. The large experience of the jet grouting works is very important.

In order to standardize the calculation method and introduce the necessary safety factors the experiments must be carried out to assess the real stress distribution of compressive zone.

Conclusions

Jet grouting piles in low retaining walls can be reinforced not only with rigid reinforcement but also with the central reinforcement bar.

The approach proposed paper comparing with Malinin, A.G and Malinin P.A (2004) method is safer and more realistic estimate compression stresses in elastic stage.

The jet grouting elements of low retaining wall can be reinforced with central bar, but it is necessary to ensure the adequate diameter size and compression strength of the grouting soil.

References


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