MODELLING THE PERMEABILITY OF A JET-GROUTED CUT-OFF WALL

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KEYWORDS

Jet grouting, cut-off wall, groundwater control, permeability, shaft

ABSTRACT

Jet grouting is a practical method to construct a sealed cut-off wall beneath a retaining wall when the excavation needs to be carried out in dry conditions. The method is frequently used in Scandinavia to seal the area between a steel sheet pile wall and the bedrock. The retaining wall subsequently has a hydraulic interface between the soil and the sheet pile, the soil and the jet grouted cut-off wall, and with the bedrock, respectively. However, the efficiency of the cut-off wall is often not possible to assess from hydraulic tests, and empirical methods are used in practical design. In the current paper, the permeability of the cut of wall is modelled from the installation and soil parameters, and the risk of encountering larger cavities in the cut-off wall is demonstrated.

1. INTRODUCTION

Development of building and infrastructure in urban environments frequently entails large excavation carried out beneath the groundwater table. Sealing the excavation from the surrounding groundwater is frequently one of the main challenges in geotechnical design. The jet grouting method was initially developed in Japan and has subsequently found worldwide use in practice, [1]. Jet grouted members of different shapes and properties can be developed at specified depths, giving the method great flexibility, [2]. In Scandinavia, excavations are frequent executed with sheet pile walls which are driven to the

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bedrock and supported with dowels. Geological conditions for this excavation method are common especially in Eastern Sweden. A schematic outline of the retaining wall and the surrounding soil is shown in Figure 1. To prevent changes to the groundwater levels in the area surrounding the excavation, a hydraulic seal is frequently added by jet grouting between the sheet pile wall and the bedrock, also shown in Figure 1. After the jet-grouted wall is constructed, the resistance to groundwater flow into the excavation, Q_{Total}, consists of the different seals: the sheet pile wall, the jet grouted wall, and the flow through the bedrock, as shown in Figure 2.

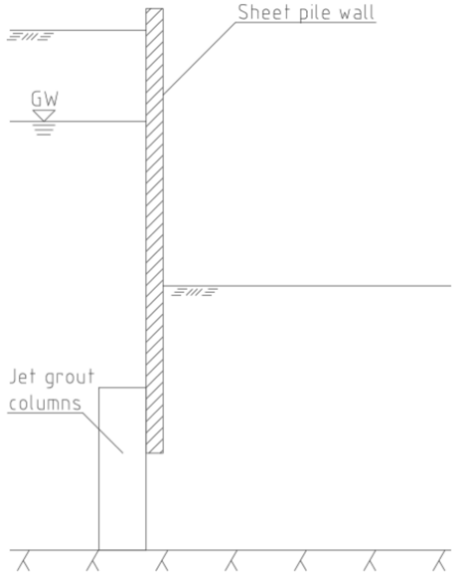

Figure 1. The typical design for jet-grouted columns for a hydraulic seal between the toe of the sheet pile wall and the bedrock

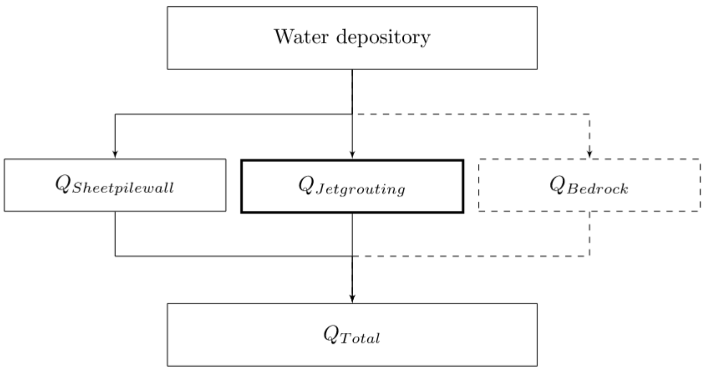

Figure 2. The parallel system with resistance for the flow of water, consisting flow through the sheet pile wall, the jet-grouted wall and the bedrock.

For the design of the jet grouted structure, the main parameter of interest for the hydraulic seal or cut-off is column diameter, as well as the geometric precision of the jet-grouted columns, [3]. The interaction between the grout and the soil during jetting has been examined in detail in [4], outlining the mechanisms by which the soil properties influence the diameter of the jet grouted structure. Methods for the prediction of the jet grouted column diameter have been developed in [5], and a comparison between different prediction methods has been demonstrated in [6].

However, the prediction of the diameter is still associated with large uncertainties. Hence a statistical approach to assess how the performance of the geotechnical structure depends on the properties of the structure. In [7], the Monte Carlo method is used to assess the structural bearing capacity of a jet grouted structure. A similar method methodology is demonstrated in the current article to assess the remaining gaps in the jet grouted seal, taking account of the variability of the jet grouted columns.

2. METHODOLOGY

The geometric representation of the jet grouted columns in the Monte-Carlo method consists of a series of discs which extended along the diameter of the jet-grouted column. Since the columns is created by a rotational motion with the jet monitor, this representation can be considered to capture some of the main mechanism of the jet grouting process: namely the dependence of the local soil layer and the rotation and elevation speed of the monitor, [4]. The basic geometrical properties of the discs are shown in Figure 3. The statistical formulation consists of the description of the diameter of the discs with the normal distribution, but a correlation between the diameter of each depth is included to represent the influence of the specific soil layer.

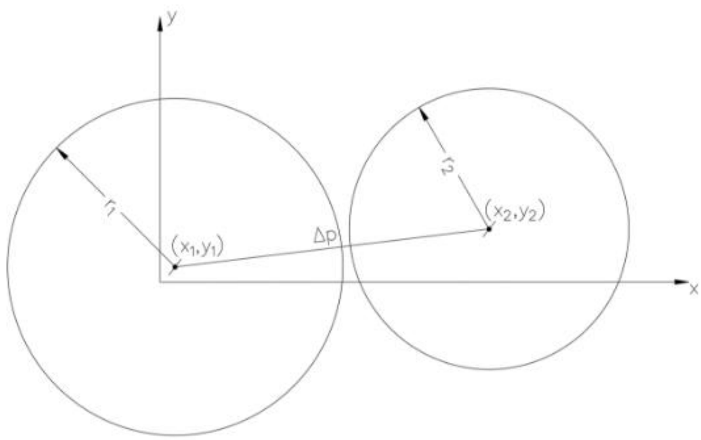

Figure 3. The geometry of the jet grouted columns in the Monte-Carlo simulation.

The following parameters are included in the statistical model:

- The number of columns
- The center-distance between the columns
- The depth to the top of the columns and the depth to the bottom of the columns
- The delta height of the discs
- the statistical distributions for the deviation in position on the ground surface
- The azimuth for the position deviation, the deviation in vertical inclination and its azimuth

The simulate the correlation between the discs at each layer, a matrix containing the discs diameters is generated. An additional correlation parameter is needed together with the mean value, and the standard deviation for the dimeter of the discs. A correlation matrix, P, is constructed with the size n×n, the diagonal consisting of ones and the rest ρ. The indices implies that the diameter in the same column is perfectly correlated with itself, and the ρ's determine the correlation factor between columns m and n which in this case indicates the row and column in the matrix. The uniform distributions are then transformed to normal distributions. The diameter matrix now consists of columns with normally distributed series with mean-value and standard deviation that are correlated with each other with the correlation factor ρ.

Figure 5 shows the diameter of the discuss in a scatter diagram, and Figure 5 shows the graphical representation of the discs for $\rho = 0{,}85$.

A simulation can subsequently be carried out with a specified set of parameters, in which the wall is simulated graphically, and the area from hollow holes emanating from the jet grouted walls is calculated. The model is implemented in the Monte-Carlo model and the resulting number of holes and the hole area are calculated, resulting in a distribution for statistical inference.

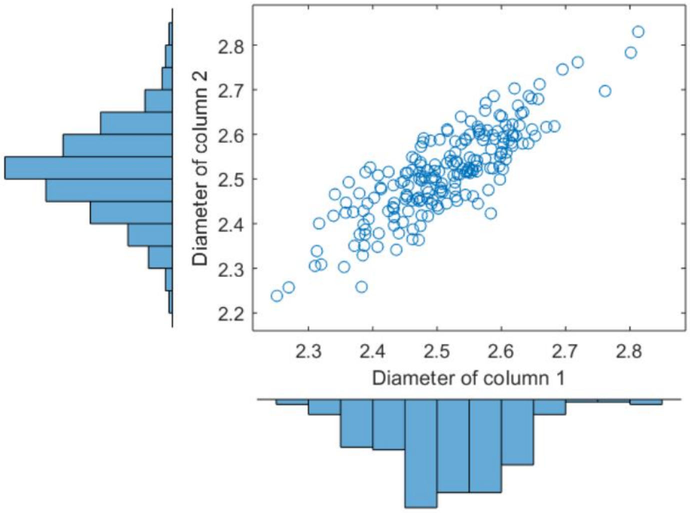

Figure 4. The correlation between the diameter of each disc at each layer for two columns with a correlation coefficient of 0,85.

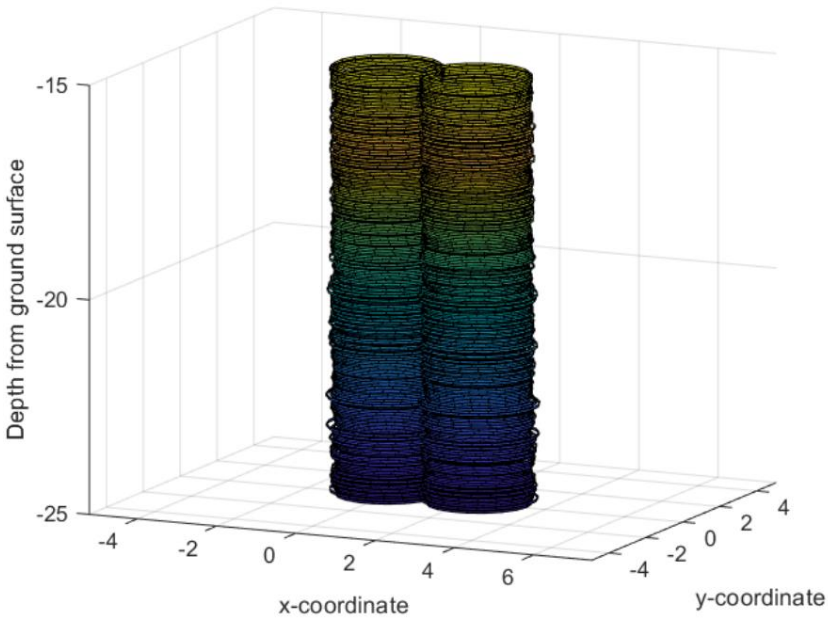

Figure 5. The graphic representation of the jet grouted columns as discs for two columns with a correlation coefficient of 0,85.

3. RESULTS

The described methodology for the Monte Carlo simulation of a jet-grouted cut-off wall allows a statistical analysis of the main parameters included in the design. The risk of groundwater flow through the jet-grouted cut-off can subsequently be estimated from Darcy's law with an estimation of the hydraulic conductivity of the surrounding soil.

A simulation was carried out for a typical jet-grouted cut-off, in which the total length was 42 m, with 2 m long jet-grouted columns. The column diameter, the center location of the column, and the inclination of the column were included in the Monte Carlo simulation.

Figure 6 displays the probability density function from the Monte-Carlo simulation. The normalized hole area, defined as the hole area divided by the total area of the wall, is shown on the abscissa on the graph. For the particular simulation, in which the column diameter was normally distributed with *N(1,0.12)*, the probability of at least one hole is larger than 98 %, and it is quite likely that the total hole area is between 0,05 to 0,1 m^2.

If the hydraulic conductivity is known, the probability of a groundwater flow into the excavation can subsequently be calculated.

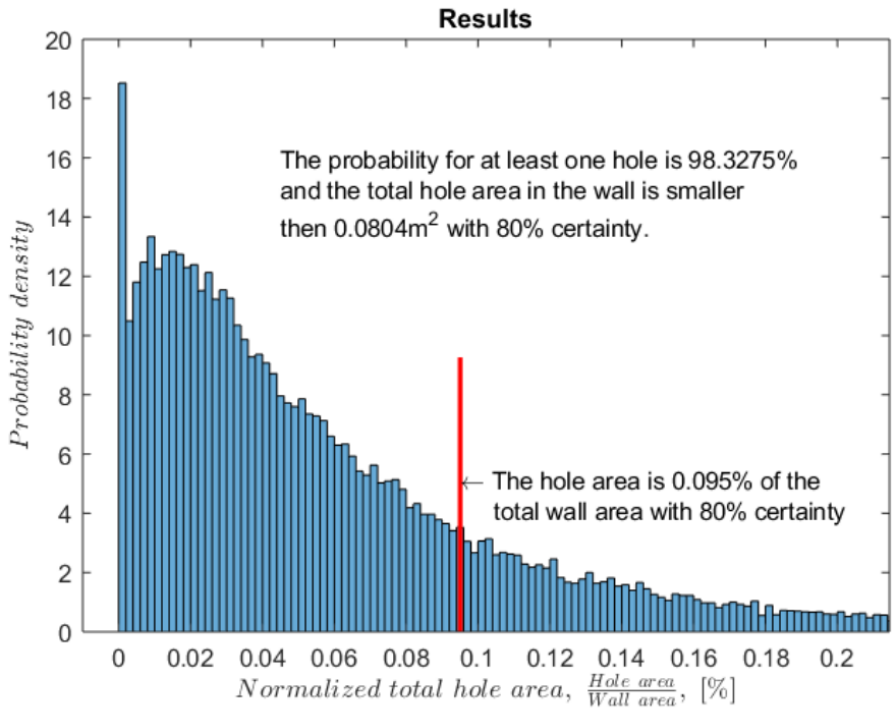

Figure 6. The probability density function for the normalized total hole area from the Monte-Carlo simulation.

4. CONCLUSIONS

A numerical procedure to carry out a Monte-Carlo simulation on a jet-grouted cut-off wall has been developed and demonstrated. The method allows the simulation of the hydraulic performance of the cut-off wall, and the influence of the main parameters in the design can be estimated, especially the influence of the column diameter.

REFERENCES

[1] Shibazaki, M. (2003). State of practice of jet grouting. In Grouting and Ground Treatment (pp. 198-217).

[2] Essler, R. (2012). The design of jet grouting from concept to execution. In Grouting and Deep Mixing 2012 (pp. 2071-2081).

[3] Sembenelli, P. G., & Sembenelli, G. (1999). Deep jet-grouted cut-offs in riverine alluvia for Ertan cofferdams. Journal of geotechnical and geoenvironmental engineering, 125(2), 142-153. https://doi.org/10.1061/(ASCE)1090-0241(1999)125:2(142)

[4] Modoni, G., Croce, P., & Mongiovì, L. (2006). Theoretical modelling of jet grouting. Géotechnique, 56(5), 335-347. https://doi.org/10.1680/geot.2006.56.5.335

[5] Zhao, L. S., Qi, X., Tan, F., & Chen, Y. (2023). A new prediction model of the jet grouting column diameter for three jet grouting systems. Computers and Geotechnics, 163, 105753. https://doi.org/10.1016/j.compgeo.2023.105753

[6] M. Brinck, K. Stigenius & A.B. Lundberg, Prediction of jet grouting diameter in Swedish soil conditions. NGM 2020. In IOP Conference Series: Earth and Environmental Science (Vol. 710, No. 1, p. 012003). IOP Publishing. 2021

[7] Modoni, G., & Bzówka, J. (2012). Analysis of foundations reinforced with jet grouting. Journal of Geotechnical and Geoenvironmental Engineering, 138(12), 1442-1454. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000718