ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2007
Seria: BUDOWNICTWO z. 112 Nr kol. 1763

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BEHAVIOUR OF NON-ANCHORED JET GROUTED RETAINING WALLS

Summary. Non-anchored jet grouted walls are acting as a gravity walls. The finite element method is used to examinate the behaviour of this structure. The influence of the mesh size on the calculated results is analysed. Emphasis of the analysis is given to the stability of the structure (Factor of Safety) as well as to calculated displacements. A simple example of a gravity wall is calculated for different meshes and results are discussed. The use of interface elements which improve the quality of results, especially for coarser meshes, is introduced. It is shown that even for very simple problems, different modelling approaches can lead to substantial differences in results. Finally, the conclusions for the use of FE codes for modelling gravity walls are drown.

ZACHOWANIE SIĘ NIEKOTWIONYCH WYKONYWANYCH METODĄ JET GROUTING ŚCIAN OPOROWYCH

Streszczenie: Niekotwione, wykonywane metodą Jet Grouting ściany oporowe pracują jak ściany oporowe ciężkie. Metoda elementów skończonych może być tu wykorzystana do analizy zachowania się takich konstrukcji. W pracy rozpatrywano wpływ wielkości siatki na otrzymane wyniki. Główny nacisk w analizie został położony na stateczność konstrukcji (współczynnik bezpieczeństwa) w stosunku do obliczonych przemieszczeń. Obliczenia przeprowadzono dla prostego przykładu ściany oporowej o różnych wielkościach siatki, wraz z analizą wyników. Pokazano, że nawet dla prostych przykładów różnorodne modelowanie zadania może prowadzić do znacznych różnić w wynikach. Otrzymane wyniki przedstawiono w podsumowaniu, w formie graficznej.

1. Introduction

Jet grouting has become popular and widely used technology in the geotechnical engineering. During 40 years of its application, the technology has greatly developed and columns of diameter over 5 m are not impossible task anymore. Jet grouting can be used for all different purposes, most often for underpinning, soil retention and for a slab sealing. Use of the jet grouting for retaining purposes will be addressed by the paper.

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Jet grouted walls can be classified as gravity walls if no anchors are used in the structure or as composite retaining structures when anchors are part of the retaining structure. The focus will be given on non-anchored jet grouted walls which are regarded as gravity walls.

2. Design of the gravity walls

Design of the gravity walls shall verify that no relevant limit state is exceeded. Verification can be done by various means, but most often is done by some calculation method.

There is a lot of conventional calculation methods for analyzing retaining structures which are usually not sufficient to provide complete overview of structure behaviour.

Finite element method is able to thoroughly examinate the behaviour of the concerned structure. It will be illustrated that the user must be cautious during the analysis otherwise misleading result can be obtained even for very simple problems.

3. Details of Analysis

Geometry of the gravity wall as shown on Fig. 1 was considered for the analysis. The height of the retained soil is 5 m. Wall embedment is 1 m and the thickness is of the wall is 1.4 m. Ground water is not present in the calculation. The material parameters for soil and jet grouted soil are listed in Table 1.

Table 1

name	type	γ_{unsat}	E_{50}^{ref}	E_{oed}^{ref}	power (m)	c_{ref}	φ	ψ	E_{ur}^{ref}	$\nu_{ur}^{(nu)}$	p^{ref}	R_f
		[kN/m³]	[kN/m²]	[kN/m²]	[-]	[kN/m²]	[°]	[°]	[kN/m²]	[-]	[kN/m²]	[-]
silt	(HS)[1] drained	18.5	20 000	20 000	0.75	5	27.5	0	60 000	0.2	100	0.9
jet grouted silt	(MC)[2] drained	19.5	-	-	-	910	27.5	0	1500 000	0.15	-	-

[1] Hardening Soil Model, reference Brinkgreve(2002)

[2] Mohr-Coulomb Model, reference Brinkgreve(2002)

3.1. FE Calculations

The example was analyzed using Plaxis 8.5 software. The goal of the analysis is to examinate the influence of the mesh used in the calculation on the results. Further the influence of interfaces is evaluated.

All performed calculations differed only in generated meshes, used element types and in the use of interfaces. Six types of different meshes were generated (tab. 2 and Fig. 1). For each mesh, set of four calculations was calculated. Each set included following calculation variants:

- 6-node elements, no interface elements around the wall
- 6-node elements, interface elements around the wall
- 15-node elements, no interface elements around the wall
- 15-node elements, interface elements around the wall

That results in total 24 different calculations which were evaluated.

Calculation phases were defined to follow the construction process of a typical jet grouted wall. Excavation was divided into 3 successive steps. As a last phase, the strength reduction method for accessing safety factor was done.

3.2. Geometry Discretization – Meshes

Parameters of generated meshes used in calculation are listed in table 2. Figure 1 shows the coarsest and the finest mesh used in the analysis.

Table 2

Mesh specifications

Mesh type	without interfaces				with interfaces			
	number of elements	average element size	number of nodes		number of elements	average element size	number of nodes	
			6 noded	15 noded			6 noded	15 noded
1	116	2.13	267	997	137	1.96	330	1207
2	224	1.53	493	1881	260	1.42	589	2217
3	430	1.1	923	3565	464	1.06	1021	3897
4	935	0.75	1958	7655	1010	0.72	2149	8337
5	1785	0.54	3678	14495	2060	0.5	4301	16841
6	4876	0.33	9893	39289	4558	0.34	9405	37696

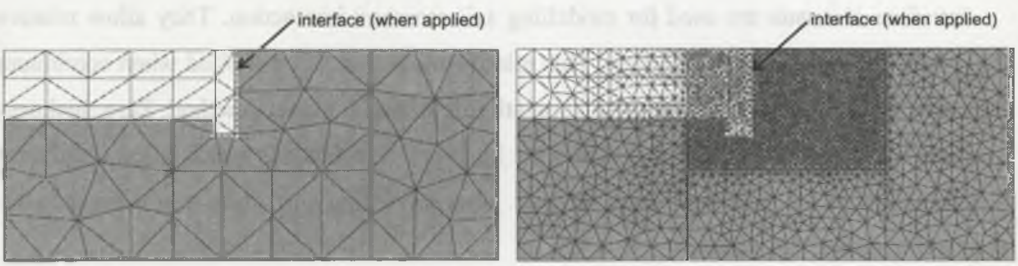

Fig. 1. Mesh type 1 (left) and type 6 right
Rys. 1. Zastosowane rodzaje siatek

The user is given option to use either 6-node triangle element or 15-node triangle element (Fig. 2) when using Plaxis 2D code. The 15-node element can be though of as a composition of four 6-node elements since the total number of stress points and nodes is equal. Nevertheless, the 15-node elements perform better than four 6-node ones (Brinkgreve, 2002).

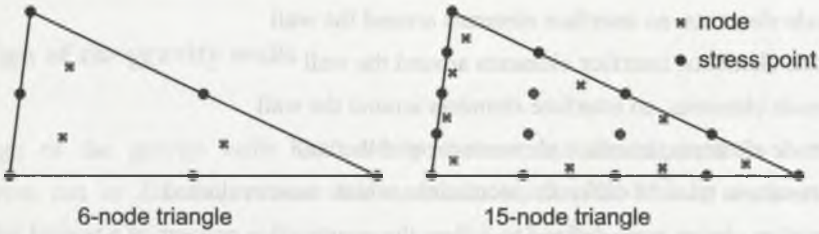

Fig. 2. Position of nodes and stress points for 6 and 15-node elements
Rys. 2. Usytuowanie węzłów i miejsc naprężeń dla 6- i 15-węzłowego elementu

The 6-node elements use quadratic interpolation function of displacements (so called shape function) whereas 15-node elements use quadric shape function. It is known that elements with higher order of interpolation of the displacements are more suitable when large displacements are present. This is particularly the case when using material strength reduction method for assessing the safety factor of a structure, as the calculated displacements are usually very large when an ultimate state is being approached. The quality of the results when using elements with lower order of interpolation can be improved by generating finer mesh.

3.3. Interfaces

Interface elements, as defined in the Plaxis code, are zero thickness elements. An elasto-plastic model is used to describe the behaviour of the interfaces. Detailed description of the elements can be found in Brinkgreve (2002).

Interface elements are used for modelling soil-structure interaction. They allow relative movements at soil-structure interface. This relative movement is prohibited when continuum elements are used because of the nodal compatibility of finite element method. Zero thickness interface elements use pairs of nodes with identical coordinates, which allows different displacements of the each node from the pair. Thus modelling slip or separation on the soil-structure interface is possible.

An example for use of interface elements can be modelling of a diaphragm wall where interfaces elements are placed around the wall in order to model a concrete-soil interface. The codes often recommend to reduce the strength of the soil-structure interface. Reduction factors depend on roughness of the surface of the structure. In Plaxis, reduction is defined by parameter R_{inter}, which can be assigned values from 0.01 to 1.0. A value of 1.0 means that the full strength of an interface is modelled.

Jet grouted walls are very rough which is caused by the nature of the jetting process during its production. Therefore, interfaces are not necessary in order to reduce the strength of the soil-structure interaction. The value of R_{inter} was set to 1.0. for all calculations performed in this paper,

The reason why the interface elements are used in this study is, that several authors as Day & Potts (1994, 1998), Langen & Vermeer (1991) suggest that the use of zero thickness interface elements can improve the quality of the FE analysis.

4. Results of Analyses

4.1. Mesh Dependency of the safety factor

Figure 3 shows the influence of the number of nodes (resp. average element size) on the calculated safety factors. The higher the number of elements the more precise results are obtained because the discretization of the problem is more detailed. Therefore, the solution with finest mesh and 15-node elements is regarded as a reference one. The most wanted situation would be when the calculated safety factors would not show any mesh dependency. All lines plotted in the Fig. 3 are inclined and thus the results are mesh dependent. Please note that the horizontal axis of the plot is in the logarithmic scale, so the inclinations of lines are exaggerated. One can see that the use of interfaces reduces the mesh dependency of calculated safety factors significantly. Therefore, it can be stated that using interfaces around the JG structure increases the quality of the results.

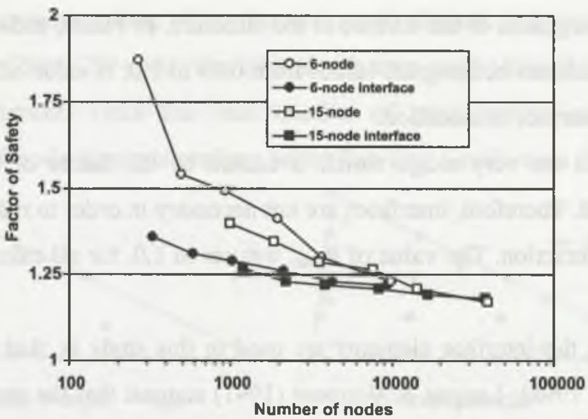

Fig. 3. Mesh dependency of the safety factor
Rys. 3. Zależność siatki od współczynnika bezpieczeństwa

Further, results prove the fact that 15-node elements perform better then four 6-node ones. Prove for this can be seen in the fact that curves for 15-node elements (with and without interfaces) mostly lay below the curves of 6-node elements (with and without interfaces) and are closer to the reference solution.

4.2. Wall displacement

Calculated displacements of the top of the wall for excavation depths of -4.0 m and -5.0 m are shown on Fig. 4. Wall displacements are again dependent on the mesh. The geometry with 15-node elements and with interfaces around the wall gives the least mesh dependency. Fact that displacements in all variants for mesh type 6 give similar results shows that the use of very fine meshes gives similar results which are independent of different modelling approaches.

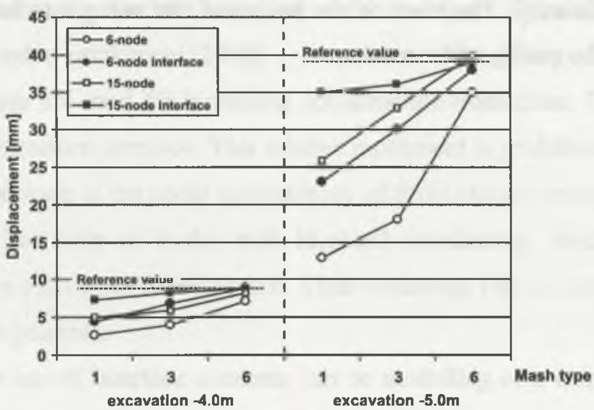

Fig. 4. Horizontal displacements of the top of the wall
Rys. 4. Przemieszczenia na szczycie ściany

4.3. Earth pressures

The total horizontal forces acting on the back of the wall are shown in tab. 3. The mesh dependency of the results is present in much lower extent in comparison to safety factors or to displacements.

Table 3

Total horizontal force [kN]			
6-node / mesh 1	97.6	6-node int. / mesh 6	86.6
6-node int. / mesh 1	94.0	15-node / mesh 6	86.6
15-node / mesh 1	91.3	15-node int. / mesh 6	85.9
15-node int. / mesh 1	88.6	Initial stresses (K_o)	179.2
6-node / mesh 6	86.6	Analytical solution*	71.1
*Full active pressure (Caquot, Kerisel & Absi (1973)			

Selected earth pressure distributions are plotted on Fig. 5. An analytical solution of full active pressure based on Caquot, Kerisel & Absi (1973) assuming full friction of soil-structure interface is plotted for comparison. It can be seen that FE calculation gives higher values of the earth pressure in lower part of the wall. This is caused by fact that the rotation of the wall does not induce large enough displacements in lower part of the wall to activate full active pressure. The oscillations of the normal stresses acting on the back of the wall are caused by tension points present behind the wall. The interfaces somewhat smooth out these oscillations, but still the distribution of stresses is not ideal. Importantly, the total value of earth pressure is consistent.

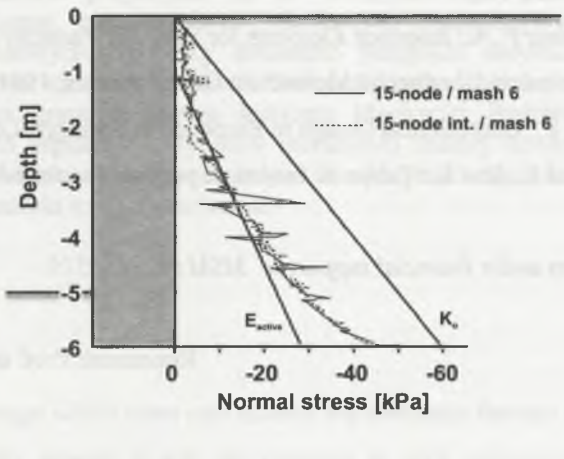

Fig. 5. Normal stresses behind the retaining wall
Rys. 5. Naprężenia normalne za ścianą oporową

5. Conclusions

The analysis of the behaviour of not-anchored jet grouted retaining walls can be well assessed by means of finite element analysis. One must be careful when performing such an analysis. The results are mesh dependent and coarse meshes do not perform well. The performance can be increased by use of zero thickness interface elements used in the calculation. Use of these elements decreases the mesh dependency of the analysis. When using infercfaces in the analysis, the same quality results can be reached with coarser meshes, which can be important factor when computational times are critical.

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The paper was written under financial support of MSM 0021630519.

Recenzent: Prof. dr hab. Jan Gaszyński