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Panels Made by the Deep Mixing Method for a Building Pit Support in a Slope

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ABSTRACT

The design and execution of a non-conventional support system for an excavation pit in a slope will be presented in this paper. Because permission of placing ground anchors in neighboring property was not given, panels made by the Deep Mixing method, extending below the level of the planned building, have been constructed. Based on the specifications of the sub soil and groundwater condition the design concept as well as analytical and numerical calculations will be discussed. The main focus is put on the construction procedure and problems during the execution of the panels. Results from deformation measurements during the construction of the panels and the excavation of the pit will be presented and discussed. In a short summary the main lessons learnt from this difficult case history will be presented.

INTRODUCTION

The design and construction of support measures for excavations is one of the main tasks in geotechnical engineering. Depending on soil and ground water conditions, adjacent structures and buildings as well as special boundary conditions on site, several options exist. One of the most difficult boundary condition is given, when support elements such as ground anchors cannot be built on neighboring ground e.g. due to legal reasons. When space for support measures is limited and subsoil and groundwater conditions are difficult, only a few feasible solutions to construct the excavation pit exist. In many of these cases struts are a proper solution for such boundary conditions. But using struts is often not convenient for the excavation and construction process itself and sometimes even not possible, especially when the excavation is located in a slope. In this paper such a case history will be discussed. After defining the specific boundary and subsoil conditions, the process of finding the optimum solution, the design of it and problems encountered during construction will be the focus of this paper.

SITE HISTORY, SUBSOIL AND GROUND WATER CONDITION

The site for the project in the county of Salzburg/Austria is characterized by a slope with an average inclination of about 15°. Several buildings existed nearby the site before the project started. Because of severe problems and damages of existing buildings in the past due to an activated landslide during the construction of the excavation pit for one of the neighboring buildings restrictive rules were given for further constructions of buidlings. One of these restrictions defined that no permission for placing ground anchors or soil nails in neighboring property was given. For the building considered here a two level excavation pit with depth of two times 6 m in average had to be constructed (Figure 1). On the hill side there was only room of about 2 m behind the required excavation boundary.

Subsoil conditions can be summarized as loose fine grained hillside fill (Layer 1) in the upper 3 to 4 m underlaid by fine lacustrine sediments (clayey – sandy silts). The lacustrine sediments have a soft consistency down to a depth of about 6 to 7 m (Layer 2) and a stiff and semi solid consistency below that level respectively (Layer 3) as shown in Figure 1. Within the fine grained soil thin interlayers of fine to medium sand have been detected. Geotechnical Parameters for these layers are shown in Table 1. Ground water conditions in the slope were governed by water bearing strata, controlled mainly precipitation events. The geological development of the site can be described as alpine postglacial sediments whereas the sedimentation took place about 10.000 years ago.

DESIGN CONCEPT

Concept and Draft Design. Because of the subsoil and general boundary conditions and the given restrictions concerning anchoring on neighboring ground a special system for the excavation pit construction has been developed. The idea was to construct panels extending below the level of the building as shown in Figure 1. The panels which are oriented in the direction of the slope could be constructed by overlapping Jet Grouting columns, cast in place Concrete Piles or by Deep Mixing Columns. The pro and contras of these different systems under the given boundary conditions will be discussed below shortly. On the hill side of the excavation pit 6 meter spanned arches – also made by one of these systems – transferring loads due to earth pressure into the panels were planned. The arches in the lower excavation step were built by using shotcrete and soil nails because no neighboring ground was influenced in this area. The concept of this idea is shown in Figure 1. The arches and panels transfer the loads due to earth pressure by side friction, base friction and partially mobilized passive earth pressure at the front of the panels into deeper stiff soil layers. Figure 2 shows a schematic sketch of the load transfer by means of the panels. Earth pressure from the slope is shown in red, the stabilizing reaction forces in green.

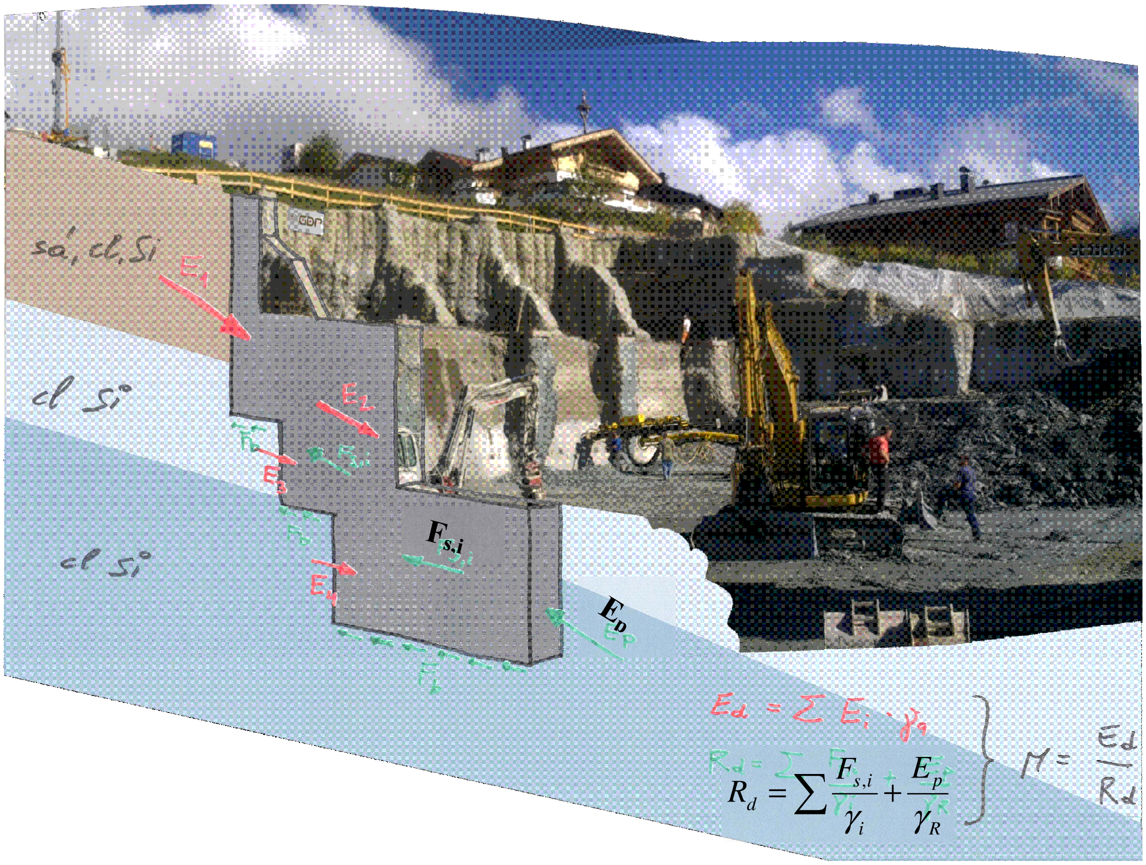

Figure 1. Support panels as concept and after construction.

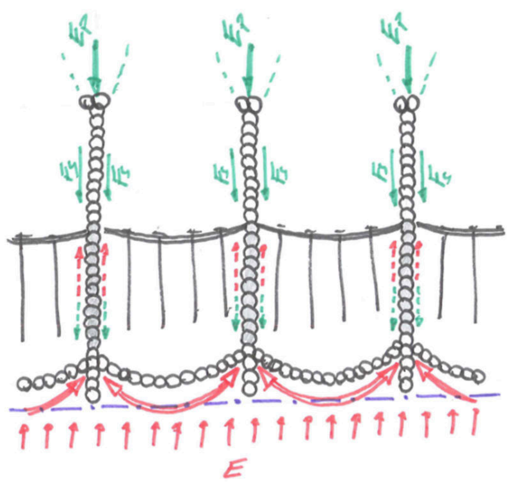

Figure 2. Schematic sketch of load transfer by panels in plan view.

The first and principle design has been done by simplified analytical calculations based on the “Palisaden Theorie” (Brandl, H., Grundbautaschenbuch 2001). For the upper layer of soft clayey, sandy silts the assumption for the earth pressure was based on a “creep pressure” (e.g. Haefeli 1945). The advantage of this system was not only to prevent ground anchors or soil nails on the neighboring ground but also to construct a very stiff system of support measures before starting the excavation itself. To construct the panels only minor excavation and fill measures had to be done in order to provide a suitable working plane. A further advantage of this system was that the panels guarantee a permanent stabilization effect of the unstable upper slope layer. In the final state the panels additionally act as foundation elements. To achieve homogeneous foundation conditions additional foundation elements made of concrete slices had to be built at the valley side of the building (where no panels were designed).

As mentioned above, overlapping Jet Grouting columns, cast in place Concrete Piles or Deep Mixing Columns were taken in consideration to construct the panels with a maximum column length of about 15 m. The main criteria for the decision finding were:

- Limitation of weight for the construction equipment because of the limited bearing capacity of a bridge on the access road
- Cautious installation technique for the columns itself because of "sensitive soils" and a severe potential for slope deformation during the construction procedure
- Guaranteed overlapping of the columns because otherwise the stiffness of the panels is not given and high deformations would have been expected during the excavation work
- Economical aspects

Concrete Piles which are seen as a cautious installation technique were excluded because heavy construction equipment would have been necessary and also higher costs were expected. Constructing the panels with jet grouting technique was estimated as very risky because of the installation procedure itself. Experiences with jet grouting technique in this type of lacustrine sediments (fines with interlayers of sand) have shown severe problems during the installation procedure in the past and therefore the mobilization of slope movements during the installation of the columns by jet grouting was anticipated. Therefore the Deep Mixing method was chosen for the construction of the columns and panels respectively. Economical aspects as well as the weight of the construction machinery were a clear advantage. The overlapping of the columns should be guaranteed by a very accurate procedure and a strict quality control. Compared to the Jet Grouting technique the Deep Mixing method was seen as clearly milder production system. One problem, which has been discussed during the decision finding, was the quality of the columns made by the deep mixing method itself. It was well known that fines with too much clay content are not easy to mix up to homogeneous columns with this method. Nevertheless, after discussion with specialists this system has been chosen for the realization of the panels.

3-Dimensional Numerical Investigations. The first design step has been done with simplified analytical models such as the "Palisaden theory". This has been used to define the principle geometry of the panels. To prove the feasibility of the proposed design and to investigate expected deformations a number of three-dimensional finite element analyses have been carried out. These analyses also served as basis for the design of the structural elements in detail. The finite element code Plaxis 3D Foundation has been used for all analyses, which are presented in this paper (Brinkgreve and Swolfs 2007). The Hardening Soil model, a so-called double hardening model, which allows plastic compaction (cap hardening) as well as plastic shearing due to deviatoric loading (friction hardening) has been employed. A more detailed description of the Hardenings Soil model can be found e.g. in Schanz et al. 1999. In this paper only the main aspects as well as the main results from the numerical calculations are presented. More details of the 3D-FE-Analysis can be found in (Lüftenegger R., Schweiger H.F., Marte R., 2014). For the 3D finite element analysis a three layer model, based on the results from the site investigation has been established. In Figure 3 the structure of the panels in the 3D-Model is shown and the most important parameters for the soil layers are shown in Table 1.

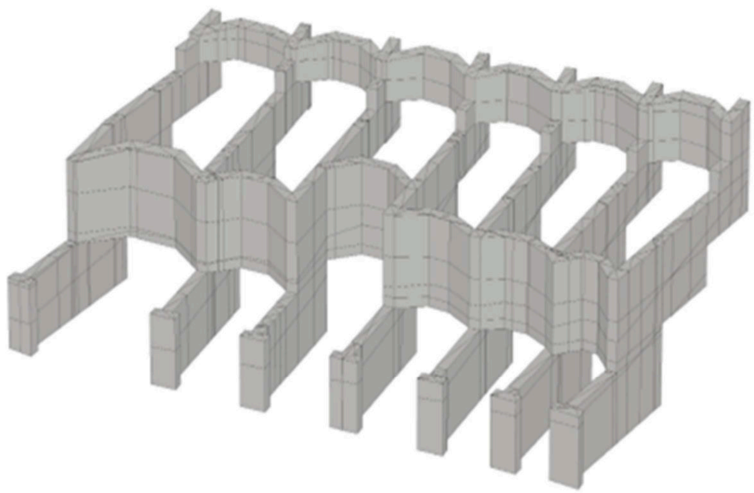

Figure 3. Layout of the panels made of Deep Mixing Columns.

Table 1. Material parameters for Hardening Soil model for soil layers.

Parameter	*Layer 1*	*Layer 2*	*Layer 3*
Friction angle, φ' (°)	25	27.5	30
Cohesion, c' (kPa)	0	1	5
Dilatancy angle, ψ (°)	0	0	0
Unit weight, γ (kN/m^3)	20	20.5	21
$E_{oed}^{ref} = E_{50}^{ref}$ (kPa)	10000	25000	45000
E_{ur}^{ref} (kPa)	30000	75000	135000
m (-)	0.5	0.5	0.5

For the material parameters for the Deep Mixing Columns a friction angle φ' = 30°, a cohesion c' = 250 kPa, a tension cut off based on reinforcement by steel rods of σ_t = 125 kPa and a elasticity modulus of 300 MPa has been chosen.

The simulation of the excavation showed a maximum horizontal deformation of about 15 mm at the front upper corner of the lower excavation step (Figure 4). Near the border of the neighboring property at the back of the panels less than about 1 cm of deformation has been calculated. Expected settlements and deformation of adjacent buildings due to the excavation were almost negligible (Figure 5). Therefore the stiff behavior of the panel support system could be confirmed. The neighboring houses were not simulated in the FE-Model in detail. An estimation of possible deformation of adjacent buildings happened by the interpreted deformation of the 3D-Model. Nevertheless the installation process of the Deep Mixing-columns for constructing the panels, which has been seen as critical could not be modelled by the Finite Element analysis. Therefore additional deformation due to the construction process had to be expected. To minimize these additional deformations a step wise construction of the Deep Mixing-columns was planned. This meant a high effort for the company as well as a well-organized quality control during the execution procedure.

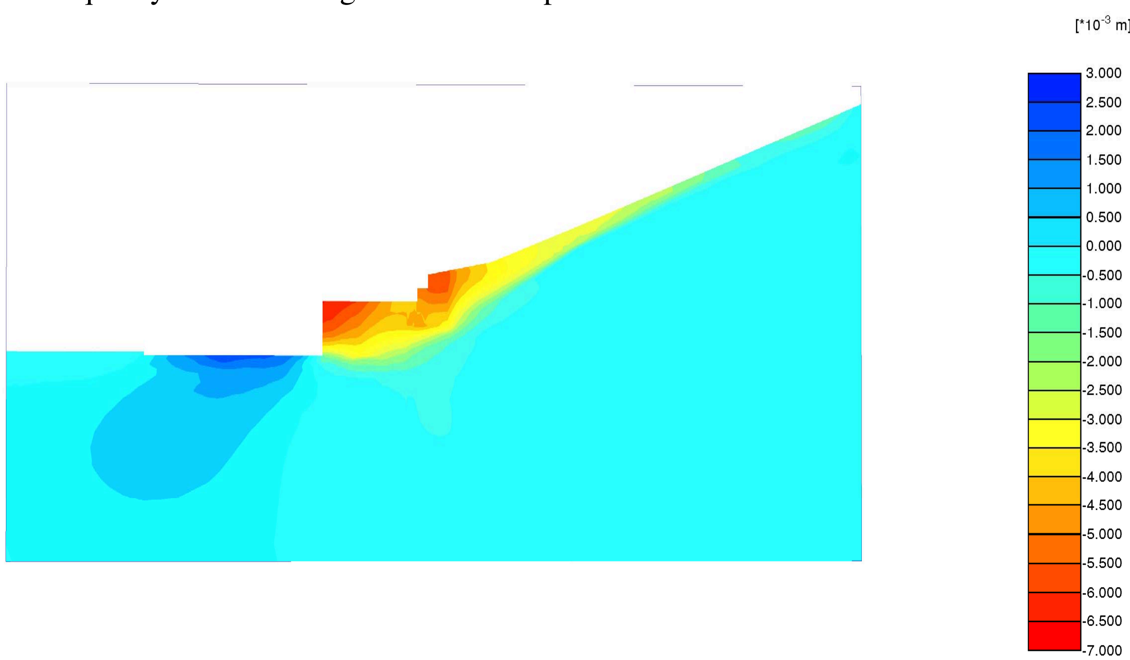

Figure 4. Calculation results with horizontal displacements.

The 3D-FE-model was also used to check the tension zones in the Deep Mixing-body on the back side. The main tension stresses were located at the connections of the arches and the panel elements. In this area the Deep Mixing -structure was reinforced with steel beams (HE-B profiles), which were installed in the fresh grout immediately after the Deep Mixing -procedure.

In Figure 6 this beam element can be seen as purple line on the back side of the panels. Further on Figure 6 shows the maximum relative shear stress at the end of the simulated excavation procedure.

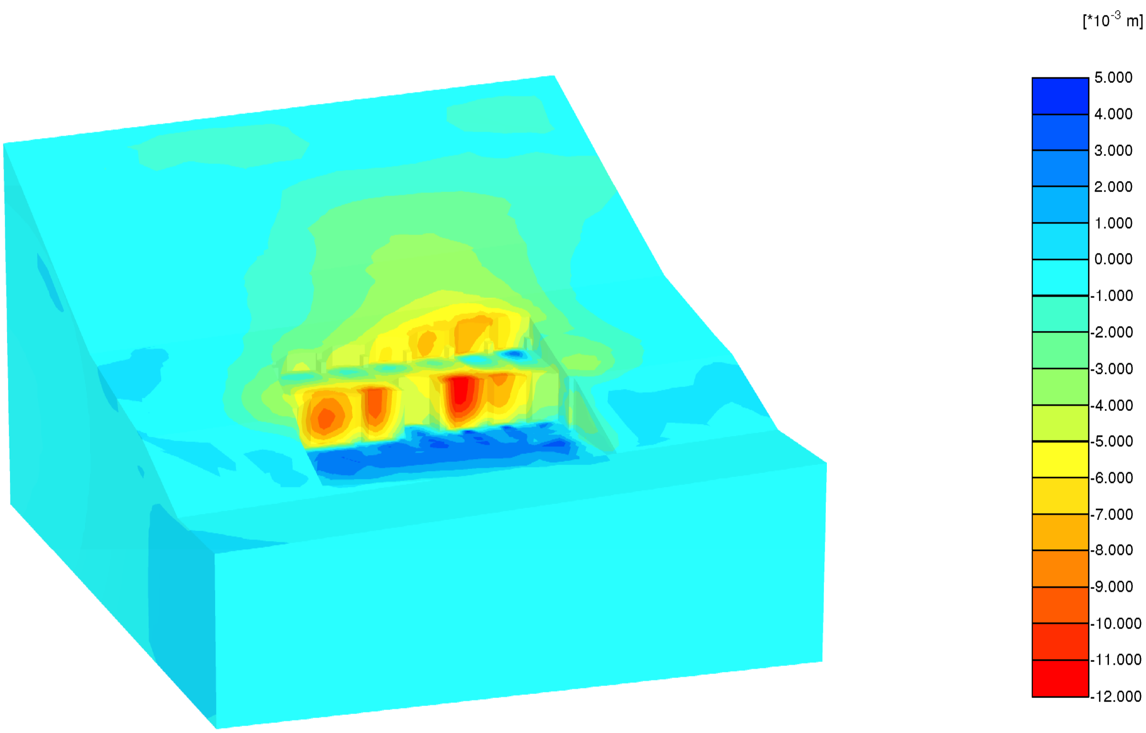

Figure 5. Calculated horizontal displacements with critical building on the hillside of the pit.

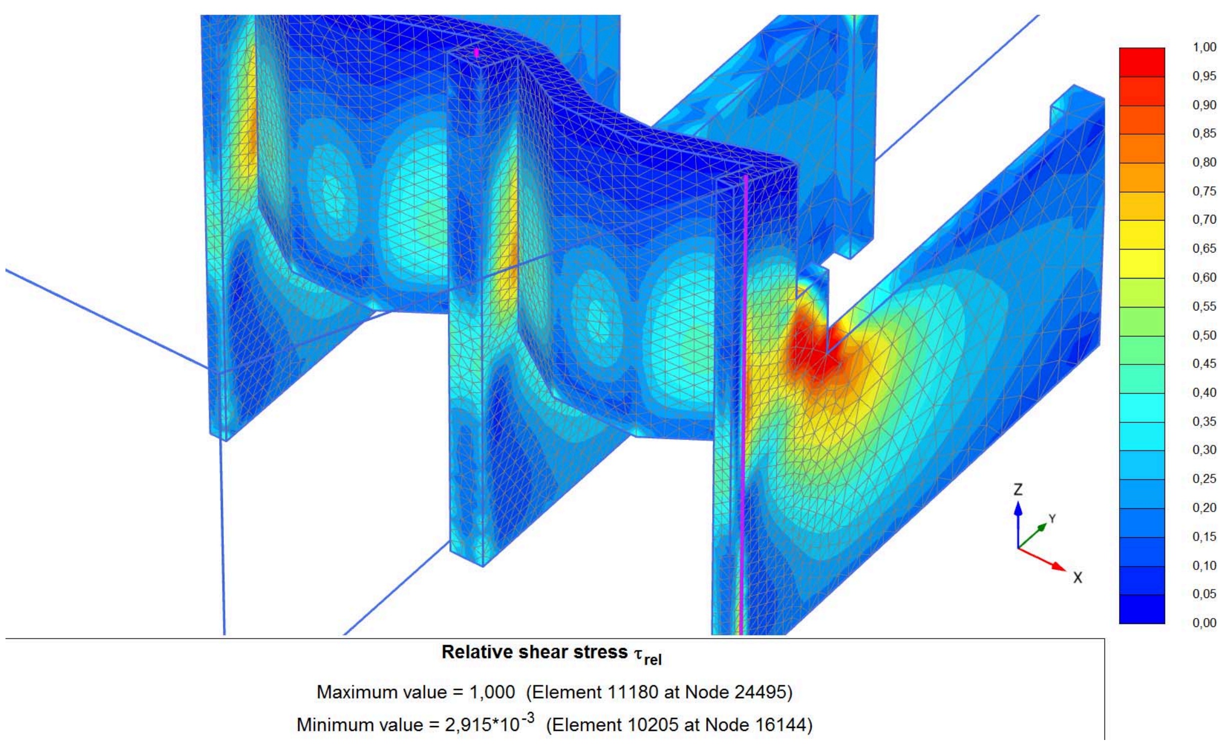

Figure 6. Relative shear stress in the panels at the end of the simulated excavation process.

EXECUTION OF THE CONSTRUCTION WORK

Generally it was expected, that the installation phase would be the most challenging part of the project. At first, the company started with a "double-auger–system" to produce the Deep Mixing-columns which did not end up with the expected results. During the procedure with up and down movements of the tool, a so-called corkscrew-effect occurred. This means, that lumps of fine grained soil clogged the drilling auger during the first penetration into the ground and during upward movements of the tool, negative pressure was produced in lower sections of the fresh column. Thus, soft soil was pulled into the mixed the column This problem resulted in discontinuities in the Deep Mixing-columns on the one side and a severe danger of deformation on the other side. Finally the Deep Mixing-columns have been produced by a single mixer system (Figure 7), which worked slower but with less obstacles.

As mentioned above the production sequence of the columns was designed as a staggered scheme. Because of logistic and time reasons the company did not work in such a way at the beginning. Producing the columns piece by piece in one row triggered severe slope deformation. Even after the company followed the design instructions (staggered scheme) horizontal slope deformation of several cm occurred. In Figure 7 the production of the columns ended with begin of August. Whereas the deformation due to the excavation procedure (starting in August up to the mid of September) was more or less within the predicted range of about one to two cm, the deformation during the Deep Mixing procedure was up to 6 cm and more. Reasons for this high deformation during the procedure of Deep Mixing Columns are seen in the context of difficult subsoil conditions with a low degree of slope stability in the upper layers and the weakening of subsoil due to the mixing procedure itself. All in all the production of the panels and the shotcrete lining in the lower part lasted about 12 weeks, including forced interruptions due to various difficulties. The production of the Deep Mixing –columns itself took 40 working days. About 100 m of columns could be produced per working day which is about half of the average value for other Deep Mixing projects. Besides the staggered working procedure the main reason for this low output was the problem of mixing up the fine grained soil (with a severe clay content) and slurry to a homogeneous column. Retained samples of the slurry – soil mixture showed strength values (unconfined compressive strength) of about 2 to 4 MPa after 7 days, about 5 to 12 MPa after 14 days and about 6 to 17 MPa after 28 days.

A further difficult aspect was the accuracy of the achieved column axis. The overlap of the columns was most important to guarantee the panel effect. For some columns additional shotcrete work had to be done during the excavation to close the gaps in the panel.

During the first excavation step on the back side of the pit, drainage boreholes through the arch-columns had be drilled to prevent hydrostatic water pressure on the back side of the walls.

Figure 7. Mixing equipment to produce the Deep Mixing Columns.

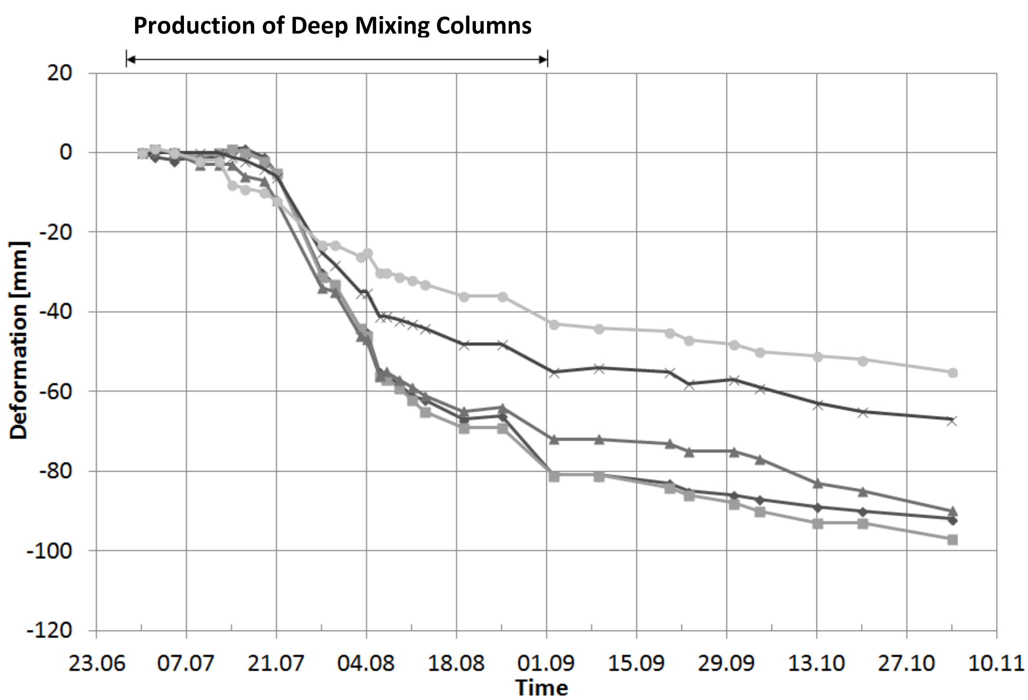

Figure 8. Measured horizontal displacements at the top of the panels.

CONCLUSION AND SUMMARY

The design and execution of a non-conventional support system for an excavation pit in a slope with difficult subsoil conditions has been presented in this paper. Panels made by the Deep Mixing method have been constructed as support system for the excavation pit because no anchoring was allowed. One main aspect learnt in this case history was, that although