NEW CONCEPT FOR DEEP EXCAVATIONS IN SOFT LACUSTRINE CLAY

UN NOUVEAU CONCEPT DE CONSTRUCTION POUR DES FOUILLES PROFONDES DANS L'ARGILE MOLLE

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SYNOPSIS: Up to now, deep excavations in soft silty lacustrine clay have often been combined with ground movements in the scale of decimeters. Damages affecting adjacent buildings have been the direct result. For the excavation works of the 60 x 60 m large and 7.3 m deep pit for the See-arkaden Starnberg in Southern Bavaria (Germany) such great deformations could not be tolerated because of the high demands at the integrity of the adjacent buildings. So by consequent use of the observational method a construction method had been developed which limited the ground mouvements around the pit as far as possible. The essential point oft the construction method of the pit is the 3,600 m^2 large soilcrete-slab with a thickness of 2 m. It is the very first time that a soilcrete-slab with these great dimensions has been constructed in soft silty lacustrine clay. The pit has been divided into three parts. The soilcrete-slab anchored by tensile piles works as a deep lying strut. Thus, the aim of minimization of deformations has been reached.

INTRODUCTION

Near the railway station of Starnberg and close by the Lake of Starnberg the Seearkaden Starnberg were erected consisting of a 60 m x 60 m large complex of buildings partitioned in residential and business premises of 3 and 4 storeys. The planning conditions required the construction of a two-storey underground garage covering the whole field of construction of 3,600 m^2. The excavation of 7.3 m depth is embedded in the soft silty lacustrine clay.

The construction area is surrounded by street blocks and in the north-east direction the excavation pit reaches near to the historical Haus Ecker (Fig.1).

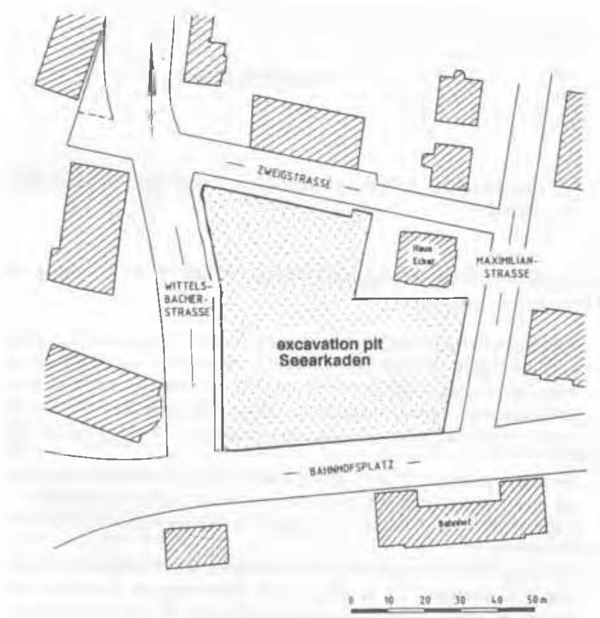

Fig. 1 Location plan with excavation pit

SOIL AND GROUNDWATER

Geological View

The construction area is situated 100 m north of the today's seaside in the region of a former glacier tongue where clays and silts have been deposited at the border of a glacier lake. That situation is typical of many lakes in the Lower Alps (Jagau, 1987) (Scherzinger, 1991); the clays and silts are summarized as lacustrine clays.

Among the alluvial deposits clays and sands were found sedimented as depositional terraces by rivulets with varying water-bearing. Beneath the lacustrine clays deposited in the holocene, pleistocene moraines consisting of compact gravelly clays outcrop in greater depths (Jerz, 1987).

Subsoil Situation

Below the filling of 2 m thickness outcrop the upper gravels till a depth of 5 m (Fig. 2). It is a question of alluvial deposits which are to be regarded as well-bearing foundation soil because of the medium dense stratification. All the adjacent buildings are founded in those gravels.

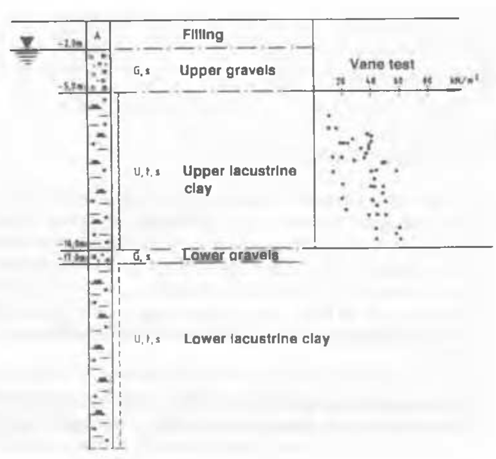

Fig. 2 Soil profile and soil classification

Beneath the upper gravels outcrop the youngest lacustrine clay layers till a depth of 16 m below the ground level, in the following designated as upper lacustrine clay. The non-preloaded upper lacustrine clay is of pulpy, softy and partly of liquid consistency. The lacustrine clay is mainly to be regarded as fine sandy silt with fine stratifications of sands, silts and clays (Fig. 3).

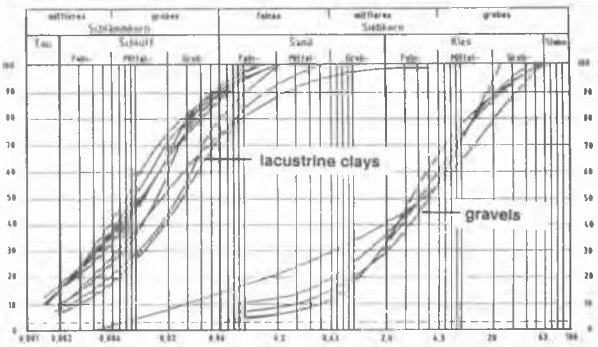

Fig. 3 Grain-size distribution

That fine stratification significantly shows the development of non-preloaded clayey-silty soils which have been sedimented at the surface of many lakes in the alpian region as well as sometimes few meters underneath well-bearing top layers like the here outcropping upper gravels. The composition and structures of the fine sedimentation are very different. Specimens of lacustrine clay mostly show horizontal layers of fine and more coarse sediments with significant change of layers. The thickness of the layers comprises the range of only a few millimeters as well as some centimeters resulting from seasonal deviations during the sedimentation process.

The low plastic lacustrine clays have a plasticity between 4 and 13 % in case of liquid limits between 20 and 30% (Fig. 4).

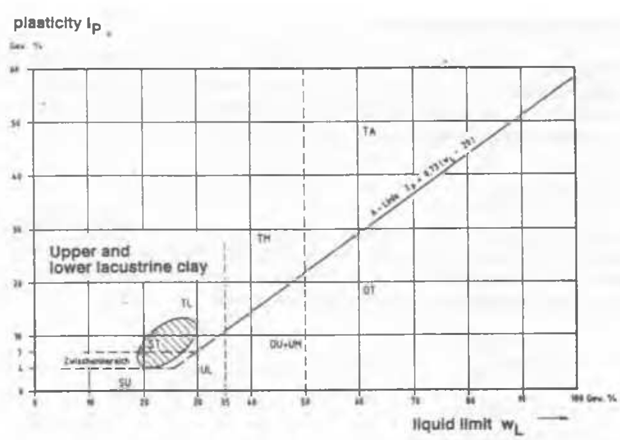

Fig. 4 Plasticity chart for lacustrine clay

Because of the great sensitiveness concerning its structure the lacustrine clay can only be classified correctly by application of special sampling methods and laboratory investigations. In case of the Seearkaden Stamberg the undrained shear-strength of the upper lacustrine clay was dominantly derived by means of vane tests; the values between $c_u = 10$ kPa and $c_u = 60$ kPa - on an average of 35 kPa - are in the range of the shear-strength determined for the lacustrine clay in the Bodensee area (Goldscheider et al., 1991) (Jagau, 1990).

Below the upper lacustrine clay occurs a 1 m thick, compact, pressure-water bearing gravel stratum of no horizontal stability. Beneath the gravel outcrops the lower lacustrine clay, being in accordance with the upper lacustrine clay concerning its granulometric composition and plasticity but showing a stiff condition with consistency values between $I_C = 0.75$ and 0.85. The undrained shear-strength was estimated with

$$c_u = 35 + 0.25 \cdot \gamma \cdot z \text{ [kPa]} \leq 80 \text{ kPa}$$

in appreciation of the investigations documented by Scherzinger, 1991.

Groundwater

The groundwater appears at 2 m under ground surface. It follows with little temporal delay the seawater level and circulates largely in the well-permeable gravels. Due to the horizontal sealing effect of the lacustrine clays the ground-water table in the lower gravels is perched.

CONSTRUCTION DESIGN

To guarantee the restriction of deformations and to avoid damages in the neighbourhood a construction design has been developed containing the following conditions:

- Application of deformation limiting supports, especially a deformation limiting supporting point in the height of the bottom of the pit before excavating.
- Measurements to avoid solifluction beneath through the sheet-wall into the pit; that deformation mechanism causes far-reaching settlement influences because of its volume-constant flow, and have to be prevented by constructive methods.

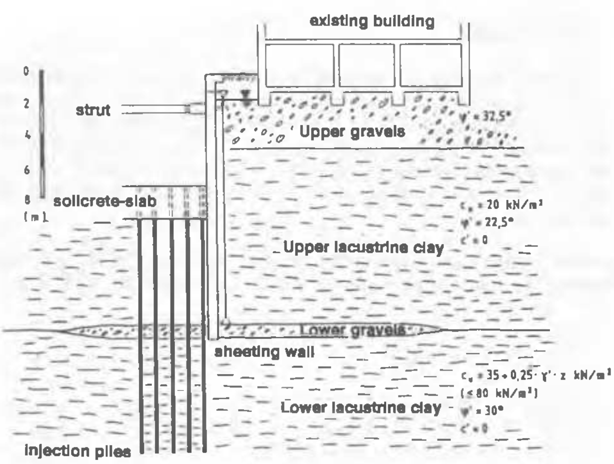

Fig. 5 Construction design and average soil mechanical classification values

The concept for solving the execution design consists of the following four parts (Fig. 5):

- Application of a deformation limiting bottom support of the sheet-walls by means of a soilcrete-slab which is working twice, firstly as a horizontal support for the sheet-wall and secondly as a spread structure protecting against solifluction (ground failure); the soilcrete-slab is to be executed when an excavation depth of 1,5 m is reached (Fig. 6).
- Vertical anchoring of the soilcrete-slab with injection piles which leed the loads into the stiff lower lacustrine clay due to the solifluction.
- Upper stiffening system with a rigid reinforced concrete frame and tube struts.
- Dividing the pit into three parts to minimize the simultaneous occurring load changes, i.e. to excavate in little steps to compensate the unloading effect by a consequent application of load with the new building (Fig. 7).

Fig. 6 Soilcrete device

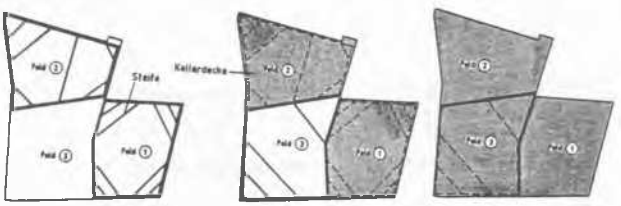

Fig. 7 Constructing sequence

The construction method of the pit (Fig. 8) was investigated not only for the classic slip circle but also in regard to the rigid body failure method, demonstrated in Fig. 9 acc. to the proposals of Goldscheider et al., 1974 and Scherzinger, 1991.

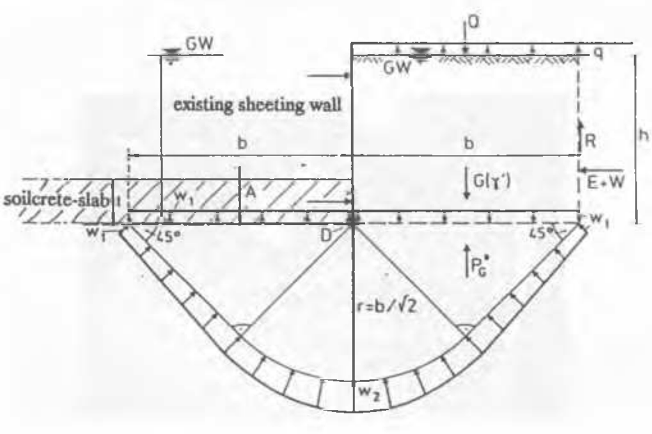

Fig. 8 Stability analysis acc. to EB 10 of EAB for the derivation of foundation anchoring forces

The anchoring forces, which were led into the lower lacustrine clay by the soilcrete-slab and the injection piles were stated at 91 kPa following the investigation results in regard to the flow around the sheet-wall.

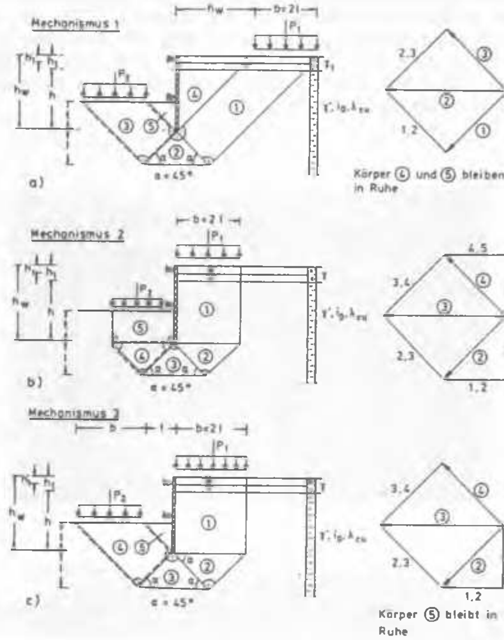

Fig. 9 Volume-constant flow of soft soils into a pit acc. to a calculation model of Goldscheider et al., 1974 and application acc. to Scherzinger, 1991

CONSTRUCTION WORK

After dividing the pit into 3 fields by means of sheet-pile bulkheads (Fig. 7), which have been put into a single-phase diaphragm-wall, 4,600 soilcrete columns have been produced from the excavation level of - 1.5 m (Fig. 10). In between the sinking range of - 7.3 m to - 9.3 m the soilcrete-slab works as a horizontal supporting structure (Fig. 11).

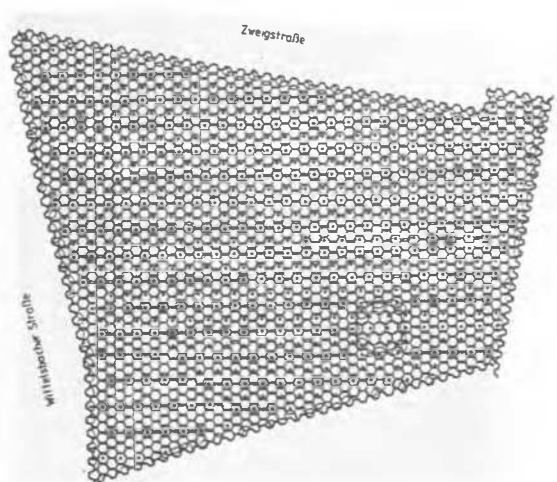

Fig. 10 Plan of soilcrete columns and injection piles

The soilcrete-slab was anchored with 1,400 injection piles of 17 m length in the lower lacustrine clay. With 3% of the injection piles the bond between soilcrete-slab and lower lacustrine clay were proved by means of a qualification test by applying double working load.

Acc. to investigation results it was found that in the first production phase no sufficient quality of the soilcrete-slab was achieved. Thus, 32 bore-holes and additionally two shafts of 4.5 m in diameter were sunk down to get the oppurtunity to observe the soilcrete-slab before performing the excavation work (Fig. 12a). Later on the diameter of the soilcrete columns were proved by a special measuring device (Fig. 13).

Fig. 11 Field 3 of the braced pit and view to the railway station and the Lake of Starnberg

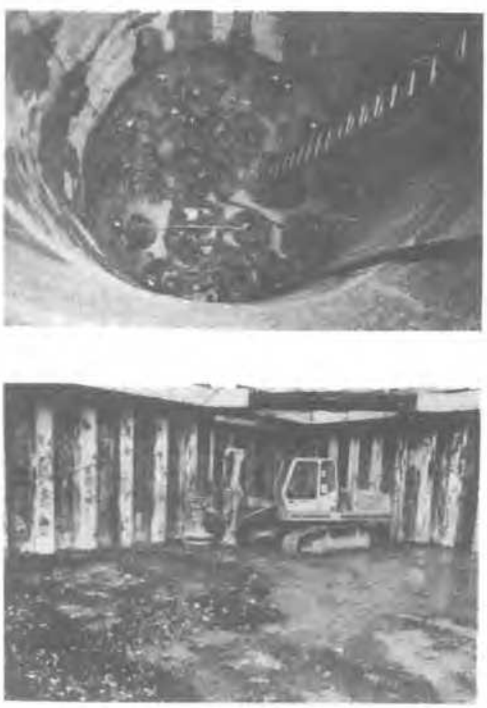

Fig. 12 Uncovered soilcrete-slab
a) investigation shaft in field 1
b) milling machine grinding the soilcrete-slab surface

From inside the investigation shafts it was discovered that, indeed, the soilcrete-slab was not fully existing. In spandrel ranges parts of lacustrine clay remained which were stabilized by bored piles.

MEASURING RESULTS

The horizontal movements of the sheet-walls have been observed by 24 inclinometers reaching down to 30 m depth. The displacements of sheet-wall heads were measured tachymetrically and by measuring lines. The sheet-wall was deformed at most 1 cm horizontally against the pit; the well-supporting effect of the soilcrete-slab is demonstrated by the bending development curve in Fig. 14.

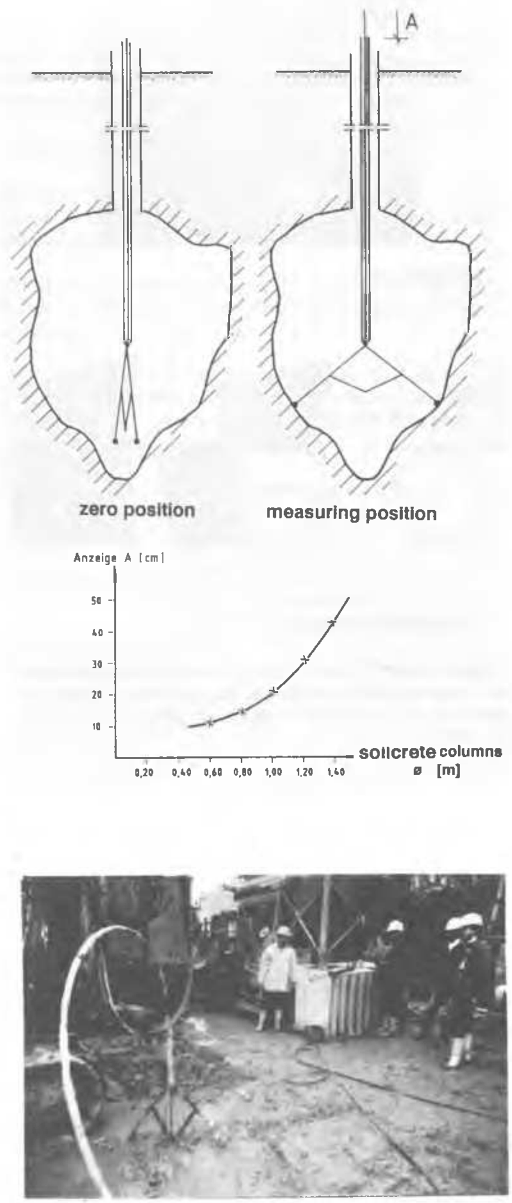

Fig. 13 Measuring device
a) schematical description
b) opened measuring device before inserting into the pipe

All strut forces have been supervised by measuring devices. In Fig. 15 a typical measuring result is shown. The calculated strut force was'nt exceeded in any strut. The measured strut forces are in a range of 1,000 to 2,000 kN and possess the typical dependence on temperature (Romberg et al., 1986).

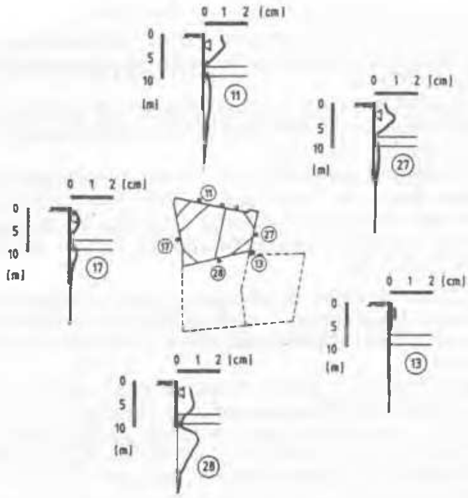

Fig. 14 Measured sheet-wall deformations

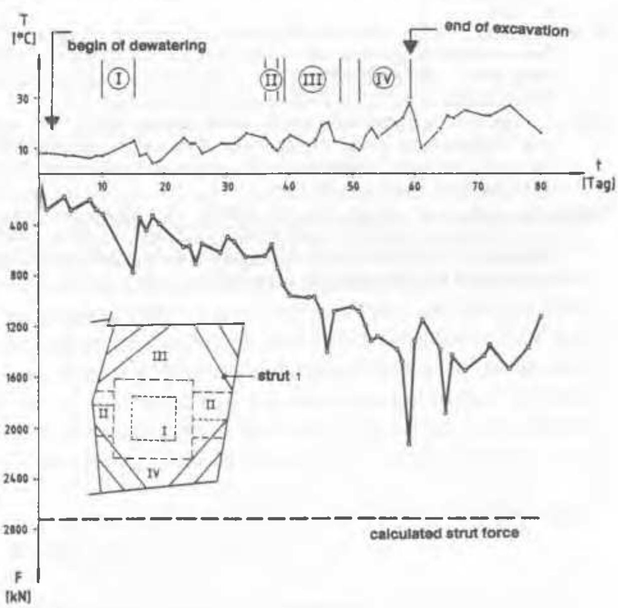

Fig. 15 Measuring of strut forces

The settlements of the adjacent buildings were monitored by a far-reaching measuring program till 90 m around the pit. 110 measuring points have been installed at the adjacent buildings. Fig. 16 shows some typical results for buildings situated in the direct neighbourhood of the excavation pit.

The most adjacent building, the historical Haus Ecker has received settlements of 1.2 cm and a tilting of 1:2,200 as a result of the construction measurements of the Seearkaden. The Haus Ecker has withstood the settlements and tiltings without any damage (Fig. 17).

The settlements decrease significantly with increasing distance from the pit (Fig. 18). Within a distance of 10 m they show an average value of 1 cm and in case of 25 m they decrease to +- 2 mm, values in the range of measuring accuracy.

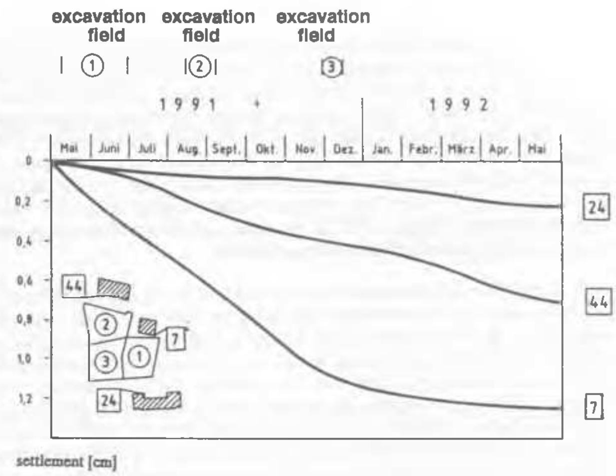

Fig. 16 Measured time-settlement development

Fig. 17 Historical Haus Ecker

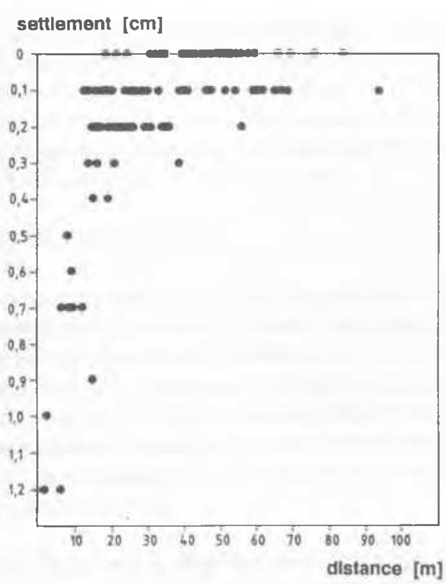

Fig. 18 Measured range of settlements

FINAL REMARKS AND PROSPECTS

The measured results of the excavation pit for the Seearkaden Starnberg executed by application of the observational method demonstrate that in case of a pit closure in soft lacustrine clay no earth abutment could be mobilized and earth pressures must be taken from stiffening construction elements above and below the subgrade surface due to the demands for deformation limitations in the inner city. Otherwise great damages in the excavation's neighbourhood can be expected. The sheet-wall must have a deep embedding depth in order to avoid the volume-constant largely sidewards emitting solifluction (Scherzinger, 1991). If the sheet-wall does not meet this aim the bottom must be anchored in the deeper subsoil.

For the first time a successful execution of a 3,600 m^2 large soilcrete-slab for the excavation of the Seearkaden Starnberg has been performed without any damages to the adjacent and partly historical buildings. The described horizontal application of soilcreting is not only of interest for deep excavations in soft soils but among others there is a possible field of application concerning the encasing of existing depositions and scrap locations (Nußbaumer et al.), whereby it is necessary to take as a basis further material testing with respect to the resistance and research work referring the production security and procedures and verification methods for the sealing efficiency.

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