PLAXIS analysis of a circular slurry trench wall construction pit enclosure in Budapest

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A backtied circular slurry trench wall was originally envisaged for the construction pit enclosure of a sewage lift station in Budapest. Using the PLAXIS and AXIS program packages the possibility of building a stable enclosure without backties or bracing was demonstrated. The structure was built safely according to the proposed design and has been operated ever since without any sign of distress. The experiences gained in using the programs and the proposed improvements are described hereunder.

The site for the proposed lift station was selected in the area of an existing, operating lift station, interwoven with utility pipelines and densely overbuilt with buildings and other structures.

Main data of the structure: The machine room is located within a 26.40 m overall diameter circular r.c. structure, founded approximately at 13.80 m depth below the average terrain level. A 10 cm thick lean concrete layer was spread on the bottom excavated and served as the base of the 80 cm thick r.c. foundation slab.

The slurry trench wall enclosure of 60 cm nominal thickness was built in straight panels which formed a polygon circumscribed around a circle of 26.48 m diameter. Answering a request of the construction company, the reinforcement of the trench wall was not connected to that of the lift station building. (On an earlier lift station project the trench wall formed a monolithic part of the load-bearing structure.) The difference between the diameters was intended to take care of any inaccuracy of trench-wall construction.

The total depth of the trench wall was 15.80 m below the track supporting the trenching machine, so that the trench itself penetrated 1.5 m deep into the practically impermeable clay subsoil.

The three types of pre-assembled reinforcement cages were 1.20, 1.80 and 2.30 m long. These were placed no wider from each other and the spacing tube than 20 cm. Reinforcement depended on the minimal rate prescribed, further on the forces acting on the wall and the lift station, respectively.

The wall panels were encased at their top in a cap beam of 60 by 65 cm cross section, the inner face of which formed a 26.40 m diameter circle. The reinforcement follows the curvature of the beam.

Soil and groundwater

The project site is situated some 130 m from the Danube bank.

From the geological point of view, the sequence of layers is typically a riparian one, in that the base consists of a practically impermeable clay soil, the top of which is approximately 15 m below the terrain. Silty sand and sand soils form irregular veins and beds in the clay.
The clay base is covered with a highly pervious layer of Danube terrace gravel, which contains a wide variety of differently graded sand.

Finely graded alluvial flood-plain sediments form the top layer of the stratification, on which random fills were deposited.

From the hydrogeological point of view the site is within the direct influence range of the Danube, where the groundwater fluctuations follow closely the changes in river water level. Owing to the proximity of the river the groundwater table rises and sinks dynamically, together with the changes in the direction of seepage flow. The range of level fluctuation may surpass several, in extreme cases even more than 8 metres. The design groundwater table is approximately 1.5 m below the terrain.

	ϕ (deg.)	c (kN/m³)	ρ (kN/m³)	k (cm/s)	m (-)	E_{OED}^{ref} (MN/m²)	E_{50}^{ref} (MN/m²)	E_{UR}^{ref} (MN/m²)	R_{int} (-)
Fill	26	1	18	10^{-5} - 10^{-3}	0.5	8	8	24	0.65
Sand, gravel	32	0	19 21	10^{-2}	0.5	15	15	60	0.67
Clay	10	100	20	10^{-6}	0.5	12	12	40	0.5

Figure 1: Soil mechanical parameters used in the Hardening Soil Model

Dimensioning the Enclosure

The enclosure was dimensioned in two steps. In the first step the task was to demonstrate that the theoretically circular pit enclosure was stable without any bracing or tieback. Modelling was performed using the PLAXIS 2D V9.1 program with the Hardening Soil Model.

The program is a two-dimensional one, though with allowance for the case of circular symmetry, so that theoretically an exact result was obtained in this case.

The input data included: soil stratification, groundwater data, trench wall geometry, surface load and construction stages (Fig. 2).

The results are presented in graphic and tabular format for each successive stage of construction: displacements (Fig. 3), soil stress diagrams (earth pressures) (Fig.4) and the loads acting on the wall.

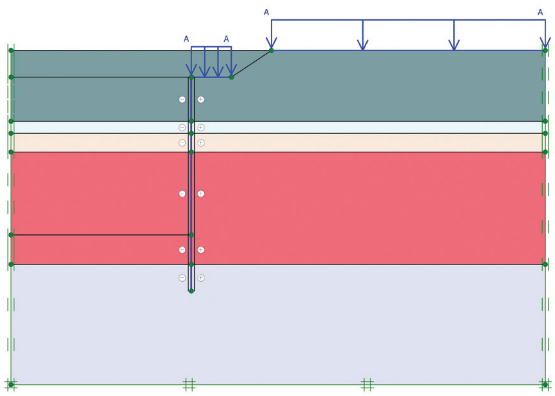

Figure 2: Soils with structural elements

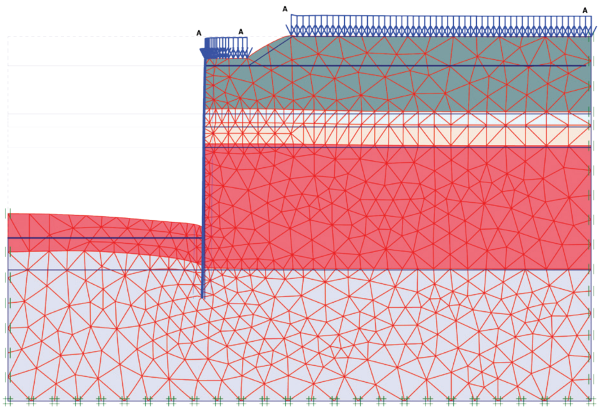

Figure 3: Deformed mesh

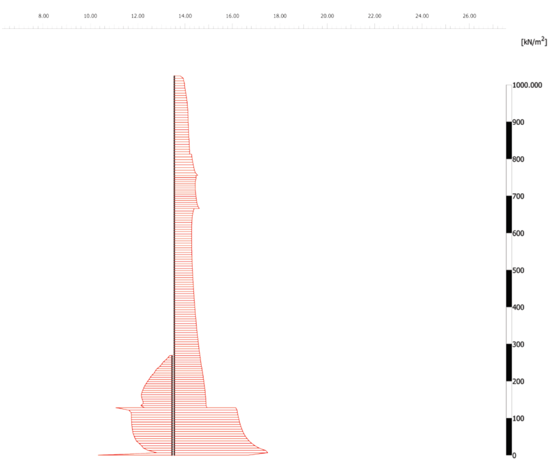

Figure 4: Diaphragm wall earth pressures

The results obtained have shown the pit-enclosure to remain stable throughout the successive stages of construction, the factor of safety against soil failure being 1.3. However, recalling that failure starts with the slumping of the upper slope, the stability of the pit enclosure remains still unaffected. It appears thus safe to conclude that the target set (a stable construction pit enclosure without bracing and tie-backs) could be achieved using the PLAXIS program.

In the second step the polygonal pit enclosure corresponding to the actual joint spacing of the trench wall was investigated. Additional local crane loads were also taken into consideration. The PLAXIS 2D model was no more capable of handling such problems, so that a shell model of the trench wall was adopted using a finite-element structural model (AXIS 3D) developed in Hungary. The earth pressures corresponding to the displacements obtained with the PLAXIS program were used in this analysis.

The trench wall panels were modelled as shell units connected by joints along their edges, which could transfer normal forces, but no moments between the adjacent ones. At their upper end the panels were encased in a continuous cap beam, whereas their lower end penetrated into the soil, where the limit bedding resistance had to be taken into account with the value obtained from the PLAXIS program. Along the rest of the panel surface only bedding which generates pressure in the adjacent soil was taken into consideration (Fig.5).

To allow for unforeseen differences in soil quality and local loads, some panels were dimensioned for additional 40 kN/m2 load. On the berm and the crest of the slope a uniformly distributed load of 10 kN/m2 intensity was assumed to act.

The following loads were assumed (with n=1.2 factor of safety throughout):

- Dead weight: Dead weight of the structure yielded by the program
- Earth pressure: From the PLAXIS program
- Water head: 13.90 m
- Surface load: 10 kN/m2 locally additional 40 kN/m2

Material qualities

- Cap beam: C25/30
- Trench panels: C25/30, at least 400 kg/m3 cement dosage
- Steel reinforcement: 500 b

Note: The Plaxis 3D Foundation program would also yield approximate results only, in that rigid (moment transmitting) panel joints could only be entered. Curved trenching would be very cumbersome to enter.

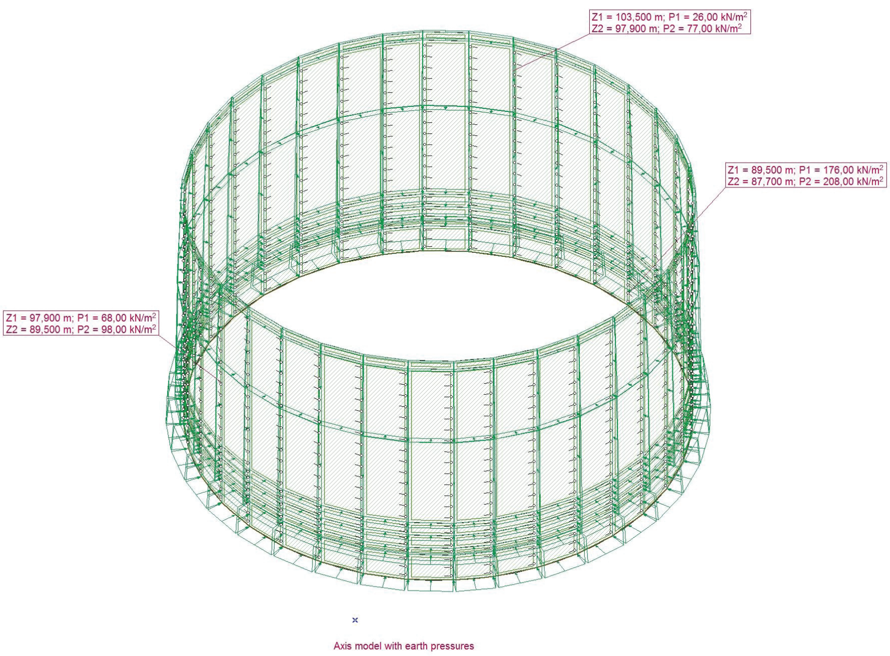

Figure 5: Heave of tunnel crown for RT1 to RT4

Results and Conclusions

The ring pressures obtained using the PLAXIS program agree very well with the results of the AXIS program (Fig.6). The displacements are virtually identical and very small, so that no structures or utility lines in the vicinity are affected (Fig.7). Local loads induce high stresses in the continuous cap beam but of these hardly any are transmitted to the trench wall. The necessary amount of reinforcing steel can also be found using the AXIS program.

The construction pit built to the proposed design was virtually dry upon completion.

Large-diameter and deep construction-pit enclosures of close to circular plan can safely be built, without any bracing or tieback. Moreover, thanks to the favourable geometry, the displacements are of the order of millimetres only and cause no damage in adjacent buildings.

The PLAXIS 2D program is eminently suited to approximate analyses, though to allow for accurate geometry and local loads the use of 3D programs is necessary. The recently developed PLAXIS 3D 2010 program will be ready for use in the near future, but at the time of designing the Plaxis 3D Foundation was only available. This is cumbersome to handle in cases of complex geometry and for modelling accurately the joints between the trench wall panels.

Proposed improvements of the program package

In conclusion, as frequent PLAXIS users, some improvements of the package are proposed with the aim of facilitating future applications.

Addition to the PLAXIS 2D 2010 program of a copy and an extension function is considered desirable. These would allow shifting/copying several points (e.g. a trench wall) in a single operation.

The PLAXIS 3D 2010 program would benefit from an improved method of inputting geometrical data, by which points, lines and polylines could be imported from Autocad. These could then be combined readily into walls and slabs in PLAXIS. The number of snap points (e.g. normals, half points, etc.) should also be enlarged.

Future improvements should include solutions for the connection of structural elements (e.g. joints and semi-rigid connection of slabs, walls, struts, etc.).

Creation of a database of materials and sections would be welcome (e.g. data of sheet piles, together with choice of pile type, etc., with input of Eurocode listings).

Budapest, March 18, 2011

Editorial note:

Some of the proposed improvements are available in PLAXIS 3D 2011 version.

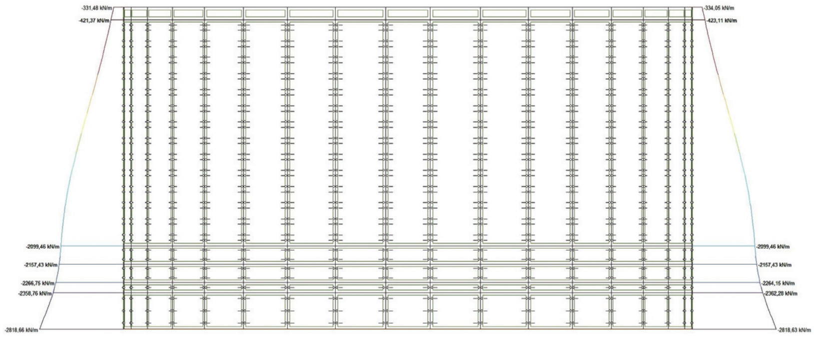

Figure 6.1: Hoop forces of diaphragm wall

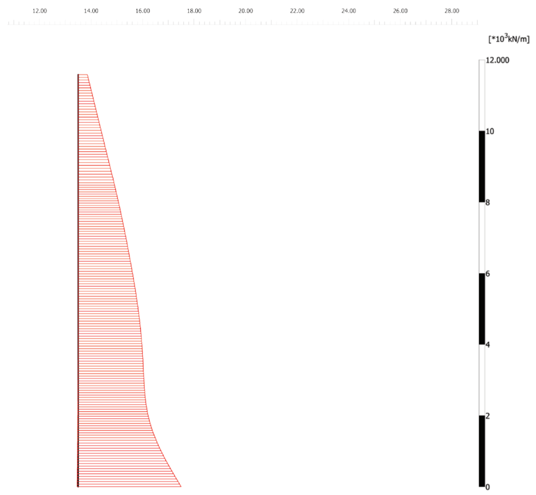

Figure 6.2: Hoop forces of diaphragm wall

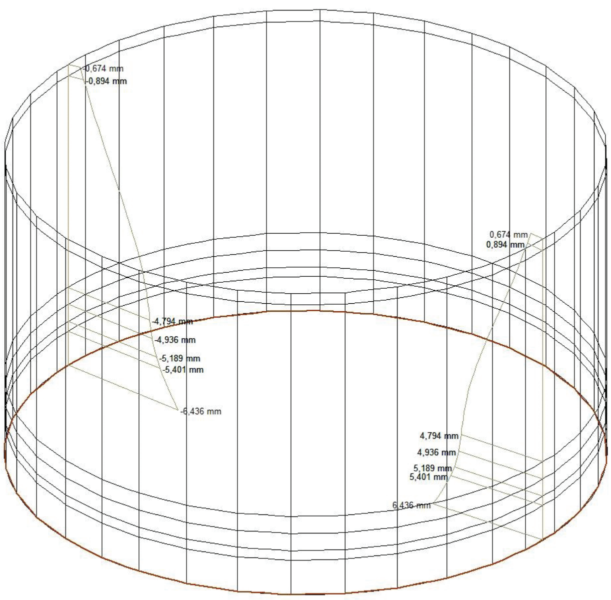

Figure 7.1: Deformations of diaphragm wall

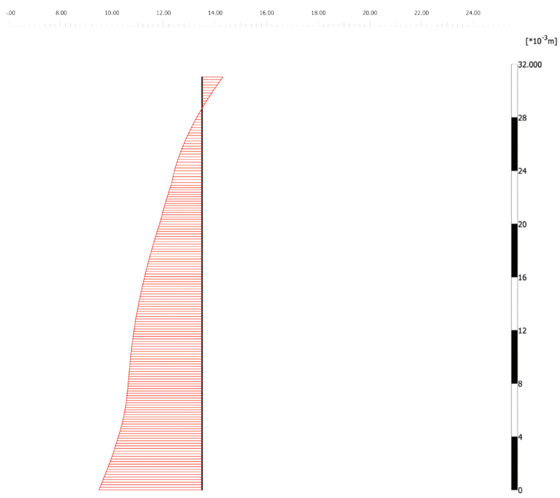

Figure 7.2: Deformations of diaphragm wall