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EXPERIENCE OF GEOSYNTHETIC ENCASED COLUMNS DESIGN, INSTALLATION AND MONITORING AT A2 HIGHWAY EMBANKMENT IN POLAND

The first professional application of geosynthetic encased columns (GEC) in Poland occurred in 2010 – 2011 during the construction of the Highway A2 (between km 60+220 and km 60+450). In this section the A2 crosses an area of very low-bearing organic soils with the thickness up to 28 m. A very detailed design and comprehensive monitoring of all construction stages ensured all requirements defined by Client concerning the allowable post-construction settlements (≤ 10 cm) and the allowable long term settlement difference (≤ 15 mm/10 m) during 30 years under operation, could be achieved.

Keywords: *geosynthetic encased column (GEC), geosynthetic material, basal reinforcement, casing, vibrator, vertical drain, monitoring system, soft soil.*

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ОПЫТ УСТРОЙСТВА ПЕСЧАНЫХ СВАЙ В ГЕОСИНТЕТИЧЕСКОЙ ОБОЛОЧКЕ И ИХ КОНТРОЛЬ ПРИ СТРОИТЕЛЬСТВЕ УЧАСТКА АВТОДОРОГИ А2 В ПОЛЬШЕ

В данной статье описывается первый профессиональный опыт устройства песчаных свай в геосинтетической оболочке в Польше в 2010 – 2011 годах при строительстве участка автомагистрали А2 (км 60+220 – км 60+450), характеризуемого очень слабыми органическими грунтами основания мощностью до 28 м. Проект устройства песчаных свай в геосинтетической оболочке включал тщательную проработку проектного решения и комплексную систему мониторинга на всех стадиях строительства и эксплуатации. Были реализованы очень жесткие требования заказчика относительно допустимой величины осадки за весь период эксплуатации конструкции (не более 10 см) и ее скорости (не более 15 мм на каждые 10 м длины сваи за первые 30 лет эксплуатации).

Ключевые слова*: песчаные сваи в геосинтетической оболочке, геосинтетические материалы, гибкий ростверк, обсадная труба, вибропогружатель, вертикальная дрена, система мониторинга, слабый грунт основания.*

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ДОСВІД УЛАШТУВАННЯ ПІЩАНИХ ПАЛЬ У ГЕОСИНТЕТИЧНІЙ ОБОЛОНЦІ ТА ЇХ КОНТРОЛЬ ПРИ БУДІВНИЦТВІ ДІЛЯНКИ АВТОДОРОГИ А2 У ПОЛЬЩІ

У цій статті описано перший професійний досвід влаштування піщаних паль в геосинтетичній оболонці в Польші у 2010 – 2011 роках при будівництві ділянки автомагістралі А2 (км 60+220 – км 60+450), що характеризується дуже слабкими органічними ґрунтами основи потужністю до 28 м. Проект влаштування піщаних паль у геосинтетичній оболонці включав ретельне опрацювання проектного рішення і комплексну систему моніторингу на всіх стадіях будівництва й експлуатації. Було реалізовано дуже жорсткі вимоги замовника щодо допустимої величини осідання за весь період експлуатації конструкції (не більше 10 см) і її швидкості (не більше 15 мм на кожні 10 м довжини палі за перші 30 років експлуатації).

Ключові слова: *піщані палі в геосинтетичній оболонці, геосинтетичні матеріали, гнучкий ростверк, обсадна труба, вібронавантажувач, вертикальна дрена, система моніторингу, слабкий ґрунт основи.*

Introduction. A Geosynthetic-Encased-Column (GEC) presents a cylinder filled with sand or gravel and encased with a stretched high tensile strength geofabric. GEC was developed by a working partnership (Möbius, Huesker and University of Kassel) in Germany in 1990-1995 [1]. Usually, GECs will be installed in triangle grids in soft or ultra-soft soils to provide sufficient bearing capacity for the foundation system for embankments [2]. Practically, all constructed embankments have been preloaded due to the required mobilization of columns and their casings (Fig. 1) [3, 4].

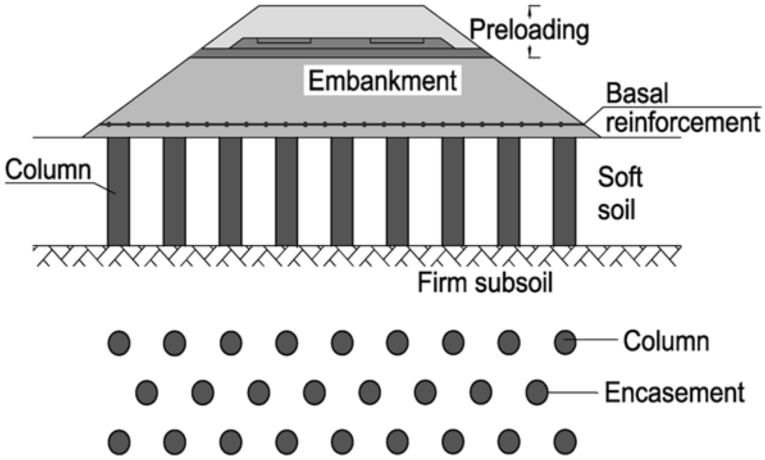

Figure 1 – GEC-foundation system for embankments with preloading

In combination with the surrounding soft soils, the geosynthetic casing provides the column with radial support, which improves the load-bearing behavior of the foundation. When the foundation system is loaded, radial forces are activated in the casing. Due to the additional radial support the stiffness and bearing capacity of columns increases depending on the tensile stiffness and tensile strength of the installed encasement. This leads to a higher concentration of stresses (arching action) on the column heads, and corresponding lower vertical stresses acting over the soft soil surrounding columns, hence reducing its settlements (Fig. 2).

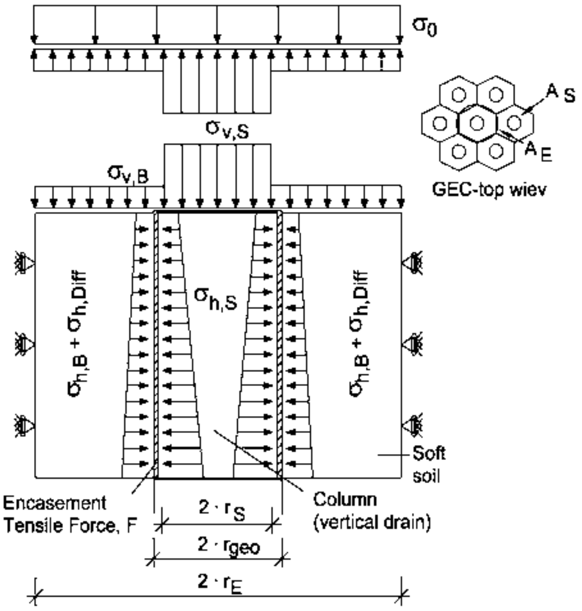

Figure 2 – GEC-foundation system, bearing and analytical model [1]

Geosynthetic encased columns act simultaneously as high efficient vertical drains, which contribute to shorten the time needed for consolidation of soft soils under the weight of embankment and preload. The stiffness ratio between columns and the surrounding soft soil can be regulated by the choice of suitable encasement. GEC are a flexible and self-regulating foundation system with virtually equal settlements of the column heads and the top of soft soil around columns. A geosynthetic basal reinforcement layer is placed above columns heads, and acts as an anti-spreading element, which partly equalizes small settlement differences between columns and the top of soft soil (Fig. 1) [2]. By the use of the preloading during construction works, the foundation of embankment can be prepared for the practically no additional post construction settlement under the traffic load.

Design of foundation system. GEC system has been successfully used since 1995 in Germany, the Netherlands, Sweden, Italy, Russia and Brazil [3, 5]. In the case of the described section of the A2 in Poland some new developments were needed due to extremely long columns, installed in soft soil deposits down to 28 m under the level of a working platform (Fig. 3 and 4). Between km 60+225 – km 60+450 GEC system with columns (diameter 780 mm and 800 mm) in a triangle grid (axial spacing 1,97 m, soil exchange ratio 15 %) was proposed. The design of columns was based on the rules given in EBGEO 2010 [2]. The stability and settlement analyses of columns were performed using the self-written software program SAND38BETA. This program enables analysis of the stability of columns in the ultimate limit state and settlements in the serviceability limit state according to EC7 – EN 1997-1. Some properties of soft soil strata and sand used in the design for the embankment and columns are shown in the Table 1. For the A2 the following out-put data was predicted using the software:

- Required long term tensile strength of the encasement: $F_{r,d}$ = 122 kN/m;
- Settlement of columns heads after 210 days of preloading: 2,33 m.

Table 1 – **Properties of soft soils and sand used for columns and embankment, Highway A2 Poland**

Soil type	Unit weight γ/γ' [kN/m]	Friction angle φ' [°]	Cohesion c' [kN/m²]	Oedom. module E_{oed} [kN/m²]	Coeff. of consolid. $c_h = 5 \cdot c_v$ [m²/s]	Creep factor c_α [-]
Sand for embank.	19/10	35	(-)	(-)	(-)	(-)
Sand for columns	19/10	32,5	(-)	(-)	(-)	(-)
Peat	11/1	15	5	500*	$1{,}59 \cdot 10^{-7}$	0,03
Gyttja	14/4	20	5	750*	$3{,}96 \cdot 10^{-8}$	0,01
Deep sand	20/10	32,5	(-)	(-)	(-)	(-)

* *E_{oed} for stress range 0-100 kN/m².*

The stability of the embankment during preloading and in the post-construction stage was analyzed using GGU-Stability software (Fig. 5). After translation from the 3D real model into a 2D analytical model, Bishop's method was used for the estimation of the capacity utilization factor (Ed/Rd). Directly, after placement of the second stage of embankment (Fig. 6) the calculated capacity utilization factor was exactly equal to 1,00. In the post-construction time due to consolidation and self-improvement of soft soil the estimated capacity utilization factor was reduced to the value of 0,76 (Fig. 5). Based on the results of stability analyses Ringtrac® 100/300 (PET encasement) and Stabilenka® 800/100 (PET fabric for basal reinforcement) were chosen.

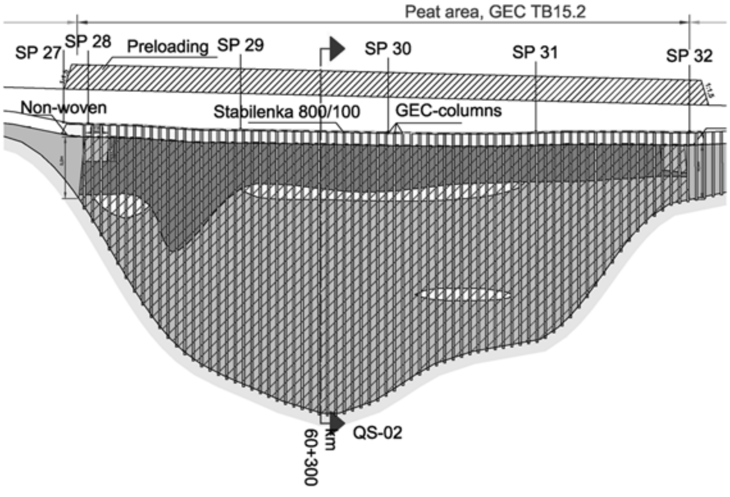

Figure 3 – GEC-longitudinal profile: embankment with preloading, km 60+225- km 60+450

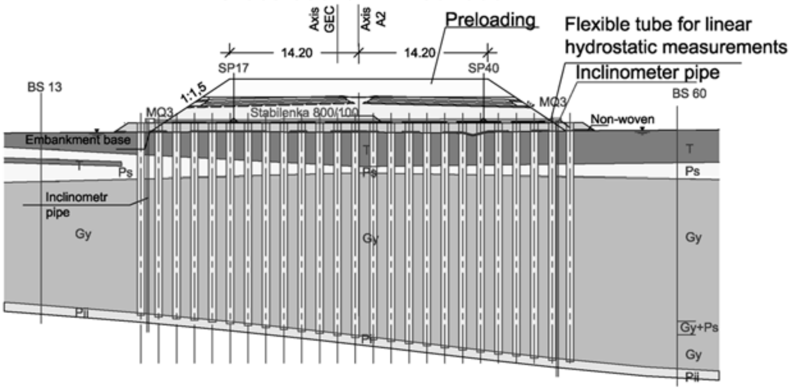

Figure 4 – GEC-cross-section, embankment with preloading, km 60+300

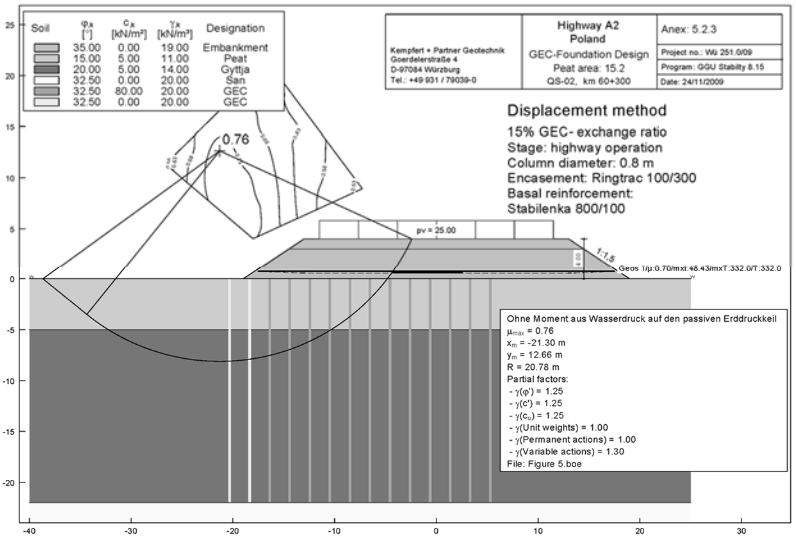

Figure 5 – Stability analysis, post-construction stage, Bishop's method

The designed construction sequence is presented in the Figure 6. Based on the planned schedule of construction works the resulting development of settlements, the consolidation time needed, for primary consolidation (preloading time) and post-construction creep settlements (secondary settlements) were estimated. The primary consolidation process was analyzed using GGU Consolidate 3,0 software, which indicated that 95 % consolidation ratio would be reached after 210 days of preloading (Fig. 6) and primary settlement would be equal to 2,33 m. Creep settlements (post-construction settlements) were calculated using the formula reported by [4]. The resulting creep settlement over the 30 years in–service after the opening of the highway operation was estimated at 7,9 cm and was lower than allowable value defined in PN-S-02205 ≤ 10 cm. Finally, based on FEM analysis the other client requirement from the tender specification could be achieved: max. calculated settlement difference ≤ 15 mm in any arbitrary position and orientation section with a length 10 m, during 30 years under the higway operation.

Construction works. The preparation of the working platform, installation of columns and basal reinforcement and installation of monitoring devices were undertaken from: april 2010 – october 2010 (fig. 6).

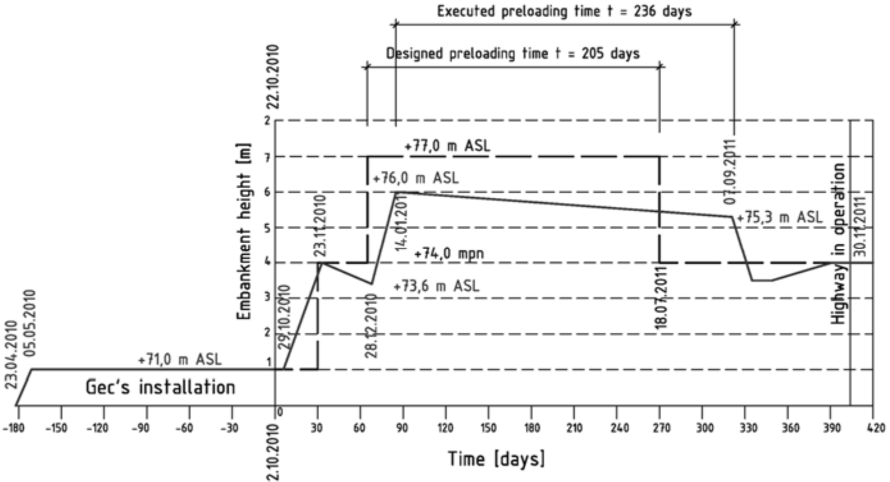

Figure 6 – Designed and realized schedule of construction works

The working platform with the thickness of 1,0 m was placed on a non-woven (CBR ≥1,500 N) and was only able to support light equipment. The heavy equipment used for the installation of columns (Liebherr LRB 255 and Liebherr LRB 155, weight ca. 1,100 kN) moved on a wooden platforms (6,0 m x 6,0 m), which were always replaced and positioned over already intalled columns, which meant that new columns were installed ahead the working front. In this way the vertical stresses equal to 30,5 kN/m² could be safetly distributed to by the newly installed columns. Two heavy machines were used for pilling works (Fig. 7). For the installation of columns a displacement method was used, which involves insertion of a closed bottom steel pipe, vibrated down into firm stratum through soft soil layers. The closed flaps form a cone at the bottom during driving of the pipes. After the placement of the geotextile encasement into the pipe, sand will be filled up to the top of the pipe and the geotexile loosened. The flaps will be opened by the initial withdrawal of the steel casing. Sand in column will be continuosly compacted whilst withdrawal under vibration and after removal of the steel pipe a column with a given diameter and length is created. To produce the longest GEC's, the process had to be adapted:

- Open pipes with attached sacrificail base plates were used (Fig. 8);
- Instead of a classical vibrator fastened on the top of steel pipes a moveable ring vibrator was utilised (Fig. 9).

The key points of the constructed foundation system are presented below:

- Number of columns: 3400;
- Soil exchange ratio: 15 %;
- Maximal column length: 28 m.

Figure 7 – Two heavy Liebherr rams during installation of geotextile encased columns, standing on wooden platform placed on already installed GECs

Figure 8 – Lost plate used at the base of the longest displacement pipes instead of standard flaps

After installation of the columns a sand leveling layer with a thickness of 30 cm was placed and basal reinforcement (Stabilenka® 800/100) installed. In this period many monitoring devices were assembled or attached to geotextiles. After the installation of all monitoring devices the first base measurements readings were taken. The main earth works (embankment with preload) were started on 29.10.2010. The embankment was placed in two stages: the 1st stage: sand layer with thickness 3 m, the 2nd stage: sand layer with thickness 2,4 m, up to the level +76,0 m ASL. A 35 day break for the partial dissipation of excess pore water pressure between both steps was needed (Fig. 6). The difference between the planned level of preload of 77,0 m ASL and the executed on 76,0 m ASL was as a result of construction settlements during the earth works. This settlement was neglected in the theoretical analysis performed in the design (assumption on the safe side).

Figure 9 – Moveable ring vibrator used for the longest displacement pipes

Monitoring. The project was accompanied by a comprehensive geotechnical measuring program to verify the assumptions made in static calculations and the achieved results of the final design. The predicted development of the consolidation process, settlements and tensile forces in the column encasement were of primary importance. Finally, the results of monitoring were decisive for the removal of the preload. The measurements are scheduled to continue for five years after the start of highway operation. The monitoring system consists of:

– 29 bench marks with telescopic connected pipes;

– 6 hydrostatic lines for settlement measurements (3 in the longitudinal direction and 3 in the crosswise direction, Lhotzky system);

– 4 sensors for measurements of vertical stresses on column heads and between columns;

– 4 columns with installed sensors for measurements of column perimeter;

– 10 vertical inclinometer pipes installed at the embankment toe for the observation of the spreading behavior of the embankment base and deeper subsoil.

The method of the hydrostatic profiles used for settlement measurements was developed by the German Company Lhotzky. This innovative method is based on the intermittent measurements of a hydrostatic pressure difference between the predefined point and the reference level. The predefined points are located along an installed flexible tube, in which a fluid will be pumped step by step. In this way the longitudinal position of fluid head will be known and the settlement profile can be determined. The total length of the six installed flexible tubes (lines) was 882 m. The number of observed points was equal to 3,528 (it means, that the points were located in the linear spacing of ca. 0,25 m. Additionally, the settlement process was controlled by geodetic measurements on 29 bench marks located on the top of a leveling layer placed above the columns heads. The results of 7 measurements sets performed in MQ 4 (longitudinal profile along the edge of embankment) are presented in Figure 10.

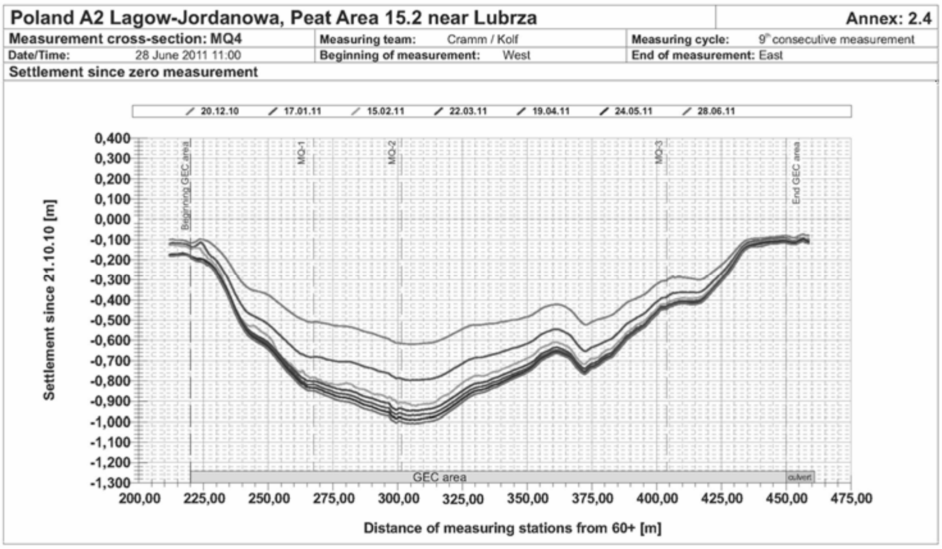

Figure 10 – Settlement in the longitudinal profile under the edge of embankment, system Lhotzky

The horizontal line marked in the Figure 10 presents the start configuration of monitoring dated October 29 in 2010. The additional seven measurements sets present the deformed base of embankment along the installed hydrostatic lines. The maximal value of settlement measured on June 28 in 2011 was equal to 1.05 m.

The predicted design value of settlement was clearly higher (s = 2.33 m). It can be explained by neglected improvement of soft soil in the analytical model. Furthermore the monitoring did not consider settlements caused by the self weight of the working platform and the leveling layer and settlements which occurred under the moving weight of the column installation equipment. This large difference between predicted and observed settlements shows a large reserve in the use of the analytical model. It means that further improvements in assumptions can be undertaken.

The diameter of the geotextile encasement was equal to the inner diameter of steel pipes used in the displacement method for the column installation. This means, that at the moment the pipe is lifted, the tensile force in the casing should be theoretically equal to zero (no tension in geotextile casing). After pipe withdrawal, the tensile force in casing depends on the changes in the perimeter of columns, which can be caused by horizontal stresses in soft soil and later by vertical load on column heads and soft soil in between. As shown in Figure 11, immediately after the pipe is lifted, the diameter of the geotextile casing was larger than the diameter of Ringtrac at three levels.

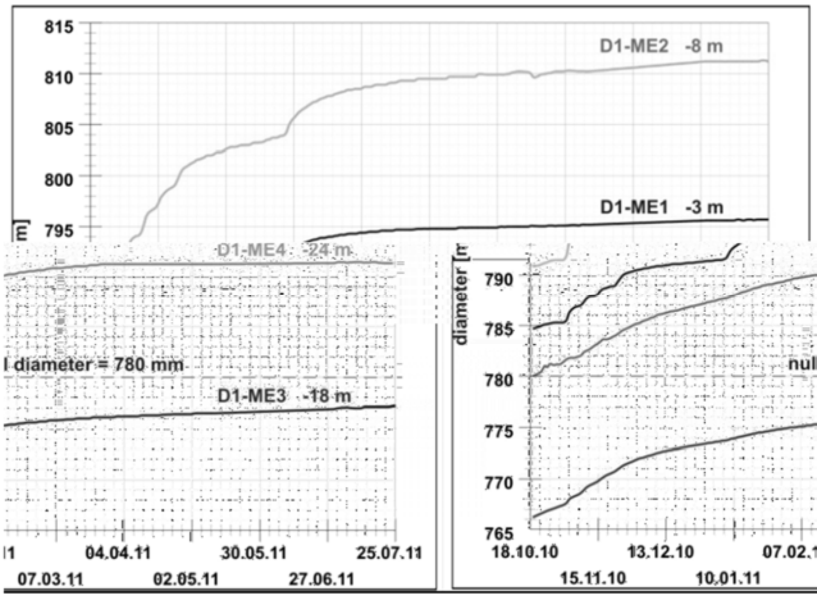

Figure 11 – Changes of column diameter during construction time, system Lhotzky

This indicates that the diameter of the observed GEC-D1 generally widened. Only at the level -18 m below the column head, the circumference of the column was lower than the circumference of Ringtrac®. This could be caused by a stiffer interlayer located at this depth, which mobilized higher radial earth pressure after the pipe withdrawal. The maximum tensile force observed in the device ME-2, located at the depth of 8,0 m (near the bottom of the peat layer). Directly after the pipe was lifted, the elongation of the geosynthetic casing was equal to 1,4 %. At the final stage of preloading, the elongation was 3,97 %. Based on the isochrones of Ringtrac®, (made from polyester), a tensile force equal to 75 kN/m was estimated, taking into account the real loading period of approximately 8 months. The predicted in service tensile force for the final construction stage was calculated at 122 kN/m. It can be said, that the design overestimated the tensile force by around 33 %.

As expected, the load transfer from embankment weight and traffic (or preload) was strongly affected by the very high difference in the stiffness between columns and surrounding soft soils. At the final stage of preloading, the vertical stress on the column head was 320 kN/m². The predicted design value for this stage was estimated at 794 kN/m². Correspondingly the observed vertical stresses on top of the soft soil were observed in the range 100-120 kN/m². In the final stage, a small growth of stresses on the column heads and a slow reduction of stresses acting on the soft soil were noticed. Three interlinked measurements, namely: settlements, tensile forces in geotextile and vertical stresses on column heads were clearly lower than predicted in the design. This large difference highlights a large reserve in the analytical model used. It means that further improvements in assumptions of the model are possible.

Summary. One section of the new road embankment constructed in 2010-2011 for the a2 highway in poland is located in an area with very deep organic subsoil, which reaches the depth of 28m. After consideration of many design options the gec system was used due to its ability for a controlled variation in this complex situation. As a decisive criterion for the proof of serviceability, the client specified the maximal allowable post-construction settlement difference between two points spaced 10 m apart over a period of 30 years ≤ 15 mm. The total post-construction settlement should be ≤ 10 cm over the period of 30 years. Based on a detailed design and an extensive monitoring it was possible to give the proof, that the designed and executed gec for this embankment fulfills these requirements.

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