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Motorway embankment on soft soil – monitoring and analysis

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ABSTRACT: The motorway A28 section between Ecomoy and Dissay sous Coursillon of 25 km crosses many compressible areas.

The autors present the embankment R302. One of the technical aspect of this complex geotechnical project consists in the construction of an Embankment of 14 m height crossing an hydraulic structure on soft soil.

Different technical solutions have been implemented in order to accelerate soil consolidation and earth construction.

The authors will present the geosynthetic techniques and design method used for the drainage of this project. They present also the monitoring taken out and the results analysis.

1 INTRODUCTION

The motorway A28 section between Ecommoy-Dissay sous Courcillon of 25 km long crosses many compressible valley bottom with embankment height of 7 to 17 m. The embankment R302 on soft soil cross a brook and the flow restoration is done by a pipe of 2000 mm diameter. The height embankment above the hydraulic structure (pipe) is 12 m. The maximum embankment height is 14.0 m.

The authors describe the drainage technique used to reduce the time construction and the consolidation time.

2 GEOTECHNICAL CONTEXT

The geotechnical studies carried out have revealed that the mechanical characteristics of the soil on site are mediocre on depth of 5.5 m and the free ground water level is at a depth of –1.3 m under the natural surface

On average, the geotechnical investigation permit to identify under a depth of 0.5–0.6 m of top soil, peat and sandy peat, the compressible alluvium constituted of fine to medium sand clay around up to depth –3.7 m. Then, it is observed compressible sand and clay sand up to –5.5 m depth and beyond this depth the soil is composed of sand.

3 TREATMENT OF COMPRESSIBLE ZONES

The geotechnical tests conducted at laboratory and in situ have shown that the puncture resistance of the soil foundation is not sufficient to construct the embankment on one stage and the consolidation time is not compatible with realization time of the project.

The theoretical settlements of the embankment were evaluated to be 30 to 35 cm. The settlements calculated under the hydraulic pipe were 10 to 15 cm.

In order to accelerate the time consolidation and the time construction of the embankment, it was decided to use geosynthetic drainage technique, to proceed at a general purge of compressible materials of 1.5 m depth and a local purge of 1.5 m depth under the hydraulic pipe, to construct the embankment on two stages.

The embankment was instrumented during the construction by two settlement cell lines (3 cells on each line), situated at the PK 30.20 and PK 30.35.

To meet the requirements of the main contractor, a flat vertical geosynthetic drainage mesh is incorporated at a depth of 5.5 m (photo 1). The calculated mesh is 3 × 3 m.

The vertical drainage is combined with an horizontal drainage (photo 2) to ensure the flow of drainage water to the lateral trenches.

The horizontal drainage system is composed of a SOMTUBE FTF geocomposite. The geocomposite

Photo 1. Installation of the geosynthetic vertical drains.

Photo 2. Horizontal geocomposite drainage.

structure is illustrated in figure 1. It is created by mechanical bonding of the following elements:

- A needle-punched, non-woven polypropylene filter layer (filter 1),
- A needle-punched, non-woven polypropylene drainage layer,
- Polypropylene mini-drains diameter 20 mm, perforated at regular intervals along two axes at 90°,
- A needle-punched, non-woven polypropylene filter layer (filter 2).

The space between the mini-drains varies from 0.25, 0.5, 1 and 2 m depending on the drainage flow rate and the geometric characteristics of the construction.

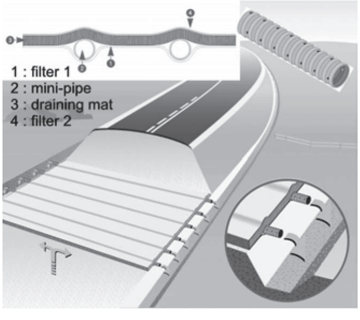

Figure 1. Horizontal geocomposite drainage structure.

4 DIMENSIONNING OF THE HORIZONTAL DRAINAGE

4.1 *Filtration*

The filter size is 80 µm and is compatible with the underlying beds.

The two filters are made of needle-punched, non-woven geotextiles specially adapted to the task of filtering.

The mechanical bonding of filter and drainage layers helps avoid all risk of slip between the filter/drainage layers and thus ensures filtration continuity. The flexibility of the SOMTUBE allows it to adapt to any ground irregularities. The last two characteristics optimise the filtering function by limiting the space in contact with the filter and consequent soil in suspension.

4.2 *Drainage*

The water evacuated by the vertical drains is collected by the non-woven drainage layer and transported to the mini-drains after having passed through filter 1.

The composite dimensions must take into consideration:

- the head loss when passing through filter 1,
- the head loss when flowing through the drainage layer,
- the head loss when entering the mini-drains,
- the head losses when flowing through the mini-drains.

4.2.1 *Hypothesis*

The head losses when passing through filter 1, already taken into consideration in the filter criteria, are not taken into consideration when calculating the drain dimensions. This is generally the case for all drainage facilities.

The non-woven layer is placed horizontally and it is therefore considered to be totally saturated. The characteristic parameter retained is the transmissivity θ. For simplicity, it is assumed that flow in the layer is straight and perpendicular to the direction of the mini-drains. The flow Q_1 transported per unit of width is given by:

$$Q_1 = v_1 t_{gtx} = -\,\theta\, i_1 \qquad (1)$$

Laboratory tests have been carried out to establish the head loss when entering the mini-drains. These tests illustrated that the head loss is negligible and corresponds at the most to several millimetres of flow in the non-woven layer.

For this application, the mini-drains are placed horizontally. To evacuate the water collected over a great length, they are considered to be completely saturated. There is not sufficient slope to consider a free surface flow inside the mini-drains. It is even quite likely, considering the difference in subsidence

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which is greater in the central segment, that they may even be under pressure.

The laboratory results indicate that the flow rate in the mini-drain may be characterised by the following form relationship:

$$Q_2 = qd^i = \alpha i^{(n+1)} \qquad (2)$$

Where:

- q_d: discharge capacity of the mini-drain,
- i: hydraulic gradient in the mini-drain
- α, n: experimental constants.

4.2.2 *Calculation of the maximum pressure inside the drain*

A uniform flow of intensity V is assumed to enter the drainage layer perpendicularly over a width of 2B, corresponding to the distance between mini-drains (Figure 2).

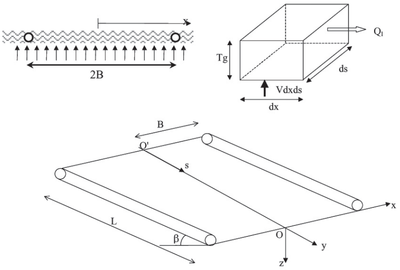


Figure 2. Flow modelisation in the geocomposite.

Furthermore, the volume collected in an element of length ds of mini-drain is given by:

$dQ_2(s) = 2vBds$

with

$$Q_2(s) = q_d\ i = \alpha\ i^{(n+1)} \qquad (3)$$

where:

- Q_2: flow transported by the mini-drain
- q_d: discharge capacity of the mini-drains
- i: hydraulic gradient in the mini-drain
- α, n: experimental constants.

i.e.

$$\frac{dh_2}{ds} = -\left[\frac{2vB}{\alpha}s + C_1\right]^{\frac{1}{n+1}}$$

h_2: hydraulic load in the mini-drains.

but $C_1 = 0$ as for $s = 0$, $i = 0$ (Q_2 is zero at $s = 0$):

$$h_2(s) = -\frac{n+1}{n+2} \times \left(\frac{2vB}{\alpha}\right)^{(1/n+1)} s^{(n+2)/(n+1)} + C_2$$

The maximum head is obtained for $s = 0$

$$(h_2)_{\max} = \frac{n+1}{n+2} \times \left(\frac{2vB}{\alpha}\right)^{(1/n+1)} L^{(n+2)/(n+1)}$$

The maximum head $h_{1\max}$, inside the drain is:

$$(h_1)_{\max} = \frac{VB^2}{2\theta} + \frac{n+1}{n+2} \times \left(\frac{2vB}{\alpha}\right)^{(1/n+1)} L^{(n+2)/(n+1)} \qquad (4)$$

4.2.3 *Use of LYMPHEA software*

A software design (LYMPHEA) has been developed in cooperation with the Laboratoire Interdisciplinaire de Recherche Impliquant la Géologie et la Mécanique (Lirigm) of the Joseph Fourier university in Grenoble and validated together with the Laboratoire Régional des Ponts et Chaussées (LRPC) of Nancy (Faure and al. 1993). It is used to process this type of configuration : horizontal ground and saturated mini-drains. However, it may also be used for other configurations (Arab and al. 2002, Gendrin and al. 2002):

- sloping ground with free flow in the mini-drains,
- constant load imposed for a certain drain distance,
- evacuation of gas,
- drainage layer with or without mini-drains.

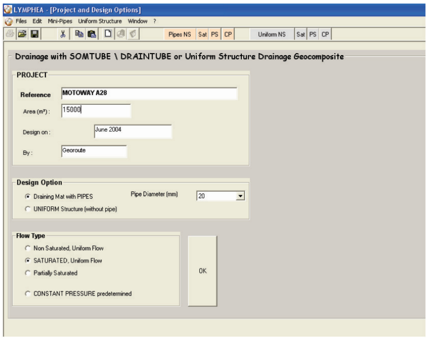
In the software, the flow in the drainage layer is considered to be uni-directional and perpendicular to the mini-drains.

The software takes the following parameters into consideration:

- the transmissivity of the drainage layer under compression,
- the flow length in the mini-drains,
- the flow slope in the mini-drains,
- the distance between mini-drains,
- the flow conditions in the mini-drains (saturated, partially saturated or not saturated)

For the motorway A28 project, dimensioning was carried out using the LYMPHEA software (figure 3), taking into consideration the hydro-geotechnical context and geometric characteristics of the construction.

The following hypothesis (figure 4) were taken into account for calculation of the drainage under the embankment:



Drainage with SOMTUBE \ DRAINTUBE or Uniform Structure Drainage Geocomposite

PROJECT

Reference: MOTOWAY A28
Area (m²) : 15000
Design on : June 2004
By : Georoute

Design Option

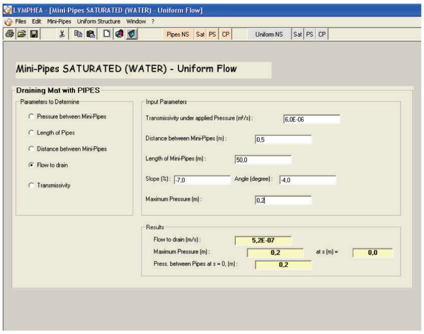
● Draining Mat with PIPES
○ UNIFORM Structure (without pipe)

Pipe Diameter (mm): 20

Flow Type

○ Non Saturated, Uniform Flow
● SATURATED, Uniform Flow
○ Partially Saturated
○ CONSTANT PRESSURE predetermined

Figure 3. presentation of the project (Lymphea).



Mini-Pipes SATURATED (WATER) - Uniform Flow

Draining Mat with PIPES

Parameters to Determine
○ Pressure between Mini-Pipes
○ Length of Pipes
○ Distance between Mini-Pipes
● Flow to drain
○ Transmissivity

Input Parameters
Transmissivity under applied Pressure (m²/s) : 6,0E-06
Distance between Mini-Pipes (m) : 0,5
Length of Mini-Pipes (m) : 50,0
Slope (%) : -7,0 Angle (degree) : -4,0
Maximum Pressure (m) : 0,2

Results
Flow to drain (m/s) : 5,2E-07
Maximum Pressure (m) : 0,2 at s (m) = 0,0
Press. between Pipes at s = 0, (m) : 0,2

Figure 4. Entry of parameters and results obtained (Lymphea).

- height of embankment: 14 m
- mini-drains saturated
- uniform flow
- two mini-drains per metre (spacing: 0.5 m)
- flow lengths: 50 m
- transmissivity of the drainage layer under stress due to 14 m of embankment: 6 10^{-6} m^2/s
- slope: –7%
- maximum pressure on the geocomposite: 0.2 m

The calculation indicates a flow entry of around 5.10^{-7} m/s for a maximum imposed pressure of 0.20 m (Figure 5) (Faure and al. 1993). This flow is quite acceptable considering the volumes attained.

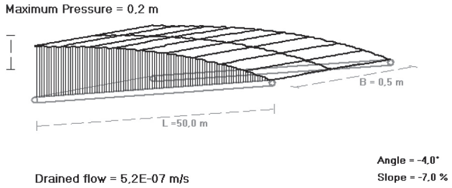


Figure 5. Piezometric surface in the in geocomposite drainage (LYMPHEA).

The settlements measured during the embankment construction are shown in figures 5 and 6. We notice that the settlement predicted (30–35 cm) is greater than the settlement measured.

5 CONCLUSION

Drainage geocomposites (horizontal and vertical) were used successfully to accelerate the consolidation and the time construction. Comparatively to the traditional solutions with permeable coarse material, geosynthetics offers great guarantee on regularity performance, rapidity on execution and saving earthwork.

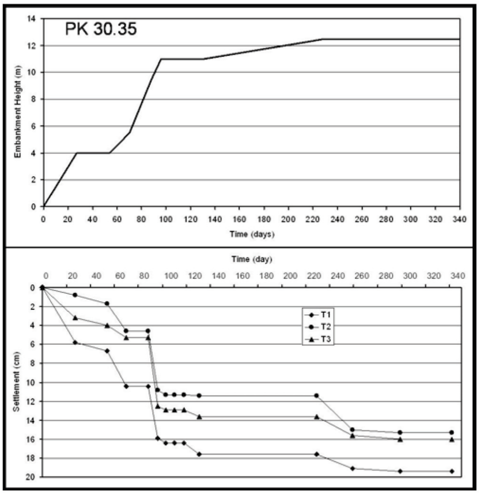


Figure 6. Settlements measured during the embankment construction at PK 30.35.

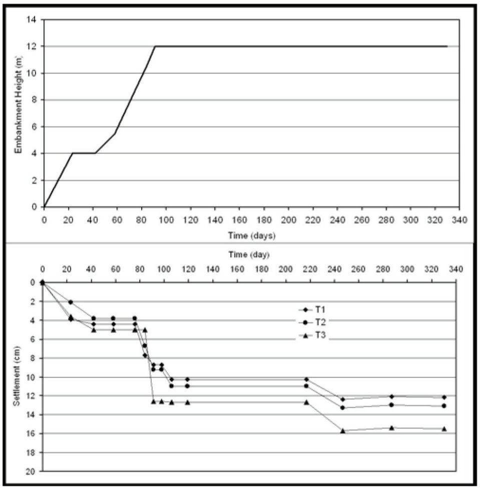


Figure 7. Settlements measured during the embankment construction at PK 30.20.

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