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THE USE OF GEOTEXTILES FOR EMBANKMENT REINFORCEMENT IN TURKU HARBOUR

UTILISATION DE GEOTEXTILES POUR LE RENFORCEMENT DES RAMBLAIS DANS LE PORT DE TURKU

ANWENDUNG VON GEOTEXTILIEN BEI DER VERSTÄRKUNG DER BÖSCHUNGEN DES TURKUER BOOTSHAFENS

The soil conditions in the Turku harbour in Finland are exceptionally unfavourable in terms of planning and realizing rigid waterfront structures i.e. quays, shoreline retaining walls or embankments etc. This is due to the prevailing deep deposits of post-glacial and glacial clays with extremely low shear strength and high compressibility characteristics. To maintain a shoreline embankment alongside a ship channel of even a moderate depth requires special measures to be taken in order to reach adequate safety against a collapse of the structure. This paper describes a case, where a shoreline embankment has been built using a composite structure of two parallel floating embankments of crushed stone and gravel, both reinforced with a woven geotextile mat.

Im Turkuer Hafen in Finnland sind die Bodenverhältnisse besonders unvorteilhaft im Bezug auf Planung und Ausführung von Uferbefestigungen, wie massive Kaianlagen, Stützmauern oder Böschungen. Dies rührt von den glazialen und postglazialen Tonablagerungen in diesem Gebiet her, die bis in grosse Tiefe reichen und eine sehr geringe Scherfestigkeit und grosse Zusammendrückbarkeit aufweisen.
Es mussten besondere Massnahmen ergriffen werden, um die Stabilität der Böschungen des langen niedrigen Sport- und Fischerbootekanals zu erreichen.
Der vorliegende Bericht schildert einen Fall, wo eine Böschung aus zwei parallel liegenden Dämmen hergestellt wurde, die mittels gewebtem Geotextil verstärkt aus Sprenggut und Kies lagenweise in eine Richtung vorgetrieben wurden.

1. INTRODUCTION

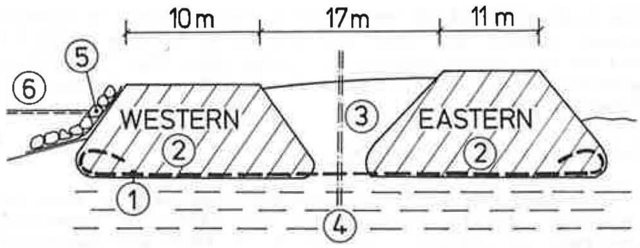
In the harbour of Turku a shoreline embankment has been built using a composite structure of two parallel floating embankments. Each of the bordering embankments is strengthened by a reinforcing mat of woven geotextile to improve the stability of the embankments. For practical assembly reasons the reinforcing mat has been spread across the total cross section of the composite final embankment, see Fig. 1.

The first stage, the construction of a 200 metres long double embankment, was completed in September 1984. In the spring of 1985 a further 200 metres extension was built. Within 5 to 10 years a harbour service road will be completed, running the length of the eastern embankment. The work will be continued by degrees to make up a total length of 1000 m. With every successive extension of the bordering embankments the area between them is being filled with miscellaneous fill.

2. INVESTIGATIONS AND SOIL CONDITIONS

On the site, Swedish Weight Soundings (WST), field vane testing and sampling were carried out. Consolidation properties (oedometer), natural water content, strength parameters and the plasticity characteristics of the samples were determined at the laboratory.

The sea bottom on the site lies at a depth of 0.5...1.5 metres below normal sea level. Post-glacial and glacial clay deposits at the site extend to a depth of 25 metres i.e. to the upper surface of the glacial till covering the precambrian bedrock. The clay deposit consists of two different layers whose soil properties are as follows.



1 REINFORCING GEOTEXTILE
2 BORDERING EMBANKMENTS
3 MISCELLANEOUS FILL
4 SOFT CLAY TO ELEVATION -25 METRES
5 EROSION PROTECTION
6 LEISURE BOAT CHANNEL, DEPTH 2.5 METRES

Figure 1 Cross section of the embankment structures

From -0.5 to -10.0 postglacial and glacial, topmost organic clay, where

- water content $W = 100...120$ %
- unit weight $\gamma = 15$ kN/m^3

- vane shear strength $c_u = 5...10$ kN/m²
- effective cohesion $c' = 2$ kN/m²
- effective angle of internal friction $\varphi' = 12°$
- liquid limit $W_L = 75...80$ %
- plastic limit $W_P = 25...30$ %
- plasticity index $I_P = 50$ %
- liquidity index $I_L = 1.3...1.7$
- modulus number $m = 6.5$
- settlement exponent $\beta = -0.4$

and from -10.0 to -25.0 glacial clay, where

- water content $W = 50...75$ %
- unit weight $\gamma = 16$ kN/m³
- vane shear strength $c_u = 15...25$ kN/m²
- effective cohesion $c' = 1.5$ kN/m²
- effective angle of internal friction $\varphi' = 13°$
- liquid limit $W_L = 85...90$ %
- plastic limit $W_P = 30$ %
- plasticity index $I_P = 55...60$ %
- liquidity index $I_L = 0.9...1.2$
- modulus number $m = 8.4$
- settlement exponent $\beta = 0.27$

3. EMBANKMENT MATERIALS

3.1 Bulk material of embankments

The bulk material of the bordering embankments is crushed stone, gravel and sand and the area between them is filled with miscellaneous fill materials. The reinforcing geotextile mat is covered with a 0.3 metre protective layer of sand.

3.2 Reinforcing geotextile

The reinforcing fabric chosen was supposed to have an ultimate tensile strength of 150 kN/m. In stability analysis an allowable stress of 70 kN/m was permitted corresponding to a strain of $\varepsilon = 7$ %. The material dimensions delivered for the purpose were: B = 4.5 metres and L = 110 metres.
In this first stage the used fabric was tested only after the embankment was already under construction. The tests were carried out by the Technical Research Centre of Finland. The tests were carried out using strips measuring 50 mm wide and 200 mm long. The test results for the fabric used in the construction of the first embankment (1984) are given in table 1.

Table 1 Geotextile testing data (1984)

Sample n:o	Ultimate tensile strength max(kN/m)	Strain at failure α_f %	Stress at a strain of 7 % α(kN/m)
3011	154.7±9.7	37.8±1.7	54.3±2.7
3012	141.2±14.5	40.6±1.1	48.7±3.2
3013	124.0±4.8	34.1±1.4	51.4±2.2

The test results were unsatisfactory in terms of the achieved stress at a strain of 7 %, with only $\alpha_7 = 50$ kN/m² instead of the value $\alpha_7 = 70$ kN/m², which had been required in the stability analysis of the embankment. Therefore a new analysis and adjustments in the working sequence were necessary.

The geotextile material delivered for the next extension phase (1985) was thoroughly tested before use. A considerable improvement in the quality of the fabric could be noted in the testing data, Table 2. This time the essential stress values α_7 complied satisfactorily with the requirements.

Table 2 Geotextile testing data (1985)

Sample n:o	Tensile strength max (kN/m)	Strain at failure α_f %	Stress at a strain of 7 % α (kN/m)
3328	159.0±16.5	16.7±1.7	74.5±5.0
3329	157.0±12.6	17.8±1.3	71.2±3.1
3330	153.0±10.6	16.9±1.8	71.2±3.3

$$F = \frac{\Sigma M_P + r\alpha_\varepsilon}{\Sigma M_A}$$

α_ε = stress at strain of ε %

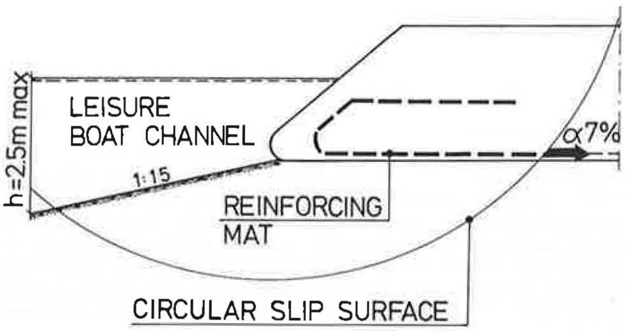


Figure 2 Stability analysis scheme of the embankment

4. STABILITY AND SETTLEMENTS

The stability of the embankments has been calculated using cφ-method based on a circular failure surface, Fig.2. It has been assumed that the additional load caused by every successive layer of embankment fill will initiate an increase in pore water pressure in the clay to an amount equal to the weight of the fill. The maximum allowable pore water pressure at every stage of the work has been limited to 20 kN/m² which was calculated to be a precondition for a required value of the factor of safety F = 1.3. In the analysis, the improvement of the stability caused by the geotextile mat was considered assuming, that the fabric is able to carry a horizontal tension of $\alpha_7 = 70$ kN/m (Fig.3).

The total settlement in the long-term has been calculated to be of the order of 3.0 metres after a consolidation period of hundreds of years. According to the oedometer test data obtained, the settlement of the embankment will reach a value of ca. 0.8 metre in the first ten years (Fig.4).

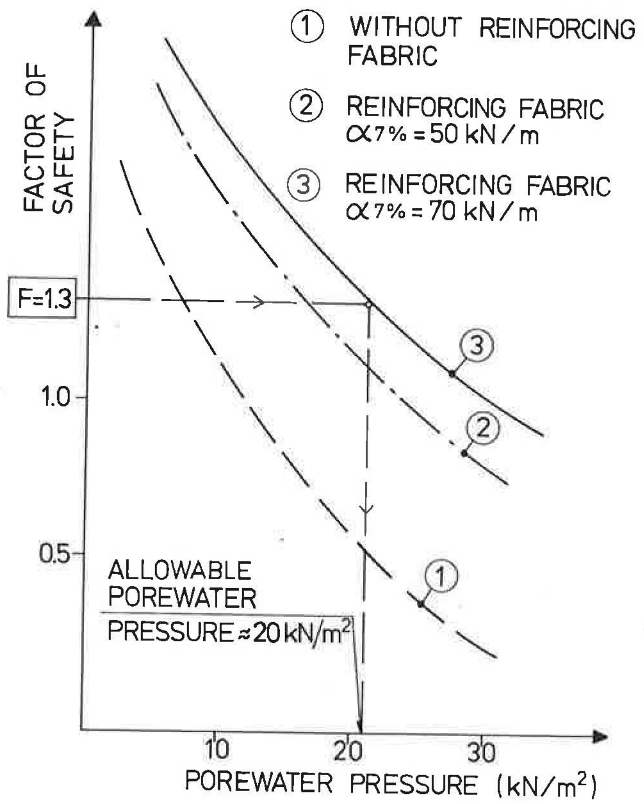


Figure 3 Correlation pore water pressure vs. factor of safety. Effect of the reinforcing geotextile mat on the factor of safety.

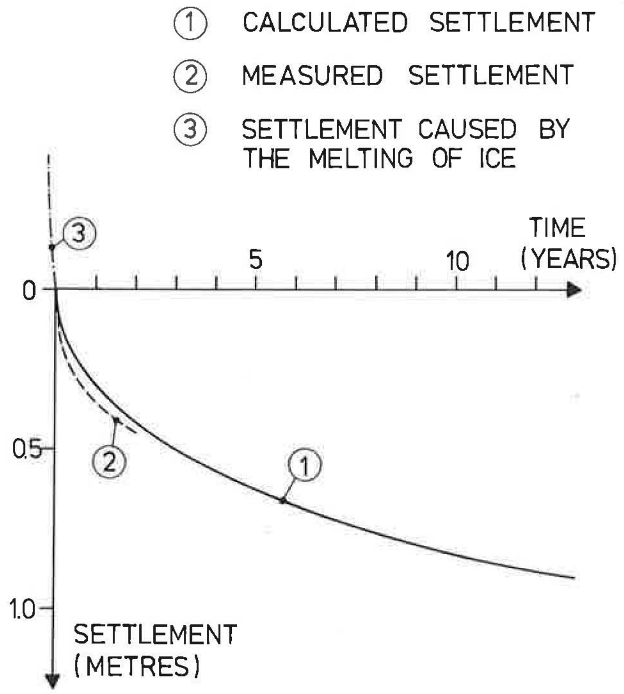


Figure 4 The estimated and measured settlements of the embankment

5. CONSTRUCTION SEQUENCE

The strips of reinforcing fabric were spread out across the embankment area in the winter time on top of the ice, stitched together and then covered with a protective layer of sand (Fig.5 and 6). In the spring, after the thaw, when the fabric with its cover of sand had sunk down to the sea bed, the successive structural layers of embankment bulk material were built up in due course (Fig.7).

Figure 5 Spreading out of the geotextile on ice

Figure 6 Laying of a protective layer of sand to cover the geotextile

The development of the pore water pressure is controlled throughout the procedure by a system of piezometers and the rate of settlement monitored with settlement gauges to control and verify the soil parameters used in the calculations. A possible reduction in the parameters will be considered in the completion of the planning and construction of the embankment.

Figure 7 Summer 1984. Ice cap melted. Bordering embankments filled in.

6. CONCLUSIONS

Until the date of this paper a 400 metres length of the embankment has been completed without any hazardous signs of lateral displacement or collapse. The continuous slow settlement of the structure requires, from time to time, an additional layer of fill to be spread on top of the existing embankment to maintain the required elevation of the crest in comparison to the sea level. Therefore, a continuous monitoring in the form of piezometric follow up of the pore water pressure in the clay strata, a levelling procedure of the settling embankment as well as keen observations as to any phenomena showing signs of an impending danger of collapse are needed during the years to come.