Performance of Two Experimental Full-Scale Embankments Reinforced with Geotextiles

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ABSTRACT : Two experimental reinforced embankments were built up with clayed silt at the Swiss Federal Institute of Technology in Lausanne. These two identical full scale structures had the same dimensions (3.60 m height, 5x5 m base). They were reinforced using two types of geotextile : the first a non-woven type with weak mechanical properties, and the second one a stiffer woven geotextile. A complete instrumental program was set up to record the behaviour of the two embankments. A program including static and cyclic loading was performed.

In this paper we compare some of the significant results of these two full-scale tests. We show the influence of the textiles' rigidity on the settlement at the embankment surface and the strain of the geotextile layers.

1 INTRODUCTION

In order to develop designing and building methods of soil structures reinforced by geotextiles, taking strains into account, experimental studies realised in controlled conditions and close to reality are essential.

During the last decade, results of several full-scale tests have been published. However, in most cases, the soils used were granular with good mechanical properties. In fact, from the economical point of view, reinforcing with geotextiles is most suitable using fine-grained soils with weak mechanical properties.

For some years, the Soil Mechanics Laboratory of the Swiss Federal Institute of Technology (Switzerland) has carried out some experimental research: Bourdeau and al (1991), Kharchafi and Dysli (1993 and 1994), to study the behaviour of steep slopes reinforced by geotextiles and using fine-grained soils, under static and cyclic loading.

This paper describes two experimental full-scale embankments built up indoors in very similar conditions, each of them reinforced by 6 layers of different types of geotextile .

2 DESCRIPTION OF THE TESTS

2.1 The full-scale structures

The two experimental embankments had the same shapes and dimensions (fig. 1a). They were composed of 6 layers of soil about 60 cm thick, each reinforced by geotextile; i.e 3.60 m total height. The bases of the structures were squares 5x5 m and their faces 75° sloped.

The loading was applied by a plate (1.50 m x 4.80 m), arranged concurrently to the face and 0.5 m from it.

2.2 Properties of the materials

For the two embankments, a compacted clayed silt with 19% water content close to its plastic limit was used. Its mechanical properties, which were determined on samples taken at the end of the full-scale tests, are: unit weight $\gamma = 17.5\ \mathrm{kN{\cdot}m^{-3}}$, effective angle of friction $\Phi' = 30°$, cohesion $c' \approx 15$ kPa and initial oedometric modulus Eoed ≈ 1600 kPa.

The first structure (test NW-1) was reinforced by a non-woven geotextile and the second one (test W 2) by a woven geotextile with (Fig. 1b) about ten times higher mechanical properties (secant modulus and tensile failure).

2.3 Instrumentation

The behaviour of the two soil bodies was studied by means of thorough instrumentation which can be summarised as follow:

(1) outside measurements: the applied force by the jack, the vertical displacements at several points of the loading plate, vertical and horizontal displacements of the two embankment faces were measured.

(2) soil measurements: 13 earth-pressure cells GLOTZL and two columns of strain magnetic gauges BISON were located in the soil.

(3) measurements in the geotextile layers: twenty strain gauges were used to measure the strains of the 5 upper layers of geotextile. The displacements of several points of the fabric were recorded with a system of Kevlar wires connected to a displacement transducer in the rear of the structure.

Most of the measurements were automatically recorded at regular time intervals.

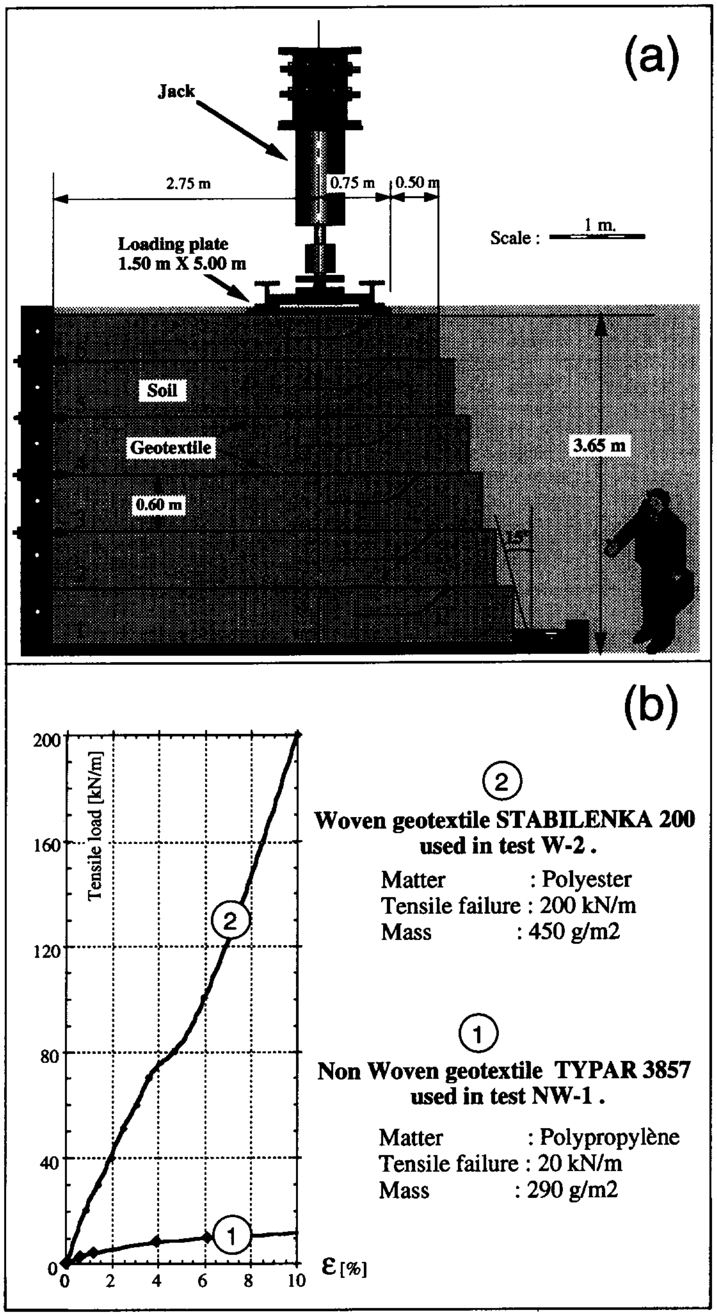

Fig 1. (a) Cross section of the two full-scale embankments, (b) Main properties of the geotextiles used.

2.4 Loading program

The same loading program (fig. 2), about 3 months long, was applied to each of the structures in 4 stages: (1) a static loading up to 380 kN (≈ 50 kPa) by 20 kN daily steps, (2) a complete unloading in three days, (3) 60'000 cycles at 0.2 Hz frequency with 300 kN of amplitude, (4) finally static loading similar to (1) up to a force of 1300 kN, i.e. a vertical stress under the loading plate about 180 kPa.

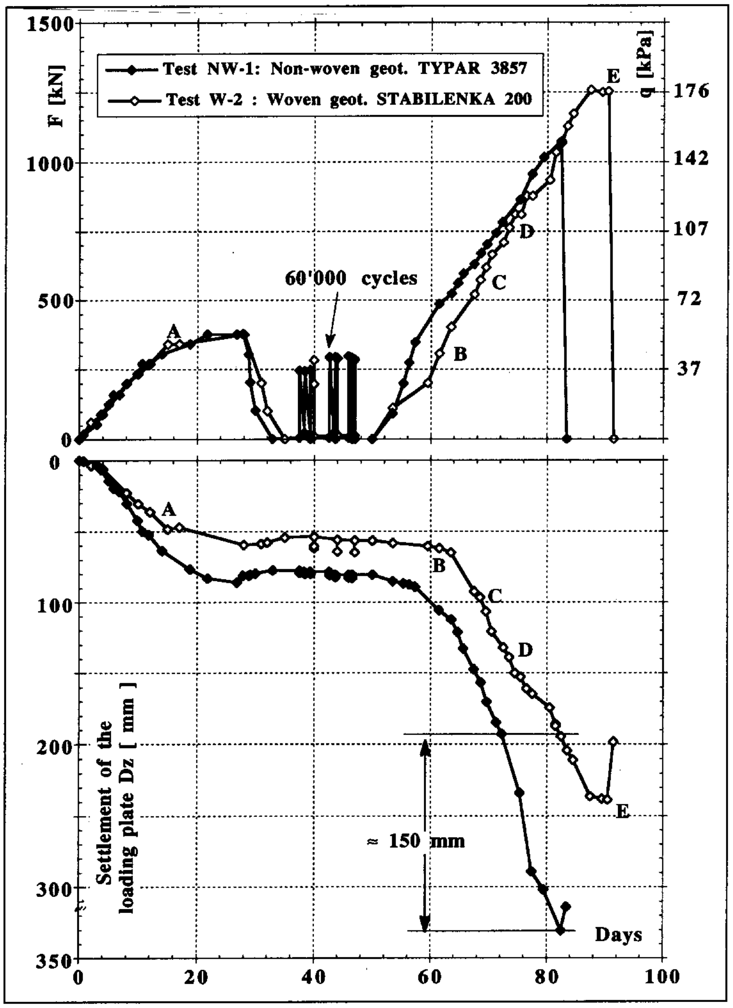

Fig 2. (a) Loading program applied to the two embankments and (b) settlement of the loading plates.

3.1 Settlements during the static loading

Reinforcing by the non-woven geotextile (test W-2) showed a clear improvement in the loading plate settlement (fig. 2b) in comparison to test NW-1 using the non-woven geotextile. The difference was 25 mm at the end of the first loading stage (point A, fig. 3) and about 150 mm at the end of the test (F≈1100 kN), i.e. 50% of gain in settlement with the woven geotextile.

In the second loading stage (B to E, fig 2), the loading plate continued to have a linear settlement for test W-2 until the end (point E, F=1300 kN), when the test NW-1 began to settle excessively and showed a large fissure at the embankment surface. It was concurrently and about

1 m from the loading plate. In the two cases (tests NW-1 and W-2), none of the geotextile layers broke.

3.2 Settlements during the cyclic loading

After the first static loading, the embankments were subjected to 60'000 loading cycles at 0.2 Hz frequency with an approximative 300 kN ($q \approx 42$ kPa) amplitude (fig. 3a).

The response of the first test during these cycles is shown in figure 3b. One can observe that the vertical displacement Dz during one cycle is very low (≈2 mm). This corresponds to a linear elastic strain of the reinforced soil.

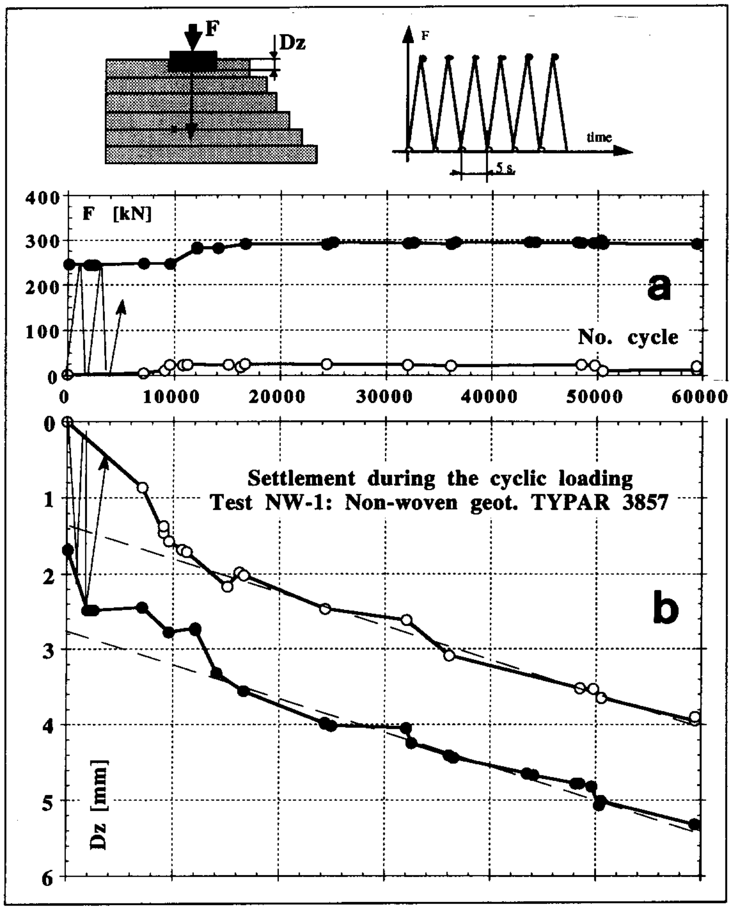

Fig 3. Response of the first test NW-1 during the cyclic loading.

At the end of the 60'000 cycles, we recorded 4 mm of irreversible settlement. About the half (≈2mm) was caused by the 16'000 first cycles and the other half by the 48'000 following cycles.

The strains for the second test W-2 were approximately the same during the cyclic loading. This proves that in the case of fast solicitations, it is the soil which supports the stress and determines the strains whatever of the type of geotextile used.

3.3 Displacements in the geotextile layers

The following figures show the displacements recorded in the 3 upper geotextile layers during the static loading. These values, measured using the Kevlar wires fixed in several points of reinforcement, are named Ux and refer to horizontal displacements of geotextile in spite of the fact that they comprise a part due to soil settlement. Ux allows us to estimate correctly the geotextile elongations between 2 successive measurement points.

3.3.1 Test NW-1:

Figure 4 shows the displacements in the 3 upper non-woven geotextile layers at 3 loading stages: q=25, 40 and 55 kPa. It may be observed that the maximum value is reached in the 5th layer. The displacements of the 6th layer are partially locked by the loading plate. A large variation of Ux behind a loading application point ($-0.75 \text{ m} < x < 0$) is also noted. The greatest strains of geotextile, and thus the greatest tensions, are situated in this zone. The measurements carried out by strain gauges confirmed these results.

The length at which the geotextile is stretched ($Ux \neq 0$) seems constant during all the loading stages and as large as the geotextile layer is higher: about 4 m for the 6th layer ($-3 \leq x \leq 1.25$ m), 2.20 m for the 5th ($-0.8 \leq x \leq 1.4$ m) and 2.20 m for the 4th.

3.3.2 Test W-2:

The displacements in the 3 upper woven geotextile layers are shown in figure 5 for 3 loading stages (A, C, E fig. 2a).

In this second test, the greatest displacements were reached in the 6th woven geotextile layer, nearest to the loading plate.

At every loading stages, one can observe that the curves Ux=f(x) of the 6th reinforcement layer are composed of two line segments. Since the slopes of these curves represent the geotextile strains ($\varepsilon_{geo} = dUx/dx$), it may be stated that for this 6th layer there are 2 zones of constant strains: the first situated below the loading plate ($-0.8 < x < 0.8$m) with high values, the second situated behind the loading plate ($-2 < x < -0.8$m) with lower strains, indeed zero strain during the first loading stages (points A and C). The strains of the geotextiles layers below the loading plate corresponding to these displacement values are about 0.5% at q=108.5 kPa (stage D) and 1.8% at q=176.6 kPa (stage E).

The maximum slope of the figure 5 curves corresponding to the greatest geotextile strain is situated below the loading plate ($-0.25 < x < 0.25$m). In the face side ($x > 0.25$), one can observe a negative slope corresponding to a low shortening of the geotextile due to a horizontal compression of the soil situated between the loading plate and the embankment face.

4 CONCLUSION

From this comparative study of two full-scale monitored embankments which were built up in the same conditions, with the same soil and reinforced by two very different geotextiles, we can draw the following conclusions:

- The efficiency of reinforcement by geotextile is proved. Even with a fine-grained soil, the embankment reinforced by the non-woven geotextile bore, without failure, twice the load provided by the limit-equilibrium methods. The geotextile strains did not exceed 10%, when its limit strain is greater than 20%.

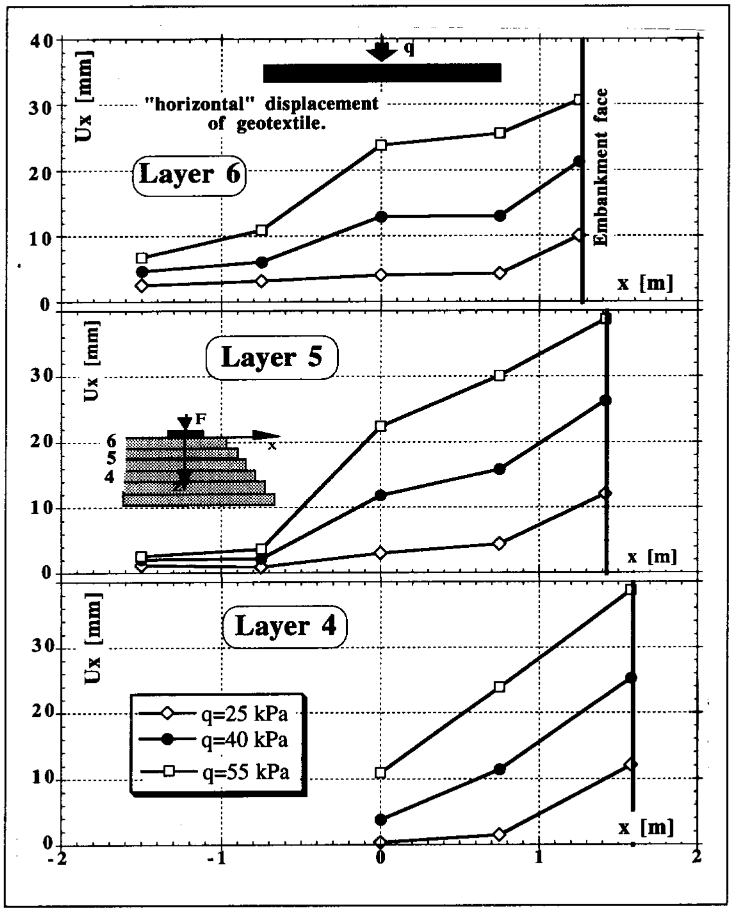

Fig 4. Displacements in the geotextile layers. Test NW-1.

- With the geotextile ten times stiffer (test W-2), the improvement of the loading plate settlement was about 50% in our test and loading conditions.
- The strains of both reinforced embankments during the cyclic loading remained very low independently of the stifness of the geotextile used.
- The displacements in the geotextile layers (fig.4 and 5) show that the non-woven geotextile was deformed in a very restricted zone situated between the loading plate and the embankment face (-1 < x < 1.5 m). On the other hand, the woven geotextile had very low strains but it moved over a larger zone (-3 < x < 1.5 m).

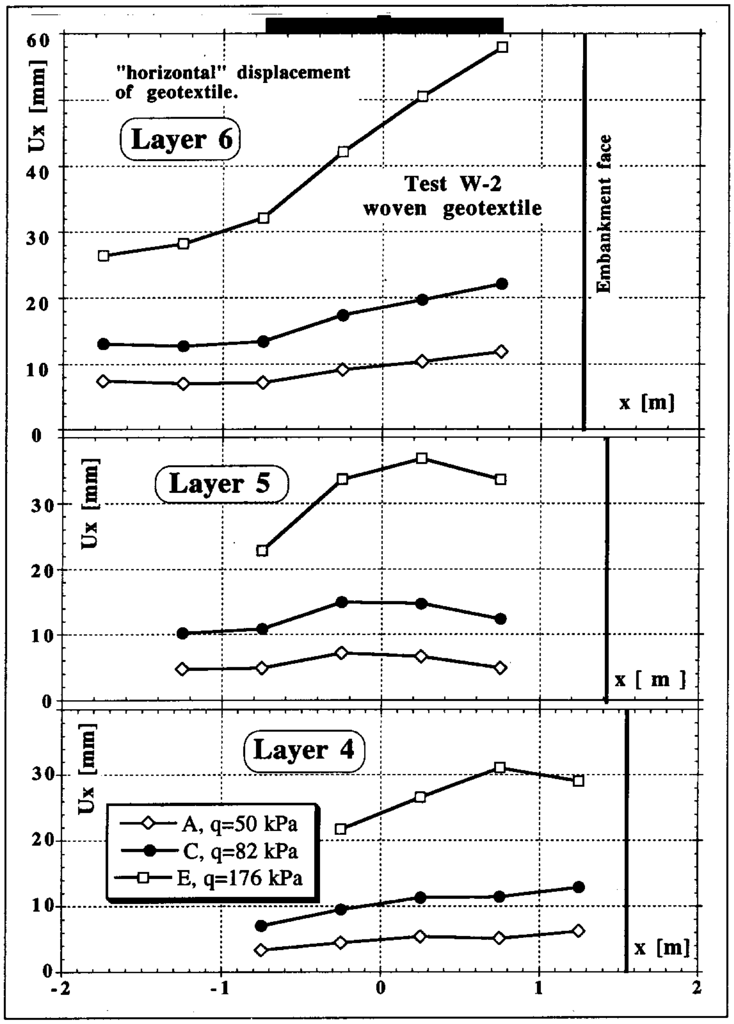

Fig 5. Displacements in the geotextile layers. Test W-2.

ACKNOWLEDGEMENTS

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