LONG TERM BEHAVIOUR OF REINFORCED WALLS: MODEL RESULTS

Gottardi Guido[1] *and Simonini Paolo*[2]

[1] D.I.S.T.A.R.T.-University of Bologna, Viale Risorgimento 2-40136 Bologna, Italy
[2] D.I.MA.GE., University of Padova, Via Ognissanti 39-35129, Padova-Italy

ABSTRACT: Small scale *1g* physical models of geosynthetics-reinforced structures - despite limitations due to their different operational stress levels - can still represent a valuable tool for the analysis of their actual behaviour, where the soil-reinforcement interaction plays a fundamental role. A new experimental research on reinforced retaining walls has been recently undertaken at the Soil Mechanics Laboratory of the University of Padova (Italy), with the main aim of investigating the long term behaviour of such soil structures, where creep phenomena - especially of polymers used as reinforcements - cannot be neglected. The paper, besides a presentation of the experimental equipment and testing procedure, shows preliminary test results in which three different types of geosynthetics were used.

1. INTRODUCTION

Reduced scale physical models represent a useful mean to analyse the behaviour of earth-reinforced structures where the interaction between soil and reinforcing elements plays a fundamental role. The experimental observations from small scale model tests may lead to the formulation of basic ideas from which rational design approaches can be developed.

Comparing centrifuge and one-gravity testing, the traditional 1g-models offer some advantages, not least the very low cost of the equipment. On the other hand, 1g-models are strongly limited by the fact that some important similarity requirements are not satisfied. Therefore, the results of these model studies cannot be directly used to provide a reliable data-base for designing the actual reinforced structures. Nevertheless, the small scale physical models still represent a very attractive way of studying the deformation mechanisms of reinforced soil walls.

Several examples of experimental investigations carried out using small scale 1g-models can be found. An exhaustive review of the researches in the Seventies was given by Schlosser and Juran (1983). All described models reproduced the behaviour of walls reinforced with metallic strips connected to rigid elliptic, circular or straight facings. The results of those tests provided a rational basis for most design methods.

The recent introduction of new suitable reinforcing elements such as geosynthetics required new experimental work. Several industrial products - geotextiles and geogrids - made of different polymers (polyester, polypropylene, polyethylene) have been produced since 1970. However, laboratory model studies on the behaviour of geosynthetics-reinforced walls have been relatively limited. Experiments have been carried out by Juran & Christopher (1989), Tatsuoka et al. (1989), Gourc et al. (1990), Palmeira & Lanz (1994), Gomes et al. (1994) and Wong et al. (1994). Most models reproduced plain-strain walls made of alternating layers of sand and woven or non-woven geotextiles or geogrids, connected to facing elements of various shapes and rigidities.

One of the most interesting aspects, recently considered by some researchers (Helwany & Wu, 1995; Karpurapu & Bathurst, 1995), concerns the study of the wall long-term behaviour. In fact, it is recognised that geosynthetic materials show time-dependent behaviour, which is influenced by many factors, the most important being the type of polymer, the structure of geosynthetic, the stress level, the temperature (e.g. Allen, 1991) and the confinements given by the surrounding soil (e.g. Mc Gown et al. 1995). The delayed deformation is particularly important when the material forming the reinforcement is polypropylene or polyethylene, which are often used to produce various types of geotextiles and geogrids.

Following an established tradition on the small scale physical modelling of boundary value problems in geotechnical engineering, a new experimental research has been recently undertaken at the University of Padova (Italy), concerning the behaviour of walls reinforced with several types of geosynthetics such as non-woven polypropylene geotextiles, woven polyethylene geotextiles and geogrids. Due to the characteristics of the geosynthetics used as reinforcements, the experimental study is aimed at the investigation of the time influence on the long-term behaviour of the reinforced structure. The paper describes the model set up and presents some interesting preliminary results.

2. THE EXPERIMENTAL SETUP AT THE UNIVERSITY OF PADOVA

The experimental apparatus used for the present research has been developed and built up at the Soil Mechanics Laboratory of the University of Padova. The physical model (1200 mm long, 400 mm wide and 600 mm high) intends to reproduce a plain strain state within the reinforced soil mass and was designed by taking into account the following main requirements:

- the sand beds must be very homogeneous and highly reproducible;
- geosynthetics positioning needs to be performed without any disturbance to the sand layers;
- the deformation mode and the possible failure mechanism should be visible and kept under control;
- the loading device must enable either load or displacement-controlled tests.

Figure 1 shows a general view of the small scale model, where the main components - lateral walls, facing elements, reinforced soil and loading plate - can be observed.

The retaining wall is made up of a set of rigid aluminium strips, hinged each other and kept vertically only by the interposition of the geosynthetic layers. The geosynthetic sheets (1200 mm long and 400 mm wide) are locked into the facing strips and spaced 70 mm. The walls is constructed from the bottom to the top by anchoring the metallic strips to a provisional vertical track, which is removed after the wall construction is completed. The sand layers are prepared by raining technique. All mechanisms for sand deposition are fully automatic and allow for the achievement of homogeneous and highly reproducible layers, the standard deviation of relative density (I_D=85%) of the layers being less than 1%.

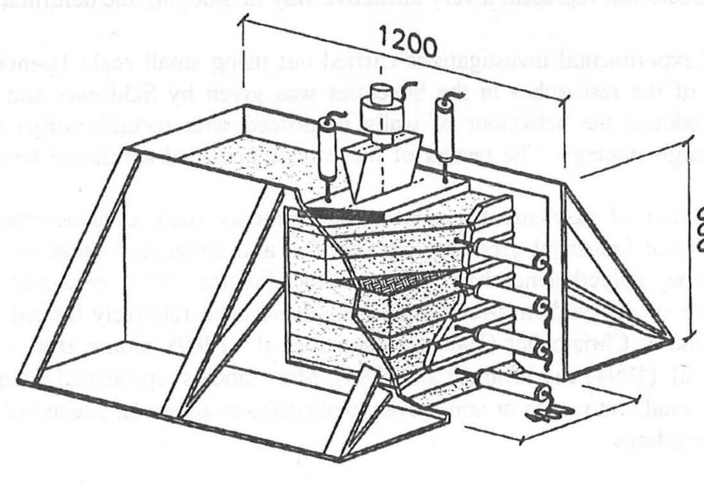

Figure 1. View of the small scale physical model at the University of Padova (dimensions in mm).

The material used for pluvial deposition is a medium-fine quartz sand coming from the mouth of the Adige river, whose characteristics are: mean particle size D_{50}=0.42; uniformity coefficient C_u=2.0; specific gravity G_s=2.71, minimum and maximum dry unit weight 13.6 e 16.5 kN/m^3. The angle of shear strength, measured from triaxial compression tests carried out with the same relative density, is in the range between 41° and 43° under confining stresses from 100 to 400 kPa.

As reinforcing materials a non-woven spunbonded geotextile, a woven geotextile and a biaxial geogrid have been selected. Their main characteristics are summarised in Table 1.

Table 1. Characteristics of the geosynthetic reinforcements.

	Non-woven	Woven	Grid
Type of polymer	Polypropylene	Polyethylene	Polyethylene
Mass per unit area (g/m^2)	110	100	230
Opening size (mm)	0.21	0.69	long. 34; trans. 37
Tensile strength (kN/m)	5.0	26.0	long. 15; trans. 30
Elongation at maximum strength (%)	40	30	17

The soil-reinforcements retaining wall system is loaded, through a rigid steel plate (200 mm x 400 mm) resting on the sand surface, by an electrical stepper motor. Load path generation and data acquisition from all measurement devices are fully automatic via a personal computer and an A/D interface. The selected position of the displacement transducers allows for the continuous monitoring of the lateral displacements of the wall and the vertical settlement and rotation of the plate. A schematic view of the test lay-out is given in Figure 2.

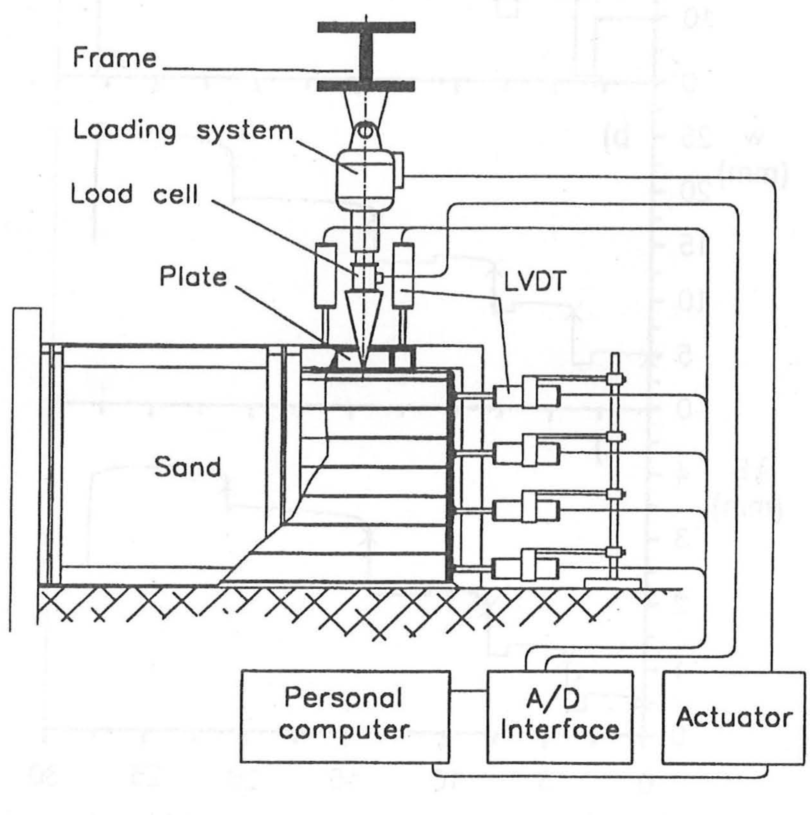

Figure 2. Test lay out.

3. EXPERIMENTAL PROGRAMME AND PRELIMINARY RESULTS

Results of the preliminary experimental programme carried out so far are presented in this section. Three tests (labelled T1, T2 and T3) were completed, all with the same load-path but using the three different geosynthetics of Table 1. Data from test T2 (woven geotextile) are first shown, whereas only a general comparison is eventually provided. Detailed results can be found in Simonini & Gottardi (1997).

Figure 3 provides essential information on the applied load Q and the relevant plate displacements versus time t. The load was increased - at constant displacement rate - up to the apparatus limit (50 kN), via successive 10 kN increments (Figure 3a). At each level the load was kept constant for a comparatively long time period (3-5 days) and then decreased of 10 kN, back to the starting value of each load step. There, the load was kept constant for a shorter time (1-3 days). Figure 3b shows the consequent vertical displacement of the plate centre-line w. X-labelled points represent the starting value of the constant-load stage: most of the vertical movement is developed in the first part, and tends rapidly to decrease with time. When the applied load is partially removed, an immediate elastic recovery is observed; however at the subsequent constant-load stage a practically negligible upwards movement is recorded.

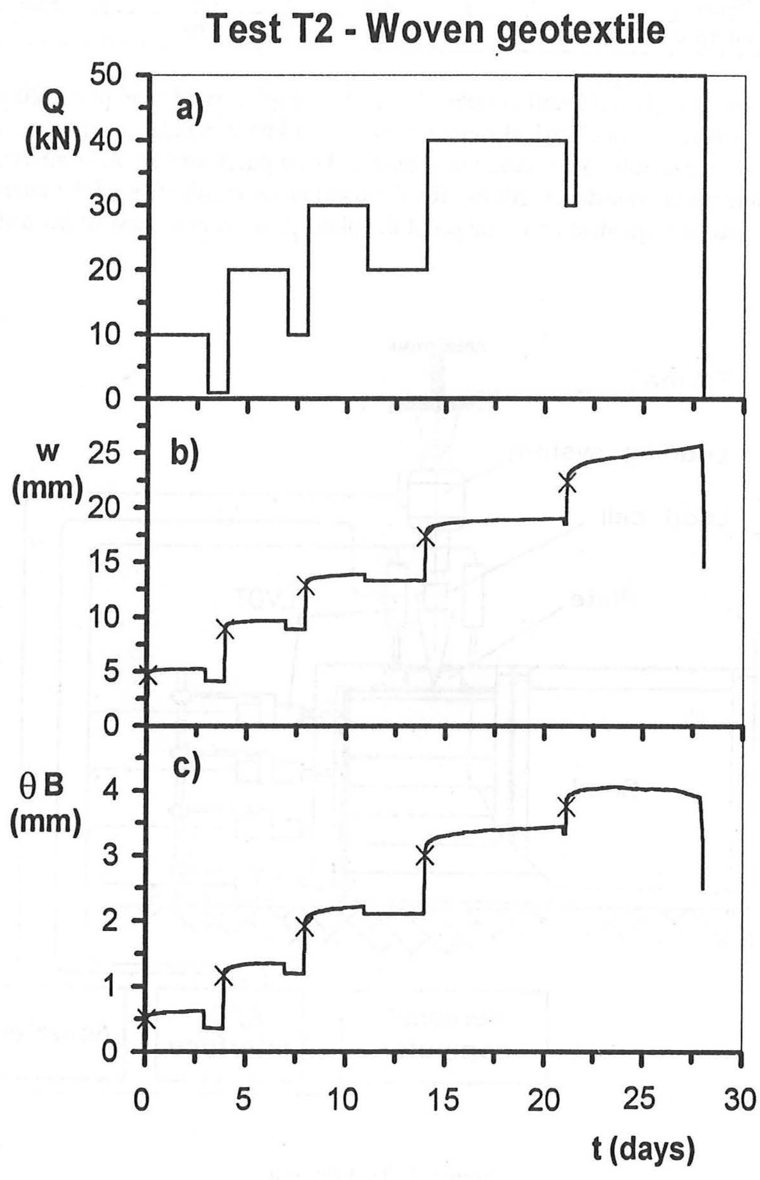

Figure 3 a,b,c. Applied load path and related plate displacements.

Total plate rotation θ (positive if clockwise), multiplied by its breadth B for dimensional homogeneity, is reported in Figure 3c: rotations trend is similar to the vertical displacements up to the maximum applied load. However, during the 50 kN constant load stage, tendency towards rotation inversion seems to be a clear evidence of a triggered failure mechanism within the reinforced soil mass. The load-displacement curve of test T2 is compared with the other tests at the end of the present section (Figure 7).

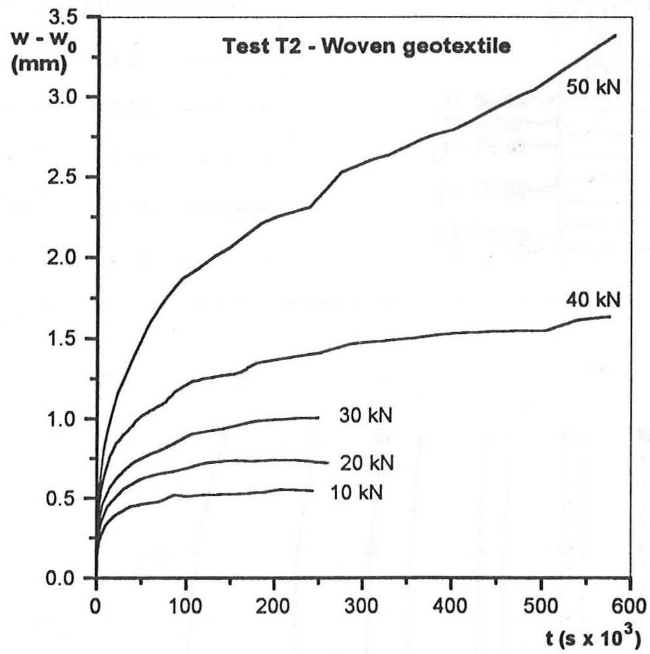

Figure 4. Vertical displacement vs. time at constant load.

The settlement-time behaviour for the 5 constant load stages (Q = 10-20-30-40-50 kN) is shown in Figure 4; w_0 represents the total displacement measured at the end of each loading stage. As expected, for a specific time (e.g. t = 72 h $\cong 259{\cdot}10^3$ s), the measured displacement (w-w_0) shows a non-linear increase with the applied stress level. Furthermore, at the highest stress level, the displacement trend, instead of declining like all the other curves, tends to indefinitely increase. Such characteristic behaviour is known as "tertiary creep" and, at long term, could lead the wall to failure at constant load.

A clear picture of the wall behaviour at the different load levels is provided in Figure 5, where measurements from all horizontal transducers (see the sketch on the top left corner) are summarised. Dashed lines represent the reinforcements position. Figure 5 shows the deformed configuration at the beginning and the end of each constant-load stage, reflecting the stress distribution applied through the top loading plate. Higher displacements - up to 25 mm - are in fact measured by transducers u_4 and u_5, whereas the lowest metal strip, laid on the first sand layer, hardly moves.

Finally Figure 6 shows the initial and deformed (at 50 kN) configuration of the reinforced soil mass behind the wall, as deduced from the movements of a coloured sand square grid inserted during the sample preparation (horizontal lines correspond to reinforcements). All reinforcements, but the shallowest, were long enough to be certainly prevented from pull-out.

A general comparison of the load-displacement curves of the footing plate for all the three tests carried out is provided in Figure 7. The different behaviour between constant rate and constant load stages is apparent. During the first loading step, the initial low tangent is due to the not perfect soil-plate contact, i.e. to a sort of bedding error. The relative importance of the different geosynthetics used with respect to the overall stiffness and strength is clearly recognisable: the non-woven geotextile is less rigid and, already after 30 kN, the rupture of the second layer from the top induced a failure mechanism on the whole soil mass. Continuous deformations with time are not negligible for all tested materials, especially for the geogrid in polyethylene, whose performance was however very good due to its better stiffness and strength characteristics. Elastic unloading-reloading stiffness surprisingly tends to increase with the stress level, in particular when far from failure.

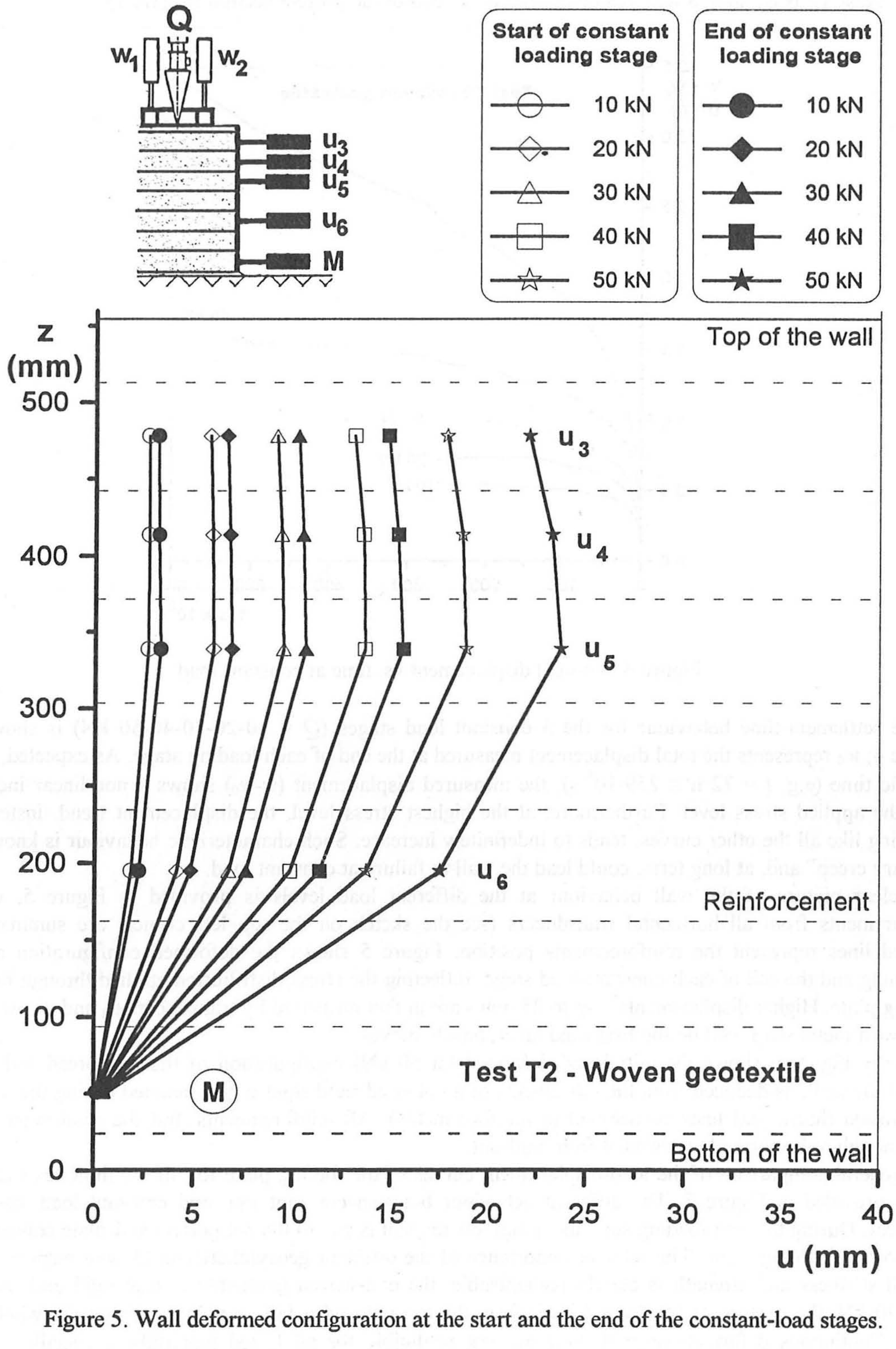

Figure 5. Wall deformed configuration at the start and the end of the constant-load stages.

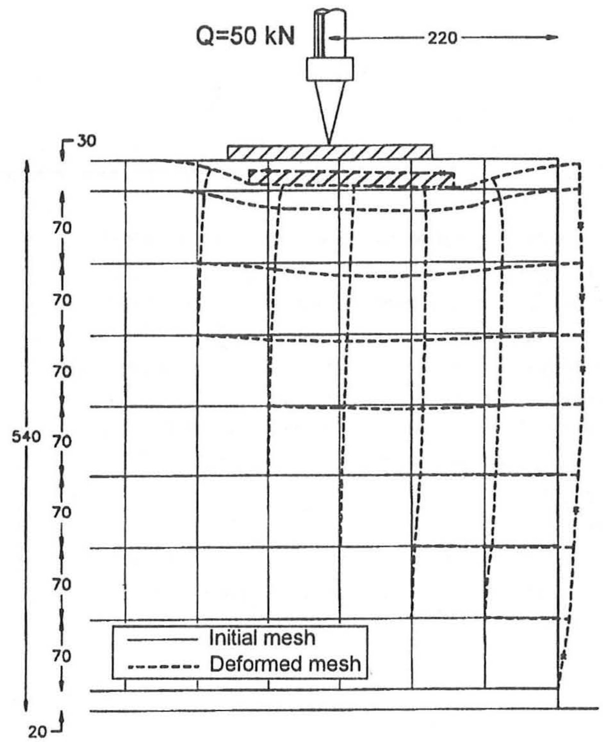

Figure 6. Deformed mesh at Q=50 kN (dimensions in mm).

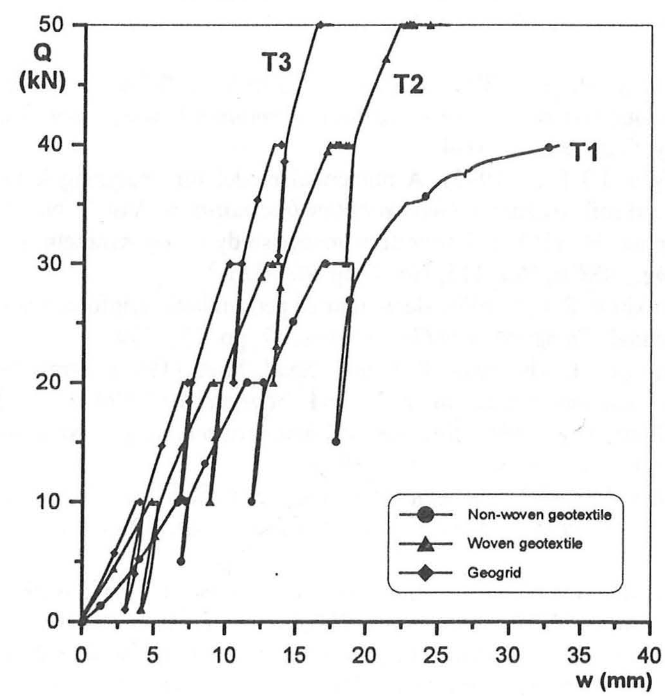

Figure 7. Load-displacement curves for all the three tests.

4. CONCLUSIONS

Preliminary results from model tests of a geosynthetic-reinforced wall have been presented and discussed. The experimental set-up has proved to provide very accurate and reliable data. The fully automatic data acquisition and control enables to carry out long-term tests, as required in order to investigate the response of reinforced walls, where creep phenomena are quite relevant and strongly affected by the soil-reinforcement interaction.

From the experimental results the following conclusions can be drawn:

- the wall behaviour is clearly influenced by the physical and mechanical characteristics of the geosynthetic used as reinforcing element. In particular the non-woven reinforced wall developed a failure mechanism characterised by large deformations, whereas the geogrid performed better, supporting the maximum allowable load without any sign of incipient collapse.
- the delayed displacements rate of the wall during the constant-load stages has shown a non-linear increase with the stress level induced in the soil mass. In addition, at the highest load levels, a "tertiary creep" failure can develop in the soil, strictly depending on the characteristics of the geosynthetic;
- no relaxation (i.e. displacement recovery) of the reinforced soil was noted during each unloading stage and for all the three tests.
- finally, the considerable displacement rate measured during the very first part of the constant-load stages underlines the importance of the applied loading rate in order to separate the relevant displacement components.

REFERENCES

1. Allen, T.M., (1991). Determination of long-term tensile strength of geosynthetics: A state of the art review. *Proc. of Geosynthetics '91 Conference*, Atlanta, USA, pp. 351-379.
2. Gomes, R.C., Palmeira, E.M. & Lanz, D., (1994). Failure and deformation mechanisms in model reinforced walls subjected to different loading conditions. *Geosynthetics International*, Vol. 1. No. 1, pp. 45-65.
3. Gourc, J.P., Gotteland, P. & Wilson-Jones, H., (1990). Cellular retaining walls renforced by geosynthetics: behaviour and design. *Proc. of the International Reinforced Soil Conference*, British Geotechnical Society, Glasgow, pp. 41-45.
4. Helwany, M.B. & Wu, J.T.H., (1995). A numerical model for analyzing long-term performance of geosynthetic-reinforced soil structures. *Geosynthetics International,* Vol. 2, No. 2, pp. 429-453.
5. Juran, I. & Christopher, B., (1989). Laboratory model study on geosynthetic reinforced soil retaining walls. *J. of Geot. Eng.*, ASCE, Vol. 115, No. 7, pp. 905-926.
6. Karpurapu, R. & Bathurst, R.J., (1995). Behaviour of geosynthetic reinforced soil retaining walls using the finite element method. *Computer and Geotechnics*, 17, pp. 279-299.
7. Mc Gown, A., Yogarajah, I, Andrawes, K.Z. and Saad, M.A. (1995). Strain behaviour of polymeric geogrids subjected to sustained loading in air and soil. *Geosynt. Int.l*, Vol. 2, No. 1, pp. 341-355.
8. Palmeira, E.M. & Lanz, D., (1994). Stresses and deformations in geotextile reinforced model walls. *Geotextiles and Geomembranes*, Vol. 13, pp. 331-348.
9. Schlosser, F. & Juran, I., (1983). Behaviour of reinforced earth retaining walls from model studies. *Development of Soil Mechanics: Model Studies*, Banerjee and Butterfield eds., Applied Sciences Publisher, London.
10. Simonini, P. & Gottardi, G. (1997). Un nuovo modello fisico per lo studio di muri in terra rinforzata con geosintetici. *IV National CNR Geotechnical Conference*, Perugia, in press.
11. Tatsuoka, F., Tateyama, M. & Murata, O., (1989). Earth retaining wall with a short geotextile and a rigid facing. *Proc. of the 12th Int. Conf. on Soil Mech. and Found. Eng.*, Vol. 2, pp. 1311-1314.
12. Wong, K.S., Broms, B.B. & Chandrasekaran, B., (1994). Failure modes at model tests of a geotextile reinforced wall. *Geotextiles and Geomembranes*, 13, 475-493.