Geosynthetics Limitations for Bearing Capacity Increase

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ABSTRACT: There are several ways of the geosynthetics functionality. Well-known mechanisms are functions of separating, filtrating, protecting and slope reinforcing. There are several publications describing the influence of geosynthetics on increasing the soft-soil bearing capacity. However, this geosynthetics functionality has not been explained satisfactorily in detail yet. The research presented here deals with clarifying the possible geosynthetics functionality. Six kinds of gesynthetics of world known producers were selected for the measurement. The measurement was carried out in the Geotechnical Laboratory Testing Field (GLTF), which is a facility constructed for full-scale geotechnical measurements. The results of static plate tests show that the contribution of the geosynthetics to the bearing capacity increase is very limited. A significant increase appears only in case of a very low bearing capacity subgrade covered by a 20cm thick subbase layer reinforced by some geosynthetics. After the static part of the experiment the GLTF was equipped with a cyclic loader to simulate real traffic loading and tests for the evaluation of possible bearing capacity increase due to geosynthetics usage were repeated.

KEY WORDS: Subgrade, pavement, geosynthetics, loading test, bearing capacity

1 INTRODUCTION

Although the reinforcing functionality of geosynthetics is described and used in connection with slopes reinforcement, there are many practical examples of geosynthetics usage as reinforcing element of pavement, subbase or subgrade layers. At the same time, this application is put to laboratory, full-scale or real construction tests. The results and outputs of the tests are very incomparable because of non-uniform test methodologies and some of them being purpose-built by geosynthetics producers. That could be the reason why the EU standards do not include this way of geosynthetics application, maybe.

Principles of the evaluation of the geosynthetics impact on bearing capacity are based either on static loading of reinforced layers (Blumme et al., 2001) expressed by the relation between loading and deformation (elastic modulus, deformation modulus or k-modulus, conversion to or from CBR), or on cyclic/dynamic loading done either by a circular plate (Perkins, 2002) or by repeated wheel running (Watn et al., 1996 and Jenner et al., 2002) evaluated by time-based deformation (number of loading cycles or wheel running vs. layer deformation). Based on the time-based deformation the back-calculation methods were formulated (e.g. van Niekerk and van Gurp, 2002).

It is essential for each experiment to take into account the following parameters: material properties (soil, aggregate, geosynthetics etc.), test condition (subsoil bearing capacity, layers compaction rate etc.), geometrical parameters (dimensions, model similarity) and test arrangement (speed, range and frequency of loading, shape of the loading wave, etc.).

Unfortunately, many published papers are missing the mentioned parameters. This is a very serious cause of incomparability of the published results. The tests are often based on "national" test methods and are valid only when using specific geosynthetics (e.g. Beckmann and Ruppert, 1994, Saathoff and Horstmann, 1999). There is a comprehensive review of sophisticated tests containing available tests parameters (Berg, 2000).

2 ENVIRONMENT, PARAMETERS AND RESULTS OF STATIC TESTS

The tests were done in the Geotechnical Laboratory Testing Field (GLTF). The GLTF is facility available for full-scale geotechnical tests, which allows the measuring in a laboratory of some geotechnical quantities that are otherwise usually measured in the field (e.g. plate test, dynamic loading test, penetration test, etc.) on various soils and soil layers for different compaction rate and for different water regimes.

The GLTF, see Figure 1, is about 10 meters long and consists of a concrete pit split by removable dividers into separated measuring (testing) spaces and a watering/dewatering drain channel separated by removable dividers too. There is a drain layer placed on the bottom of each measuring space covered with a grate with a drainage geotextile (filter). Both the concrete pit and the drain channel are interconnected at their bottoms. A moveable frame can be slid in the longitudinal direction along a guide-way (rails) fastened on the top of the pit. The moveable frame serves for mounting or supporting the measuring equipment (plate test, CBR in situ test equipment, etc.) and can be blocked in both horizontal and vertical directions during testing.

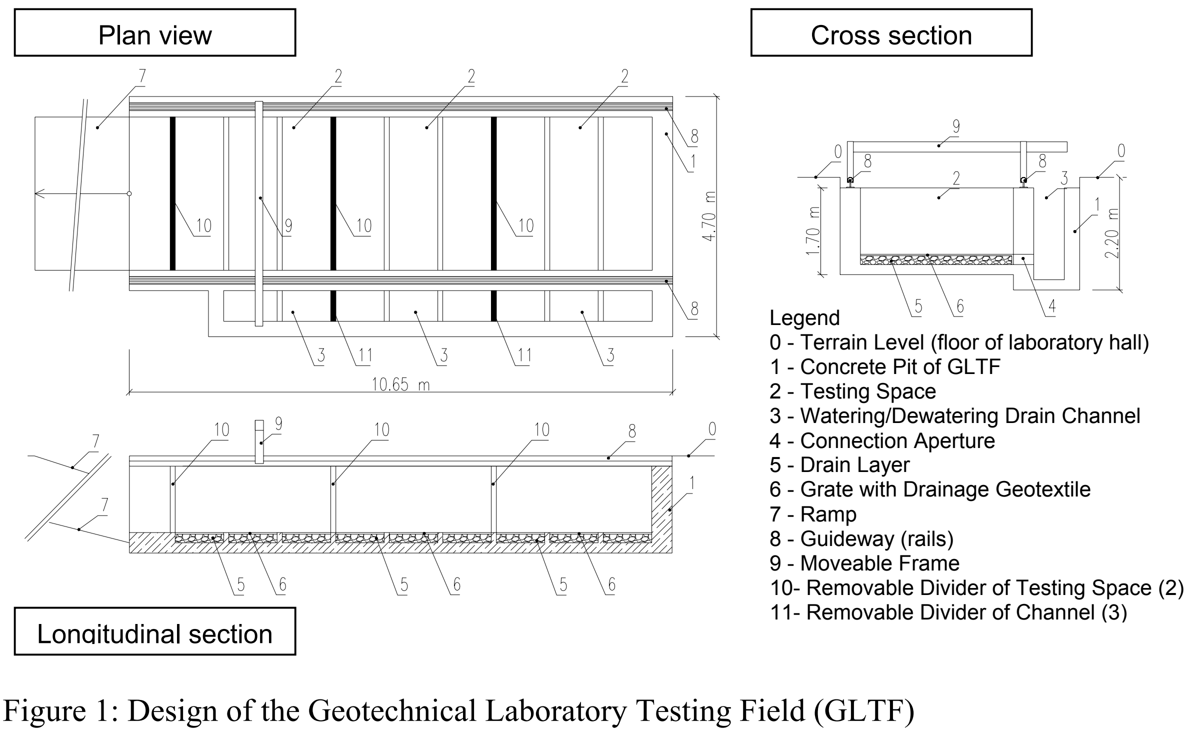

Figure 1: Design of the Geotechnical Laboratory Testing Field (GLTF)

2.1 Tests arrangement

As indicated above, the tests were carried out in the GLTF that had been divided into three testing spaces of a same size (3 m x 3 m). There were five series of tests. One series means two geosynthetics measuring in one step – one by one in each of two testing spaces (laid on subgrade), and in one testing space that was kept without geosynthetics for a comparison. The first and the second series of testing were done on a subgrade with modulus of deformation about E_{v2} = 5 MPa, and the third, fourth and fifth series were carried out on a subgrade with modulus of deformation about E_{v2} = 15 MPa. The subsoil was spread and compacted into GLTF layer by layer up to the final thickness of 70 cm. The material of the subsoil layers was the same for both 5 MPa and 15 MPa subgrade moduli (different bearing capacities were achieved by the moisture content of the subsoil).

Individual series of testing varied in types of used geosynthetics and subbase layers thicknesses laid on geosynthetics (or directly on the subgrade in case of the geosyntetics-free testing space). The first series had thickness of the first subbase layer 20 cm and the second subbase layer 20 cm (i.e. 40 cm subbase layer in total). The second series of testing had thicknesses of the subbase layers 15 cm + 15 cm = 30 cm in total. The third, fourth and fifth series had the same thicknesses of subbase layers 20 cm + 10 cm = 30 cm in total. An example of the test arrangement is shown in Figure 2. Parameters of each of the five series of testing are concentrated in Table 2.

Deformation characteristics as bearing capacity view were obtain from the static plate test according to German Standard DIN 18 134 and were measured on subgrade and on the first and on the second subbase layers.

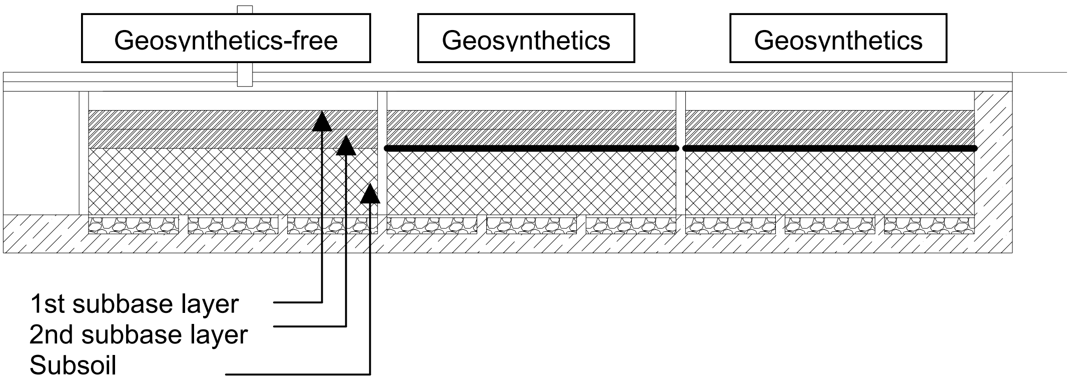

Figure 2: The test arrangement in GLTF

2.2 Material parameters

Used subsoil:

- Weak subsoil was simulated by clayey soil with high plasticity.
- Grading:
    - g (2.0 – 60.0) ... 0 %,
    - s (0.063 – 2.0) ... 5 %,
    - f (0.0 – 0.063) ... 95 % = m (0.002 – 0.06) ...55 % + c (0.0 – 0.06) ... 40 %
- Moisture content: w_{nat} = 28.9 %, $w_{opt,PS}$ = 21.5 %
- Plasticity: w_L = 51 %, w_P = 17 %, I_P = 34 %, I_C = 0.64

Used material for subbase layers:

- Unbound gravel material (fraction 0 – 32 mm),
- Grading:
    - g (2.0 – 60.0) ... 70 %,
    - s (0.063 – 2.0) ... 27 %,
    - f (0.0 – 0.063) ... 3 %
- Particles: d_{10} = 0.3, d_{30} = 2.0, d_{60} = 9.0, C_U = 27, C_C = 1.65
- Density: $\rho_{d,min.}$ = 1.669 kg.m^{-3}, $\rho_{d,max.}$ = 2.208 kg.m^{-3}

Tested geosynthetics are listed in Table 1.

Table 1: Tested geosynthetics

Symbol	Name of geosynthetics	Producer	Type of geosynthetics
A	Armatex G PET (+PVC) 55/55	Kordárna	woven geogrid (flexible)
F	Fornit (PP) 40/40-35 T	Huesker	woven geogrid (flexible)
G	Geolon PP 60	Nicolon	woven geotextile
P	Polyfelt TS 700	Polyfelt	non-woven geotextile mechanically and heat-solidified
S	Secugrid 60/60 (PET)	Naue Fasertechnic	geogrid (welded strips)
T30	Tensar SS30	Tensar International	extruded geogrid (rigid)
T40	Tensar SS40		extruded geogrid (rigid)

Composition of tests through the five testing series is displayed in Table 2.

Table 2: Composition of tests through the five testing series

Testing series	Average subgrade modulus E_{v2} (MPa)	Subbase layers thickness $1^{st} + 2^{nd}$ = total (cm)	Tested geosynthetics (* (see symbol in Table 1)
1^{st}	5	20 + 20 = 40	G + T30
2^{nd}		15 + 15 = 30	S + P
3^{rd}	15	20 + 10 = 30	F + A
4^{th}			G + T30
5^{th}			T40 + S

(* As described in paragraph 2.1 one testing series consists of testing two geosynthetics and a comparison measurement on the geosynthetics-free testing space.

2.3 Results

Table 3: Test results of static tests

Testing series	Subgrade deformation modulus E_{v2} (MPa)	Testing space of GLTF	Symbol of tested geosynthetics (see to Table 1)	Subbase			
				1^{st} layer		$1^{st} + 2^{nd}$ layer	
				thickness (cm)	E_{v2} (MPa)	thickness (cm)	E_{v2} (MPa)
1^{st}	5	I	Geosynthetics-free	20	17.90	40	53.66
		II	G		23.23		56.51
		III	T30		24.90		55.41
2^{nd}	5	I	S	15	11.30	30	22.06
		II	P		9.94		17.43
		III	Geosynthetics-free		10.11		18.18
3^{rd}	15	I	F	20	27.18	30	34.82
		II	A		29.79		37.06
		III	Geosynthetics-free		28.43		38.53
4^{th}	15	I	G	20	25.17	30	33.28
		II	T30		29.79		34.86
		III	Geosynthetics-free		28.43		34.20
5^{th}	15	I	T40	20	25.94	30	35.19
		II	S		27.87		35.54
		III	Geosynthetics-free		29.26		37.74

The pre-described values of subgrade deformation modulus 5 MPa and 15 MPa for the 1st and 2nd testing series and for 3rd, 4th and 5th testing series respectively were achieved with difficulties by water content changing in the subsoil. The modulus was measured three times in each testing space. Values 5 MPa and 15 MPa are rounded off the average value (e.g. the minimum value was 5.75 MPa and the minimal value was 4.37 MPa in the first series).

The first subbase layer was spread just after subgrade modulus measurement because of the subsoil drying up. Subbase modulus of deformation was measured again three times in each testing spaces. Values in Table 3 are the average values of deformation modulus in each testing space.

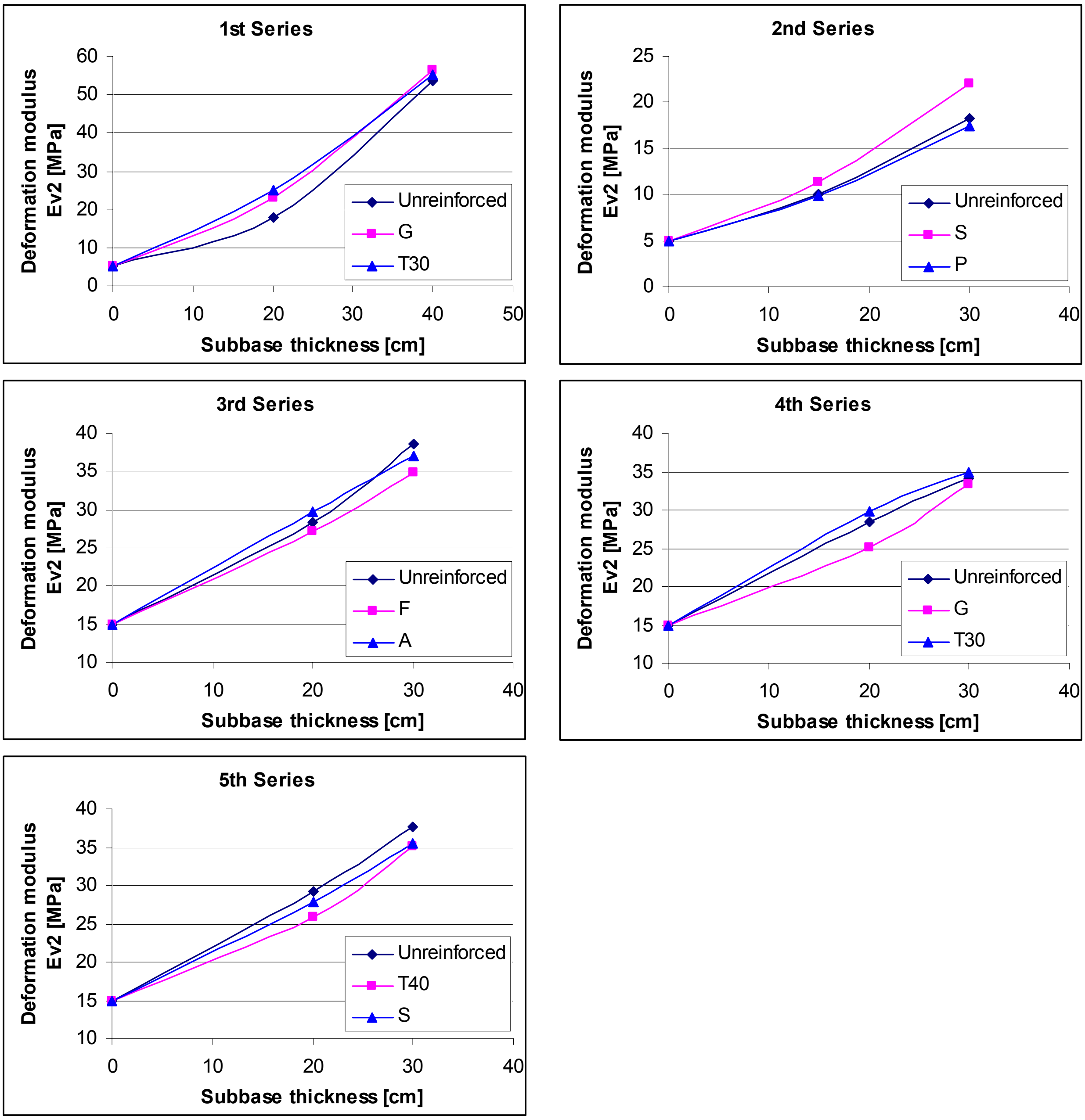

Figure 3: Test results of static tests

The test results of the five testing series are concentrated in both Table 3 and Figure 3. In this place it is necessary to highlight again that the thicknesses of subbase layers vary from series to series. They are 20 cm for both 1st and 2nd subbase layers in case of the 1st testing series, 15 cm in case of 2nd testing series and in case of 3rd, 4th and 5th series the 1st subbase layer was 20 cm and 2nd layer was 10 cm (compare with Table 2).

While the subgrade values 5 MPa and 15 MPa had been chosen as representatives of very weak and weak subgrades before measurement, the subbase thicknesses were adjusted during the measurement to ensure the best geosynthetics effect on the bearing capacity.

2.4 Discussion on static tests results

As demonstrated in Table 3 the bearing capacity increase due to geosynthetics usage is significant on the first 15cm subbase layer spread on geosynthetics laid on very weak sugrade of 5 MPa deformation modulus only (see 1st series and 1st subbase layer measurement). Partly the same effect is visible in 2nd series (geosynthetics “S” vs. geosynthetics-free testing space).

Other testing series did not demonstrate any effects of geosynthetics on the bearing capacity increase. The test results of these measurements are the same (geosynthetics used or unused) within the frame of statistical discrepancies.

On the other hand, the explanation of geosynthetics behaviour as a tool of bearing capacity increase is based on the static plate test only. This presumption is fully causative, because the plate static test is widely used for evaluation of new-built subgrade in many European countries (Germany, Austria, Czech Republic, Slovakia, etc.). However, this test cannot take into account future construction behaviour, which seems to be very important in case of geosynthetics, whose incidence could increase through the exploitation time in a construction. Therefore, testing under cyclic loading was arranged.

3 ENVIRONMENT, PARAMETERS AND RESULTS OF TESTS UNDER CYCLIC LOADING

Considering the results of the static tests it was decided to continue in observation of geosynthetics behaviour under cyclic (dynamic) loading. In respect of the GLTF parameters, cyclic loading via circular plate with a diameter of 30 cm (the same as for the static plate test) was chosen. For this purpose, it was necessary to design, fabricate and open a new facility – the PneuTester. Analogous facilities were used by Penner, 1985 and Perkins, 2002.

3.1 Facility

The facility for cyclic testing (except the GLTF, see Chapter 2) consists of:

1. Pneumatic loading system (PneuTester, see Figure 4):
   - source of compressed air – compressor Schneider 850-270 ST
   - compressed air set-up unit FRC-1/2-D
   - pneumatic piston chamber DNG 250
   - proportional reducer, pass valve, small items (silencers, connecting hoses, etc.)
2. computer based electronic measuring and control system with soil and geosynthetics stress gauges, strain indicators, software.

   The PneuTester facility is displayed in Figure 4.

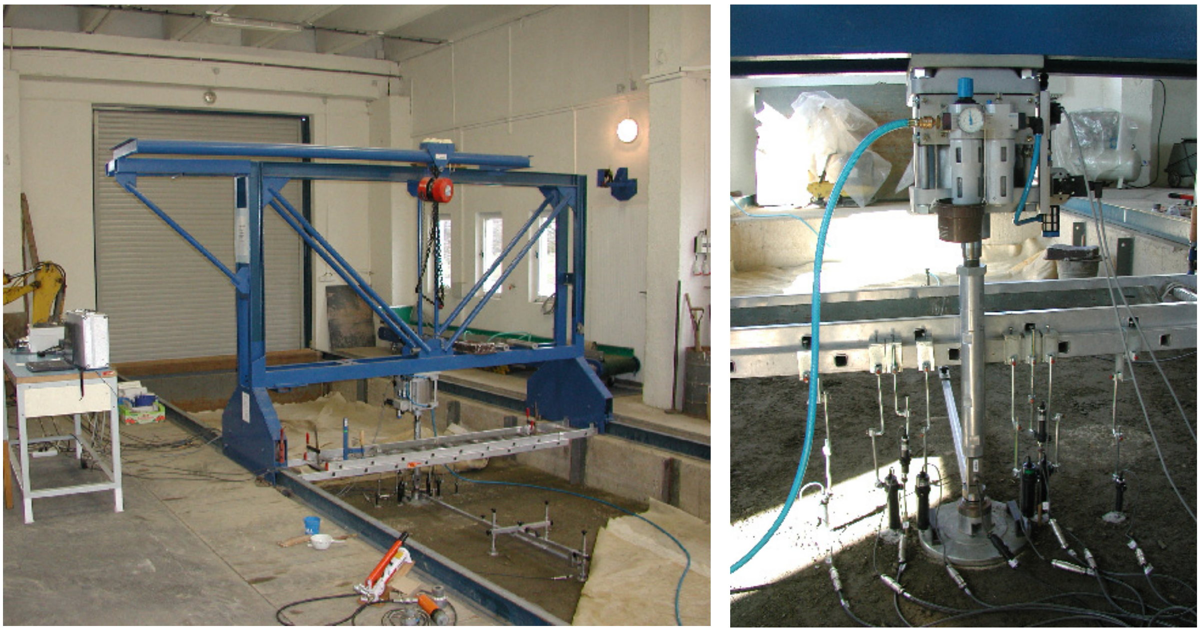

Figure 4: The PneuTester in the GLTF

3.2 Tests arrangement

The research plan was composed as described hereinafter and the tests and their methodology are still in progress. The GLTF was divided into three testing spaces of a same size (3 m x 3 m) again. It is supposed that ten series of tests will be carried out on subgrade with deformation modulus E_{v2} = 5 MPa and 15 MPa as within the static tests. Up to now, two testing series have been done (meaning of a testing series is the same as described in Chapter 2).

As in case of the static tests, the subsoil was spread and compacted into GLTF layer by layer up to the final thickness of 70 cm. The material of the subsoil layers was the same as described in Chapter 2.2.

Individual series of testing vary in the types of used geosynthetics. Thicknesses of subbase layers are (will be) the same in all series 20 cm – 1st layer and 10 cm – 2nd layer, i.e. 30 cm total thickness of the subbase layer.

Parameters of the cyclic loading was determined with respect to the similarities to real traffic loading: stress under the loading plate – 0.4 MPa, loading frequency – 0.5 Hz, number of cycles – min. 100 000 (informatively in some cases 500 000 and 1 mil.).

3.3 Measured quantities

Within the tests the following quantities were measured:

1. Modulus of deformation E_{v2} – before and after cyclic loading
2. E – modulus – continuously during the tests
3. Contact stress and deformation – continuously during the tests
4. Stress on subgrade level under the plate centre
5. Deformation on subgrade level under the plate edge (2 sensors)
6. Deformation at the top of subbase layer in horizontal distances of 20 cm, 40 cm and 60 cm (from the plate centre)
7. Air temperature and temperature of the sensor support

3.4 Results

The basic outputs are in the form of graphic relations between the deformation characteristics (permanent deformation under the plate, elastic modulus) and the number of loading cycles. An example of such output is in Figure 5, where is compared deformation two reinforced and one unreiforced subbases.

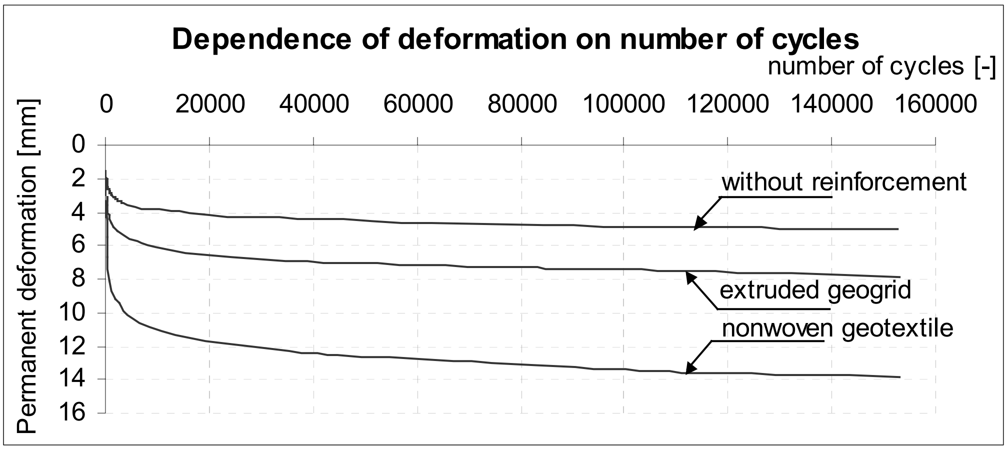

Figure 5: Dependence of subbase deformation on number of cycles

The test resulted in Figure 5 was done on 1st subbase layer (i.e. 20 cm thick). Deformation moduli of subbase in the test are shown in Table 4.

Table 4: Specific test parameters of the test

	Extruded geogrid	Nonwoven geotextile	geosynthetics-free (without reinforcement)
E_{v2} (before test)	26,33	26,87	30,88
E_{v2} (after test)	52,45	52,68	53,31

Apart from these graphs, such as in Figure 5, the main relation to the stress behaviour will be calculated, and mutual relations and dependencies of other outputs of the monitoring carried out will be observed, i.e. relations between deformation values, behaviour and stress in various places of the construction.

3.5 Discussion on tests under cyclic loading

As demonstrated in Figure 5 it was found out that reinforced subbase layers prove higher deformation within loading than unreinforced subbase. This unexpected result shown exemplarily in Figure 5 is validated also by another test (two series of tests were carried out as mentioned).

This preliminary result (= geosynthetics usage decreases resistance of subbase against deformation) is insofar serious that we do not state names of producers and we will return to the test methodology for detail analyze of the result. This is very interesting theme for scientific discussion within the Conference.

4 CONCLUSION

Full-scale tests are preferred for their predicative ability, as they are not affected by model testing inaccuracy. Their results are useful for back-calculation when defining calculation processes and for designing constructions. The results of the carried out measurement using the static plate test for the evaluation of geosynthetics benefits in case of reinforced subbase pavement layers on weak subgrade, and cycling loading tests as the basis are summarized as follows:

- A significant benefit of geosynthetics usage in case of static tests was evident only on a very small scale (in case of the subgrade bearing capacity about 5 MPa expressed by modulus of deformation and on subbase layers of up to 30 cm thickness).
- Static plate test carried out in accordance with German standard DIN 18 134 has a limited scale (in relation to the standard limit values of the loading stress or deformation) – especially due to this, it cannot express/reflect the reinforced geosynthetics (usage) benefit.
- Traffic loading time-based simulation can be done, apart from the test carried out by repeated wheel running, through cyclic loading tests of the tested layers using a circular plate, as in static plate test, which enables monitoring the progress of the time-based deformation and deformation moduli (with them minimum number of cycles 100 000).
- Cyclic tests constructed by the PneuTester started in our laboratory after having finished the verification tests. The results of the experimental measuring, which will be carried out in the years 2005-2006, will be continuously evaluated and it is expected that when they finish, their results will be used for the reinforced geosynthetics usage evaluation for the specific usage.

It is expected that especially cyclic tests will contribute to answering the open question, i.e. to a definite evaluation of reinforced geosynthetics benefits for the specific usage. And subsequently to contribute to stating both design methods and control mechanisms.

5 ACKNOWLEDGEMENT

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