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Laboratory test method to evaluate the installation damage of geotextiles

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ABSTRACT: A laboratory method of assessing survivability of geotextile installed into the pavement structure was developed. The damage of geotextile has been estimated in terms of the remaining tensile strength and energy absorption reduction due to compaction and traffic forces.

The approach is based on simulation of damage by constructional plant and other vehicular traffic applied on top of the road structure with a geotextile interlayer. A special sector-shaped press was used to apply the vertical cyclic loads to the model of pavement structure. The cycling simulates compaction process with different moving loadings depending on changeable stiffness of the whole structure.

A clear correspondence was found between the magnitude and duration of cyclic load application and the rated properties of geotextile. To take into account these findings an additional evaluation criterion is recommended – the retained strength test. It can be also used as a criterion to determine the acceptable compaction process of layers during construction and the optimal depth of a geotextile in the road structure.

1 INTRODUCTION

The survivability of geosynthetics and geotextiles (GT) is of major concern in many geotechnical applications. It is known that (1) a GT will not perform any function if it is destroyed during installation; (2) a critical period in the life of a GT is during the installation rather than during the service life and (3) usually if the GT survives the installation-induced stresses, it will also withstand the in-service stresses. Therefore, the theme of the current research is to develop a laboratory test method for GTs to evaluate their remaining performance after installation on design stage.

2 SCOPE OF STUDY

The essence of the laboratory test method is in simulation of forces caused by construction equipment and transferred to the GT cushion through the granular bearing layer. The method comprised four phases: (1) determination of the compaction/traffic loading mode; (2) calculation of the vertical stress (compression tensions) arising in the structure on the GT installation level caused by construction machines operation; (3) the compaction phase using a sector-shaped press and (4) post-compaction tensile testing of the GT and evaluation of the GT's remaining strength.

3 TEST METHOD

3.1 *Compaction/traffic loading mode*

Compaction/traffic forces on covering (aggregate) layer has to be determined to evaluate the magnitude and sequence of stresses transferred to the GT fabric placed between two grain strata. Therefore, for each i-th working operation the "wheel (track) – aggregate layer" contact pressures p_i, loading area diameter D_i, and aggregate layer thickness h_i are identified. Total time of the load application to the point on the surface is evaluated according to the traffic speed V_i, number of passes by the same track n_i and track overlaps Δl_i.

3.2 *Vertical stress*

To simplify calculations, the grain strata of different kind with GT interlayer were reduced to equivalent uniform half-space using the equation (Radovskiy 1988):

$$h_{\text{eqv}} = h_B \sqrt[3]{\frac{1}{2}\left(\frac{E_B}{E_S} + 1\right)} \qquad (1)$$

where h_B and E_B – are thickness and elasticity modulus of upper grain layer, respectively, and h_{eqv} – equivalent thickness of upper grain layer, converted to subbase modulus E_S.

Vertical stresses σ_{GT} at the depth $z = h_{eqv}$ for the uniform stratum caused by the loading of circled area with diameter D and intensity p can be found using the equation (Timoshenko & Goodier 1970):

$$\sigma_{GT} = p\left[1 - \left(1 + \left(\frac{D}{2z}\right)^2\right)^{-\frac{3}{2}}\right] \qquad (2)$$

The pneumatic tire intensity value p is about equal to the air pressure in the tire. In case of loading by track with the contact width b the vertical stress can be calculated as

$$\sigma_{GT} = \frac{2p}{\pi}\left[\operatorname{arctg}\left(\frac{D}{2z}\right) + \frac{bz}{2((b/2)^2 + z^2)}\right] \qquad (3)$$

The above formulas allow calculating the vertical compression σ_{GT} on the GT-level during the construction of covering aggregate layer for each working operation.

3.3 *Equivalent loading simulation*

3.3.1 *Model of the structure*

The steel mould 230 × 125 × 90 mm ($L \times W \times H$) contains a 40 mm thick compacted sand base supporting a GT test specimen 125 × 350 mm (so that the specimen equally overlap the mould edges), which in turn is covered with a 50 mm thick layer of crushed stone (20 mm diameter).

Such model was selected because of: (1) coarse- and fine-grained layers are used in the majority of geotechnical structures; (2) in most cases the GT is placed between crushed stone and sand and (3) GT is damaged the most when in contact with angular particles.

3.3.2 *Sector-shaped press*

To simulate the dynamic load passes over the surface, a specially designed compaction machine was used (Fig. 1). The compaction energy applied via the sector-shaped steel roller with an arch radius R_{arc} = 200 mm, arch length L_{arc} = 220 mm, and contact width W_c = 50 mm. The load value P_i can be adjusted with the set of extra loads F_i. The cycling is preset to 94 passes per minute (i.e. 47 forward-backward repetitions) and corresponds to vehicle velocity of 0.4 m/s. The mould with testing materials is placed into a trolley sliding in carriage rails.

The mode of equivalent loading is calculated such that the stress value σ_{GT} on GT-level and its loading time t_{GT} corresponds to construction traffic forces. At the same time it was assumed that the determining factor in transition from reality to simulation is not the number (j) of repeated passages over a certain point but mainly the total loading time on this point for each i-th working operation $\sum_j t_{ij} = t_{GTi}$. To evaluate the dependence of the GT remaining properties on the loading mode, the testing should be performed at three loading levels: $0.5\sigma_{GT}$, σ_{GT} and $1.5\sigma_{GT}$.

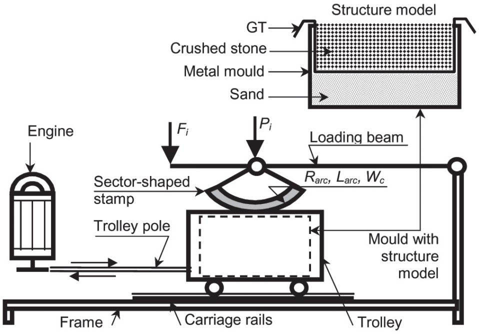

Figure 1. Sector-shaped press scheme.

3.4 *Evaluation of retained strength of the GT*

Once the loading test is complete, the extension testing conducts for the damaged GT using tension machine with constant rate movement according to EN ISO 10319. The results compare to the properties of the undamaged samples. The load at failure, strain at failure, and energy absorption are used to evaluate the retained properties of the GTs.

4 EVALUATION OF DAMAGE RESISTANCE (EXAMPLE)

Required was the evaluation of the survivability of a GT interlayer laid on sand subbase and covered by 40 to 70 mm sized stone. Three different nonwoven thermally bonded polypropylene GTs were tested. Table 1 gives the GT mechanical properties. The bedding half-space consisted of a quartz sand with gradation factor 2.0, and elasticity modulus E_S = 100 MPa. A 260 mm thick aggregate layer consisted of crushed quarried rock with elasticity modulus E_B = 400 MPa.

Construction of aggregate layer consists of eight working operations (Table 2) with corresponding loading mode parameters p_i, D_i, h_i, V_i, n_i and Δl_i. (see paragraph 3.1). These parameters are recalculated into the mode of equivalent loading with the vertical loads value σ_{GTi} on the GT-level and loading time t_{GTi}.

4.1 *Laboratory tests*

To examine the GT damage during a simulation event, the model was subjected to static and dynamic loads.

Table 1. Mechanical properties of the tested GT.

Type	GT-1	GT-2	GT-3
Energy absorption, kJ/m^2 (EN ISO 10319)	5,8	5,8	9,7
Tensile strength, kN/m (EN ISO 10319)	12,6	13,1	20,0
Elongation, % (EN ISO 10319)	55	55	55
Strength at 5%, kN/m (EN ISO 10319)	5,2	5,7	8,2
Puncture CBR*, N (EN 12236)	1850	2000	3000
Dyn. cone penetration, mm (EN 918)	32	23	21
Grab strength, N (ASTM D4632)	1050	1100	1680
Tear strength, N (ASTM D4533)	335	475	550

Table 2. Operations of aggregate layer construction.

Operation	p_i, MPa	σ_{GTi}, MPa	t_{GTi}, s
1. Stone distribution, grade 40-70	0.37	0.34	30
2. Layer compaction	0.50	0.28	21
3. Stone distribution, grade 40-70	0.37	0.26	30
4. Layer compaction	0.50	0.18	21
5. Bitumen pouring	0.60	0.17	2
6. Stone distribution, grade 10-20	0.60	0.17	4
7. Layer compaction	0.50	0.15	21
8. Technological traffic	0.60	0.16	80

4.1.1 *Testing of the control samples*

Tests were first performed on 50 mm wide samples. Then, the stress value was recalculated for standard 200 mm width specimens according to the correlation equation (Diederich 2004) for the tested GT types:

$$R_{20} = 0,2263\ Q_5 + 0,9673 \qquad (4)$$

where R_{20} is the tensile strength of 200 mm wide sample, and Q_5 – the maximum load of 50 mm wide sample.

To compare the control and the damaged samples, 50 mm wide strips were cut out of the damaged area and tested according to EN ISO 10319 methods. The results were then recalculated for the standardized 200 mm width. In addition, the absorption energy (W) of GT was calculated as:

$$W = \int_0^{\varepsilon_p} \sigma \varepsilon)d\varepsilon \qquad (5)$$

where ε_p is the sample strain at maximum force and $\sigma(\varepsilon)$ and ε – stress and strain during the test, respectively.

4.1.2 *Static mode*

The load was applied through a 50 mm diameter circular plate with contact pressures of 0.17, 0.34 and 0.51 MPa. The pressure was maintained for 210 s.

It was noticed that only at sufficiently high pressure (1.8 MPa) the weakest type of the tested GTs tended to get lower retained strength and elongation. This result allows to assume that static loading is not representative enough to simulate the GT damage and additional tests were performed in dynamic mode.

4.1.3 *Dynamic mode*

To obtain relationship “cyclic load – GT retained properties” three loading levels were selected with contact pressures of 0.19, 0.34, and 0.38 MPa. The vertical cyclic loading time $\sum t_{GTi}$ was maintained for 210 s. After extraction, the samples were analyzed with respect to damage. For GT-1 type the damaged area was found to be up to 18%. Stronger types – GT-2 and GT-3 had less defects and smaller damaged area. Remaining stress-strain testing followed these inspections.

4.2 *Evaluation of results*

On the stress-strain curve for the control samples, three sections can be determined that correspond to the elongation range 0–5–21–>55% (Fig. 2). In the range ε = 0–5% the tested GTs developed a rigid behavior due to the strength of the thermally bonded filaments. In the range ε = 5–21% the filament links start to break and the product starts to delaminate. For ε = 21–>55% the plastic yielding of polypropylene is observed up to the break point.

Experimental relationship “$\sigma - \varepsilon$” can be adequately approximated by logarithmic or logistic functions and together with (5) the energy absorption value can be found for logarithmic (6) and logistic (7) approximations as:

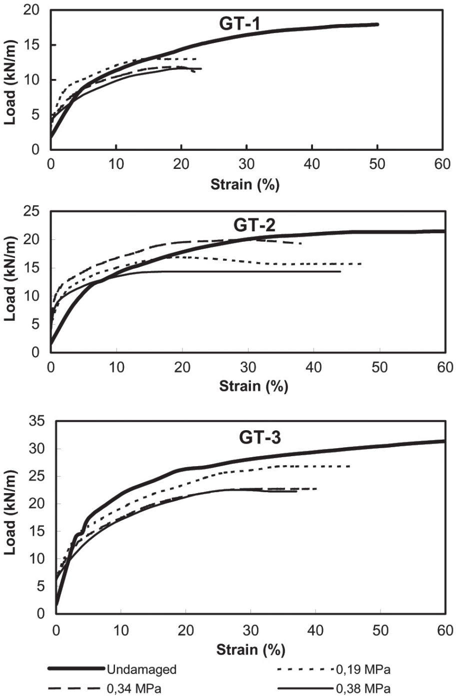

Figure 2. Comparison of stress-strain test results for undamaged and damaged GTs with different compaction forces.

$$W = (a + b\,(\ln \varepsilon_p - 1))\varepsilon_p \qquad (6)$$

$$W = L_0\,[\varepsilon + L_1^{-1}\,\ln|\,1 - L_1 \exp(-L_2\,\varepsilon_p)|] \qquad (7)$$

where a, b, L_0, L_1 and L_2 – are trial parameters (Table 3).

Results for damaged GTs show that retained absorption energy value has clear correlation to the GT type and compaction force (Fig. 3). It appears that tested GT types have the critical stress range between 0-0.2 MPa where the absorption energy value drops the most intensely (Fig. 4). Based on the remaining strength value it is possible (1) to determine the optimal type of GT for given compaction and traffic forces or (2) to select safe loading modes for given GT type or (3) to determine required thickness of aggregate layer to achieve safe compaction for the GT. The plots shows that GT-2 type is the most efficient for described herein example in terms of "remaining strength – GT cost".

Table 3. Parameters of logarithmic and logistic functions.

	a	b	L_0	L_1	L_2	ε_p	W (f. 6)
GT-1	4.48	3.28	17.9	0.0188	3.04	50	7.0
GT-2	5.74	4.11	23.2	0.0487	2.40	60	11.1
GT-3	9.86	5.25	31.2	0.0112	3.06	60	15.7

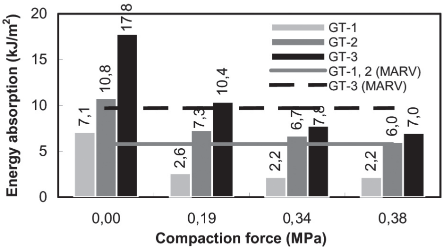

Figure 3. Comparison of the experimental energy absorptions with the manufacturer's minimum energy absorption values (i.e. minimum average roll value, MARV).

5 CONCLUSIONS

- Dynamic simulation on the sector-shaper press more realistically reflects performance of GT due to involvement of wedging forces from crushed aggregate particles on the sand subbase.

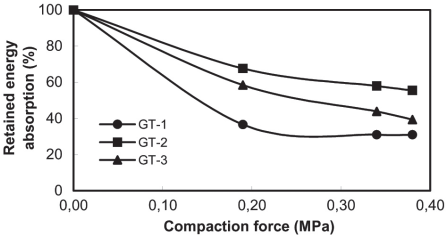

Figure 4. Comparison of retained energy absorption versus compaction forces.

- Suggested approach can be considered as a basis for development of the standard test method. Stiffness of the stamp and subbase bedding can be varied by means of flexible casing and layers and requires additional research.
- To make an express estimation of GT survivability their nominal properties are to be supplemented with installation damage tolerances.
- Calculations based on nominal mechanical properties of GT can result in essential error. The design needs to take into account the remaining properties of the GT after installation.

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