Investigation into the Efficiency of Strengthening of Subgrade at the Proof Ground of Road Surface

Andrzej Surowiecki
The International University of Logistics and Transport in Wroclaw, Poland

The aim of the investigation is the analysis of strengthening systems of road surfaces situated at the weak subgrade. The paper presents three systems of strengthening of road surface using geotextiles. The results of the analysis of road surface deformation moduli values are discussed. The value of deformation modulus on the basis of measurements of vertical displacements of loaded road surface was calculated. The investigations at the proof ground of road surface was executed. Particular efficiency of the use of GEOWEB cellular mattress as strengthening of road surface was confirmed.
Keywords: motor road, proof grounds of road surface, strengthening.

1. SELECTED ISSUES CONCERNING ROAD SURFACE AND SUBGRADE MECHANICS

The design of a roadway is an assembly of layers whose behaviour under load is characterized, among others, by E_0 deformation modulus and v Poisson ratio. The purpose of this design is to transfer loads from the vehicle to the ground, while maintaining restrictions on the value of the vertical stress at the surface-ground contact. Maximum stress (usually called the critical stress) which does not cause an area plasticization at the subgrade level, is generally accepted as a measure of bearing capacity of the subgrade. Therefore, the following condition is valid: $q_{dop} \leq q_f\ (F)^{-1}$, where q_f is the load limit, and F = 2-3 is the confidence factor.

Mechanics of road surface and subgrade is therefore generally a notion containing bearing capacity issues and the state of stress and strain of roadway construction, including an active subgrade area.

The textbook [12] gives the range of the area, assuming the stress on the wheel contact with the road as $\sigma_{1,s}$ = 0,6 MPa. For example, the light wheel (pressure P = 13 kN, the surface of print F = 0,021 m^2) creates an active area, i.e. an area of significant value of stress $\sigma_z \geq$ 0,054 MPa to a depth of approximately 0,35 m. The area of stress of the values of $\sigma_z \geq$ 0,054 MPa for wheels with pressure of P = 45 kN (print area of F = 0,076 m^2) extends to a depth of more than 0,6 m.

While solving geotechnical issues the following subgrade models are used: single-parameter models (e.g. Winkler model), two-parameter models (e.g. Fiłonienko-Borodicz model, Pasternak model) and multi-parameter models. Among the ground strength parameters, which are the measure of bearing capacity one should consider the California Bearing Ratio *CBR* [%] and E_0 deformation modulus [MPa]. The roadway bearing capacity is generally determined by the shear strength τ_f.

Subgrade in transport engineering is classified depending on its bearing capacity. In catalogues of typical surface construction [6, 7] four groups of subgrade bearing capacity (G1, G2, G3 and G4) are distinguished. Subgrade qualified for the group G1 does not require strengthening. For the other groups, catalogues [6, 7] present ways to bring the substrate to the G1 domain, consisting of replacing the soil to a certain depth or the use of a strengthening system.

The problem of bearing capacity expansion in transport engineering is discussed in detail in the literature [1]. Two groups of road subgrade strengthening methods are distinguished, i.e.

physical-mechanical and physical-chemical. The first group consists of land reinforcement, i.e. the installation of inserts made of various materials. This type of road subgrade reinforcement is considered in this paper. Inserts, located in the direction of tensile forces, take a part of these forces on the basis of cooperation with the ground, depending on the characteristics of materials and other factors.

2. THE EFFICIENCY OF ROAD SUBGRADE STRENGTHENING IN THE LIGHT OF SITE TESTS

2.1. THE AIM, SUBJECT AND SCOPE OF RESEARCH

The aim, subject of study, scope and method, and the results of investigations are discussed.

The aim of this study was to estimate the impact of use of three adopted strengthening systems installed in the road subgrade on the increase of bearing capacity.

The subject of research is the road surface with three strengthening systems using geosynthetics. The results of the analysis of values of road surface deformation moduli are presented. The deformation moduli were calculated based on the measured vertical displacement of loaded road surface. The research was carried out on test sites, which constituted physical models of road.

Three strengthening solutions were compared, based on the results of measurements of vertical surface deformation on the stretch of temporary road constructed on the test site of the Military Academy of Land Forces in Wrocław [14]. The purposefulness of the use of geosynthetics as the strengthening of road surface was confirmed.

2.2. RESEARCH LOCATION

The research road section was a road with unimproved surface (the roadway was a layer of mineral aggregate) with reinforcement, situated on a subgrade with a bearing capacity of lower classes, by [6, 7]. The designing of the research location was based on three assumptions: low surface strength parameters, surface design should provide quick installation, applied load reaching a maximum value of Q = 115 kN/computing axle [6, 7].

Reinforcement layer was installed directly on the subgrade, underneath the road surface (Fig. 1). The following materials were used: the *Polyfelt TS60* non-woven polypropylene filament [11]; *Tensar SS30* polypropylene geogrid with the aperture of 39 x 39 mm [2]; *GEOWEB* system polypropylene spatial lattice (cellular mattress) [4, 8, 15] filled with 20/40 mm crushed basalt creating a structural layer of a thickness of 0,08 m.

The surface was made of three-layer aggregates. The top-down order of layers was as follows: crushed stone sand; 8/16 mm key aggregate, coarse aggregate containing a mixture of 20/40 mm crushed basalt and brick and concrete debris. Four variants of surface construction were proposed (Table 1), and created in the form of four research road sections, each with a length of 10,0 m and a width of 3,5 m:

- variant I without reinforcement (reference variant), with the total thickness of the structure h_c = 0,45 m;
- variant II with reinforcement consisting of single mat (geotextile) placed on the ground subgrade (h_c = 0,40 m);
- variant III with reinforcement consisting of two layers (the geogrid located on the geotextile serving as the bottom layer, with the overall structure thickness of h_c = 0,35 m)
- variant IV with reinforcement consisting of the cellular mattress located on the geotextile (h_c = 0,24 m).

Based on measurements of the vertical displacements of the ground loaded with a vehicle, values of the deformation modulus, which is the measure of bearing capacity, were calculated. The research was comparative, i.e. the results were compared with the results of measurements of the reference section (the section without reinforcement).

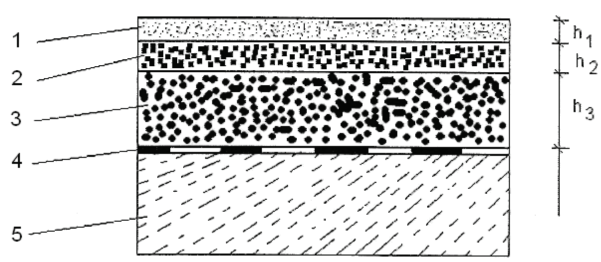

Fig. 1. Vertical section through the construction of the road surface [14]: *h* - layer thickness, *1* - roadway surface (crushed stone sand), *2* - roadway surface (key aggregate), *3* - foundation (coarse aggregate), *4* – geosythetic, *5* - ground subgrade

Table 1. Specification of surface structures on a particular research road section

Layer material	Symbol h_i	The layer thickness of surface construction h_i [m]			
		Road section I (reference)	Road section II	Road section III	Road section IV
Crushed stone sand	h_1	0,10	0,10	0,07	0,06
Key aggregate	h_2	0,15	0,10	0,10	0,08
Coarse aggregate	h_3	0,20	0,20	0,18	-
Geosynthetic	h_{geo}	-	geotextile	geotextile + geogrid	geotextile + *GEOWEB* mattress 0,10
Overall thickness $h_c = \sum h_i$		0,45	0,40	0,35	0,24

Source: [14]

2.3. GROUND SUBGRADE DEFORMATION MODULUS

The study of ground subgrade deformation moduli was carried out using static (VSS plate) [3-5, 10] and dynamic (Light Drop-Weight Tester ZFG 02) [3, 4, 9] method through measurements of subsidence. The measurements were made for each of the four road sections before laying the surface. The measuring points were located in the longitudinal axis of the road, at both ends and in the middle of each section. The arithmetic mean value was calculated from the measuring points at both ends, so that for each of the four sections two values of primary static modulus and two values of secondary static modulus were calculated, which altogether gives sixteen values. In the case of the measurement of the dynamic modulus, the study resulted in 8 values (four sections with two modulus values each).

The static moduli were calculated according to the formula [13, 17]:

$$E = (3\,\Delta p \cdot D) \cdot (4\,\Delta s)^{-1} \qquad (1)$$

where:

Δp – increment in load within 0,05-0,15 MPa range,

Δs – increment in subsidence within the range of load change,

D = 0,3 m – loading plate diameter.

The measurement results are given in Table 2. The values of the deformation moduli suggest a low bearing capacity of the subgrade, while the values of the primary and secondary module quotients $n_{2/1} = E_2/E_1$ exceeded the value of 2,20, which points to insufficient compaction of the subgrade.

Table 2. The values of subgrade deformation moduli

Measuring point localization	Static moduli [MPa]			Dynamic moduli E_d [MPa]
	E_1	E_2	E_2 / E_1	
Section limit	11,94	28,04	2,35	16,51
Section centre	7,33	20,90	2,85	10,06

Source: [14]

2.4. SURFACE DEFORMATION MODULUS

The surface deformation moduli research was carried out analogously to the subgrade deformation moduli research, i.e. using the static method (VSS plate) and the dynamic method, using the dynamic tester probe. In the case of VSS plate measurements a range of load-unload cycle was carried out in the following stages:

* load: 0-0,05-0,15-0,25-0,35-0,45-0,55 MPa;
* unload: 0,55-0,35-0,15-0,05-0 MPa.

The values of subsidence taken in the instance of unitary pressure change (Δp) under the plate within the 0,25-0,45 MPa range were assumed for calculations. The deformation moduli for respective research road sections are given in Table 3. In general, the values of deformation moduli for respective road sections do not present significant differences, which may be caused by the diversity of constructional thickness of the surface. The lowest values of the moduli are presented by the road section without geotextile reinforcement, while the highest are presented by section IV containing the surface of the lowest thickness h_c = 0,24 m, where the most advanced reinforcement system, i.e. the cellular mattress located on the geotextile, was installed. Comparing the modules for sections IV and III, it was found that the use of spatial lattice instead of the geogrid constitutes (due to bearing capacity of the surface) an equivalent of a layer of the thickness of Δh_e = 0,11 m made of stone aggregate, i.e. it reduces the thickness of the structure by the value of Δh_e. Comparing the modules for sections IV and II, it was concluded that the additional reinforcement in the form of the cellular mattress reduces the required thickness of surface structure by the value of Δh_e = 0,16 m. The installation of the spatially structured reinforcement layer (section IV), in comparison to the aggregate surface without reinforcement, results in achieving comparable bearing capacity at the surface structure thickness reduced by the value of Δh_e = 0.21 m. This type of solution is clearly beneficial in the case of temporary road construction or the construction in crisis conditions. Moreover, the most favourable ratio of E_2/E_1 modules was observed in the case of section IV. This result indicates an active influence of cellular mattress on the aggregate compaction conditions in the road surface.

Table 3. The values of surface deformation moduli

Research Road section type	Static moduli [MPa]			Dynamic modulus E_d [MPa]
	E_1	E_2	E_2 / E_1	
I, h_C= 0,45m	21,77	79,88	3,67	37,81
II,h_C= 0,40m	31,61	82,73	2,61	47,30
III,h_C= 0,35m	39,13	83,73	2,14	48,11
IV, h_C= 0,24m	49,73	85,79	1,72	49,22

Source: [14]

2.5. SURFACE DEFLECTION

Measurements of vertical displacement values, which measure surface deflections were performed on all four research sections of the road with a Benkelman's deflectometer [13], using external load of 100 kN. The load was realized as the pressure on the rear axle of the truck. The deflections were measured under the wheel, at five appropriately selected points of the road, along the direction of movement of the car, during the first and the third passage. The conclusive mean deflection was calculated at each road section for the first and third passage, as the arithmetic mean of the values taken at the five measuring points. The comparison of mean surface deflections in respective research road sections is presented in Table 4. The lowest values of deflections $y_{śr}$ and the smallest decline of the value of deflections $\Delta y_{śr}^{1\text{-}3}$ (for the third passage compared to the first passage) were recorded for the section IV, which shows the influence of the spatial geolattice on the reduction of the vertical surface displacement and on the acceleration of the process of surface building aggregate compaction. In the case of the remaining road sections, the deflection values $y_{śr}$ and the decline of the value of deflections $\Delta y_{śr}^{1\text{-}3}$ reach greater values for each of the three passages, which points to the gradual nature of the surface building aggregate compaction. The analysis of the aforementioned strengthening systems indicates particular effectiveness of the spatial geolattice, resulting from the favourable cooperation conditions of this type of insert with the granular material filling the lattice (the aggregate grains wedge themselves in the cell-sections which form the geolattice).

It is worth noting the positive results of the experiments using the *GEOWEB* lattice as a reinforcement layer for low bearing capacity railway tracks [8].

Table 4. Mean surface deflections

Research road section type	Mean deflection $y_{śr}$[mm]		Decline of the value of deflections $\Delta y_{śr}$ [mm]
	First passage $y_{śr1}$	third passage $y_{śr3}$	
I (reference)	1,83	1,44	0,39
II	1,64	1,40	0,24
III	1,55	1,35	0,20
IV	1,41	1,30	0,11

Source: [14]

3. CONCLUSION

The concept of the research program assumed the low bearing capacity of the subgrade. The values of the secondary deformation modulus and quotient of the secondary and primary moduli of the value above the value of 2,2 confirm the assumption about the placement of the research road sections on weak and insufficiently compacted subgrade. The research confirms the usefulness of the analyzed geotextile reinforcement systems for non-strengthened surface structures (suggested for temporary roads, access roads, company roads, municipal roads, etc.) and in the case of emergency reconstruction of roads damaged in crisis situations. The reinforcement system consisting of the *GEOWEB* cellular mattress placed on geotextile (research section IV) proved to be particularly efficient. Assuming comparable static deformation modulus values, the necessary thickness of the surface structure with the above mentioned reinforcement is reduced by approximately 50% relative to the thickness of the surface structure without any reinforcement.

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Andrzej Surowiecki
The International University of Logistics and Transport in Wroclaw, Poland
andrzejsurowiecki3@wp.pl