Reinforced Soil as Road Subsoil Strengthening (Model Investigation)

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The issue of distortion and load bearing capacity of non-cohesive, monogenic and two layer soil, with vertical reinforcement, was analyzed. Separate inserts, single, double, triple and complex were used. Resistance parameters, in function of their characteristics, referring to reinforcement inserts, were evaluated. Soil base bearing capacity was calculated, on the basis of the research results of large size physical models distortion state, constructed on laboratory scale.

Keywords: reinforced soil, strengthening of road subsoil, model investigation.

1. INTRODUCTION

Safety and comfort are the basic parameters of modern road transport networks. The level of these indicators is highly dependent on infrastructure condition, in particular on the roads and subsoil construction. Therefore, all the elements forming road constructions should be subject to constant assessment. Research on a new technique in normal traffic conditions is difficult, and it is also time consuming. In such cases, laboratory tests or measurements on separate experimental objects can be helpful.

In the process of necessary highways modernization, in order to adapt to increased traffic, increased axial thrust and speed, one of the main technical measures is to strengthen the soil whose load bearing capacity is often insufficient.

The aim of the paper is to analyze the issue of the ground highways physio-mechanical system strengthening, in particular with the use of land reinforcement technique. The results of laboratory model, on the use of geo synthetics effects, in order to increase the capacity of ground foundation base or subsoil, are presented.

The research was carried out with reference to two types of soil base: uniform (i.e. monogenic) and two-component. It reflects road surface layered substructure system. Theoretical generalizations of the research results consist on individual models strength parameters calculations.

2. DEFORMATION OF MONOGENIC REINFORCED SOIL BASE

The results of experimental studies, of soil, reinforced with geo-textiles in the form of mats and nets, are discussed. The aim of the study was to determine the effect of reinforcement deformability reduction, and simultaneously increase of load bearing capacity of a soil layer, which is permanently deformed.

The subject of research were changes in horizontal pressure and vertical deformation size and distribution, of non-cohesive soil samples (coarse sand, loosely poured, of internal friction angle $\varphi = 29°$).

The following types of reinforcement were used:

1) Geo-textile Typar ® SF94, of tensile strength 25,0kN and of elongation with maximum tensile force equalling 70%;
2) Geo-textile Typar ® SF111 of tensile strength 29,0kN and of elongation with maximum tensile force equalling 70%;
3) Geo-grid Fortrac ® type R90/90-20T of tensile strength 90,0kN and of elongation with maximum tensile force equalling 10%;

4) grid, of steel bars, 3.5 mm of diameter (square holes 30 x 30 mm and 14 x 14 mm alternatively), for comparison.

The details of the inserts strength properties are presented in publications [1, 4, 5, 11, 12]. Samples of the sand were placed in a steel, rectangular tray (Fig. 1). The construction of the walls and bottom tray allows pressure measurements of the soil horizontal and vertical pressures. The bottom elements simulate one-parameter subsoil. Vertical symmetrical bearing load capacity of the samples was implemented as static pressure in the range 0-19,62 kN, through a rigid steel square plate, with a side of 0.32 x 0.32 m, located horizontally and centrically. The construction details of the test station can be found in publications [6-11]. Reinforcement was placed horizontally in the samples, specifically perpendicularly to the load surface- in this case (Long N. T. F. and Schlosser) maximum anisotropic cohesion was reached [2, 3, 12].

Due to the comparative nature of the research, the test results, for the soil base reinforcement, were compared to the results obtained for the standard samples (without reinforcement). The graphs shown in figure 2 present single horizontal pressure of samples, reinforced with single, triple and two singles fleece, placed in levels covering the zone of maximum side pressure of the soil. The numbers in parentheses indicate the percentage of horizontal pressure reduction, relative to the pressure of non-reinforced sand.

Figure 3 presents a graph of reinforced sand horizontal pressure: fleece, geo-grids, and, comparatively, grid of steel bars of diameter d = 3.5 mm square and of square holes 32 x 32 mm (rods shaped spatially).

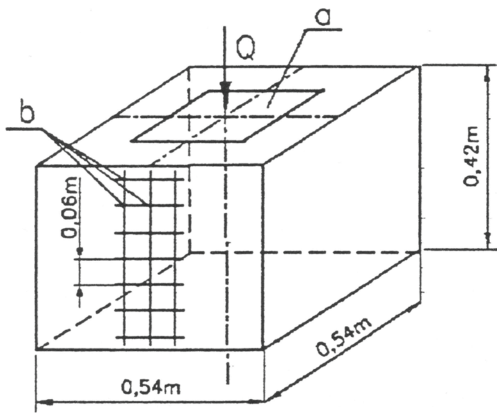

Fig. 1. Construction and basic parameters of the test station[6-11]: a - overloading plate; b –sensors of horizontal pressures.

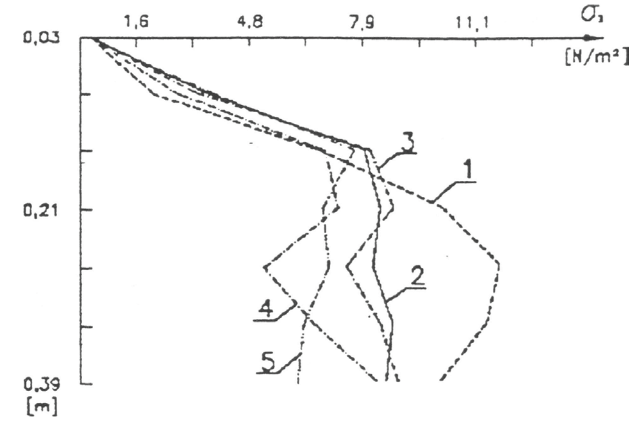

Fig. 2. Individual horizontal pressure on the height of the sample of reinforced sand [11]: 1 – non-reinforced sand; 2 - a single fleece reinforcement at the level of 0.21 m (86%); 3 - another type of fleece single level of 0.21 m (85%); 4 – triple fleece at the level of 0.21 m (69%); 5 - two single fleece at the levels of 0.21 m and 0.33 m (70%). 19.62 kN load condition, poured loose sand.

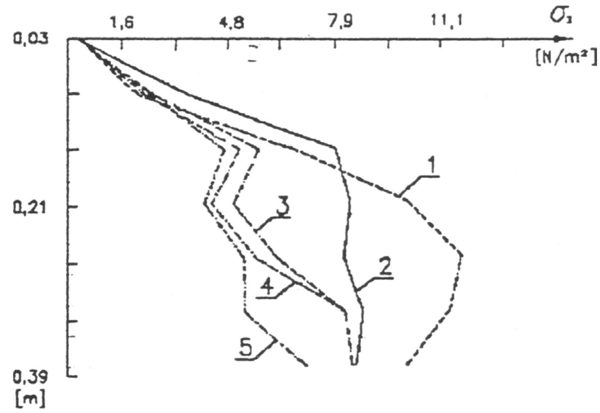

Fig. 3. Side pressure of a loose poured sand sample with a load capacity of 19.62 kN [11]: 1 - a pattern; 2 - a single fleece on the level of 0.21 m (86%); 3 - single horizontal geo-grid 0.21 m (57%); 4 - single steel grid; 5 - two geo-grids on the levels of 0.21 m and 0.33 m (44%).

The numbers in brackets indicate the percentage of reinforcement efficiency. Sand side pressure reduction, by applying flexible, but high-strength geo-grids, is comparable with the effect of reinforcement with steel grid. At the test station there is a possibility of generally active pressure bench measurements. Therefore, the K pressure coefficient may vary in the range of K0 quiescent to K_{min} value. K_{min} value is an equivalent to the pressure coefficient in a limit state of an active horizontal stress by Rankine. The experimental values of the internal friction angle, of reinforced and non-reinforced sand, were determined from the dependence of the overall according to [2, 3, 7, 8, 9]:

$$\sigma_{3min} \cdot (\sigma_{1max})^{-1} = K_{min} = \tan^2 (45^0 - 0,5\ \varphi) \quad (1)$$

where K_{min} is, obtained from the tests, a coefficient of horizontal pressure in an active limit state of horizontal stress σ3 (σ3 < σ1), while σ1 is vertical stress.

Figure 4 shows the effect of increasing the sand internal friction angle, in function of the number of reinforced inserts: mats and geo-grids located at the level of 0.21 m. Assuming, that reinforced soil acquires the characteristic of the anisotropic cohesion [2, 3, 11, 12], the change in function of the amount of reinforcement can be determined, with the following equation:

$$c = f_0 = \tan (45^0 + 0,5\ \varphi) \cdot (2\ e)^{-1} \quad (2)$$

where f_0 - strength tensile reinforcement calculation per unit of a layer width; e - vertical distance between horizontal layers of reinforcement.

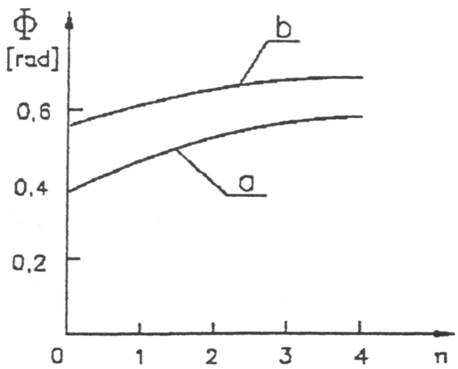

Fig. 4. The effect of increase in the angle of internal friction of the sample sand reinforced with fleece and geo-grid located on the level of 0.21 m [9, 11]; 0 – non-reinforced; 1- single fleece; 2 - Double fleece; 3 – triple fleece; 4 - single geo-grid; and - sand poured loosely; b - pre-compacted sand.

The phenomenon of coherence leads to the soil increased shear strength. The impact of reinforcement on the soil increased shear strength can be determined based on the results of research, taking as a basis the criterion of Mohr-Coulomb [2, 11, 12].

$$\tau_f = p_z \cdot \tan \varphi + c \quad (3)$$

where, according to [2, 3], p_z is vertical tension defined by the equation (which is also analytical graph description of reinforced soil sample destruction, on the level of principal tensions)

$$p_z = p_y \cdot \tan^2 (45^0 + 0,5\ \varphi) + p_0 \quad (4)$$

while p_0 is vertical tension (so-called beginning) expressed by dependence:

$$p_0 = 2\ c \cdot \tan (45^0 + 0,5\ \varphi) \quad (5)$$

or

$$p_0 = f_0 \cdot \tan^2 (45^0 + 0,5\ \varphi)\ e^{-1} \quad (6)$$

Symbols in the formula (6) are the same as in equation (2). The tension p_0 is the largest load value, at which in the reinforced soil there is no horizontal deformation. The higher the tension value p_0 is, the greater the efficiency of the reinforcement is.

If the settling of the reinforced soil sample of the height h equals Δh and results from vertical compressive tension p_z, the experimental strain rate $E_{d,0}$ is:

$$E_{d,0} = p_z \cdot h \cdot (\Delta h)^{-1} \quad (7)$$

The strength parameters of the soil samples, for different cases of horizontal reinforcement, are shown in fig. 5 [9, 11].

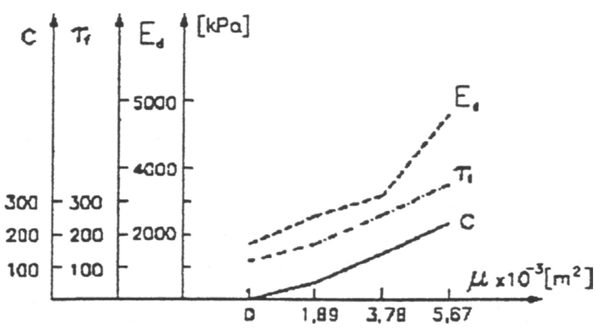

Fig. 5. The strength parameters of soil samples as a function of the amount of reinforcement with geogrids (μ - the percentage of reinforcement) [9, 11].

3. BEARING CAPACITY OF TWO LAYER REINFORCED SOIL BASE

Solutions of labour theory of reinforced soil (used in civil engineering) developed so far, basically refer to ground-base (monogenic). In practice there are usually layered soils, for example foundation of roads with different physical properties in particular layers. Below the results are shown, of loose two-layer base reinforcement deformability, subjected to vertical static loading. The aim of the study was to identify the fundamental physical phenomena, that characterize behaviour of loaded two-component reinforced base, as a function of adopted variable factors. A test station is shown in figure 1.

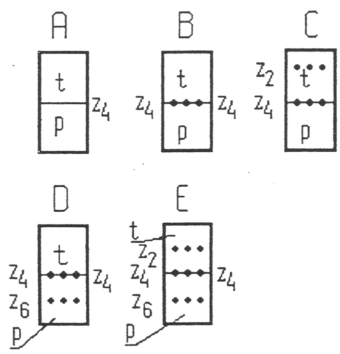

Fig. 6. Diagrams research models [10]: A model is a model (without reinforcement) t - rubble, p - sand, ... reinforcement --- boundary of base layers, *z* - level location of reinforcement or boundary of base layers.

The figure 6 presents research models diagrams: two-layer base samples [10].

The layers differ in particle size distribution and the internal friction angle: crushed basalt 20/40 (φ = 38°) and coarse sand (φ = 29°). Reinforcement in the form of a grid of high-fibre polyester weave a simple mesh size 14 x 14 mm. Mesh size of the mesh is adapted to the size of sand grains, so that the efficiency of the reinforcement material is much greater than that of chipping. Grains of crushed stone are quite large in relation to the size of the grid reinforcement and applied to be reckoned with slides. Load samples in the range 0-0,15 MPa was carried out the same as in studies deformation uniform medium. Charts horizontal pressure models, base reinforcement geo-grids illustrated in figure 7.

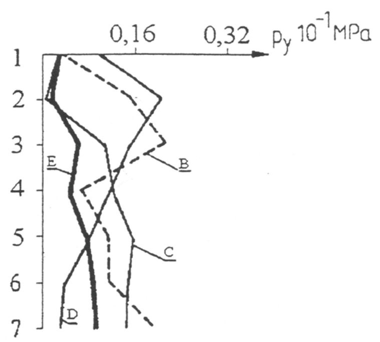

Fig. 7. Charts horizontal pressure models, base reinforcement geogrids [10]: B, C, D, E - models.

For individual models the shear strength τf and experimental indicator strain Ed, 0, which was considered as the bearing capacity of the base, are calculated. These parameters are calculated from the formulas given in the previous section and summarized in table 1.

Table 1. Endurance parameters of samples [10].

Model	τ_f [kPa]	$E_{d,0}$[kPa]	K
A	113.75	1,692.18	0.78
B	173.61	2,542.61	0.41
C	258.84	3,578.26	0.30
D	201.17	3,174.36	0.32
E	346.31	5,316.92	0.21

4. BEARING CAPACITY WITH COMPLEX REINFORCMENT

The diagram and the basic parameters of the test station and the methodology of the research are presented above. Complex reinforcement (called the "mattress") is a system of two horizontal planes (mats or nets), cooperating with each other. Reinforcement mat is constructed from two geo-grids with holes of 14 x 14 mm, separated by grit, forming a closed coating [10].

Schemes research models can be found in figure. 8 [10]. The test results of the side pressure are shown in figure 9 [10]. A sharp reduction in the value of the horizontal pressure, in relation to the pressure of the sample, reinforced with two cylinders, arranged independently, was observed. Reducing the horizontal pressure is a function of, among others, the thickness of the mattress.

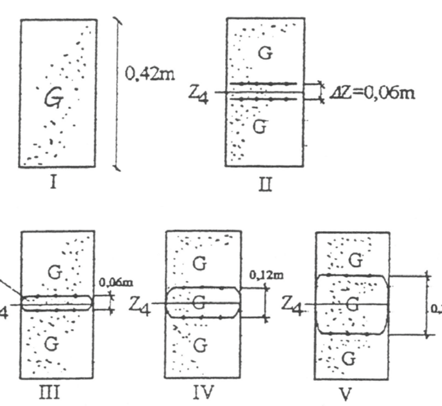

Fig. 8. Diagrams research models [10]: G - basalt grit; I-V - models; z4 - reinforcement location level.

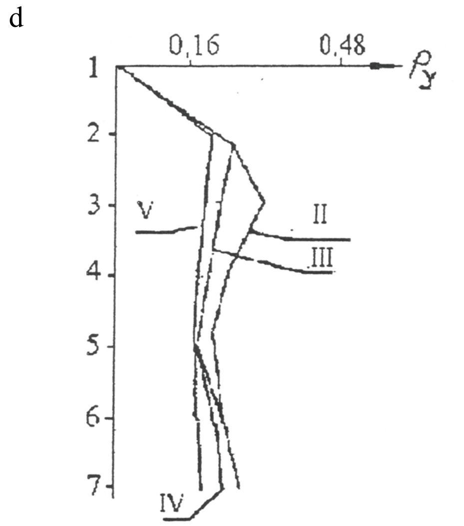

Fig. 9. Horizontal pressure for models II, III, IV, V, [10].

In order to evaluate test samples resistance to an external load, so called experimental rate of deformation was calculated, using the formula (7). The results of the calculations are presented in the table 2 (the sample load q = 0.19 MPa).

Table 2. Endurance parameters of samples [10].

Model	Strain indicator $E_{d,0}$ [kPa]
I	1016,92
II	1760,36
III	1946,18
IV	2211,60
V	2300,41

5. FINAL REMARKS

The influence of reinforcement with geo-textiles on horizontal pressure reduction was observed, and also the influence on the associated reduction of subsidence (considered as growth capacity) high dimensional sample of non-cohesive sample. These influences are dependent on the inserts number and arrangement The effects of reinforcement with geo-grids of woven high-strength polyester fibres are not only qualitatively, but also quantitatively comparable with the effects of the reinforcement with metal nets with rigid rods.

Under certain conditions, internal friction angle φ of the material sample reinforced with geo synthetics increases to a degree, comparable with metal nets reinforcement. Increasing the value of the angle φ is dependent on the number and arrangement of the inserts.

In the base initially concentrated, reinforcement effects are smaller than loosely poured (approx. 10%), which is the basis of conclusion, that the most effective is the reinforcement of weak soil, therefore of smaller value of internal friction angle.

Incorporation of reinforcing layers in the road surface, can contribute to vertical stress reduction by more than 30%, as a result of more favourable distribution of the stress. Reinforcement work efficiency is dependent on the soil and inserts characteristics.

In the laboratory model of reinforced soil, it is possible to control the course and urge value, of bulk soil medium two layer system, taking into account the following possibilities: proper selection of components volume, location and selection of reinforcement, and reinforcement parameters.

With a single insert reinforcement, it can be placed at such a depth in the matrix ground, that minimum pressure in two layer model is obtain, with minimal participation of the layer with favourable mechanical characteristics.

The results confirmed the rationality of reinforcement use in the form of "mattress" in soil base. This type of reinforcement generates further reduction in horizontal base thrust (limiting deformation, both horizontal and vertical) of at least 15%, with reference to the horizontal pressure of soil base, reinforced with two independent inserts, at the levels corresponding to the location of both the horizontal (top and bottom) surfaces of the mattress. An additional effect is dependent on the width of the mattress (determined by vertical spacing of the reinforcement horizontal planes) and on the type of coating material (characterized by tensile strength and stiffness of the material and friction resistance in soil base).

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