

Lateral Earth Pressure in Non-Cohesive Soils, Reinforced with Geotextiles in the Light of Laboratory Research

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The subject of the paper is the non-cohesive medium layer with geotextiles reinforced as foundation in communication building engineering. The influence of horizontal bidirectional reinforcement on the change of value of horizontal pressure in the laboratory physical models of ground medium layer is estimated. The most important effects reinforcement have been observed, regarding increasing model load capacity.

Keywords: geotextiles, reinforcement, ground medium, earth pressure.

1. GEOTESYNTHETICS AS A WAY OF REINFORCING COMMUNICATION BUILDINGS

Soil reinforcement with synthetic materials (also called geotextiles or geosynthetics) in civil engineering emerged in the late 60s and 70s. [4]. Their numerous advantages contributed to introducing geosynthetics. Their advantages have been analysed in the literature, for example. [2, 3, 4, 13, 14]. Some of them are listed as follows:

- Adequate tensile strength, durability, insensitivity to aggressive chemical influence;
- Ability to ensure appropriate cooperation with the medium soil;
- Significant flexibility, allowing use on highly deformable soils;
- Uncomplicated technology of geotextiles incorporation.

Geotextiles can play at the same time several functions (for example filter, drain, reinforcement layer, separating layer). Geotextiles used nowadays in construction of reinforced lands are as follows: textiles, non-woven polyester fabric, mesh surface, made of plastic (also called geogrids), composite strips, cellular mattresses [2, 4]. Geogrids of glass fibres used as reinforcement of bituminous road pavements, polypropylene fibres in polyethylene (which plays two functions: filtration and separation), drain or separate geo composite, made

of filter grid, wrapped in non-woven fabric or with non-woven fabric on one side, and on the other side with plastic foil (functions: ground reinforcement, ensuring embankments stability), are among the new generation geotextiles [3, 13, 14].

Reinforcement of ground structures with geosynthetics is made of various types of plastics [4, 13], for example polyethylene, polypropylene, polyvinyl chloride, polyester, polyamide, chlorosulphonated polyethylene. Currently, there are technological possibilities of obtaining geosynthetic materials with the desired coefficient of friction relative to the centre ground, therefore the problem of ensuring quality of interaction between these components has been solved. Therefore, in geosynthetic retaining structures, instead of, originally required, non-cohesive soils, lower quality material can be used, such as dusty sand or sandy clay.

S. Rolla [4] classifies geotextiles according to the method of manufacturing, dividing them into two groups: geotextiles of the first and second generation. the woven and non-woven geotextiles are the first generation geotextiles. Geotextiles of the second generation are called complex, and among them we can list, among others, synthetic composites, geotextiles formed by the combination of non-woven fabrics or impregnated and so-called mattresses, or spatial structures (*geocell mattress*). The mattresses are used, among others, to

strengthen the ground beneath road surfaces or embankments bodies.

Reinforcement with geosynthetic tapes of *Paraweb-2S®* composite has been applied since 1992 in retaining structures [13]. The tapes are composed of high strength, corrosion-resistant, polyester fibres, protected by polyethylene.

Generally speaking, geotextiles can be used as:

- Strengthening of the ground (foundations, embankment, roads, airport runways, etc.)
- Drains, filters and layers of separation in road or rail pavement and in the ground beneath communication embankments,
- Embankments with vertical walls reinforcement, slope stability protection,
- Strengthening the surface, for example road surface and preventing the so-called reflected cracking, which occurs in the upper surface of the foundation due to errors in base layers.

Over the last years, innovative technologies in civil engineering, have been introduced, based on the use of geosynthetic reinforcements modified systems [5]. Global standards require geosynthetics technical efficiency for a period of 80-120 years, and keeping over this period at least 80% of the value of technical parameters, that geosynthetic had at the moment of its incorporation [1].

For the need of this paper, geotextiles as considered as reinforcement of road base. Analysis of the three-dimensional strain state of reinforced soil is carried out, based on the results of experimental studies, made on physical models, developed on the laboratory scale.

2. SITE, MODELS COMPONENTS AND THE RESEARCH METHOD

Models of soils were placed in a rectangular steel tray of dimensions 0.54 x 0.54 m in a plan and height $H = 0.42$ m (fig. 1) [6-13]. It is designated for vertical and horizontal deformation models testing, simulating representative road surface work. The construction of the walls and of the bottom allows to estimate the unit value of the unit of the lateral thrust and of vertical pressures of ground model to the bottom, on the basis of measurement of linear, horizontal and vertical displacement of the model. The walls reflect resistance of the areas of the medium surrounding the model, while the bottom is modelled single-parameter ground (Winkler type).

The walls and the bottom of the container consist of a stationary frame, with mechanical

pressure sensors installed on its entire surface. They are completed with modular elements with dimensions of 0.06 x 0.06 m, acquiring independently local soil medium pressure. The surfaces form a regular array of level measurement and of columns, forming a single plane of inner walls and of the bottom of the container, with a square grid with a side dimension $M = 0.06$ m.

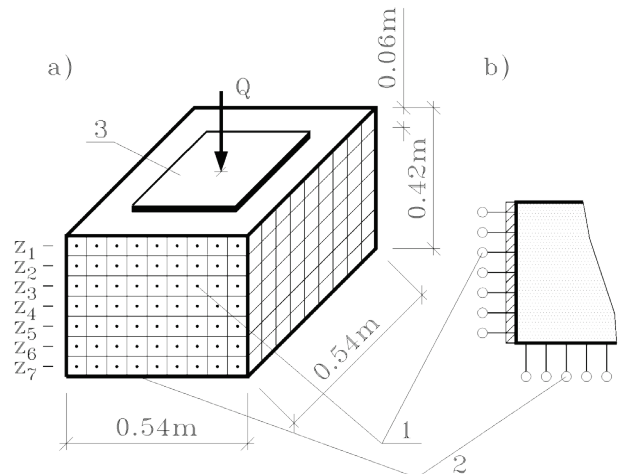


Fig. 1. The scheme and basic parameters of the test [6-13]: a - general view, b - vertical section through the wall 1 - Mechanical sensor of horizontal pressure 2 - vertical pressure sensor, 3 - plate overloading with dimensions 0.32 x 0.32 m transferring the load on the sample of reinforced soil (model), $z_1 = 0.03$ m; $z_2 = 0.09$ m; $z_3 = 0.15$ m; $z_4 = 0.21$ m; $z_5 = 0.27$ m; $z_6 = 0.33$ m; $z_7 = 0.39$ m - horizontal measuring Q - vertical static load test [kN] (Station is located at the Institute of Civil Engineering at Wrocław University of Technology).

Horizontal stress, which is soil pressure (in the range of from rest to the border of the active) in any module of the container wall is calculated by multiplying $\sigma_y = C_s \cdot y$ [N/m²], where C_s is the elasticity constant of the single-wall pressure sensor, and y - horizontal displacements of the module against the centre ground, recorded by linear displacement sensors.

The rule is identical in the case of calculating the pressure of the soil sample to the substrate.

A model of external static load (soil layer) was introduced, as centric vertical load, with Q concentrated force in the range 0-19,62 kN. It was realised with hydraulic lift, by the means of the rigid, square, steel plate located horizontally on the model ceiling with a side of 0.32 m. Maximum load range was adopted, in such a way, to avoid displacing soil material from below the plate and not to exceed the range of the sensors and the

displacement area of the elastic mechanical sensors pressure. With the value of $Q_{max} = 19.62$ kN, the unit pressure of the plate loading model of ground is: $q_{max} = 0.19$ MPa.

Road surface models were made of a matrix and reinforcement inserts.

The matrix was a thick sand, having a particle size ratio $U = d_{60} \cdot (d_{10})^{-1} = 1,66 < 5$. Physical characteristics were as follows: bulk density of 16.90 kN / m³, moisture 0.3%, angle of internal friction of loosely spread state $\varphi = 30^\circ 20'$ (I_{DI}), after the initial concentration $\varphi = 36^\circ 40'$ (I_{DIX}). The concentration took place during the initial loading process to the Q_{max} value and relieving by the means of the force to zero (I_{DIX}).

The role of the reinforcement insert is, partially, taking over the horizontal forces of lateral pressure, generated by stress from the vertical load of soil. Accordingly, the reinforcement was located horizontally, perpendicularly to the plane of the load. The model in question of medium ground is in a spatial state of tension and deflection. Therefore, due to the horizontal forces directions, mat, grid or mesh are suitable forms of reinforcement. The construction of the container enables axial symmetry of the load and deformation of the tested ground sample (the model). Considering orthogonality direction of the principal tensions, plain was used as reinforcement, in the directions corresponding to the directions of principal axes in relation to the horizontal projection of the container and the planes mat. The reinforcement inserts were thus made of the materials:

- Fortrac® R 90/90-20 geogrid T (polyester with polymer coating) [1]: $M_p = 780$ g/m² superficial mass, $R_{r,pd} = R_{r,pp} = 90$ kN/m (isotropic material) tensile strength on both directions,, $\varepsilon_r \leq 10$ % elongation at break in two directions, 20 x 20 mm mesh size,
- Typar® SF 111 geo-nonwoven material (polypropylene fibres) [3]: $M_p = 375$ g/m², $R_{r,pd} = R_{r,pp} = 30$ kN/m (isotropic material), $\varepsilon_r \leq 55$ %,
- Fibertex® geotextile F-45 M [1]: $M_p = 500$ g/m², tensile strength in longitudinal direction $R_{r,pd} \geq 26$ kN/m, $R_{r,pp} \geq 36$ kN/m, $\varepsilon_r \leq 75$ % in the transverse direction.

3. THE RESULTS OF THE RESEARCH ON GROUND MEDIUM MODEL DEFORMATION

Designing research tests, the research questions have been asked, on the issues of:

- The impact of reinforcement on reducing ground deformation,
- The relationship of quantity and distribution of the reinforcement in the centre ground, with the size of the total lateral pressure force and distribution of unit ordinates pressure,
- Area of reinforcement influence in the medium, depending of inserts quality and on material (model matrix).

Lateral earth pressure of sand models, reinforced with geotextiles.

2. Research laboratories programme is presented in the table No 1., while the research models schemes in the drawing No 1.

Table 1. The laboratory test models of sand, reinforced with non-woven materials [13].

Test number	Kind of reinforcement	Number of reinforcement inserts	Reinforcement arrangement
1	geotextile mat /non-woven material or geogrid/	Single geotextile mat or geogrid at the depth	$z_2 = 0.09$ m
2			$z_4 = 0.21$ m
3			$z_6 = 0.33$ m
4		Triple geotextile mat at the depth	$z_2 = 0.09$ m
5			$z_4 = 0.21$ m
6			$z_6 = 0.33$ m
7		Two single geotextile mats at the depths	z_2 and z_6
8			z_4 and z_6
9			z_5 and z_6
10	Three single geotextile mats at the depths	z_2 and z_4 and z_6	

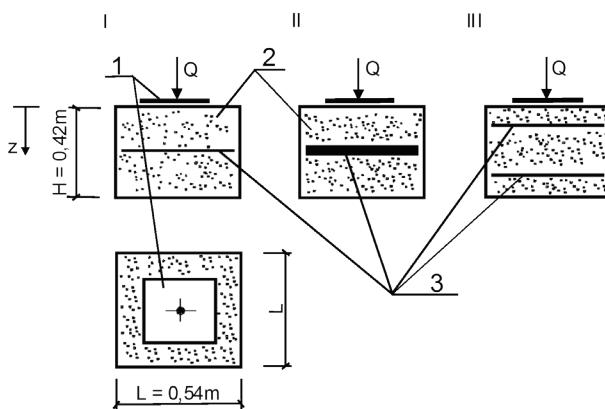


Fig. 2. Research models schemes [13]:

- I - reinforcement with single geotextile / geogrid at a variable depth;
- II - reinforcement with triple geotextile / geogrid at a variable depth;
- III - two single geotextiles / geogrids at a variable depth of the model;
- 1 - plate overloading 0.32 x 0.32 m;
- 2 - the medium ground (sand);
- 3 - geotextile / geogrid.

Fig. 3 illustrates horizontal pressure of sand samples reinforced with geotextiles, localized on stable measurement level, $z_d = 0.21$ m, with a load of $q = 0.19$ MPa. Achieving the characteristics of elasticity in samples, reinforced with geosynthetic mats is relatively delayed in relation to the comparative reinforcement- geogrid. The total lateral pressure in relation to the standard rate (model without reinforcement), obtained with a load of $q = 0.19$ MPa are given in Table. 2.

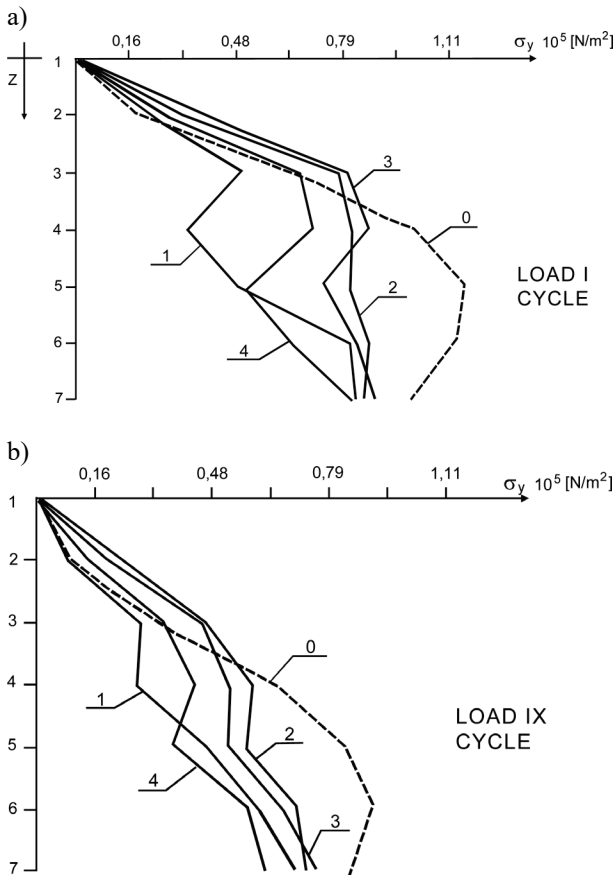


Fig. 3. Lateral pressure of samples of sand reinforced with geosynthetics [13]: a - I cycle load b - series IX load 0 - pattern (model without reinforcement), 1 - Fortrac® geogrid R 90 / 90-20 T 2 - single geotextile Typar® SF 111, 3 - single geotextile mat Fibertex® F-45 M, 4 - triple Typar® SF 111. The inserts on measuring level $z_d = 0.21$ m. State of test load $q = 0.19$ MPa.

Geotextile mat (geotextile, Geo-textile), due to its structure stratifies matrix model (grainy medium), therefore the conditions of its work are other than the grid, the slated openwork element, where some grains of soil can freely move through its holes. It is material deformable to a large degree. Soil cooperation with this type of insert it is possible by way of friction. Mass soil

displacement (particles of grain) caused by deformation, due to the load, is possible only along the surface of the mat. In contrast, vertical movements of soil grains, located in the zone of contact with the mat, are a result of vertical deformations of the mats or central and local deflection, trough deformed surface, or as a result of subsidence within the overall plane of the geosynthetic.

The mat deforms to a large degree, under the influence of the load, placed vertically on the ceiling model and sinks together with the overburden soil. The size of subsidence depends on, among others, the location of the inserts in the ground model.

Based on the research results, functioning of the two phases of geosynthetic mats can be observed, in mechanical terms:

Phase I - subsidence (vertical movement) of the mat with overlay of the loaded soil.

Phase II - the partial acquisition of the tensile forces from the soil medium, by way of friction. the mat is deformed, in the form of a central basin. As expected, also vertical deformation of the mat is observed, which consists of crushing (compression) of the mat plane under the influence of the vertical component of tension. The geosynthetics are extended in both directions. ΔL growth of the length ($L = 0.52$ m is the dimension of the side of the square surface of the mat used in the study) is accompanied by the cross-section decreasing (thickness) of the mat:

$$\Delta t = t - t' = t \cdot \nu \cdot \varepsilon \tag{1}$$

where:

t – primary thickness of the mat [mm];

t' – thickness after deformation [mm];

$\varepsilon = \Delta L/L$ individual longitudinal deformation; unit

ν - transverse expansion coefficient.

Horizontal tearing forces, from tension of horizontal friction in the loaded soil, can have influence on the numerical value of the element Δt . The non-woven material, by way of friction, takes over partially these forces. Changing the value of Δt . depends on:

- subsidence caused by permanent changes in the medium soil (for example consolidation)
- subsidence, which is the result of elastic deformation of the soil grains.

Table 2. The total lateral pressure R_y^* in relation to R_y [13].

Kind of reinforcement	Reinforcement distribution z_k [m]	Total lateral pressure R_y^* [%] in relation to the model $R_y = 100$ [%]			
		Cycle I of loading $Q = 19.62$ kN		Cycle IX of loading $Q = 19.62$ kN	
		<i>Typar</i> ® SF 111	<i>Fibertex</i> ® F-45 M	<i>Typar</i> ® SF 111	<i>Fibertex</i> ® F-45 M
Single geosynthetic mat	$z_2 = 0.09$	97.44	98.03	98.04	98.49
	$z_4 = 0.21$	84.12	84.64	89.71	89.90
	$z_6 = 0.33$	97.61	97.73	98.19	98.41
Geogrid <i>Fortrac</i> ® R 90/90-20 T	z_2	73.31		75.43	
	z_4	52.08		55.94	
	z_6	69.09		72.23	
Plane of trip geosynthetic mat	z_2	88.10	89.11	90.66	91.29
	z_4	67.73	67.91	89.31	89.71
	z_6	89.08	89.31	90.68	91.41
Two planes of single geosynthetic mat	z_2, z_6	80.47	82.01	81.28	83.99
	z_4, z_6	69.11	70.33	71.34	71.89
	z_5, z_6	83.04	84.78	84.66	85.16
Two geogrids <i>Fortrac</i> ® R 90/90-20 T	z_2, z_6	46.89		50.46	
	z_4, z_6	37.98		41.78	
	z_5, z_6	49.03		52.11	
Three planes of single geosynthetic mat	z_1, z_4, z_7	67.96	69.03	69.12	71.22
	z_2, z_4, z_6	59.11	60.51	61.53	61.42
	z_3, z_4, z_5	67.07	67.22	69.27	70.41
Three geogrids <i>Fortrac</i> ® R 90/90-20 T	z_1, z_2, z_7	65.84		70.47	
	z_2, z_4, z_6	22.12		33.16	
	z_3, z_4, z_5	26.41		33.02	

Δt value can be permanent deformation, partial, or totally flexible. The degree of Δt , the single mat "pressing", depends, among others, on the number and distribution of the inserts.

Impact of geosynthetics on reduction of lateral pressure and on changes of pressure diagrams has been observed, depending on the number and distribution. The effects of geosynthetics in terms of volume, are lower, than, for example of *Fortrac*® R 90 / 90-20 T geogrids, for which a reduction in horizontal pressure in the range of 50% has been obtained. Only the triple layer of geotextile provides the reduction of lateral pressure of more than 30%. Qualitative phenomena have similar character and similar effect to the *Fortrac*® geogrids, because there is also a reduction zone of pressure ordinates. However, maximum reduction of pressure ordinate takes place below the level of the geomat location, because, due to the load of the soil, the geotextile settled in the first phase of work. (Fig. 3, curves 2, 3, 4).

Fig. 4 shows the enlargement of the angle of ϕ internal friction of the sand models, depending on the method of reinforcement with *Typar*® SF 111 geotextile, located on the test level of the test container $z_4 = 0.21$ m (the centre of the height of the model), a single, double and triple non-woven fabric. The angle of internal friction is a parameter determining the shear strength of the models,

which is a measure of the load. The curves in Fig. 4 relate to: loose sand (a) and pre-compacted sand (b) [13]. The ϕ , angle of internal friction was calculated according to, well-known in the geotechnical formula, for the event of a border state in the active non cohesive medium [13]:

$$\sigma_{y,min} \cdot (\sigma_{z,max})^{-1} = K_{min} = \text{tg}^2 (45^\circ - 0,5 \cdot \phi) \quad (2)$$

where:

K_{min} – experimentally obtained, coefficient of lateral pressure of the border state of active horizontal tensions σ_y , ($\sigma_y < \sigma_z$), σ_z – vertical tension

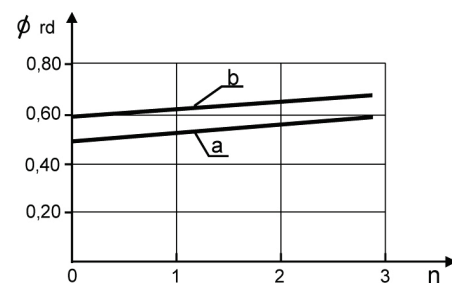


Fig. 4. ϕ , angle of internal friction of the modelled layer of the sand in the active border state of σ_y , horizontal tensions. Reinforcement with *Typar*® SF 111 geotextile at the $z_4 = 0.21$ measurement level [13]:
 $n = 0$ – non reinforced (model), $n = 1$ – reinforcement with a single mat, $n = 2$ – with a double mat
 $n = 3$ – with a triple mat, a – non-condensate sand, b – condensate sand.

As it results from the analysis of the impact of the reinforcement insert on the reduction and run of the curve of the lateral pressure, below and above economic distribution of the reinforcement, its impact on the reduction of the horizontal ground pressure decreases. When the inserts are placed at the extremes, (fig. 5 a, c), the v , area of the impact of the reinforcement is minimal. Central distribution of the reinforcement (fig. 5b), is characterised by the area of impact of $v = v_{max}$, maximum reach, and maximum reduction of lateral pressure, resulting from this fact.

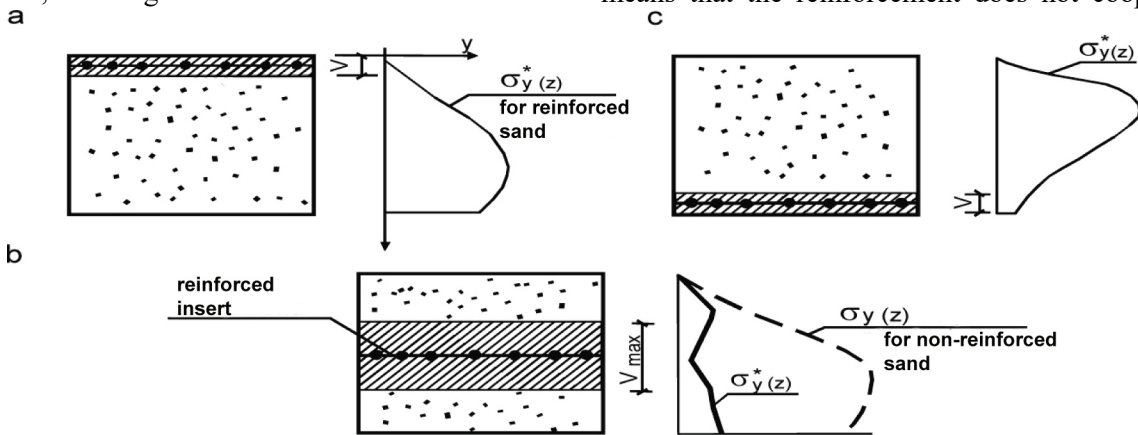


Fig. 5. The local area of homogeneity of the composite (referred to the vertical width v) as a result of interaction of the soil with reinforcement [13]: a, c – extreme distribution of the insert; b - Economic location of inserts --- lateral pressure of reinforced medium; - - - Pressure of non-reinforced medium.

The area of the v impact depends, among others, on the kind and state of the soils, and on the factors regarding reinforcement (for example geometrical and material parameters of the inserts, distribution of the inserts). Cooperation "granular medium - reinforcement" is satisfying, when the inserts do not separate the soils, are rigid enough and are characterised by a large degree of resistance on tension, and are situated in a zone of maximal ordinates of lateral pressure, measured for non-reinforced medium. The highest efficacy of the reinforcement, considering reduction of the earth pressure, takes place, when the values of the ordinates on the σ_y pressure diagram are maximum. The most beneficial case of the reinforcement distribution, is, when, the area of "cooperation" of the reinforcement with the soil covers with its range the largest possible area of the diagram of the lateral pressure of the non-reinforced medium.

In the case of reinforcing a ground medium with two inserts, their common distribution (vertical arrangement $\Delta z = \Delta z_{border}$) can be designated in such a way, that the maximum reduction of the lateral pressure, and the same

time, the highest possible efficacy of the work of reinforcement achieved. In this case the curve of the individual lateral pressure (diagram) between the layers of arrangements of neighbouring inserts does not show any convexity or concavity (case I on the fig. 6), and probably the areas of the impact contact. Enlarging the vertical inserts spaces over Δz_{border} affects negatively the reduction of the lateral soil pressure - case II in Fig. 6: the curve of the earth pressure between the levels of the location of the inserts has a convex shape, which means that the reinforcement does not cooperate

with each other through their zone of influence of the medium.

Decreasing the vertical spaces below the Δz_{border} is connected with the impact zones overlapping- a similar effect takes place, similar to the distribution of the lateral pressure of the ground reinforced with the single insert (case III-fig.6: a fragment of the ground lateral pressure curve between layers of insert arrangements has concave shape).

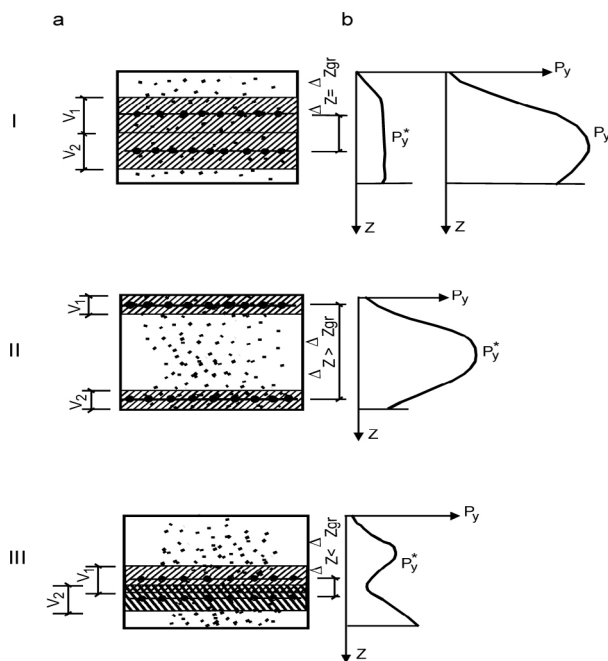


Fig. 6. zones of local homogeneity of the double-reinforced medium [13]: a - cases I, II, III zones of interaction of ground with inserts for two reinforcement layers; b - graphs unitary lateral pressure resort reinforced p_y^* for the cases I, II, III; v_1 , v_2 - the vertical dimension of cooperation zone.

4. SUMMARY

1. Reinforcement, arranged perpendicular to the plane of the load, increases the load capacity of the soil layer, loaded vertically, due to reduction of vertical and horizontal deformation. Reduction of distortion improves strength parameters. Smaller vertical deformation of tensile soil is connected with reduction of the horizontal pressure. Reinforcement partly takes over the strength of the horizontal soil pressure.

2. Reinforcement cooperates with the soil in the area around the reinforcement. In the area of the reinforcement impact, the soil- fragmented non-homogenous medium, obtains locally characteristics of homogeneity.

3. In the case of pre-concentrated soil, the impact of the reinforcement on the size of subsidence and lateral pressure is smaller than in loose soil. With increase of the soil compaction degree, the angle of internal friction increases and the role of the reinforcement in the specified load range reduces. The efficiency of the reinforcement is thus the largest in weak soils, showing a small value of the internal friction angle.

4. Geotextiles impact on reducing lateral pressure and reduction of vertical deformation was proven, depending on the number and distribution

of non-wovens in the ground medium. A textile mat reduces lateral pressure to a much lesser extent than the geogrid. Observations on the behaviour of the loaded soil medium, reinforced with geotextiles, are the basis for the construction design (light-weight, low-cost, simple technology, with fast installation and reliable in operation) in the field of road engineering, railway and bridge construction.

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