INFLUENCE OF SOIL BACK PRESSURE OF THE LOWER SLOPE ON THE DISTRIBUTION OF PRESSURES BETWEEN THE ROWS OF THE PILES OF THE MULTI-ROW RETAINING STRUCTURES

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ABSTRACT

In the article, the results of the estimation of an influence of soil back pressure of the lower slope on the distribution of the landslide pressures between the rows of the piles of the multi-row retaining structures. The conditions of a stable soil and an unstable one as well as a dugout from the lower slope side have been considered. The analysis has been carried out on the basis of the distribution of the forces between the rows of the piles according to the spatial numerical model study data of the multi-row pile structures taking into account the elastic embedding of the piles below the slip surface as well as the rigidly fixed piles. It has been shown that soil development from the lower slope side in the immediate vicinity of the pile retaining structure results in a significant redistribution of the forces between the pile rows and the increase of the bending moments in the piles from the side of the dugout. A significant underload of the piles of the intermediary rows of the multi-row structures has been registered.

Keywords: anti-landslide retaining construction; soil back pressure of the lower slope; pile rows; distribution of landslide pressures; bending moments in piles.

INTRODUCTION

An increase of stability of the insufficiently stable dips and slopes as well as a landslide mass grouting are often carried out with the use of the pile retaining structures. Depending on the geological conditions, a multi-row arrangement of the piles is sometimes used in order to stabilize the soil. Efficiency, reliability and safety of the operation of such structure is conditioned mainly by a correct estimation of the landslide forces between the pile rows.

But at present, there is no unified approach as far as a nature and the quantitative characteristics of the distribution of the landslide pressures in the pile antilandslide structures are concerned. For example, according to some experimental data [3] an irregularity of the distributional property of the soil in a force transfer between the free pile rows was discovered. A uniform distribution of the pressures between the rows was obtained when the piles were united with the help of a rigid grillage. It has been shown that a soil type (sands and clay loams were compared) has no influence with a nature of the distribution of the pressures. According to the results of other trough tests [5] in the sand soil with the models of the free-standing piles (the piles that were not united with the help of a cap), it was registered that a difference in the distribution of the bending

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moments in the piles between the rows does not exceed 10%. On this ground, it is suggested to accept a uniform distribution of the landslide pressures between the rows of the piles being arranged chequerwise.

There are other investigation results. The laboratory experiments in the trough [1] have shown that a value of pressure on the piles in the rows depends on their arrangement in plan view. The found value of the pressure on the first row is greater than on the second row. When the distance between the rows is increased, this difference is increased as well. It has been registered that a distribution of the pressures between the pile rows value is changed depending on the landslide load level and the landslide soil type.

The own investigations of the authors within the framework of the numerical experiments in the flat position [4] show that the distribution of the pressures between the pile rows depends greatly on their arrangement in plan view as well as on the strength properties and the deformation properties of the soils. Maximal pressure in any quantity of the rows is exerted on the first row of the pile elements (up to 60% to 80%). Each next pile row undergoes smaller part of pressure as compared with the previous one.

The investigations in the spatial position [2] for a customary pile spacing used in the design practice (L=3D) and the rarefied one (L=6D) prove that the distribution of the landslide pressures between the rows of the piles and the internal reactions on them (without dependence on the conditions of fastening of their heads) is determined by the load level and is characterized by a significant irregularity. There was registered a qualitative and quantitative similarity of the distribution of the pressures between the rows of the piles being united with the grillage (being elastically embedded into the non-displaceable soil) with the results of not only spatial modeling with rigid fastening of the piles all along the full length, but of a plane problem solution [4].

We should note that all the above mentioned data mark an antilandslide structure state under the conditions of the soil back pressure of a slope, which is situated below. But in reality, soil mining of the lower slope is often carried out under a protection of the pile structures (for example, when the highways are made in a hilly country). The numerical investigations in the flat position for the single-row structure have shown that a stress-strained state of the soil near the piles depends greatly on a value of the soil back pressure of the lower slope.

In order to analyze an influence of the soils of the lower slope on the operation of the multi-row pile structures, we have made the numerical experiments, which enlarge and itemize the results of the investigations being carried out earlier: under the conditions of the stable state, the unstable one and a dugout of soil of the lower slope.

INVESTIGATION PROCEDURE

A series of the numerical experiments in the special position was carried out in order to investigate a distribution of the landslide pressures and a redistribution of internal forces between the rows of the piles. The computations were performed with the help of the finite difference method using *FLAC3D* program for the two-row pile arrangement, the three-row pile arrangement and the four-row pile arrangement. In the computation, there were used two numerical models: with elastic embedding of the piles into the non-displaceable soils below the slip surface and with rigid grouting of the piles.

Model with Elastic Embedding of the Piles. In plan view, a numerical model with elastic embedding of the piles is a fragment of a multi-row structure with the piles being arranged chequerwise, which is restricted by the symmetry planes, which intersect the centres of the piles of an even row and an odd row and are normal to the structure axis (Fig.1, a). In depth, the model is divided by the slip surface in the form of a contact surface between the landslide soils and the non-displaceable soils. Strength characteristics on the slip soil depend on the properties of the landslide soil and are determined taking into account the contact strength coefficient η_2 (Table 1).

In the rated diagram, each pile is given as a half of a shell of the circular section. Thickness of the shell is assumed to be such that its normal stiffness should be equivalent to stiffness for a stuffed concrete pile of a circular section. The piles can be united with the help of a grillage. In this case, their shells are extended to a mark of its top. The grillage is a shell of the rectangular section of such thickness that its normal stiffness should be equivalent to stiffness for a stuffed concrete grillage in a section

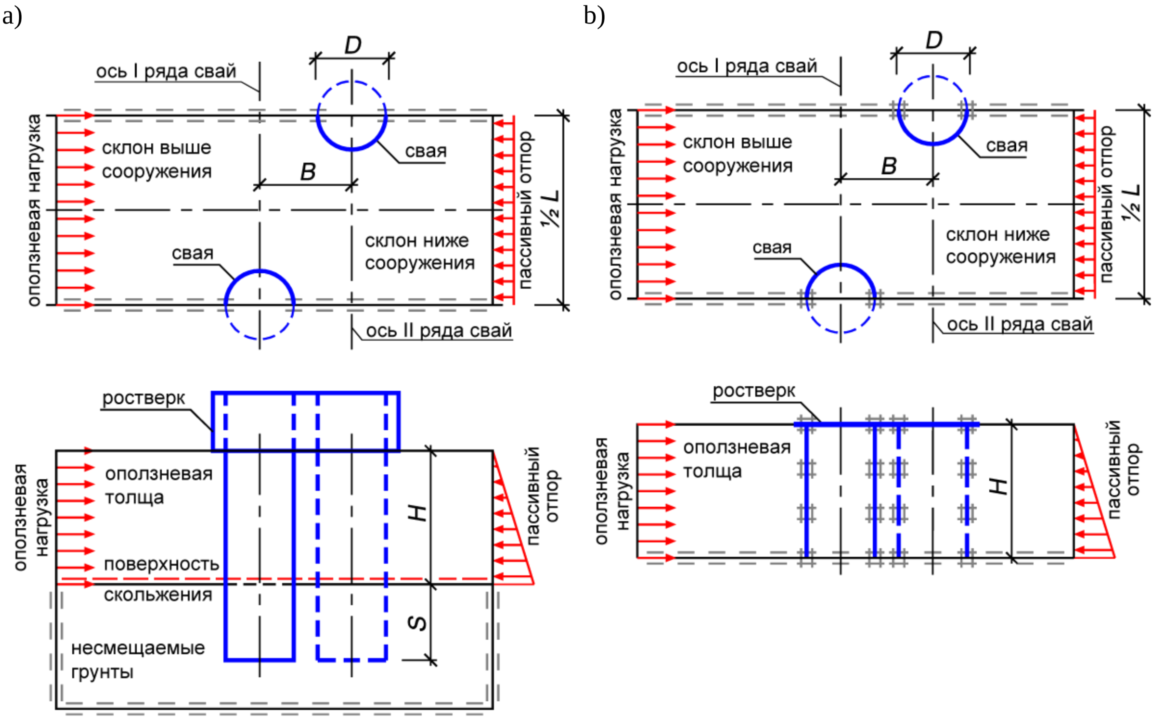

Figure 1. Design model of the spatial problem of the interaction of the soil with the piles of the two-row structure with (a) elastic embedding of the piles and (b) structure with rigid grouting of the piles (up view in plan, down view in section)

Table 1. Physicomechanical characteristics of the soils

Characteristics of soil	Value of	
	landslide soils	non-displaceable soils
unit weight γ, *kN/m*^{3}	18,9	22,0
unit cohesion *c*, *kPa*	38,0	–
angle of internal friction φ, *degree*	17,0	–
angle of dilatancy ψ, *degree*	0,0	–
modulus of deformation *E*, *MPa*	30,0	50,0
Poisson's ratio μ	0,38	0,15
strength coefficient at the contact with the pile η_1	0,6	–
strength coefficient on slip surface η_2	0,5	–

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between the rows of the piles. The shells of the piles and the grillage are fastened between them in the intersection points. In order to take into account, the possibility of a slip or a separation of the soil from the piles and the grillage, the contact surfaces between the soil and the shells are used. Strength characteristics on the pile surface depend on the properties of the landslide soil and are determined taking into consideration the contact strength coefficient η_1 (Table 1).

The following boundary conditions are accepted: there is a restraint of displacement in the normal direction along the plane of symmetry, along the downwardly directed plane of the model as well as below the slip surface along the planes from the sides of the upper part of the slope and the lower one; daylight surface is free; the pile shells are fastened in the plane of symmetry (a restraint of displacement in the normal direction and a turn round a trace of the intersection with the plane of symmetry of the model). The main dimensions of the model are accepted likewise [2].

The behavior of the landslide soil has been described with the help of Mohr-Coulomb model. The computations have been made for clay, the characteristics of which are given in Table 1. The strength properties of clays have been assumed according to the average data of the engineering-geological studies at some landslide entities of Krasnodar Region. The behavior of the non-displaceable soil has been described with the help of the elastic model. Their characteristics are given in Table 1.

In order to estimate an influence of the scale effect, the numerical experiments have been carried out for the piles of the model dimension and the as-built dimension with the ratio of the diameter and the length 1:25. The pile field configurations, which have been considered in the investigation, are given in Table 2.

The following variants of the conditions of an interaction of the soil of the lower slope with the pile structure have been considered: "stable" soil (the strength characteristics along the whole slip surface are assumed to be the same); "unstable" soil (the strength characteristics along the slip surface below the last row of the piles over the slope are assumed to be zero); "dugout" of soil of the lower slope (modelling of the dugout below the structure over the slope by means of stratified deactivation of the corresponding soil clusters).

Loading of the model included the following stages: the computation of stresses in the soil due to sole weight, the creation of the pile shells with soil deactivation in their volume, slip surface activation, dugout of the soil of the lower slope (if necessary) and the creation of a landslide load.

The landslide load was modeled by means of a boundary condition for landslide thickness in the plane of active landslide pressure upwards the structure over the slope in the form of the specified displacement (as nodal speed per calculated cycle). Soil

Table 2. Pile field configuration parameters

Parameters	Structure	
	model one	as-built one
pile diameter *D*, *mm*	20	500
relative spacing of piles in a row *L*/*D*	3,0	3,0
distance between pile rows *B*/*D*	3,0	3,0
landslide depth *H*/*D*	15,0	15,0
depth of pile embedding into non-displaceable soils *S*/*D*	7,5	7,5

back pressure was reckoned via a value of the lateral component of every day pressure of soil in the state prior the landslide in the plane of passive resistance below the structure over the slope (within the limits of landslide thickness).

Loading was carried out step by step with a constant gain of the displacements. Each step included a dynamic increase of the landslide displacement and a static balancing of the model. The following values were registered during the loading process: pressures in the plane of the application of the landslide load (landslide pressure); resultant landslide pressure on the piles; bending moments in the piles (being calculated by means of the summation of the moments from the forces in the shell elements being parallel to the pile axes).

Model with Rigid Grouting of Piles. On the whole, the assumed procedure of the computation of the numerical model with rigid grouting of the piles is similar to the procedure for the model with elastic embedding of the piles below the slip surface. In this case, the main differences are in a lack of non-displaceable thickness of the soils and resistance to soil displacement over the slip surface as well as rigid grouting of the piles in the planes of symmetry being transverse to the axis of the structure (Fig. 1, b).

Grillage is assumed to be a flat shell being arranged at the level of the daylight surface of the soil. A limitation of the displacements in the normal direction is a boundary condition for the slip surface.

ANALYSIS OF MODELLING RESULTS

Stable Soil of Lower Slope. A distribution of landslide pressures between the rows of the piles is non-uniform and depends on the load level. The first row of the piles takes up the largest landslide pressure (Fig. 2, 3). The second row and the subsequent rows of the free-standing piles with elastic embedding are loaded with greater regularity, but the last row is loaded greater than the intermediary rows. A unification of the piles with the help of rigid grillage results in an increase of irregularity of the distribution of the landslide pressures between the rows. The first row of the piles takes up the maximal fraction of pressure, which exceeds the total fraction of pressures on the rest rows. In the rest rows, the pressures on the piles are decreased successively.

On the whole, a nature of the distribution of the bending moments (Fig. 4) in the rows of the free piles with elastic embedding corresponds to the distribution of pressures, but irregularity in the rows is somewhat less. A unification of the piles by the grillage results in a significant redistribution of the internal forces from the irregular external loads. But a complete equalization of the internal forces in the piles does not take place. The piles of the first row are the most loaded ones throughout the main extent depthwise. The bending moments are distributed between the rest rows thereabouts evenly. The difference of the bending moments between the first row and the next rows can be 1.2fold to 1.5fold. A significant increase of the bending moments is registered near grillage of the multi-row structures in the piles of the last rows. The difference in the fraction of the taken up bending moment between the piles of the first row and the last row can be 10 to 30%. Two-row pile structures with grillage are the most effective ones as far as the distribution of the internal forces is concerned; the difference of the fractions of the bending moments in the rows does not exceed 5 to 10%. It is necessary to mention an influence of the scale effect: irregularity of the distribution of pressures

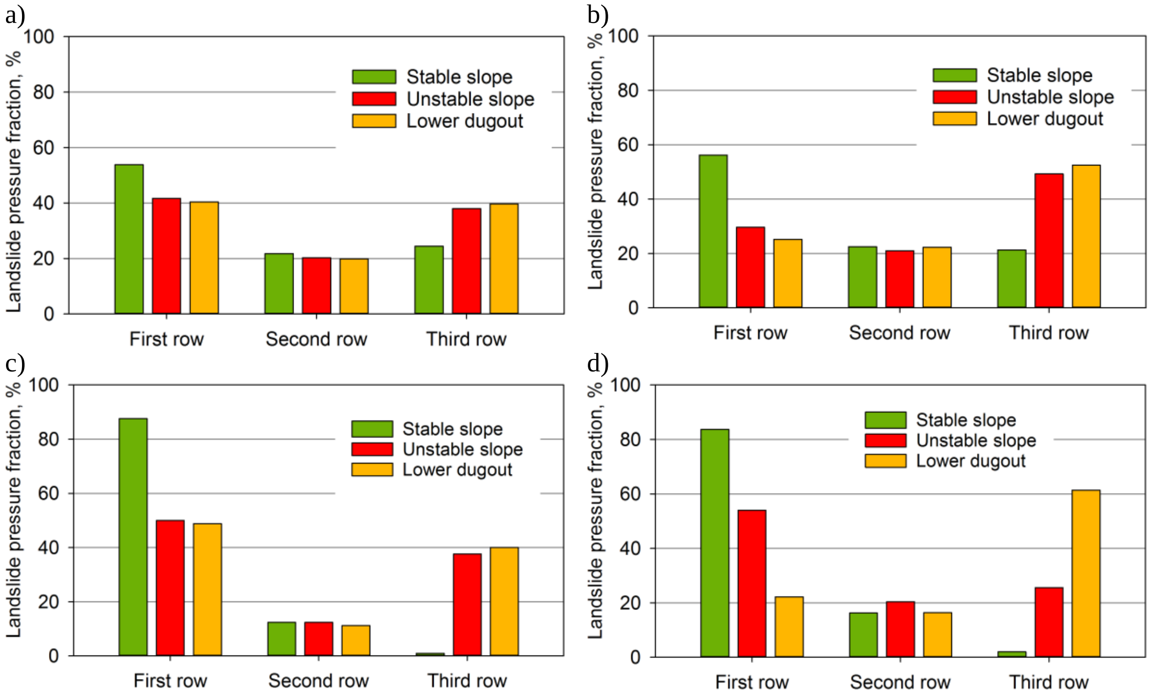

Figure 2. Distribution of landslide pressures between the piles of the three-row structure taking into consideration the rigid embedding of the piles into the non-displaceable soil at the displacement development stage over the whole slip surface: the free-standing piles of (a) model diameter and (b) as-built diameter, the piles, which are united by the grillage, of (c) model diameter and (d) as-built diameter

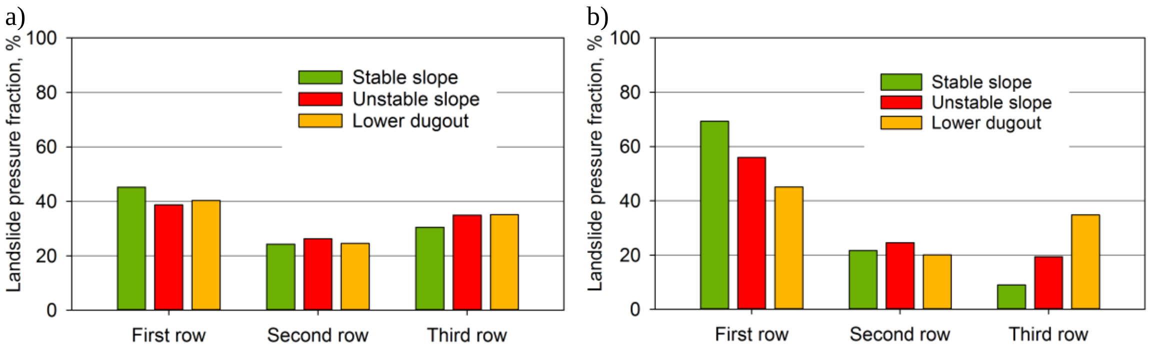

Figure 3. Distribution of landslide pressures between the piles of the three-row structure taking into consideration the rigid embedding of the piles into the non-displaceable soil at the last loading stage: (a) the free-standing piles and (b) the piles, which are united with the help of grillage, of as-built diameter

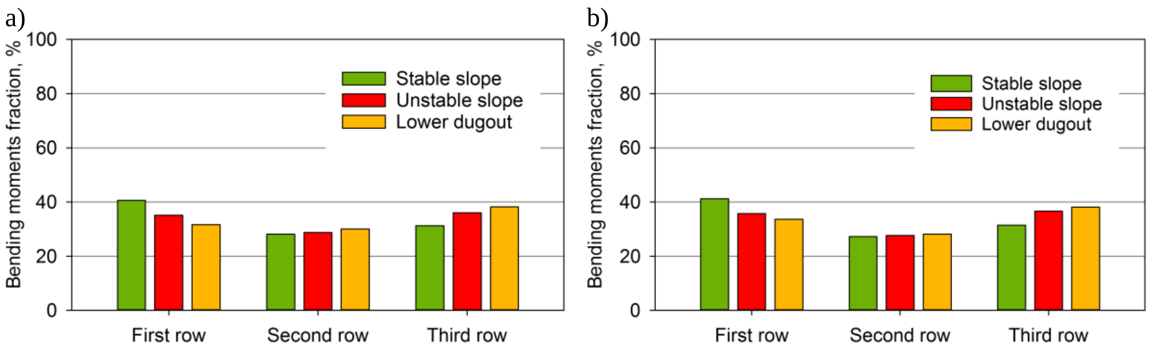

Figure 4. Distribution of bending moments between the piles of the three-row structure taking into consideration the rigid embedding of the piles into the non-displaceable soil at the last loading stage: (a) the free-standing piles and (b) the piles, which are united with the help of grillage, of as-built diameter (at the depth of more than 2.5D from the grillage bottom)

between the rows of the piles is manifested greater for the piles of as-built diameter.

Unstable Soil of Lower Slope. A distribution of landslide pressures (Figs 2, 3) differs greatly from the one under the conditions of “stable” lower slope. At the initial steps of loading in case of the displacement development over the whole slip surface, the fraction of the landslide load on the last row of the free-standing piles with elastic embedding is higher by 15 to 30%, and it is lower by 12 to 30% on the first row of the piles. Landslide pressure on the last row of the piles of the as-built diameter exceeds the load on the piles in the first row. Practically, the load fraction in the middle rows of the multi-row structures is not changed. In the rows of the piles being united with the help of grillage, the registered difference is even higher: the fraction of the landslide load on the last row of the piles is higher by 19 to 45%, and it is lower by 26 to 45% on the first row. The difference in the pressure distribution in the rows of the free-standing piles and the piles being united with the help of grillage is decreased considerably; for the piles of the model diameter, it becomes the smallest one (up to 2 to 17%). Further increase of the landslide load results in the distribution of the landslide pressures in the rows and a vivid approximation of their correlation to it under the conditions of “stable” lower slope. But the largest difference remains for the multi-row structures: the fraction of pressures on the free-standing piles of the first row is higher by 6 to 9%, and it is lower by 3 to 7% on the piles of the last row. For the structures with grillage, such difference is higher, it is 13 up to 21% and 10 to 24%, respectively. We should note that the landslide pressures on the outside rows of the piles of the model diameter exceed the load on the intermediate rows 1.4fold to 3.1fold in the three-row structure and 1.7 to 4.5fold in the four-row structure. For the piles of the as-built diameter, such correlation is 1.4 to 1.5 and 1.8 to 2.0, respectively. As compared with the piles with rigid grouting all over the length, the least difference of the fraction pressures on the piles is registered for the piles of the as-built diameter when the piles are united with the help of grillage (up to 6%). Maximal deviation is fixed for the free-standing piles of model diameter.

The distribution of the internal reactions of the piles is changes not so vividly (Fig. 4). When the displacement is developed along the whole slip surface, the last rows are loaded greater than the first ones. The difference in the fractions of the bending moments in the free-standing piles is 3 to 13%; it is 3 to 8% in the structures, which are united with the help of grillage. When the constant distribution of forces in the piles is set up, the load in the first pile rows and the last ones is practically adjusted. Meanwhile, the fraction of the bending moments in the intermediate rows is less than in the outside ones by 6 to 12%, e. s. 1.2fold to 1.5fold. We should note that at this stage a soil wedge is formed before the structure with a landslide soil creep over the structure.

Dugout of Soil of Lower Slope. On the whole, a nature of the influence of the lower dugout is similar to the conditions of “variability” of the soil of the lower slope (as compared with the “stable” soil). But the influence degree is somewhat higher (Figs 2, 3). The difference of the pressure fractions on the last rows at the stage of the development of displacement over the whole slip surface is 1% to 18% for the piles of the model diameter and 17% to 53% for the piles of the as-built diameter. When the landslide load is increased, the pressure distribution is adjusted. The difference of the pressure fractions in the outside rows is as follows: in the piles of the model diameter, it is 1% to 3% (the free-standing piles) up to 16% to 21% (the piles being united by the grillage); in the piles of the as-built diameter, it is 3% to 14% (depending on a number of the rows of the piles). The landslide load on the intermediate rows of the multi-row structures is considerably less than in the outside rows. The difference of the pressure fractions is as follows: for the piles of the model diameter, it is 12% to 33% (differs 1.5fold to 4.9fold); in the piles of the as-built diameter, it is 13% to 24% (1.4fold to 2.3fold less). Pressure distribution convergence for the piles with elastic embedding and rigid embedding is considerably less than for the conditions of the “unstable” soil of the lower slope. The minimal difference in the pressure fractions is registered for the piles of the as-built diameter, which are united with the help of grillage (2% to 19%).

Irregular distribution of the internal reactions of the piles (Fig. 4) to the external load under the conditions of the dugout is somewhat higher as compared with the conditions of the “unstable” soil of the lower slope. When the displacement takes place over the whole slip surface, the last rows are loaded greater than the first ones. The difference in the fractions of the bending moments in the free-standing piles is 11% to 31%; in the structures with grillage, it is 6% to 24%. At the time of an establishment of the constant distribution of forces between the piles, the bending moments in the outside rows are adjusted. Meanwhile the fraction of the bending moments in the intermediate rows is less than in the outside one by 5% to 9%, or 1.2fold to 1.4fold.

CONCLUSION

On the grounds of the above-mentioned data, it is necessary to note the following:

1. The distribution of the landslide pressures and the bending moments between the piles is remarkable for a considerable irregularity.
2. A unification of the piles of the multi-row structures with the help of grillage does not result in a complete adjustment of the internal forces in the piles.
3. The state of the soil of the lower slope exerts a considerable influence on the distribution of the bending moments between the rows of the piles. In case of the stable lower slope, the piles of the first row are the most loaded ones over the main length in depth. In case of the unstable state or dugout of soil from the side of the lower slope, the piles of the last row are the most loaded ones; the piles of the intermediate rows are underused to a considerable extent (1.2fold to 1.5fold).
4. From the point of view of equal loading of the piles in the rows, two-row structures are the most effective ones.

REFERENCES

[1] Adashi T. et al., Model tests on the preventive mechanism of landslide stabilizing piles, *Doboku gakkoy rombunsu*: *Proc. of JSCE*, pp 243-252, 1988

[2] Derevenets Ph.N., Matsiy S.I., Influence of interpile distance on the distribution of pressures between the rows of the piles of the retaining structures, *Geotechnics*, vol. 3, pp 46-58, 2017.

[3] Ginsburg L.K. et al., Force distribution between the rows of the piles of the antilandslide construction, *Basements, foundations and mechanics of soils*, vol. 2: pp 7-11, 1990.

[4] Matsiy S.I., Derevenets Ph.N., Interaction of the landslide soil with the piles taking into consideration a configuration of a retaining structure, *Basements, foundations and mechanics of soils* vol. 2, pp 8-12, 2007.

[5] Suvorov M.A., Computation of the multi-row antilandslide structures, *Thesis for the degree of Doctor of Philosophy*, Ufa, 2010