

**LANDSLIDE PROTECTION STRUCTURE IN THE FORM  
OF COUNTERFORTS MADE OF BORED PILES**

<sup>1</sup>**Osadchy V.S.**, PhD., Assistant Professor,  
ovs1455@gmail.com, ORCID: 0000-0001-8153-8635

<sup>1</sup>**Anisimov K.I.**, Assistant Professor,  
anisimov@ogasa.org.ua, ORCID: 0000-0002-0447-3927

<sup>1</sup>**Baadzhi V.G.**, Assistant,  
baadzhi@ogasa.org.ua, ORCID: 0000-0002-6974-9082

<sup>1</sup>*Odessa State Academy of Civil Engineering and Architecture*  
4, Didrichson street, Odessa, 65029, Ukraine

**Abstract.** At present, we are witnessing an intensive urbanization which is also typical for most regions of Ukraine. As consequence, there is an increase in the anthropogenic pressure on certain territories that's why the problem of the development of such phenomena as landslides has become particularly relevant. The landslides are one of the most common exogenous geological processes creating environmental and technogenic hazards. The reasons for their activation can be divided into natural and man-made. The landslide processes of natural origin arise, as a rule, on the coast, on the slopes of river valleys and in the network of gullies and ravines. The technogenic landslides are observed in the construction sector, reconstruction and operation of buildings and structures built on a plot of slopes with difficult engineering and geological conditions. With the aim of preventing the occurrence of landslides and related emergencies of a man-made and natural nature, it is necessary to implement economically and environmentally sound anti-landslide measures before the start of economic development of landslide and landslide hazard areas.

In building on landslide and landslide hazard slopes or on artificial slopes, it is necessary to keep large masses of soil in stable state. The occurrence and activation of landslides leads to the formation of unacceptable deformations, disruption of the slope stability as well as the destruction of buildings and structures. The deformations of buildings and structures located on or near slopes occur from landslide processes that cannot be stopped by regular landslide prevention works. In these cases, retaining anti-landslide structures made of bored and cast-in-place piles embedding in stable bedrocks and combined with reinforced concrete grille are used to protect against the formation of landslides. Such structures are one of the most optimal, technological and cost-effective methods for stabilizing landslide dislocations. The choice of the anti-landslide retaining structures type and their location on the slope depends on the value of the shear stress and its distribution along the slope, the power of the shear rock mass, the configuration of the slope, the state of shear at the time of building and other factors.

In this work, the main existing structures of transverse and longitudinal retaining pile-type anti-landslide structures, their advantages and disadvantages, conditions of application were analyzed. As a result of this, a new design retaining anti-landslide structure with increased loadability and reduced consumption of materials has been proposed. The landslide protection structure is made in the form of the counterforts run parallel to the length of the shear slope formed of round bored piles, whose diameter increases in the direction of shear displacement. While, the piles are laid with their lower ends in firm grounds and combined from above with reinforced concrete grille of variable height with an inclination of the bottom surface towards base of slope. This structure is designed to stabilize landslide hazard and landslide slopes as well as to increase stability of the slopes plots on which buildings and structures for various purposes are operated, reconstructed and built.

**Keywords:** slope, sliding surface, landslide protection structure, bored piles, counterfort, girder grill, "diaphragm wall".

**Introduction.** The landslides are among one of the most dangerous exogenous geological processes. They lead to the destruction of buildings and structures, loss of valuable agricultural land, damage to roads and railways, death and injury to people. The main natural factors that cause the landslides development and activation are the geological structure, the hydrogeological conditions, the lay of the land, the climate, the intensity of nontectonic activity as well as the technological impact.

On the territory of Ukraine, the greatest spread of landslides was observed in Odessa, Trans Carpathian, Ivano-Frankivsk, Kiev, Chernivtsi, Dnepropetrovsk and other regions. In the Odessa region, more than 5 thousand landslides were registered and the area of landslide hazard areas occupies almost 20% of the region's territory. In recent years, landslides were increasingly taking place in the territory not only of the city, but also in other settlements of the Odessa region (Chernomorsk, Sanzhiyka, Fontanka). The abrasion processes and related avalanching-landslide developments developed on the coast form a threat of destruction of residential and public buildings, resort complex facilities and communications. The current state of the coast, within populated areas, requires the urgent application of systematic measures to conduct construction, reconstruction or repair of landslide prevention structures.

The number of residents of large cities of Ukraine was increasing year by year resulting in the need to build additional housing, commercial and office space, recreational complexes. In this context, there is a need for construction development of the plots with complex engineering-geological conditions on which landslide processes are developed. This leads to the activation existing and new man-caused landslides. While, it is necessary to solve the issue of ensuring the stability of large masses of soil by using landslide prevention structures.

The landslide prevention structures of engineering protection include structures perceiving shear stress of a landslide masses of soil and are designed to increase the coefficient of slope marginal stability. The main ones are bored piles with or without girder grill, keys that cross the weakened zone and are fixed in a strong stable base, supporting walls, counter berms, counterforts as well as anchorages [1]. The choice of the retaining landslide prevention structures type depends on many factors such as engineering-geological and hydrogeological conditions of the construction site, the lay of the land, the kind and amount of the operating loads, the power of the shear rock mass, the state of slope at the time of building, the significance and cost of objects to be protected. In engineering practice, pile structures laid in firm groundside most widely used as the most economical and technological. They are optimal for the power of the shear rock mass up to 15-20 m. With increasing shear depth and increasing value of the shear stress, the construction of such structures is associated with large amounts of work and significant material consumption.

On the basis of the above, of particular practical interest are new pile-type retaining landslide prevention structures. And also it must be effective structures with increased loadability and reduced consumption of materials designed to stabilize landslide hazard and landslide slopes plots.

**Analysis of designs of retaining landslide prevention structures made of bored piles.** The retaining landslide prevention structures are used to prevent landslide and avalanching deformations if it is impossible or economically impractical to use other engineering protection equipment. These structures, in the landslide prevention system, in many cases (mountainous terrain, urban development etc.) are the only structures the use of which allows to fix the landslide site or increase the stability of the slope in a landslide hazard area [2].

One of the most effective landslide prevention structures of engineering protection are structures made of deep-embedded bored and cast-in-place piles (single-row and multi-row) located across the landslide masses, laid in a strong underlying layer and combined from above with reinforced concrete grille. In some cases, it is allowed to use inclined piles and driven piles. The prefabricated driving piles are used at low shear power and only when they are immersed in pilot boreholes or by pile pressing method [3, 4].

The single-row structure made of bored and cast-in-place piles is installed with a relatively low power of the shear body. It can be made in the form of piles located with a certain step close to each other (tangential piles) or with an overlap (bored piles). At significant depths of the shear rock mass, the multi-row structure should be installed. The use of a multi-row structure makes it possible to significantly improve the structural scheme of landslide prevention structure through the formation of multi-stable frame in the ground. The distance between the piles and their location on the slope should exclude flow around and pushing through the ground.

With increasing shear stress, bored piles are affected by large bending moments in value which leads to increasing the number of piles or their diameters. This results in increased the volume of drilling operations and material expenditures. It should be noted that both single-row and multi-row structures don't always work at rotational slips [5]. In the event of exposure of high-power shear body, extreme horizontal load is transmitted to the piles and Internal forces are produced for which it is impossible to select reinforcement at selected pile diameter, both in transverse force and bending moment. As a consequence, the piles do not correspond to ultimate limit state, namely, to the strength of the pile material.

Recently, anchors that fix the girder grill to the bedrock have been increasingly used as part of the structures of pile landslide prevention retaining structures [6]. Such pile structures with anchored girder grill become a few economical than usual pile landslide retaining structures because anchoring the head of the structure can reduce the number of rows of piles, their diameters and lengths. However, the mechanism of interaction of elements of pile-anchor structures of landslide prevention structures has not yet been sufficiently explored. The reliability and safety of such structures is ensured by the choice of large sizes of structural elements and the use of inflated assurance coefficients [7].

In some cases, when there is marked sliding surface of the shear masses, key-piles can be used [8, 9]. The keys are used with a relatively low-power of the main deformed horizon and the possibility of laying in firm bedrocks. The distance between the keys and the depth of embedding in firm bedrocks are determined by calculations based on the conditions for preventing soil penetration between the keys. The mark on the top of the keys is determined from the condition of avoiding to produce "crawling" effect.

In the field of geotechnics, there are also longitudinal retaining structures (deep-laid pile counterforts) [10] which hold the shear masses by point resistance and side friction. In doing so, the piles forming the counterforts can be located with a certain step or close to each other and the piles diameter can increase in the direction of the shear body displacement [11]. The retaining landslide prevention structures made of counterforts formed by separate piles cannot be used to stabilize deep landslides because each pile of which the counterfort is made, works as a separate element.

Among the large number of retaining landslide prevention structures types which are protected by patents and copyright certificates of different countries, it is also possible to highlight vertical walls laid in the underlying soils of the base and located along the landslide with a decrease in the distance between adjacent walls. The vertical walls formed by rows of drilling piles and combined with a reinforced concrete grille and mounted in such a manner that they form separate wedge-like structures [12]. The disadvantages of these structures can also be attributed to need to install a large number of piles and the impossibility of their use to hold large in value horizontal loads.

If it is necessary to perceive large shear stresses, separate piles are replaced by bored piles [6] which are made using the "diaphragm wall" method. The use of the "diaphragm wall" method allows the use of retaining landslide prevention structures even if there are fluid soils on the slope. The disadvantage of this structure is that its construction is associated with large amounts of work and significant material consumption.

**Goal and tasks of the study.** The goal of the work is to develop an effective landslide prevention structure, increased loadability and reduced consumption of materials designed to stabilize landslide hazard and landslide slopes as well as to increase stability of the slopes plots on which buildings and structures for various purposes are operated, reconstructed and built.

The desired goal was achieved by solving the following tasks of the study:

- to perform an analysis of designs of pile-type retaining landslide prevention structures;
- to analyze designs of longitudinal retaining structures in form of deep-laid pile counterforts;
- to develop design of landslide prevention structure in the form of counterforts made of bored piles row;
- to perform numerical modeling of interaction of masses of soil with elements of retaining structures.

**Study methods.** The goal of the work was achieved by analyzing existing designs of the pile-type retaining landslide prevention structures, the results of on-site inspections of landslide and landslide hazard areas of real slopes of Odessa (on the French Boulevard, on the territory of the Greek Park, on Dumskaya Square) as well as the results of numerical modeling of interaction of masses of soil with elements of retaining structures.

**Results of the study.** The work presents a new design of a pile-type retaining landslide prevention structure which is made in the form of the counterforts run parallel to the length of the shear slope. Thus, the counterforts formed of round bored piles, whose diameter increases in the direction of shear displacement. The bored piles are laid with their lower ends in firm grounds and combined from above with reinforced concrete grille.

The authors of the article filed applications for useful model patent and invention in Ukraine. The design of retaining landslide protection structure in the form of counterforts made of bored piles is shown in Fig. 1-3.

The landslide protection structure is made in the form of counterforts, whose longitudinal axes are parallel to each other, consisting of bored piles 1 of different diameters, which are installed in the shear masses of the soil 2, cut through the sliding surface 3 and buried by the lower ends in stable bedrock 4. The counterforts are combined with each other from above with reinforced concrete grille 5 of variable height with an inclination of the bottom surface.

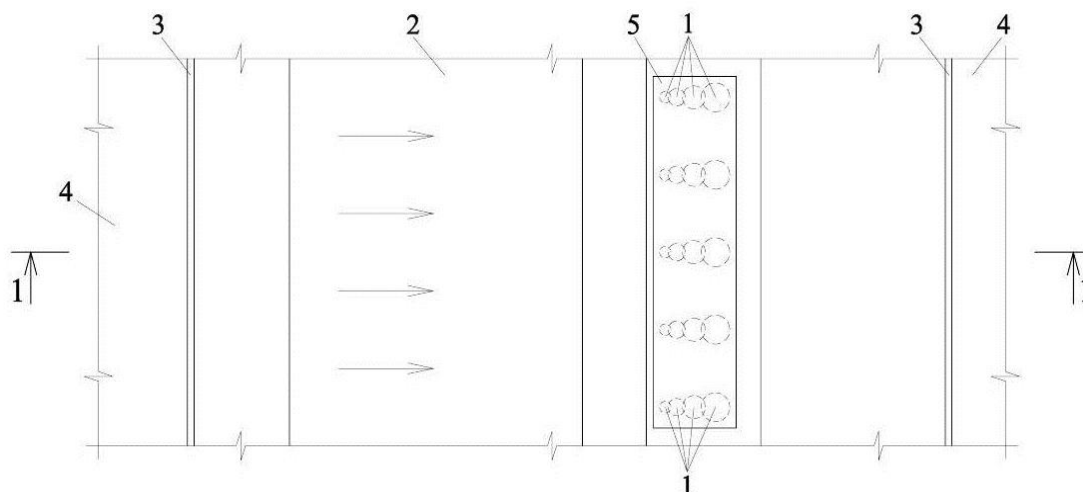


Fig. 1. Plan of the landslide prevention structure

The landslide prevention structure is being constructed as follows. After execution the works on clearing and planning the site as well as breakdown and securing the axes of the structure, drilling wells for bored piles of the largest diameter begins and filling the wells with a concrete mixture to the full height. Then drilling wells for bored piles of a smaller diameter (through one diameter) and performing their concreting.

At the next stage, after a set of concrete insignificant strength, starting to drill wells for bored piles of intermediate diameter with drilling the edges of neighboring piles.

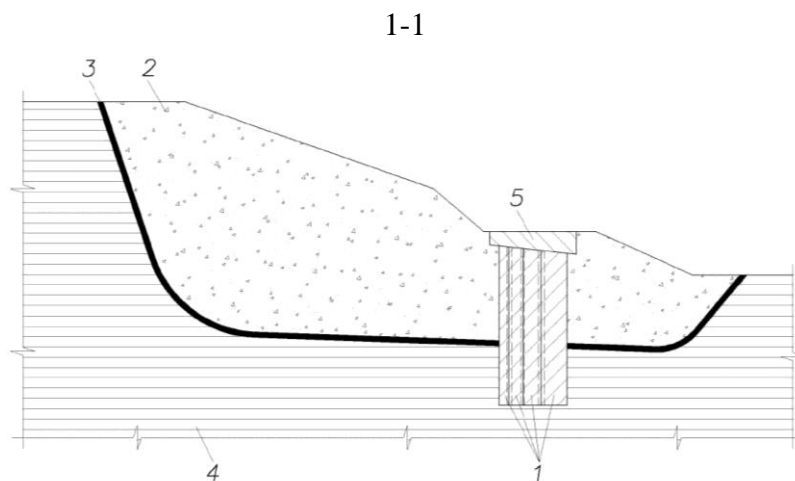


Fig. 2. Cross-section of landslide prevention structure

Other bored piles forming counterforts are arranged in a similar way, whose longitudinal horizontal axes are parallel to each other and coincide with the direction of shear masses displacement. The reinforcement is performed after one pile, neighbouring bored piles are still concrete. It is also possible to reinforce all bored piles with frames of the appropriate shape which does not prevent further work. The number of piles forming counterforts and their diameters depends on the specific natural conditions. After manufacturing all bored piles forming counterforts, starting to install monolithic reinforced concrete grille.

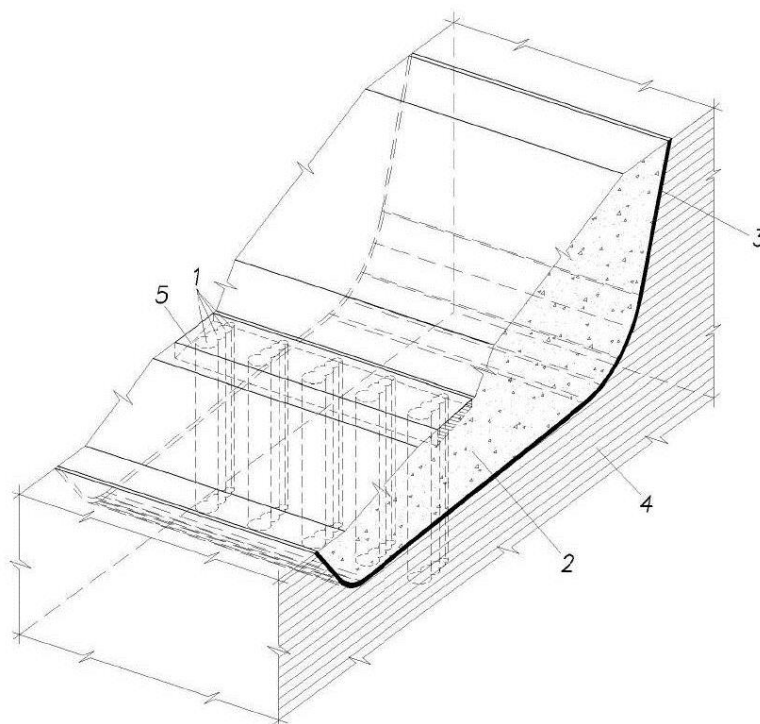


Fig. 3. General view of the landslide prevention structure

The landslide prevention structure works in the following way. When the shear activated, the shear masses of the soil 2 is displaced towards the counterforts which resist the shear stress by their point resistance and side friction. As the shear body moves, the ground is pushed into the space between the counterforts. As a result of the ground compression, additional reactions of counterforts side thrust appear creating additional forces of friction. The interaction of the ground with the rough side surfaces of the counterforts leads to an increase in forces of friction. The girder grille of variable height with

inclined bottom surface contributes to the compaction of the ground pushed between the piles and the appearance of forces of friction along the girder grill bottom surface. The significant forces of friction combined with compaction of the ground lead to its jamming between the counterforts. After that, row of counterforts together with the ground operate as a single retaining cement-bound wall.

In order to assess the economic efficiency of the proposed design of the retaining landslide prevention structure, idealized three-dimensional finite element design schemes were constructed (Fig. 4, 5) and a numerical experiment was performed. The numerical experiment was implemented in the licensed geotechnical software package Midas GTS NX. Previously, geometric models were created in the BricsCAD software package and then imported directly into Midas GTS NX.

The physical and mechanical properties of the grounds making up slope, the geometric profile and the sliding surface configuration are taken in accordance with the real ground and topographic conditions that are inherent in the slopes of the Odessa Black Sea coast.

The numerical experiment consisted in determining the stress-strain state of the ground masses and the coefficient of slope marginal stability for two variants of designs of retaining landslide prevention structures. In the design schemes, the pile structures and the ground masses are defined as three-dimensional finite elements. The soil behavior is described by Mohr-Coulomb model. The strength of ground layer of the disturbed structure is taken equal to 0.5 m. The contact of the ground with the field elements of landslide prevention structures is carried out via planar interface. The step and diameters of the piles were selected so that when each of the variants of landslide prevention structures was used to hold the shear body, the same coefficient of marginal stability were obtained.

Variant 1 (Fig. 4). The design of the landslide prevention structure is made in the form of counterforts made of bored piles. The diameters of the piles forming the counterforts are 1000, 800 and 600 mm. The length of the piles is assumed to be 23 m, the piles laying depth below the sliding surface is 6 m. The length of the counterforts is 2.1 m, the step of the counterforts is 2.5 m.

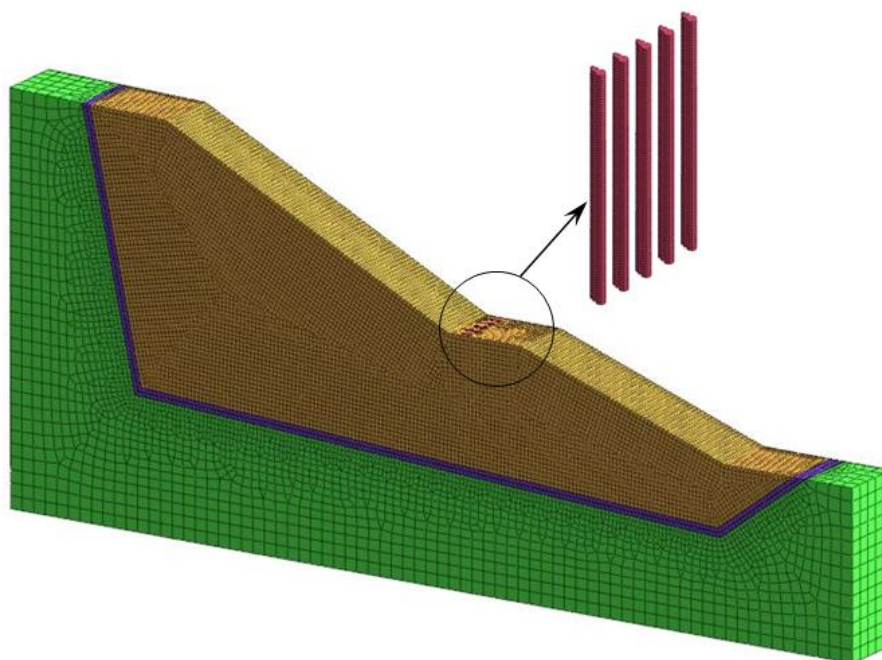


Fig. 4. General view of the design schemes with the landslide prevention structure in the form of counterforts made of bored piles with diameter 1000, 800 and 600 mm (variant 1)

Variant 2 (Fig. 5). The landslide prevention structure is made of two rows of bored piles with diameter of 1000 mm. The length of the piles is assumed to be 23 m, the piles laying depth below the sliding surface is 6 m. The step of piles and the distance between rows is 2 m.

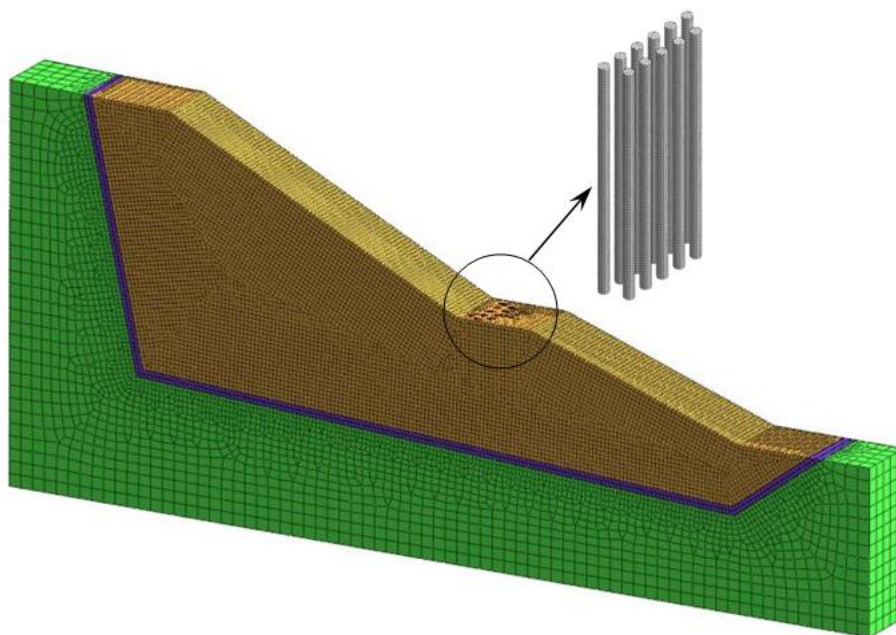


Fig. 5. General view of the design scheme with a landslide prevention structure consisting of two rows of bored piles with a diameter of 1000 mm (variant 2)

As a result of determining the stress-strain state in the calculated slope, zones of maximum shearing strengths were obtained (Fig. 6) on the soil of the disturbed structure and the value of the coefficient of marginal stability obtained by reduction method (reduction of strength), which was 1.22.

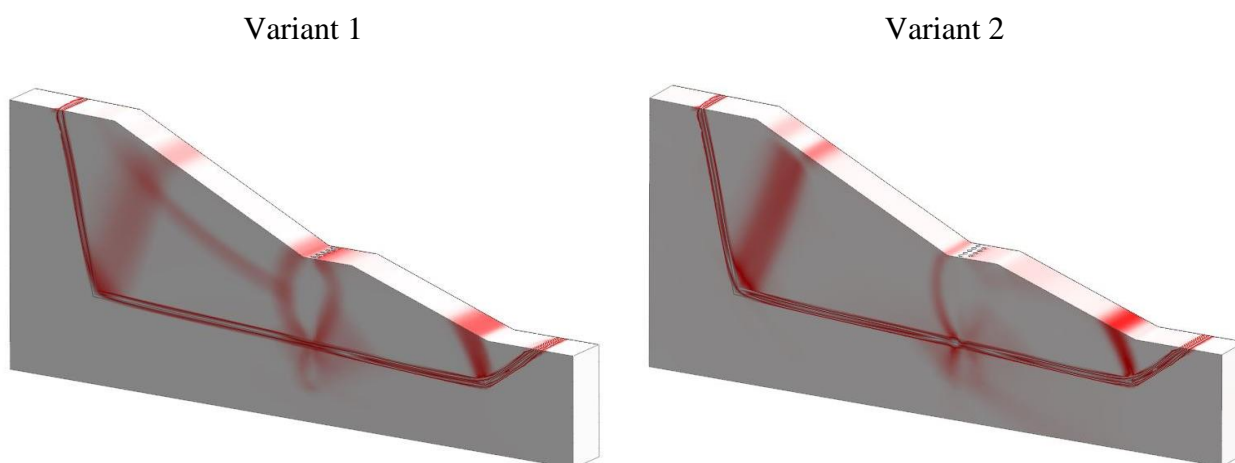


Fig. 6. Zones of maximum shearing strengths taking into account landslide prevention structures

Based on the results of preliminary calculations, it was found that the use of design of landslide prevention structure in the form of counterforts made of bored piles (variant 1) with the selected diameters and step of elements, allows to save on material up to 15.4%. Therefore, the use of the proposed design also allows to save on the volume of drilling operations.

**Conclusions:**

1. The choice of the type of retaining landslide prevention structures depends on engineering-geological and hydrogeological conditions, the topography of the slope, the kind and amount of the operating loads, the power of the shear rock mass, the significance and cost of objects to be protected and is performed on the basis of a technical and economic comparison of variants.

2. The use of retaining landslide prevention structures made of bored piles to stabilize landslide hazard and landslide slope is advisable when there is marked sliding surface and there is below the deformation zone of firm and stable grounds in which retaining elements can be laid.

3. The work presents a new design retaining anti-landslide structure with increased loadability and reduced consumption of materials has been proposed.

4. The design of landslide protection structure in the form of counterforts made of bored piles is intended for stabilize landslide hazard and landslide slopes as well as to increase stability of the slopes plots on which buildings and structures for various purposes are operated, reconstructed and built.

5. The step of the counterforts and the diameter of the bored piles that form them are determined depending on the value of the shear stress and the physical and mechanical properties of the grounds in the alignment of the structure, taking into account preventing ground penetration between the counterforts.

6. Based on the results of preliminary calculations, it was found that the use of design of landslide prevention structure in the form of counterforts made of bored piles with the selected diameters and step of elements, allows to save on material up to 15.4% in comparison with the design made in the form of two rows of bored piles.

7. The calculation methodology and recommendations for the design of landslide prevention structures in the form of counterforts made of bored piles can be developed after conducting experimental studies and numerical modeling of the interaction of elements of structure with the ground masses at different diameters and number of piles as well as the distance between the counterforts.

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## ПРОТИЗСУВНА СПОРУДА У ВИГЛЯДІ КОНТРФОРСІВ З БУРОСІЧНИХ ПАЛЬ

<sup>1</sup>Осадчий В.С., к.т.н., доцент,  
ovs1455@gmail.com, ORCID: 0000-0001-8153-8635

<sup>1</sup>Анісімов К.І., доцент,  
anisimov@ogasa.org.ua, ORCID: 0000-0002-0447-3927

<sup>1</sup>Бааджи В.Г., асистент,  
baadzhi@ogasa.org.ua, ORCID: 0000-0002-6974-9082

<sup>1</sup>Одеська державна академія будівництва та архітектури  
вул. Дідріхсона, 4, м. Одеса, 65029, Україна

**Анотація.** В даний час у світі спостерігається інтенсивна урбанізація, що характерна і для більшості регіонів України. Як наслідок, відбувається збільшення антропогенного навантаження на окремі території, через що особливу актуальність набула проблема розвитку таких явищ як зсуви. Зсуви є одним з найпоширеніших екзогенних геологічних процесів, які створюють екологічну та техногенну небезпеку. Причини їх активізації можна поділити на природні та техногенні. Зсувні процеси природного походження виникають, як правило, на морському узбережжі, на схилах річкових долин та в яружно-балкових мережах. Техногенні зсуви спостерігаються при будівництві, реконструкції та експлуатації будівель і споруд, що зводяться на ділянках схилів зі складними інженерно-геологічними умовами. З метою запобігання виникненню зсувів та пов'язаних з ними надзвичайних ситуацій техногенного і природного характеру необхідно здійснювати економічно та екологічно обґрунтовані протизсувні заходи перед початком господарського освоєння зсувних та зсувонебезпечних територій.

При будівництві на зсувних та зсувонебезпечних схилах або штучних укосах доводиться утримувати у стійкому стані великі масиви ґрунту. Виникнення і активізація зсувів веде до утворення неприпустимих деформацій, порушення стійкості схилу, а також руйнування будівель та споруд. Деформації будівель та споруд, що розташовані на схилах або біля них, відбуваються від таких зсувних процесів, які неможливо зупинити за допомогою звичайних протизсувних заходів. У цих випадках для захисту від утворення зсувів застосовуються утримуючі протизсувні конструкції з буронабивних паль, з закладенням в стійкі корінні породи та об'єднані залізобетонним ростверком. Такі споруди є одними з найбільш оптимальних, технологічних і економічно ефективних методів стабілізації зсувних зміщень. Вибір типу утримуючих протизсувних споруд і місця їх розташування на схилі залежить від величини зсувного тиску і його розподілу уздовж схилу, потужності зсувної товщі, конфігурації схилу, стану зсуву на момент будівництва та інших факторів.

В роботі проаналізовані основні з існуючих конструкцій поперечних та поздовжніх утримуючих протизсувних споруд пальового типу, їх переваги і недоліки, умови застосування. В результаті цього, запропонована нова конструкція утримуючої протизсувної споруди підвищеної несучої здатності та зниженої матеріаломісткості. Протизсувна споруда виконана у вигляді паралельних довжині зсувного схилу контрфорсів, що утворені з круглих буросічних паль, діаметр яких збільшується в напрямку переміщення зсуву. При цьому палі закладені нижніми кінцями у стійкі ґрунти та об'єднані зверху залізобетонним ростверком змінної висоти, з похилом нижньої грані у бік подошви схилу. Ця конструкція призначена для стабілізації зсувонебезпечних та зсувних схилів, а також підвищення стійкості ділянок схилів, на яких експлуатуються, реконструюються та будуються будівлі і споруди різного призначення.

**Ключові слова:** схил, поверхня ковзання, протизсувна споруда, буросічні палі, контрфорс, ростверк, «стіна у ґрунті».

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