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Experimental research of retaining walls with structural surface

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The retaining walls are one of the most widespread types of engineering structures. Behaviour numerous studies of various soils with soaking have showed that their bearing capacity and compliance are closely related to their moisture content degree. To obtain information on the displacements and sediments of model structures and grounds, the hour-type indicators are used. The carried out researches have shown that with the same ground base, loading and boundary conditions, evident for a retaining wall with a structural surface, there is an inclusion in entire soil massif work. The uniformity of the structures and the ground base general deformations, in turn, provides retaining wall with a structural surface greater stability.

Keywords: experimental results, retaining wall, structural surface

Експериментальні дослідження підпірних стін зі структурною поверхнею

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Рассмотрено проектирование в условиях дефицита городских территорий, которое требует от инженера комплексного подхода для решения задач надежной эксплуатации зданий и сооружений и сохранения окружающей среды. Установлено, что подпорные стены – один из наиболее широко распространенных видов инженерных сооружений, которые нашли применение в строительстве. Изучено многочисленные исследования поведения различных грунтов при замачивании, при этом зафиксировано, что их несущая способность и податливость (жесткость) находятся в тесной зависимости от степени их влажности. Отмечено, что повышение влажности сопровождается снижением жесткостных характеристик основания, что может вызвать неравномерное оседание. С целью определения оптимальных конструктивных параметров предложенной конструкции подпорной стены со структурной поверхностью проведено экспериментальные исследования. Для получения информации о смещениях и осадках модельных конструкций и основания использованы индикаторы часового типа ИЧ-10, прогибомеры 6-ПАО. Определено, что при одинаковом грунтовом основании (геометрия слоев и физико-механические характеристики), нагрузке и граничных условиях очевидным для подпорной стенки со структурной поверхностью есть включение в работу всего массива грунта и равномерное перераспределение напряжений на контакте по лицевой и фундаментной плитам. Равномерность общих деформаций конструкций и грунтового основания, в свою очередь обеспечивает большую устойчивость подпорной стены со структурной поверхностью, а также повышает несущую способность основания за счет возникновения «арочного» эффекта (образование разгрузочных сводов и упругих ядер).

Ключові слова: результаты эксперимента, подпорная стена, структурная поверхность

Introduction. In connection with a significant increase in investment in the construction industry and, accordingly, production volumes in the conditions of a deficit in urban areas, especially in the last decades of Ukrainian economy development, the use of sites with complex terrain and hydrogeological situation has sharply increased. Design in such conditions requires the engineer to take an integrated approach to solve problems of buildings and structures reliable operation and preserve the environment, and construction on unsuitable territories is associated with solving social, economic and environmental issues.

The retaining walls are one of the most widespread engineering structures types, which have found application in industrial, civil, urban, road and railway construction. To the arrangement of the retaining walls, a number of requirements are presented, most of which are based on the territory geotechnical conditions study, which requires engineering protection.

According to expert estimates, 90% of Ukraine territory is characterized by complex engineering and geological conditions, deteriorating due to the impact of natural and man-made factors [1].

Analysis of the latest sources of research and publications. The current normative documents recommend that calculations for determining the walls position stabilityagainst shear, tilting, turning, determining base local strength and its load-carrying capacity should be carried out in calculating the retaining walls, structural elements and joints strength should be ensured. Calculations should be made on base deformations. But in the conditions of extra work areas and subsidence grounds, it is not always possible to implement the available technical solutions, since they are not suitable for working conditions. The existing retaining wall designs are not designed for additional forces from horizontal soil displacement, which causes stress concentration in the lower part of the faceplate, which leads to structure destruction [2, 3].

Behaviour numerous studies of various soils (loess subsidence, gypsum, hacked, karst, etc.) with soaking showed that their bearing capacity and compliance (rigidity) are closely related to the degree of their moisture content. At the same time, an increase in humidity is accompanied by a decrease in the base rigidity characteristics, which can cause uneven subsidence [4, 5].

Allocation of previously unresolved parts of a common problem. Experimental studies have shown that the stress-strain state of the substrate is largely determined by the structure, operating conditions and loading characteristics [2]. In this regard, there is a need to develop new design solutions for retaining walls capable of perceiving additional impact from an unevenly deformable base.

Formulation of the problem. The aim of the work is obtained during the experiment on the retaining walls with a structured surface study results processing and analysis. To process the experiment results, a software package MS Excel has been used.

In order to determine the optimal design parameters of a retaining wall with a structural surface proposed design, and to identify the qualitative patterns of its joint work with the base, an experiment was conducted.

The experiment was carried out on small-scale models in a specially designed chute (fig. 1). At modeling the method of the expanded similarity, where geometrical, mechanical and power analogues with a real object are maintained [6, 7], was applied.

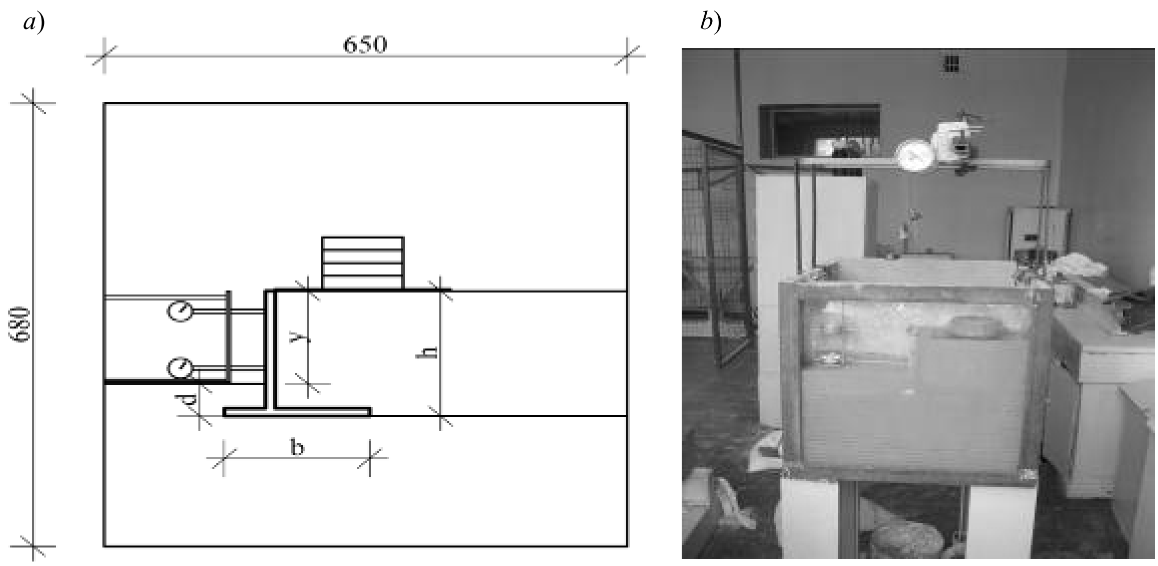

Figure 1 – **Experimental research:**
a) scheme for installing a retaining wall in the tray;
b) general view of the tray with installed wall and measuring devices

As a base soil in the models, a loam of broken structure was used. To create a uniform foundation, the soil was dried to a full loss of moisture and crushed by grinding in a mortar to a powdery state. Then the resulting powder was sieved through a sieve with a hole diameter of 0.5 mm. Considering the necessary soil moisture content, its density and volume determined the necessary amount of powder and water for its moistening. Humidification was carried out by a nebulizer with mixture constant stirring. Paste base was laid in layers of 15 mm, the compaction was carried out by a rammer made in the form of a rod with a welded base of a square cross section of 200 g. The purpose of preparing the model base was to obtain physicomechanical characteristics similar to natural soil.

Loams with the following characteristics were simulated (E = 13,5 MPa, c = 19,5 kPa, γ = 1,82 t/m^3, φ =22°).

The base model physical and mechanical properties were determined using the PLL-9 field laboratory in accordance with the methodology [8]. The strain modulus was determined with the help of a compression device of the Litvinov system. The coefficient of soil cohesion and the internal friction angle were determined by means of a shear device P10-S. Sampling was carried out from a tray with a step height of 150 mm, the results of certain characteristics are presented in (table 1), soils comparative characteristics are presented in (table 2).

Structural features of the retaining wall with a structural surface: a monolithic retaining wall of the angular type, which has voids on the contact surface of vertical and foundation elements, in the form of truncated pyramids of the same size and directed in a smaller base into the interior [9, 10]. With the development of the deforming load in time, that is, with soil vertical and horizontal movements with respect to the monolithic wall of the angular type, after its installation, soil gradual penetration into voids occurs.

Table 1 – Sample test results

№ point	The depth of sampling from the top of the array, m	Volume weight, γ, т/m^3	Modulus of deformation, E, MPa	Shift parameters		
				tgφ	φ°	c, MPa
1	2	3	4	5	6	7
1	0,15	1,826	9,3	0,38	21	0,014
2	0,15	1,812	9,5	0,32	18	0,019
3	0,3	1,831	8,9	0,36	20	0,016
4	0,3	1,822	9,1	0,46	25	0,012
5	0,45	1,816	8,5	0,48	26	0,009

Table 2 – Comparative characteristics of soils

Name of soil	Physicomechanical characteristics of the base			
	E, MPa	c, кPa	γ, т/m^3	φ, deg.
Full-face soil	13,5	19,5	1,82	22
Model base	5,62	6,8	1,71	22
Coefficient of transition	1/1,5	1/1,5	1	1

Premature filling of voids is prevented by sheets of elastic material. As a resiliently compliant material, a polyethylene film was used with the following characteristics: thickness of 200 µm, density of 916 kg / m^3, tensile strength of 165 kgf / cm^2.

Models of retaining walls were made using the method of layer-by-layer creation of a physical object using digital 3D model (fig. 2, a, b). For this, 3D printer Graber i3 was used.

The tray tests were carried out in a metal tray with a transparent front wall made of plexiglas. The tray dimensions are 600 × 650 × 680 mm. Its edges are made of corners 80 × 80 mm, the upper belt of steel strips with a width of 50 mm. All facets except for the front are made of chipboard 16 mm and rigidly fixed by two corners 60 × 60 mm. The working space for installing the retaining wall is fenced off by a partition of 16 mm chipboard. To prevent soil friction against tray wall, walls inner part was covered with an easily deformable polyethylene film in two layers with a layer of technical petroleum jelly [11].

The purpose of the first series of tests was to identify structural factors influence degree on the model bearing capacity of the proposed retaining wall of a special type.

The second series of tests ws conducted to compare anti-shear position stability of the retaining wall of the corner type and a retaining wall of a special type.

a)
b)

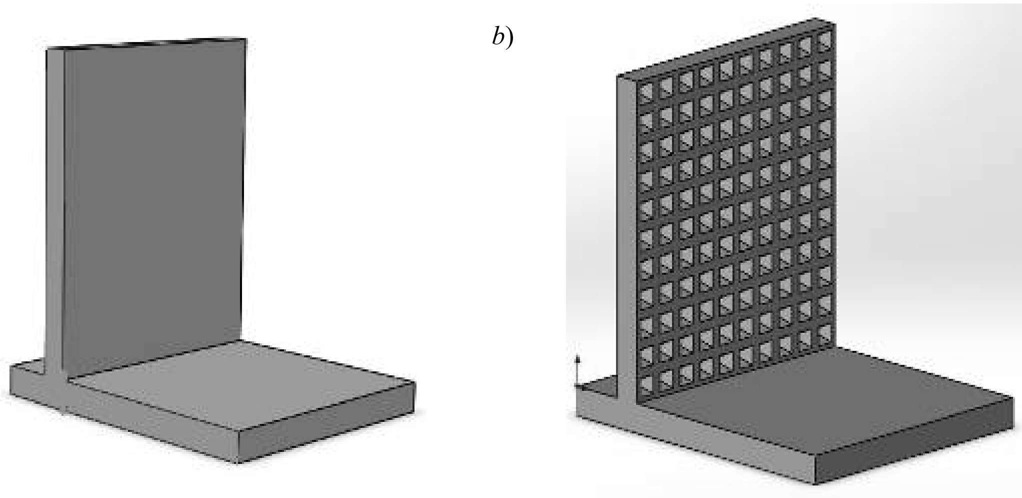

Figure 2 – **Experimental models:**
a) angled retaining wall; b) retaining wall with structural surface

Tray reparation for testing was carried out by installing it on the supports and the inner surface was covered with a polyethylene film. The second layer of polyethylene film was laid after applying a layer of technical petroleum jelly.

The base model preparation was carried out by layer-by-layer laying of pre-prepared ground paste. Each layer of paste was compacted by a rammer. When reaching a pre-marked height, the ground surface was planned, then a retaining wall was installed. Further, soil paste layered laying from the front side of the vertical retaining wall element continued until the mark indicated on the retaining wall. Backfilling was also performed using paste, the paste was laid layer by layer with a seal of 0.95 from the base under the foundation element to the top face of the retaining wall. A metal plate with dimensions of 150 × 200 mm was laid on the planned backfill surface.

To obtain information on the displacements and sediments of model structures and grounds, hour-type indicators IH-10, 6-PAO deflectometer were used, which were verified in the center of metrology, standardization and certification. Before retaining wall free surface, a bar with two clock-type indicators (fig. 3a) was rigidly installed to measure wall horizontal deformations (displacements) in two levels. Over the retaining wall, on a specially prepared console, there were installed deflectors (fig. 3, b), for measuring vertical deformations (displacements). All instrument readings were set to the initial values and recorded in the log.

Load on the platform was created in steps of 1.5 kPa. The load was maintained until soil conditioned stabilization. The model sedimentation rate, which does not exceed 0.1 mm in 30 min, was taken as a criterion for deformation conditional stabilization. Each subsequent stage of pressures was also maintained during the time of conditional stabilization.

Models loading models was carried out until the full loss of retaining walls stability. The devices values were recorded, then the graphs were constructed.

a)
b)

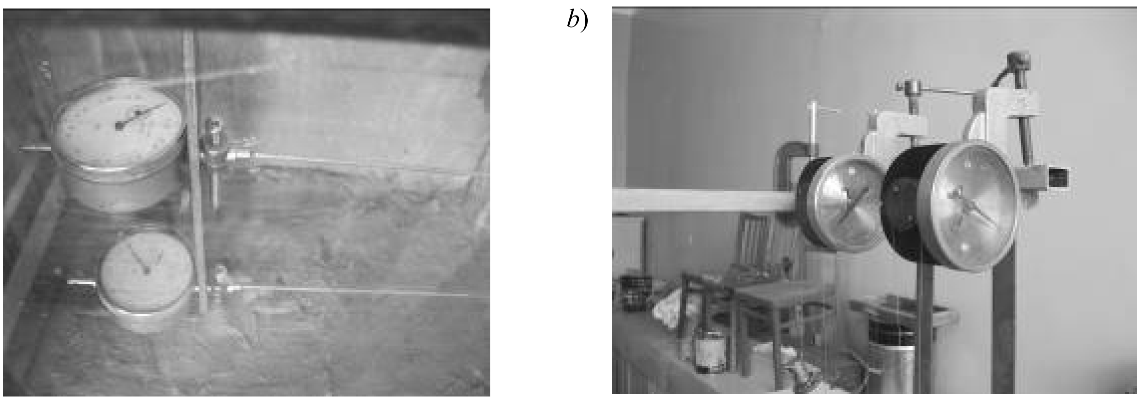

Figure 3 – **Measuring instruments:**
a) dial indicators IH-10; *b)* deflectometer 6-PAO

For retaining wall of angular type, the indications of hour-type indicators and deflectors indications were recorded (fig. 4, a, b); for the retaining wall with the structural surface, the indications of the hour-type indicators and deflectors indications were recorded (fig. 5, a, b).

Based on the data obtained, sediments of retaining walls (a corner wall type retaining wall, a retaining wall with a structural surface) were built (fig. 6).

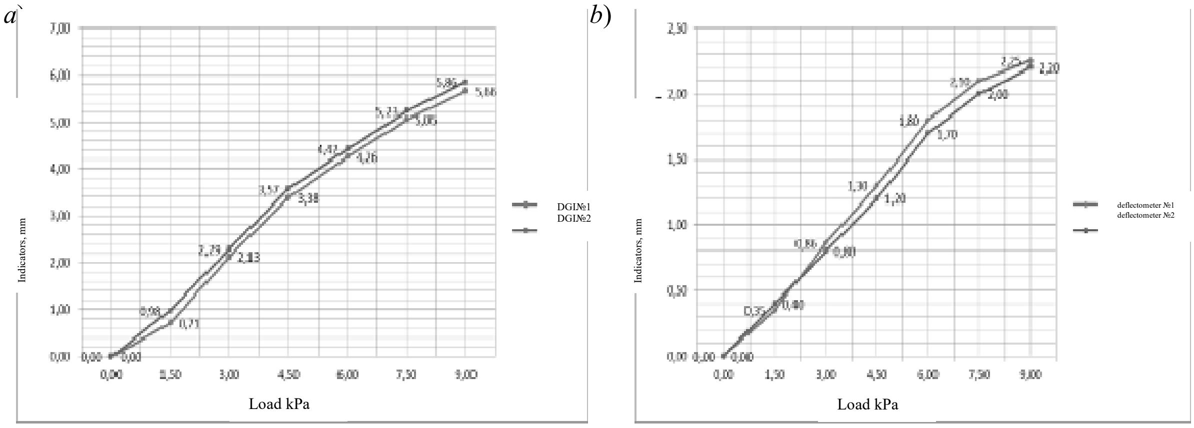

Figure 4 – Charts: *a)* indication of dial gauge indicators; *b)* indications of deflectometer

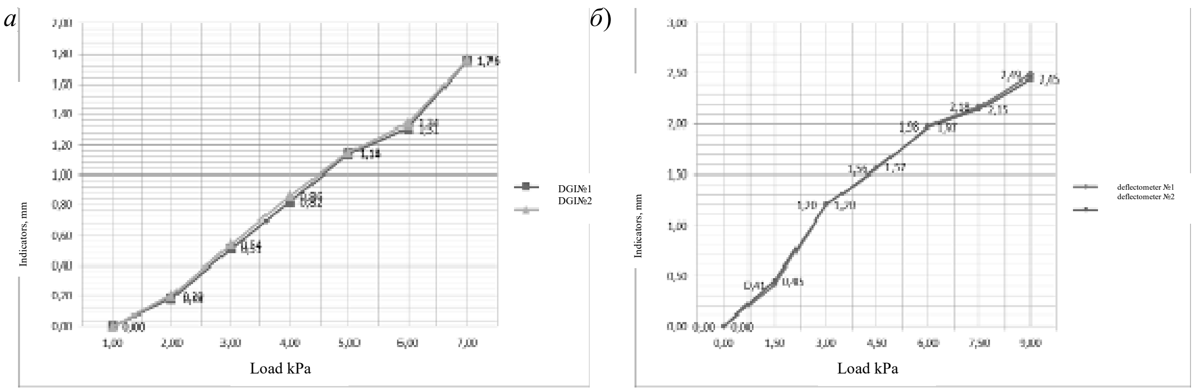

Figure 5 – Charts: *a)* indication of dial gauge indicators; *b)* indications of deflectometer

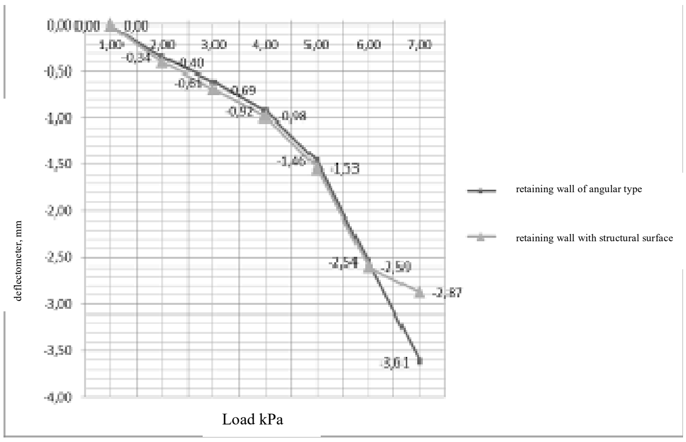

Figure 6 – **The draft of retaining walls**

It can be obvious from the graphs on (Figure 5) that the readings of hour-type indicators and deflectors have more similar indications than on the graphs (Figure 4), which indicates that the retaining wall with the structural surface moves and settles more evenly.

These graphs (Figure 6) show that the retaining wall with a structural surface has a large draft (by 18%) than the retaining wall of the corner type at the initial stage of loading the working platform, this indicates a gradual penetration of the soil into voids. With the passage of time, when the load increases, precipitation stabilization is recorded. With increasing load, retaining wall with the structural surface draft decreases, which is evident in the graph. In order to achieve the same draft of the retaining walls, 28% more load was applied to the retaining wall with a structural surface than to the retaining wall of the corner type.

Conclusions. The carried out researches have shown that with the same ground base (geometry of layers and physicomechanical characteristics), loading and boundary conditions, evident for a retaining wall with a structural surface, there is an inclusion in the entire soil massif work and uniform redistribution of stresses at the contact along the face and foundation slabs. The structures and ground base general deformation uniformity, in turn, provides greater stability of the retaining wall with a structural surface, and also increases base bearing capacity due to the appearance of an "arched" effect (the formation of unloading vaults and elastic cores).

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