UDK 624.131.21+624.131.3:624.138.22

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EXPERIMENTAL STUDY OF SHEAR STRENGTH ANISOTROPY OF GRANULA MEDIUM CONSIDERING TECHNOLOGY FACTORS

This article presents the results of experimental studies of the shear strength anisotropy of dry bulk material considering its preferred orientation of its flat particles to the shear plane as the effect of technological factors. The samples of a composite medium that was investigated, was mixture of silica sand with broken shells of mussels in a volume proportion 70% of sand and 30% of shells. Filling of the shear cell was conducted at different angles to the shear plane 0°, 30°, 60 ° and 90 °. For each angle of filling three series of experiments was conducted. Determined degree of anisotropy, as expected, was substantial, the largest difference in the angle of internal friction was 8% at an angles of filling 0° and 30°, and difference in the cohesion was 89,5% at an angles of filling 0° and 90° respectively.

Keywords: *anisotropy of shear strength parameters, fill technology, composite granular medium, direct shear test.*

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ АНІЗОТРОПІЇ ХАРАКТЕРИСТИК МІЦНОСТІ ЗРУШЕННЯ СИПУЧОГО ҐРУНТУ З УРАХУВАННЯМ ТЕХНОЛОГІЧНИХ ЧИННИКІВ

Наведено результати експериментальних досліджень анізотропії міцності зрушення сухого сипучого матеріалу з урахуванням переважної орієнтації його плоских часток до площини зрушення як наслідок технологічних факторів заповнення. Досліджено зразки композитного середовища, зокрема суміші кварцового піску з битими черепашками мідій в пропорції об'ємів 70% піску та 30% черепашника. Засипання грунту в пазуху обойми зрушення здійснювалося під різними кутами до площини зрушення – 0°, 30°, 60° і 90°. Для кожного кута такого засипання проведено три серії експериментів. Установлене значення ступеня анізотропії, як і передбачалося, виявилось істотним, найбільша різниця в куті внутрішнього тертя склала 8% при куті засипання 0° та 30°, а в зчепленні – 89,5% при куті засипання 0° і 90°.

Ключові слова: *анізотропія характеристик міцності ґрунту, технологія засипання, композитне сипуче середовище, пряме зрушення.*

Introduction. Due to the relatively low energy of cargo transportation by water transport, water ports development is an essential element of coast-economy countries and continents.

Ports cargo turnover is determined by many factors, from natural to man-made, including equipment of cargo fronts, sufficient depth and size of planned harbors for the handling of modern ships of significant displacements.

During the construction works of a new and reconstruction of existing port berthing structures such as piers; berths, quay walls, dolphin structures etc., backfill is an integral part of their structure, which often dredged from nearby underwater quarries. Backfill materials are usually granular mixture of sand and shell in a certain proportion.

Artificial backfills of stone, soil, discrete granular medium, in particular soils of underwater excavation and dredging works of the water areas and aquatic approaches are highly heterogeneous and anisotropic [1] by the natural conditions of sedimentation and lithification.

In addition, both factors, heterogeneity and anisotropy, are significantly dependent on the technology of backfilling works - nature and sequence of ground mass creation [2]. In the practice of construction, this is confirmed by the practical impossibility of creating perfectly homogeneous and isotropic soil mass.

Experience has shown [1] that the consideration of anisotropy in determining of the lateral earth pressure on the retaining structures may reduce the cost of bearing elements.

Thereby, presented data indicate that the artificial soil deposits exhibit significant shear strength parameters anisotropy depending on technological factors.

Analysis of recent sources of research and publications. According to several studies, there are two types of anisotropy properties of soil. The first type of anisotropy associated with the layering of textural elements presented by soil layers with different particle size distribution, structure and physical and mechanical properties are described by Ornatskii [3], and Harr [4]. The authors noted that the most common deviation of the structure of the soil mass from isotropic due to the presence of layering that occurs both naturally and artificially. The second type of anisotropy is determined by the predominant spatial orientation of anisometric particles. In the theory of granular media, that developed by Ornatskii [3]; Geniev [5] and Kandaurov [6] noted that the soil grains which are asymmetric, settle in massive with greater in surface area oriented horizontally under action of gravitation.

Terzaghi in his work [7] drew attention on filling technology research, where he pointed that the direction of backfilling of the back wall of the retaining wall greatly affects its lateral pressure. Therefore, the backfilling technology affect the strength parameters of the Coulomb’s theory.

To analyze the effect of anisotropy on the shear strength parameters of the soil are most commonly used direct shear and triaxial compression devices of different design.

It is known that oblong flat soil particles at shearing process within the shear plane tends to become parallel to the shear plane orientation [8]. The soil particles are turning round to position, in accordance with the direction of shear stress. Obviously, the larger the angle of rotation, the greater the required force necessary to achieve the shear failure.

Based on experimental investigation Ewertowska – Madej [8] states that in samples cut perpendicular to the layering, the soil particles rotate about 90°, which leads to higher values of shear resistance in comparison to the samples cut parallel to the layering. Zaretsky in his work [9] reported that the influence of the orientation of the structural elements on shear strength of clay soils and grain orientation in the non-cohesive soils qualitatively similar.

Based on the experiments in triaxial device Arthur [10] and Oda [11] presented the results of studies of natural sandy soil and artificial sand deposits dumped in water and in air with the additional study of the impact of the preferential orientation of the particles longer axis along dumping layers. The degree of anisotropy was assessed. The anisotropy degree was defined as the ratio of the difference between the principal stresses in the tests when the maximum stresses was directed respectively normal and parallel to the dumping layers. Maximum shear strength was obtained for the samples, which longitudinal axis and the direction maximum stress was normal to the bedding layering, and the minimum – at the coincidence of the direction of maximum stress and the «layering» plane. For soil dumped into the water, with a spherical particle shape, this ratio was close to 1, at axes length ratio of the particles in the range 0,5 – 0,7 degree of anisotropy ranged from 0,85 – 0,90.

Filimonov [12], [13] conducted a detailed study of shear strength and permeability of dredged sandy soils and tailings dam material of mining and processing plants. Samples of dredged soil was taken at the angles 0°, 30°, 45°, 60° and 90 ° to the layering. Drained direct shear tests have shown that the shear strength along the layers of dredged material was smaller than across the layers. The author obtained a quantitative characteristic – the anisotropy coefficient of shear strength, which varies depending on the normal stress transmitted to the sample in the range of 1,05 to 1,8 and more. Filimonov considered that the main reason for the shear strength anisotropy was formation of "layering" as a result of the orientation of the sand particles basal planes in the pulp flow direction.

Vynnykov in his works [14, 15] performed experimental study of the anisotropy of the filled bulk soils and artificial beddings. Shear strength parameters of the soil sample in the vertical and horizontal directions was determined. Shear stregth was investigated on the direct shear testing machine and anisotropy coefficients was determined as the ratio of the parameters in a plane perpendicular to the plane of isotropy to the corresponding parameters in the plane of isotropy. The soil samples were taken from different depths, the coefficients of anisotropy for the tangent of the angle of internal friction was in the range of 0.76 to 0.95, and cohesion varied in range of 0,77 to 1,05. The author points to the need to consider shear strength parameters anisotropy when evaluating of a stress-strain state of the soil beddings and notes the dependence of the anisotropy parameters of bulk soil on time and the conditions of dumping.

Direct shear tests of gravel in the natural conditions and sand of different particle size distribution were conducted by Dunstan [16]. The author notes that the anisotropy of the compaction is the result of directional deposition of material during its formation.

Molenda et al. [17] conducted interesting experimental study of shear strength parameters of wheat depending on the technology of backfilling of grains. As a result internal friction angles at different orientations in grain filling differed by 16%, and the character of the shear test curve was different.

In the works of Shkola [18] and Voitenko [19] given a wide and detailed overview of the literature on experimental and theoretical research on shear strength anisotropy of natural and artificial soils. Based on the analysis of literature and own experience [18] it was concluded that the substantial anisotropic properties is inherent to artificial massives formed by hydraulic dredging or dumping under certain conditions and peculiarities of construction technologies and preparing of the massives.

Highlight unsolved parts of the general problem. Accordingly, to the analysis of the experimental studies it can be concluded that the anisotropy of shear strength characteristics of backfilling considering technological factors is not sufficiently studied. There is no experimental data of shear strength parameters anisotropy of the composite granular backfill with respect to the orientation of the flat particles and volume ratio of flat particles in filling.

Considering the shear strength anisotropy of soil backfill is essential for identification of the reserves of bearing capacity and improvement of the operation of existing structures.

Formulation of the problem. Determination of shear strength parameters anisotropy of the composite granular material considering technological factors of backfill at 0°, 30°, 60° and 90° to the shear plane.

Material and methods. Tested samples of the material was dry mixture of silica sand of the Drava river basin located in the north-western region of Croatia and the crashed seashell of mussels (hereinafter referred to as – the composite medium) mixed in a volume ratio of 70% of sand and 30% of the seashells.

This type of material commonly found in underwater quarries of sea and river ports and used to backfill the cells of marine hydrotechnical structure by dredging works.

Direct shear test was conducted on a standard direct shear apparatus manufactured by «Premur» Ltd. (Pic. 1), with the shear cell dimensions: 11×11×9 cm.

Picture 1 – The direct shear apparatus

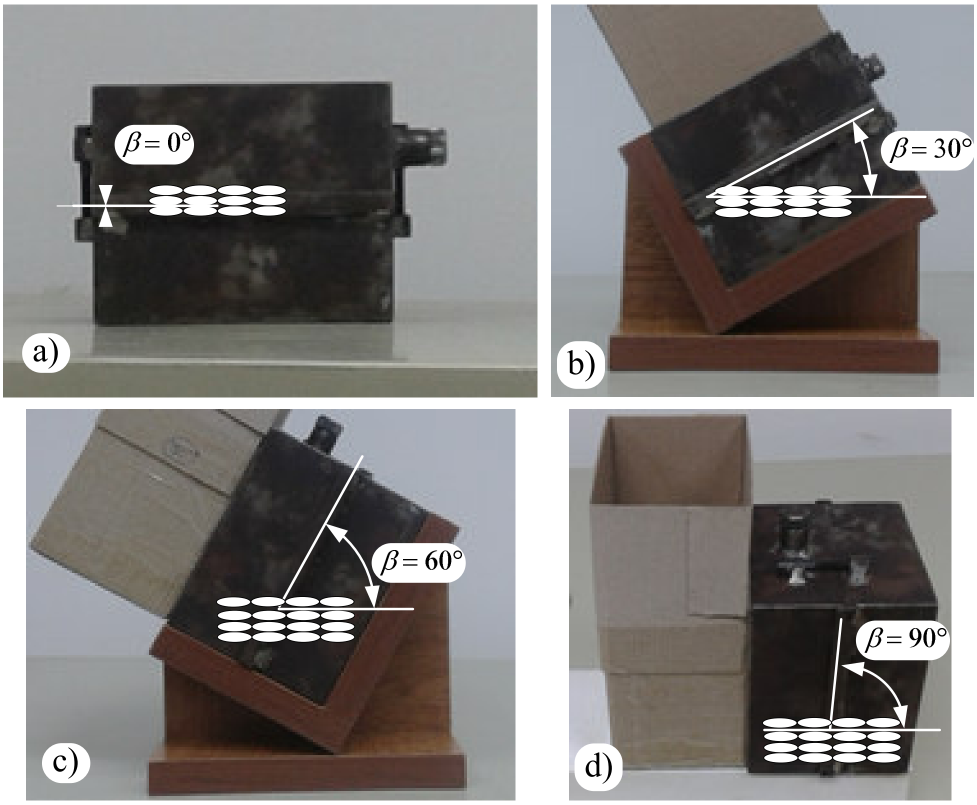
The direct shear apparatus operates in such a way that lower part of the shear cell is moving with the constant velocity, while the upper part rests on the dynamometer, wherein the cell bottom displacement is measured. Direct shear tests were performed in accordance to British Standard BS 1377; Part 7; clause 4 [20].

Direct shear test were performed for different angles of orientation of the flat particles (shell) to the shear plane □ = 0°, 30°, 60° and 90°.

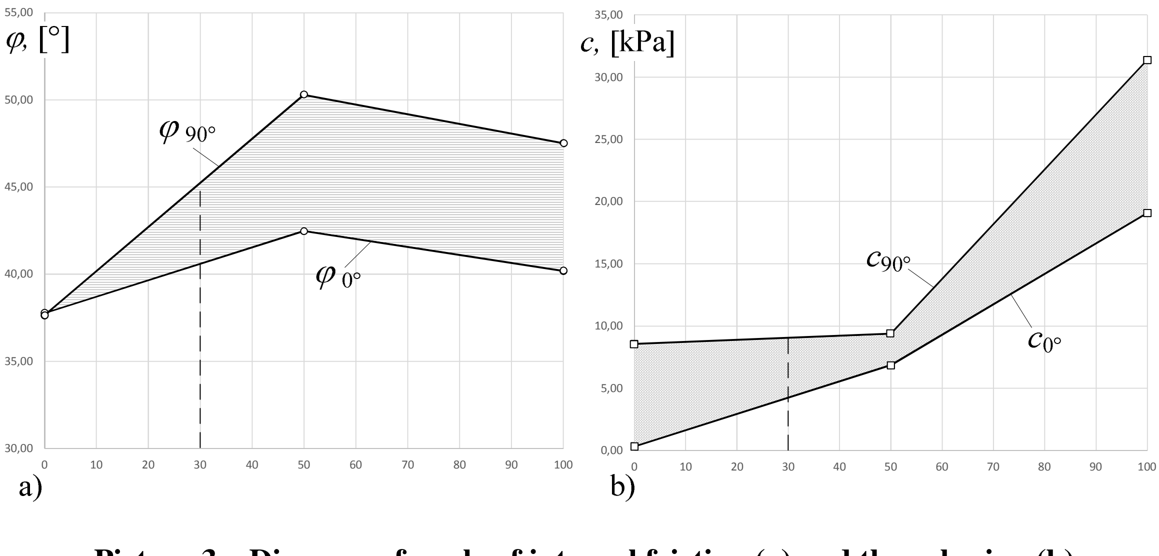
Heterogeneous mixture of composite medium was mixed thoroughly before backfilling in the shear cell. By the additional equipment shown on (Pic. 2) was achieved the desired angle of filling. The material was filled in layers of about 1 cm thickness. After each layer of filling, the shear cell was slightly shacked in the horizontal direction so that the particles laid down in a horizontal position.

To achieve the reliability of the results 3 series of experiments were performed for each angle of filling. Each experiment included three direct shear tests at different normal stress – 10 kN/m2, 20 kN/m2 and 40 kN/m2. As a result 36 direct shear test were conducted. Direct shear tests were carried out at a shear rate of 0.2 mm/min. Unit weight was measured for each test sample of the material.

To determine the volume ratio of sand and shells of the composite material additional experiments were conducted. For that purpose following composite medium were tested: sand without shells, a mixture of sand and shells in a volume ratio of 1:1 and shells without sand. The direct shear test was made at orientations 0° and 90° to the shear plane. As a result, a plots of the anisotropy of the shear strength parameters of material depending on volume content of seashells in the sand was built (pic. 3 a and b).



Picture 2 – Additional equipment for achieving the desired angle of backfill



Picture 3 – Diagram of angle of internal friction (a) and the cohesion (b) related to a volume proportion of flat shell particles filled at angles of 0 ° and 90 °

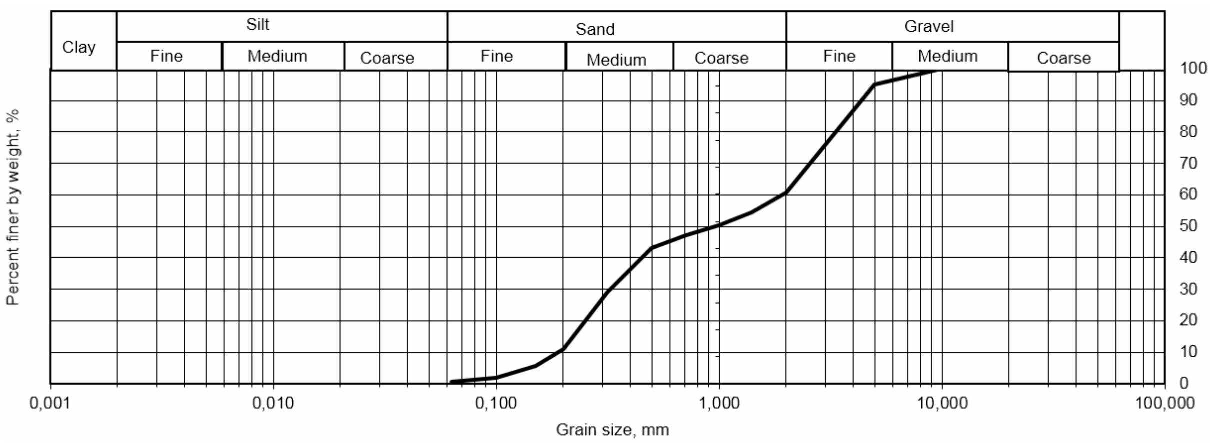
In process of select of the volume ratio attention was paid to such volume ratio in which there is a significant difference between the angle of internal friction and cohesion in relation to the orientation of flat particles and volume content of the shell in composite medium. In accordance with the obtained diagram (Pic. 3) composite medium with a volume ratio – 70% of the sand and 30% of the shells was chosen.

The chosen composite material (Pic. 4) had a geotechnical characteristic shown in Table 1, and its grain size distribution diagram is shown on (Pic. 5. All laboratory tests carried out in accordance with BS 1377 [20].

Table 1– Characteristics of a composite medium

Parameters	
Unit weight, γ (kN/m^3)	16,81
Unit weight of the solid particles, γ_s (kN/m^3)	27,00
Moisture content, *w* (%)	0,22
Effective size, D_{10}	0,20
Coefficient of uniformity, C_U	10,00
Coefficient of curvature, C_C	0,27

Picture 4 – Particles of composite medium



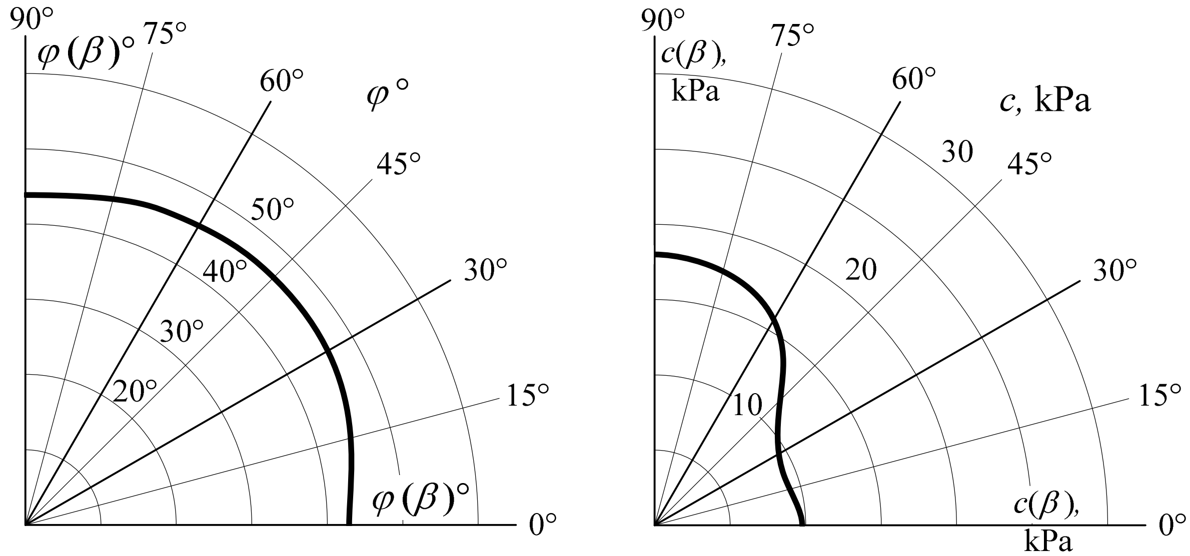
Picture 5 – Diagram of composite medium grain size distribution

Test results. As a result of the direct shearing tests the strength parameters of the composite material was obtained due to the orientation of the flat particles to the shear plane. The experimental results are shown in Table 2.

Based on the data from Table 2 by using the arithmetic average of the angle of internal friction φ and cohesion *c* in relation to the angle of orientation of flat particles β the anisotropy hodograph was built (Pic. 6).

Table 2 – The experimental results of direct shear test

Angle, °	№ of exp.	Avg. unit weight	φ, °	c, kN/m^2
0	1	16,61	41,17	11,22
	2	16,24	43,79	9,90
	3	16,99	43,73	8,18
30	1	17,41	49,31	6,03
	2	17,28	44,95	10,54
	3	17,26	44,78	11,94
60	1	17,33	44,46	16,75
	2	17,06	50,92	11,11
	3	17,04	42,41	19,43
90	1	16,05	40,94	21,60
	2	16,36	45,73	15,94
	3	16,41	44,98	16,49



Picture 6 – Hodographs of anisotropy of shear strength parameters of the backfill, *c* and φ

Conclusions. The direct shear test of composite material – mixture of sand with shell in volume ratio of 70% to 30% was conducted considering the predominant orientation of the flat particles to the shear plane of 0°, 30°, 60° and 90°.

At different angle of particles orientations β, significant anisotropy of strength parameters was discovered. The difference of internal friction angle φ and cohesion c was 8% and 89,5% respectively.

Maximum value of internal friction angle appears at orientation $\beta = 30°$ to the shear plane, while maximum of cohesion at 90°.

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Стаття надійшла 12.12.2015