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COMPARISON OF TEST RESULTS TO DETERMINE THE PARAMETERS OF SOIL STRENGTH TO ENSURE THE STABILITY OF EARTH SLOPES

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Abstract

The content of large soil fractions in soils complicates the experimental part of the research, but, the modeling method makes it possible to determine the effect of soil filler on slope stability.

The article presents the results of experimental study of the strength of coarse-clastic soils with different percentages of large fractions of gravelly soil (up to 20 mm) and aggregate (up to 5 mm) in the study of slope stability. The studies were carried out on three types of experimental equipment, which confirms the reliability of the results obtained. Recommendations are given for applying the values of the strength characteristics of coarse-grained soils in calculating the stability of slopes.

The results of the tests are carried out in a tray and shear testing devices. Mixture of soil fractions from 2 mm to 50 mm. Purpose of the tests is to determine the actual parameters of soil strength φ and C, taking into account the effect of impurities on the stability of slopes.

Reliability of the results confirmed the comparability of the results of previous tests. Tray allows for testing models of slopes composed of mixtures of sand fractions from 2 mm to 20 mm. Model sizes slopes are defined relative to the size tray. Tray dimensions – length 1400 mm, width 500 mm, height 1000 mm.

The design of the shear device allows to investigate coarse soils of different factions. The diameter of the fractions were tested for shear device area of 100 sm^2 is from 2 mm to 20 mm.

The diameter of the fractions were tested for shear device area of 1000 sm^2 – from 5 mm to 50 mm. The experiments were performed in the laboratory «Geotechnics in Construction» in KazGASA.

Keywords: test results, diameter of the fractions, models of slopes, gravel soil, soil strength, stability of earth slopes, shear.

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1. Introduction

In Almaty and foothill, there are dominated areas by coarse soils. Stability of slopes consisting of coarse-grained soils, provided their work together with fillers, filling the voids between the larger particles. But the diversity of soils and the influence of inclusion requires careful experimental study.

It is known that coarse soils not only have great strength, low deformability and resistance to external influences, in contrast to other soils, allow targeted control of their properties in a fairly wide range. This property allows successfully apply them in construction of earth constructions, as well as in hardening of slopes.

Experience of designing on coarse soils shows that as input values are used primarily strength characteristics only aggregate impact is major factions are not considered. It results to using range low mechanical and uneconomical design decisions [1–5].

Currently, there are many researches on the bearing capacity of coarse-ground, and also on the effect of the size fractions [5–9]. Researches of such ground are carried out on increased shear devices or in the field [10–13]. Consider some famous results [1–3] on the effect of large fractions of strength base.

In 1963, experiments were conducted on shear device size 20×20×10 cm objective studies to clarify the influence of particle size and density of the sample to the strength of coarse soils in the laboratory hydraulic engineering constructions VODGEO Research Institute [1]. Experiments were conducted on limestone gravel fractions d = 1–3, 3–5, 5–7, 7–10 mm. Research conducted in extremely dense (ηmin) and limiting the loose (ηmax) states. Angle of friction of the investigated fractions has changed in the range from 30° φ = 30 and φ = 46° 30 when the size of the loose gravel addition from 1–3 to 7–10 mm. Experiments to determine the resistance to shift gravel solid build demonstrated the dependence of the angle of internal friction on the size of the studied fractions of φ = 41° 30 in d = 1–3 mm to φ = 50° 30 at d = 7–10 mm. From the results of the experiments revealed that the friction angle of the studied fractions increased when the size of gravel.

In the laboratory of the foundations DalNIISA test stony-clay mixtures were made on monoplanar shear device Far Eastern PromstroySRIprojekt annular rings with a diameter of 50 cm, a height of 24.5 cm Size of detrital and gruss inclusions ranged from 2 to 80 mm. The gap between the ring is 5 mm. Tested mixtures containing large fractions 25, 35, 50, 70 %. From these experiments it was concluded that the increase in the percentage of coarse fraction of soils leads to an increase of the angle of internal friction and reduce traction.

In the laboratory TNISGEI [3] were carried experiments at a shear device design with monoplanar shift on gravel soils containing sand and clay particles. Dimensions 7 cm diameter rings, height 4 cm, the size of the inclusions from 10 to 2 mm. Tested mixtures containing large fractions of 15 %, 85 %. The experimental results concluded that the size of the major factions are not decisive for the magnitude of the angle of internal friction. Strength of coarse soils are mainly determined by the amount and composition of the aggregate.

From the foregoing discussion seen that the recovered data are somewhat different. Resulting in a need further testing on similar grounds.

Determination of the increase in the bearing capacity of the base soils, by constructing diagrams by the experimental method to determine the indicators φ and C. And to establish the dependence of the influence of the proportion of inclusions on the strength properties of the base soils.

Research objectives:

– obtain high values of the strength characteristics of soils using as a filler for sand and clay, the inclusion of large fractions up to 20 % of the strength properties of the soil in the form of a filler;

– obtain with an increase in the content of large fractions of 25 %, 50 %, 75 % and an increase in the angle of internal friction φ;

– make a model tray device for testing, and show that the presence of filler increases the stability of the slopes;

– based on the results obtained and the construction of soil displacement diagrams, analyze the visual change and obtain the optimal strength parameters φ, C.

These experimental studies were carried out to solve the problem of durability of foundation pits and slopes. The research and processing presented in the article provide a solution to the main scientific and urgent problems – increasing the reliability and efficiency of protecting the territory in difficult geological conditions.

The results of the study involve the study of visual changes in the state of soils using the method of diagramming.

2. Materials and methods

The laboratory KazGASA (Almaty, Republic of Kazakhstan) test soils with coarse sand filler was performed on monoplanar shear KazGASA design (**Fig. 1**) [4].

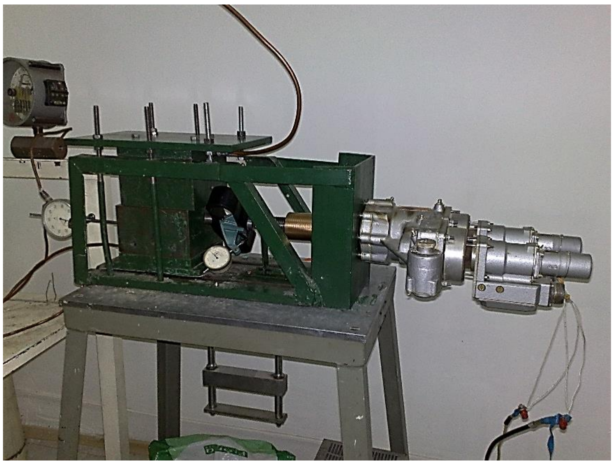


Fig. 1. General view of a shear device

In contrast to the earlier known, the instrument provides a more even distribution of stresses in the slice at the expense of the normal symmetrical *N*, shear forces and *T* mobile bottom box. Increasing the thickness of the walls of the boxes allow the device to reach the relative shear sample value equal to 15÷20 %.

Operation is organized in kinematic mode (controlled deformation) with the ability to control at any given time as the shear stress and shear strain.

Appliance serves the test equipment, allowing to monitor and measure the following variables: the vertical load *N* in the case of static loading, horizontal shear force *T*, move box instrument *U*.

In a shear device normal stress on the soil sample attached, evenly on the top and bottom boxes with air passed through the receiver. Air is pumped of the compressor. In the clip using a rubber membrane, which transmit force to the camera on the boxes.

Upper box rigidly clamped by bolts, the lower is in a mobile state. Move the bottom box is on the ball on the guide rails. Ferrule starts moving under uniform shear a horizontal screw jack. Presence reduces the friction between the ball race and a slide table, on which the lower clip.

Speed of movement the bottom mobile device box determined by the together work of the motor and gearbox. The shear of boxes 0.1 mm/min.

For the experiments used a modified version of the instrument monoplanar cut, the general form of which is shown in **Fig. 2**.

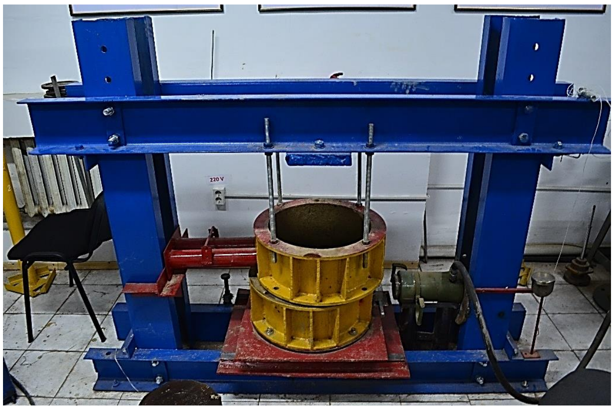


Fig. 2. General view of a shear device

In contrast to the earlier known, the instrument provides a more uniform distribution of stresses in the slice at the expense of the normal symmetric $N{\cdot}T$ and shear effort. Operation is organized in kinematic mode loading. The device has the ability to control at any given time as the shear stress and shear strain. Movement of the lower mobile device component is created by a hydraulic jack. **Fig. 3** shows the scheme of a modified shear device allowing to investigate the soil fraction with a diameter up to 80 mm.

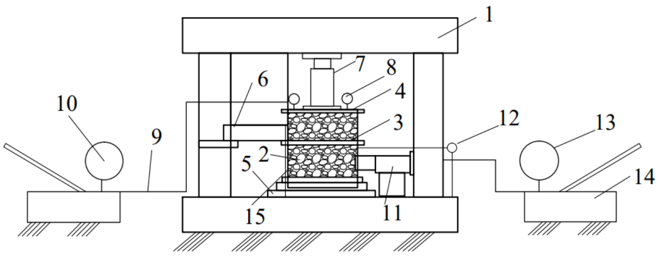


Fig. 3. Scheme of the modified shear device allowing to investigate the soil fraction with a diameter up to 80 mm: 1 – power rack; 2 – mobile component; 3 – stationary component; 4 – upper stamp; 5 – balls on runners; 6 – catch; 7 – vertical jack; 8 – indicators; 9 – hand pump station for vertical jack; 10 – manometer; 11 – jack to move horizontally; 12 – deflectometer; 13 – manometer; 14 – hand pump station for horizontal jack; 15 – soil sample

In a shear device soil sample has a cylindrical shape with a diameter $d = 41$ cm, cross-sectional area $F = 1320$ cm^2 and a height of $H = 43$ cm. Investigated soil detected.

Shearing test conducted in static mode at normal voltages corresponding to the pre-compaction pressures. The pre-compression was maintained in accordance of ST RK 1277-2004.

All experiments were performed on kinematic scheme loading mode controlled deformation. Asked moving and fixed value of shear force T. The gap between the fixed and movable clip device was constant during all experiments and equal to 1 cm.

3. Results and discussion

In accordance with the test program has been tested samples of coarse ground No. 1, No. 2, No. 3 to determine peak and depreciated strength $\sigma = 100$; 230 kPa. Soil density was $\rho = 1.86$ g/cm^3, $\rho = 1.714$ g/cm^3, $\rho = 1.57$ g/cm^3 respectively; $W = 4–7$ %.

Diagrams of shear resistance of soil samples No. 1÷No. 3 are shown in **Fig. 4, *a*, *b***.

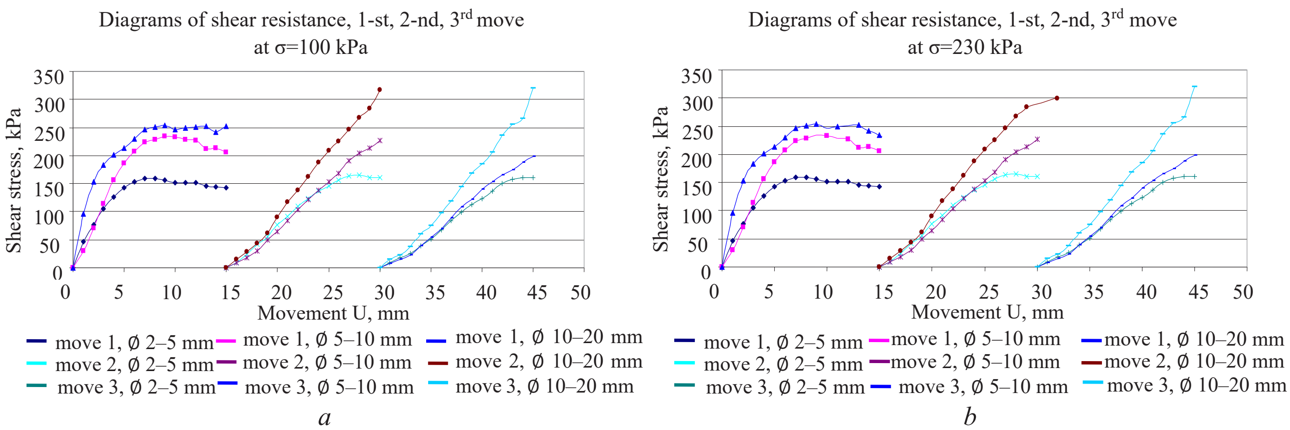


Fig. 4. Results of the shear test (KOG) 2–5 mm, 5–10 mm, 10–20 mm; $\rho = 1.86$ g/cm^3, $\rho = 1.714$ g/cm^3, $\rho = 1.57$ g/cm^3: *a* – shear stress at 100 kPa; *b* – shear stress at 230 kPa

From the diagram of shear resistance that the values that characterize the residual strength, the relevant limit values of shear stresses at the absolute deformation of the specimen is 15 mm.

To achieve the actual value of the residual shear resistance of the sample was made up to 3 times.

The first movement of the mobile device box shift from 0 to 15 mm corresponds to the stage of formation of peak strength, the subsequent displacement corresponding to the formation of the residual strength.

From the diagram of shear resistance (σ = 100 kPa) in **Fig. 4, *a***, the first movement of the box can be seen that the shear strength of the soil sample number 1 increases monotonically with increasing strain. After about 7–8 mm resistance falls. At the absolute deformation 10–12 mm stabilized and resistance remains constant. This is explained by the fact that at a constant uniform load soil particles come in a more stable position and formed an area shift.

For soil samples No. 2, No. 3 (first shift, σ = 100 kPa) observed the same dynamics of the chart, but the shear strength increases with increasing strain jumps. This is explained by the large size fractions of the soil, as during deformation they slide with each other.

Thus, for soil samples No. 1÷No. 3 in the diagram of shear resistance for the first movement of the box is characterized by the concept of peak and residual strength.

Repeated shifts in the charts shows for soil No. 2, No. 3 compacted, but the shear strength still increases monotonically with increasing strain, but without sharp jumps. It is possible to see that the fraction of soil quickly come to a more stable position, but because of size fractions of the resistance continues to grow, that is, ground shift is not fully developed and completely.

Also on the charts repeated shifts shows that for soil samples No. 1÷No. 3 residual strength not. Since there is no drop charts, it is more characteristic of constant strength. This is so that the graphs of shear resistance continue to rise during the entire shift pattern. All subsequent changes stabilize ground shift, but the fall of chart values are observed.

Table 1 shows the values of the strength properties of coarse soil density ρ g/cm^3, the angle of internal friction φ, °C and clutch, kPa for soil samples No. 1–3.

Table 1

The values of the strength properties of coarse soil density ρ g/cm^3, the angle of internal friction φ, °C and clutch, kPa for soil samples No. 1–3

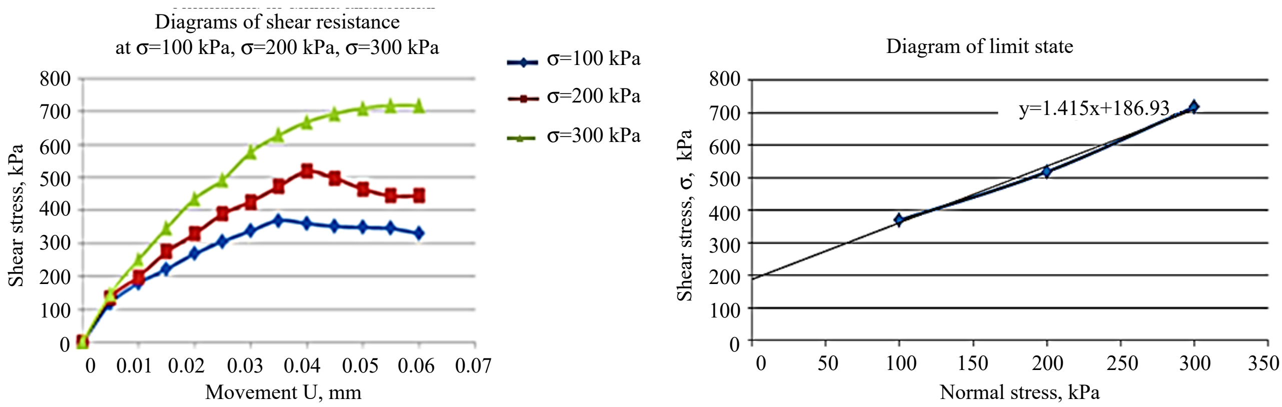
Laboratory number of soil	Granulometric composition, ∅, mm	Shear, No.	ρ, g/cm^3	φ, °	c, kPa
1	2÷5	1-st	1.86	43	68.5
		(2+3)/2	–	56	1.25
2	5÷10	1-st	1.714	45	135.9
		(2+3)/2	–	60	41.4
3	10÷20	1-st	1.57	68	5.42
		(2+3)/2	–	65	103

Additional researches on definition of strength characteristics of the soil were carried out at the second stage of the underground in Almaty. Sites on the route underground to explore the depths of 24.0 m allocated 5 geotechnical elements. Of them studied only soil samples – gravel soil with loam and loamy sand soil fillers of up to 20–30 %, with the inclusion of boulders up to 300 mm before 15 %.

Thickness of the layer is 9m. According to the engineering-geological surveys for the layer installed internal friction angle of 36°, the clutch 27 kPa, deformation modulus 68 MPa. And with a sandy pebble soil aggregates to 20–25 %. Content by weight: boulders – to 12.5–29.0 %, with a gravel of boulders increases to 30.2–34.0 %, pebble 27.8–63.2 %, gravel – 5.5–22.8 %. Fragments of is well rounded. Certain thickness 9.0–34.0 m. Angle of internal friction is 41°, the clutch – 36 kPa and modulus of deformation – 75 MPa.

The value of shear recorded every 5 mm movable box device on the manometer installed on the pump unit jack. The typical form of diagrams and shear strength limit state is shown in the figures below (**Fig. 5**). **Table 2** shows all the preliminary results of laboratory studies of coarse soils.

The results support the fact that the presence of inclusions in the coarse soil greatly increases the resistance of soil shear. Instead of the recommended first for the angle of internal friction of 36–41 degrees and a clutch 27–36 kPa, obtained respectively 54–55 degrees and 163–206 kPa. Such an increase in adhesion may explain the phenomenon of engagement only fractions of the soil.



a *b*

Fig. 5. Results of the shear test (COH) 2–5 mm, 5–10 mm, 10–20 mm on a shear device: *a* – diagram of shear resistance; *b* – diagram of limit state

Table 2

Summary table of preliminary laboratory results of coarse ground

Depth of sampling, m	Number of experience	strength parameters	
		φ, degrees	C, kPa
	1–6	54.4	197
5.5	7–12	54	216
	The mean standard value	54.2	206,5
	1Б–6Б	55.3	201
9.5	7Б–12Б	54.4	125
	The mean standard value	55	163

Tray is a rectangle of length 1400 mm, width of 500 mm and a height of 1000 mm (**Fig. 6**). Structural reinforcement frame is made of metal square 50 mm to 30 mm.

Fig. 6. General view of the experimental tray

For the convenience of classification, as determined by grain composition (GOST 25100-95), conditionally divided into two parts-with particles larger than 2 mm (gravel, gruss) and less than 2 mm (soil filler). Percentage of coarse fraction and aggregate was specified in each experiment separately.

When tested in the tray to the left of the tray filled soil model given structure and compacted to achieve the desired density. On top of the soil through the stamp and dynamometer applied vertical load. In reality, the load comes from standing next to a building, road or other object. Then gradually removed the partition in the middle of the tray. There by modeling the production of soil excavation. Follow the observation of the behavior of the soil. Reaching the limit state is the collapse of the slope of the pit. The experiences recorded fracture pattern, the value of the failure load, the maximum deformation of the stamp (**Fig. 7, 8**). Model tests were conducted with different compositions of the soil. Each type of soil composition was different diameter fractions and percentages of filler.

According to test results in a tray built charts, which determine the influence of soil on the draft of a stamp in action loads (**Fig. 9**).

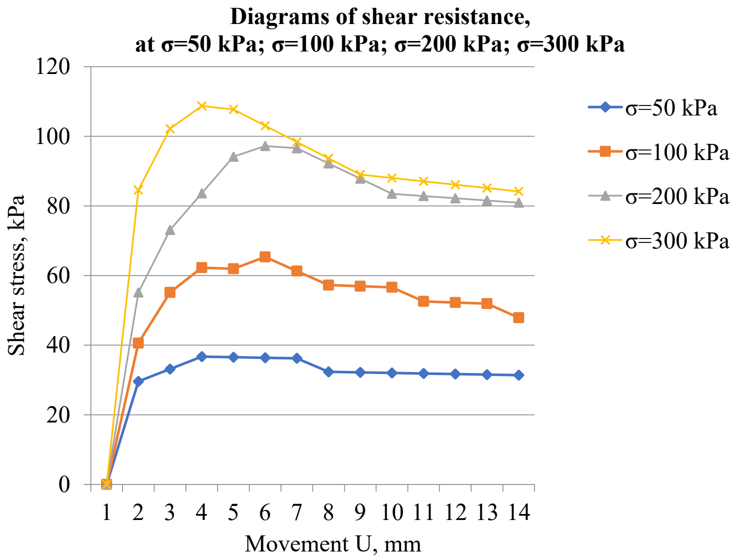


Fig. 7. Diagram of stress in the soil samples, which tested in the tray

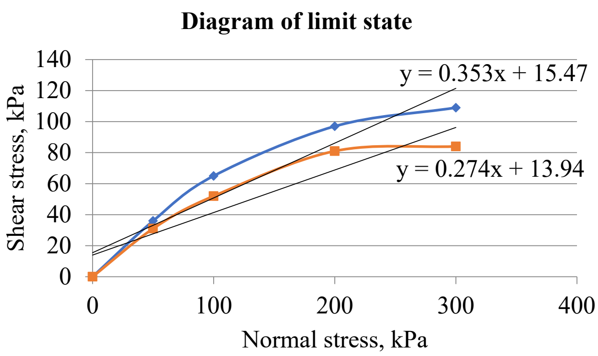


Fig. 8. Diagrams of peak and residual stress in the soil samples, which tested in the tray

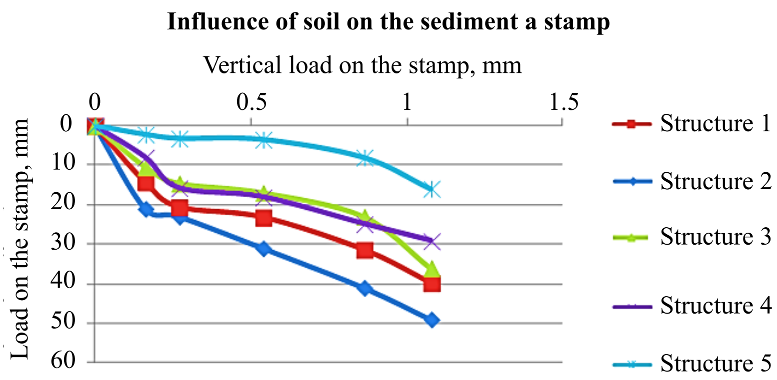


Fig. 9. Diagrams load on the stamp and stamp precipitation

From the test data, it was found that when the content of coarse fractions less than 20 % of the soil properties are determined by the properties of the core. The effect of large fractions on soil properties observed in the content of over 20 % and a further increase leads to higher fractions of soil properties (**Fig. 9**). Increase soil strength intensely manifested in the content of coarse fractions in the range of 45 to 70 %.

Although the that the strength properties of coarse-grained soils with different types of aggregates were investigated mainly in synthetic mixtures, the results shown in **Table 3**, are guaranteed as indicators of strength of coarse soil's natural structure and density, undoubtedly higher.

Table 3
The influence of the filler on the strength characteristics of the soil

No.	Sand, %	Foam plastic, %	Crushed stone, 5–10 mm, %	Crushed stone, 10–20 mm, %	φ, °
1	90	10	–	–	19
2	65	10	25	–	25
3	40	10	50	–	32
4	65	10	–	25	28
5	40	10	–	50	36

It should be noted that the results of the determination of the angle of internal friction and cohesion specific to infant formula tested in the laboratories DalNIISA and KazGASA to shear devices of different sizes were comparable, and suggest that the increase in coarse fraction more than 25 % regardless of the type of aggregate, leads to an increase in strength base.

4. Conclusions

Parameters of the physical and mechanical properties are listed in the geotechnical reports for coarse soils, often characterize the properties of the filler, but not coarse soil properties in general.

It is confirmed as a place box for sand and clay to aggregate content that inclusion of large fractions to 20 % of the strength properties of the soil by the form filler.

With increasing content of large fractions of 25 %, 50 %, 75 %, it is an increase of the angle of internal friction, respectively, to 33 %, 44 % and 73 %. Nature of the change clutch «*C*» is very controversial. Takes place and the increase and decrease the value of «*C*».

Tests have confirmed the statement in the paper tray, that the presence of soil aggregates increases the stability of slopes. The dependence of the effect of the fraction of inclusions on the strength properties and therefore greater stability of the slope has been confirmed.

Shear tests confirmed that the shear stress is defined as the peak and the residual resistance in the initial shift, and monotonically grows resistance during subsequent deformation.

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