

Strength investigations of foundation of allocation of main structures of Pskem hydropower station on Pskem river

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Abstract. This paper presents the results of geomechanical studies of the siltstone massif experimental carried out in the right-bank adit at the site of the Pskem HPP dam. Primary shear experiments were carried out at 6 normal pressures on the stamp σ : 0.5 MPa; 1.0 MPa; 1.5 MPa; 2.0 MPa, 2.5 MPa, and 3.0 MPa.

1 Introduction

The Pskem HPP is planned for construction in the Bostanlyk district of the Tashkent region, 120 km northeast of Tashkent, in the middle reaches of the Pskem River. The nearest settlement is the village of Kyrdaptыр, located on the right bank of the Pskem River, 5 km below the alignment section. The Pskem River, 73 km long, is the largest of the unused rivers of Uzbekistan, completely located on the republic's territory. The construction site extends along the river valley from the left-bank tributary of the Ispaysay stream upstream to the settlement. The dam site is located 1.2 km above the mouth of the right-bank tributary of the river. Pskem - Oromzadasay stream. The reservoir will spread from the dam site 19 km upstream to the village of Pskem [1,2].

Following the engineering-geological description of the massif set out in the report of Hydro project JSC (Tashkent), the experimental sites are located in the rocks of the Neogene age, represented by massive-layered siltstones [3,4].

The layered sequence of Neogene rocks, occurring monoclinally, structurally forms the northern flank of the Pskem graben-syncline. The rock layers extend at an acute angle to the riverbed and fall on NW-300-3300 at 50-55° from the left side of the canyon to the right.

Bedding cracks in the thickness of the Neogene deposits are not found everywhere and are fixed mainly during a sharp change in the lithological composition of the rocks [5–7].

The documentation of the experimental (sub-stamp) sites included the fixation and sketching of all cracks longer than 10 cm, measuring their azimuths and dip angles, and

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identifying the presence and type of filler. According to the documentation results for each site, the fracture voidness coefficient (FVC) was calculated [8–10].

The documentation of the experimental sites showed that at the base of the stamps, there are cracks with a width, mainly no more than 0.1-0.2 mm, and only on sites No. 8, No. 11, and No. 12, the width of individual cracks reached 3 mm. The documentation did not reveal subhorizontal cracks oriented towards the upstream or downstream, which increased the strength characteristics of the massif in the shear direction [5,7,11,12].

2 Methods

Strength (shear) tests of the massif and "concrete-rock" contact When conducting shear experiments, the following equipment is used:

four hydraulic jacks DG-200 (two for creating a given normal load and two for a shear load); two hydraulic pumps NRG-7080 and two exemplary pressure gauges MO-600.

To measure the displacements of the stamp, dial gauges IC-10 are used with an accuracy of measuring displacements of 0.01-0.02 mm and with a rod stroke of 10-25 mm for measuring vertical displacements and 50 mm for measuring displacements in the shear direction [13–16].

To minimize friction losses along the dies' upper face when displaced, the transfer of normal forces to this face is carried out through special rollers [3,17–19].

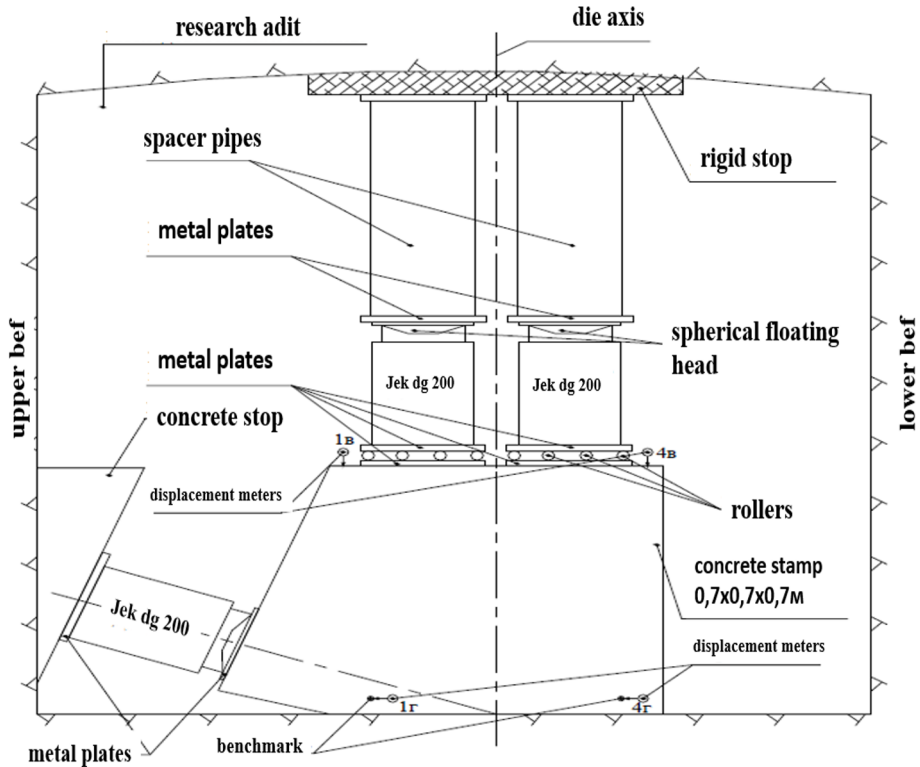


Fig 1. The scheme of shear experience

When conducting shear experiments, a momentless loading scheme is used: the direction of the shear load is set so that it passes through the center of the stamp base. In this case, the direction of the shift should be from upstream to downstream, i.e., correspond to the

direction of shear forces acting on the dam [20]. Shear experiments are carried out at the following 5 values of the specific normal load: 0.5 MPa; 1.0 MPa; 1.5 MPa; 2.0 MPa, and 3.0 MPa. On each stamp, 2 primary shear experiments and 3 repeated shears along the resulting displacement surface are performed. Initial experiments are proposed to be carried out using the so-called "floating" point method, which Hydro project specialists have successfully tested in several hydrotechnical facilities.

During the experiments, both horizontal (in the shear direction) and vertical movements of the dies are measured with an accuracy of 0.01-0.02 mm. Measurements are carried out along 8 reference points, fixed on the upper face and in the lower part of the side faces of the stamp (Fig. 1). Each of the shift experiences is carried out in the following order. First, a given value of normal pressure is applied to the stamp. After that, the system is kept until conditional stabilization. The latter can be considered secured if, for at least 10 minutes, the rate of stamp sedimentation, controlled by the corresponding benchmarks, does not exceed one or two indicator divisions (0.01-0.02 mm).

After that, the initial readings are taken for all indicators, and a shear load corresponding to the lower loading stage is smoothly applied to the stamp. The value of the initial loading stage and the interval between subsequent stages are selected from the condition that their number equals 7-10. As the limit state is approached, the magnitude of the shear load steps is recommended to be reduced.

Observations of the displacements of all measuring benchmarks at each step of the shear load are made until the conditional attenuation of displacements, characterized by a difference in displacements in the shear direction of not more than 0.05 mm over the last 20 minutes of observations. In this case, the first reading is taken immediately after reaching the designated level of shear load; the second and subsequent readings are taken after 5-10 minutes or more, depending on the rate of deformation stabilization. After achieving conditional stabilization of shear displacements, they move to a new stage of shear load [21–25].

It should be considered that the closer the shear load is to the limit, the slower the attenuation of displacements occurs. Signs of the closeness of the limiting state are the transition to a noticeably nonlinear character of the dependence of the horizontal longitudinal (in the shear direction) displacements of the stamp u on the values of the shear (tangential) stresses τ , as well as the rise of the stamp, fixed by indicators that control its vertical displacements.

The moment of ultimate shear resistance (ultimate shear strength) is determined by the cessation of pressure rise in the jacks, which create a shear force during continuous operation of the pump, and by the continued displacement of the stamp. At this point, it is necessary to register the maximum shear force, which will determine the ultimate shear strength. After that, the shear load is slightly reduced until the movement of the stamp stops. The shear load then slowly rises until the displacement resumes, which continues until the measurement limit on the indicators is reached. The transcendent displacement of the stamp is accompanied by the fixation of the loads applied to it and the values of horizontal displacements.

During the experiment, the constancy of the normal load on the stamp is closely monitored, which can change under the influence of its vertical displacements during shear. In addition, due to the inclined position of the shear load, the transition to a new stage automatically increases the normal load, so this transition must be accompanied by a corresponding decrease in the forces in the vertical load jacks.

On each stamp, 3 repeated tests are performed on the shear zone (crack) formed as a result of the first experiment. Repeated tests are carried out at specific normal loads of 1.0, 2.0, and 3.0 MPa. Repeated tests are performed using a simplified procedure, namely at 5-7 loading steps and with a shorter stabilization time at each step.

The results of repeated shifts refine the residual shear strength parameters along the formed shear surface. After testing, the dies are overturned to analyze the nature of the destruction and sketch (photograph) the shear surface.

In this case, the percentage of the parts of the shear surface passing through the concrete, rock, and contact "concrete-rock" is determined. The results of each completed experiment on one stamp are presented as dependences of horizontal and vertical displacements on the magnitudes of shear stresses. The results of the repeated tests are presented as a dependence of the shear stresses at which the repeated shear occurred on the magnitude of the normal stresses.

The characteristics of shear resistance - the coefficient of friction $\operatorname{tg}\varphi$ and the amount of adhesion C - are calculated as parameters of the linear dependence $\tau = \sigma \operatorname{tg}\varphi + C$, using the least squares method for the pairs of values " $\sigma - \tau$ " obtained in the experiments.

Photo 1 shows concrete dies BSh-7 and BSh-9 prepared for shear testing. When performing primary shear experiments, the magnitude of the shear stress τ applied to the stamp and the horizontal u and vertical v displacements of the stamp caused by this stress were recorded. The normal stress on the stamp was kept constant. The output data from the results of the experiments were the ultimate shear strength τ_{sr} , the horizontal movement of the stamp u_{pr} , at which the ultimate strength and residual shear strength τ_{res} were achieved (during the second shear). The results of each completed shear experiment were presented as dependences of the horizontal displacements of the stamp u on the magnitude of the shear (tangential) stresses τ . The indicated graphic dependencies, as well as the dependencies of the vertical displacements of the stamps $v=f(\tau)$,



a) stamp BSh-7



b) stamp BSh-9

Fig 1. Placement of power and measuring equipment during execution of shear punch tests

3 Results and Discussion

When performing primary shear experiments, the magnitude of the shear stress τ applied to the stamp and the horizontal u and vertical v displacements of the stamp caused by this stress were recorded.

The normal stress on the stamp was kept constant. The output data from the results of the experiments were the ultimate shear strength, the horizontal movement of the stamp upper, at which the ultimate strength and residual shear strength τ_{res} were achieved (during the second shear).

Attention is drawn to the large shear strength value ($\tau_{pr} = 3.38$ MPa) obtained during the second shear on the BSh-8 stamp at a low value of the normal load $\sigma = 1.0$ MPa. Therefore, this value can be considered a random outlier and was not considered when determining the calculated shear parameters (coefficient of friction and adhesion).

The results of the remaining 11 primary shear experiments are shown in fig. 2. By statistical processing of the obtained results, the following normative values of shear parameters were obtained - friction coefficient $\text{tg}\phi$ and adhesion C : $\text{tg}\phi_H = 1.40$, $C_H = 0.47$ MPa.

The corresponding Coulomb dependence of the ultimate shear strength on the value of the normal pressure applied to the stamp has the following form:

$$\tau_{pr} = 1.40 \sigma + 0.47, \text{ MPa}$$

To obtain the calculated shear parameters, it is necessary to divide the obtained standard values $\text{tg}\phi_H$ and C_H by the soil reliability factor γ_g

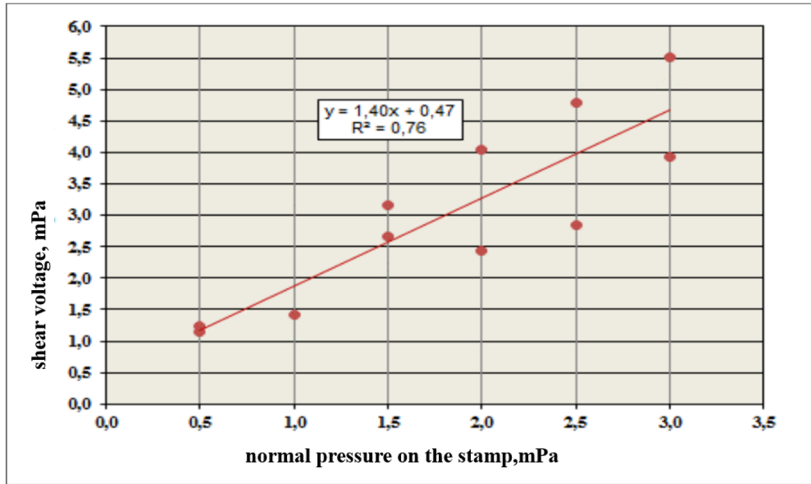


Fig 2. Dependence of ultimate shear strength on value of specific normal load on concrete stamps BSh-7 ÷ BSh-12

To obtain the calculated shear parameters, it is necessary to obtain $\gamma_g > 1.25$ obtained on the ground; the value $\gamma_g = 1.25$ is taken, and we obtain the following values of the calculated characteristics: $\text{tg}\phi_p = 1.12$ and $C_p = 0.38$ MPa.

In addition to the soil safety factor γ_g , the recommendations of Russian State Standards SNiP 2.02.02-85 and SP 23.13330.2011 [4] provide an additional safety factor for a possible discrepancy between test conditions and field conditions. Taking this into account, as well as the rather large scatter of experimental data obtained, which caused an increased value of the coefficient γ_g , the following values of shear parameters can be finally recommended as calculation ones:

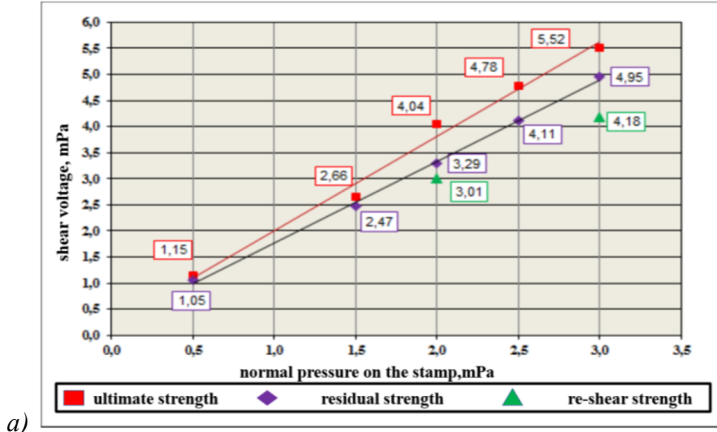
$$\text{tg}\phi_p = 0.90 \text{ and } C_p = 0.30 \text{ MPa}$$

The value of residual strength tres can be estimated from the results of primary experiments, in which the die displacements were fixed after reaching the ultimate strength (second shear experiments on each die). In Fig.2. shows a comparison of the values of limiting tres and residual tres of shear strength obtained in the experiments under consideration (respectively, without taking into account and taking into account the data of the second shear on the BSh-8 stamp), performed on the same dies. In Fig.3, the primary experiments (second shift) data are compared with the data from all repeated experiments.

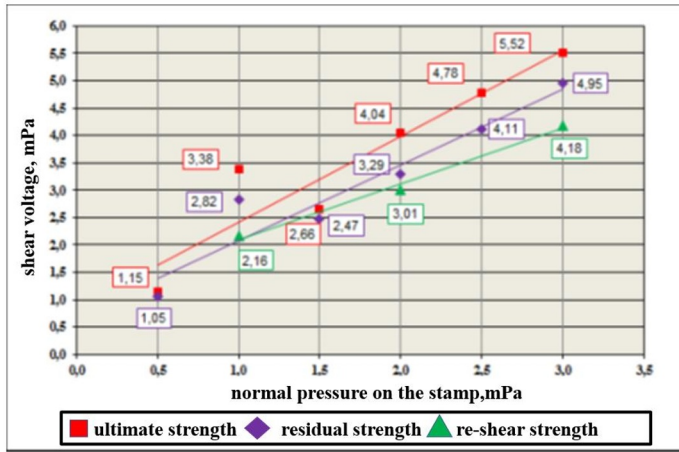
Analysis of the given data shows that the residual shear strength determined during primary experiments is less than the ultimate strength by 7.1÷18.6%, with an average value of about 12%. According to the results of repeated shifts performed in the range of normal stresses of 1÷3 MPa, the residual shear strength was obtained less than the ultimate strength by 14.2%-36.1% with an average value of about 25%.

Note that the need to use the residual shear strength in calculations may arise after strong earthquakes or other extreme force effects on the rock mass, which cause even small displacements.

Following the recommendations of SP 23.13330.2011 [4], the value of γ_g should be determined according to GOST 20522 with a one-sided confidence level $\alpha = 0.95$. The performed calculations showed that the reliability coefficient on the ground, in this case, is $\gamma_g = 1.33$. Considering the provision of SP 23.13330.2011 (clause 5.16), according to which even small shifts were caused in the reliability coefficient.



a)



b)

Fig 3. Values of ultimate τ_{sr} and residual τ_{res} shear strength obtained in primary shear tests (second shear) and in repeated tests without taking into account (a) and taking into account (b) data on the BSh-8 stamp.

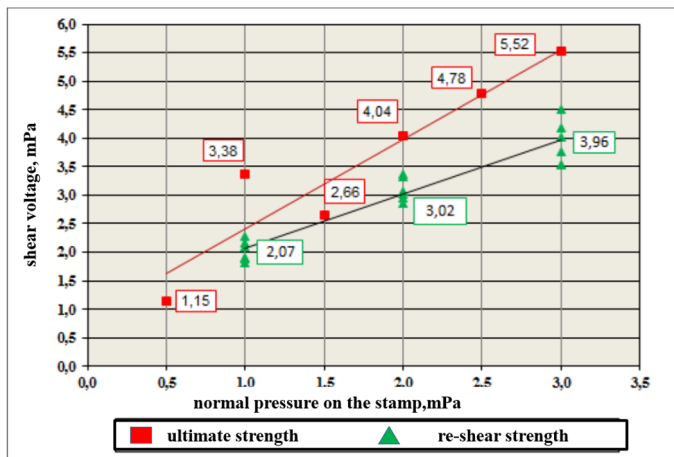


Fig 4. Comparison of ultimate shear strength τ_{sr} obtained in primary shear tests (second shear) with shear strength obtained in all repeated tests.

After completion of the shear tests, the dies were overturned, and the resulting shear surface (cleavage) was sketched. Such a survey made it possible to reveal the nature of the destruction and determine the areas along which the shear surface passed.

For example, photo 2 shows a snapshot of the shear surface obtained when testing stamp No. 11. In the photograph, the part of the shear surface that passed through the massif is highlighted with a white stroke along the “concrete-rock” contact, with a red stroke. As you can see, the shear surface mostly passed through the array in this case.



Fig 5. Shear surface after testing dies No. 11.

4 Conclusions

➤ This paper presents the results of geomechanical studies of the siltstone massif, carried out in the right-bank experimental adit at the site of the Pskem HPP dam.

➤ Field geomechanical studies included stamping experiments to determine the strength (shear) characteristics of the "concrete-rock" contact. These studies were carried out at 6 sites located in the experimental adit. The experiments were carried out on concrete stamps with a base size of 0.7 m x 0.7 m. In total, 6 deformation and 12 shear tests were performed. The stamps were shifted from upstream to downstream, corresponding to the direction of the main loads that would act on the dam.

➤ The value of the coefficient of fractured voidness (FVC) of rocks at the experimental sites is insignificant and averages 0.23%. According to the existing classification, the rocks tested were mainly weakly fractured and very weakly fractured. During the engineering-geological documentation of the experimental sites, no sub-horizontal cracks were found, oriented towards the upstream or downstream, along which the displacement of the stamps could occur.

➤ Based on the results of shear experiments, the following design parameters of shear strength along the massif and at the “concrete-rock” contact can be recommended: $\text{tg}\phi_p = 0.90$ and $C_p = 0.30$ MPa.

➤ The obtained deformation and strength characteristics of the siltstone massif significantly exceed the corresponding indicators previously adopted for performing computational studies for the Pskemskaya HPP.

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