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The Fault Estimation in Hydraulic Engineering

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ABSTRACT

The study of tectonic faults is one of most actual and difficult problems in engineering geologic theory and practice. The fault structure, its genesis, morphology, age and mechanism of formation, morphometric parameters (fault width, the extension of fault surface, etc.) have an impact on the geotechnical and anisotropic properties of the rock massif, hydrogeologic conditions, slope stability and others.

The analysis of geological structures of foundation of hydroelectric facilities, such as Rogun Hydroelectric station at Vakhsh river (Tajikistan), Inguri Hydroelectric station (Georgia), Krasnoyarsk Hydroelectric station and Sayan-Shushenskoye Hydroelectric station (both at Yenisei river in Russia) is in the basis of this paper.

This paper is based on the thesis that the fault zone has to be regarded as a special engineering geologic massif, which is characterized by the stretched form, zonal structure, unfavorable engineering geologic conditions, and it complicates the fault estimation. The author suggests to pay principle attention to the detailed study of the fault structure, composition, sizes and other fault peculiarities. The paper represents the significance of the material rock composition in the fault estimation. Many factors influence on the fault parameters, such as strain state, material rock composition and others. This paper considers material rock composition, as one of the factors.

The author has studied the fault zones peculiarities on the basis of the analysis and generalization of materials on the fault tectonics received during investigations in the regions of different geologic formations. These peculiarities should be taken into consideration during engineering geologic researches.

For the quantitative estimation of geotechnical and hydraulic properties in faulting zones the relative ratio was calculated.

1. INTRODUCTION

According to modern notions in engineering geology, ruptures are considered as complex dynamic systems where physical and chemical transformation of substance takes place. Therefore, it is possible to introduce a structural and material meaning into the concept of a fault and to consider it not as a disjunctive boundary of the division, but also as a special geological body possessing the following main features: 1 - is multi-component geological body in which rocks of different degree of fragmentation are distinguished; 2 - has a certain, inherent only to them internal structure, formed in a special tectonic environment, and is characterized by a certain combination of rocks; 3 - has undergone the same geological processes and has the same type and regionally maintained engineering and geological features; 4 - ranks a certain place in the modern structure of the Earth's crust.

In practice of engineering-geological researches at fault studying the basic attention is given to revealing of possible modern activity and an estimation of their influence on physical and mechanical properties and filtration properties of rock massifs. Nevertheless, material and morphological peculiarities of faults, such as internal structure, thickness of faults and separate zones, level of change of physical-mechanical and filtration properties, are poorly studied parameters. Although they fully determine the properties of rock massifs, they can influence on the formation and activation of exogenous processes and be considered as weakened surfaces on which displacements can occur.

2. REGULARITIES OF FAULTING CONSEQUENCES IN VARIOUS GEOLOGICAL CONDITIONS

Construction experience, a variety of designs and methods of strengthening of the bases give the chance to use almost any geological and structural conditions for the construction. Therefore, the question of engineering and geological features of the internal structure of faults, properties and parameters of both individual subzones and the faults as a whole, often faces geologists in engineering research. One of the main, most relevant issues for engineering geology in relation to faults can be considered is the assessment of the area of fault changes (Barykina, 2014).

Sherman S.I. (1983) understands the zone of dynamic influence of the rupture, which is determined by the character of its formation and its subsequent life. Within this zone, the rock massif is exposed by the mechanical, structural and petrographic changes.

The research is based on the author's personal researches of the patterns of fault structure on the basis of analysis of literary and materials of engineering-geological researches on sites of seventeen hydroelectric power plants: Inguri HPS, Rogun HPP, Khudoni dam, Krasnoyarsk HPP, Sayano-Shushenskoye HPP, Toktogul HPP, Nurek HPP, Charvak HPP, Chirkey HPP, Ust-Kamenogorsk HPP, Bukhtarmin HPP and others. For the analysis the materials of engineering and geological surveys of the Institute "Hydroproject" were used. More than 40 faults of different order (II - IV) on sixteen characteristics were considered, among which are: the age of folding, lithological and petrographic composition of the containing rocks, stress-strain state of the territory, physical-mechanical and filtration properties of the containing rocks and rocks of bursting zones, etc.

The analysis has shown that the material and morphological features of ruptures are conditioned by the history of geological development, the material composition of rocks and the character of modern movements that determine the stress-strain state of the massif.

3. PECULIARITIES OF FAULT STRUCTURE IN DIFFERENT ROCK COMPLEXES

Six rock complexes can be distinguished by the nature of the faults: granite-gneiss, gabbroid, metamorphic shale, effusive-sedimentary, carbonate, and terrigenous. The main differences between these complexes are manifested in the ratio of capacities of different subzones, in the degree of change in the physical-mechanical and filtration characteristics of rocks of the dynamic influence zone in comparison with intact massifs.

Since the power of the dynamic influence zone is determined by a complex of factors, let us consider, for example, one-age discontinuous structures of the third order in carbonate, effusive-sedimentary and terrigenous complexes. Thus, the width of the right-bank fault-slip detected in the Cretaceous limestones of the Inguri HPS is 10 - 20 m, whereas the thickness of the faulting structure breaking through the Cretaceous sandstones, siltstones and argillites of the Rogun HPP is 30 m, and the fault in the left-bank adjoining of the Khudoni dam has a capacity of 20 - 30 m. So, it has been revealed that the maximum fracture structures of the same order are manifested in rocks of the terrigenous complex. They are characterized by intensive fragmentation of rocks and maximum power of subzones. Ruptures are slightly weaker in the effusive-sedimentary rocks, the thickness of zones and the intensity of fracturing in them is less than in terrigenous rocks, but much more than in rocks of granitogneiss complex, shale metamorphic complex and carbonate complex. In the rocks of both granite-gneiss complex and metamorphic shale complex, the thickness of fracture zones is less, but all subzones are pronounced. The weakest bursting disturbances are manifested in carbonate rocks, which is most likely explained by their high plasticity.

On the other hand, it is necessary to take into account that infiltration metasomatism may increase the monolithic value of the array, but, as a rule, the strength of the array is not restored to its original value. For example, at the Sayano-Shushenskoye HPP, steeply falling discontinuous structures healed with quartz and carbonates are singled out, as well as gently sloping structures filled with clay material, but in some places hollow. That is, infiltration metasomatism on steeply falling structures has led, to some extent, to the restoration of strength, but to the complication of hydrogeological conditions, as the permeability of this area is characterized by great heterogeneity, due to the fact that the healed steeply falling structures are a screen for filtration flow, while the low-falling ones are characterized by increased specific water absorption (more than 4 l/min).

4. QUANTITATIVE ASSESSMENT OF ROCK PROPERTIES CHANGES IN FAULT ZONES

To estimate the change of physical-mechanical and filtration properties in fracture structures, relative coefficients were calculated for each parameter for each of six rock complex. This coefficient characterizes the comparative change in the properties of rocks in the zone of dynamic influence in comparison with the properties of rocks of the host massif. To characterize the change in relative coefficients for the lithological complexes we have identified (Table 1), the maximum change have the filtration characteristics - so, the value of specific water absorption in the faults can increase by an order of magnitude (one hundred times) (in the ruptures in granites), and can practically not change (in the zones of ruptures in the metamorphic shale). Minimal changes are characterized by strength characteristics - the value of resistance to compression (the interval of change of 0.31 in gabbro to 0.44 in granite).

Thus, the specific water absorption in the ruptures may increase by more than a hundred times (at the base of the Krasnoyarsk HPP), and may practically not change (in the ruptures in the Sayano-Shushenskoye HPP). The interval of change in strength characteristics (the value of compression strength) varies from 0.29 in the gabbro of Ust-Kamenogorsk to 0.44 in the limestone of the Inguri HPS. The internal friction coefficient varies from 0.47 (in the metamorphic shale of the Sayano-Shushenskoye HPP) to 0.89 (in the limestone of the Inguri HPS). The interval of change of the deformation modulus varies from 0.08 (in granites of Krasnoyarsk HPP) to 0.58 (in metamorphic shale of Sayano-Shushenskoye HPP).

The given data show that all the studied parameters - deformation, strength and filtration - in the zones of dynamic influence change significantly, and the physical and mechanical properties decrease and the filtration properties increase. Thus, the change in the deformation modulus varies from 6 to 57% of the saved array. The maximum change in the deformation module and specific water absorption occurs in the breaking zone of the Krasnoyarsk hydroelectric power station. This is explained by the large-scale crushing of rocks and the presence of permeable gently sloping cracks in the complex bursting zones. The deformation modulus is least of all changed in the rocks of fracture fractures that break the ortho- and paraslates of the Sayano-Shushenskoye HPP base. The paradox of a small change in both the deformation modulus and other filtration and physical-mechanical properties in this case is explained by the cementation of crushed rock with quartz and carbonate minerals, which brings all the values in the faults to the values noted in the rocks of the host massif.

Thus, the maximum change of physical-mechanical and filtration properties is inherent in the granite-gneiss complex. In rocks of carbonate complex the change of properties is minimal, that is caused by wide development of processes of recrystallization of crushing products and hydrothermal changes of rocks. Between these two complexes the following rock complexes are located (in descending order of the relative property change coefficient): effusive-sedimentary, terrigenous and gabbroid.

Thus, the analysis of the influence of thickness of the fault zone, its internal structure, the degree of rock disintegration on the real composition of rocks has shown that the physical, mechanical and filtration properties of rocks in the zone of dynamic influence depend not only on the properties of the rocks of the host massif, but also on the features of secondary transformations that occurred with the massif during geological life.

5. ENGINEERING-GEOLOGICAL CLASSIFICATION OF FAULTS

On the basis of the analysis the engineering-geological classification of tectonic structures by level of their complexity was developed (Barykina, 1997). Static (genetic and morphological characteristics) and dynamic (modern mobility) characteristics are considered in classification. Each factor was analyzed by the level of its influence on the complexity of engineering-geological conditions. The separation of faults on the basis of the rating is carried out taking into account the "weighting" of each individual factor by means of points. Scores are assigned to the complexity of engineering-geological conditions for each factor under study (and the more complex are the conditions, the higher is the score). All faults are divided into three types: simple, complex and very complex. Each type is distinguished by the sum of points that characterize each factor.

Table 1 : Average values of comparative property change coefficients for different rock complexes

Rock complexes	Coefficient characterizing the level of changes of engineering and geological characteristics in rocks of fault zones								
	E	R_c	V	E_{dyn}	K_f	$tg\ \varphi$	c	K_{rup}	q
Granite-gneiss	0,19	0,44	0,63	-	5,09	-	-	3	66,3
Gabbroid	-	0,31	0,68	0,43	-	0,64	-	-	8,94
Effusive-sedimentary	0,25	0,40	0,59	-	8,50	0,77	0,38	-	8,33
Metamorphic shale	0,57	-	-	-	-	0,47	-	3,4	1,60
Carbonate	0,36	0,38	0,50	0,49	50	0,84	0,47	2,44	12,31
Terrigenous	0,34	0,40	0,63	-	18,56	0,49	0,31	1,78	2,61

As an example, an interesting structure - the Rogun HPP is being built now in the Republic of Tajikistan (Fig. 1). The area of this hydroelectric complex is located within the junction zone of the two largest structural regions of Central Asia - South-West Tien Shan and Tajik depression. Seismic activity of the region is very high, up to 9 points. Located in the upstream of the Vakhsh River in Tajikistan, the dam with a height of about 350 m is located in a single tectonic block, limited by sub-parallel Ionakhsh and Gulizindan regional faults.

The sides of the Vakhsh River canyon are composed of Cretaceous sediments and represent a strata of unevenly interlayered sandstones and siltstones with interlayers of argillites.

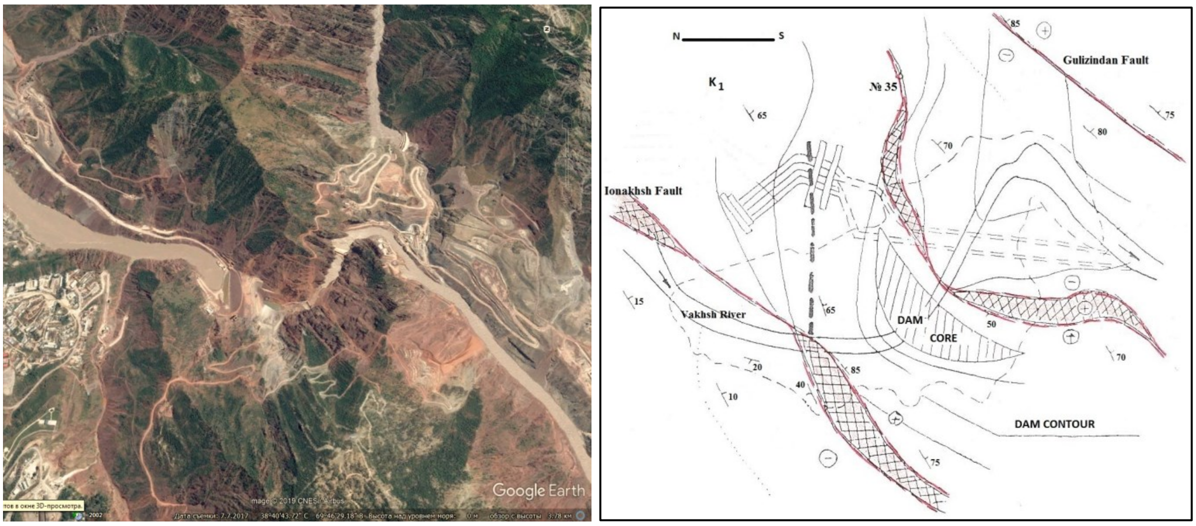

Figure 1: Rogun construction site on the Google Earth (2019) and tectonic structure of the site (Kolichko, 1985)

The layer decline is monocline, close to the vertical direction, with a northeastern strike. All the structures of the hydroelectric complex are located in a large, relatively preserved block of rocks, limited by two major faults - the Ionakhsh Fault and Fault 35 (Fig. 1). The dam of the Rogun hydroelectric power station is located directly in the zone of influence of the Ionakhsh Fault. Here, the fault, extending parallel to the spread of rocks, falls to the south-east at an angle of 75-80°. In the upper water body of the Ionakhsh Fault is represented by two tectonic sutures limiting the subzone of crushing and milonitization. The largest distance between the displacements is 80 m. The shifter subzones are made of tectonic friction clay, with the main shifter (southeast) thickness reaching 1.5 m, and the secondary (northwest) - 0.3 m. The largest of the related of Ionakhsh Fault is the fault No. 35, which is a gentle ripple. The area of dynamic influence reaches 30 m, and the displacer of this disturbance is represented by a friction clay with a thickness of 10-15 cm. In the fault zones, local groundwater pressures of up to 10 - 15 m are recorded. A characteristic feature of these faults is their modern mobility, which is estimated based on the data of regime observations. In the case of an earthquake of magnitude 9, the possible magnitude of displacement may be several tens of centimeters.

Engineering-geological type of faults at the Rogun HPP site: 1. Morphocinematic type, time of occurrence and peculiarities of internal structure - ripple, mesozoic, complex - 3 points; 2. Lithological-petrographic complex of rocks - terrigenous - 2 points; 3. Epigenetic transformations - in faults strongly crushed and weathered rocks - 3 points; 4. Modern dynamics - active (high horizontal stress causes high values of displacement - up to 1-3 mm/year) - 3 points; 5. Spatial location - subvertical, at the base - 3 points; 6. Hydrogeological features - local pressures - 3 points in RTS zones. The sum of the points is 17, so the engineering and geological type of tectonic fracture structures of the Rogun HPP section is very complicated.

6. CONCLUSIONS

1) Engineering assessment of faults for the construction is an urgent problem of engineering geology, which is of great practical importance.

2) Substance and morphological features of faults are depend on the history of geological development of territory, material composition of rocks and the nature of modern movements that determine the stress-strain state of the massif.

3) Six rock complexes can be distinguished by the nature of the influence on the substance and morphological features of faults.

4) In order to estimate the change of physical-mechanical and filtration properties in faults it is proposed to calculate comparative coefficients for each parameter for different rock complexes.

5) It is necessary to estimat faults taking into account the mechanism of formation and morphocinematic type of fault; appearance time and internal structure; lithological and petrographic complexes of rocks; epigenetic transformations; modern mobility; position in the massif and hydrogeological conditions.

6) Weakness of the modern methodical and theoretical basis for solving this problem, ambiguity of the assessment of the dynamic influence zone requires its further scientific and methodical development using the experience of engineering and geological research and construction.

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