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Deformations in a weathered rock crust next to a dam

Les déformations dans la croûte rocheuse intempérisée au voisinage d'un barrage

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SYNOPSIS: Local deformations were noticed in the area of the spillway during the erection of a rockfill dam. The investigations showed that the respective slope had been yielding slowly before the beginning of the construction works. The dam itself, which has an arched shape and leans almost perpendicularly against the slope, has had a favourable effect on delaying the creeping. The weighting embankment erected on the upstream side of the spillway has also contributed to the stabilization of the slope.

INTRODUCTION

The rockfill dam with central clay core is erected in the southern slopes of the Balkan Mountain. It is 72.5 m high, the crest width is 8 m and its length along the crest is 265 m (Fig. 1). It lays on dolomites, marls, quartzites and siltstones..

Figure 1. Layout of the dam

The object of the present paper is the stability of the right walley slope in the area of the spillway. The slope consists of Upper Cretaceous sediments of flysch type - siltstones, claystones and marls, with finegrained sandstone intercalations 0.2 to 0.5 m thick. They are the result of rythmic sedimentation in a basin with differentially expressed processes of transgression and regression. Middle Triassic dolomites outcrop under the Upper Cretaceous sediments towards the slope base.

In contrast to the general dip of the rock formations to the west, the dip of the Upper Cretaceous sediments, established from observations of the terrain and in the adit (Fig. 2) is south-southeast with a variation of the dip azimuth from 145° to 182°. The inclination of the layers is 32° on the average and varies in a very wide range in the adit - from 28° to 61°. The layers in the flysch complex and the sedimentary cracks have a dip direction opposite to the slope inclination (towards the massive). Three systems of tectonic cracks were established (Fig. 2), one of which has a strike azimuth, coinciding with that of the sedimentary cracks. The tectonic cracks have an inclination of 75° to 85° and a dip towards the river.

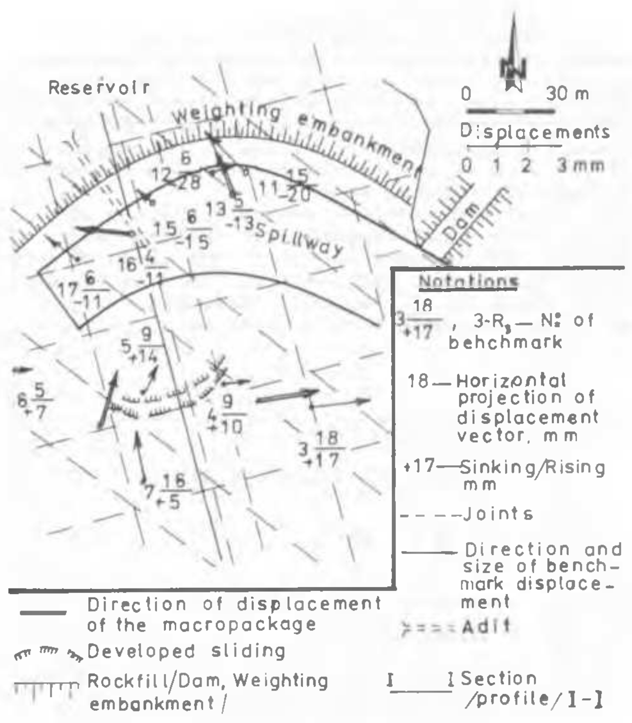

Figure 2. Cracks in the massive and displacement of the benchmarks

Tectonic cracks with a strike of 120° to 130° predominate. The demarcation of the rock blocks within the massive usually is not along separate cracks, but along "bundles" of cracks, where the cracks are closer to each other than in the separate blocks. The separation of the rock blocks and packets in their base is explained with the presence of discharge and weathering cracks, parallel to the slope surface relief. The weathering depth of the rock massive varies, and it has been more intensive in the tectonic zones (up to 10 m wide), the tectonic bundles and the surfaces of stratification. Particularly strong has been the weathering of the siltstones, claystones and thin layered marls, which have been transformed into paper shales. The sandstones which have undergone brittle destructions, are cracked, and in the tectonic zones they are broken. The depth of the weathering zone in the rock massive is 15 to 25 m established during the investigations and grouting works.

The geological conditions thus described do not presume instability in the slope rocks, although slip surfaces with steep dipping (75° to 85°) towards the river were found in the dolomite bedding during the investigations. However gravitational movements were established in the course of the construction works.

BEARING CAPACITY AND STABILITY OF THE SUBGRADE UNDER THE SPILLWAY

The spillway structure was erected in 1979. Two years later deformations were established, consisting in cracking and displacement of some blocks and of the discharge canal bottom. The basic cause of these deformations was the incorrect grouting techniques adopted for the seepage control curtain under the spillway and the areal cementation. Reasons for this assertion were also the observations after the suspension of the grouting works, which indicates a relative stabilization of the deformations and the lack of new cracks in the slab and in the spillway blocks.

The first observations showed a tilting of the spillway blocks towards the upstream side. This tilting is possible due to non-uniform, although very small, deformations. This is proven by the checking of the local strength, expressed by the strength condition of Mohr-Coulomb:

$$\tau_a < \tau_r .$$

$$\tau_a = (\sigma_1 - \sigma_3)\sin\beta . \cos\beta ,$$

$$\tau_r = (\sigma_1 \sin^2\beta + \sigma_3 \cos^2\beta)\,tg\varphi + c;$$

$$\sigma_{1,3} = \frac{p}{\pi}(\alpha \pm \sin\alpha),$$

where τ_a - active tangential stress,

τ_r - shear strength,

σ_1, σ_3 - maximum and minimum principal stresses from the constant load p,

β - the acute angle between the shear surface and the direction of σ_1 (in this case the inclination of the cracks $\beta = 30°$ is adopted),

φ and c - angle of internal friction and cohesion (cracks with clay filler are adopted where $\varphi = 16°$ and c=0.01MPa),

p - average load on the subgrade (in this case p = 0.161MPa).

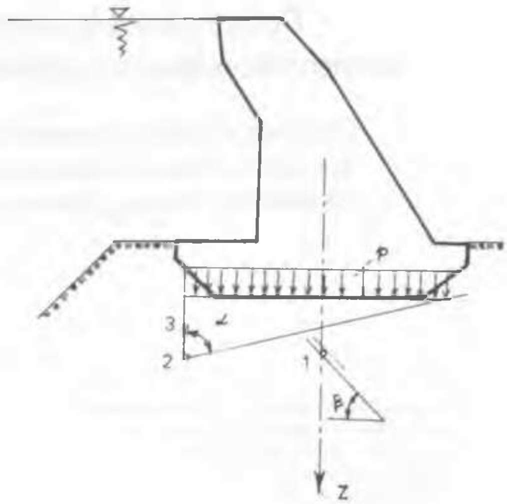

Figure 3. Section across the spillway

TABLE I

Point	z	σ_1	σ_3	τ_a	τ_r
	m	MPa	MPa	MPa	MPa
1	2,0	0,153	0,068	0,0370	0,0356
2	2,0	0,117	0,017	0,0431	0,0391
3	1,0	0,124	0,026	0,0428	0,0425

Three points are considered - under the edge, and in the spillway axis - according to Fig. 3. The calculation results are given in Table I.

The results of Table I indicate that under the adopted prerequisites the condition of local stability nearly missed being fulfilled. This confirms our assumption that the tilting of the spillway blocks was possible because of the minimum deformations of the subgrade due to insufficient local strength in the cracks with clay filler.

The stability of the circular cylindrical surface passing through the edge of the spillway structure was checked (Fig. 4). The condition at rapid emptying of the reservoir (i.e. complete saturation of the massive) is considered and the efect of the seismic forces is taken into account.

The calculations give a safety coefficient F = 1.02 without weighting embankment and F = 2.0 with embankment consisting of an additional upstream rockfill. On the basis of the calculations it is recommended to erect such a rockfill as an obligatory condition guaranteeing the local stability of the structure.

GENERAL SLOPE STABILITY

The geodetical surveys established movements, although very small, of the benchmarks, not only of the spillway but also of the slope. The hypothesis emerged, that a creeping phenomenon existed in the massive before the construction works began and still continuing, spreading over the weathered flysch crust, which is the result of gravitational processes due to the slope steepness, the river erosion and the lithological composition of the rocks.

Similar packet creeping in the weathered crust of a rock massive in Bulgaria was established in the Triassic and Cretaceous flysch sediments and Paleozoic magmatic and metamorphic rocks in road and other types of construction.

To prove the general slope stability an investigation was carried out along the circular cylindrical slip surfaces (Fig. 4) based on the landslide and the data from the adit. The safety coefficients for φ =25.75° and c = 66kPa, established with shear tests of rock material in a large cassette, and for φ = 25.75° and c = 0, are given in Table II.

In the investigation of the second case (Table II) the weighting embankment erected in the slope under the spillway is taken into account. Table II shows that the construction works have not decreased the slope stability in the direction under consideration. The condition of the natural slope was close to the limit state.

TABLE II

State	F	
	φ = 25°45' c = 66 kPa	φ = 25°45' c = 0
Natural slope (before erection)	1,50	1,11
Under operation (emergency case)	1,93	1,19

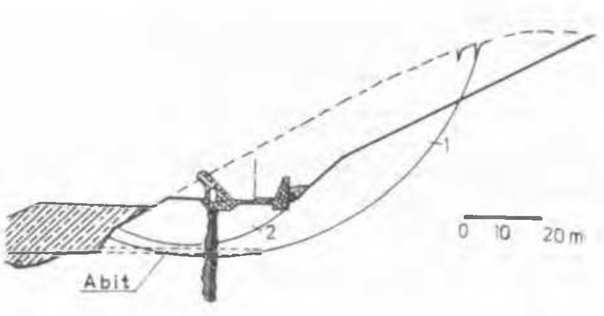

Figure 4. Section I - I for stability calculation

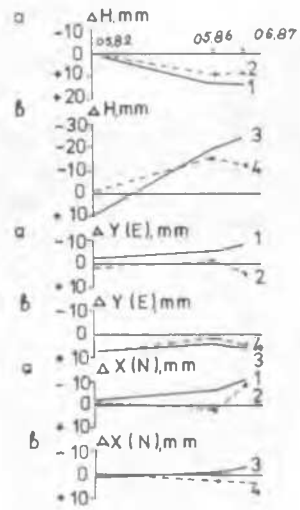

Figure 5. Displacement of benchmark groups
a - Massive; b - Spillway; E - East; N - North; Arithmetic average:
1 - for benchmarks R_3 and R_4;
2 - for benchmarks R_5, R_6 and R_7
3 - for benchmarks R_{11} and R_{12}
4 - for benchmarks R_{14}; R_{16}; R_{17}.

TABLE III

Benchmark	Displacement	Inclination
Massive	Downwards	
R_3	25 mm	43°
R_4	13 mm	49°
R_5	17 mm	57°
R_6	9 mm	55°
R_7	16 mm	18°
Spillway	Upwards	
R_{11}	25 mm	53°
R_{12}	29 mm	80°
R_{13}	14 mm	23°
R_{14}	16 mm	67°
R_{15}	13 mm	72°
R_{16}	12 mm	72°
R_{17}	12 mm	62°

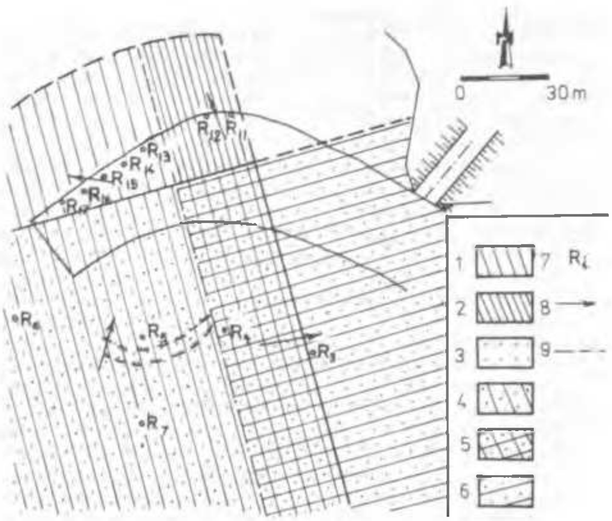

Figure 6. Zonding after the character of the displacement of the rock packets.
1 - Zone of rising; 2 - Zone of more intensive rising; 3 - Zone of sinking; 4 - Active rock packet with north-northwestward movement;
5 - Active rock packet with displacement varying in time and in space: north-northwestward and east-northeastward; 6 - Packet with east-northeastward displacement; 7 - Benchmark No.; 8 - Displacement direction of the rock packets after the indications of the benchmarks; 9 - Probable boundary of the zones of rising and eastward displacement

GEODETICAL SURVEY

A network of 50 benchmarks was laid to survey the deformations in the spillway blocks, the retaining walls and the bottom of discharge canal and the area around it (Fig. 2). The measurements conducted as early as 1982 indicate a relative stabilization of the displacements. Small visible movements as the benchmarks only on the spillway slope, and a slight tilting of some of the blocks towards the reservoir are noted. The size and the inclination of the displacement vector for a 5 year period of observation of the separate benchmarks are given in Table III.

In order to characterize the movement of the micropackets in the slope, the benchmarks are grouped according to their direction of movement. The displacement of the benchmarks during the period of observation is shown in Fig. 5. Fig. 2 gives the sum of the horizontal projections of the benchmark displacement vectors and the direction of movement of the vector groups. The cracks in the massive, the deformations in the spillway and the benchmark displacement direction allow the demarcation in the rock massive of zone of different character and direction of movement of the macropackets (Fig. 6).

CONCLUSIONS

(1) Deep gravitational movements (creeping) have existed and continue to take place in the weathered crust of the massive in the spillway slope. These have no direct effect on the stability of the dam and its appurtenant structures. Certain separate deformations are only temporary.

(2) The construction works have not impaired the stability of the slope as a whole. Just the opposite - the dam erected perpendicularly to the slope has produced a favourable effect for slowing down and stopping the slope creeping. This effect is reinforced by the arched-shaped layout of the dam. A positive effect on the slope stability has been exerted also by the fill erected upstream of the spillway.These factors have changed the creep direction of the rock packets towards the river into a new direction along the river flow, with a probable slowing down and final stabilization.

(3) In order to clarify the mechanism and the rate of movement of the rock packets, it is necessary to continue the survey of the benchmarks of the network, which is to be extended, and to include subsurface benchmarks as well.

(4) In case there is any danger for the spillway, it will be necessary to remove rock masses from the slope in the area of the active rock packets (Fig. 6) and to increase the resistance against rising and horizontal displacement eastwards, possibly by anchoring.