THE RESULTS OF FIFTY YEARS MONITORING OF THE STRAIN DYNAMICS OF THE FAULT CROSSING THE LARGE ENGURY DAM FOUNDATION

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Abstract. *The high Enguri arch dam (271 m) was erected in the 1970s in the canyon of the river Enguri. The dam area is a zone of high seismicity with the moment magnitude Mw = 8. It is close (several hundred meters) to the large Ingirishi active fault (Figure 1). The high seismic and geodynamical activities together with the dense population downstream of the dam made the Enguri dam with its one billion cubic meters water reservoir a potential source of a major catastrophe in Georgia. In turn, this means that the dam should be under permanent monitoring. Accordingly, this problem is the object of research of the M. Nodia Institute of Geophysics and European Specialized Centre "Geodynamical Hazards of High Dam" of the European-Mediterranean Open Partial Agreement on Major Disasters, organized in 1996 by the Council of Europe.*

Key words: *Enguri Dam, fault crossing dam foundation, fault strain dynamics*

Introduction

In this paper we consider the results of half-century permanent monitoring of deformation of the fault zone, which is crossing the dam foundation. This leads to understanding complicated dynamics of the fault zone deformation, reflecting a joint influence of local tectonics, man-made engineering stresses and environmental factors. The strain-rate on the fault in the period 1974 – 2019 varied between 250-150 μm/year, but in the last years, 2019-2024 the strain rate abruptly fell to zero. The change of the strain regime in the last years can be connected either with the final stabilization of the fault or with a temporary braking of fault motion by a strong asperity on the fault interface, which can lead to dynamical discharge of accumulated strain.

Study area,material and methods

The permanent multi-disciplinary geodynamical/geophysical monitoring network was organized in the dam area [1, 2, 3] in order to control the stress–strain state in the foundation of the dam according to existing standards [4]. Monitoring of the fault zone (FZ) strain and local seismicity began several years before the start of reservoir filling in April 1978. The monitoring system of Enguri Dam and its foundation (Figs. 1 ,2, 3) includes a network of tiltmeters, strain-meters and reverse plumblines in the dam body, meteo-station, water level gauge for monitoring water level in the lake. After the organization of the European Specialized Centre "Geodynamical Hazards of High Dam", the monitoring network improved significantly. Automation of monitoring data retrieval and their telemetric transfer using Internet connection, ensure obtaining information on the strains in dam foundation and its body in a close to the real time regime. This is important for operative detection of strain dynamics' deviations from the background (design) pattern and finding possible sources of anomalous behavior. The M. Nodia Institute of Geophysics and European Centre "Geodynamical Hazards of High Dams" developed the real-time geotechnical telemetric monitoring system of large dams (DAM-WATCH). This low-cost early warning system consists of tilt sensors (tiltmeters, APPLIED GEOMECHANICS Model 701-2) and quartz strainmeter with optical registration (Laser model R-39568, Green HeNe Laser, 633 nm and Laser Position Sensor OBPA-9L), which are connected to terminals and central controllers and by a GSM/GPRS modem transmits the data to the diagnostic center in Tbilisi (Fig.1, 2, 3). The fixed and free parts of the strainmeter are located on the intact rocks on the opposite sides of the fault zone (FZ); the full length of the strainmeters' quartz tube is 22.5 m. This means that the device records displacement of the intact blocks, divided by the fault zone in the normal to the fault plane direction, so it records the fault zone's extension/contraction.

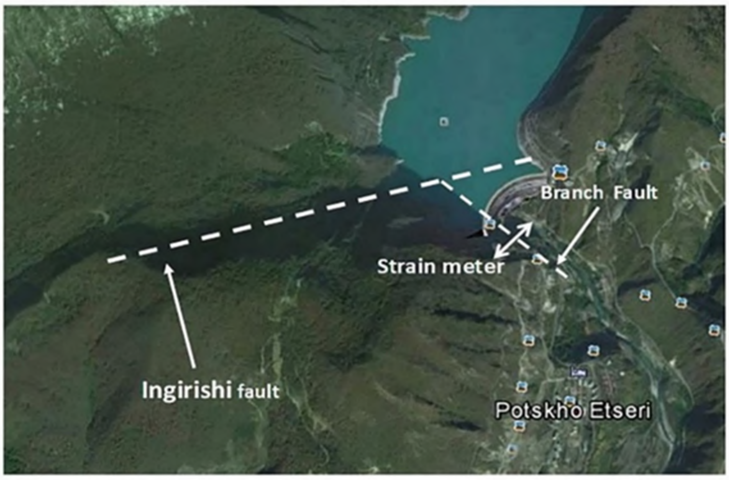

Fig.1. Google image of Enguri Dam area. The main tectonic units of the area are Ingirishi fault and its branch, which is crossing the foundation of Enguri dam as well as the tunnel 3413, where the strainmeter is installed (see also scheme 2).

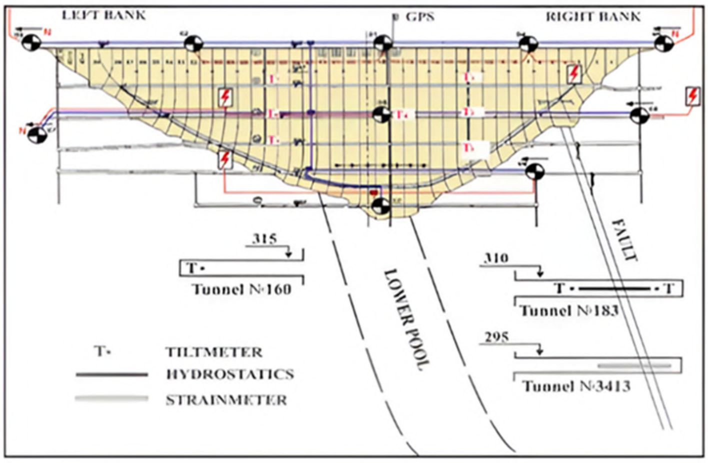

Fig. 2. The monitoring system at Enguri High Dam. The strainmeter is installed on the fault crossing the dam, in the tunnel N3414, at the distance 120 m from the dam foundation.

Transmission system, connected sensors installed at Enguri Dam area are carried out by the group of German Geophysicists from Karlsruhe of Technology.

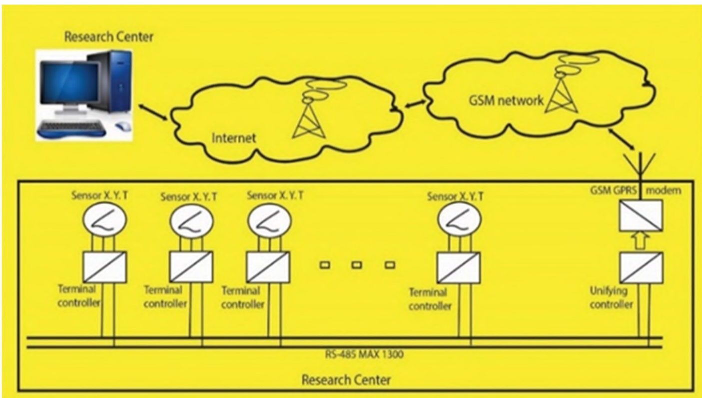

Fig 3. Transmission system, connecting sensors installed at Enguri dam with monitoring centre in the Institute of Geophysics

Results

The strain rate history of the branch fault crossing the Enguri Dam is complicated: it reflects the strong variations in the slip velocity [5]. The initial strain rate (SR) values for 1974-1985 reflect the natural (tectonic) component dynamics of the fault strain rate: V1= 250 μm/year; this SR characterizes the mechanical properties of the natural system of force chains in the fault gorge under the natural strain rate. In the following 1985-2004 period velocity decreased to V2 = 160 μm /year, which can be due to the damage of the initial system of force chains in the fault volume by water load cycles as a result of the reversed–stress fatigue effect. In the following epoch (2004-2013) the strain rate V3 increases to almost initial value V3 = 233 μm /year, which can be interpreted as the result of temporary healing of disrupted force chains. In the following period V4 the strain rate decreased again to 150 μm /year, i.e. it almost returns to V2, which again can be explained by the repeated weakening of force chains in the fault gorge. This repeated pattern of slip from 1974 to 2013 can be explained by the quasiperiodic slip process with alternating velocity of slip, due to varying fault surface roughness.

In the last years, 2019-2024 the strain rate abruptly fell to zero: V5 = 0 μm. The change of the strain regime in the last years can be connected either with the final stabilization of the fault or with a temporary full braking of the fault motion by a strong asperity/asperities on the fault interface. In the last case, the stress on the fault will build up, till attaining the critical stress value, necessary for overcoming the resistance of asperity/asperities in a dynamical manner. The dynamical discharge of the accumulated energy can generate an earthquake. Taking into consideration the length of the dam-crossing fault (2-3 km) the magnitude of EQ can be of the order of M3-4 [6,7], which should not be dangerous the dam structure, as according to previous engineering assessment [8], the Enguri Dam should withstand the impact of the maximal expected earthquake of magnitude M8.

Table 1. Periods with different strain rates of trend, from the data, presented in Fig. 4.

Number of periods	Periods: month, years	Strain rate α in the period, microns/year
1	May 1974-Feb. 1985	250
2	Feb. 1985-May 2004	160
3	May 2004-May 2013	233
4	May 2013-Apr. 2019	150
5	Apr. 2019-Aug.2024	0

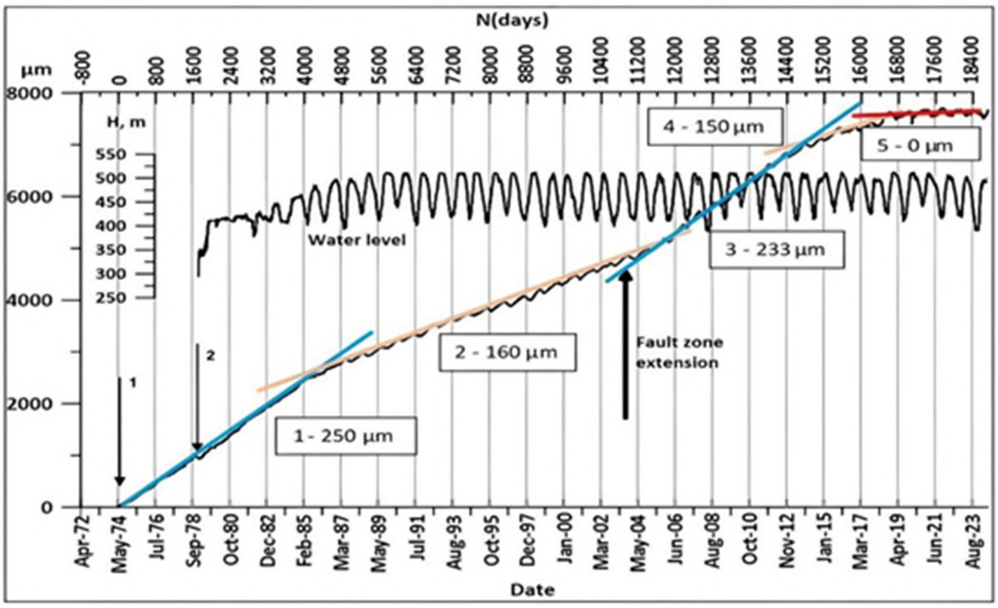

Fig. 4. WL in the Enguri lake from 1978 (upper curve) to 2023 and the data of the extension/compaction of the branch of the large Ingirishi fault, crossing the foundation of the dam (lower curve). Arrow 1 corresponds to the start of strainmeter monitoring and arrow 2 – to fault compaction by approximately 90 μm at WL, rising to 100 m in 1978. The upper horizontal axis shows the number of days from the zero day (1 May 1974) to August 2024. Note different strain rates during 50 years of the observation period.

Conclusion

It cannot be excluded that strain on the dam-crossing fault is governed by the deformation of the main Ingirishi fault of which the dam-crossing fault is a side fault. In this case, the leading seismogenic factor will be the main Ingirishi fault, which is characterized by much larger seismic potential, than the small side fault. As the existing strain observation system of Enguri Dam does not cover the main Ingirishi fault, the problem should be studied in detail by installation of strainmeter and seismic station on the Ingirishi fault and analysis of its dynamics.

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