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Geophysics

Long-Term Strain Dynamics of the Fault Crossing the Engury Dam Foundation

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With 271 m in height, the Enguri arch dam (West Georgia) is one of the highest dams of its kind in the world. It was constructed in the river Enguri gorge in the 1970s. The region adjoining Enguri Dam is characterized by high geodynamic and seismic activities and the area is densely populated. All this makes the area a source of potential major technological catastrophe. Accordingly, this issue is the object of research of the M. Nodia Institute of Geophysics and European Specialized Centre "Geodynamical Hazards of High Dams" of the European-Mediterranean Open Partial Agreement on Major Disasters, established by the Council of Europe in 1996. In the present paper, we consider the results of half-century permanent monitoring of deformation the fault zone, which is crossing the dam foundation. This lead to understanding of 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 of 1974-2019 varied between 250-150 µm/year, but in recent years (2019-2023) the strain rate has abruptly dropped to zero. The change of the strain regime may be connected either with the final stabilization of the fault or a temporary braking of fault motion caused by a strong asperity on the fault interface, which can lead to dynamical discharge of the accumulated strain. *© 2024 Bull. Georg. Natl. Acad. Sci.*

Enguri Dam, fault crossing dam foundation, fault strain dynamics

Enguri Dam Monitoring system

A permanent multi-disciplinary geodynamical and geophysical monitoring network was organized in the dam area [1-5] in order to control the stress–strain state in the foundation of dam according to existing standards [6]. Monitoring of the fault zone (FZ) strain and local seismicity began several years before the start of reservoir filling in April 1978. The Enguri Dam monitoring system and its foundation (Fig. 1) include 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 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 the 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 deviations in the strain dynamics 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" have developed the real-time geotechnical telemetric monitoring system of large dams (DAMWATCH). 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. The fixed and free parts of 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 fault zone's extension/contraction.

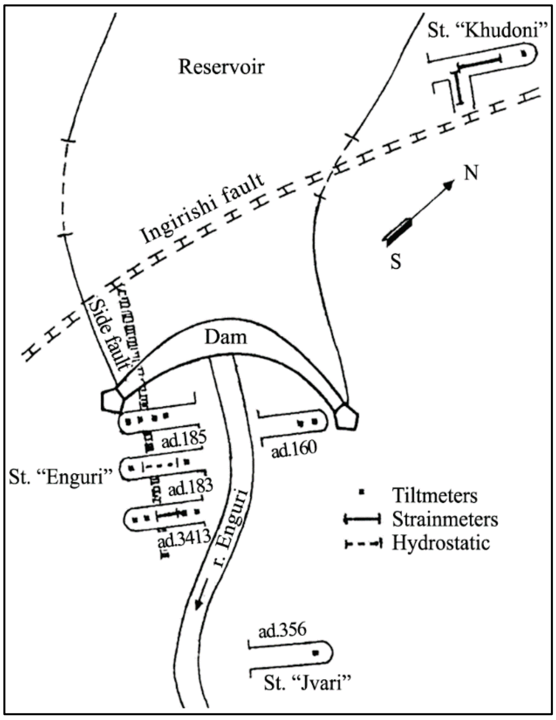

Fig. 1. Adits arrangement scheme of tiltmeter-strainmeter and hydroststic stations in EHEPS region [1].

Results

Figure 2 presents a long history of both the water level (WL) change in the Enguri reservoir H, (meters), as well as the fault zone extension – FZE (i.e. displacement of the normal to the fault plane of the free end of the strainmeter). It is evident that the fault dynamics reflects joint influence of two main factors: one of them leads to piecewise-linear in time displacement (slow trend component) and the other one – to quasiperiodic oscillations, decorating the main trend. The long-term piecewise-linear trend documents persistent separation of fault faces (Fig. 2), extending to summary value 7000 μm (7 mm) during whole observation period.

As the trend component with the same strain rate was recorded even before dam construction and lake filling, we attribute the long-term strain component to the slow regional tectonic stress action. At the same time, the fault zone extension rate (FZER) for the long-term strain component changes significantly with time, reflecting action of some non-stationary factors. As it was expected, quasi-periodic FZ deformation, decorating the general trend after 1981 mirrors the yearly variation of WL in the Enguri lake from 1978 (upper curve) to 2023 as well as the data on the extension/compaction of the branch of large Ingirishi fault, crossing the foundation of the dam (lower curve).

Table. Periods with different strain rates of trend, from the data, presented in Fig. 2

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.2023	0

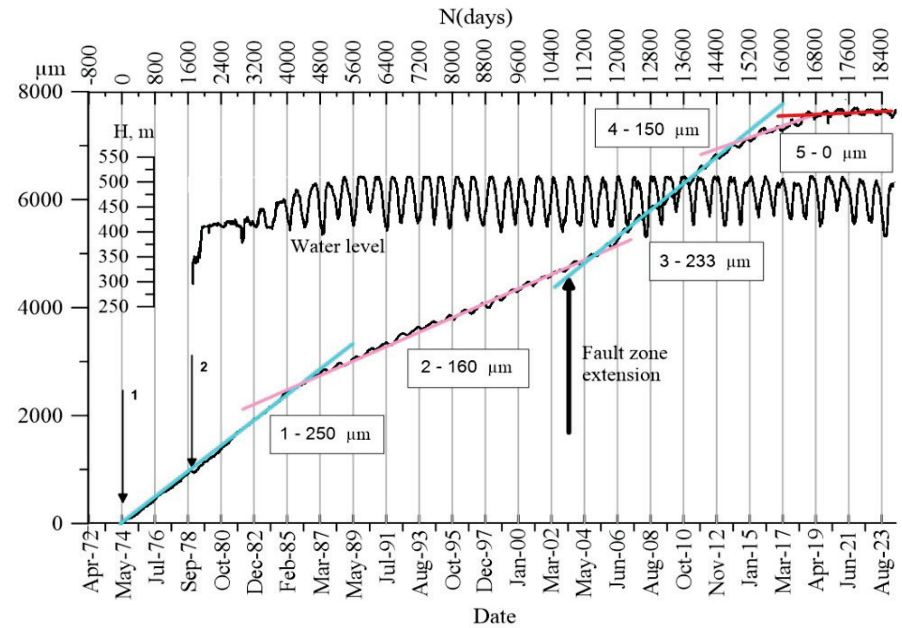

Fig. 2. WL in the Enguri lake from 1978 (upper curve) to 2023 and the data of the extension/compaction of the branch of large Ingirishi fault, crossing the foundation of the dam (lower curve). Arrow 1 corresponds to the start of strainmeter monitoring and arrow 2 – to fault compaction by approximately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

Discussion

The strain rate history of the branch fault crossing the Enguri Dam is complicated reflecting the strong variations in the slip velocity [7]. 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 period 1985-2004, the 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 reversed–stress fatigue effect. In the following years (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. almost returns to V2, which again can be explained by the repeated weakening of force chains in the fault gorge. This repeated slip pattern from 1974 to 2013 can be the explained by quasiperiodic slip process, with alternating velocity of slip due to varying fault surface roughness.

In the recent years (2019-2023), the permanent component of the strain rate abruptly fell to zero: $V5 = 0$ μm. The change of the strain regime 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 this 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 could be in the range of M3-4 [8, 9], which is not dangerous for the dam structure. According to previous engineering assessment [10], the Enguri

Dam is designed to withstand the impact of the maximal expected earthquake of magnitude M8. Of course, it cannot be excluded that the strain on the dam-crossing fault is governed by the deformation of the main Ingirishi fault, of which the dam-crossing fault is a secondary fault. In this case, the leading seismogeneous factor would be the main Ingirishi fault, which is characterized by much larger seismic potential, than the smaller side dam-crossing fault. As the existing strain observation system at the Enguri Dam does not cover the main Ingirishi fault, the problem should be studied in detail by installation of strain-meter and seismic station along the Ingirishi fault to analyze its dynamics effectively.

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გეოფიზიკა

ენგურის კაშხლის ფუძის გადამკვეთ რღვევაზე დაძაბულობის გრძელვადიანი დინამიკა

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მაღლივი ენგურის კაშხალი (271 მ სიმაღლე) დასავლეთ საქართველოში არის ერთ-ერთი უმაღლესი კაშხალი მსოფლიოში. ის აგებულ იქნა მდინარე ენგურის ხეობაში გასული საუკუნის 70-იან წლებში. ენგურჰესის მიდამოებს ახასიათებს მაღალი გეოდინამიკური და სეისმური აქტივობა. გარდა ამისა, ეს რეგიონი მჭიდროდ არის დასახლებული. ყოველივე ეს მიანიშნებს, რომ რეგიონი შესაძლოა გახდეს დიდი ტექნოგენური კატასტროფის არე. შესაბამისად, ეს პრობლემა არის მ. ნოდიას გეოფიზიკის ინსტიტუტის და ევროპის საბჭოსთან არსებული ცენტრის „მაღლივი კაშხლების გეოდინამიკური რისკების" კვლევის საგანი. წინამდებარე ნაშრომში განიხილება კაშხლის ფუძეში გამავალი რღვევის ზონის დეფორმაციის ნახევარ-საუკუნოვანი მუდმივი დაკვირვებების შედეგები. ამან საშუალება მოგვცა გაგვერკვია რღვევის ზონის რთული დინამიკა, რომელსაც განსაზღვრავს როგორც ლოკალური ტექტო-

ნიკა, ისე ხელოვნური საინჟინრო დაძაბულობები და სხვა გარეშე ფაქტორები. რღვევაზე დაძაბულობის ცვლილების სიჩქარე ვარიირებდა 1974-2019 წწ. პერიოდში 250-150 მიკრომეტრის ფარგლებში, მაგრამ ბოლო წლებში – 2019-2024 წწ. – დაძაბულობის ცვლილების სიჩქარემ უეცრად იკლო ნულამდე. ბოლო წლებში დაძაბულობის რეჟიმის მკვეთრი ცვლა შეიძლება აიხსნას როგორც რღვევის საბოლოო სტაბილიზაციით, ასევე რღვევის მოძრაობის დროებითი დამუხრუჭებით რღვევის სიბრტყეში ძლიერი დაბრკოლების არსებობის გამო. ამას შესაძლოა მოჰყვეს დაგროვილი დაძაბულობების დინამიკური განმუხტვა – მიწისძვრა, რომლის შესაძლო მაგნიტუდა შეფასებულია.

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