GHHD-OPA report for 2020

, European Centre "Geodynamical Hazards of High Dams"
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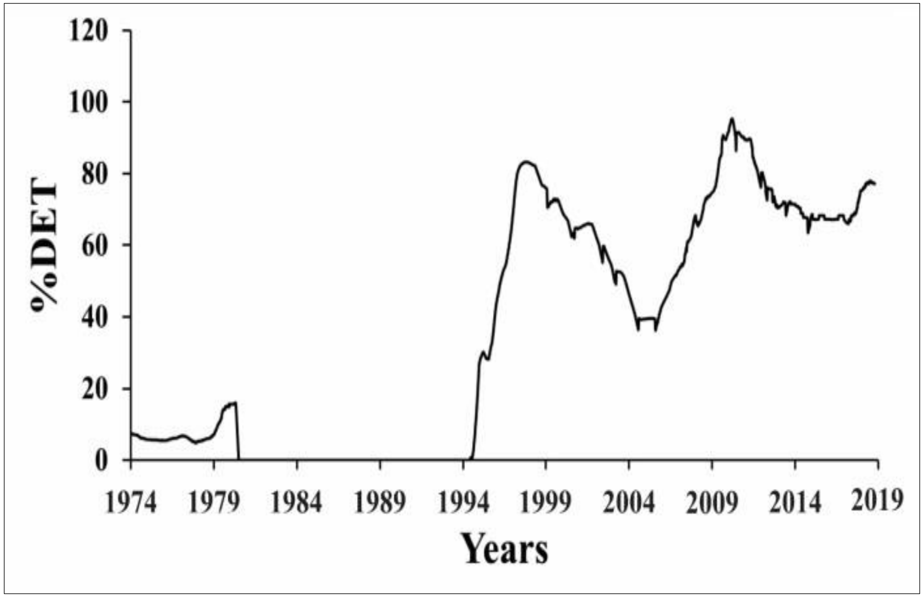
WP.1. Compilation of computer program for analysis of tilts/strains/seismicity monitoring data of the dam and surrounding area for detecting deviations from the normal behavior.

In physics and technology, a nonlinear system is a system in which the change of the output is not proportional to the change of the input.. Most of real earth materials reveal nonlinear reaction to mechanical disturbance. We show in our previous publications that dam deformation under seasonal water load also follows nonlinear dynamics pattern – namely, it demonstrates hysteretic behavior during reservoir load-unload cycles (T. Chelidze et al. Complex dynamics of fault zone deformation under large dam at various time scales. Geomechanics and Geophysics for Geo-Energy and Geo-Resources. 2019). Our group published several papers, devoted to analysis of tilts, strain and seismicity time series in Enguri dam area, using different tools of nonlinear dynamics. It is interesting to note that the singular spectrum analysis (SSA) reveals periodicities in the reservoir-triggered seismicity (RTS) of the Enguri dam area (Peinke et al. 2006; Matcharashvili et al. 2010; Telesca et al. 2012; Chelidze and Matcharashvili 2015). Namely, clear annual periodicities, as well as some higher order cycles (6 months) were extracted from (local) earthquake time series. The 1 year cycle is absent in the seismic data of the reference (1974–1978) period, which means that annual cycles in both FZE and seismic (RTS) time series reflect quasi-periodic local man-made geodynamics, connected with the annual load-unload of reservoir.

- **Cycles with periods, multiple to the leading period can appear in FZE (Fig. 8b) and seismic time series (Telesca et al. 2012) as a result of High Order Synchronization (HOS), which is characteristic for nonlinear systems (attractors), subjected to a weak periodic external forcing (Pikovsky et al. 2003; Chelidze and Matcharashvili 2015).**
- **It is evident, that there are three distinct periods of seismic activity with different levels of ordering/synchronization: i. 1974-1981, the period before dam construction – the low values %DET from 8 to 18%. The weak synchronization can be connected with such regular natural processes as seasonal load–unload of area due to snow cover and its melting; ii. 1981- 1995 - a weak natural regularity is destroyed by reservoir filling and transient regime – the seismicity lags behind establishment of regular water level variation regime (approximately in 1985) by 10 years probably due to a time lag between deformation rate and seismic response temporal pattern (compare figures 1 and 2); iii. 1995-2019 – the period of high determinism (%DET 40-80%) in seismic regime, which became synchronous with a regular water level variation. The same we see for the % of laminarity (%LAM), which is similar to %DET: it reports the percentage of recurrent points in vertical structures of recurrent plots (trapping times of the system in in a specific state), whereas %DET gives the same for diagonal structures.**



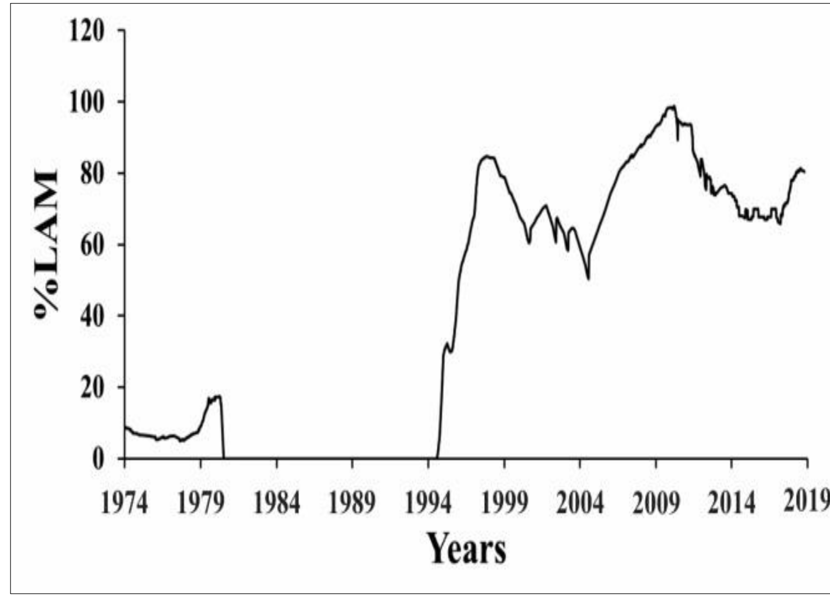


Fig. 1. %DET,%LAM of interevent times sequences (M1.7threshold It is evident, that there are three distinct periods of seismic activity with different levels of ordering/synchronization: i. 1974-1981, the period before dam construction – the low values %DET from 8 to 18%. The weak synchronization can be connected with such regular natural processes as seasonal load–unload of area due to snow cover and its melting; ii. 1981- 1995 - a weak natural regularity is destroyed by reservoir filling and transient regime – the seismicity lags behind establishment of regular water level variation regime (approximately in 1985) by 10 years probably due to a time lag between deformation rate and seismic response temporal pattern (compare figures 1 and 2); iii. 1995-2019 – the period of high determinism (%DET 40-80%) in seismic regime, which became synchronous with a regular water level variation. The same we see for the % of laminarity (%LAM), which is similar to %DET: it reports the percentage of recurrent points in vertical structures of recurrent plots (trapping times of the system in in a specific state), whereas %DET gives the same for diagonal structures

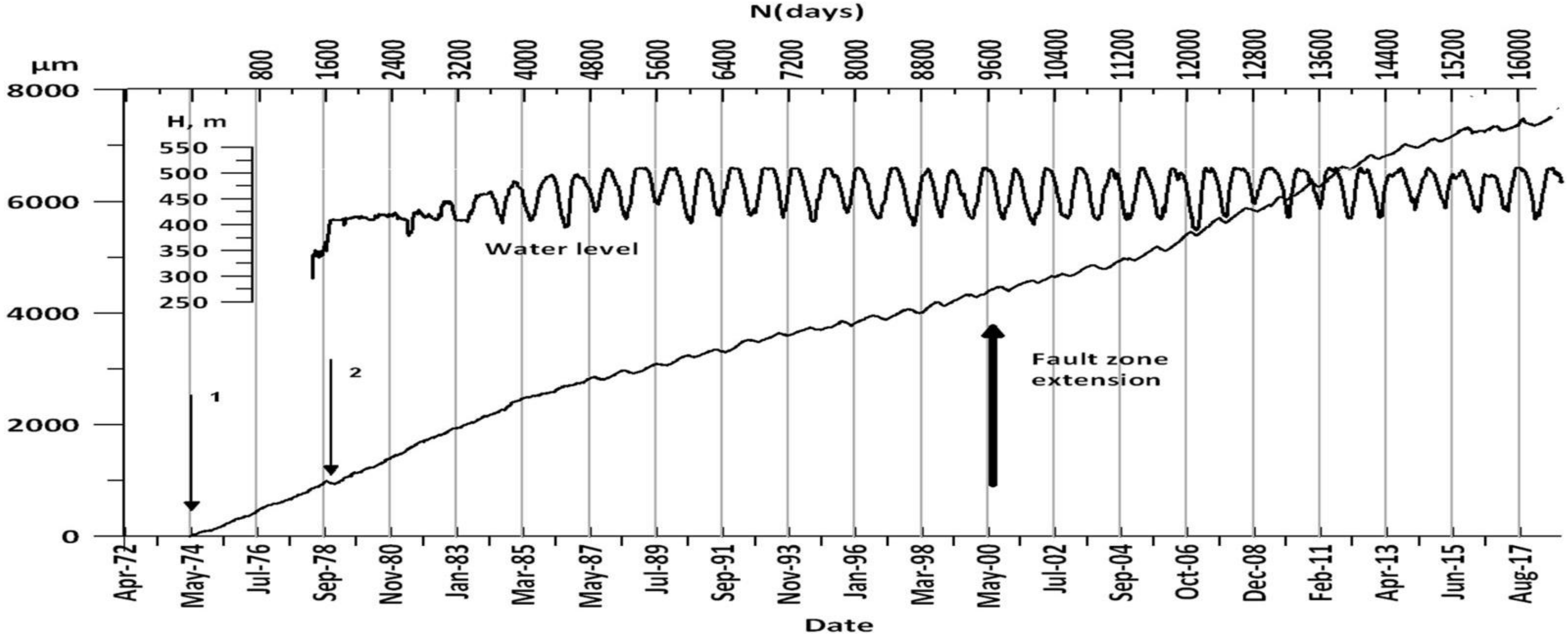
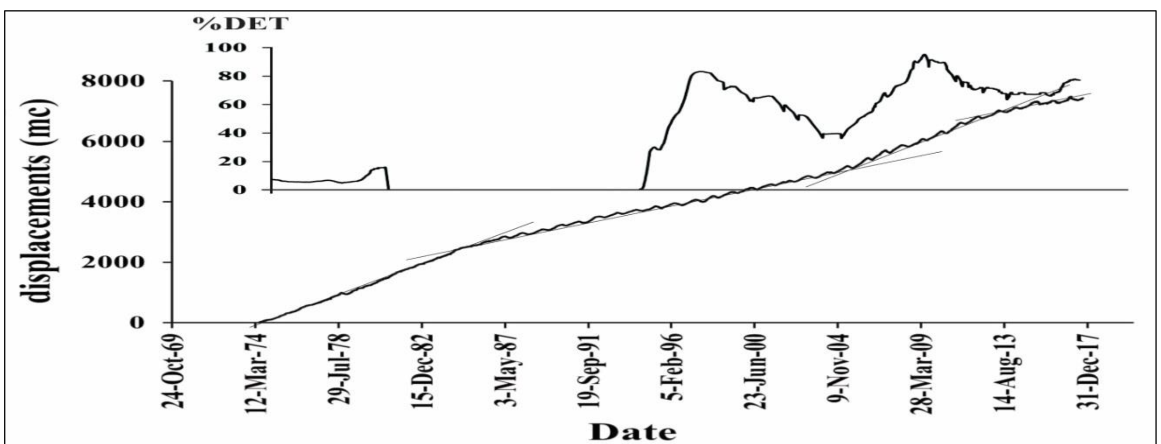


Fig. 2a. WL in the Enguri lake from 1978 (upper curve) to 2017 and the data on the extension/compaction of the branch of large Ingirishi fault, crossing the foundation of the dam (lower curve). Arrow 1 in corresponds to the start of strainmeter monitoring and arrow 2—to fault compaction by approximately 90 lm 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 1917.



In Fig.2b we compare %DET of seismic regime(upper curve) and extensometer data (lower curve). It is evident that the seismicity is weakly deterministic till 1980 (%DET is in the range 8-18. We can conclude that: i. the start of high determinism of seismicity lags behind beginning of regular load-unload of reservoir (around 1984) by approximately 11 years; the lag of the fault strain (Fig.2a) is much less – around 4 years. So, it seems that synchronization of seismic process with regular variation of water level in the lake is much more inertial than that of the strain regime

Fig. 2b. Comparison of %DET of seismic regime (upper curve) and extensometer data (lower curve).

WP2. Information on satellite technology for monitoring dam and surrounding area deformation.

- GHHD is one of partners in the development of big international project DAMAST –Dams and Seismicity, **(**Technologies for safe and efficient management of hydropower reservoirs) coordinated by the **Karlsruhe Institute of Technology (KIT)** Institute of Applied Geosciences. In the DAMAST project, **German, Georgian and Armenian** partners are examining the underlying processes as well as safety-relevant parameters of water reservoirs using the example of the Enguri Dam in the Caucasus. Using the example of the Enguri Dam in the seismically active region of the North Caucasus, DAMAST will investigate which hazards arise through the operation of water reservoirs, such as initial filling or annual water level changes, and how these hazards can be reduced. The DAMAST project aims to make a contribution to the systematic reduction of hazards at water reservoirs as well as to their long-term and efficient operation. The objective is to develop monitoring concepts that can also be transferred to other dams in comparable locations. The project will be implemented using innovative methods for the collection and analysis of relevant data. Different methods will be used in a modular monitoring concept for the acquisition of seismological, meteorological, geodetic and geological data, including remote sensing techniques with satellites and ground-based systems, well logging, modern seismic recording techniques, terrestrial radar interferometry, underwater drones, multi-beam bathymetry, multi-frequency echo sounding and sampling for sediment characterization, and novel mini-sensors. A combination of geodetic and remote sensing methods is used to record the response of the dam to load changes and compare it with vertical and horizontal displacement patterns in its surroundings. We expect to observe vertical ground deformation of cm-magnitude in response to the annually varying water level, and we aim to estimate fault shearing and regional strain built-up in the tectonically active region.

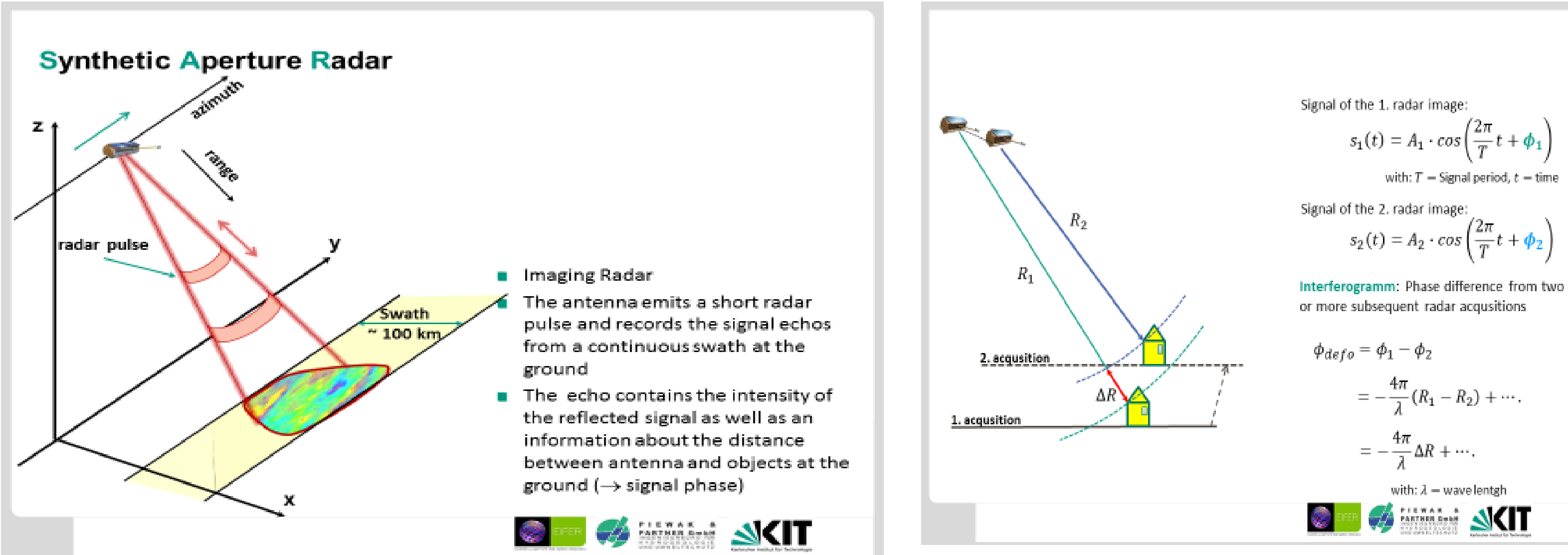


Fig. 3 a, b. The principle of Synthetic Aperture Radar

The general idea is that the project related GNSS observations support and augment any local geodetic measurements that might be carried out by GHHD or other scientific/private institutions around the ENGURI dam. Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location of the object as well as the change of location using Synthetic Aperture Radar (SAR), (Fig. 3 a, b). In the Fig. 4a the impression of the planned regional GNSS campaign network is shown (to be adjusted). Besides satellite observations, the local structure monitoring will be organized, using combination of ground-based SAR (GBSAR) observations and high resolution satellite SAR system to monitor deformation at the dam structure and reservoir slopes. Evaluation of local surface displacement time series will be done by Persistent Scatterer Analysis (PSI) of Ground Based SAR (GBSAR) and satellite data.

The assessment of seismic hazard of dams is an important component of dam safety complex (ICOLD. Bulletin 137: reservoirs and seismicity —state of knowledge. Paris: Committee on Seismic Aspects of Dam Design, International Commission on Large Dams; 2011). DAMAST plans to restore the destroyed seismic network in the Enguri dam with six shallow borehole seismometers plus one sensor in the deep (200 m) borehole. Installation of sensors began in September 2020 (Fig. 5 a, b).

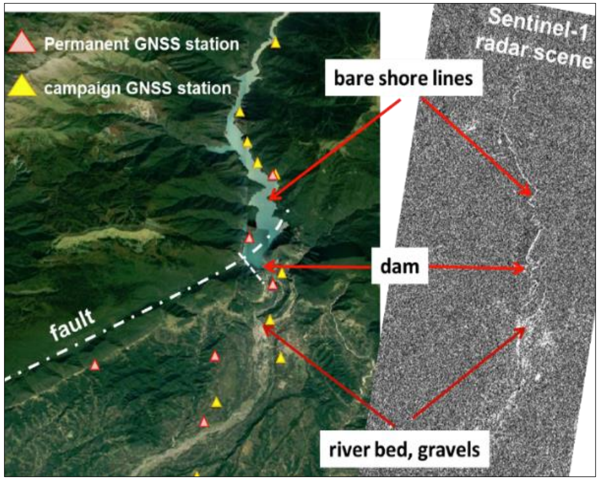


Fig.4 a, b. (a) The planned GNSS network in the area of Enguri Dam (left); (b) Setup of a 24-hour GNSS-test-measurement near the dam. Points on solid ground (concrete, rock) were selected for the GNSS campaigns.) Massive ground bolts should allow a precise repeated installation of GNSS antennas (right)

Fig.5 a, b. (a -left) The German-Georgian team after installation of seismometer - 3C-seismometer is now standing 19.2 m below ground, at the bottom of the shallow well. The seismometer hanging cable has to be anchored at surface; (b- rigth) all components of the seismological stations are connected inside the water-proof box. Everything is looking fine. Seismic background noise is very low.

WP3. Compilation of electronic schemes for cost-effective telemetric acceleration/tilt unit for the dam monitoring

- One of the main components of 2020 project is developing of data acquisition and transmission system using modern instrumental /technological platforms. For monitoring of accelerations, vibrations and tilts of the object from the many types of new devices we choose the instruments based on the MEMS technologies. Beginning from 2005, the sensors, based on MEMS are the most frequently used sensors in monitoring networks. The technical characteristics of such sensors are permanently improved and this makes them very effective for different monitoring applications, including platforms for controlling stability and current characteristics of buildings and constructions.
- After thorough analysis of existing models we choose for the project realization MEMS type tiltmeter: producing company: „Jewell Instruments“; device modification: AMI two-component tiltmeter; model AMI-2-10-V1 (MEMS); the input range+/- 10deg for each component; analog output; the output range 0-5 Volts.
- For recording accelerations we also choose MEMS-type accelerometer: producing company: „Jewell Instruments“; device modification: AMI three-component accelerometer; model AMA-3-02-G-V1 (MEMS); the range +/-2g for XYZ acceleration components; analog output; the output range 0-5 Volts.
- The output signals from analog devices will be sent to preliminary amplification module. The module contains balance extender, sending the output signal to analog input of a remote acquisition module, which ensure suppression of noise and spectral filtration of the useful part of input signal frequencies, amplification of the signal and detection of the current level of variations.
- After analog processing the output signals are sent to the input terminal of the digital processing module, analog to digital converter. Here the observed data are analyzed in the real time and the data of events are sorted by special algorithms for following management of recording/transmission functions.
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