Applying the statistical method of GNSS time series analysis for the detection of vertical displacements of Dnister HPP-1 dam

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SUMMARY

The research presents a method for deformation monitoring of engineering structures based on a statistical analysis of GNSS time series. The construction of Dnister hydroelectric power plant (HPP) is an active intervention in geological-tectonic, geodynamic and hydrological conditions, which can lead to intensification of deformation processes around the area. In order to differentiate the kinematics of the Dnister HPP-1 dam, a method consists of detection covariance interrelationships between GNSS time series for the period from 01.07.2017 to 31.03.2021 is performed. Authors calculate the covariance interrelationships between all pairs of MP01-MP05 permanent GNSS stations of Dnister HPP-1 dam. Epochs 2017.8, 2019.0, and 2019.4 are characterized with extreme values of covariance coefficients. Based on the analysis, it is found that the amplitude of vertical oscillations of MP01 station is 3-8 times larger than the scale at other stations of the dam for similar epochs. The method can be additionally used to monitor the entire GNSS network of the Dniester HPP-1, not just the dam.

Keywords: GNSS time series, deformation monitoring, vertical displacements, covariance coefficient, Dnister HPP-1
Introduction

Construction of hydroelectric power plants (HPP) is an active intervention in geological-tectonic, geodynamic and hydrological conditions, which can lead to intensification of deformation processes of engineering structures and, as a consequence: to death, accidents, destruction, and material damage (Tretyak et al., 2017). Dnister HPP-1 was built on the Dnister river and is located 60 km northwest of Mohyliv-Podilskyi, Vinnytsia region (48°35′35″N, 27°27′18″E). The purpose of the hydro unit is complex: electricity supply, regulation of spring and rain floods, land irrigation, water supply of settlements with water.

Determination of reliable parameters of displacements and deformations of concrete and soil dams is especially important due to several factors. First, the station has been operating since 1981 (40 years) that increases the risks caused by equipment wear and tear, subsidence in building blocks and requires proper maintenance and monitoring. Second, there are a couple of geodynamics phenomena (Brusak & Tretyak, 2021) that caused by tidal loadings, non-tidal atmospheric and ocean loading, and unexpected processes in the middle of the Earth, in particular, earthquakes in this region (Savchyn & Pronyshyn 2020), which can cause sudden extreme loads and serviceability limit state of the Dnister HPP-1 dam.

Methods and theory

In order to increase the safety of the Dnister HPP-1 dam, a special automated stationary system for monitoring the spatial displacement of structures (SSMSDS) is constructed (Fig.1). SSMSDS is modern software and hardware complex, which include multisystem GNSS-receivers, robotic electronic total stations, precision inclinometers, and telecommunication equipment (Tretyak et al., 2017).

Figure 1 Scheme of base and control points geodetic points of SSMSDS of Dnister HPP-1

This study differentiates the kinematics of the GNSS network of SSMSDS for monitoring the spatial displacements of the Dnister HPP-1 dam for the period from 01.07.2017 to 31.03.2021 according to a specially developed method for detecting short-term displacements of the Earth's surface by statistical analysis of GNSS time series (Tretyak & Brusak, 2021).

Based on the method the time series of a pair of GNSS stations are analyzed. First, we determine the period length $\Delta t$ within the results of two time series are compared. Second, we change the formed period for displacement analysis gradually by one day from the beginning of observations through the whole time series. Accordingly, for the middle epoch of the studied period, we perform a statistical analysis of time series within this period. The first middle epoch $T_{mid}=T_{initial} + \Delta t/2$, where $T_{initial}$ – initial epoch of time series. If the period $\Delta t$ is shifted by a time series with an interval of one day, $T_{mid}$ will also change by one day. For each epoch $T_{mid}$ and the period $\Delta t$ the covariance coefficients
according to the displacements of one type of the coordinates are determined. The covariance coefficient shows simultaneous and unidirectional displacements (Tretyak & Brusak, 2021).

Bernese GNSS Software with an automatic module Bernese Processing Engine is used to calculate the daily coordinates of the stations. IGS network stations around the Dnister HPP-1, which operated stably during this period, are selected as reference stations. The result of the calculations is a network solution based on the strategy of double differences.

Figure 2 shows the duration and integrity of the time series of solutions of permanent GNSS stations of the Dnister HPP-1 dam for the period from 01.07.2017 to 31.03.2021. The data from MP01-MP05 stations came almost continuously with small intervals. As for the MP06 station, it is not included in the study, as the solutions for these days have large errors and discrepancies in the results.

Example

The detection of covariance interrelationships between all pairs of MP01-MP05 permanent GNSS stations for the period from 01.07.2017 to 31.03.2021 is performed. For example, Figure 3 shows the time series of changes in the covariance between the MP02-MP03 stations for the period from 01.07.2017 to 31.03.2021, with $\Delta t = 0.2$ years.

Figure 3 Time series of covariance changes between MP02-MP03 GNSS stations

The figure highlights the epochs of extreme values of covariance coefficients, which indicate the anomalous kinematics of these control points. Other anomalous values of covariance coefficients are not selected, because the time series for these periods has data gaps. Extreme values of covariance coefficients of time series between control points MP02-MP03 are on the epochs 2017.8, 2019.0, and 2019.4. Similar time series with such epochs of anomalous covariance coefficients are obtained for the remaining pairs of control points.

Figure 4 shows the time series of the vertical change of the control points MP01-MP05 for the selected epochs 2019.0 with extreme covariance connections. It can be seen, that the time series of the change in the vertical of the MP01 station differs significantly from the time series of the other MP02-MP05 stations. This also happens for epochs 2017.8 and 2019.4.
Finally, we calculated total covariance for MP01-MP05 stations for each period with high covariance (Table).

<table>
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<th>Station name</th>
<th>Covariance</th>
<th>Station name</th>
<th>Covariance</th>
<th>Station name</th>
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</tr>
</thead>
<tbody>
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<tr>
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<td>8.2</td>
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<td>MP05</td>
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<td>8.7</td>
</tr>
</tbody>
</table>

The significant difference between the covariance coefficients of MP01 station and the others indicates differences in the kinematics of these points for the epochs of manifestation of the extreme values of the covariance coefficients. Each of the stations is located on a separate building block (Fig. 5). The probable cause of the anomalous kinematics of the vertical displacements of the MP01 station is the adjacency with the administrative building of the block on which it is installed.

Figure 4 Time series of the vertical change of MP01-MP05 for the epoch \(T = 2019.0 \pm 0.1\)

Figure 5 Location of MP01-MP06 GNSS stations relative to the contractive blocks of the dam
Conclusions

In order to differentiate the kinematics of the Dnister HPP-1 dam, a method for generalizing the displacements of GNSS stations based on statistical analysis of time series has been developed. We detect high covariance interrelationships between all pairs of MP01-MP05 GNSS stations of SSMSDS Dniester HPP-1. It is established that the extreme values of the covariance coefficients of the time series between the GNSS stations of the Dniester HPP-1 dam for the period from 01.07.2017 to 31.03.2021 are on the epochs of 2017.8, 2019.0, 2019.4. Based on the analysis of time series of changes in the vertical position of MP01-MP05, it was found that the amplitude of oscillations of the vertical displacements of the control point MP01 is 3-8 times larger than the scale at other control points for similar epochs. The probable cause of the anomalous kinematics of the vertical displacements of the MP01 control point is the adjacency with the administrative building of the block on which it is installed.

References


