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MONITORING OF DEFORMATION PROCESSES OF THE ELEMENTS OF ENGINEERING STRUCTURES OF HYDRAULIC FACILITIES

Y.A. Onanko, Ph.D.

Institute of Water Problems and Land Reclamation of NAAS of Ukraine, Kyiv, Ukraine;
https://orcid.org/0000-0002-7231-1188; e-mail: yaonanko1@gmail.com

Abstract. *Monitoring the technical condition of hydraulic facilities is crucial for ensuring their safe operation. This process usually involves monitoring environmental variables (e.g., concrete dam levels, temperature, piezometer readings), as well as geometric and physical variables (deformation, cracking, filtration, pore pressure, etc.), the long-term trends of which provide valuable information for facility managers. Research of the methods for analyzing geodetic monitoring data (manual and automatic) and sensor data is vital for assessing the technical condition and safety of facilities, especially when applying new measurement technologies. The age of hydraulic structures in Ukraine is 50–60 years and more, and their technical condition has deteriorated due to long-term operation. Their technical capabilities and reliability have decreased due to improper maintenance. In addition, insufficient consideration of environmental factors during operation has contributed to a decrease in the reliability of these structures.*

Most reservoirs and hydroelectric power plants were built in the mid-20th century and have been under constant operation. Due to significant operational life, negative changes often occur in their technical condition. Atmospheric, chemical, and other aggressive factors also contribute to the destruction of hydraulic facilities and their elements in water. This can lead to serious damage to both the facilities and the elements of hydraulic systems dependent on them. An additional negative impact factor on the condition of hydraulic facilities in Ukraine is missile and drone shelling and other damage as a result of military operations. Therefore, there is a need to develop a device that can be used when monitoring relative static and variable deformation, plasticity, and creep of samples from various elements of engineering structures, materials, elements, and assemblies in hydraulic engineering, construction, and industry.

Keywords: *deformation, hydraulic facilities, engineering structures, strain sensor, measuring device*

Relevance of the research. The factor influencing the environment is the technical condition of the hydraulic facility. Maintaining the structure in proper condition is an important aspect. It ensures the safety of the territories adjacent to the hydraulic facility. Maintaining the facility properly also eliminates the risk of environmental disaster and river pollution. Many existing hydraulic facilities are old, and their planned service life has exceeded [1–3]. It often happens that in cases of visible damage to the structure or its modifications, it is necessary to re-determine the static dimensions of the structure and calculate the necessary stability. To effectively detect damage, it is important to conduct a regular assessment of the technical condition of hydraulic facilities [4–6]. This is necessary for the proper functioning of the structure. Methods for assessing the technical condition developed by scientists using visual analysis and field measurements, as well as the latest technology, in particular laser scanning, are tools that significantly improve the work of specialists in the hydraulic field [7–9].

Deformations of soil foundations of hydraulic facilities, as a possible factor influencing the deformation processes of elements of engineering structures of hydraulic facilities, depend both on changes in volume (as a result of compaction, swelling, etc.), and on the deformation of individual soil phases (soil skeleton drift, of pore water compression, as well as inclusions of vapors and gases) [5–8]. An important influencing factor is the difference in the mechanical properties of the soil at different positions of the sample during the study, or the so-called mechanical anisotropy (for example, deformation anisotropy, strength anisotropy, swelling anisotropy), and sometimes the difference in filtration properties, or filtration anisotropy. The anisotropy of mechanical soil properties is explained by their ordered structure with a preferential parallel orientation of particles in a certain direction [2–4].

Analysis of recent research and publications. There are known devices for measuring deformations of structural elements [10-12] containing a strain gauge beam, which in turn contains a curved strain gauge element with support legs. To increase the reliability of the device, it has two permanent magnets, one of which is a groove. One reference line of the strain-element is rigidly fixed to one of the magnets and the other is freely mounted in the groove of another magnet and it has a base with lateral racks and a platform for mounting the racks, installed on the structure. Tensometric sensors are installed in the deformation areas of the base and racks [13].

The disadvantages of known devices are that they can only be used on laboratory samples, which are significantly different from the design in the defective structure, the low accuracy of measurement of relative deformation *ε*, and a limited class of the studied materials. The nearest analogue is a measurement device containing curvilinear strain-element with reference lines [14–17]. When deforming the sample the distance between the magnets changes, which leads to deformation of the strain-element, which is fixed by a measuring device [18–21]. The weakness of this device is the low accuracy of measuring relative deformation due to the small distance between the reference magnetic lines, as well as the limited class of studied materials.

Purpose of the research is to increase the sensitivity and reliability of measuring the relative static and variable deformation $\varepsilon = \frac{\Delta l}{l_0}$, plasticity, creep $\varepsilon = \frac{\partial}{\partial t}$ of the samples of the studied materials and the possibility of studying these processes in various elements of engineering structures directly during their operation after shelling with missiles, shells, and drones; expanding the class of engineering structures that are tested after deformations ε occurred as a result of military operations.

Materials and methods of the research. Field and laboratory experimental studies of monitoring deformations of structural elements of hydraulic facilities were carried out when using a developed device for measuring deformation ε of engineering structure elements.

Results of the research and their discussion. The goal is achieved by the fact that the proposed device has a strain element – an elastically curved strip with a strain sensor on it, which is connected to the electrical signal registration and recording system. The elastically curved strip is glued (welded) to an engineering structure element.

The design and operation of the device is explained by the drawing in Fig. 1 and Fig. 2. The design of the developed device is shown in Fig. 1. The device consists of an elastically curved strip, with a strain sensor on it, which is connected to the electrical signal registration and recording system. The elastically curved strip is glued (welded) to an engineering structure element.

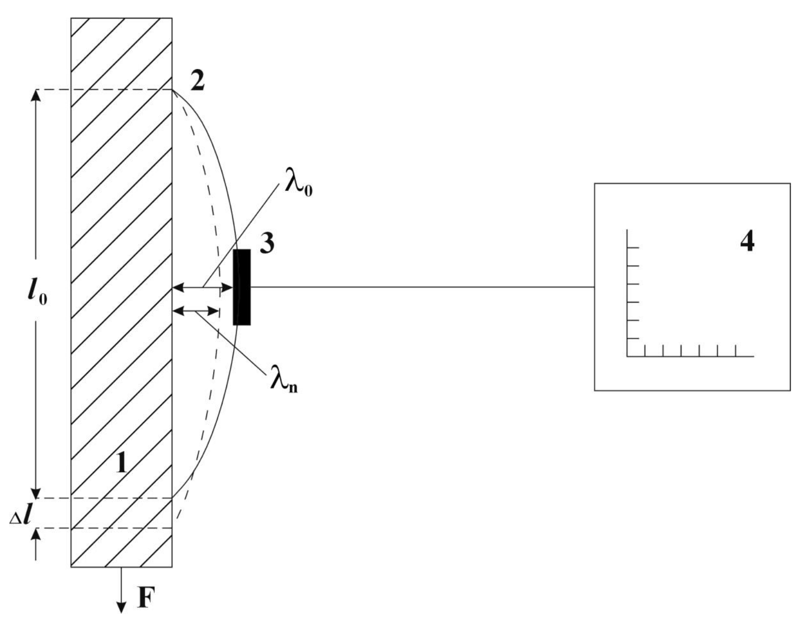

Fig. 1. Design of a device for measuring the deformation of engineering structure elements:
1 – engineering structure element, 2 – elastic bent strip, 3 – strain sensor, 4 – electrical signal registration and recording system

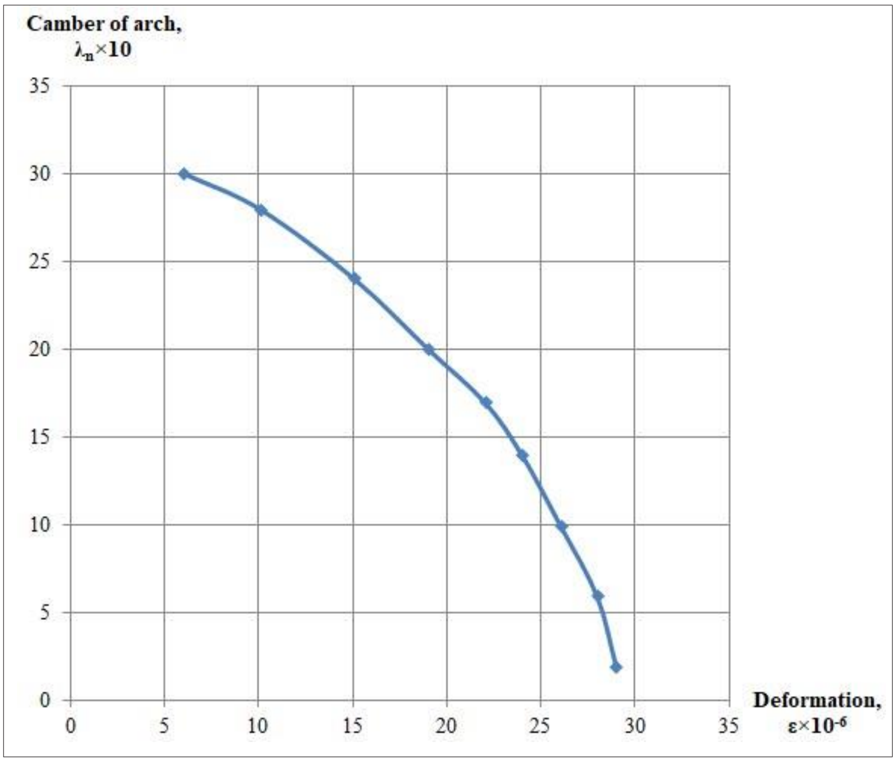

Fig. 2. Diagram of the dependence of an engineering structure element deformation $\varepsilon(\lambda_n)$ on the camber of arch λ_n of an elastic bent strip

Fig. 2 shows a diagram of the dependence of the deformation of an engineering structure element $\varepsilon(\lambda_n)$ on the camber of arch λ_n of an elastic bent strip. Deformation readings are obtained by a graphing measuring device, to which an electrical signal from a strain gauge is supplied.

The device works as follows. An elastic bent strip with a strain sensor on it is glued (welded) to the engineering structure element. A variable $\sigma(t)$ or constant σ_0 deformation stress is applied to the engineering structure element, which leads to a change in the length Δl of the engineering structure element, and, consequently, the camber of arch λ_n of the elastic bent strip. The magnitude of this bent λ_n is converted into an electrical signal by means of the strain sensor and recorded by a measuring device, a graph plotter.

The relationship between the relative static deformation $\varepsilon = \frac{\Delta l}{l_0}$ of the engineering structure element and the camber of arch λ_n of the elastic bent strip is described by the Chebyshev formula for a tensioning catenary [22–25]:

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{8}{3} \times \frac{\lambda_0^2 - \lambda_n^2}{l_0^2}, \qquad (1)$$

where l_0 is the initial length of the engineering structure element, Δl is the change in the length of the engineering structure element, λ_0 is the initial length of the camber of arch of the elastic bent strip, λ_n is the camber of arch of the elastic bent strip with the changed length of the engineering structure element.

Thus, the proposed system of features provides the possibility of high-precision measurement of both plastic and elastic deformations ε based on the quadratic dependence $\Delta l \sim \lambda_n^2$ between the relative change in the length of the engineering structure element Δl and the and the camber of arch λ_n of the elastic bent strip glued (welded) to this element. The measurement of the values of the camber of arch $_n$ is made when using a strain sensor mounted on the specified strip. The proposed approach allows achieving a relative accuracy of deformation measurement at the level is $\frac{\Delta\varepsilon}{\varepsilon} \approx 10^{-7}$. The highest sensitivity of the device is achieved when the cambers of arch of the elastic strip are small $\frac{\lambda_0}{l_0} = 10^{-2} \div 10^{-3}$.

Conclusions. The task of creating a device for measuring the deformation *ε* of engineering structural elements was completed. The technical and economic advantages of the device over the most progressive similar technical ones are in simplifying the design and reducing the cost of devices implementing the proposed method. They make it possible to perform a periodic automatic, rather than continuous, control of the deformation ε of an engineering structural element, increase the accuracy of measurements of the deformation of an engineering structural element twice (elastic deformations ε with an accuracy of $\frac{\Delta\varepsilon}{\varepsilon} \approx 10^{-7}$ as well as expand the class of tested engineering structural elements, including non-magnetic ones.

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МОНІТОРИНГ ДЕФОРМАЦІЙНИХ ПРОЦЕСІВ ЕЛЕМЕНТІВ ІНЖЕНЕРНИХ КОНСТРУКЦІЙ ГІДРОТЕХНІЧНИХ СПОРУД

Ю.А. Онанко, Ph.D.

Інститут водних проблем і меліорації НААН, Київ, Україна;
https://orcid.org/0000-0002-7231-1188; e-mail: yaonanko1@gmail.com

Анотація. *Контроль за технічним станом гідротехнічних споруд має вирішальне значення для забезпечення їх безпечної експлуатації. Цей процес зазвичай включає відстеження змінних навколишнього середовища (наприклад, рівні бетонної дамби, температури, показання п'єзометрів), а також геометричних і фізичних змінних (деформація, розтріскування, фільтрація, поровий тиск тощо), довгострокові тенденції яких надають цінну інформацію для менеджерів об'єктів. Дослідження методів аналізу даних геодезичного моніторингу (ручного та автоматичного) та даних датчиків є життєво необхідними для оцінки технічного стану та безпеки об'єктів, особливо при застосуванні нових технологій вимірювання. Вік гідротехнічних споруд в Україні становить 50–60 років і більше, а їх технічний стан погіршився через тривалу експлуатацію. Їх технічні можливості та надійність знизилися через неналежне обслуговування. Крім того, недостатня*

увага до факторів зовнішнього середовища під час експлуатації сприяла зниженню надійності цих конструкцій.
Більшість водосховищ і гідроелектростанцій були побудовані в середині 20 століття і з тих пір постійно використовуються. Через вік в їх технічному стані часто відбувалися негативні зміни. Атмосферні, хімічні та агресивні фактори також сприяють руйнуванню гідротехнічних споруд та їх елементів у воді. Це може призвести до серйозних пошкоджень як самих споруд, так і залежних від них елементів гідротехнічних систем. Додатковим фактором негативного впливу на стан гідротехнічних споруд в Україні стали обстріли ракетами, снарядами, дронами та інші ушкодження одержані внаслідок воєнних дій. Тому виникала потреба в розробці пристрою, що може бути використаний при дослідженні відносної статичної та змінної деформації, пластичності, повзучості зразків з різних елементів інженерних конструкцій, матеріалів, елементів, вузлів у гідротехніці, будівництві, промисловості.
Ключові слова: *деформація, гідротехнічні споруди, інженерні конструкції, тензодатчик, пристрій для вимірювання*