MAIN CAUSES, SIGNS, AND CONSEQUENCES OF AGING OF CONCRETE DAMS

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Aging of any structure is a natural process, but this problem became urgent only in recent years when long-operating dams began to lose reliable life.

The XVII ICOLD Congress (Vienna, 1992) was devoted to problems of aging of dams and foundations — to the results of the effect of the time factor reducing the original reliability of the structure [1].

An analysis of on-site observations of the behavior of long-operating dams and studies of processes in the earth’s crust and interaction of a hydro development with the geological environment permit distinguishing several causes of aging of dams:

- long-acting hydraulic pressure can cause leaching of concrete, plugging of drain wells, erosion of the grout curtain, i.e., the main constantly acting load with time leads to a change in the original parameters of the seepage, stress, and strain states;
- cyclicity of the seasonal temperature effects and change in the upper pool level also can lead with time to irreversible phenomena in elements of the dam and foundation, especially in parts of structural members with smaller safety factors as a consequence of design errors and violations of construction technology. A special role is played by the high rate of filling and emptying the reservoir, which the change in water saturation of the foundation and banks cannot keep up with. Additional off-design forces occur, which can gradually lead to negative consequences;
- the dynamic loads related to operation of the turbines, discharge of water through spillways and bottom outlets and intense transport loads on the dam crest also promote the accumulation of irreversible phenomena in individual elements of dams, concrete, and rock as a material;
- the effect of the geological environment into which the hydro development is inserted. Disturbance of the equilibrium state of the canyon with construction of the hydro development does not eliminate natural processes inherent to the crust as a consequence of gravitational forces, creep, and slow waves. Only a change in the rate and direction of action of these forces change, with time the dam begins to experience loads due to convergence of the banks, creep of the banks, etc.
- Water saturation of the foundation and banks in the region of the dam as a consequence of a new hydrological regime creates additional loads on the dam and also can be the cause of movement of rock masses along clay interlayers, revival of tectonic fractures and slides.
- High gradients of stresses and seepage heads in the foundation of rock masses and bank abutments can cause opening of old fractures, movement of individual rock blocks, nonlinear deformation of the foundation, etc.

It should be noted that the consequences of the effect of the aforementioned factors on the dam depend on its original safety margins, which determines the individuality of the behavior of each hydro development. There are cases of an increase of reserves of strength and stability of the structure, elastic work during long operation, and rapid loss of the original.

Aging usually begins to be manifested in individual elements of the structures and foundation, not being a process equally encompassing the entire hydro development. Changes occur mainly in those parts of the structure in which design errors, which caused smaller reliability reserves, or violations of construction technology occurred.

In a generalized form a sign of aging is the irreversible component in the parameters controlling the seepage, stress, and strain state of the "dam—foundation" system, which is manifested in an increase of seepage discharges through the body of the dam, its foundation, and bank abutments, increase of uplift pressure, redistribution of stresses, renewal of settlement, etc.

The most known and widespread signs of aging of a structure are related to a decrease of the effectiveness of the watertight contour and weakening of concrete as a material.

During long operation plugging of drain wells and erosion of cement from grout curtains occur, which leads to an increase of uplift pressure, discharges, piping, change in the hydraulic regime in the foundation, its decompression.

The causes of degradation of concrete are its leaching, cavitation and temperature effects, and variable water level.

The strength characteristics of massive concrete, as rule, increase with time. According to the data of on-site observations, the concrete of the Dnepr and Svir' hydrostation dams during 60-year operation has increased in strength by 2-3 times and no signs of gradual weakening of its structure are noted [2]. At the same time, on every concrete structure there are local zones of surface concrete being damaged. These are mainly zones with a variable water level and spillway faces. If carefrul fulfillment of the necessary technological measures, optimally selected composition of the concrete, and designs cannot prevent cavitation phenomena, then destruction of concrete under the combined effect of the varying water level and alternating temperature is virtually inevitable.

Leaching also weakens concrete. The biochemical nature of leaching processes was established from the results of microbiological studies conducted by the B. E. Vedeneev All-Russian Hydraulic Engineering Research Institute (VNIIG), Institute of Antibiotics and Enzymes, and Institute of Microbiology and Virology, Ukrainian Academy of Sciences. A community of microorganisms known as destroyers of inorganic materials, particularly metal and concrete, was found in all samples of leaching products taken at all large hydro developments in Russia and CIS regardless of the location and climatic conditions of the reservoir. Leaching processes markedly intensify in ecologically troubled reservoirs [3].

Reactivity of the aggregate leading to complete destruction of concrete has not been detected so far in domestic dams. In foreign dams the alkali–aggregate reaction has become the main cause of destruction of concrete as a material [1].

Worsening of the static behavior of concrete structures as a consequence of an increase of discontinuity of the profile due to irreversible opening of joints and cracks, decompression of the foundation, nonlinearity of foundation deformations, occurrence of off-design additional forces in the rock masses enclosing the hydro development can become a serious consequence of their aging.

And, finally, the most dangerous consequence of aging is related to a prefailure situation, when the reserves of reliable operation are exhausted. At present there are no such signs in domestic dams, but certain negative phenomena developing with time are observed.

Destruction of concrete in the zone of variable water levels is a ubiquitous phenomenon, and repair measures have a temporary character.

Unceasing leaching of concrete is observed on the spillway sections of the Ust'-Ilim, Shul'binsk, Bukhtarma, Inguri, and Chirkey dams, where communities of microorganisms exceeding background values severalfold have been detected.

Signs of aging in the form of constantly increasing decompression of the foundation are observed on the Bratsk dam in the powerhouse sections. However, it must be kept in mind that a set of causes, including technological miscalculations, act there, due to which the dam took on the head with a discontinuous profile with virtually ungrouted column joints [4].

Such violations of construction technology on the Ust'-Ilim dam led to seasonal opening of joints on the upstream face, which with time can become an irreversible process.

Aging of structures can be monitored only on the basis of on-site data, among which an important role is played by visual inspections (inventory of cracks and observation of their development; outflows of bypass seepage; new centers of seepage in the body of the dam, bank abutments, foundation; removal of soil; condition of the upstream and downstream faces, including underwater surveys).

With respect to instrumental observations, aging is displayed by the occurrence of an irreversible component, which can be the consequence of a gradual change in the former scheme of static behavior of the structure.

The stages of analysis of on-site observations consist of collecting data, singling out the inelastic component of the monitored parameters, and establishing the new scheme of static behavior of the dam and actual loads on the structure.

To analyze the consequences of aging it is necessary to determine the cause-and-effect relations, to demarcate the parameters causing aging and parameters characterizing the consequence of this process. Thus, for instance, weakening of concrete in the form of cracking can be both the result of force effects due to the redistribution of acting forces and a consequence of leaching and aging of concrete as a material and of the hydraulic pressure of the seeping water.

An increase of uplift pressure can be the consequence of decompression of the foundation or difficult discharge of the seepage flow.

Repair and restoration works are assigned only after establishing the causes of the change in the monitored parameters indicating aging of the dam—foundation system.