

# OPERATIONAL MEANS OF INCREASING SEISMIC STABILITY OF EARTH DAMS

by

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## SYNOPSIS

Proposed are operational methods of increasing seismic stability of earth dams. The methods are based on the employment of special devices, actuated during earthquakes by a signal of accelerometers-starters of a seismometric network. Given are evaluation results of the feasibility of the methods and a preliminary estimation of their efficiency.

## INTRODUCTION

Various constructional means of increasing earth dam seismic stability are known (description of those methods can be found in [1]). However, their practical use involves additional costs which, taking into account large sizes of dams, makes the whole project more expensive and tends to delay the construction period.

The above reasons explain the importance of the operational means of increasing seismic stability of large dams. The operational means are based on using various devices which are activated by a signal of accelerographs-starters within a seismometric network. According to the requirements of the Design Standards adopted in the USSR [2, 3], these devices are always installed on the unique structures. Considering that the time lag between the arrival of a seismic wave and the onset of structural response ranges no less than 1-3 secs (this period is of no danger to a structure and, besides, the "swaying" of such a large structure as a dam takes another 5-7 secs, it is clear that there will be enough time (at least 6-10 secs) to actuate the antiseismic devices, bearing in mind that for the purposes outlined above launching devices of the momentary or short-time action may be utilized (electromagnetic, explosive, etc).

Two operational methods of increasing dam seismic stability were tested at the B.E.Vedeneev Research Institute of Hydraulic Engineering, namely: 1) the aeration of the upstream water to absorb hydrodynamic pressure arising from seismic motion and acting upon the upstream face of a dam\*. 2) utilization of special filtering devices to increase the stability of upstream slopes of earth dams\*\*.

Both methods are aimed at improving the stability of upstream prisms of earth dams which are especially vulnerable to earthquake effects.

The first of the above methods serves the purpose of reducing the inertial seismic load resulting from the "added" masses of water of the re-

\* Savinov O.A., Krasnikov N.D., Natarius Y.I. et al. Means of increasing the stability of the upstream slope of a rock fill dam. a.p. 445122, 37-74.

\*\* Savinov O.A., Natarius Y.I., Sheinin I.S., Eisler L.A. et al. Rock and earth fill dams. a.p. 437824, 28-74.

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reservoir. During earthquakes compressed air is transmitted from the surface of the upstream edge into the reservoir and a zone of aerated water is created above the upstream face. Even a slight volume of bubbles containing in water may reduce the effective elasticity modulus tens or even thousands of times (depending upon the pressure). Since the first approximation of the value of the inertial seismic load of water masses in the reservoir may be assumed directly proportional to its elasticity modulus one can easily conclude that by aeration this load may be reduced to the limits within which it can be ignored altogether. As is evident from tests performed at the VNIG, the energy absorption shows a marked rise (tens of times) with oscillations of the liquid, which conduces to stilling the vibrations of both the reservoir content and the dam body.

The employment of this method may assist in improving seismic stability of earth structures with upstream prisms made of sand or sandy gravel as well as of concrete arch dams.

The total value of the "added" masses of water is unimportant comparing to the whole mass of the earth structure, but it can be confronted with the mass of the section liable to fail during an earthquake. Thus, if one follows a widely adopted stability evaluation procedure by a slip circle, the horizontal inertial seismic loads arising from the "added" masses of water may for some cases reach or even surpass the value of the inertial loads induced by the mass of the failure prism itself. The outlined method is embodied in the following way. A small compressing station supplying compressed air into a branched network of pipes through receivers is located on the dam body or near the dam.

The network comprises trunk and distributive pipes located at the upstream slope of the dam. The pipes of the trunk line at their outlet into the distributive system are supplied with valves of short-time action and are always filled with air. At the ends of the pipes valves of the inverse action may be located. The perforated distributive pipes will always be filled with water. The whole system is activated by an accelerometer-starter which provides the momentary operation of the valves at the appropriate disturbance level.

The efficiency of the system was tested by investigations of the dam of the Nurek hydropower system. The problem was outlined for a condition that protection must be provided to an upstream slope to a depth of 100 metres and a width of 300 metres. The estimated saturation of water by air bubbles is 3%, the minimum height of a layer of aerated water at the moment of arrival of seismic waves vulnerable to a structure is 1 metre. According to the test data obtained, the estimated saturation of a layer of such parameters may be achieved over a period of 3-4 secs, which satisfies the requirements of the problem. The required capacity of the air supplying device may be adequately provided by installing two or three receivers-vessels for condensed hydrocarbon designed for the operating pressure of 18 atm; filling of the vessels and keeping them pressurized is effected by serially produced compressors with a total driving capacity of 132 kw. The whole cost of the aerodynamic installation including the cost of the expenses due to mounting the equipment and constructional expenses does not exceed 80-90 thousand roubles while the economic advantages resulting from its utilization substantially surpass this figure.

By an example of the Nurek hydropower project it was estimated that the use of the aeration device tends to reduce the equivalent inertial seismic loads acting upon the failure prism by approximately two times, allow-

ing to increase substantially the slope gradient and thus to reduce the volume of the upstream prism by 2-2.5 mln. m<sup>3</sup>.

By ~~the second~~ method seismic stability of the upstream wedge of the dam is improved with the aid of the following arrangement. Over the contour of a probable failure prism from the side, facing the washing filtering clay core, an inclined filtering layer is placed, into which several levels of pipes are installed along the dam axis. The pipes are connected with the diversion main for transmitting water into the tailrace. The outlets of each diversion main are supplied with locks equipped with momentary opening devices.

For the case under investigation the use of electromagnetic locks may prove most efficient though other devices are not improbable. Electromagnetic locks are connected by an electric circuit with accelerographs-starters of the seismometric network; thus the operation is started after the first shock of a strong earthquake. Then water starts flowing out of the discharge pipes with a seepage flow arising simultaneously and directed towards the boundaries of the potential failure prism which becomes pressed to the main body of the structure.

The efficiency of this method was tested in 1975, when preliminary investigations were undertaken to the following end: a) the determination of a time in which the seepage flow and the attendant effective stresses in the upstream material become stable; b) the influence of the resulting stress state upon the upstream prism stability; c) the estimated value of the effect resulting from the introduction of this value into the construction practice.

To determine the time in which the seepage flow and the resulting stress state become stabilized, a problem of seepage loading of a saturated soil layer with an unloaded water-covered surface and resting on a rigid ideally permeable base was studied at the VNIG by a research engineer L.A. Eisler. Seepage loading is performed by decreasing the pressure in the water which fills the pores of the rigid base according to a certain law  $P(t)$  and, in particular, a law of a stepwise variation (momentary opening of the pipeline locks overlooking the tailrace).

The problem was formulated for the zero initial conditions and solved assuming a small value of compressibility of water and soil particles but with consideration for compressibility of the soil skeleton.

The investigation method will not be outlined here. However, it is important to indicate that the principle aim of the investigation is to demonstrate that the seepage flow for all the practical cases stabilizes momentarily.

With the values of the permeability coefficients characteristic for gravel and sandy gravel soils ( $K_p = 0.005-0.010$  m/sec) often utilized for placing into the external prisms of the rock fill dams, the time  $t_0$ , at which the stationary effective stresses stabilize, amounts to 0.07 secs for a 10m thick layer and 0.7 secs for a 100 m thick layer. The effect of increasing the stability of the upstream prisms of rock fill dams was tested by a detailed evaluation of the dam of the Rogun hydropower project.

The calculation scheme is presented in Fig. 1a where the central cross section of the dam is shown. A presumed zone of siting the filters and spillway pipes is shown by skewed lines. The calculation is based on the assumption of momentary stabilization of the effective stresses after the locks come into action. The following data were introduced into the calculations: static loads according to the design scheme, inertial seismic loads

corresponding to the zone with seismicity IX (Modified Mercally Scale) with the average propagation velocity of the transverse waves in the dam body  $C_2 = 600$  m/sec (with four natural vibration modes taken into consideration) and the water pressure tending to increase the effective stresses in the soil.

For the purpose of comparing the evaluation results obtained with account of the influence of the seepage flow which increases the effective stresses in the soil and without consideration of this effect, a method was worked out, by which the "pressing effect" was substituted by an equivalent inertial load.

The calculation results are plotted in Fig 1b. Curve 1 is a variation of the design accelerations (according to the CHuII II-A, 12-69) over the height of the structure, curve 2 is a variation of the horizontal component of the "equivalent acceleration" a equiv; curve 3 - the resultant.

The last curve reveals that the "pressing effect" of water totally neutralizes the seismic effect over the whole dam height. The upstream prism equipped with outflow pipes by the above method shows a better stability than the downstream prism when subjected to a strong earthquake of seismicity IX by MMS. Seismic influence remains dangerous only for an upstream section adjoining the dam crest. Stability of this section can be maintained by special measures.

Under such conditions the upstream slope can be made even steeper than the downstream slope. As proved by the calculations, for a dam of the Rogun type, the utilization of special seepage devices may lead to the reduction of the dam body volume by 3.5 mln. m<sup>3</sup>.

#### CONCLUSIONS

1. The application of the operational means of increasing seismic stability of large dams is feasible and under the appropriate conditions may become efficient.
2. Judging by the preliminary evaluation results, both methods proved effective, which allows to recommend them for detailed investigation from the point of view of their future practical employment.

#### REFERENCES

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