THE SOLUTION OF SEISMIC STABILITY PROBLEMS ON SMALL-SCALE MODELS BY OPTIC METHODS

by

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INTRODUCTION

The evaluation of the stress state of hydraulic structures under seismic impacts assumes special importance for high or spread structures (dams, valleys, etc.). The application of mathematical methods for the solution of these problems is yet too cumbersome. Therefore developed are methods of investigation of hydraulic structural stress state by testing small-scale three-dimensional models using measuring devices of polarizational optics as well as the traditional and holografic interferometry. The developed methods were applied for the investigations of the unstationary stress waves in a high arch dam under seismic impact, estimation of natural vibration modes and frequencies of an arch-gravity dam and its aggregate block, determination of the distribution of hydrodynamic pressure in the vicinity of the structural pressurized edges.

Investigations of a high arch dam. The problem was idealized as follows: the stress state of an arch dam is determined on plane and three-dimensional models, the materials of the dam, foundation and embankment (rocks) are studied as uniform, continuous, isotropic, linear-elastic (visco-elastic) continuum, seismic impact (seismicity IX) is idealized by pulses of the prescribed shape and duration. Tests were performed by photoelasticity methods. The design of a device for unstationary problems and the description of its operation are presented in /1/. It should be noted that even in a formulation thus idealized the solution of the problem involves operational and methodic difficulties.

Three-dimensional model of an arch dam and the adjoining sections of the foundation and the embankments was manufactured out of PMMA with a scale M=1/5000 . The unstationary stresses in a number of arch sections of the dam, including the crest, as well as in the central cantilever section were investigated. For visualization of the stress state of the above sections a "glued -- in polariscope" method was utilized /2/. Thin framings characterizing the position of the section under study, were produced of epoxide compound. Fixed by a high-speed cinematography ($\omega = 1.5\times10^6$ 1/s), an optical picture allows to determine in the limits of two-dimensional problem of elasticity the stress state of a studied section of a three-dimensional model. The models were loaded by a cupped shaped pulse with a plane front. The relation of a pulse length (λ), dam height (H) and dam length along its axis (L) were $\lambda/H = 1.0$; $\lambda/L = 0.55$. These relations correspond to a seismic impact with a predominant period T = 0.2 sec. Studied were an impact directed across stream (from the side of the right and left abutments) and the impact directed along stream (as viewed from the pressurized and downstream edges of a dam). For each case of an impact separate load histories were studied over both the entire height of an edge abutment and the plane of the dam foundation.

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The following conclusions may be drawn from the studies of the stress state of the dam when a stress wave resulting from a seismic effect propagates inside. Under the vertical effect the stress state of the dam is characterized by the stress variation with time according to a law closely approximating a law of variation of the acting load. The wave propagating along the dam, involves the arch sections into vibrations, having a shift with respect to time and frequency. The distribution of stresses in each section of an arch in relation to the thickness of the arch is homogeneous and corresponds to a sign of the acting wave. Along the vertical extent of the dam the stresses decrease starting from the crest downward resulting form the increase of the dam thickness. The increase of stresses is noted in the support section of the arches: the highest values are $\sigma = 1{,}3\sigma_0$, $(\tau_{max}) = (0{,}8-0{,}9)\sigma_0$ in the section $z = H$; the lowest $(\tau_{max}) = 0{,}4\sigma_0$ in the section $= 0{,}23H$. In the key section of the dam the stresses at the points identical by their arrangement are lower approximately 1.5 times than the corresponding stresses of the support section. The contour stresses on the concave edge of the dam surpass (10-15%) those on the convex edge. No substantial difference of the right and left sides of the dam under seismic impacts is registered. The stress state of the dam under loading in plane of the foundation across the stream is characterized by small stresses of the value of $(0.2-0.3)\sigma_0$.

Under the vertical seismic impact along and against stream, the principal parameters characterizing the stress state are identical to those above. However, the stresses in the dam under the impact directed against the stream are higher than those resulting from the impact directed along the stream. The values of these stresses are commensurable with the stresses developed under the transverse impact and are equal to $(1.0-0.8)\sigma_0$. Under the longitudinal impact the stresses in the key and the support sections are small, with the value of $(0.15-0.20)\sigma_0$. With the seismic impact acting in the dam foundation (along and across the stream) the stresses are insignificant and practically coinside with the values, obtained for the similar loads across the stream. The values for the stresses σ_0 are given in fractions of the amplitude of the acting seismic load.

Investigation of natural vibration modes and frequencies of hydraulic structures. The evaluation of seismic loads of hydraulic structures by a linear spectral seismic stability theory demands the availability of the information on modes and frequencies of structural vibrations. These data for complex structures is not always available by means of calculations; in this case model tests are performed.

Natural vibration modes and frequencies of an arch-gravity dam were evaluated on spatial small-scale models using vibrational-measuring system based on holografic interferometry principles in the modifications of a real time scale and an averaged exposure of a hologram. For an exact fixing of a model resonant state a contactless capacitance type sensor was used permitting a simultaneous registering of amplitude-frequency characteristics in separate points of the model. The utilization of the above deivices substantially aided in the investigation of the higher natural vibration frequencies of the structure and especially in the investigations into the vibration modes corresponding to those frequencies. For an arch-gravity dam (a model of PMMA with a scale M=1/2000) twelve frequencies were determined and the corresponding vibrational modes were identified. Among the latter, besides the simplest theoretically predicted modes, detected were several rather complex modes, the existance of which in the structure was not expected. In Fig. 1 presented is an interferogram of such a mode. As each interference line of a scheme corresponds to the lines of equal and particular vibration amplitudes, the interferogram ensures the exact quantitative mode decording.

The same technique proves useful for the determination of vibrational modes for structures of increased complexity. An aggregate block of a hydropower station, the natural vibration modes and frequencies of which are investigated with a purpose of evaluating its stress state under operational dynamic loads, may serve as an example of such a structure.

Over 20 resonant frequencies and the corresponding vibration modes were defined. Owing to complexity of a three-dimensional block model, vibrations of elements or groups of elements were defined separately. Interferograms of a) mode vibration of a series of block piers at a frequency 6.54 cps; b) one of the natural vibration modes of a housing for a generator of the same block are shown in Fig. 2.

The results obtaine illustrate the advantages of golografic interferometry for kinematic analysis of hydraulic structures at an early stage of their design.

<u>The determination of fields of hydrodynamic pressure in the vicinity of a structural pressurized edge.</u> The calculations of seismic loads of hydraulic structures interacting with water pressure are performed taking into account hydrodynamic pressure in addition to seismic inertial forces. Within the limits of small-scale modelling for registering the fields of hydrodynamic pressures, the principles of holografic interferometry of vibrating processes were applied. The object of registering are the fields of hydrodynamic pressures close to models installed in the reservoir with a rectangular section and translucent walls. The effect of a phase modulation of light by sound at low frequencies (up to 500 khz) is known as modulation of Raman-Nath /3/. Reconstructed images of the pressure fields are two-dimensional and contain interferential bands of a geometric locus of equal pressures (isobars).

A wide range of problems of evaluations of pressure actihg upon hydraulic structures with dams and reservoirs of different configuration and accounting for the elastic properties of the model parameters and the impedance properties of the soil was solved by the above method. Tests may be performed in a wide frequency range, including frequencies close to the acoustic resonance of the medium, i.e. when the liquid compressibility effect shows up at a maximum.

By a holografic method of temporary averaging performed are measurements of pressure fields about a rigid dam (pressure edge), executing horizontal harmonic vibrations with a frequency close to a first natural resonance of a liquid considered as an acoustic medium. In a test installation gas lasers (He-Ne) were employed. Fig. 3 shows an interferogram of a pressure field near the pressurized edge. To estimate the influence of the absorbing properties of the bottom of the reservoir under acoustic resonance utilized are materials which simulate the soil properties with respect to acoustic resistance. The results obtained prove that for rock foundations seismic hydraulic pressure at resonances show an increase 1.5-2 times compared to a value defined by a Vestergaard formula (without account for compressibility).

The utilization of solid pulse lasers in holografic recording schemes of hydrodynamic pressure fields allows to increase the range of problems to be covered, including the investigation of the unstationary processes.

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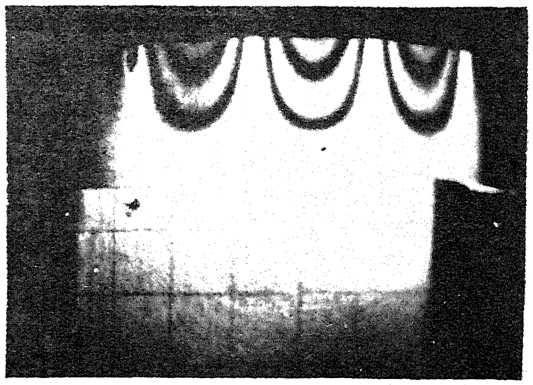
Fig. 1

a



b

Fig. 2

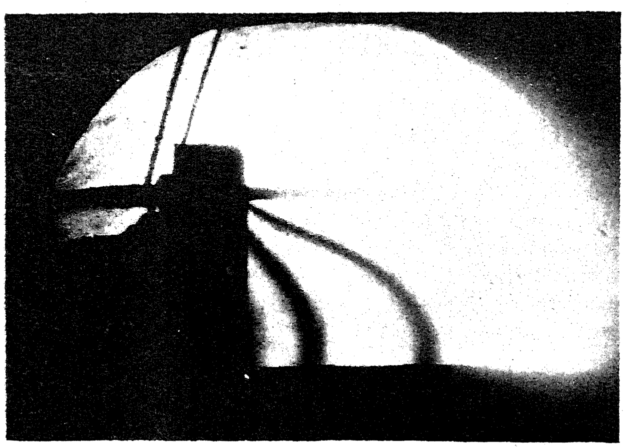


Fig. 3