WAVE GENERATION IN A RESERVOIR AND HYDRODYNAMIC PRESSURE IN TUNNEL AND CONDUITE OF HYDROELECTRIC PLANT DURING AN EARTHQUAKE

by

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SYNOPSIS

The problem of water wave generation in a reservoir (water storage basin) due to the residual deformations (seismotectonic displacements, landslides and avalanches) arising in the reservoir area during an earthquake, was theoretically investigated. As a result of the numerical analysis simplified formulae were obtained for the determination of the maximum rise of water level at the dam site. The calculation results were compared with the experimental data and observations in real conditions.

On base of analytical solutions obtained for some simplified schemes of hydro plant pressure systems, the probabilistic characteristics of hydrodynamic pressure due to an earthquake were determined. Numerical calculations were carried out for the system, consisting of a tunnel, surge reservoir and pressure conduit. Simplified formulae, convenient for design are also offered.

INTRODUCTION

The earthquake design of dams requires the determination of the main parameters of gravity water wave, which might be generated in the reservoir during an earthquake. The principal purpose of such a calculation is to establish the necessary exceeding of dam crown above the high water level. At the same time, when investigating the earthquake resistance of pressure tunnels and conduits of hydroelectric power plants, it is important to know the way of determining the hydrodynamic pressure in them. That pressure may reach a significant value, when the ground oscillations are directed along the axis of pressure tunnel.

The purpose of our investigations was to work out the calculation method of the water level maximum rise at the dam site and of hydrodynamic pressure in pressure system of hydroplant during an earthquake.

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1. WATER WAVE GENERATION IN A RESERVOIR

Using the small amplitude wave theory, we have obtained a solution of a boundary value problem of the oscillations of an ideal, incompressible liquid in a reservoir, having a given displacement velocity at its sides and bottom during a definite period of time. The reservoir was schematized as a rectangle (two dimensional problem) or as a rectangular parallelepiped (three dimensional problem) (1).

The digital computer analysis for the case of the vibrational type of seismic action (fig.1) using a recorded earthquake axelerogramm showed, that the waves on the water surface were relatively small (the height about 1 m.). At the same time the waves of a considerable amplitude are generated during earthquakes followed by some residual deformations which arise in the vicinity of reservoir area. They can be primary (seismotectonic displacements in the epicentral zone) as well as secondary (landsslides, avalanches).

As it follows from the three dimensional problem solution (1), the wave height $\eta(x,y,t)$ is characterized by the following dependance:

$$\eta^* = f(\ell^*,\ \ell_1^*,\ \lambda^*,\ x_o^*,\ v^*,\ t_o^*)$$

where $\eta^* = \eta/h$, $\ell^* = \ell/h$, $\ell_1^* = \ell_1/h$, $v^* = v/\sqrt{gh}$, $\lambda^* = b/\ell$, $x_o^* = x_o/h$, $t_o^* = t_o\sqrt{g/h}$; h, ℓ, ℓ_1 - is the depth, length and width of the schematized reservoir; 2b is the extention of the area subjected to deformation; x_o is coordinate of its centre; v and t_o are the velocity and duration of the deformation process (displacement), g is the gravity acceleration.

The intensity of the water wave process in the reservoir during the seismotectonic displacements depends on the orientation of the fault line relative to the reservoir as well as on the direction and displacement value along the line. Fig.2 shows the most probable schematized displacement forms of the reservoir bottom (fig.2 a,b,c,d,), side (fig.2f) and of all basin (fig.2e,g), when the reservoir and the fault line are located differently.

By numerical analysis it was found out, that the wave process was more intensive in case of vertical seismotectonic displacements. We also obtained a simplified formula for the maximum water level rise at the dam in case of vertical reservoir bottom displacement (2) (fig.2a),

$$\eta_{max} = D_v\,[\,2\lambda^* + \kappa\,(1.12 - 3.10\lambda^*)\,]\ ,\quad (\,t_o^* \leq 25\,)$$

where $\kappa = 1.3$ when $2\lambda^* \leq 0.35$; $\kappa = 1.2$ when $2\lambda^* > 0.35$; D_v is the estimated amplitude of the vertical displacement.

Fig.3 shows a design scheme which was used in the investigation of the wave generation in the reservoirs, when some landsslides and avalanches occured in them. Using the numerical analysis for relatively narrow reservoirs ($\ell^* \leq 6.0$), and for $x_o/\ell \geq 0.3$, a simple formula was obtained

$$\eta_{max} = K_1(2/\pi \ell^* \ell_1^* + \mathcal{J}^*/2\ell_1^*)D_h \ , \qquad (t_o^* \leq 10)$$

where D_h is the maximum horizontal displacement amplitude at the side of reservoir, which depends on the landslide size and the water depth; $K_1 = 1.1$ when $t_o^* \leq 7.5$; $K_1 = 1.0$ when $7.5 < t_o^* \leq 10$; $\mathcal{J}^*$ is defined by the following expression

$$\lg [f(\lambda^*) - \mathcal{J}^*] = (\alpha_1 \lambda^* + m_1)A + \alpha_2 \lambda^* + m_2 \ ,$$

where $f(\lambda^*)$ and $\alpha_1, \alpha_2, m_1, m_2, A$ are the functions and coefficients dependent on the varying limits of λ^* and ℓ^* ; D_h and t_o are to be determined by the geology and soil mechanics studies data

The results of calculations by the exact theoretical formula in the case of vertical displacement (fig.2a) give good qualitative coincidence with the data of observations on Hebgen lake (USA) during the earthquake of 1959 (3) (fig.4).

2. HYDRODYNAMIC PRESSURE IN PRESSURE TUNNELS AND CONDUITS OF HYDROPLANTS DURING AN EARTHQUAKE.

To solve the problem of determination of the hydrodynamic pressure in pressure tunnels and conduits of hydroplants during an earthquake, one dimensional equation of the unsteady motion of water in pipelines was used (4). At the first stage the analytical solution of the problem was given. Since the diameter of a conduit was small, as compared to its length, transverse vibrations were neglected. The pressure tunnel and the pressure conduit were considered independently, i.e. the pressure wave propagation in surge reservoir was neglected. That is acceptable at a relatively small height and large diameter of the reservoir. The value of a hydrodynamic pressure in the inlet of the conduit was taken as such at the point of the upstream face corresponding to the gravity centre of the inlet section and might be determined by the well-known formulae for a plane upstream face or for a cylindrical reservoir.

The boundary value problem solutions were obtained in the Duhamell Integral form, which assumes both determinical and probabilistic approach while defining the hydrodynamical pressure. Certain formulae were derived on the base of obtained solutions (5) for the main probabilistic characteristics of the hydrodynamic pressure in tunnels and pressure conduits.

The following dependance was obtained as a result of numerical value of the hydrodynamic pressure standard

$$\sigma(x/\ell) = \sigma_o(x/\ell) P_o \ ,$$

where x is a longitudinal coordinate; ℓ is the conduit length; P_o is the standard value of the hydrodynamic pressure in the inlet section of the conduit, $\sigma_o(x/\ell)$ is the relative value of standard which can be taken from the diagramms (fig.5 and 6).

The obtained analytical solutions are necessary for the evaluation of constructios work conditions at the preliminary stage of design.

The computer program had been also outworked for an exact determination of the hydrodynamic pressure in the complex branching systems of hydropower plants. Some numerical calculation series were carried out,recorded accelerogramm (El Centro) being used as an external action. The numerical analysis shows that the hydrodynamic pressure in pressure tunnels and conduits due to an earthquake is 20 per cent greater when elastic characterisitics of surge reservoir are taken into account than in the case when it's not,and that the maximum values of the hydrodynamic pressure is three times more than its standard.

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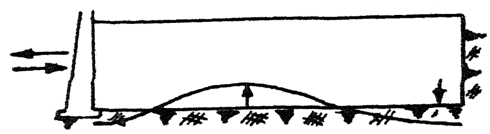

Fig.1. Scheme for the case of the dam and reservoir bottom vibrations, when a progressive seismic wave is propagating in a ground

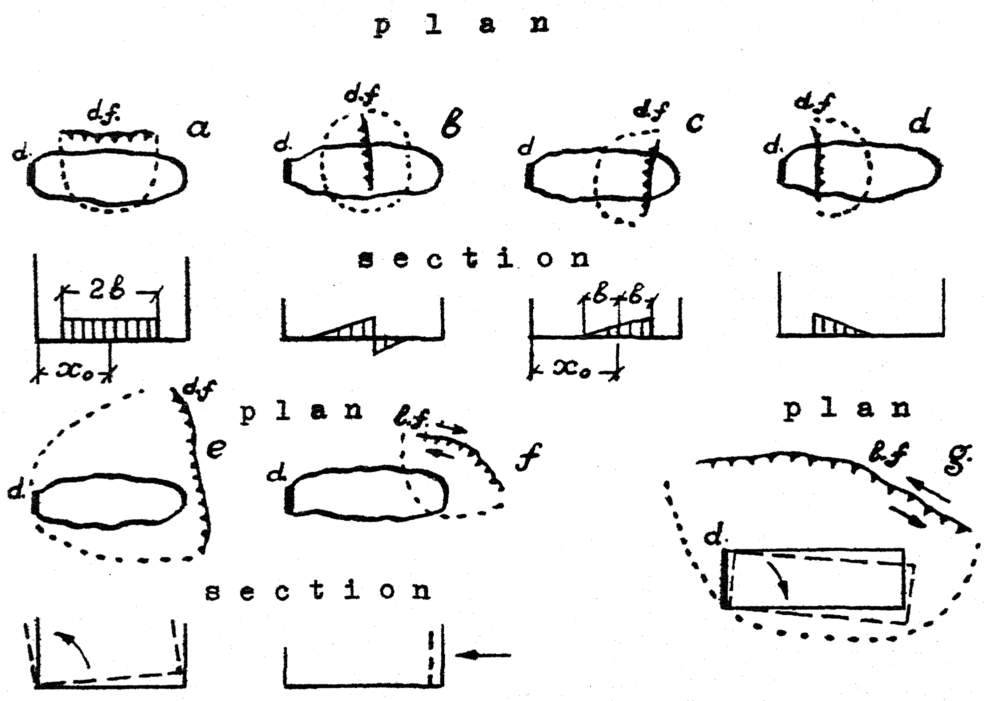

Fig.2. Schemes of different seismotectonic displacements in the reservoirs area. df - dip fault; l.f. - lateral fault displacement; .... limits of a possible deformation area; d - a dam.

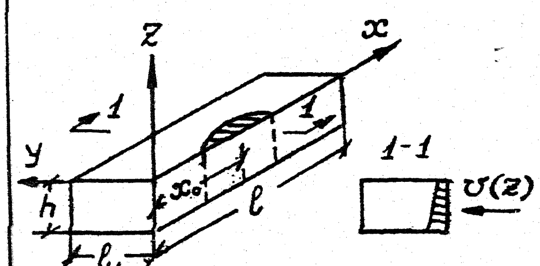

Fig.3. Scheme in a case of the displacements due to avalanches and landslides at the side of the reservoir

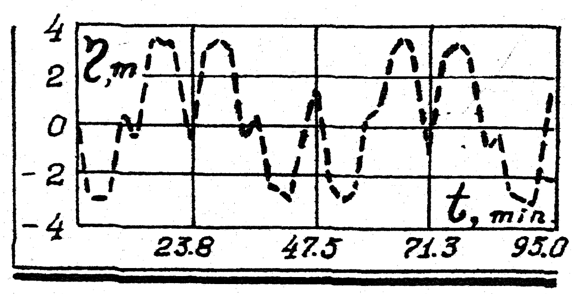

Fig.4. Diagramm of $\eta = f(t)$ for the case of wave generation in the Hebgen lake (USA)

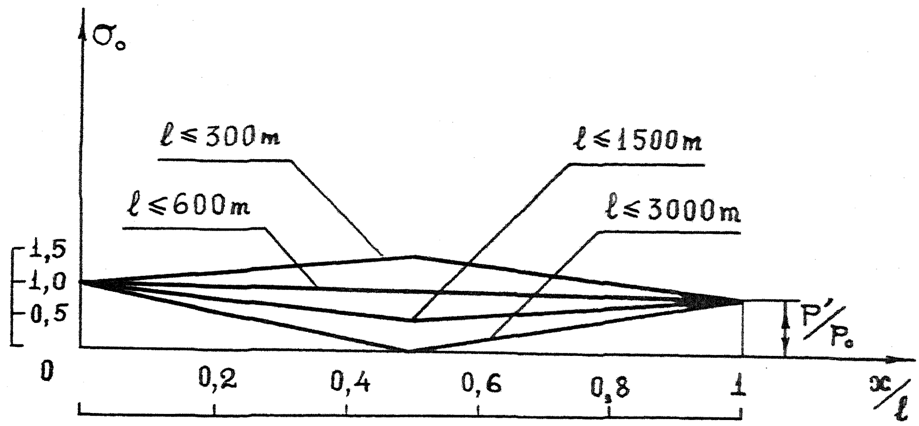

Fig.5. Diagramm for determining σ_0 for the case of a pressure tunnel with a surge reservoir at the end. P' is a pressure standard at the bottom of a surge reservoir.

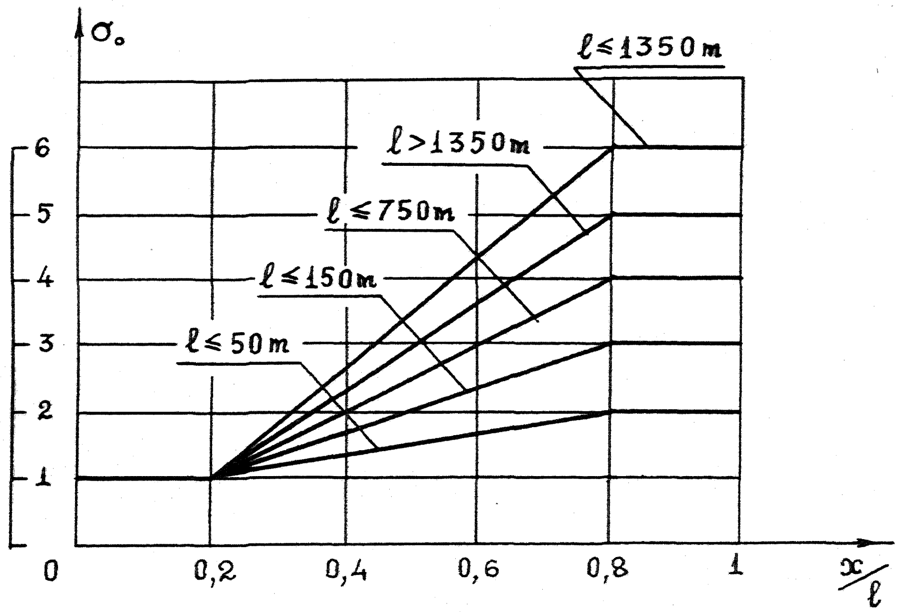

Fig.6. Diagramm for determining σ_0 for the case of pressure tunnel or a conduit with a locked gate at the end.