30 Mar 2001, 10:30 am - 12:30 pm

Dynamic Design of Ground Dams Under The Action of Dynamic Loads

S. I. Umarkhonov
Institute of Mechanics and Seismic Stability of Structures of Academy of Sciences of Republic of Uzbekistan, Uzbekistan

DYNAMIC DESIGN OF GROUND DAMS UNDER THE ACTION OF DYNAMIC LOADS

S.I. Umarkhonov
Institute of Mechanics and Seismic Stability of Structures of Academy of Sciences of Uzbekistan, Academgorodok, Tashkent -Uzbekistan-700147, Fax: (8-371)-162.71.52, e-mail: iskan@seismo.com.uz.

ABSTRACT

Stress-strain state and non-stationary dynamic behavior of ground dam under kinematic action in the form of synthetic seismogram are studied in the paper by the method of finite differences. The regularity of deformation of dam material was taken as elasto-plastic one. Numerical results obtained are given in the form of graphs. The author of this paper worked out the methods using the finite-differential methods of M.Wilkins' scheme and carried out the design of non-homogeneous ground dam with account of wave processes occurring in the body of the dam on seismic action. Numeric solutions of closed system of differential equations using different equations of state (elastic, elastoplastic and with account of rheological characteristics of ground) of dam material were obtained. Basing on results of the calculations dynamic behavior and stress-strain state of ground dam under seismic load in the form of record of synthetic seismogram were studied. The zones of formation of plastic flows of ground leading to a loss of bearing capacity and stability of the dam were revealed and the stability of dam slopes under seismic action was assessed.

INTRODUCTION

Ground dams as it is well known have a complex geometry and structure of physical construction. An erection of step-by-step setting and non-homogeneity of the material of the dam lead to a certain difficulties of theoretical investigation of dynamic behavior of ground dams under the action of different loads. Solutions with account of these factors (complexity of geometry, non-homogeneity, conditions of structure, etc,) as well as the pressure of water at non-stationary conditions of loading do not lend themselves to analysis of stress-strain state of discussed dams. In [1] stress-strain state of ground dams with account of non-stationary processes occurring in the body of the dam was studied using the method of finite differences. In these studies almost all possible peculiarities of the dam were investigated, such as non-homogeneity (the core of the dam), non-linear deformity (plastic characteristics, water-saturation) and complexity of geometry. But stress-strain state and non-stationary behavior of the dam are considered in the initial moments of time (in thousands fractions of a second) during the process of dynamic loading, that is before the moment of time when the propagating wave reaches the upper crest of the dam. In [2] the methods of numeric investigation of ground dams with account of wave theory are worked out. The possibility of application of this method in duration of several seconds in the process of dynamic loading was shown. In this paper the dynamic behavior of Charvak dam on the action of damping kinetic effect (synthetic seismogram) with account of wave processes occurring there was numerically investigated using the approach given in [2].

STATEMENT OF THE PROBLEMS.

Let the prolonged uniform ground dam standing on a rigid foundation present a trapezoid outline in cross section. We will assume that from the moment of time $t \geq 0$ the dynamic action from the foundation begins to act on this dam. If an acting kinematic action is taken in the form of synthetic seismogram the law of change of rigid foundation has the following form

$$U_x = A_x \exp(-at)\sin(2\pi t / T),$$
$$U_y = B_y \exp(-bt)\sin(2\pi t / T) \quad \text{at} \quad t \geq 0 \qquad (1)$$

here A_x and B_y are the amplitudes of maximum horizontal and vertical displacements, a and b – parameters characterizing the degree of damping of these amplitudes, T – time of acting load.

The equation of motion for plane-deformed ground dam in Cartesian system of coordinates has a form

$$\rho \frac{dv_x}{dt} = \frac{\partial S_{xx}}{\partial x} + \frac{\partial P}{\partial x} + \frac{\partial \tau_{xy}}{\partial y}, \quad \rho \frac{dv_y}{dt} = \frac{\partial S_{yy}}{\partial y} + \frac{\partial P}{\partial y} + \frac{\partial \tau_{xy}}{\partial x}. \qquad (2)$$

here ρ is a density of the material of the dam, v_x and v_y – velocities of the particles, P – hudrostatic pressure, $S_{xx}, S_{yy}, \tau_{xy}$ - deviators of the tensors of stresses. Total stresses σ_{xx}, σ_{yy} and σ_{zz} respectively are calculated from the relations

$$\sigma_{xx} = S_{xx} + P, \quad \sigma_{yy} = S_{yy} + P, \quad \sigma_{zz} = S_{zz} + P. \qquad (3)$$

The regularities of deformation of ground dam material are taken in the form of elastic-plastic law [3]:

$$\frac{dP}{dt} = K\left(\frac{dV}{dt}\right)/V; \qquad (4)$$

$$\frac{dS_{xx}}{dt} + \lambda S_{xx} = 2G\left(\frac{d\varepsilon_{xx}}{dt} - \frac{dV}{3Vdt}\right),$$

$$\frac{dS_{yy}}{dt} + \lambda S_{yy} = 2G\left(\frac{d\varepsilon_{yy}}{dt} - \frac{dV}{3Vdt}\right), \qquad (5)$$

$$\frac{dS_{zz}}{dt} + \lambda S_{zz} = 2G\left(0 - \frac{dV}{3Vdt}\right),$$

$$\frac{d\tau_{xy}}{dt} + \lambda \tau_{xy} = 2G\frac{d\varepsilon_{xy}}{dt},$$

here $V = \rho_0/\rho$ is a relative volume, $\varepsilon_{xx}, \varepsilon_{yy}, \varepsilon_{xy}$ – components of deviators of stress, G and K – modulus of shear and volume compression respectively, λ – functional defined by Mises-Schleiher condition of yielding:

$$2J_2 = S^2{}_{xx} + S^2{}_{yy} + S^2_{zz} + 2\tau^2_{xy} \leq 2\frac{Y^2(P)}{3}, \qquad (6)$$

$$\lambda = (2GW - dJ_2/dt)/(2J_2),$$

$$W = \sum S_{jj}\left(\frac{d\varepsilon_{jj}}{dt} - \frac{dV}{3Vdt}\right) + \tau_{xy}\frac{d\varepsilon_{xy}}{dt},$$

here $\lambda \equiv 0$ at $J_2 < Y(P)^2/3$, $\lambda > 0$ at $J_2 = Y(P)^2/3$

Here *Y(P)* is a generalized condition of yielding and according to [3] is taken in the form

$$Y(P) = Y_0 + \frac{\mu P}{1 + \mu P/(Y_{PL} - Y_0)},$$

here Y_0 – cohesion, μ – coefficient of friction, Y_{PL} – limit value of shear strength of ground.

The connection between the tensor of velocities of deformation and velocities of the particles is fulfilled by the relation:

$$\frac{d\varepsilon_{xx}}{dt} = \frac{\partial v_x}{\partial x}, \quad \frac{d\varepsilon_{yy}}{dt} = \frac{\partial v_y}{\partial x},$$

$$\frac{d\varepsilon_{xy}}{dt} = \frac{1}{2}\left(\frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}\right). \qquad (7)$$

Using Eulerian variables it is necessary to add an equation of continuity to make a closed system of equations (2)-(7):

$$\frac{dV}{dt} = V\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right). \qquad (8)$$

Before the application of dynamic load (1) ground dam is taken as unstressed, unstrained one and in rest. If take this as an initial conditions, the system of differential equations (2)-(8) with free from stresses boundary conditions on slopes and crest and with condition (1) on the lower surface of the dam describes a complete picture of non-stationary behavior of ground dam.

Method of solution. Discussed problem is solved by the method of finite differences. In contrast to [1] we will use a finite differential scheme described in [4] and worked out in [3,5] for discussed types of problems. Here the following should be stated. In [3,7] the scheme [6] meant for the equations in Eulerian variables is used. As it is well known in Eulerian spaces the displacements of the particles are defined by the positions of the points in current and initial moments of time. That is why the coordinates of points of lower surface of dam in current moments of time are defined by relation

$$x = U_x + x_0, \qquad y = U_y + y_0,$$

here x_0, y_0 are an initial coordinates of lower surface of dam. U_x, U_y – displacements defined by an expression (1).

Calculating the stresses by step method in [4] the values of increment of components of deformation (not a velocity of deformation) are used. So the connection of deformation with kinematic parameters in (7) is fulfilled by infinitely small increment. In this case the correlation (7) could be used to describe great deformations, summing up infinitely small changes. This shows an advantage of worked out method [2,5] comparing with [1] in study of dynamic behavior of ground dam. In conclusion we should state that the reliability of the method of design is substantiated in [5] by the solution of test example which shows a good coincidence of numeric result with an exact solutions for quadrangular structures.

NUMERIC CALCULATIONS

Numeric results and their analysis. Consider the results of design on dynamic behavior on the example of Charvak ground dam under the action of loads (1). Geometrical characteristics of the dam were taken as following: the height of the dam of canal bed section equals 168 m, the width of the crest – 12 m, the steepness of the back of a dam – 1:2, and lower part – 1:1.9. Physical and mechanical characteristics correspond to an initial data: the density of the dam material equals 2300 kg/m^3 the velocities of longitudinal and cross wave propagation respectively 1500 m/s and 625 m/s the cohesion of the ground $G/600$, coefficient of the angle of friction 0.4, limit value of shear strength of dam material - $22Y_0$.

Placing the beginning of the count of Cartesian coordinates on a lower point of the back of the dam and directing Ox axis along the foundation and lower surface of the dam we will trace the dynamic behavior in the points situated in near-crest back zone (A), in back zone near the foundation (B),along the center of core near the foot of the dam foundation (C) and in the center of the core of the dam (D). Coordinates of these points are taken as equal: A{329m,157m}, B{98m,37m}, C{342m,37m} and D{342m,80m}. Numerical results obtained are presented in graphs (fig. 1-4). First of all the problem was solved under the action in vertical direction only, that is $A_x = 0$, $B_y = 0{,}25$, b=1 and T=0,5 sec in (1), the solutions are given in fig. 1-2. Fig. 3-4 correspond to solutions at $A_x = 0$ and a=b and parameters of vertical action were not changed. Curves 1-4 in fig. 1-4 correspond to points A,B,C and D respectively.

Fig. 1 gives the changes of horizontal (a) and vertical (b) stresses in time, it shows the appearance of insignificant stresses in slope zone near the free surfaces of the dam. Here maximum stresses in modulus reach 2 MPa. Significant stresses occur in central core zone of the dam (curves 1,2, fig. 1). Maximum values of the amplitudes of the stresses appear near the foot of the foundation along the center of the core in initial moments in the process of loading. Later with time duration these stresses become less.

A great interest is risen by the occurrence of residual deformations. Changes of horizontal (a) and vertical (b) deformations in time are shown in fig. 2. The values of deformations in all discussed points of the dam occur in initial moments of time. With duration of time their changes become stable causing here residual deformations. Maximum horizontal residual deformations are in near-crest back zone (curve 1, fig.2,a). These deformations become negative, that is the loosening of dam ground against the direction of coordinate axis Ox occur. Insignificant residual deformations appear in lower parts of the dam including the back zone of the dam. In central part of the dam as well as in near-crest zone a residual deformations are significant (curve 4, fig. 2,a). The same picture is observed in changing of vertical deformations in time (fig. 2,b). Here the greatest compacting of the ground occur in near-crest zone of the dam. As it is seen from fig.1 and 2 even without the motion along the axis Ox given by boundary conditions in (1) there appear a horizontal components of stress and strain. Naturally it is caused by the complexity of the dam (the waves are reflected from slope boundaries).

By the same way the stresses and strains are changed in discussed points of the dam in time at a given values of foundation displacements in both directions (fig.3 and 4). Here maximum values of the amplitude of stresses appear in central part of the dam, and significant residual deformations – in near-crest zone of the back of the dam. Thus under the action of dynamic load in the form of synthetic seismogram (1) on ground dam from the foundation the most dangerous are the initial moments of time as it could influence the stability of the slopes.

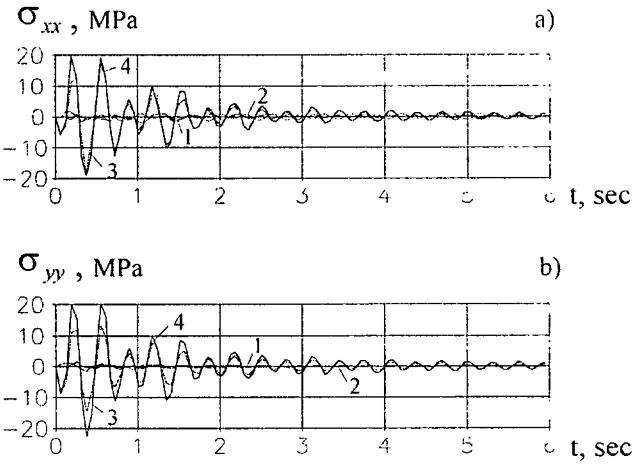

Fig.1.Change of stresses in time.

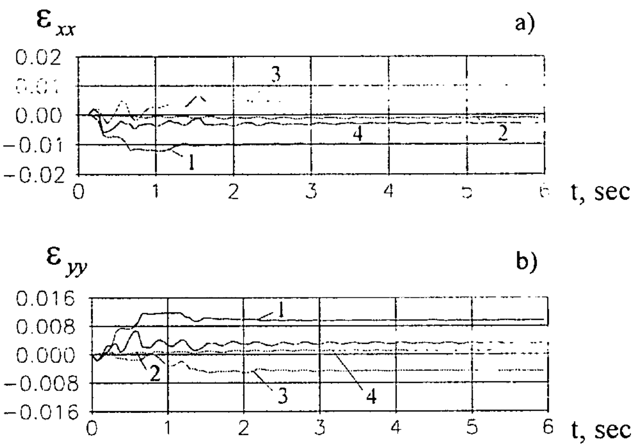

Fig.2. Change of deformation in time.

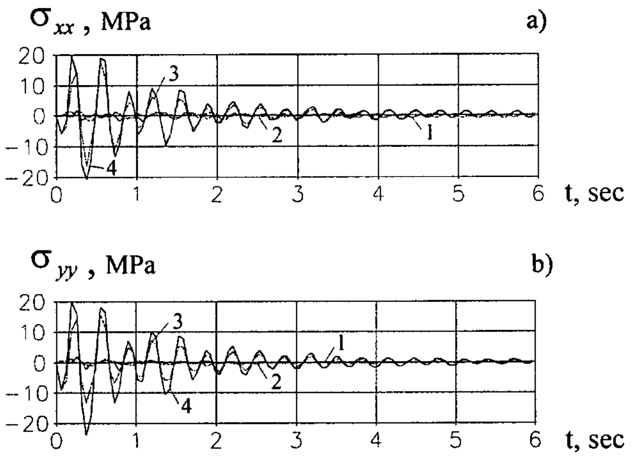

Fig.3. .Change of stresses in time.

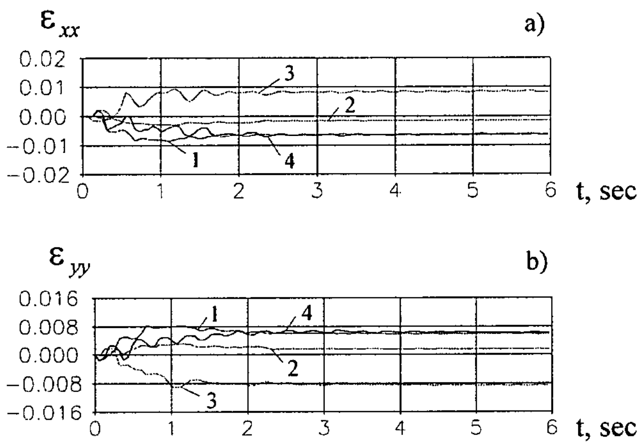

Fig.4.Change of deformation in time.

REFERENCES

Zaretskiy, Y.K. and Lombardo, V.N. [1983]. *Statics and Dynamics of the Ground Dams.*@ Energoizdat, Moscow (Russian).

Salyamova, K.D. and Khusanov, B.E. [1998]. Numeric study of dynamic behavior of ground dams with account of wave theory. @ Transactions of Academy of Sciences of Azerbaijan. Series of Physical and Mathematical Sciences, No 3-4, pp.260-267.

Grigoryan, S.S. [1967]. Some Questions of Mathematical Theory of Deformation and Damage of Rigid Rock Mass. @ Prikl. Mat. Mekh., No 4, pp.643-669 (Russian).

Wilkins, M.L. [1964]. Calculation of elastic-plastic flow. @, in: *Methods Computat. Phys*, Acad. Press 3, 211-263, New-York-London, pp.211-263.

Khusanov, B.E. and Salyamova, K.D. [1998]. Finite-Differential Method for Dynamic Design of Ground Dams. @ Dokl. AN RUz, No 9, pp.20-25 (Russian).