Vibration of Foundation Bases and Shock Waves in Soils

Vibration des Bases de Fondations et Ondes de Choc dans des Sols

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SYNOPSIS Experimental calculation procedure for the investigations of vibrations, the stress-strain state and the stability of soil of the foundation bases for machines with dynamic loads is discussed. Given are the examples of the investigations of the stress state and dynamic stability of the soils of the foundations for turbo-machines of the Kostroma thermal power plant and others power plants on the basis of the above procedure. Presented are the estimates of the theoretical and experimental data on the shock wave structure, the motions beside the shock wave front and the deformability in terms of the void ratio and cohesion of the soil. Discussed are the effects of the moisture additives, the speed of deformability and the interaction between dilatation and pore pressure for the state of complete saturation of the soil.

The arrangement of foundations for turbo-aggregates of thermal and nuclear power plants as well as for other machines with intensive dynamic loads generates a need for determining the stress-strain state and the vibration stability /2, 3/ of saturated cohesionless or poorly cohesive soils underlying the foundations.

For the solution of these rather complicated problems a multipurpose testing and calculation procedure was worked out, including the investigations of the site geology and the assessment of the actual dynamic soil properties (elastic, viscous, plastic, so on) /2/ for the design of the foundation base.

The algorithm and programme are developed for the computations of the plane static and dynamic stress-strain behaviour of the foundation soils under the prescribed foundation displacements or the external forces acting upon the foundation. The computations are based on the finite difference procedure. In this case various factors are taken into account, i.e. the actual geologic foundation structure, the variation of the static and dynamic soil moduli with the static stress state and the dynamic strain amplitudes, the possibility of occurrence of the irreversible shear strains and so on. Transmission of the disturbance waves from the foundation through the boundaries of the calculated area is provided. The stress and strain tensor components (σ_{ij}, ε_{ij}) of the maximum tangent and normal stresses (τ_{max}, σ_n) as well as the angle of inclination to the coordinate axes of the area affected by these stresses are defined from the calculations. This procedure is followed by the evaluations of the structural stability and the vibration deformation properties of the soils for the design conditions of the static stress and dynamic loading state. The evaluations are carried out through the uniaxial compression and simple shear tests. The structural stability and the liquefaction potential of the saturated soils are assessed by the critical parameters of the dynamic influence and, if necessary, by the allowable value of the excess pore pressure.

After the first test the soil is considered stable it the design maximum stresses or strains do not surpass their critical experimental values (at which the residual volumetric strains do not yet occur) for any foundation point examined.

In the opposite case the excess pore pressure for various points of the foundation is obtained by the consolidation theory methods using the vibration strain test curves and the foundation stability is checkes afterwards with consideration for the excess pore pressure.

The described procedure was used for the stability evaluations of the foundation soils underlying the turbo-aggregates of the Kostromskaya thermal power station and some others.

Figure I shows the tangent dynamic stress amplitudes τ in the foundation base of the width b = 31 m (in the longitudinal direction the foundation is considered infinitely long) under the vibrations amplitudes A = 10 mkm.

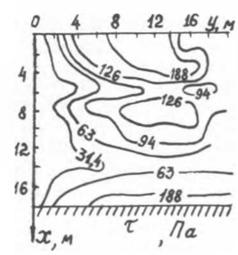

Fig. 1

The tangent dynamic stress amplitudes in the foundation base

Down to the depth H = 18 m the foundation is composed of moraine clays and underlying sands with relatively similar characteristics: ρ = 1.88 T/m^3, and the Lame constants λ = 4567 MPa, μ = 138.5 MPa.

Due to symmetry, only the first half of the foundation is shown in the Figure.

The design τ and critical τ_{cr} tangent stresses (obtained from the tests on vibro-shaking table) for the depths 7 m, 5 m and 4 m below the foundation base are summarized in Fig. 2. The comparison between τ and τ_{cr} reveals that the foundation soils are dynamically stable.

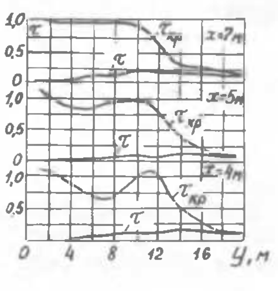

Fig. 2

The design and critical tangent stresses for the depths 7 m, 5 m and 4 m below the foundation base

The experimental data on the soil behaviour under explosive loading is usually treated in terms of the dilatation plasticity theory with account for the strain velocity effect. The dilatation shows itself as the proportionality $\dot{\varepsilon}^p = \Lambda |\dot{\gamma}^p|$ between the volumetric plastic strain velocity $\dot{\varepsilon}^p$ and the plastic shear velocity $\dot{\gamma}^p$. The plastic strain velocities are non-zero if the flow condition $|\tau| = \alpha\sigma + C$ (in which τ - tangent force, σ - pressure, C - cohesion) is observed. According to the static tests the modulus of the dilatation velocity $\Lambda(\varepsilon^p, \sigma)$ is inferior to the internal friction coefficient $\alpha(\varepsilon^p)$, which suggests that the flow obeys the nonassociated rule $\dot{\varepsilon}_{ij}^p = (\sigma_{ij} + \sigma\delta_{ij})\dot{\lambda} + (C\alpha^{-1} + \sigma)\delta_{ij}$. The two additional required functions $\lambda(x_i, t)$, $\gamma(x_i, t)$ in the flow rule are determined from the dilatancy and flow conditions /6/.

Laboratory measurements of the velocities V(r, t) of the particles behind the front of spherical symmetric explosion wave (V.N. Rodionov et al) confirm that the first kinematic integral $V(r, t) = V_o(t)\, r^{-n}$ is followed for Λ = const /4/. Here $n = (2\sqrt{3} - 2\Lambda)/(\sqrt{3} + 2\Lambda) = 1.5 \div 1.8$, which corresponds to the statically varying values $\Lambda = 0.18 \div 0.09$. The second kinematic integral for the soil density field (void ratio n_{soil}) was found by S.Z. Dunin and V.K. Sirotkin. For the varying dilatation velocity the numerical calculation methods are to be used /5/.

The investigations of the residual density (A.N. Bovt et al) of cemented porous material (n_{soil_o} = 0.25, velocity of sound V_o = 3 km/s, crush strength 200 atm) show that at the distances up to $R_1 = r/a_o = 2.5$ (where a_o - the initial radius of the soil cavity due to explosion) decompaction takes place whereas the range $R_1 \leq R \leq R_2 = 4$ is characterized by compaction resulting from the shock wave and the dilitational intensification of compaction.

Dilatation does not occur in the uniaxial plane waves (absence of large shears) therefore the soil compaction in this case is inferior to that observed in spherical-symmetric waves. This fact is confirmed by the experimental results from explosions (Khristophorov et al) performed in compressed powder of NaCl. In other words, non-holonomicity (dependence on the path of loading) of the variation of density with pressure and shear is observed.

Besides, no loosening zones exist in the plane explosion waves. The volumetric strain delay (G.V. Rykov) can also be attributed to the dilatation phenomenon. The peak values of compaction and pressure in the wave do not coincide because the shear which intrensifies the pore squeezing, develops beyond the diverging front. The delay may be also explained by the velocity effects. In clays and moist soils sensibility to the strain velocity depends on the actual viscosity of water. However, it is not so for dry soils. The matter is that the rate of the crack growth and the dry friction sliding cannot surpass the limiting value (the velocity of Rayleigh wave or a smaller velocity). Therefore the time of the pressure build-up in a wave is not long enough for the complete pore closure to occur and the dynamic compressibility during the explosion is less than the static one which is confirmed by the above mentioned experiments with NaCl. Thus, the dynamic moduli correspond to a plastic wave.

In the explosion tests the effect of the pore closure was considerably weakened because the sand was subjected to confining pressure (Stoks, Ebeido, Zelmanov, etc.). Under the spherical-symmetric explosion the plastic wave velocity is constant for a large range of motion. It can be shown that it is equal to the velocity of Rayleigh wave. The analysis of the plane wave data (Fig. 3) for two levels of confining pressure (various values of V_o) shows that the dynamic plastic compressibility (solid lines) is lower than the static one (dashed lines). As the propagation velocity of the non-elastic front is less than the speed of sound, the propagation of weak waves is not influenced by the plastic state.

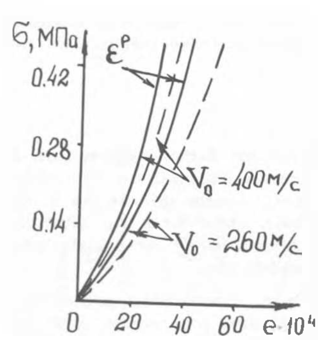

Fig. 3

The dynamic plastic compressibility (solid lines) and static one (dashed lines) for two levels of confining pressure (various values of V_o).

The propagation of weak waves obeys the elasticity theory; the non-elastic sliding waves which propagate with lower speed engender a special type of attenuation The characteristic time of the "relaxation due to sliding" for sands is equal to 10^{-4} s.

When the pores are saturated with water the dilatation is limited by the compressibility of the solid and liquid soil phases. The increase in the pore pressure due to dilatation results in the soil liquefaction.

REFERENCES

Eisler, L.A. (1976). The assessment of the excess pore water pressure of dams and embankments under seismic impact. Izvestia VNIIG,(111), L., Energia, p. 36-44.

Krasnikov, N.D. (1970). Soil dynamic properties and methods of their determination. Stroyizdat, 239 p.

Savinov, O.A. (1979). Modern design and calculations of foundations for machines. L., Stroyizdat, 200 p.

Nikolaevsky, V.N. (1967). On the relations between volumetric and shear strains and on the shock waves in soft soils. Reports of the AN SSSR, (177), p. 542-545.

Nikolaevsky, V.N. et al (1980). The effects of dilatation as a result of underground explosion. Numerical treatment. Reports of the AN SSSR, (250).

Nikolaevsky, V.N., Rice, J.R. (1977). Current topics in nonelastic deformation of geological materials. Highpressure Sci and Technol., (2), p. 455-464.