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Peculiarities of Soil Structure Interaction in Construction with Artificial Bases

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SYNOPSIS: A technique is suggested to increase seismic resistance of constructions by using alternative artificial bases. Two types of artificial bases are considered: a (consolidated) soil pad and a pile foundation (with or without pile grating). Criteria have been established for the foundation parameters required depending upon the foundation versus construction stiffness ratio. The construction of a consolidated soil pad 3 m thick (h~3m) with deformation module $E_0>30$MPa on soils, which are referred, according to the All-Union Building Standard Specifications (SNIP,1982), to soil category III, is shown to reduce the level of surface accelerations by a factor of 1.5-2. The thickness of a pad for massive stiff structures has to be minimum and provide the bearing capacity of the foundation. In many cases an artificial base in the form of a pile foundation is desirable. This footing is most efficient in construction on a layer of strongly compressible soil 10-15m thick overlying solid rock. The effects of such an artificial base on the dynamic characteristics of structures, as well as the properties of pile operation are discussed in the present paper.

INTRODUCTION

Recently it has become necessary to construct buildings on the high-compressible soils in seismically hazardous areas, in which earthquakes of magnitude 9 may occur.Such a target emerged in constructing the new regions in Ashkhabad, Petropavlovsk-Kamchatsky, Krasnovodsk, Leninacan etc.These regions, according to SNIP (1982), are not good for building since the building site with the high-compressible soils requires increasing the calculated seismicity by magnitude 1, in this case it becomes of M=10.

If the soil conditions at a building site are nonuniform in depth, then, according to SNIP (1982), provided there is no seismic microzonation, the seismicity is calculated based on the properties of the soil, which dominates within the upper 10-m layer of the footing. However, this recommendation was not well-grounded and its formal use may result in paradoxical situations. Thus, if the thickness of the stiff soil, which dominates within the upper 10-m stratum, is 4.99 m, then the building site, according to SNIP (1982), is referred to the seismic zone of M=10, but the same site with 5.01 m thick stiff soil is referred to the seismic zone of M=8,i.e. the calculated loads on the construction differ within the factor of 4 in this case. In practice, while using the mentioned SNIP's recommendation, the artificial base in the form of a sand-gravel pad 5 m thick is believed to provide seismic safety of buildings. To find a solution to this problem we need a detailed grounding. In addition, it is necessary not only to evaluate the optimum thickness of a consolidated pad, but also to determine its size in plan and its elasticity. Unfortunately, the required recommendations are unavailable. In this study, an attempt is made to provide clarification of this problem.

COMPUTATION TECHNIQUES FOR SEISMIC CAPACITY OF STRUCTURES ON ARTIFICIAL BASES

In evaluating the seismic capacity of the "construction-artificial base-soil" system, the different data concerning this system should be taken into account: the different elastic, inertial and damping properties of its elements, nonuniformness and infinity of soil stratum, lack of information on seismic effects inside the area of footing and at the surface, when a structure and a pad are available, etc. To consider the above factors, a finite element method (FEM) is generally used. In the USSR such studies were made at the Research Institute of Foundations by Il'ichev et al. (1986) and elsewhere.

Titov and Uzdin (1989) have developed a technique and software allowing consideration of the above-enumerated properties within the framework of FEM. This technique is based on application of the infinite finite elements (IFE) and the damping boundary (DB).Earthquake-like excitation was exerted by using Lombardo's procedure (1973).The computation scheme of the "construction-artificial base-soil" system modified by the authors is presented in Fig.1. This system is described by the following matrix equation:

$$MY + B_vY + B_hY + RY = -MY_0, \qquad (1)$$

where:M and R = The inertia and stiffness matrices

Y = System migration vector

Y_0 = Kinematic disturbance vector

B_v = Matrix of viscous damping due to energy losses on the damping boundary

B_h = Matrix of hysteretic damping of the system

As applied to the problems of seismic resistance, the technique of system (1) solution developed by

Uzdin (1982; 1986) is based on spectral expansion of system (1) and analytical presentation of the solution using the main coordinates. The above-mentioned theoretical speculations form a basis for the numerical analysis of the problem under study.

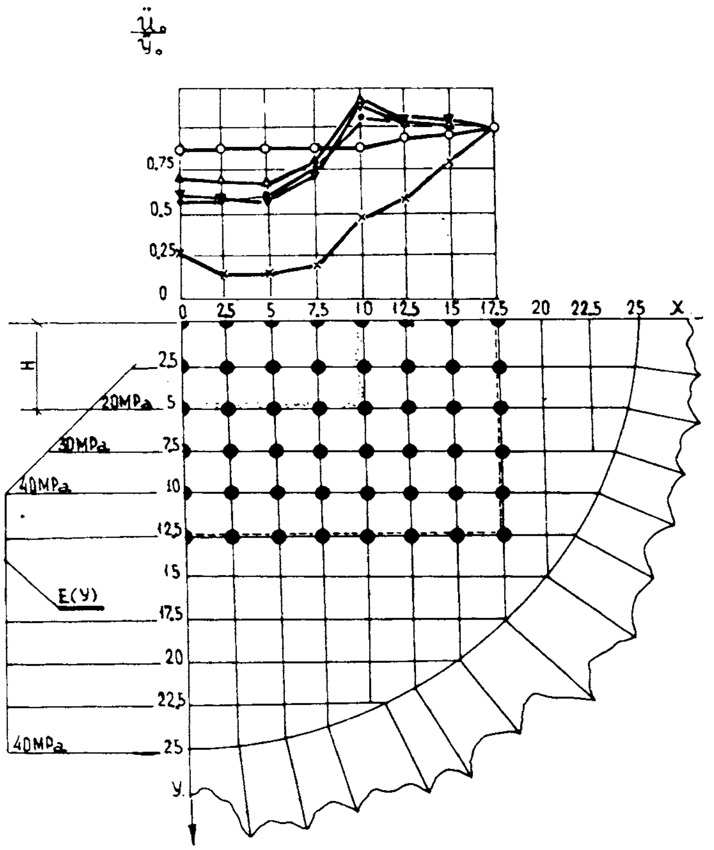


Fig. 1 Calculation Scheme and Curves of Relative Accelerations of the Soil Surface, the Condensed Pad Is Available

—○— = Curve of relative accelerations without a pad

—△— = Curve of relative accelerations with a pad having H = 1 m

—▽— = Curve of relative accelerations with a pad having H = 3 m

—●— = Curve of relative accelerations with a pad having H = 5 m

—×— = Curve of relative accelerations with a pad having H=5m at E=const=5 MPa

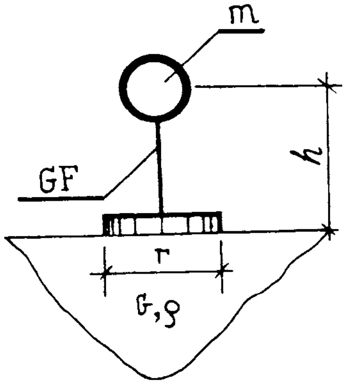
— — — = Damping boundary

┈┈┈ = Boundary of condensed pad at E=60 MPa

$\ddot{U}_0$, $\ddot{Y}_0$ = Maximum accelerations at a point with and without a pad

EFFICIENCY OF ARTIFICIAL BASE IN THE FORM OF A CONSOLIDATED PAD

The computation studies made have demonstrated that the approach to designing artificial bases depends on the degree of inverse influence of construction on the base vibrations. To evaluate this effect, the parameters of interaction have been introduced (Uzdin,1989). Of them the most substantial are: the dimensionless resonance frequency of construction vibrations $a_0 = \omega r/V$ and the relative mass of construction $m_0 = m/\rho r^3$, where ω is the eigenfrequency of the construction vibrations, r is the radius of a stamp, which is equal to the area of footing, V is the velocity of shear waves in the footing, ρ is the density of footing, and m is the mass of construction. The $m_*(a_0)$ ratio in Fig.2 shows the degree of influence of construction on the base vibrations. When $m_0 < m_*$, the inverse influence of the construction on the footing is negligible.



$$a_0 = \frac{\omega r}{v}\ ;\ m = \frac{m}{\rho r^3}$$

$$v = \sqrt{G/\rho}\ ;$$

$$æ = \frac{K_x h^2}{K_\varphi} \sim \frac{h^2}{r^2}\ .$$

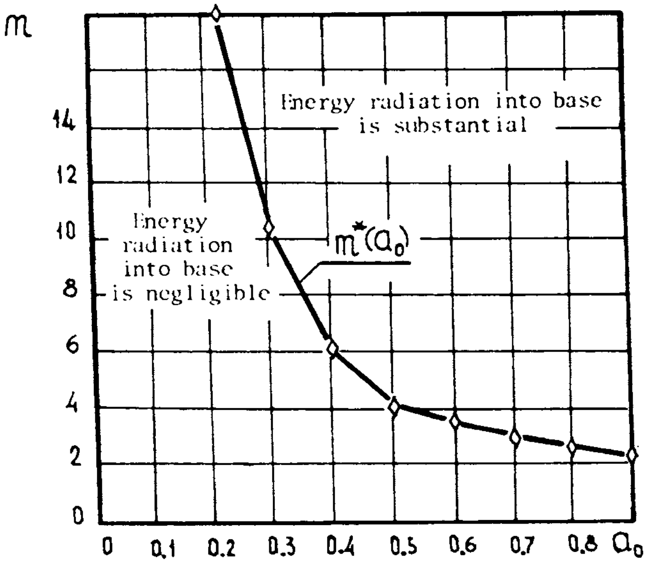


Fig. 2 A Degree of Influence of Construction on Base Vibrations

In this case the stress condition of a soil profile does not limit the seismic capacity of a building and the criterion for the efficiency is the maximum acceleration at the surface of the artificial base. Simultaneously, the loads on the construction decrease with increasing thickness of the layer of condensed filling in. For such constructions, the artificial base parameters (thickness h, width B, elasticity module E) may be selected not considering the influence of the construction itself. To select the dimensions of the base, we shall apply to the characteristic diagram of the surface accelerations presented in Fig. 3.

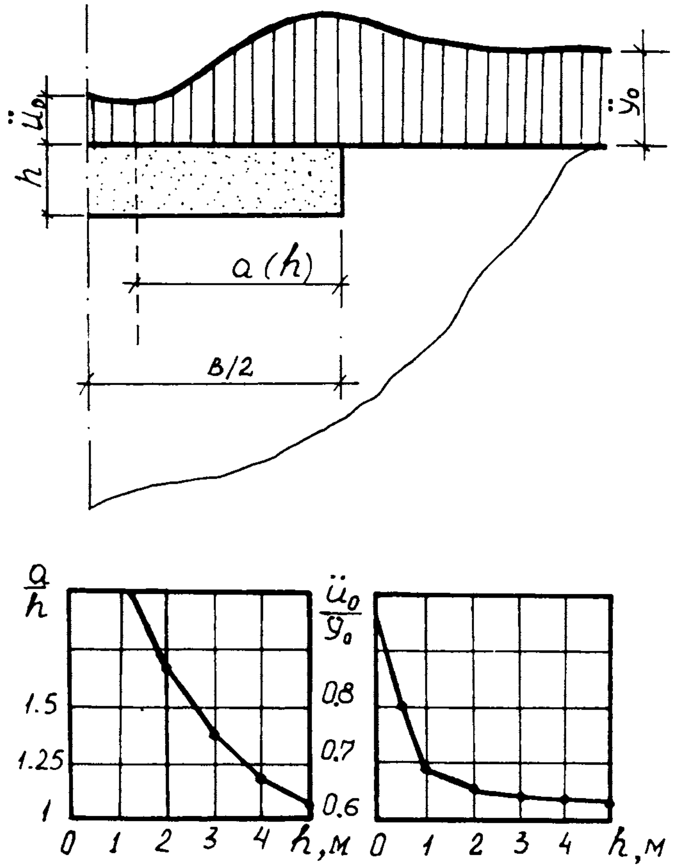


Fig. 3 Diagram of Superficial Soil Accelerations at E = 60 MPa

As shown in Fig. 3, two zones can be distinguished in the diagram: the first, with uniform acceleration curves in the central part of a pad, and the second, with extension ,located near to the border of a pad, with the alternating acceleration curves. In accordance with the efficiency criterion taken, its quantitative estimate can be expressed in the form of a ratio of the maximum acceleration in the central part of a pad, $\ddot{U}$, to the maximum acceleration of the natural footing, $\ddot{Y}_0$. Based on numerous calculations, a plot of $\alpha = \ddot{U}/\ddot{Y}_0$ versus the thickness of a pad, h, has been constructed. In Fig. 3 this dependence is given for the case E = 60 MPa. The construction should evidently be placed in the first zone of the artificial base with the uniform distribution of acceleration along its surface. Then the width of a pad, B, can be determined by the formula:

$$B = B_0 + a(h), \qquad (2)$$

where B_0 is the width of a construction. The $a(h)$ plot constructed on the basis of numerous calculations is also shown in Fig.3. Concurrent use of dependences $\alpha(h)$ and $a(h)$ makes it possible to design artificial bases for light and flexible constructions by the following method: the thickness of a pad, h, is determined from the required level of acceleration decrease, α; then the value of a from the obtained h using the plot $a(h)$ and the required size of a pad from formula (2). The dependence $\alpha(h)$ allows us to specify the SNIP's recommendations related to the calculated seismicity value of the building site and eliminate the paradoxical situation of a jump-like change in the calculated seismicity value when the thickness of the poor soil overgoes the 5.0-m interface.

The construction of the artificial base can result in significant reducing the building site accelerations (approximately by a factor of 1.5 or 2). The thickness of a pad is desirable to be of about 3 m. Further increase in thickness of a pad in many cases is undesirable, since at a depth of more than 3 m even high-compressible soils have E = 20.0-30.0 MPa. This is commensurable with the elasticity of a pad.

Now we shall consider the case of a massive stiff construction, when $m_0 > m_*$, i.e. when the inverse influence of construction on base vibrations is large. Analysis made on the basis of numerous calculations of construction vibrations has shown that the inertial loads in this case prove to be smaller than those in the analogous conditions on the solid rock footing and they do not limit the bearing capacity of the construction because of large energy dissipation into soil. The determinative feature is here the bearing capacity of the footing itself, which serves as a criterion for determining the efficiency of a condensed pad. Calculations have also demonstrated that the inertial seismic load on a construction increases with increasing thickness of a layer of the artificial base, approaching thereby the analogous load when the base is stiff. In all the cases considered, a pad with $h < (1.5\text{-}2.5)$m proves to be sufficient to provide the bearing capacity of the base. This is illustrated in Fig. 4 showing the character of the critical state of the base with and without a 2-m thick pad.

The artificial base in the form of a uniform soil pad is noted for nonuniformity of the acceleration and stress field in the zone of its contact with the natural soil which reduces its seismic resistance.Investigations have shown that in order to increase the seismic resistance of the system, it is necessary to construct a laminated pad with deformation module which decreases with increasing distance from the construction. In practice, on loose loessal soils, volcanic ashes and the other strongly compressible soils, the laminated artificial base is created by ramming the foundation trench and by constructing a two-layer pad of dense sand and sand-gravel mixture. As a result, the building becomes less costly and its reliability increases.

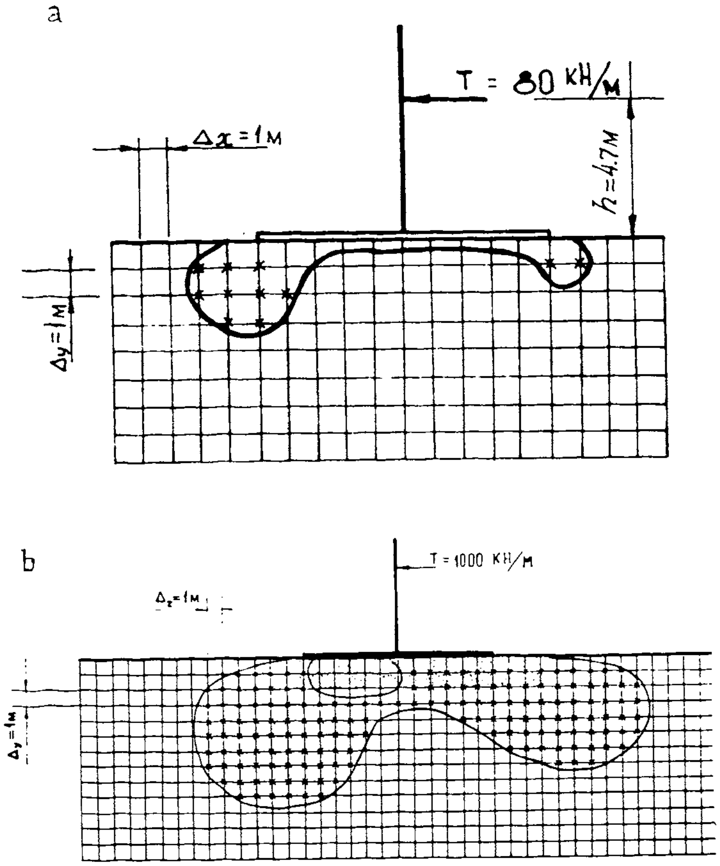


Fig. 4 Critical State of the Soil Base Without (a) and With (b) a 2-m Thick Pad

ARTIFICIAL PILE BASE

In some cases, in order to provide steadiness of the construction, there is a need to use artificial bases in the form of a pile grating with an intermediate soil pad. In this case piles increase the bearing capacity of the foundation and the intermediate pad serves as a seismically isolating element between the pile base and construction. Such a construction was first used in Chile, and on the basis of experimental studies made at the Research Institute of Foundations (Barkan et al.,1972), SNIP (1982) makes recommendations to use in seismic regions the pile bases with an intermediate pad. Unfortunately, the necessary data on designing buildings on such bases are unavailable.In this connection, in the Kamchatkan Branch of DALNIIS a study was made on typical buildings constructed on a layer of volcanic ash overlying rock (Klyachko,1982;1984; 1985; Klyachko and Putintsev,1988; Klyachko and Uzdin,1989). Calculations were made for various thicknesses of the overgrating pad and ash layer. Also the different constructions of the pile grating mat were used, separate (for each pile) and continuous. As a result, the pile capacity and seismic load on buildings were determined and the following conclusions were drawn:

1. The artificial base in the form of a pile grating with an intermediate pad provides the required seismic resistance of a building and its base.
2. In the seismic (M=9) regions the seismic load on 4- and 5-storied buildings constructed on strongly compressible soils proves to be lower than the analogous load on buildings located on solid rock.
3. The thickness of a layer of intermediate pad, which is required to rule out the transmission of horizontal load from the building on the piles, was calculated to be approximately 50 cm. This confirms the conclusions drawn by the Research Institute of Foundations earlier during experimental investigations.
4. Pile functioning was established to be substantially different for a pile base with an intermediate pad, the thickness of which was less than 50 cm. Piles prove to be overloaded by 40-60% in the case of a separate pile grating mat and by 10-15% in the case of the continuous pile grating mat.

CONCLUSIONS

As a result of study on interaction of a construction and two types of artificial base (a soil pad and pile base) overlying the poor soil, a method was developed to reduce the seismic load on a construction with the help of special artificial base construction. The results of this study are used in designing and building the earthquake resistant structures on the collapsible soils of Middle Asia, volcanic ashes and slimy sands of Kamchatka, clayey soils of North Armenia and in the other seismic regions of the USSR.

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