

Vertical Impedance of Rigid Shallow Foundation on Layered Water-Saturated Soil

<https://doi.org/10.31713/MCIT.2019.48>

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Abstract— Methods have been developed for numerical analysis the vertical oscillations of rigid plate with a liquid-impermeable sole rested on the layer (Biot's model) with a rigidly restrained lower edge. The plate sole is liquid-impermeable. The analysis of the impedance functions depending on the oscillation frequency, the geometry of the system and the mechanical parameters of the soil model is carried out.

Keywords— soil-structure interaction; shallow base vertical impedance; layered soil; Biot's model; dynamic contact problem; orthogonal polynomials method.

I. INTRODUCTION

Under the foundations or hydraulic engineering structures, thermal and nuclear power stations blocks there is a noticeable dependence of the reaction of the base on the frequency of oscillations and the size of the sole. The aim is to numerically simulate the dynamic interaction of slabs with a water-saturated layered soil base. We consider a number of features of dynamic interaction of shallow foundations with the basis of poroelastic fluid-saturated (PELS) dispersed soil, when it is important to analyze the vertical oscillations. The aim is to numerically simulate the dynamic interaction of slabs with a water-saturated layered soil base.

Methods of integral transformations for differential equations with partial derivatives have obtained an analytical solution of the problem of moving the solid and liquid phases of the surface of a porous-elastic fluid-saturated (PELS) layer with a clamped lower face on the action of a distributed load (Lamb's problem). A water-saturated base of the horizontal-layered structure using the Biot's model [2, 3, 5] is under modeling. Tested by experimental and theoretical studies, this phenomenological model is widely used for modelling the dynamics of fluid-saturated soil under structures and train roads, offshore structures, as evidenced by dozens of contemporary publications in acoustics and engineering.

II. BIOT'S MODEL

Prerequisites and equations of Biot's model, statement and methods of solving problems, analysis of the results are given in [1, 3, 4, 5]. In a wave model of a two-phase medium, a solid porous elastic soil skeleton contains a porous compressible fluid. These phases interact with each other under dynamic loading, due to the filtration motion of the fluid in the pores

(with averaged filtration coefficient k_f) and the wave processes, elastic, viscous and inertial interactions result.

Three frequency dependent body waves propagate in the medium. The second longitudinal wave occurs as a result of the interaction of phases.

III. DYNAMICS CONTACT PROBLEM

Dynamic contact problem is modeling of vibrations of a system of several bodies at determination of contact pressures within the framework of models of their materials and contact conditions.

Method of orthogonal polynomials is presented for solving dynamic contact problems for the foundation system have been presented in the works of H. Popov, V. Seimov, etc. [7, 8].

In the book [5] the time-dependent contact pressures, directly below the pore-impermeable sole of the foundation, are the effective stresses in the solid porous soil skeleton and the pore pressure are represented by integral-differential ratios of Chebyshev orthogonal polynomials with unknown frequency-dependent coefficients. This also takes into account specially confirmed root features of the distribution of effective stresses, which ensures the efficiency of numerical resolution.

Row-by-orthogonal polynomial representation allows us to reduce the system of integral equations to an infinite system of linear algebraic equations, to estimate the coefficients of the system in the form of integrals from complicated complex functions, and to find a numerical solution by the method of improved reduction. Dynamic contact problem solution algorithm for foundation plates on poroelastic water-saturated soil base is as follows

- To solve differential equations, the method of integral transforms (Laplace in time and Fourier in coordinates) is used.
- Equations of the movement of the foundation or contact conditions for displacements (to determine the response to a single movement) are compiled.
- Define character expressions of displacements transformants of contact surface of solid and liquid phases under loads distributed.
- From the contact conditions, we write down the integral equations of the contact problem.

- We determine the features of the kernels of the integral equation.
- Orthogonal polynomials are chosen, which are eigenfunctions of integral operators with these features.
- Representation of unknown contact pressures in the form of series of orthogonal polynomials with unknown coefficients, taking into account the peculiarities, allows transforming integral equations of the first kind to an infinite system of linear algebraic equations (ISLAE) with respect to the coefficients of the series after transformations.
- After a numerical solution of the ISLAE by the method of improved reduction determines contact pressures, resultant reaction and plate displacement for a given frequency of forced oscillations.

IV. NUMERICAL RESULTS

The response to a single rigid plate vertical movement commonly called impedance [3]. Vertical component of impedance for harmonic oscillations is determined by the formula as in:

$$Z = R / W, \tag{1}$$

where R is the harmonic vertical force; and where W is the vertical displacement of the rigid plate outsole in soil-foundation interface. Impedance is presented in the form [3]:

$$Z = K + i \omega C, \tag{2}$$

where both K and C are functions of the circular frequency ω . According to the definition of Gazetas [3], the real component, K , termed "dynamic stiffness," reflects the stiffness and inertia of the supporting soil; its dependence on frequency is attributed solely to the influence that frequency exerts on inertia, since soil properties are practically frequency independent. The imaginary component, ωC , is the product of the (circular) frequency ω times the "dashpot coefficient," C ; the latter reflects the radiation and material damping generated in the system (due to energy carried by waves spreading away from the foundation and energy dissipated in the soil by hysteretic action, respectively).

The dimensionless frequency set as $\zeta = a \omega / c_2$, where a is the half width of the foundation and where c_2 is the reference share wave velocity [2, eq. (5.4)]. Below we consider the impedance as $Z = Z c_2 / a$ and we use indexes 0, s, and f that are the total, solid and liquid phases impedance components, respectively.

Computer programs have been developed for determining impedance and contact pressures. ISLAEs are compiled and solved with complex coefficients in the form of improper

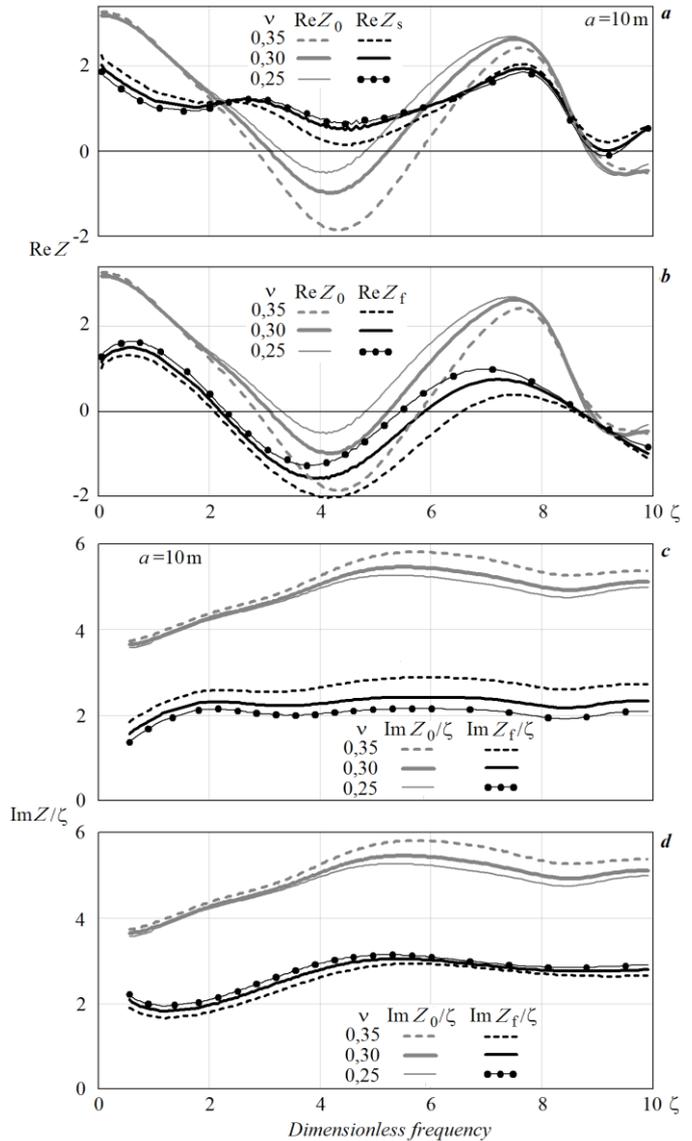


Figure 1. Comparison of stiffness, damping coefficient and their components for phases at Poisson's ratio $\nu=0,25; 0,30; 0,35$ and porosity $\nu=0,48$

integrals of complex functions containing Bessel functions for plane deformation and spatial problem.

A. Rectangular rigid plate on PELS halfspace

In the article [6] the compliances (impedance reverse functions) are evaluated for the harmonic rocking and vertical motions of rigid permeable and impermeable square plates bearing on a PELS halfspace. The effect of changing the Poisson's ratio ν of the solid skeleton PELS half-space within the characteristic values for sandy soil stiffness of the base (gray curves) and its phase contribution (black curves) shown in Figure 1. *a, b*. Graphs on Figure 1. *c, d* illustrates the change in frequency of the damping coefficient (attenuation): total (gray curve) and its components for phases (black curves).

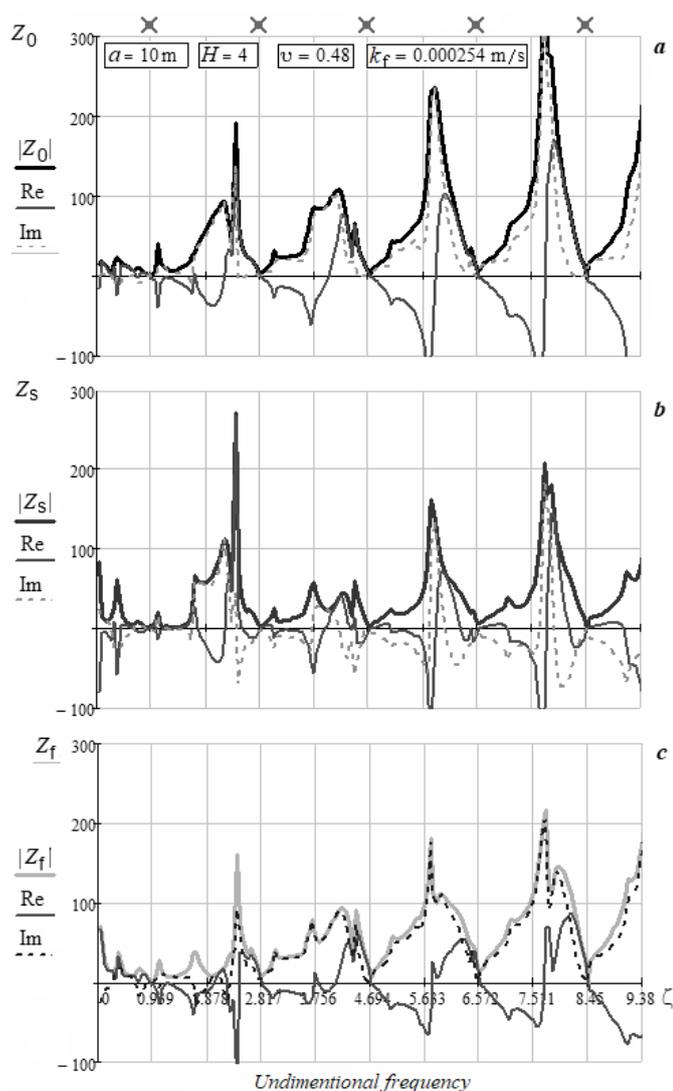


Figure 2. Comparison of impedance module, stiffness and damping coefficient and their phase components for rigid string $a=10$ m on layer $H/a=4$; at $k_f=0,000254$ m/s; Poisson's ratio $\nu=0,25$ and porosity $v=0,48$

B. Rigid string on PELS layer

The sequence of solutions and some results are presented in [4]. In a layer of thickness H on frequencies ζ_N the normal waves of mode N in the PELS layer are generated and W is theoretically unlimited at dimensionless frequencies:

$$\zeta_N = (N+1/2) / (H \beta_1), \quad (3)$$

where $\beta_1 = c_2 / c_1(\zeta)$, and where $c_1(\zeta)$ is the velocity of the first longitudinal wave in a two-phase medium. In the intervals between these frequencies the stiffness and the dashpot coefficient of the substrate change in a complex way. Examples are considered with a value of c_2 of the order of 250 m/s. Above the graph in Figure 2.a, the icons \times shows the locking frequencies ζ_N of the layer.

CONCLUSION

The technique of dynamic contact problems solution for impermeable rigid plates on poroelastic liquid-saturated half-

space is developed. The results obtained indicate a significant effect of the liquid phase and the phase interaction when compared with the impedance functions for the single-phase model. It leads to the change of amplitude-frequency responses, the additional damping and essentially manifests itself in stress-strain state of the construction. The advantages of the method are as follows: time saving of calculations compared to FEM, physically sound formulation of tasks, the use of mathematical transformations to create an effective computational model, possibility of using impedance functions in complex design schemes and supplementing regulatory methods.

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