Natural and Forced Vibrations of Axisymmetric Structure Taking into Account the Viscoelastic Properties of the Base

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ABSTRACT

The paper considers an inhomogeneous elastic system; axisymmetric construction with foundation and foundation. Investigations of the interaction of the structure with the base. To study the interaction of the structure with the base, a cylindrical base model cut from half space is used in the calculations. It is believed that the lower part of the base is stationary, and the side surface is free. The eigenfrequencies and vibration modes of the considered heterogeneous system are determined. The influence of the geometric and physico-mechanical parameters of the base on the dynamic characteristics of the structure is investigated, the problem of the natural vibrations of the heterogeneous construction-base system is solved.

KEYWORDS: *heterogeneous elastic system; axisymmetric construction with foundation and foundation; natural frequencies and vibration modes; design-base system; amplitude-frequency characteristics.*

Publications overview

In connection with the increasing volume of construction in areas of high seismic activity in the country, the attention of researchers is increasingly attracted by the problems associated with the calculation of buildings and structures for seismic resistance, taking into account real soil conditions. Numerous studies carried out in different countries have shown that the response of a structure to a seismic effect depends significantly on the stiffness of the foundation. This difference is due to the fact that for structures located on a flexible base, part of the vibration energy is dissipated due to the radiation of stress waves in the base, as well as due to the viscosity of the base material.

As is known, consideration of the influence of the soil on the seismicity of massive, rigid structures, laid at a considerable depth, is of great importance. Such structures include, for example, buildings of nuclear power plants. When studying the seismic resistance of such structures, one of the main issues is the assessment of the dynamic impact of the structure-soil system (Clough R., Penzin J. 1979)

It is generally recognized that it is necessary to take into account the real mechanical properties of the soil, primarily rheological, which determine the dissipative properties of the "structure of the soil", such as the decay rate of free and resonant amplitudes of forced vibrations.

An essential aspect of this problem is a comprehensive experimental examination of both the mechanical properties of real soils and the interaction of the structure with the soil. Such experimental studies are very laborious and costly. Therefore, it seems very expedient, and sometimes necessary, to carry out a preliminary mathematical (with the help of a computer) examination of the model of the "structure-soil" system, which will subsequently be investigated in the course of a seismodynamic experiment.

As you know, in theoretical calculations of a structure, taking into account the interaction, a finite soil model is used, since the solution of the problem for structures of complex configuration is possible using the finite element method or the finite difference method.

Consider limiting cases. When $H_3 = 0$, the model corresponds to the vibration of a structure with an absolutely rigid fixed base, the natural frequencies of the model will turn out to be significantly higher (due to the imposition of additional constraints) than the vibration frequencies of the real system.

In another limiting case ($H_3 \gg D_3$), the base model is an elastic bar, the natural frequencies of which can be made arbitrarily small by increasing the depth H_3. Thus, an unreasonable choice of the base parameters H_3 and D_3 leads to the appearance of parasitic effects that completely distort the real picture.

It seems obvious that the dynamic behavior of the model changes continuously as the parameters change between the indicated situations, we believe that the model has the right to exist only if there is a sufficiently wide range of variation of the parameters H_3 and D_3, in which the natural frequencies and modes of oscillations of the system are from these parameters are practically independent. The research in this paper aims to establish such areas for the model shown in Fig. 1.

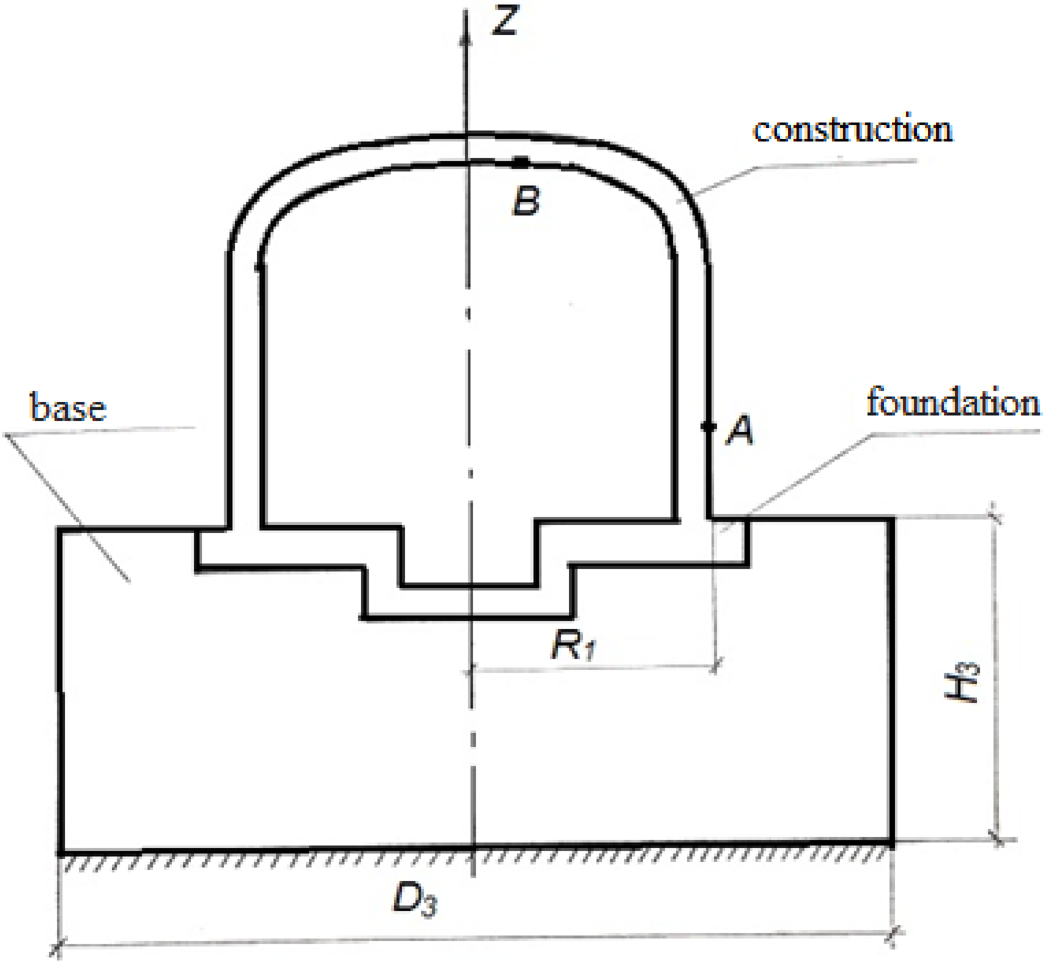


Figure 1. A domed structure with a base.

Statement and scheme for solving the problem of natural and forced vibrations of an inhomogeneous viscoelastic system "construction-base"

An inhomogeneous elastic system is considered; axisymmetric structure with foundation and base. The structure occupies volume V_1, foundation V_2, and base V_3 (Fig. 1). To study the interaction of the structure with the base, a cylindrical base model cut from a half-space is used in the calculations. In this case, it is considered that the lower part of the base is motionless, and the side surface is free (Zenkevich O. (1979). It is necessary to determine the natural frequencies and vibration modes of the considered inhomogeneous system.

The mathematical formulation and scheme for solving the problem of natural vibrations is similar with nonaxisymmetric natural vibrations of elastic axisymmetric bodies. The difference is that the integration of the expression:

$$\delta A = -\int\limits_{V_1+V_2+V_3} \left(\sigma_{ij}\delta\varepsilon_{ij} + \rho\ddot{\vec{u}}\delta\vec{u}\right) r dr dz d\varphi = 0, \tag{1}$$

produced by volume $V = V_1 + V_2 + V_3$

The mathematical formulation and scheme for solving the problem of forced vibrations of a viscoelastic construction-base system is similar to the solution of problems of forced vibrations of axisymmetric spatial bodies. In contrast, this expression is integrated over the volume

$V = V_1 + V_2 + V_3$.

Solution and analysis of the problem of natural and forced vibrations axisymmetric design, taking into account the interaction with the base

To study the influence of the geometric and physical-mechanical parameters of the foundation on the dynamic characteristics of the structure, the problem of natural vibrations of the inhomogeneous system "structure-foundation" (Fig. 1) was solved.

The geometric characteristics of the structure were taken without taking into account the foundation.

Physical and mechanical characteristics and geometric parameters of the base varied within the following limits:

$\frac{H_3}{R_1} = 0{,}2 \div 2{,}5$; $\frac{D_3}{R_1} = 2{,}0 \div 5{,}0$; $\frac{E_3}{E_1} = 0{,}01 \div 2{,}0$;

$\frac{\mu_3}{\mu_1} = 0{,}02$; $\frac{K_3}{K_1} = 0{,}02$; $\frac{\rho_3}{\rho_1} = const.$

The parameters indicated with the index I correspond to the construction, and those with the index 3 correspond to the base. Figure 2 - a), b) shows the graphs of the dependence of natural frequencies on relative geometric parameters ($\frac{H_3}{R_1}, \frac{D_3}{R_1}$) of the base.

From the analysis of the results (natural frequencies and modes of vibration) of the "structure-base" system, depending on the geometric dimensions and physical and mechanical characteristics of the base, the following can be identified. With a relative depth $\frac{H_3}{R_1}$ not exceeding ~ 0.7, the lowest (first five) natural frequencies are established, and the corresponding vibration modes of structures remain almost the same as in the case of rigid clamping.

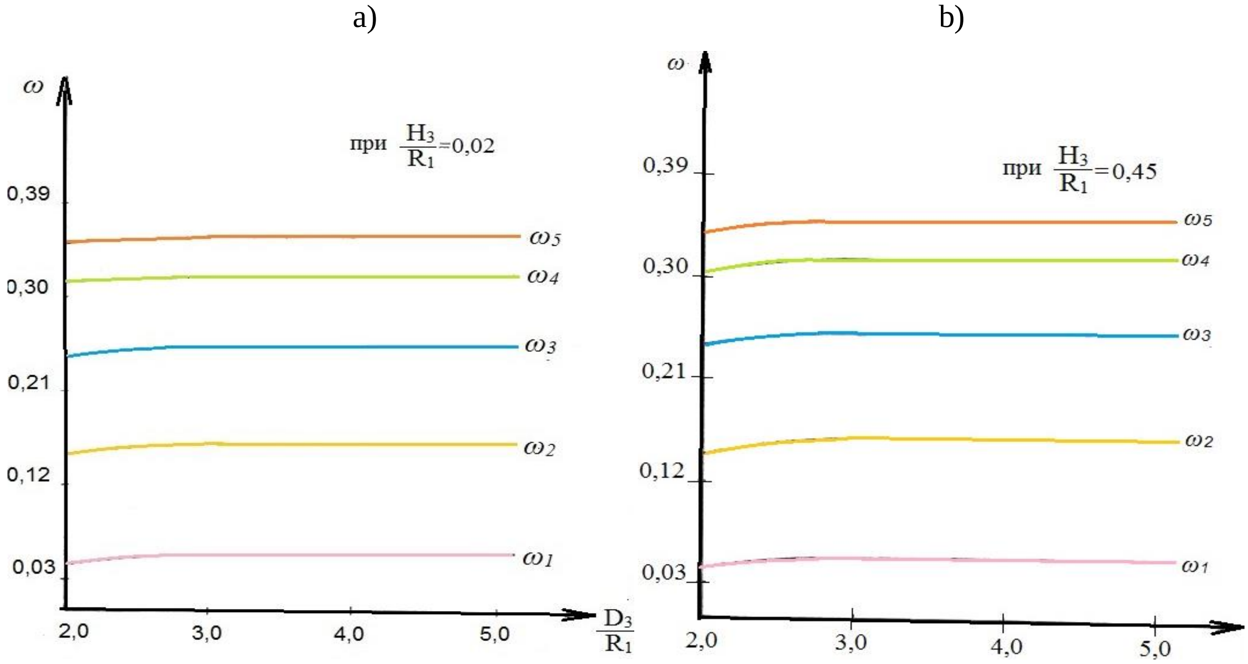


Figure 2. Graph of the dependence of natural frequencies ω: a) on D_3/R_1 at $\frac{H_3}{R_1} = 0{,}02$, b) on D_3/R_1 at $\frac{H_3}{R_1} = 0{,}45$.

If the ratio $\frac{H_3}{R_1}$ exceeds 0.7, then the natural frequencies, starting from the third, change. In this case, the natural modes of vibration of the system, corresponding to the changed frequencies, describe the vibrations of the base, and the structure itself behaves like an absolutely rigid body.

It was found that for the structure under consideration, the optimal dimensions of the base are within the following limits: $0{,}2 \leq \frac{H_3}{R_1} \leq 0{,}7;\ 2{,}2 \leq \frac{H_3}{R_1} \leq 5{,}0.$

If the dimensions of the base are kept within these limits, the dynamic characteristics of the structure are more stable, i.e. the natural mode of vibration of the system describes the vibrations of the structure itself, while the absolutely rigid body.

Further, the problem of forced vibrations of the structure was solved taking into account the viscoelastic properties of the foundation. In the calculations, the external influence is taken as follows:

$$\begin{aligned} & u_r = a_0 \cos\varphi * \sin Pt \\ Z = -H_3: \quad & u_\varphi = a_0 \sin\varphi * \sin Pt \qquad (2) \\ & u_z = 0 \end{aligned}$$

where a_0 is the amplitude, P is the frequency of the forcing action.

The dimensionless parameters of the relaxation kernel were taken as follows:

$A = 0{,}008;\ \alpha = 0{,}1;\ \beta = 0{,}005;\ \Gamma = \int_0^\infty R(s)ds = 0{,}1,$

(low viscosity)

$A = 0{,}04;\ \alpha = 0{,}1;\ \beta = 0{,}005;\ \Gamma = \int_0^\infty R(s)ds = 0{,}6.$

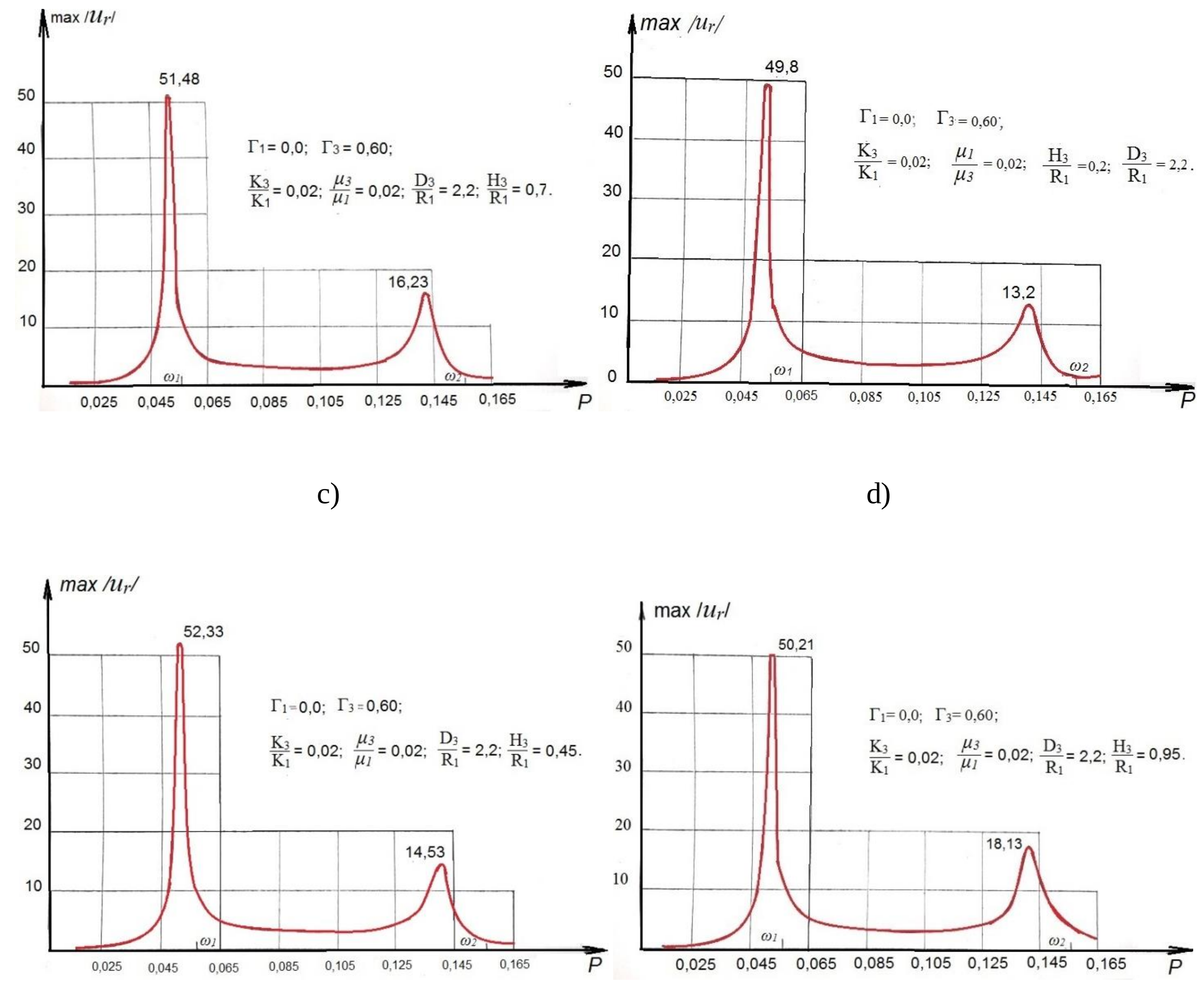
(high viscosity)

The first combination corresponds to the case when the creep deformation is a small fraction (10%) of the total deformation. The second combination describes a material with significant viscosity - creep deformation exceeds elastic and accounts for 60% of the total deformation. In the future, in the notation of the physical and mechanical characteristics and viscosity of the material, we will take the index 1 - construction, 2 - foundation and 3 - base.

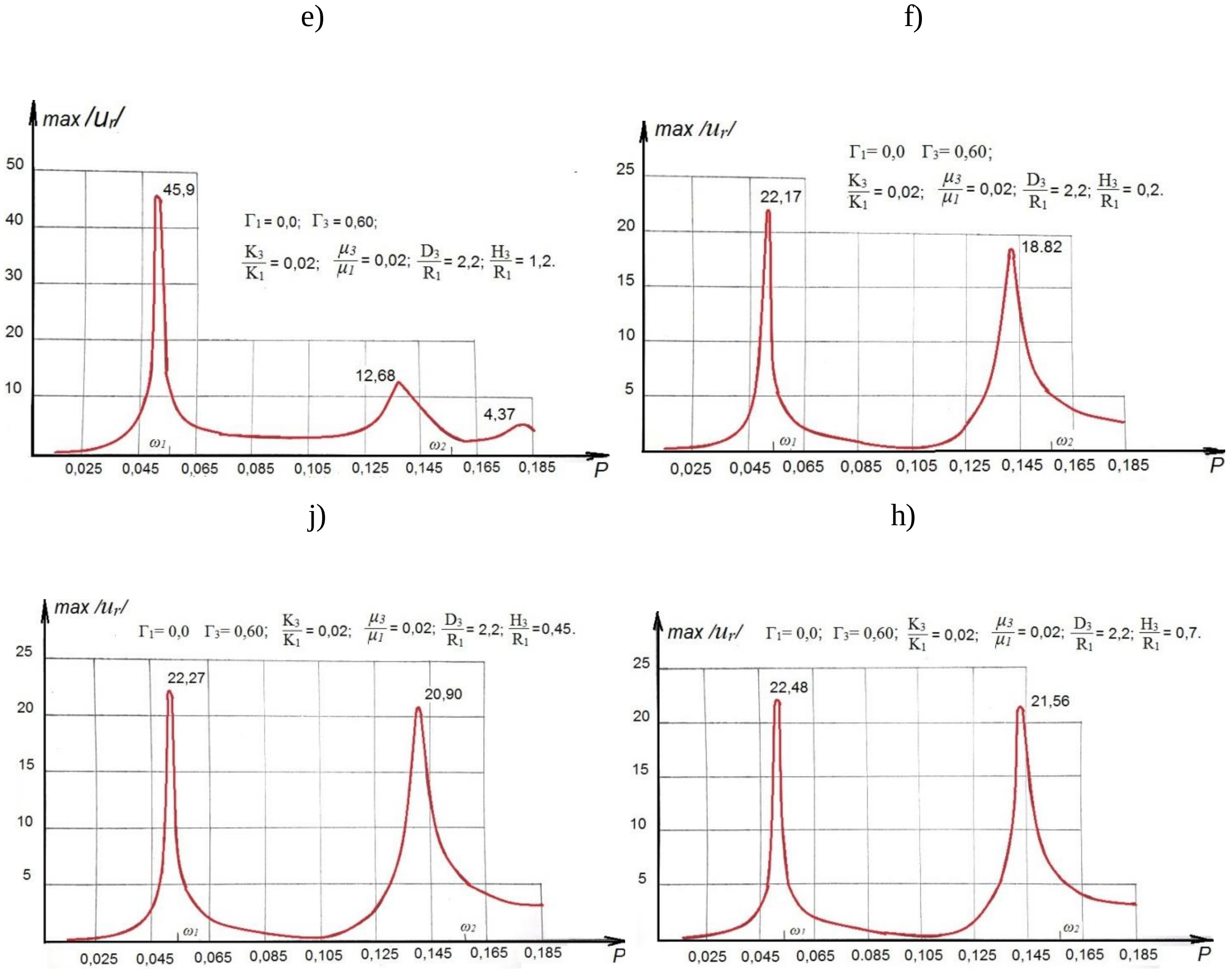
With the help of the developed algorithm and programs, the behavior of the structure was investigated for various geometric and physical-mechanical parameters of the structure itself and the foundation.

Analysis of the calculated data showed that to obtain a result with acceptable accuracy, the required number of eigenforms N in the expansion should be 4-5. The result of research in this work was the amplitude-frequency characteristics for several points of structures, depending on the frequency of the forcing action. In fig. 3- a), b), c), d), e), f), g), h) show the amplitude-frequency characteristics at the points of the structure for different for different geometric parameters of the base.

a) b)



c) d)

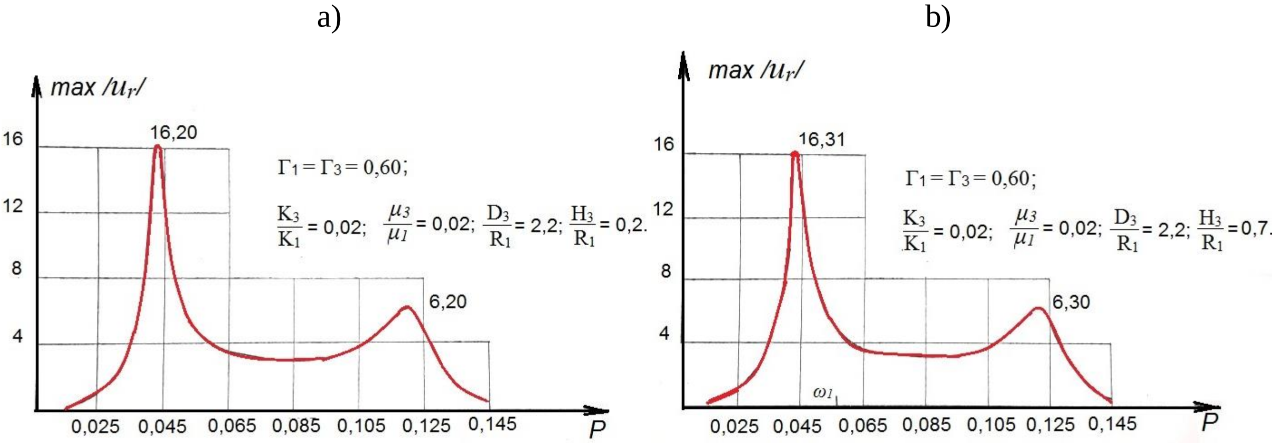


e) f)

j) h)

Figure 3. Frequency response for / u_r / at point B.

In fig. 4 - a), b) shows the amplitude-frequency characteristics for the case when the base and structure are viscoelastic. Figure 5 shows the amplitude-frequency response at point B of the elastic structure, taking into account the elastic foundation and the viscoelastic foundation.



a) b)

Figure 4. Frequency response for / u_r / at point B.

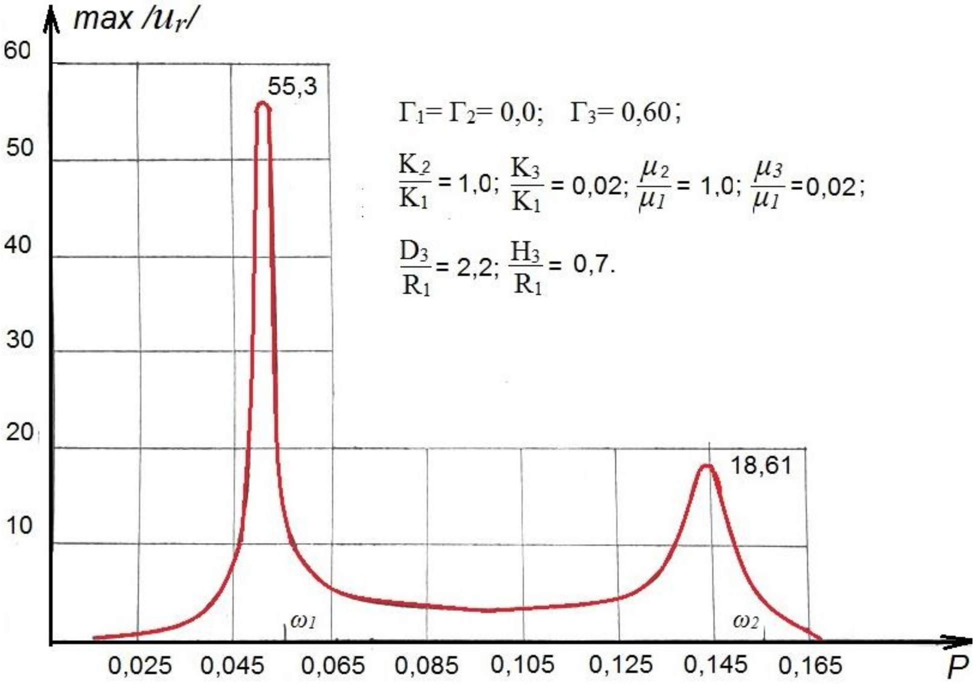


Figure 5. Frequency response for / u_r / at point B.

Analysis of the results (amplitude-frequency characteristics) of the "structure-base" system showed that, within the optimal size of the base ($2{,}2 \le \frac{D_3}{R_1} \le 5{,}0;\ 0{,}2 \le \frac{H_3}{R_1} \le 0{,}7$), the movement of various points design for a sufficiently wide frequency range of the forcing action remains almost constant (stable). The results of the dependence of the amplitude-frequency characteristics on the dimensions of the base model are fully consistent with the results of the study of natural frequencies and natural modes of vibration of the system from the specified parameters.

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