Research Article

Research Of The Work Of The System "Base - Foundation With A Damping Layer-Building" On An Inhomogene Soil Base

[1]Associate Professor Makhmudov Said Makhmudovich, [2]Doctoral student Abduraimova Khadicha Rakhmankulovna

[1]Supervisor candidate of technical Sciences,
[1,2] Tashkent Institute of Architecture and civil Engineering, Republic of Uzbekistan, Tashkent.

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Abstract: An engineering technique has been developed that allows calculating the interactions between the structure of the beam foundation when constructing the upper and lower beams, the parameters of the damping layer from the condition of controlled loading of the foundation, or the stress-strain state of the system "base - foundation with a damping layer - building". An example of calculating a damping layer in accordance with the developed methodology is given, as well as a comparison of the results of an engineering and numerical solution, and a good convergence of the results is obtained.

Key words: damping layer, building structures, special Gegenbauer polynomials, reactive soil pressures, modulus of elasticity, approximation of reactive pressures.

Introduction

The construction of foundations has a significant impact on the labor and material costs of construction and, depending on the design features, accounts for 15-20% of the total cost of the building. A promising way to reduce the cost of foundations is to optimize the operation of foundation slabs with a soil base by applying new structural solutions for foundations.

At present, the calculation and design of modern buildings largely depends on the correct identification of the quality of the soil, the choice of structures and their sizes, as well as on the material for making the foundations. In this regard, it becomes necessary to develop new and improve existing methods for calculating the foundations of building structures on a soil foundation.

Currently, Uzbek and foreign scientists have studied methods of optimizing the operation of foundations by actively regulating their interaction with the soil base. Research in this direction was carried out by N.A. Tsytovich, V.A.Florin, E.Vinkler, N.M. Gersevanov, M.I. Gorbunov Posadov, B.N. Zhemochkin, I.A. Simvulidi, N.I. Fuss, G.G. Boldyrev, E.A. Sorochan, Ya.A. Pronozin, A.N. Tetior, Z.G. Ter-Martirosyan, Yu.K. Zaretsky, T.R. Rashidov, T.Sh. Shirinkulov, G. Khojimetov, S.M. Makhmudov, Kh.Sh.Turaev, A.Xasanov etc. However, the coverage of the issue, as a rule, is limited to recommendations based on empirical and numerical dependencies.

In the case of a damping layer made of natural materials, an intermediate layer of mineral materials of varying degrees of compressibility is arranged under the sole of the upper foundation beam. It can be a combination of sand and crushed stone [1,2], sand and concrete [3], a homogeneous material with varying degrees of compaction [4]. The advantage of this approach is the availability and low cost of layer materials, and in the case of compaction, there is no need for imported material as such.

The effectiveness of foundations with a damping layer is due to the reduction of deflections and internal forces in the foundation; reducing its material consumption; expanding the scope of flexible foundations; reduction of efforts in overground structures from uneven foundation settlement. At the same time, the constructive simplicity and manufacturability of construction, inherent in the foundations of traditional forms, is preserved.

Thus, the study of the interaction between the structure of the beam foundation when constructing the upper and lower beams of the damping layer in their contact zone with a heterogeneous soil base is an urgent task.

The article discusses the search for general principles for calculating the damping layer, when constructing the upper and lower foundation beams, which makes it possible to regulate the operation of the system "base - foundation with a damping layer - building".

The modern approach to joint calculations of the system "base - foundation with a damping layer - building" implies work [5] within the framework of a single model that combines the aboveground and underground parts, with minimal simplifications. This approach provides a higher quality of the final result, but requires more powerful computing resources, advanced software systems and the corresponding qualifications of the calculator.

This direction of development of joint calculations is the most promising. Solid foundations in the form of flat slabs experience an energetically unfavorable bending state that requires significant material costs to form a section with sufficient bearing capacity.

Outstanding engineer, academician V.G. Shukhov noted that.

"Any building structure lying on a solid elastic foundation, for example on sand, will be the more rational, the less it will work in bending, that is, the less its moment of inertia will be."

The purpose of the work is to study the interaction between the structure of the beam foundation when constructing the upper and lower beams of the damping layer in their contact zone with a heterogeneous soil base.

At present, the attention of many researchers is attracted by the foundation model in the form of a continuously inhomogeneous medium, i.e. a medium in which the modulus of elasticity of the soil changes with depth according to a power law.

The method of T.Sh.Shirinkulov [7], which combines the engineering approach and the mathematical rigor of the solutions of the theory of construction lying on a deformable foundation.

The method is based on the approximation of reactive pressures and base settlements; special Gegenbauer polynomials are applied. T.Sh.Shirinkulov [7] achieved a high degree of convergence of the approximation process. He showed that in most cases it is sufficient to restrict oneself to only two or three terms of the expansion. This simplification makes it possible to calculate a variety of engineering problems on the interaction of beams and slabs, including those with complex geometry, with a given degree of accuracy, bypassing complex differential and integral calculus. Relative simplicity and versatility led to its extensive practical application in the field of construction and geotechnical calculations.

The method was recommended for use in reinforced concrete structures and foundation engineering, research based on it changed the idea of the work of randbeams and lintels supporting brick walls.

The spatial problem of interaction between the structure of the beam foundation when constructing the upper and lower beams of the damping layer in their contact zone with an inhomogeneous soil base is reduced to a flat selection from the middle of the foundation beam by two parallel planes of a design beam of unit thickness. Such an assumption in practical calculations is possible when the length of the foundation significantly exceeds its width, when the foundation beam is in a state of cylindrical bending over most of its length.

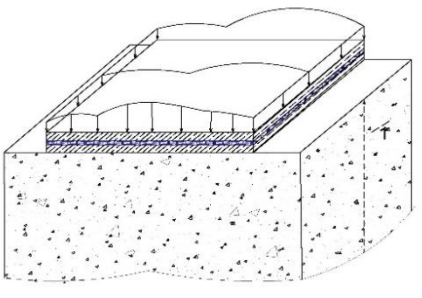
Consider the application of the T.Sh. Shirinkulova [7] to solve the problem of interaction between the structure of the beam foundation when constructing the upper and lower beams of the damping layer in their contact zone with a heterogeneous soil foundation, which combines the engineering approach and the mathematical rigor of the solutions of the theory of construction lying on a deformable foundation (Figure 1).

The advantage of the method is the possibility of discrete use of a damping layer of different stiffness when arranging a damping layer between the upper and lower foundation beams under different sections of the lower foundation beam.

The damping layer during the device between the upper and lower foundation beams within the area is under compression compression, the pliability of the layer is brought to the pliability of the point support.

Slight curvature of the surface due to the laying of a damping layer of different thickness is not taken into account, the surface of the upper and lower foundation beams is considered flat.

a)



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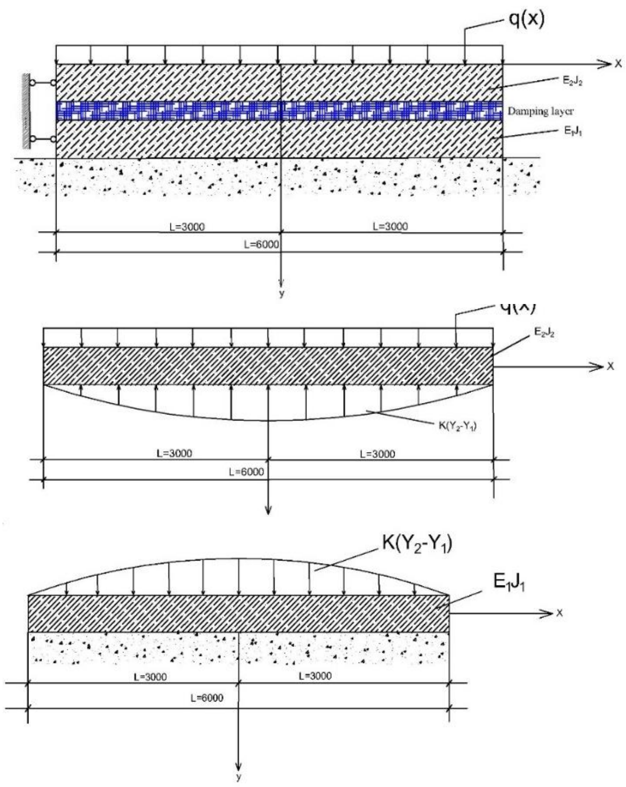


c)

Figure 1 - The problem of calculating a beam with a damping layer between the upper and foundation beams.
a - general scheme;
b - calculation scheme of the method of T.Sh. Shirinkulov and S.M. Makhmudov;
c - the main scheme of the lower foundation with a compensating layer on an elastic foundation:

The calculation involves only the vertical forces between the lower foundation beam and the heterogeneous subgrade. It is shown that the influence of the forces of friction and adhesion of the foundation beam to the base is small and can be neglected in the further calculation.

The work formulates the following principle: “the values of the reactive soil pressures on the lower foundation beam from the side of the heterogeneous subgrade can be changed depending on the rigidity of the foundation beam EI, its length L, the modulus of deformation of the subsoil Em, the magnitude, nature and location of the load. This makes it possible to regulate the reactive soil pressure within the required limits by appropriate selection of the rigidity and length of the foundation beam”

Let us consider the possibilities of reducing the unevenness of the subgrade settlement and bending moments in the foundation structure with a damping layer using a practical example.

Basic equations and a method for their solution.

Consider a foundation beam consisting of two layers connected by damping layers (Fig. 1.) Suppose that the damping layer is such that it does not transfer tangential forces.In this case, the design scheme of foundation structures with a damping layer can be considered as two foundation beams between which are located damping layer (Fig. 1.)

The upper foundation beam is designed for a load consisting of an external load $q_{(x)}$and a reaction of elastic ties $K_{(Y_2-Y_1)}$.

The load $K_{(Y_2-Y_1)}$and the reaction of the soil base $P_{(x)}$ are applied to the lower foundation beam: where K is the stiffness of the elastic layer.

The differential equations for the bending of the upper and lower foundation beams, taking into account the indicated loads, are written in the following form:

$$E_2 J_2 \frac{d^4 Y_2}{dx^4} = q_{(x)} - K_{(Y_2-Y_1)} \qquad (1).$$

$$E_1 J_1 \frac{d^4 Y_1}{dx^4} = K_{(Y_2-Y_1)} - P_{(x)} \qquad (2).$$

We introduce new unknown functions.

$$\left.\begin{aligned} Z_1 &= Y_2 + Y_1 \\ Z_2 &= Y_2 - Y_1 \end{aligned}\right\} \qquad (3).$$

Then equations (1), (2), taking into account (3), will be written in the following form:

$$\left.\begin{aligned} E_2 J_2 \frac{d^4 Z_1}{dx^4} + \left(1 - \frac{E_2 J_2}{E_1 J_1}\right) K Z_2 &= q_x - \frac{E_2 J_2}{E_1 J_1} P_{(x)} \\ E_2 J_2 \frac{d^4 Z_2}{dx^4} + \left(1 + \frac{E_2 J_2}{E_1 J_1}\right) K Z_2 &= q_x + \frac{E_2 J_2}{E_1 J_1} P_{(x)} \end{aligned}\right\} \qquad (4).$$

The equation binding the subsidence of the soil base $V_{(x)}$ with the reactive pressure of the base $P_{(x)}$ according to [7] has the form.

$$V_x = \frac{\alpha l}{\pi E_m l^m} \int_{-1}^{1} \frac{P_{(x)}}{/x - s/^m} ds \qquad (5)$$

Where E_m- soil deformation modulus at depth

m - coefficient of soil heterogeneity

$$\alpha = \frac{1}{2}(1+m)(2+m)(3+m)$$

Thus, the solution to the problem of the bending of foundation structures with a damping layer on an inhomogeneous soil foundation is reduced to solving equations (4).

Having found the function Z from (4), bearing in mind the designation (3), from equation (1), we can determine the function Y_1 and Y_2. Next, consider the case when the upper and lower foundation beams have the same rigidity, i.e.

$$E_2 J_2 = E_1 J_1 = EJ$$

In this case, equations (1), (2) can be represented in the form.

$$\frac{d^4 Z_1}{dx^4} = \frac{l^4}{EJ}\left[q(x) - P_{(x)}\right] \qquad (6).$$

$$\frac{d^4 Z_1}{dx^4} + 4\alpha^4 Z_2 = \frac{l^4}{EJ}\left[q(x) + P_{(x)}\right] \qquad (7).$$

Где $\alpha^4 = \frac{Kl^4}{2EJ}$

The reaction of the reactive soil base $P_{(x)}$, following [7], can be represented as.

$$P_{(x)} = \frac{1}{\sqrt{(1-x^2)^{1-m}}} \sum_{n=0}^{\infty} A_n C_n^{\frac{m}{2}}(x) \qquad (8).$$

Where $C_n^{\frac{m}{2}}(x)$ are orthogonal Gegenbauer polynomials, which, according to, are determined by the formula:

$$C_n^{\frac{m}{2}}(x) = \sum_{j=0}^{\leq[\frac{n}{2}]} \frac{(-1)^j 2^{n-2j} \Gamma\left(\frac{m}{2}+n-j\right)}{\Gamma(\frac{m}{2} J!\,(n-2j)!} X^{n-2j} \qquad (9).$$

Where $\Gamma_{(x)}$ is Euler's gamma function.

Substituting (8) into (6), we obtain a solution to equation (6) in the form:

$$Z_1 = \frac{l^4}{EJ}\left[\sum_{n=1}^{\infty} C_n \frac{X^n}{n!} - \sum_{n=0}^{\infty} A_n f_n(x)\right] \qquad (10).$$

Where functions $f_n(x)$ are tabulated [102]:

A_n, C_n - unknown coefficients, which are determined from the boundary conditions and from the contact condition.

The solution to equation (7) can be represented as:

$$Z_2 = AU_1(\alpha x) + BU_2(\alpha x) + CU_3(\alpha x) + DU_4(\alpha x) + D(x) \qquad (11).$$

Where $U_1(\alpha x), U_2(\alpha x), U_3(\alpha x), U_4(\alpha x)$ known functions of A.N. Krylov:

$$\Phi_{(x)} = \frac{l^4}{\alpha^3 EJ}\int_0^x U_4\alpha(x-Z)\left[q_{(z)} + \sum_{n=0}^{\infty} A_n (1-Z^2)^{\frac{m-1}{2}(Z)}\right] dz \qquad (12).$$

Substituting (3) into (10), we have.

$$Y_2 + Y_1 = \frac{l^4}{EJ}\left[\sum_{n=1}^{\infty} C_n \frac{x^n}{n!} - \sum_{n=0}^{\infty} A_n f_n(x)\right] (1.22) \qquad (13).$$

Substituting (3) into (11), we obtain

$$Y_2 - Y_1 = AU_1(\alpha x) + BU_2(\alpha x) + CU_3(\alpha x) + DU_4(\alpha x) + \Phi_{(X)}(1.23) \qquad (14).$$

From (13) and (14) we find:

$$Y_1 = \frac{1}{2}\left\{\frac{l^4}{EJ}\left[\sum_{n=1}^{\infty} C_n \frac{x^n}{n!} - \sum_{n=0}^{\infty} A_n f_n(x)\right] - AU_1(\alpha x) - BU_2(\alpha x) - CU_3(\alpha x) - \right.$$
$$\left. - DU_4(\alpha x) - \Phi_{(X)}(1.24) \right. \qquad (15).$$

Arbitrary constants $C_n (n = 1,2,3,4)$, A, B, C, D are determined from the boundary conditions of the considered problem, and the coefficients $A_n (n = 0,1,2, \dots \dots \infty)$from the condition of contact of the surface of the foundation beams with a soil base.

To illustrate the calculation method, we will consider some problems.

From the condition of contact of the surface of the foundation beam with the soil foundation is written in the form:

$$Y_{1(x)} = V(x) \qquad (16).$$

As a result, the bending moment and shear force are determined as follows.

$$\mathrm{M}_1(\mathrm{x}) = -\frac{1}{12EJ}\sum_{i=0}^{\infty} A_{2i} f_{2i}^{11}(x) + 2A\alpha^2 U_3(\alpha x) - \frac{1}{2} C\alpha^2 U_1(\alpha x)$$
$$- \frac{l^4}{2\alpha^3 EJ}\sum_{i=0}^{\infty} A_{2i} Y_{2i}^{11}(x) + \frac{P}{2EJl}[d_2 + 6d_4 x^2] \qquad (17).$$

$$Q_1(x) = -\frac{1}{12EJ}\sum_{i=0}^{\infty} A_{2i} Y_{2i}^{11}(x) + 2A\alpha^3 U_2(\alpha x) + 2C\alpha^3 U_4(\alpha x)$$
$$- \frac{l^4}{2\alpha^3 EJ}\sum_{i=0}^{\infty} A_{2i} Y_{2i}^{11}(x) + \frac{6Pd_4 X}{EJl}: \qquad (18).$$

Thus, formulas (17), (18) completely solve the problem of calculating foundation structures with a damping layer lying on an elastic non-uniform soil foundation.

To find the numerical values of the reactive pressure of soil foundations, deflection of a beam, settlement of foundations, bending moments, shear forces, foundation structures with a damping layer lying on an elastic inhomogeneous soil foundation. compiled a program for LIRA 9.6.

Let's look at an example. Foundation structure with a damping layer, loaded with a uniformly distributed load of intensity $q_{(x)}$

Results and Discussion

We will take as deformative characteristics.

$$q_{(x)} = 100 \text{ кПа} \quad ; \quad l = 6{,}0\text{м}, h = 0{,}20\text{м } m = \frac{1}{6};\ E_2 = E_1 = E = 3.15 * 10^5 \text{ кг/см}^2.$$

$$J_1 = J_2 = J = 3{,}75\text{м}^4;\ E_0 = \frac{500\text{кг}}{\text{см}^2};\ \mu_0 = 0{,}35;\ \text{ч} = 0{,}4\text{м}:\ m = 0{,}25;$$

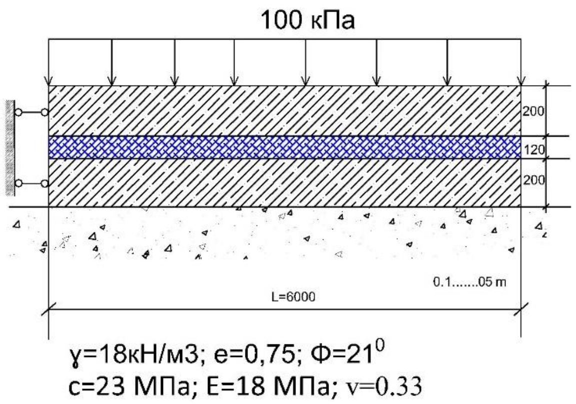
$$m = 0{,}5;\ \ m = 0{,}75;\ E_{0,25} = 236{,}7\frac{\text{кг}}{\text{см}^{2.25}}\ ; K = 3{,}1;\ \text{E}_{0,5} = 111{,}483\frac{\text{кг}}{\text{см}^{2.5}};$$

$$K = 1{,}88;\ E_{0.75} = 70{,}474\ \frac{\text{кг}}{\text{см}^{2.75}};\quad K = 1{,}49.$$

In the design case, the control parameter of the "base - foundation with a damping layer" system will be the slab thickness, varying in the range from 0.1 to 0.5 m with a step of 0.1 m (Figure 2 a). the flexibility index of the foundation beam varies from absolutely flexible to absolutely rigid.

The numerical calculation of the system (Figure 2 b) showed that with an increase in the stiffness of the beam, there is a decrease in its deflection and an increase in internal forces, the beam resists the uneven settlement of the base due to reserves of internal stiffness. The described design case generally corresponds to the logic of the standard engineering design of the foundation slab, expressed by an intuitive algorithm: “we increase the rigidity of the foundation until the condition for the ultimate deformations of the base is met - we have an increase in the internal force - we increase the strength by installing additional reinforcement”. Obviously, this approach leads to overspending of material on the foundation.

a)



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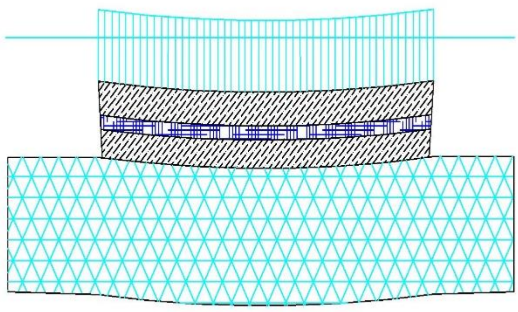

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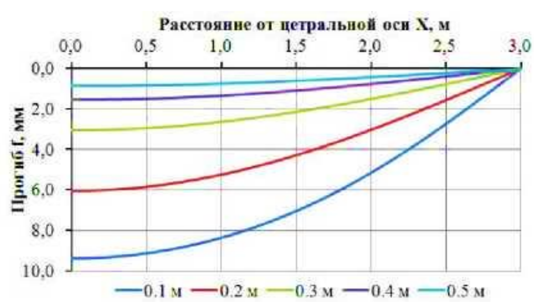

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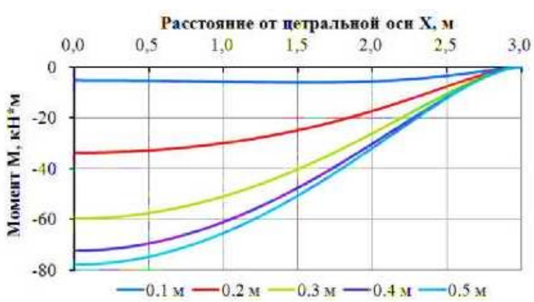


Figure 2 - Interaction of beams of various thicknesses with a subgrade:

a) settlement scheme; b) deformed scheme; c) deflections in the foundation; c) bending moments in the foundation

Thus, the study of the interaction between the structure of the beam foundation during the construction of the upper and lower beams of the damping layer in their contact zone with an inhomogeneous soil foundation will make it possible to regulate distribution of reactive pressures along the bottom of the foundation beam, based on considerations of minimizing efforts in the body of the foundation or adapting the construction object to specific soil conditions. The expediency of using such foundations is determined by the following conditions:

1) in the case of a uniformly loaded flexible foundation beam, when constructing the upper and lower beams of the damping layer, it will reduce deflections and bending moments in the structure.

2) in the case of a foundation beam of a structure with a rigid structural scheme, the arrangement of the upper and lower beams of the damping layer in the span will allow concentrating pressures along the force axes, relieving the span zone, and reducing bending moments in the foundation beam.

Consider an example of a practical calculation of foundation structures with a damping layer lying on an elastic non-uniform soil foundation. A reinforced concrete beam having a length of 6.0 m and a thickness of 0.20 m rests on an elastic foundation with a modulus of deformation *E0=500 кг/* см^2 and Poisson's ratio μ_0 = 0.35; The modulus of elasticity of the material of the beam is $E_2 = E_1 = E = 3.15 * 10^5$ кг/см^2. Poisson's ratio μ_0*=0,2*.The beam is loaded with a uniformly distributed load *q=100 кПа*. It is required to determine the characteristics of the damping layer from the condition of equality of the external load and the reactive pressure of the subgrade.

We will take [7] for deformative characteristics.

$$m = \frac{1}{6};\ E_2 = E_1 = E = 3.15 * 10^5\ \text{кг/см}^2.$$

$$J_1 = J_2 = J = 3{,}75m^4;\ \ E_0 = \frac{500\text{кг}}{\text{см}^2};\ \mu_0 = 0{,}35;\ \ \text{ч} = 0{,}4\text{м}:\ \ m = 0{,}25;$$

$$m = 0{,}5;\ \ \ m = 0{,}75;\ \ E_{0,25} = 236{,}7\frac{\text{кг}}{\text{см}^{2,25}}\ \ ; K = 3{,}1;\ \ \text{E}_{0,5} = 111{,}483\frac{\text{кг}}{\text{см}^{2.5}};$$

$$K = 1{,}88;\ E_{0.75} = 70{,}474\ \frac{\text{кг}}{\text{см}^{2.75}};\ \ \ \ K = 1{,}49.$$

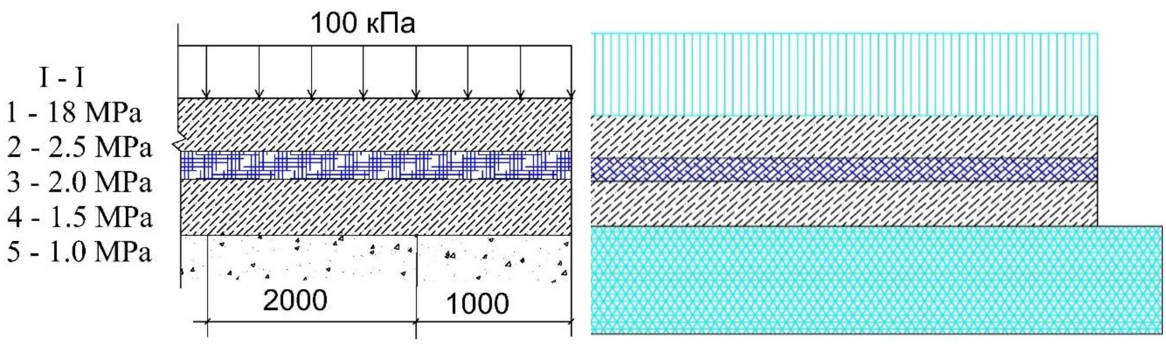
In the design case, the thickness of the slab is taken to be 0.2 m and the vertical load is redistributed from the central one to the edge zone with a width of 1.0 m while maintaining its total value. Under uniform loading of the foundation beam, it significantly deflects in the center, while the maximum value of the bending moment is up to 8 times less than in the case of an uneven load.

With a further increase in the load on the edge, there is a bending of the slab in the center, an increase in the uneven settlement and bending moment. Thus, it has been shown that by adjusting the distribution of the payload, it is possible to provide more favorable operating conditions for the foundation.

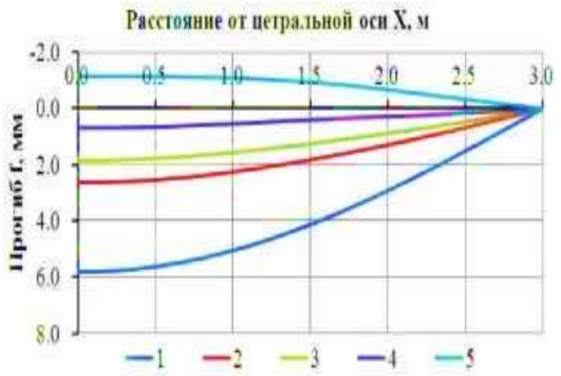
In the design case, an intermediate damping layer with a width of 1.0 m, a thickness of 0.2 m and with a variable modulus of deformation was introduced between the upper and lower beams under the edge of the foundation beam (Figure 3 a).

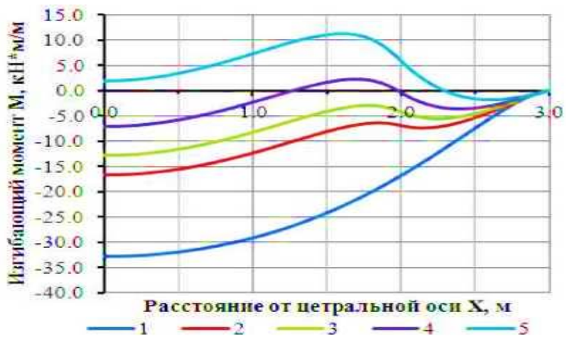
According to the calculation (Figure 3 b - Figure 3 c), by varying the deformation modulus of the damping layer, it is possible to equalize the base settlements and reduce the bending moments in the foundation beam up to 7 times with a slight increase in the absolute settlement. Achievement of the specified technical result is simpler and more technological than in the previous examples.

a) **b)**



c) **d)**





f)

Figure 3 - Plane problem with a damping layer between the upper and lower foundation beams of different stiffness:
a) design scheme; **b)** deformed scheme (option 4); **c)** deflections in the foundation beam; **d)** bending moments in the foundation beam; **f)** a graph of the dependence of the uneven settlement and the area of the diagram of bending moments for

The arrangement of a beam foundation between the upper and lower foundation beams with a damping layer on an inhomogeneous soil foundation will allow regulating the distribution of the reactive pressures of the foundations along the foot of the foundation beams, based on considerations of minimizing efforts in the foundation body or adapting the construction object to specific soil conditions. The expediency of using such foundations is determined by the following conditions:

Thus, formulas (8), (10), (15), (17), (18) completely solve the problem of calculating foundation structures when installing the upper and lower foundation beams of the damping layer for the operation of the system "base-foundation with a damping layer-building ".

The choice of material for the damping layer is of great practical importance. In order for the device of the layer to be justified and expedient from both economic and technical points of view, the material must meet the following requirements:

1. High degree of compressibility;

2. Sufficient strength characteristics to ensure the mechanical preservation of the material during the laying of the layer and the device of the slab;

3. Low cost of the material and its availability;

4. Uniformity of structure, predictability of mechanical and physical properties;

5. Durability, as well as resistance to environme

There are two main approaches to choosing the

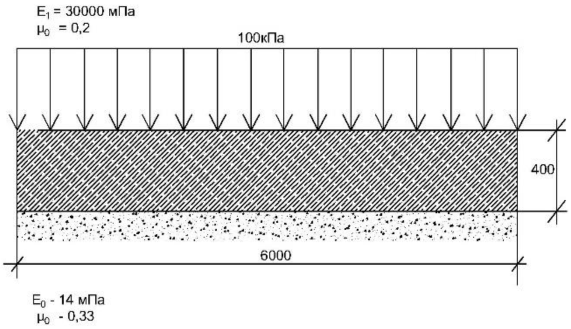
1. Device of a damping layer made of mineral m

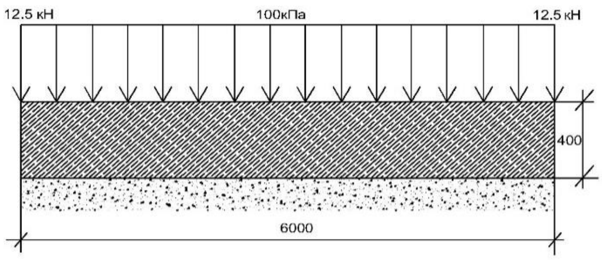
2. Device of a damping layer made of organic m

To find the numerical values of the reactive pre ... 5), settlements of foundations (8), bending moments (17), ... ng layer lying on an elastic inhomogeneous soil foundatior

The calculation scheme of the problem is shown

a) b)





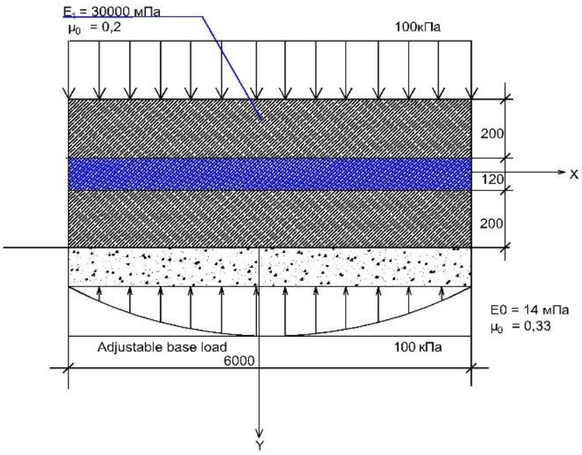
c) d)

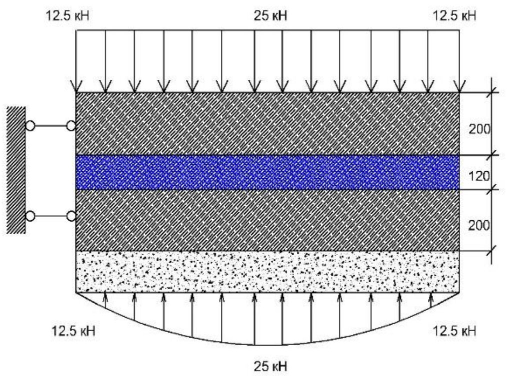
Figure 5 - Calculation of the foundation beam without a damping layer:
a) - initial data; b) - design scheme; c) - reactive pressures; d) - moments and deflections in the foundation beam

Conclusions

The basic system will be similar to that shown for in Figure 6.

a) b)





c) d)

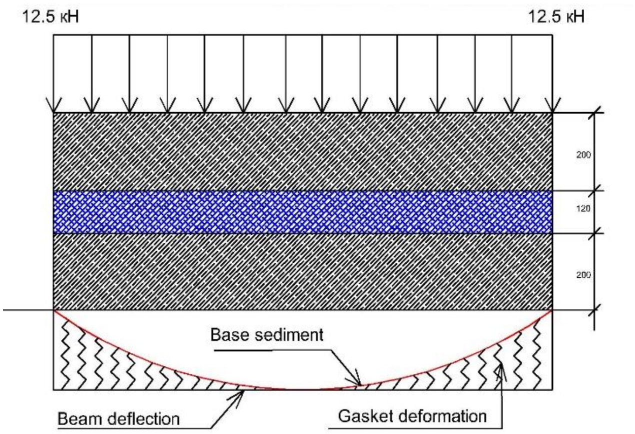


Figure 6 - Calculation of the damping layer for a foundation beam with a uniform load:
a - initial data; b - design scheme; c - graphic interpretation; d – thick the thickness of the layer thickness

Based on the results of an analytical study, the study of the interaction between the structure of the beam foundation when constructing the upper and lower beams of the damping layer in their contact zone with a heterogeneous soil foundation, the following conclusions should be drawn:

1. The effectiveness of the construction of a beam foundation between the upper and lower foundation beams of the damping layer on a non-uniform soil foundation has been substantiated.

2. A calculation method has been proposed for assessing the influence of the interaction between the structure of the beam foundation during the construction of the upper and lower beams of the damping layer on the operation of the foundation-foundation with a damping layer-building system".

3. The basic principles of the rational arrangement of damping elements have been developed;

4. An engineering method for calculating the parameters of the damping layer, the reactive pressure of the soil base and the internal forces of the system "base - foundation with a damping layer - building" has been developed;

5. It has been proved that the design of the damping layer significantly allows you to regulate the stress-strain state of the system "base - foundation with a damping layer - building"

6. It was found that the arrangement of the beam foundation between the upper and lower foundation beams of the damping layer on a heterogeneous soil foundation made it possible to redistribute contact pressures and forces in the foundation beam, reduce the values of bending moments by 2.5 times, and deformations by almost 10 times, reduce the total cost of the foundation by 25%.

7. In this example, taking into account the heterogeneity of the soil base leads to a decrease in the calculated bending moments. For example, when m = 0.75; decreases by 50% compared to m = 0;

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