Yessenov Science Journal
КӨЛІК, ҚҰРЫЛЫС, АҚПАРАТТЫҚ ЖҮЙЕЛЕР ЖӘНЕ ЭНЕРГИЯ
ТРАНСПОРТ, СТРОИТЕЛЬСТВО, ИНФОРМАЦИОННЫЕ СИСТЕМЫ И ЭНЕРГЕТИКА

УДК 624.131.52/53: 624.15
DOI 10.56525/UISE6718

CALCULATION OF STRUCTURES LYING ON AN ANISOTROPIC BASIS

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Abstract. The definition of the nucleus and the influence function of a transversally isotropic half-space is considered. Expressions of displacement and internal forces in an infinite base plate are obtained, taking into account their deepening into the rock mass, as well as the effect of the anisotropy of the base on the distribution of deflections and internal forces. The results obtained serve as a reference for the reconciliation of the results obtained by numerical and computer methods. This calculation algorithm allows us to estimate the bearing capacity of an anisotropic soil base.

Keywords: foundation, soil base, anisotropic, displacement, base plate.

Introduction. In the practice of construction of civil and industrial buildings, a variety of structures lying on an elastic base are widely used. A large group of such structures consists of adjacent slabs and strips, which, following the terminology of B.G.Korenev [1], we will call uninsulated in the future. Most of the non-insulated structures are floors of industrial and civil buildings, airfield and road surfaces, bottoms of locks and dry docks, plates of hydraulic structures, etc., the problem of calculation of which is of great practical importance and attracts the constant attention of numerous researchers.

The properties of the soils bearing these structures are very diverse. Usually, in computational models of foundation soils, the soil is considered as a homogeneous isotropic body, whose physical properties are the same at all points and in all directions. However, experimental studies show that almost all soils have anisotropic properties. This is due to the textural and structural features of the soil.

The variety of soil properties makes it difficult to create a single model of the foundation. Detailed information on the history of the creation of various models of the foundation is given in [2]. The calculation models of the base can be divided into the following groups:

1. Schemes based on the theory of local elastic deformations (Winkler model).
2. Schemes based on the theory of general elastic deformations (elastic half-space model).
3. Combined and special models of elastic base.

The hypothesis of direct proportionality between the local deformation of the base and the pressure on it was put into practical use after the publication of the work of Win-Clair [3], who accepted the dependence between the pressure on the soil and the local elastic sediment of the soil in the form of:

$$P = k*w \tag{1}$$

where p - is the pressure on the soil;
w - is the local elastic sediment of the soil;
k - is the proportionality coefficient.

However, this model has a number of disadvantages: the variability of the proportion-ality coefficient k, which depends on the size of the foundation, does not take into account the limiting properties of the soil outside the loaded area. The desire to eliminate these disadvantages of the Winkler model led to the creation of a new model describing the base in the form of a homogeneous elastic half-space. G.E.Proctor [4] and K. Vikgardt [5] proposed this model independently. Its elastic proper-ties are described by two physical quantities: the deformation modulus E_0 and the Poisson's ratio v_0, determined experimentally. The relationship between loads and deformations according to this model is taken based on the Boussinesq [16] formula in the form:

$$w(x,y) = \frac{2(1-v_0^2)}{E_0} \iint_F \frac{P(\xi,\eta)d\xi d\eta}{\sqrt{(x-\xi)^2+(y-\eta)^2}}, \tag{2}$$

where ξ, η - are the coordinates of the application of a single concentrated force;
x, y – coordinates of the point where the displacement is determined.

For the first time, the elastic half-space model was used in the work of N.M.Gersevanov [6]. Further development of the theory of calculating structures on an elastic half-space was obtained in the works of L.S.Gilman [7], B.N. Zhemochkin and A.P. Sinitsin [8], M.I. Gorbunov - Posadov [9], V.I. Kuznetsov [10], and G.Ya. Popov [11], V.A.Florin [12], A.I. Zeitlin [13], I.Ya. Shtaerman [14], etc.

In almost all the above-considered computational models of the foundation, the soil is viewed as a homogeneous isotropic body, the physical properties of which are the same at all points and in all directions, however, studies in our country and abroad show that almost all soils have anisotropic properties. This is due to the directional effect of gravity during their formation, textural and structural features of soil deposits. Thus, the layered texture of the array, consisting of mixing layers of clay and sand, makes the soil anisotropic. Or, for example, a homogeneous soil mass with inclusions of horizontal lenses of frozen water or mountain organic layers will be anisotropic if considered as a whole. Soils having a certain type of structure – columnar structure (forest) or cellular (silt, quicksand) have anisotropic properties.

Thus, the creation of methods for calculating structures on an elastic linearly deformable base, taking into account its anisotropic properties, is an urgent task. Obtaining accurate analytical solutions to these problems makes it possible to make design solutions more economical and reliable.

Consider the stress-strain state of an infinite plate lying on an elastic transversally elastic half-space under the action of a concentrated force at the origin. Let's determine the magnitude of the internal forces in the plate, taking into account its deepening into the soil massif.

The formula for determining the deflection of the plate taking into account the deepening in the soil massif has the form (1):

$$w(\xi,z)=\frac{Pl^2}{2\pi D}\int_0^\infty \frac{\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot J_0(\xi\lambda)\,d\lambda}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3} \tag{3}$$

We present the formulas for the resistance of the base and the internal forces in an infinite base plate lying on a transversally isotropic base, taking into account the deepening:

$$p(\xi,z)=-\frac{P}{2\pi l^2}\int_0^\infty \frac{\lambda\cdot J_0(\xi\lambda)\cdot d\lambda}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}, \tag{4}$$

$$M_r(\xi,z)=\frac{P}{2\pi}\left\{\begin{array}{l}\displaystyle\int_0^\infty \frac{\lambda^2\left(J_0(\lambda\xi)-1/\xi\lambda\cdot J_1(\xi\lambda)\right)\cdot\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}d\lambda+\\ \displaystyle+\frac{\mu_1}{\xi}\int_0^\infty \frac{\lambda J_1(\xi\lambda)\cdot\left(\tilde{k}_2\cdot e^{-S_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-S_2\tilde{z}\lambda}\right)}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}d\lambda\end{array}\right\}; \tag{5}$$

$$M_\theta(\xi,z)=\frac{P}{2\pi}\left\{\begin{array}{l}\displaystyle\mu_1\int_0^\infty \frac{\lambda^2\left(J_0(\lambda\xi)-1/\xi\lambda\cdot J_1(\xi\lambda)\right)\cdot\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}d\lambda+\\ \displaystyle+\frac{1}{\xi}\int_0^\infty \frac{\lambda J_1(\xi\lambda)\cdot\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}d\lambda\end{array}\right\}; \tag{6}$$

$$N_r(\xi,z)=\frac{P}{2\pi l}\int_0^\infty \frac{\lambda^3\cdot J_1(\xi\lambda)\cdot\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)}{1+\left(\tilde{k}_2\cdot e^{-s_1\tilde{z}\lambda}-\tilde{k}_1\cdot e^{-s_2\tilde{z}\lambda}\right)\cdot\lambda^3}d\lambda; \tag{7}$$

As is known, the anisotropic transversally isotropic half-space is characterized by elastic and shear modules different in the vertical E_z, G_z and horizontal E_r, G_r directions. The anisotropy degree k_E of the elastic half-space [15] is characterized by the ratio of the elastic modulus in the horizontal direction E_r: $k_E=E_z/E_r$ [15]. In the event of an equality of modules of elasticities $Ez = Er$ will get a special case of the anisotropic base - isotropic half-space.

Shear modules for the isotropic case is at $k_E = 1$ [16]:

$$G_z = G_r = E/2(1+\nu_0), \quad (8)$$

Where, E and ν_0 - modulus of deformation and Poisson's ratio of isotropic base.

(8) determine the value of shear modulus Gz for an isotropic base, but for anisotropic base G_z – is an independent value, which is determined experimentally, but because the real soils are always quite low shear resistance, in the future you can always take its lowest value for any ratio of elastic modulus k_E. Taken from here:

If $k_E < 1$ shear modulus:

$$G_z = E_z/2(1+\nu_z), \quad (9)$$

If $k_E > 1$ shear modulus:

$$G_z = E_z/2(k_E+\nu_z). \quad (10)$$

Materiel and methods.

2.1 The method of generalized solutions. The creation and development of methods for the effective and accurate solution of problems about the work of structures lying on a deformable base is one of the most important problems in structural mechanics. The method of generalized solutions is used in this article. The use of the theory of generalized functions led to the creation of so-called generalized solution methods [18], the essence of which is that the introduction of generalized functions allows us to extend the differential equations of equilibrium of structures given in a bounded domain to an unlimited one, which allows us to apply integral Fourier transforms to solve them. In accordance with the method of generalized solutions, we replace the rectangular plates under consideration with an unlimited plate loaded with a given load. Discontinuities in the deflection functions and its derivatives along the lines of plate sections are taken into account using additional functions selected in the form of boundary condition operators from generalized functions with unknown density. When calculating plates of great length, depending on the place of application of the load, the tasks of calculating infinite, semi-infinite and quarter-infinite plates are distinguished. The problem of calculating a rigid plate on an elastic base is the main solution [18] when calculating structures on a deformable base.

2.2. Calculation of the plate taking into account its deepening into the soil massif

Let us define the internal forces in an infinite plate lying on a transtropic half-space. The anisotropic base is also characterized by Poisson's ratios in the vertical ν_z and horizontal ν_r directions and, for the case of the transversally isotropic half-space, they are assumed to be $\nu_z = \nu_r$. Depending on which soils serve as the basis for the foundation slab, the values of the deformation modules can vary from a value equal to 50 MPa for gravelly sands of large and medium size, to a value of 5.0 MPa for loam, and the Poisson's coefficients of the soil take values from 0.30 for Sands and sandy loam to 0.42 for clay soils. Based on these characteristics, we find the deflection and other calculated values for different values of physical parameters, which we take as follows: E_z*=2МПа; 1МПа; 50МПа;* E_r*=10МПа;* $\nu_z = \nu_r = 0.3$. The Poisson's ratio of the plate material $\nu = 1/6$.

2.1. The case of isotropy: $k_E = 1$. Table1 and figure1 show dimensionless deflection diagrams in an infinite base plate loaded with a concentrated force $P=1$ applied at the origin at different values of the depth. The reliability of the obtained results is confirmed by the exact coincidence of the obtained results for the isotropic case with the known solution of Schechter O.Y [17].

Tables 2, 3, 4 show the value of values, and in figures 2, 3, 4 - diagrams of bending moments and transverse forces in an infinite foundation plate loaded with concentrated force $P=1$.

The results show that the values of deflections and internal forces of the Foundation slab decrease with increasing depth. For example, the values of deflection at the point $z = 0$, the deflection of the plate is equal to $w = 0.385$, and at $z = 10$, $w = 0.054$, i.e. the value is less than 7.1 times more than on the surface. A similar pattern is observed for internal efforts.

2.2 The case of anisotropy: $k_E = 5$. In tables 5,6,7,8 values of quantities are given, and in figures 5,6,7,8 - diagrams of deflections, bending moments and transverse forces in an infinite base plate loaded with concentrated force $P=1$ at values $z = 0, 2, 3, 5, 10; Ez=50$ *MPa; Mr* $= 10$ *MPa*.

The results show a significant effect of the base anisotropy on the distribution of deflection values and internal forces with changes in the depth of the Foundation plates. For example, the values of the deflection of the plate at z = 10 for isotropic case, equal to $w = 0.054$, and at $z = 10$ for the anisotropic case, respectively – $w= 0{,}118$, the value of the deflection is higher by 2.2 times than the value of the deflection of isotropic plates because of the same depth.

The obtained analytical expressions of deflections and internal forces in the foundation slab, taking into account its penetration into the ground mass, allow solving a number of problems in an analytical form for both infinite and finite foundation slabs using the methods developed in [18]. The calculation of plates lying on the surface of an anisotropic base, i.e. at z = 0, is considered in [15, 19]. The study of the regularities of the distribution of displacements inside and on the boundary of the deformable half-space under the action of a concentrated force applied to the boundary plane was carried out in [20].

Table 1

ξ	$z=0$	$z=1$	$z=3$	$z=5$	$z=7$	$z=10$
0.0	0.385	0.324	0.173	0.108	0.078	0.054
0.2	0.376	0.319	0.173	0.108	0.078	0.054
0.4	0.359	0.305	0.171	0.107	0.077	0.054
0.6	0.338	0.288	0.168	0.107	0.077	0.054
0.8	0.315	0.269	0.164	0.106	0.077	0.054
1.0	0.291	0.25	0.159	0.104	0.076	0.054
1.2	0.268	0.232	0.153	0.103	0.076	0.054
1.4	0.247	0.215	0.147	0.101	0.075	0.054
1.6	0.226	0.198	0.141	0.099	0.074	0.053
1.8	0.207	0.183	0.135	0.097	0.073	0.053
2.0	0.19	0.169	0.129	0.095	0.072	0.053
2.2	0.174	0.157	0.123	0.092	0.071	0.052
2.4	0.159	0.145	0.117	0.09	0.07	0.052
2.6	0.146	0.135	0.111	0.088	0.069	0.051
2.8	0.134	0.125	0.106	0.085	0.068	0.051
3.0	0.124	0.117	0.101	0.083	0.067	0.05
3.2	0.115	0.109	0.096	0.08	0.066	0.05
3.4	0.106	0.102	0.092	0.078	0.064	0.049
3.6	0.099	0.096	0.088	0.076	0.063	0.049
3.8	0.093	0.09	0.084	0.073	0.062	0.048

4.0	0.087	0.085	0.08	0.071	0.061	0.048

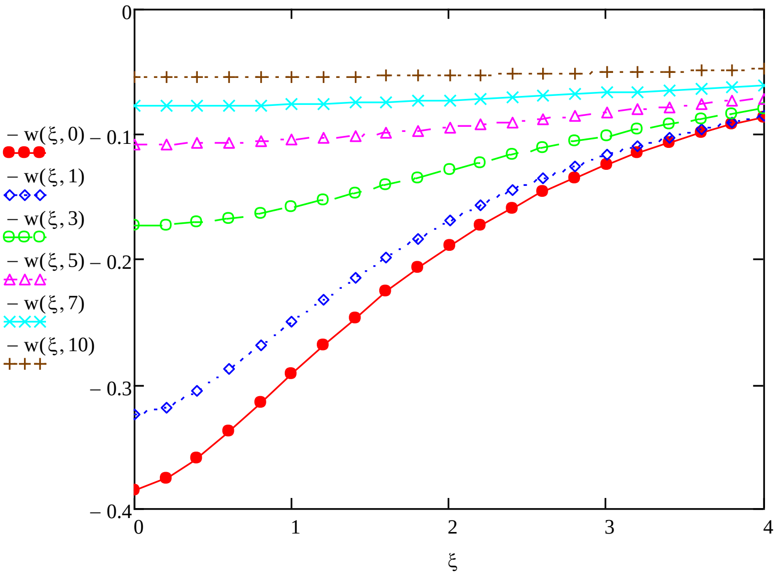

Figure 1. Diagram deflection in infinite plate at k_E = *1* loaded by concentrated force *P=1*, taking into account the recess at *z = 0, 1, 3, 5, 7, 10*.

Table 2

bv	*Mr(ξ,0)*	*Mr(ξ,1)*	*Mr(ξ,3)*	*Mr(ξ,5)*	*Mr(ξ,7)*	*Mr(ξ,10)*
0.0	0.952	0.367	0.043	0.01	0.00372	0.001233
0.2	0.305	0.287	0.042	0.01	0.0037	0.00123
0.4	0.17	0.151	0.039	0.009793	0.003689	0.001285
0.6	0.097	0.072	0.034	0.009366	0.003607	0.001271
0.8	0.052	0.037	0.029	0.008798	0.003494	0.001251
1.0	0.022	0.015	0.023	0.008115	0.003354	0.001226
1.2	0.00263	$1.46 \cdot 10^{-6}$	0.017	0.007347	0.00319	0.001197
1.4	-0.01	$-9.475 \cdot 10^{-3}$	0.012	0.006523	0.003	0.001163
1.6	-0.019	-0.015	0.00725	0.005674	0.002805	0.001124
1.8	-0.024	-0.018	0.00358	0.004827	0.002592	0.001082
2.0	-0.027	-0.02	0.00073	0.004	0.002371	0.001037
2.2	-0.028	-0.021	-0.00138	0.003227	0.002146	0.000982
2.4	-0.027	-0.02	-0.00286	0.002506	0.001921	0.000939
2.6	-0.026	-0.019	-0.00386	0.001852	0.001699	0.000818
2.8	-0.025	-0.018	-0.00448	0.001269	0.001482	0.000834
3.0	-0.023	-0.017	-0.00482	0.000758	0.001274	0.0007797
3.2	-0.021	-0.016	-0.00495	0.000319	0.001076	0.0007252
3.4	-0.019	-0.014	-0.00495	$-5.173 \cdot 10^{-5}$	0.000889	0.0006708
3.6	-0.017	-0.013	-0.00485	-0.00036	0.000715	0.0006168
3.8	-0.016	-0.012	-0.00469	-0.000611	0.000555	0.0005636

4.0	-0.014	-0.01	-0.004489	-0.000812	0.000408	0.0005115

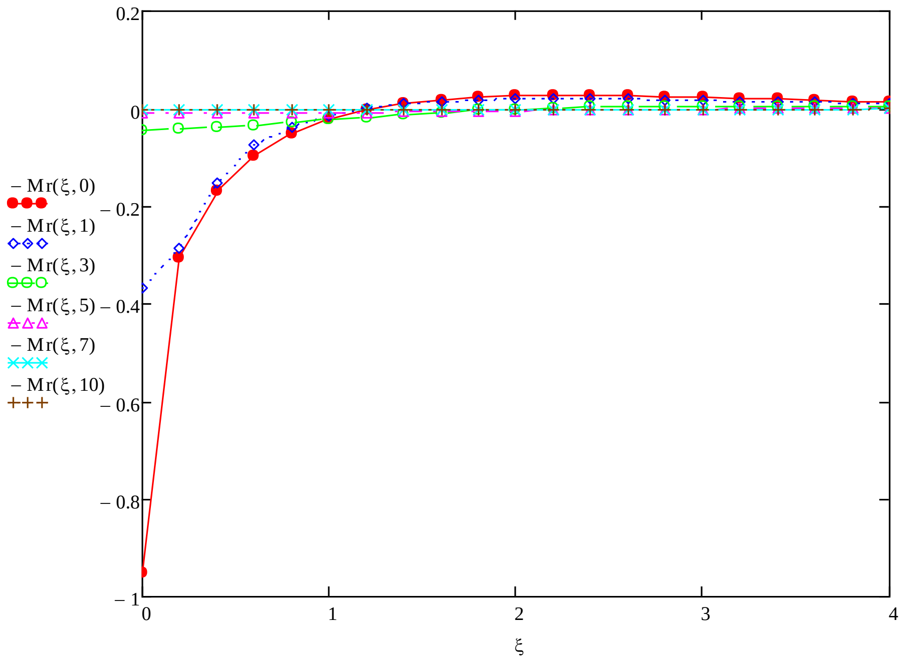

Figure 2. Diagram of bending radial moments in an infinite plate at $k_E = 1$ loaded by a concentrated force $P=1$, taking into account the deepening at $z = 0, 1, 3, 5, 7, 10$.

Table 3

ξ	$M\theta(\xi,0)$	$M\theta(\xi,1)$	$M\theta(\xi,3)$	$M\theta(\xi,5)$	$M\theta(\xi,7)$	$M\theta(\xi,10)$
0.0	0.952	0.366	0.043	0.01	0.003707	0.001085
0.2	0.415	0.319	0.043	0.01	0.003747	0.001083
0.4	0.276	0.229	0.041	0.009943	0.003718	0.00129
0.6	0.199	0.161	0.038	0.009695	0.00367	0.001282
0.8	0.148	0.118	0.035	0.009361	0.003605	0.00127
1.0	0.112	0.089	0.031	0.008955	0.003523	0.001256
1.2	0.086	0.068	0.027	0.008491	0.003426	0.001239
1.4	0.066	0.052	0.023	0.007984	0.003316	0.001219
1.6	0.051	0.04	0.02	0.007449	0.003195	0.001196
1.8	0.039	0.031	0.017	0.0069	0.003065	0.001171
2.0	0.03	0.024	0.014	0.006351	0.002929	0.00144
2.2	0.023	0.019	0.012	0.005812	0.002787	0.00116
2.4	0.018	0.015	0.009879	0.005292	0.002642	0.001085
2.6	0.014	0.012	0.008284	0.004797	0.002497	0.0008249
2.8	0.01	0.009109	0.006961	0.004332	0.002352	0.00102
3.0	0.007949	0.007188	0.005867	0.003901	0.002208	0.0009864
3.2	0.006064	0.005694	0.004961	0.003503	0.002068	0.0009519
3.4	0.004618	0.00453	0.00421	0.003141	0.001932	0.0009169
3.6	0.003518	0.003622	0.003586	0.002812	0.0018	0.0008818

3.8	0.002694	0.002915	0.003065	0.002515	0.001675	0.0008465
4.0	0.002056	0.002362	0.00263	0.002248	0.001555	0.0008115

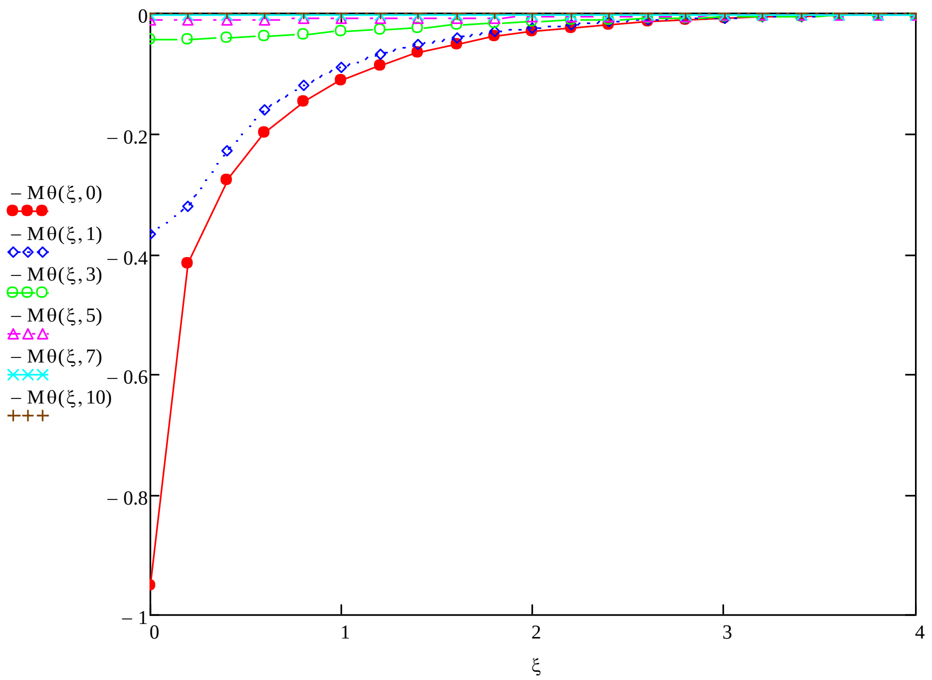

Figure 3. Diagram of bending tangential moments in an infinite plate at $k_E=1$ loaded by concentrated force $P=1$ with allowance for deepening at $z = 0, 1, 3, 5, 7, 10$.

Table 4

ξ	$N_r(\xi,0)$	$N_r(\xi,1)$	$N_r(\xi,3)$	$N_r(\xi,5)$	$N_r(\xi,7)$	$N_r(\xi,10)$
0.0	-0.0007956	$-5.623\cdot10^{-6}$	$-6.519\cdot10^{-8}$	$-5.274\cdot10^{-9}$	$-1.128\cdot10^{-9}$	$-1.991\cdot10^{-10}$
0.2	-1.291	-0.846	-0.013	-0.001084	-0.0002053	-0.00003974
0.4	-0.728	-0.761	-0.024	-0.002117	-0.0004056	-0.00007898
0.6	-0.497	-0.396	-0.032	-0.003053	-0.0005963	-0.0001172
0.8	-0.328	-0.232	-0.037	-0.003855	-0.0007731	-0.0001539
1.0	-0.203	-0.167	-0.038	-0.004495	-0.0009324	-0.0001597
1.2	-0.13	-0.117	-0.036	-0.00496	-0.001071	-0.0001947
1.4	-0.098	-0.08	-0.033	-0.005248	-0.001188	-0.0002215
1.6	-0.083	-0.056	-0.028	-0.00537	-0.001281	-0.0002459
1.8	-0.064	-0.039	-0.024	-0.005341	-0.00135	-0.0002677
2.0	-0.04	-0.027	-0.019	-0.005187	-0.001396	-0.0002869
2.2	-0.019	-0.018	-0.015	-0.004932	-0.001419	-0.0003032

2.4	-0.009771	-0.012	-0.011	-0.004605	-0.001422	-0.0003168
2.6	-0.009539	-0.006903	-0.008616	-0.004229	-0.001406	-0.0003275
2.8	-0.009621	-0.003619	-0.006404	-0.003827	-0.001375	-0.0003354
3.0	-0.00478	-0.00132	-0.004694	-0.003418	-0.001329	-0.0003407
3.2	0.002563	0.0002567	-0.003391	-0.003017	-0.001273	-0.0003434
3.4	0.006659	0.001303	-0.002407	-0.002633	-0.001208	-0.0003438
3.6	0.005363	0.001963	-0.001668	-0.002275	-0.001138	-0.0003419
3.8	0.002038	0.002344	-0.001115	-0.001947	-0.001063	-0.000338
4.0	0.00125	0.002526	-0.0007024	-0.001652	-0.000986	-0.0003323

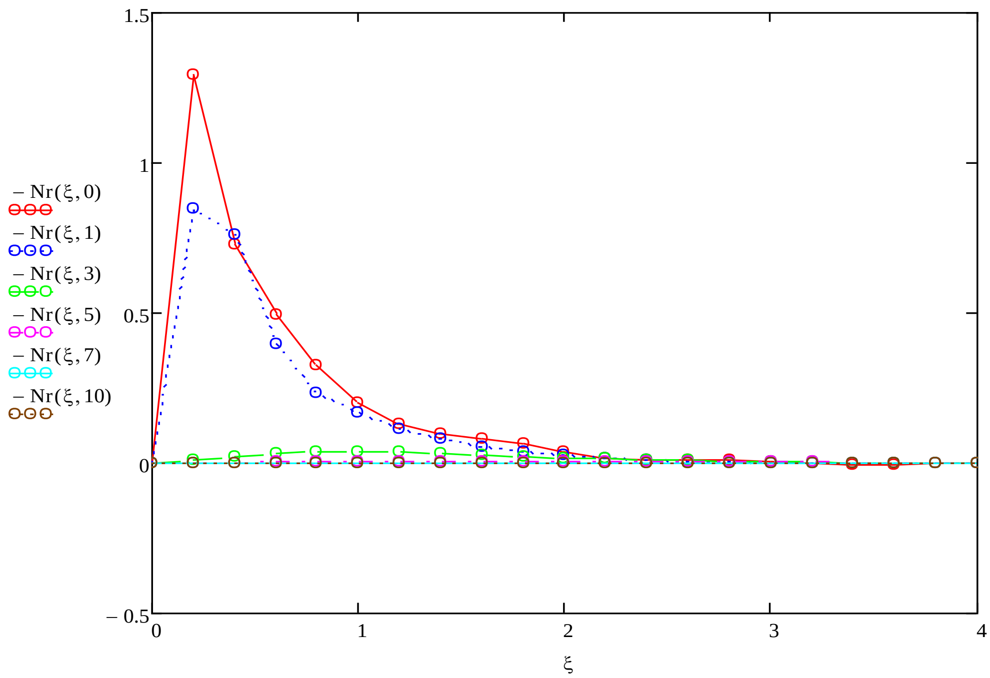

Figure 4. Diagram of transverse forces in an infinite plate at $k_E = 1$, loaded with concentrated force $P=1$, taking into account the deepening at $z = 0, 1, 3, 5, 7, 10$.

Table 5

ξ	$z=0$	$z=2$	$z=3$	$z=5$	$z=7$	$z=10$
0	0.385	0.347	0.322	0.225	0.166	0.118
0.2	0.336	0.353	0.321	0.225	0.166	0.118
0.4	0.359	0.363	0.317	0.223	0.166	0.118
0.6	0.338	0.364	0.311	0.221	0.165	0.118

0.8	0.315	0.349	0.301	0.218	0.164	0.117
1	0.291	0.319	0.289	0.214	0.162	0.117
1.2	0.268	0.286	0.274	0.21	0.16	0.116
1.4	0.247	0.262	0.258	0.204	0.158	0.115
1.6	0.226	0.247	0.241	0.198	0.156	0.114
1.8	0.207	0.235	0.225	0.191	0.153	0.113
2	0.19	0.22	0.209	0.184	0.15	0.112
2.2	0.174	0.201	0.195	0.176	0.146	0.111
2.4	0.159	0.181	0.181	0.169	0.143	0.109
2.6	0.146	0.165	0.169	0.161	0.139	0.108
2.8	0.134	0.154	0.158	0.153	0.135	0.106
3	0.124	0.146	0.147	0.145	0.131	0.105
3.2	0.115	0.137	0.138	0.138	0.127	0.103
3.4	0.106	0.126	0.129	0.131	0.122	0.101
3.6	0.099	0.115	0.121	0.124	0.118	0.099
3.8	0.093	0.105	0.113	0.118	0.114	0.097
4	0.087	0.099	0.106	0.112	0.109	0.095

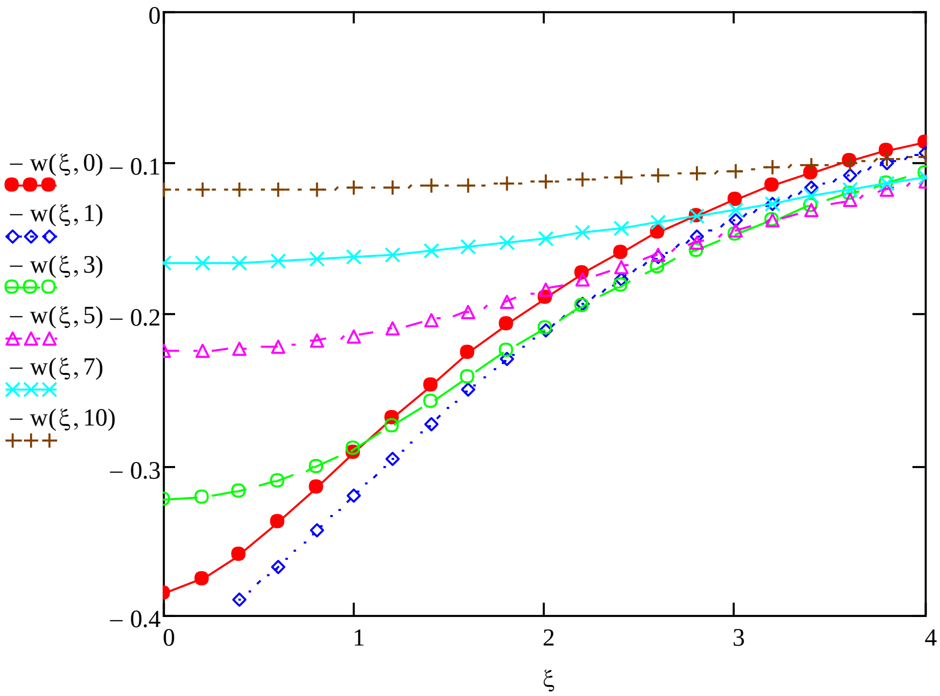

Figure 5. Diagram deflection in infinite plate at $k_E = 5$ loaded by concentrated force $P=1$, taking into account the recess at $z=0, 2, 3, 5, 7, 10$.

Table 6

ξ	*Mr(ξ,0)*	*Mr(ξ,2)*	*Mr(ξ,3)*	*Mr(ξ,5)*	*Mr(ξ,7)*	*Mr(ξ,10)*
0	0.952	-0.445	0.08	0.027	0.012	0.003779
0.2	0.305	-0.208	0.084	0.028	0.011	0.003911
0.4	0.17	0.197	0.089	0.028	0.011	0.003911
0.6	0.097	0.477	0.093	0.028	0.011	0.003909
0.8	0.052	0.417	0.09	0.028	0.011	0.003904

1	0.022	0.107	0.078	0.027	0.011	0.003895
1.2	0.00263	-0.177	0.057	0.026	0.011	0.003879
1.4	-0.01	-0.232	0.033	0.024	0.011	0.003855
1.6	-0.019	-0.079	0.00961	0.021	0.01	0.003819
1.8	-0.024	0.099	-0.00759	0.018	0.009695	0.00377
2	-0.027	0.143	-0.017	0.015	0.009092	0.003703
2.2	-0.028	0.04	-0.021	0.011	0.008358	0.003619
2.4	-0.027	-0.094	-0.02	0.006744	0.007502	0.003513
2.6	-0.026	-0.139	-0.018	0.003154	0.006545	0.003386
2.8	-0.025	-0.073	-0.016	0.00002318	0.005515	0.003236
3	-0.023	0.026	-0.014	-0.002539	0.004444	0.003064
3.2	-0.021	0.067	-0.013	-0.004496	0.003369	0.00287
3.4	-0.019	0.025	-0.013	-0.005876	0.002323	0.002657
3.6	-0.017	-0.048	-0.013	-0.006748	0.001337	0.002426
3.8	-0.016	-0.081	-0.013	-0.007202	0.0004359	0.002181
4	-0.014	-0.051	-0.013	-0.007335	-0.000363	0.001925

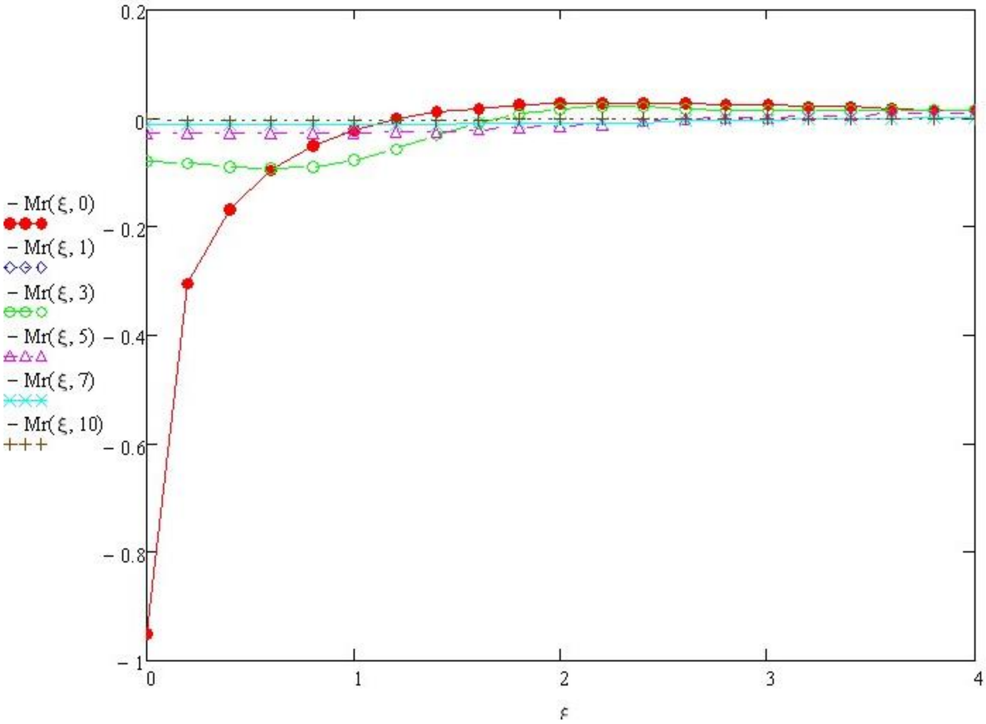

Figure 6. Diagram of bending radial moments in an infinite plate at $k_E = 5$ loaded by a concentrated force $P=1$, taking into account the deepening at $z=0, 2, 3, 5, 7, 10$.

Table 7

ξ	$M\theta(\xi,0)$	$M\theta(\xi,2)$	$M\theta(\xi,3)$	$M\theta(\xi,5)$	$M\theta(\xi,7)$	$M\theta(\xi,10)$
0	0.952	-0.557	0.077	0.027	0.013	0.003471
0.2	0.415	-0.287	0.083	0.028	0.011	0.003911
0.4	0.276	-0.033	0.086	0.028	0.011	0.003911
0.6	0.199	0.193	0.089	0.028	0.011	0.00391
0.8	0.148	0.263	0.09	0.028	0.011	0.003908
1	0.112	0.183	0.085	0.027	0.011	0.003903

1.2	0.086	0.059	0.076	0.027	0.011	0.003896
1.4	0.066	-0.006628	0.064	0.026	0.011	0.003884
1.6	0.051	0.011	0.05	0.025	0.011	0.003867
1.8	0.039	0.061	0.039	0.023	0.01	0.003843
2	0.03	0.082	0.029	0.021	0.01	0.003811
2.2	0.023	0.055	0.023	0.019	0.009728	0.003769
2.4	0.018	0.007698	0.018	0.017	0.009293	0.003718
2.6	0.014	-0.018	0.015	0.015	0.008796	0.003655
2.8	0.01	-0.007643	0.013	0.013	0.008248	0.003581
3	0.007949	0.02	0.011	0.011	0.00766	0.003494
3.2	0.006064	0.034	0.009218	0.008993	0.007048	0.003396
3.4	0.004618	0.023	0.007573	0.007517	0.006427	0.003287
3.6	0.003518	-0.000720	0.006084	0.006273	0.005813	0.003167
3.8	0.002694	-0.015	-0.00481	0.00524	0.005217	0.003037
4	0.002056	-0.009513	-0.00380	0.004394	0.00465	0.002899

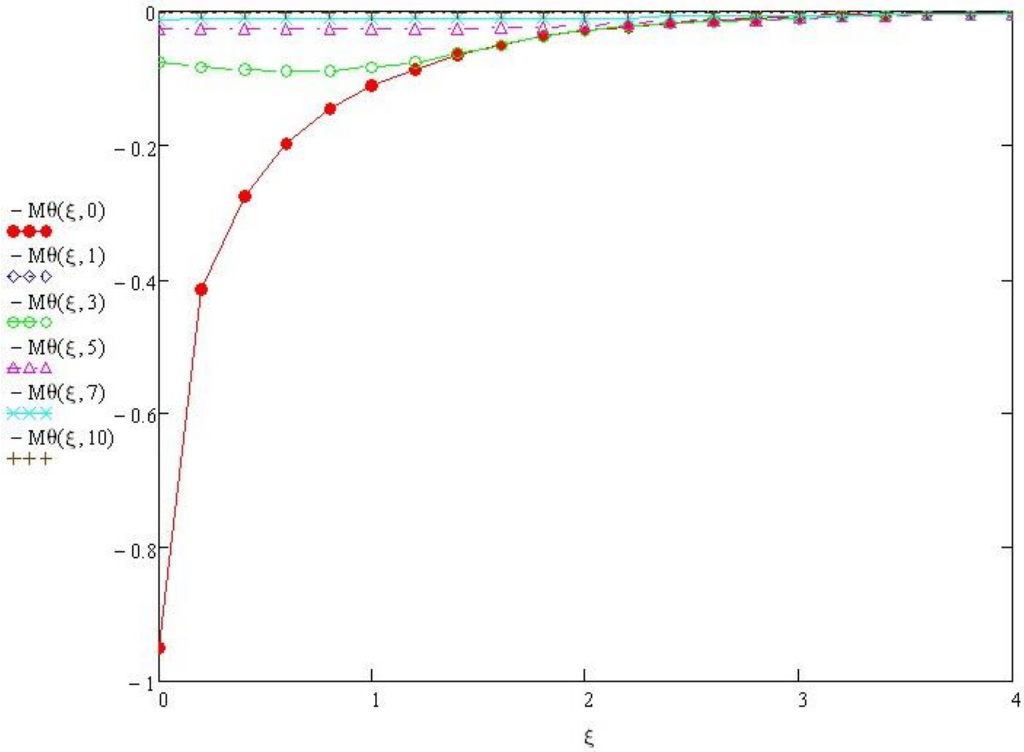

Figure 7. Diagram of bending tangential moments in an infinite plate at k_E = *5* loaded by concentrated force *P=1* taking into account the deepening at *z=0, 2, 3, 5, 7, 10.*

Table 8

ξ	$N_r(\xi,0)$	$N_r(\xi,2)$	$N_r(\xi,3)$	$N_r(\xi,5)$	$N_r(\xi,7)$	$N_r(\xi,10)$
0	- 0.0007956	0.00001855	2.169E-07	3.67E-09	9.93E-10	-9.22E-10
0.2	-1.291	2.136	0.026	0.0004097	0.00001301	1.16E-05
0.4	-0.728	2.571	0.034	0.0004119	- 0.00001104	-7E-06
0.6	-0.497	1.082	0.012	-0.0003401	-0.0001065	-1.8E-05
0.8	-0.328	-0.927	-0.035	-0.0002072	-0.000302	-3.7E-05
1	-0.203	-1.803	-0.092	-0.0004834	-0.000618	-6.8E-05

1.2	-0.13	-1.124	-0.134	-0.0008461	-0.001064	-0.00011
1.4	-0.098	0.194	-0.146	-0.013	-0.001635	-0.00017
1.6	-0.083	0.944	-0.129	-0.017	-0.002313	-0.00024
1.8	-0.064	0.659	-0.093	-0.02	-0.003067	-0.00033
2	-0.04	-0.176	-0.055	-0.023	-0.00385	-0.00043
2.2	-0.019	-0.721	-0.025	-0.024	-0.004612	-0.00054
2.4	-0.009771	-0.559	-0.006837	-0.023	-0.005298	-0.00067
2.6	-0.009539	0.04	0.0004201	-0.021	-0.005859	-0.0008
2.8	-0.009621	0.478	0.0005551	-0.019	-0.006257	-0.00093
3	-0.00478	0.409	-0.002303	-0.016	-0.006466	-0.00106
3.2	0.002563	-0.012	-0.005065	-0.013	-0.00648	-0.00118
3.4	0.006659	-0.351	-0.006175	-0.009499	-0.00631	-0.0013
3.6	0.005363	-0.324	-0.005432	-0.006851	-0.005979	-0.0014
3.8	0.002038	-0.015	-0.003464	-0.004663	-0.005521	-0.00148
4	0.00125	0.256	-0.001147	-0.002951	-0.004973	-0.00154

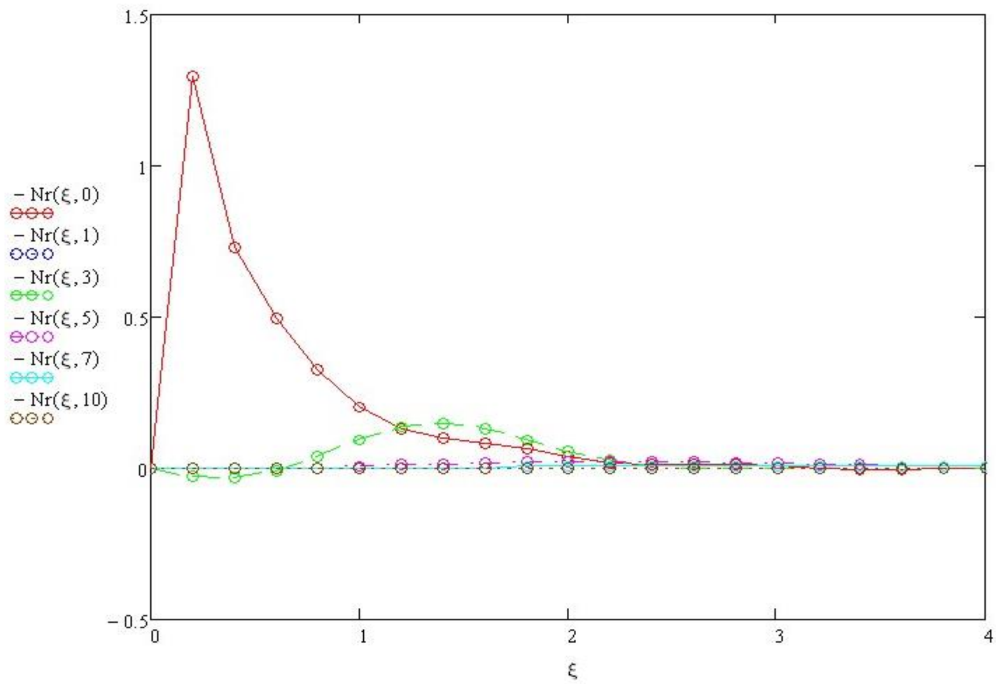

Figure 8. Diagram of transverse forces in an infinite plate at $k_E = 5$, loaded with concentrated force $P=1$, taking into account the deepening at $z = 0, 2, 3, 5, 7, 10$.

Results And Discussions.

3.1. Results of the first case – isotropic base, at k_E = 1. The results obtained show that the values of deflections and internal forces of the foundation plate decrease with increasing depth. For example, the deflection value at the point z = 0 is equal to w = 0.385, and at z = 10, w = 0.054, i.e. the value is less than 7.1 times than on the surface. A similar pattern is observed for internal efforts.

3.2 Results of the second case – anisotropic base, at k_E = 5

The results obtained show a significant effect of the anisotropy of the base on the distribution of deflection values and internal forces with a change in the depth of the foundation slabs. For example, at z = 10, the de-flection value of the plate for the isotropic case is - w = 0.054, and at z = 10 (Table 1), and for the anisotropic case, respectively – w= 0.118 (Table 5), the deflection value is 2.2 times greater than the deflection value of the plate on an isotropic base with the same by deepening.

3.3 The results obtained in this paper can also serve as a criterion for evaluating the reliability of the results obtained in numerical studies. The obtained analytical expressions of deflections and internal forces in the foundation slab, taking into account its penetration into the ground mass, allow solving a number of problems in an analytical form for both infinite and finite foundation slabs using the methods developed in [18]. The calculation of plates lying on the surface of an anisotropic base, i.e. at z = 0, is considered in the works [15], [19]. Studies of the regularities of the distribution of displacements inside and on the boundary of a de-formable half-space under the action of a concentrated force applied to the boundary plane on it were carried out in work [20].

Conclusions. An effective analytical solution was obtained; an algorithm and a program for calculating a plate lying on a linearly deformable base under the action of arbitrary loads were developed. An effective analytical solution was obtained; an algorithm and a program for calculating a plate lying on a linearly deformable base under the action of arbitrary loads were developed. The effect of the anisotropy of a linearly deformable base on the distribution of deformations and forces in an infinite plate is investigated. Analytical expressions of deflections and forces in an infinite plate obtained using the method of generalized solutions are comparatively simple and allow for effective numerical implementation.

The results obtained in this paper can also serve as a criterion for evaluating the reliability of the results obtained in numerical scientific research.

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АНИЗОТРОПТЫ НЕГІЗДЕ ЖАТҚАН ҚҰРЫЛЫМДАРДЫ ЕСЕПТЕУ

Абстракт. Трансверсальды изотропты жартылай кеңістіктің ядросы мен әсер ету функциясын анықтау қарастырылады. Шексіз тірек тақтасындағы иілу мен ішкі күштердің өрнектері олардың тау жыныстарының массивіне тереңдеуін, сондай-ақ негіздің анизотропиясының иілу мен ішкі күштердің таралуына әсерін ескере отырып алынады. Алынған нәтижелер сандық және компьютерлік әдістермен алынған нәтижелерді салыстыру үшін нұсқаулық болып табылады. Бұл есептеу алгоритмі анизотропты топырақ негізінің жүк көтергіштігін бағалауға мүмкіндік береді.

Кілт сөздер: іргетас, топырақ негізі, анизотропия, орын ауыстыру, тірек тақтасы.

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РАСЧЕТ КОНСТРУКЦИЙ, ЛЕЖАЩИХ НА АНИЗОТРОПНОМ ОСНОВАНИИ

Абстракт. Рассмотрено определение ядра и функции влияния трансверсально изотропного полупространства. Выражения прогиба и внутренних сил в бесконечной опорной плите получены с учетом их углубления в массив горной породы, а также влияния анизотропии основания на распределение прогибов и внутренних сил. Полученные результаты служат ориентиром для сверки результатов, полученных численными и компьютерными методами. Этот алгоритм расчета позволяет нам оценить несущую способность анизотропного грунтового основания.

Ключевые слова: фундамент, грунтовое основание, анизотропия, прогиб, бесконечная плита.