Calculation model of the "building-foundation" system on anisotropic base and deformation calculations

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ABSTRACT

In the construction of new buildings and facilities although the requirements of construction laws, building codes are observed, the heeling process and the collapse of the urban high-rise buildings are continuing at different speeds. Unfortunately, the number of such collapses and destruction in the world continues to this day. The purpose of this article is to show the mechanisms of collapse and patterns of deformation of loose and water-saturated soils of the construction site, which often have anisotropic structures by creating a calculated mechanical and mathematical model. A brief overview shows the state of the issue on the scale of the consequences of the collapse of modern high-rise buildings in the world. Attention is drawn to the lack of knowledge of the soil bases of structures of anisotropic structure. A computational model of a soil ground of complex anisotropic structure and algorithms for its application in practical calculations are proposed. The results of studies and their analysis, the regularities of the deformation state of the system consisting of foundation and buildings base, depending on the angle of inclination of the inclined layered base are developed in the study as well. In the form of tables and a large number of drawings there are the elucidated basic laws of inclination of buildings and structures that took place in large cities of Kazakhstan.

Keywords: soils, deformation, base, collapse, destruction.

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1. Introduction

Present day construction of urban buildings is characterized by the height and strength of the structural, foundation and ground bases. At this, the grounds can be completely different both in composition and in strength. Bad grounds include loose, saline and water-saturated soils. In the course of constructing new buildings and structures, although the requirements of the construction laws, SNiPs are observed, the processes of tilting and collapse of urban high-rise buildings continue with different speeds. The causes are very diverse. Not to mention violation of the laws of building codes, up to not studying the laws of the soil environment deformation of a complexly heterogeneous, that is, anisotropic structure, which serves as a foundation. Here it is necessary to carefully study the structure of the construction area geology. The southern capital of Kazakhstan, the capitals of Kyrgyzstan and Tajikistan are located on the sloping foothill plains, which originate from the foothill shelves. There are a lot of such examples in the world. Such sedimentary strata of the Quaternary period are highly developed, especially from the Pleistocene neotectonics, which continues to this day. Within millions years of weathering, temperature and chemical decomposition, eluvial deposits predominate in the strata of the soil massif closer to the mountains. Due to such a particularly complex soil structure, newly built high-rise buildings in the city of Almaty began to deform with tilts of 32 cm, 37 cm and 40 cm (Figure 1).

Figure 1. Tilting high-rise buildings of the Zerdeli microdistrict in the Algabas district of Almaty city

On June 1, 2016 monolithic residential building No. 136 in the Algabas-6 microdistrict of the Alatau district of the city of Almaty tilted 37 centimeters. By the end of 2019 cracks appeared on the walls of house 1/ No. 179 in the Zerdeli microdistrict of the Algabas district and increased with a crash from the basement to the 9 floors roof. People once again ran out of house No. 179d almost in panic. The house became empty quickly. This is the fourth house in the area. These numbers have grown by the summer of 2020 to 6 houses in the area [1-3].
A little earlier, in 2012 an even worse situation happened in the city of Karaganda in Kazakhstan. The houses of the new Besoba microdistrict began to collapse with tilting one after another at a rapid pace (Figure 2) [4-8]. This story ended with the fact that the government commission decided to demolish all the houses in this new microdistrict.

Figure 2. Collapsed houses in the Besoba microdistrict in Karaganda city

We draw attention to the following circumstance. The Nura river flows near the city of Karaganda. In addition, the houses of the Besoba microdistrict were erected on the site of a former lake. The Kargalinka River flows near the tilted houses of the Zerdeli microdistrict of the city of Almaty. This suggests that filtration processes in soils inevitably take place here.
Carried out and ongoing, both domestic and foreign studies dealing with foundations and bases show that they mainly relate to the reinforcement of the foundation itself and various strengthening of the foundation soil [9-12]. However, there remains an unexplored pattern of subgrade obliquely layered anisotropic structure, which entails the foundation and the building collapse.
Therefore, the purpose of writing this article is to show consistently the regularity of soil deformation of the proposed construction site, which is at first under its own weight, that is, the geostatic stress field; then to

consider the deformed state of the subgrade, taking into account the weight of the foundation; and finally to do this taking into account the gravitational weight of the high-rise building. Here the regularities of deformation of the system that consists of the base-foundation-building, are already considered. We study the deformed state of the dry ground base taking into account its water saturation.

Preliminarily, there is developed a computational mechanical-mathematical model of a soil massif of the obliquely layered anisotropic structure, then an algorithm of modeling by the finite element method (FEM).

2. Theoretical overview

To establish the types and nature of the collapse of modern high-rise buildings and structures, Figures 1 and 2 below show two examples of major events of such a nature. On June 29, 1995 in Seoul the building shopping center Sampung (Sampoong) collapsed. This was the largest man-made disaster in the history of South Korea. Within 20 seconds, the South wing completely collapsed, killing 502 people and filling up another 1.500 with wreckage [1]. Figure 3 shows a picture of the collapse of the Sampung shopping centre in Seoul in 1995.

Figure 3. The process of collapse failure of the shopping center in South Korea

Another collapse, a larger one, of high-rise buildings in history occurred on April 24, 2013 in Bangladesh, which accidentally coincided with the Karaganda collapse, the episode of which is shown in Figure 4. To this date this accident is the most significant in the world history. As a result of the collapse, 1.129 people were killed and more than 2.500 injured. In a matter of seconds, a huge 8-storey shopping and industrial center Rana Plaza collapsed, leaving only the first floor intact. At the base of the foundations there was an underground lake, no measures to protect the building structures were carried out.

Figure 4. The process of collapse failure of the 8-storey building of the commercial and industrial center Rana Plaza in 2013

From the drawings it is not difficult to notice that before the collapse the building was significantly heeled. This clearly demonstrates unevenness of the sediment deformation of the soil base. Almost all the houses of Karaganda microdistrict collapsed slowly through the stages of heeling. The Almaty 9 floors were inherent with exactly the same character.

After the analysis of the collapse of modern buildings and constructions we have carried out analysis of existing approaches and models in the study of the foundation soil in the general case of a complex structure. Here it is necessary to pay attention not only to the heterogeneity of the soil composition, but also to the impact on the magnitude and nature of its deformation: the stratification, the influence of inclination angle of the layers and anisotropy. In SNiPs [2-5] which are the main building laws, the most complete recording is missing. The reason for this is the complexity of solving this problem by analytical methods. If in an isotropic medium the elastic state of the array is determined by two constants-the Poisson's ratio ν and the young's modulus E, then the state of the anisotropic medium, in particular the transtropic one, is determined by five constants. They are two young modules E_1, E_2, shear modulus G_2, two Poisson's ratio – ν_1 and ν_2. Therefore, the real responsible engineering structures are modeled and solved only by numerical methods. Let us consider the problem of determining the regularity of the deformation states of the soil base in the general case of an inclined-layered structure. As the power of influence is to join the weight of foundation by the self-weight of soil.

The first works on the account of anisotropy of the soil and the base are systematized in the work of A.K. Bugrov and A.I. Golubev [6]. If we consider the soil isotropic structure, there are different models taking into account many factors. Some of them are listed in the book of V.A. Babeshko, V.A. Voloshin and V.P. Dyba [7]. For example, attention was paid to the issues of designing of bases and foundations of buildings and structures of high-rise buildings in the works of V.K. Fedulov and L. Artemova [8], O.A. Shulyatyev [9]. V.V. Ledenev, V.P. Yartsev and V.G. Odnolko [10], V.M. Antonov [11].

The following works of foreign authors are dedicated to the study of the nature of the destruction of various foundation steel structures interacting with the soil base. In the work of B. Kalantari [12], a large review of the condition of the foundation erected on loose soils was carried out. The character of the lateral displacement of the soft soil of the foundation was considered by J.Q. Liu and J.L. Liu [13]. X.S. Chenga, G. Zhenga, Y. Diaoa, T.M. Huanga, C.H. Denga, Y.W. Leia and H.Z. Zhou [14] studied the mechanism of active destruction of the pit held console adjacent piles. A. Pirmoz and M. Liu [15], A.H. Arshian and G. Morgenthal studied the mechanism of active destruction of the pit held by cantilever piles [16].

The analysis of the review shows the absence of a mathematical model for the anisotropy of the soil of the inclined-layered structure. In scientific and practical relation, it is necessary to study and establish first the laws of soil deformation of construction sites, taking into account the anisotropy of the structure far from the design stage of construction. Then you need to study separately the foundation – base and then-the deformability of the entire system consisting of the base – foundation – building. To carry out such studies, it is necessary to create a mechanical and mathematical model of the soil mass, which generally has an inclined – layered structure.

3. Materials and methods

The review of a huge number of sources shows the absence of a mathematical model of soils of inclined-layered structure, not to mention the destruction. J.S. Erzhanov, S.M. Aytaliyev, J.K. Masanov created model of rocks with inclined layered structures in consideration of the stability of mine workings [17]. This model of sloping rock mass is quite suitable for soil arrays of similar structure. On the basis of this model, we create a computational finite element scheme for the study of elastic stability under the foundation soil layer in general case for the inclined-layered structure. As it is known from the theory of elasticity, the components of deformations and stresses, being a function of displacement, have three components in each computational point of the plane domain in the plane problem. The components of the voltage present across the components of deformations in the form [17] (1):

$$\begin{Bmatrix} \sigma_x \\ \sigma_z \\ \tau_{xz} \end{Bmatrix} = \begin{bmatrix} d_{11}\ d_{12}\ d_{13} \\ d_{21}\ d_{22}\ d_{23} \\ d_{21}\ d_{22}\ d_{23} \\ d_{31}\ d_{32}\ d_{33} \end{bmatrix} \quad (1)$$

where $\sigma_x, \sigma_z, \tau_{xz}$ are stress components, $\varepsilon_{x,}\ \varepsilon_z, \gamma_{xz}$ – deformation components, matrix $[D]$ – the elements of which are the coefficients $d_{ij}, i = 1,2,3; j = 1,2,3$ is the matrix of elastic characteristics. Strain components are expressed through components of displacement (2-5):

$$\varepsilon_x = \frac{\partial u}{\partial x}, \quad (2)$$

$$\varepsilon_z = \frac{\partial w}{\partial x}, \quad (3)$$

$$\gamma_{xz} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}. \quad (4)$$

$$\{\varepsilon\}^T = \{\varepsilon_x, \varepsilon_z, \gamma_{xz}\}. \quad (5)$$

The generalized Hooke's law for flat sections of a soil base of a layered structure by analogy of the work [17] has the form obtained by striking out the corresponding rows and columns for the transition to the flat case (6-8):

$$\sigma_x = c_{11}\varepsilon_x + c_{13}\varepsilon_z + c_{15}\gamma_{xz}, \quad (6)$$

$$\sigma_z = c_{31}\varepsilon_x + c_{33}\varepsilon_z + c_{35}\gamma_{xz}, \quad (7)$$

$$\tau_{xz} = c_{51}\varepsilon_x + c_{53}\varepsilon_z + c_{55}\gamma_{xz} \quad (8)$$

As mentioned above, Hooke's law (6)-(8) contains 5 independent anisotropy coefficients. According to this study, Hooke's Law for the soil base of the inclined–layered structure (φ≠0) taking into account the angle of inclination φ has the form (9-19):

$$c_1 = cos^2\,\phi, \quad (9)$$

$$c_2 = sin^2\,\phi, \quad (10)$$

$$c_3 = cos^4\,\phi, \quad (11)$$

$$c_4 = sin^4\,\phi, \quad (12)$$

$$c_5 = sin\,\phi\,cos\,\phi, \quad (13)$$

$$c_6 = sin^2\,\phi\,cos^2\,\phi. \quad (14)$$

$$c_0 = (1+\nu_1)(n(1-\nu_1) - 2\nu_2^2), \quad (15)$$

$$c_{11} = c_{22} = (E_1(n-\nu_2^2))/c_0, \quad (16)$$

$$c_{13} = (\nu_2 E_1)/(n(1-\nu_1) - 2\nu_2^2), \quad (17)$$

$$c_{33} = ((1-\nu_1)E_1)/(n(1-\nu_1) - 2\nu_2^2), \quad (18)$$

$$c_{55} = G_2. \quad (19)$$

The expressions for the elasticity coefficients (1) go to the next form (20-25):

$$d_{11} = c_{11}c_3 + 2(c_{13} + 2c_{44})c_6 + c_{33}c_4, \quad (20)$$

$$d_{12} = c_{13} + (c_{11} + c_{33} - 2c_{13} - 4c_{44})c_6, \quad (21)$$

$$d_{13} = (c_{11}c_1 - c_{33}c_2 - (c_{11} + 2c_{44}) \cos 2\phi)c_5, \quad (22)$$

$$d_{22} = c_{11}c_4 + 2(c_{13} + 2c_{44})c_6 + c_{33}c_3, \quad (23)$$

$$d_{23} = (c_{11}c_2 - c_{33}c_1 + (c_{13} + 2c_{44}) \cos 2\phi)c_5, \quad (24)$$

$$d_{33} = c_{44} + (c_{11} + c_{33} - 2(c_{13} + 2c_{44})c_6. \quad (25)$$

If we substitute the values of $c_{1,\dots,}c_6$ from (9)-(14) into the last expression, we get (26-31):

$$d_{11} = c_{11} \cos^4(\phi) + c_{33} \sin^4(\phi) + 2(c_{13} + 2c_{44}) \sin^2(\phi) \cos^2(\phi), \quad (26)$$

$$d_{12} = c_{13} + (c_{11} + c_{33} - 2(c_{13} + 2c_{44})) \sin^2\phi \cos^2\phi, \quad (27)$$

$$d_{13} = (c_{11}c_1 - c_{33}c_2 - (c_{13} + 2c_{44}) \cos 2\phi) \sin\phi \cos\phi, \quad (28)$$

$$d_{22} = c_{11} \sin^4(\phi) + 2(c_{13} + 2c_{44}) \sin^2\phi \cos^2\phi + c_{33} \cos^4\phi, \quad (29)$$

$$d_{23} = (c_{11} \sin^2\phi - c_{33} \cos^2\phi + (c_{13} + 2c_{44}) \cos 2\phi) \sin\phi \cos\phi, \quad (30)$$

$$d_{33} = c_{44} + (c_{11} + c_{33} - 2(c_{13} + 2c_{44})) \cos^2(\phi) \sin^2(\phi). \quad (31)$$

For an obliquely layered medium, the matrix of elastic characteristics [D] through the elasticity coefficients will have the form (32):

$$[D] = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ & d_{22} & d_{23} \\ d_{ji} = d_{ij} & & d_{33} \end{bmatrix} \quad (32)$$

The elasticity matrix [D], unlike the horizontal stratification, will be completely filled, which means that there will be no zero elements. The number of independent coefficients will be 6. Using algorithms (1)-(32) of this new computational model of the soil, which has a sloping layered structure, we can form the equation of equilibrium of the finite element method. According to the algorithms above (1)-(32) the computer program of the account is made. A brief FEM algorithm for solving this problem is reduced to the following. Basic resolving equation of the FEM – equation of equilibrium has the following form [18] (33):

$$[\boldsymbol{K}]\{\boldsymbol{U}\} = \{\boldsymbol{P}\}. \quad (33)$$

where $[K]$ – stiffness matrix of the system; $\{U\}, \{P\}$ – vectors of unknown displacements and known forces that are formed for the considered finite element from the weights of the overlying elements and reduced to nodal points. After solving the system of equations (33), the components of the displacement vector $\{U\}$. Components of strain and stress are calculated using the following well-known relations of the FEM (34-35)

$$\{\varepsilon\} = [B]\{U\}, \quad (34)$$

$$\{\sigma\} = [D]\{\varepsilon\}, \quad (35)$$

where $\{\varepsilon\}^T = \{\varepsilon_x, \varepsilon_z, \gamma_{xz}\}$– components of strain; $[B]$– gradient matrix; $\{U\} = \{u, \vartheta\}$ – vector components of displacements; $\{\sigma\}^T = \{\sigma_x, \sigma_z, \tau_{xz}\}$– vector components of strain; $[\boldsymbol{D}]$– matrix of elastic characteristics.

To reveal the true picture of the influence of "poor soil" on the deformation states of the "building – foundation – base" system, we solve the problem in the following sequence. First, we determine the deformation state of the layered soil of the construction site in an intact form, depending on the magnitude of the angles of inclination of the layers, which means its natural state. In this case, the size and shape of the final design area is assigned based on the size of one of the future trapezoidal pit. In the second step, we will solve the problem of the influence of the anisotropy of the base soil on the size and shape of the deformation of the foundation structure.

In the third step, we solve the problem of determining the regularity of the deformation state of the entire system consisting of the building, foundation and bases of a generally complex anisotropic structure.

4. Results and discussion

4.1. Calculation of the deformation state of the soil of the construction site of an anisotropic structure

To check the reliability and accuracy of the solution of the problem according to the proposed model of calculation, the problem of Schechter, which has an analytical solution [19], is pre-solved. The meaning of this task is as follows. In the middle of the plate of infinite length, lying on the half of the applied concentrated load P. FEM representation of this task is shown in Figure 5. This problem closely reflects our problem of the “foundation – base” system and has an exact solution. The paper presents the exact values for the vertical component of the movement, which is: w_z^{Anal} =0.33 on the contact of the plate with the ground base.

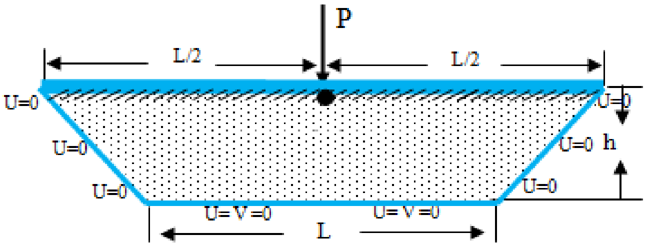

Figure 5. Strain of the foundation plate of infinite length on the elastic half-plane

As a test, this problem is solved by the finite element method for the computational domain shown in Figure 5, with the following geometric dimensions: *L*=100м, *h*=40м, P=100 t. Elastic characteristics of the half-plane: E=1·102 МПа, ν =0.4 and the foundation plate with a height 0.5 m: E=2.1·104 МПа, ν=1.6. The system studied is under the conditions of plane deformation. On the vertical axis of symmetry under the foundation on the contact point there are circle vertical component movements: w_z^{Anal} =0.33 cm, which exactly coincides with its analytical solution. See Table 1 the values of physical and mechanical properties of real soils with the anisotropic structures are given.

Table 1. Physical, mechanical and strength properties of some soils with anisotropic structure

No. p/p	Soils	Young Modulus, Mpa		Poisson Ratios		Shear Modulus, MPa	Volume weight	Adhesive force, Mpa		Internal friction angles, degree	
		E_1	E_2	ν_1,	ν_2,	G_2	γ	C_1	C_1	φ_1	φ_2
1	Clay loam	30.0	15.0	0.36	0.24	7.60	2.00	0.03	0.06	19	23
2	Ground	10.0	20.0	0.30	0.40	7.40	1.90	0.080	0.120	20	24
3	Fine sand	81.3	85.0	0.28	0.30	32.70	2.11	0.002	0.002	35	37

Source: [1].

The dimensions of the computational domain are shown in Figure 6: basement height of 5 m, the length of the foundation is 15 m, the width of the calculation field on the earth's surface -40 m, base width of the computational domain is 30 m, the width of filling materials 3 m, height of the computational domain -15 m.

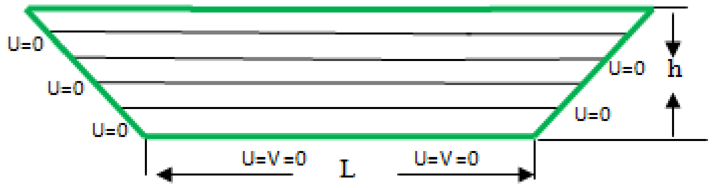

Figure 6. Calculation scheme for determining the deformation fields of horizontally layered soil before the development of the pit

After that, the finite element studies to determine the regularities of the stress state of the soil of the construction site, the angle for the theoretical calculation of the change from zero to 90^0. See Table 1 for the values of physical and mechanical properties of real soils with anisotropic structures. The results of calculations to determine deformation states for different angles of layers are shown in Figures 7-9 below.

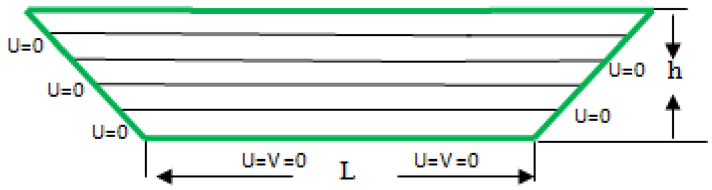

Figure 7. Calculation scheme for determining the deformation fields of horizontally layered soil before the development of the pit

Note: black dots are the points of analysis. L – left, C – Central and R – right point.

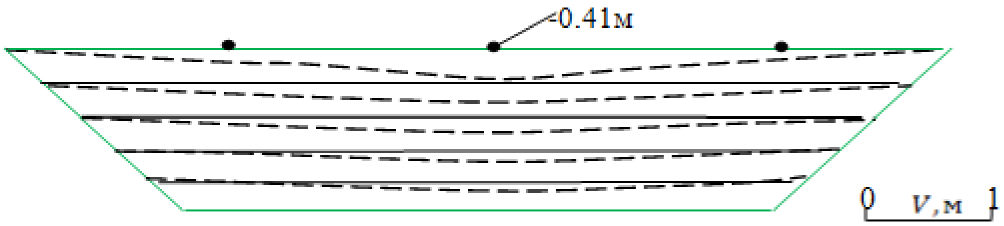

Figure 8. Elastic deformation of the bases at horizontal stratification, φ=0

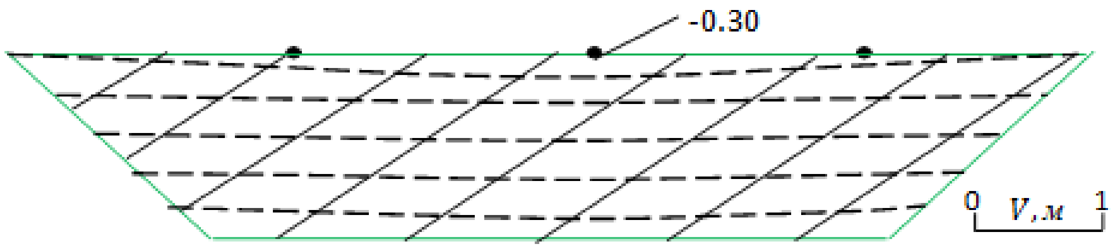

Figure 9. Elastic deformation of the anisotropic structure bases. The angle of inclination of the plane of isotropy-φ=45°

The dimensions of the computational domain, shown in Figure 5: basement height of 5 m, the length of the foundation is 15 m, the width of the calculation region on the earth's surface - 40 m, base width of the computational domain is 30 m, the width of filling materials 3 m, height of the computational domain -15 m. After that, the finite element studies to determine the regularities of the stress state of the soil of the construction site, the angle for the theoretical calculation of the change from zero to 90^0. The results of calculations to determine deformation states for different angles of layers are shown in Figures 8-10.

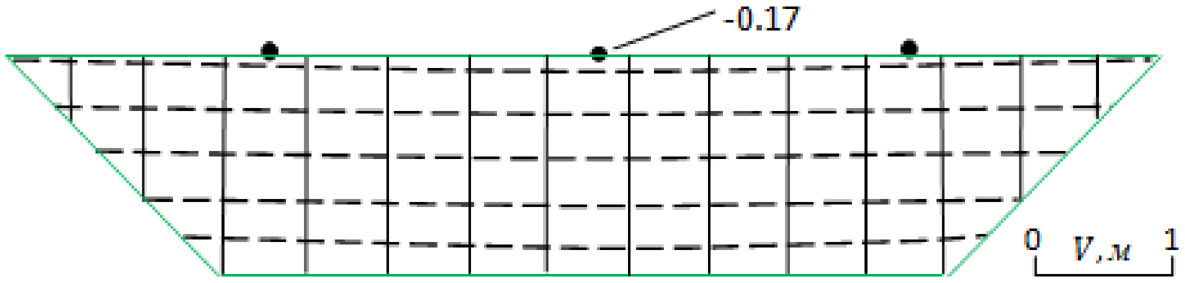

Figure 10. Elastic deformation of the bases of an anisotropic structure. The angle of inclination of the plane of isotropy is φ=90°

From the diagrams of the displacements of Figure 7, we note that the maximum deformation of the entire body of the base downwards is symmetrically vertical with respect to the axis and the surface of the base. The maximum deflection of the vertical component of the central point on the earth's surface of the foundation, marked with a black point, is V=0.41 m. Consider the case of vertical stratification. Although rare in nature, there are such structures with nearly vertical strata on the steep slopes the type of Koktobe in Almaty city (Figure 8). On their slopes of the sunny side every year more and more houses and various engineering structures are built.

The analysis of these diagrams shows that the soils on the basis of structures on the construction site in the natural state have heterogeneous deformations. The steeper the occurrence of soil layers, the smaller the amount of deformation. Thus, with the help of the proposed new calculation model of the soil, the regularities of the deformed state of the sloping base of the construction site structures are clarified.

4.2. Calculation of the influence of the foundation on the soil deformation of the base with inclined layered structure

Let us turn to the second task. For structural elements of the foundation the following values of physical and mechanical properties are valid: E=1.704·10^4Mpa, ν=0.25, γ=2.5·10^2 Mn/m^3. For ground base the same data remains. For filling materials: E=0.60·10^4Mpa, ν=0.28, γ=2.3·10^2 Mn/m^3. To analyze the deformation fields we select some characteristic calculation points. These points are shown in Figure 11.

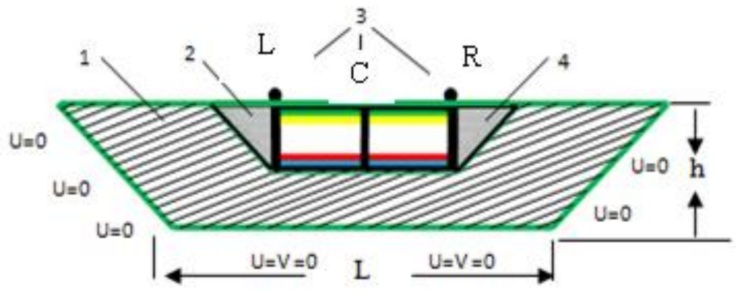

Figure 11. Calculation model for a problem of fundament – inclined-layered soil base

Note: These three points, which are on the surface of the foundation, marked with letters: L – left; C – central and R – right, relative to the central vertical axis: their locations are shown in black circles.

Physical and mechanical properties of the massif: elastic constants and volume weight for the massif of isotropic structure are: E=1· 10^2 Mpa, $\nu = 0.2$, $\gamma = 2.0 \cdot 10^{-2}$МН/м^3. Such parameters for an anisotropic structure massif are equal to: $E_1 = 0.576 \cdot 10^2$Mpa, $E_2 = 0.256 \cdot 10^2$Mpa, $\nu_1 = 0.31$, $\nu_2 = 0.28$, $G_2 = 0.12$Mpa and volume weight – $\gamma = 2.2 \cdot 10^{-2} MH/м^3$. For this calculation area, the previous breakdown is left: 9604 finite elements with 9801 nodal points. The results of the determination of different deformation states of the own weight of the soil and the foundation structure are shown in Figures 12-17.

To compare the differences between the soil of isotropic structure and the soil of anisotropic structure, deformation state of the soil of homogeneous isotropic structure is separately investigated. Physical and mechanical properties of soil with such structure are equal to: E=0.71·104Mpa, v=0.31, γ=2.0·102 Mn/m3. Since the horizontal stratification (angle φ=0) area has an elastic symmetry, the deformation field will also be symmetrical, and with isotropic homogeneous soil will be more symmetrical. Therefore, Figure 6 shows the line in red on the right half of the axis of symmetry, the plots for the isotropic variant, and the plots for the anisotropic variant on the left.

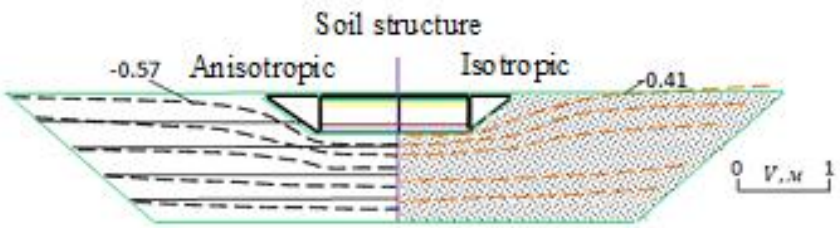

Figure 12. Comparative plot of displacement (deformation) of the soil and the foundation

The results correspond to: the left part – to the soils of an anisotropic horizontally layered structure (φ=0), and the right part – to the isotropic structure. Although soils have approximately the same elastic properties, due to the stratification and anisotropy, the left part is deformed more than the right one.

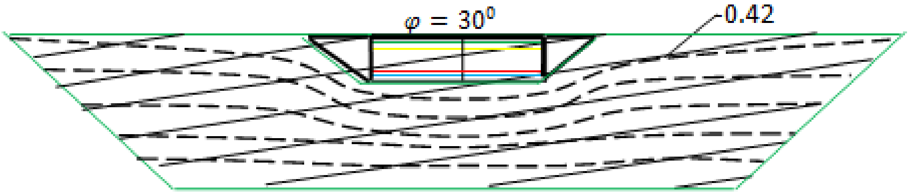

Figure 13. Diagrams of displacements (deformation) of the foundation and soils of the inclined-layered structure (φ=30°)

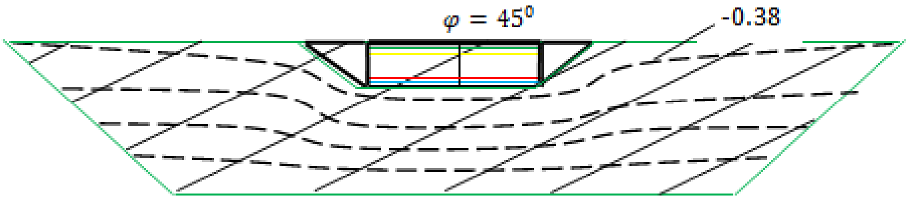

Figure 14. Diagrams of displacements (deformation) of the foundation and soils of the inclined-layered structure (φ=45°)

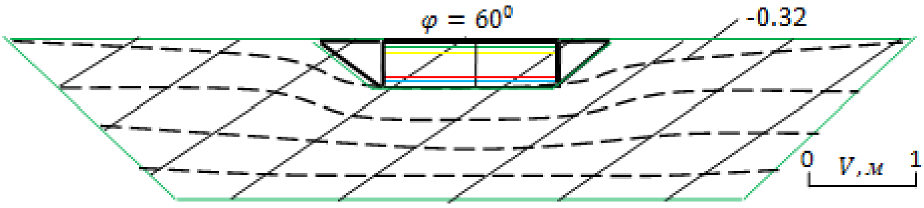

Figure 15. Diagrams of displacements (deformation) of the foundation and soils of the inclined-layered structure (φ=60°)

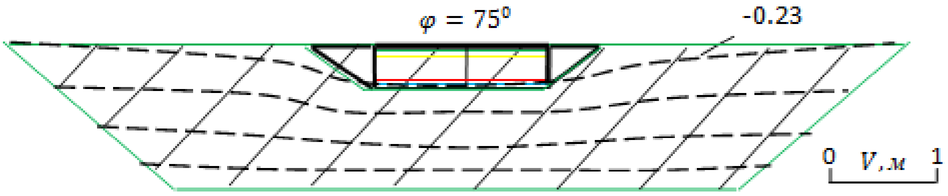

Figure 16. Diagrams of displacements (deformation) of the foundation and soils of the inclined-layered structure (φ=75°)

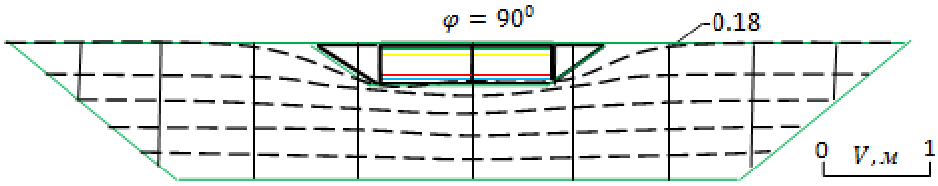

Figure 17. Diagrams of displacements (deformation) of the foundation and soils of vertically layered structure (φ=90°)

The largest strain on the diagrams is observed when the angles of the layers are closer to the horizontal stratification. The lowest deformation occurs at vertical stratification, at φ=90°. Thus, using the proposed calculation model of soil structure studied basic regularities of deformation as under foundation subgrade depending on the magnitude of the angle of the foundation soil. It is important to consider when designing a foundation of a high-rise building and structures.

4.3. Calculation of deformation states of the “building – foundation – base” system

The initial data of the problem for calculations and calculation algorithms for the five types of loads were presented in the second section. Figures 18a and 18b show the design area of the system consisting of the building, bases and foundations horizontally (left figure) and inclined-layered (right figure).

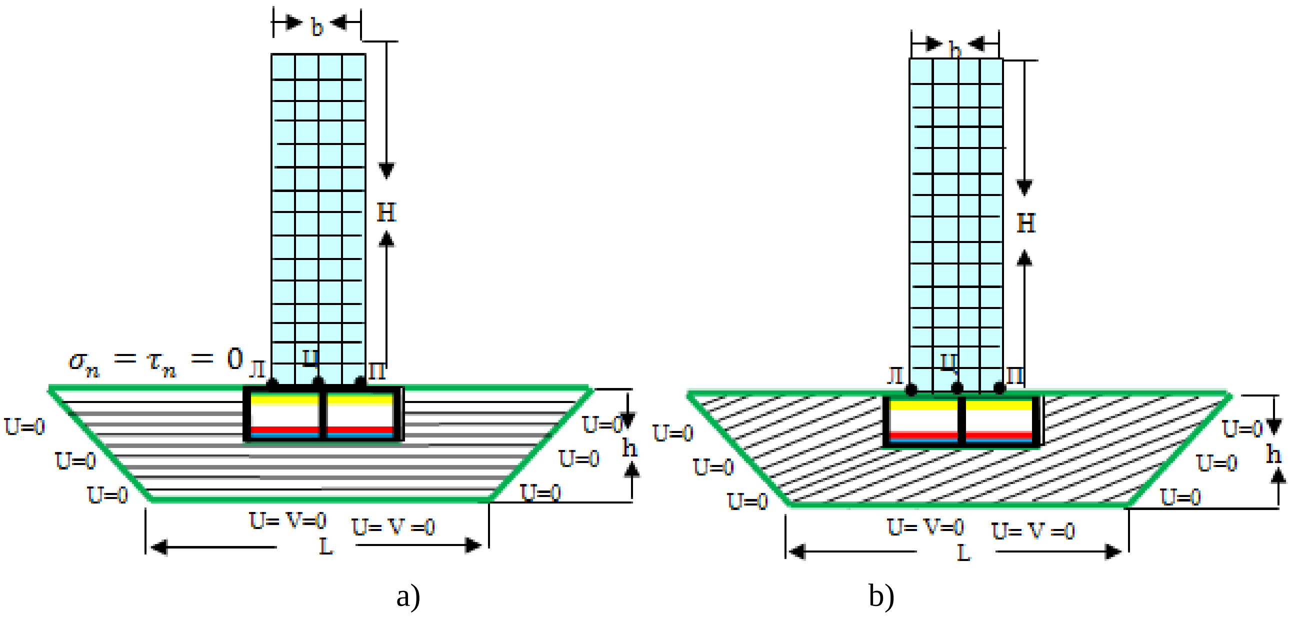

Figure 18. a) horizontally layered variant (left picture) and b) inclined-layered base (right picture)

Black circles on the base of the building show the points selected for the analysis. Here are shown mixed boundary conditions of the problem, which are given by the stress components σ_n, τ_n for the free earth surface and displacements u, v at the lateral boundaries and on the lower base. Due to the large size of the stiffness matrix of the system, an algorithm for dynamic shift of the RAM segment is developed. The analysis of the results is shown in the form of dependency graphs for displacement fields and stress plots. The main factor affecting the stress concentration is the angle of the layers. Calculations for all 5 problems were carried out with a step φ=5°. Figures 19-21 show the deformation diagrams in the form of displacement components obtained from the action of these forces, omitting the presentation of the algorithms of the impact of wind forces.

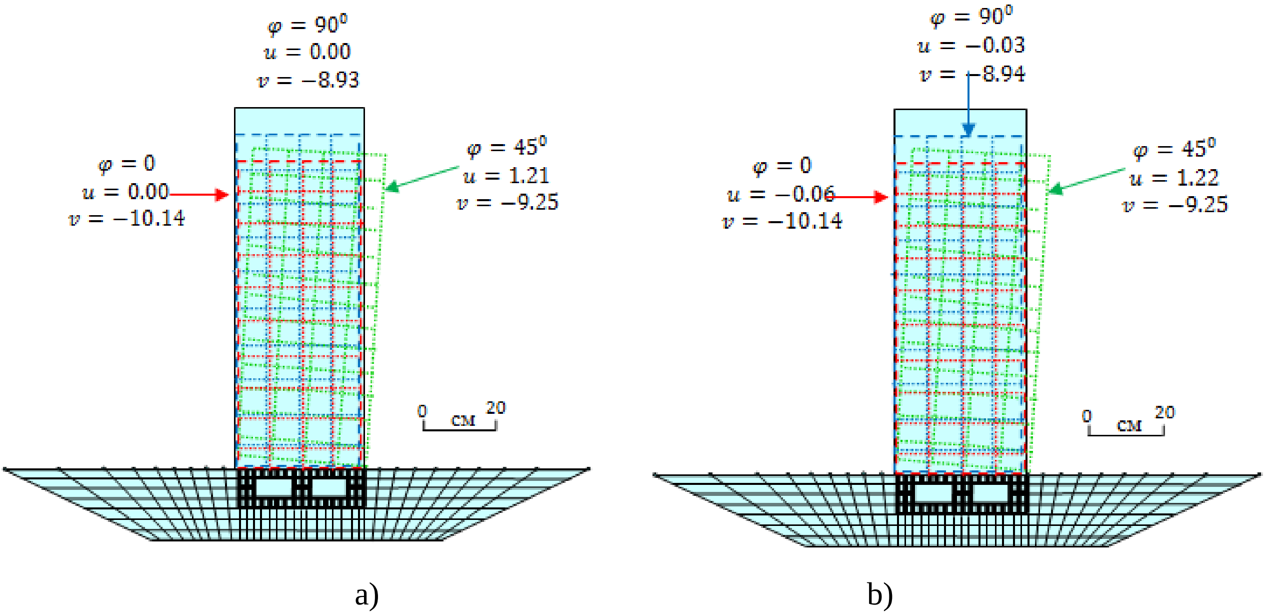

Figure 19. The left (a) figure shows deformation states of the building from the loads of its own weight, at different angles of the isotropy plane of the ground layers at the base: φ=0, φ=45° and φ=90°; the right (b) figure shows deformation states of the building from the load of tectonic compression at different angles of the isotropy plane of the ground layers at the base: φ=0, φ=45° and φ=90°

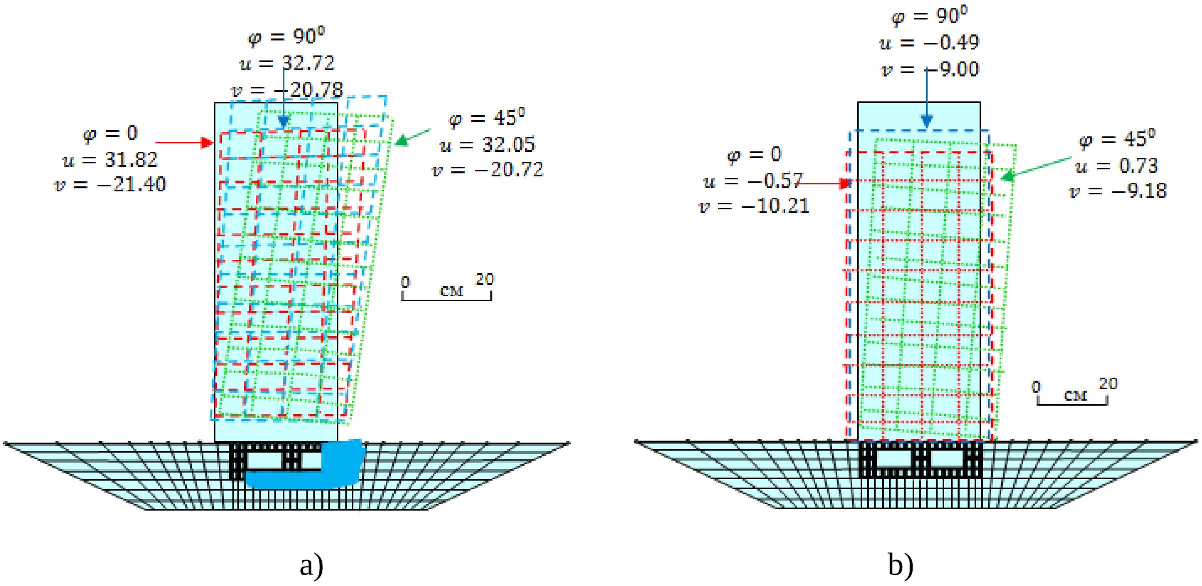

Figure 20. The left (a) figure demonstrates deformation state of the building from the load of its own weight, taking into account the hurricane pressure on the wall of the building on the left side at different angles of the plane of isotropy of the ground layers at the base: φ=0, φ=45° and φ=90°; the right (b) figure shows deformation state of the building taking into account the water saturation under the foundation of the soil base with the right base at different angles of inclination of the plane of isotropy of the soil layers at the base: φ=0, φ=45° and φ=90°

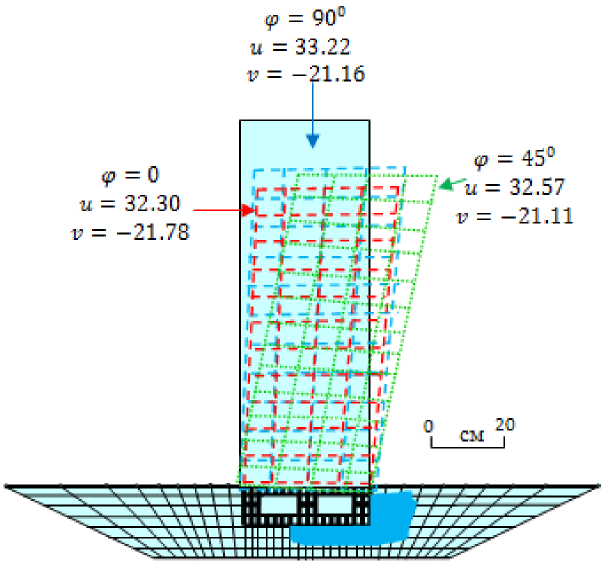

Figure 21. Deformation conditions of the building from the complex of geostatic, gravitational, tectonic, wind loads and water saturation of the soil bases at different angles of the plane of isotropy of the soil layers at the base: φ=0, φ=45° and φ=90° the stability of the system building – foundation – pan-layered anisotropic basis

5. Conclusions

The study and systematization of physical and mechanical properties of soils of heterogeneous structure are typical for the construction sites of Almaty consistently solved the problem of determining the SSS (stress-strain state) on geostatic, gravitational, tectonic, wind and hydrostatic loads. It was found that the values and the nature of the deformation of the intact soil with the isotropic and anisotropic structures are different. In all variants of water penetration to the base of the building leads to its deviation from the center of gravity. This scenario was observed during the collapse of the houses of the neighborhood "Besoba" in Karaganda. The results of our calculations coincide with the value of the inclination on 32 cm 9-storey building in Algabas – 6 microdistrict in Almaty. By conducting research and multivariate calculations it was discovered that the greatest danger to the collapse of the building are hidden penetration of water to the base of the foundation.

Thus, the studies conducted by modern methods of mechanical and mathematical modeling and numerical methods of calculation, the coincidence of the results (34 cm) with the observed (32cm) and the measured values of the inclination of the building of houses "Algabas" of Almaty city shows high reliability of the results. As a result of the study the analysis allows to develop the next mathematical model step of management of the state of stability of high-rise buildings and structures.

6. Acknowledgments

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