The algorithm for solving the problem of accounting work of system “foundations-load-bearing floor” with phased modeling in modern CAD

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Abstract. For buildings, that have shallow Foundations under columns and Load-bearing floor the mutual influence of these structures on each other is characteristic. The Foundations of the frame are forced to perceive additional loads from Load-bearing floor. Load-bearing floor gets non-uniform deformation, occurring from the supporting influence of Foundations. This leads to a change in the character of distribution of internal bending moments in the Load-bearing floor. To take into account such a complex mutual influence of these constructions in the one calculation model is difficult. To solve the problem, it is suggested to use a special algorithm. An algorithm for a phased solution to the problem of calculating the system “Foundations – Load-bearing floor” is suggested. It allows to take into account the features of the real work of constructions. The case of shallow Foundations and a Load-bearing floor is considered. In this case plate loads the Foundations, and Foundations limit plate displacements. The problem was solved by computer modeling of the system deformation process “Foundations – Load-bearing floor”. The plate of the Load-bearing floor is considered as a plate on elastic foundation with a restriction of deformation in places where pad foundation under a column are connected. The influence of Foundations on the Load-bearing floor displacements restriction was modeled by connection of the final stiffness. The problem is formulated as linear. The task solving was made in program complex “Lira”.

1. Introduction

Industrial enterprises often need to build new or reconstruct existing buildings. Such a need occurs in the case of, for example, new production launch. There are production in which large loads are supposed to be transferred to the floors of the building. This is especially true for warehouse buildings, factory buildings, buildings with heavy equipment installation. In the described conditions for the perception of large loads, the floors perform a special design. Floors are made of concrete with calculated reinforcement. Floor of such construction is called “Load-bearing floor” [1-4].

Usually Load-bearing floor of the building and supporting frame of the building are made separated from each other. In this case, expansion joint are used. The specified separation allows you to reduce the impact of loads from the floor of the building on building supporting frame foundations. This is especially important when using shallow foundation. For these foundations, it is impossible to completely avoid the effect of floor loads on the frame foundations. In such situation, it is necessary to solve the task associated with the problem of additional loading of the frame foundations at the design stage. Floor loading is additional for building frame foundations. A feature of this load is the
remoteness in time of its occurrence. This load shows its influence on the frame foundations in stages. First comes the load from the weight of the floor during its manufacture, during the construction of the building. Then there is a load from heavy equipment, materials and technics, that is, a load during the operation of the building. At the same time, the load that appears during the operation of the building has a significantly larger value than the weight of the floor.

The load, delayed by the time of occurrence, is applied to the steady state of the base-foundation system. This means that the new load is able to change the stable state of existing foundations of the building frame. In this situation, significant precipitation of frame foundations is possible, including uneven. Taking into account history of loads application is possible by applying the step-by-step modeling algorithm. The algorithm involves a series of calculations. Each calculation should model a specific stage of loads application. In each calculation, changes in the deformation properties of the base-foundation system must be taken into account. The following is an example of solving this problem using modern CAD tools.

2. Materials and methods

During designing a new production building (figure 1), the authors implemented an algorithm for phased modeling of the calculation model “Foundations – Load-bearing floor”.

![Figure 1. The model of “Foundations – Load-bearing floor”](image)

Task description. The researched building has a metal supporting frame. Under the columns of the building are columnar shallow foundation. The building is intended for the production of sunflower oil. Planned output is 50 tons of products per day. The processing line is equipped with heavy facilities. According to the task, the equipment is installed directly on the floor of the building. Load
of equipment has uneven character. The placement of equipment is uneven in the area of building (figure 2). Floor loads range from small concentrated masses to large distributed masses. Of the most significant loads, the loads from the frame bases with floor installation of containers with a volume of 20 m$^3$ each stand out. The accepted scheme of building floor loading leads to uneven loading of the building floor structure and soil under it.

Figure 2. Scheme for applying loads to the Power floor Load-bearing floor.

Obtaining an engineering design solution was preceded by numerical researches of the system “Foundations – Load-bearing floor”. Taking into account the proximity of the relative position of the frame columns and equipment on the floor of the building. The presence of building Foundations additional loading influence from the Load-bearing floor is well illustrated in the diagram (figure 3). The influence of building foundations on stress-strain state of the Load-bearing floor becomes apparent when a significant difference in the values of their deformations is detected. The settlement of building foundations and deformation of the Load-bearing floor depend on the loads, the characteristics of the base soils, the geometry of the foundations and the rigidity of the Load-bearing floor. It is possible to take into account such a complex mutual influence of foundations and Load-bearing floor on each other only by phased modeling [3-6].

Figure 3. Loading/deformations scheme of the “Foundation and Load-bearing floor”.

The authors suggested an algorithm for phased modeling of the calculation model “Foundations – Load-bearing floor” (figure 4). The algorithm provides determination of the foundations required characteristics at certain points in the life cycle of the calculation model. As a separate stage of modeling, the task of determining the required characteristics of calculation model under known
conditions of its loading and known initial parameters of the model is taken. In total, three stages were analyzed. Each stage corresponded to a specific moment of the researched building loading. The implemented algorithm assumed a gradual refinement of calculation model reaction to changing loading conditions. When simulating the calculated load, the sequence of their application was taken into account. At each modeling stage, the question of need to adjust the geometric characteristics of building columns foundations of the accepted at the previous stage was decided. During implementing the described algorithm, the adjustment of accepted decisions characteristics made by the elements of the computational model located above the foundations was not considered.

Figure 4. Step-by-step modeling algorithm for the “Foundations – Load-bearing floor” system.

Calculations that did not take into account the influence of Load-bearing floor on the building columns foundations were taken as the first stage of modeling. For the first stage, it is assumed that there is no influence of the Load-bearing floor on the condition of the building frame foundations. A similar situation is possible while providing a full guarantee of independence of the frame and Load-bearing floor from each other. At the first stage, an analysis of a three-dimensional rod model of the building frame on the effect of static and dynamic loads is made. The specified calculations were performed using the calculation complex “Lira”. The characteristics of the aerial part of the building and the
required characteristics of the foundations for the building columns were determined. As a result of the analysis, design characteristics of building frame and its foundations were determined. In further studies, characteristics of the building frame were not taken into account and did not change. In further studies, adjustments were made only to characteristics of foundations under columns of the building.

At the second stage of modeling, a new calculation model was created. The new model was made only for reinforced concrete floor plate. Calculation model based on plate finite elements (FE) was made in program complex “Lira”. The model is a plate on an elastic base. Elastic foundation simulates soil properties. The properties of the soil were taken under the assumption that it works as a linearly deformable half-space. The design characteristics of the soil were determined as a result of engineering and geological researches at the construction site. Soil properties were included in the calculation model by assigning the stiffness coefficients of the elastic foundation to the finite elements (elastic bed coefficient). The foundations of the building frame were modeled with special finite elements. In program complex “Lira” there are special finite elements – a single-node finite element of elastic connection. These FE were used to model the foundations for the columns of the building (figure 5). The model was designed for loads from the building frame and the weight of the reinforced concrete plate. The load from the frame is accepted according to the results of first stage model calculation. The load due to the weight of the plate was inputted as evenly distributed. As a result of the second stage model analysis, the deformations of the plate, the movement of the building foundations were determined, and also new characteristics of the foundations and the required rigidity of the plate were calculated.

![Figure 5. Calculation model of a plate with columnar shallow foundations.](image)

At the third stage of modeling, the following adjustments were made to the plate calculation model. Added technological loads on the power plate. Added information about the movements of the frame foundations. Corrected information on the elastic characteristics of FE modeling the foundations. Corrected the elastic bed coefficient for FE, modelling the plate. The elastic characteristics for the frame foundations and elastic bed coefficients for the plate were calculated in the second stage of calculation. As a result of analysis of model at the third stage, final thickness of plate, its reinforcement and design deformations were determined, and final characteristics of the building foundations, their design displacements were calculated.

### 3. Results and discussions
The constructive solutions of Foundations and Load-bearing floor obtained by the suggested algorithm allowed to take into account all possible negative factors. At the final stage of the modelling, the reinforcement of the plate of the Load-bearing floor was calculated. Plate reinforcement was calculated twice. First, without taking into account the influence of building frame foundations
rigidity, that is, for a model of a plate on an elastic foundation with the same rigidity characteristics under the entire plate. Then, taking into account the influence of building foundations rigidity. It was found that reinforcement is required more for the plate, calculated taking into account the influence of foundations rigidity. This is explained by presence of more stiffness characteristics of plate areas at foundations. The greater stiffness of these areas is estimated in comparison with rigidity of base under the rest of the plate. Foundations support the plate [7, 8]. Moreover, the values of bending moments in the plate are greater than when it is freely supported on the ground. Increase in bending moments leads to increase in the design reinforcement. Increase in the estimated reinforcement of the plate was 30%.

Obtained at the final stage of the computational model deformation calculating were acceptable small values. The supporting effect of building foundations can significantly reduce the amount of Load-bearing floor deformation. On figures 6, 7 the values of plate deformations are presented, calculated without taking into account and taking into account the influence of foundations. The difference in the maximum deformation values was 88.56%.

Figure 6. Calculation of the plate on an elastic base without taking into account the influence of the rigidity of the foundations of the building frame.

Figure 7. Calculation of the plate on an elastic base, taking into account the influence of the rigidity of the foundations of the building frame.

4. Conclusions
The research allowed to make the following conclusions:
1. The suggested stage-by-stage modeling algorithm allows to take into account the complex mutual influence of Foundations and Load-bearing floor on each other.
2. Taking into account the mutual influence of the building foundations and the Load-bearing floor plate can significantly change the distribution of internal forces in the plate and as a result of its reinforcement. For the presented example, the change in reinforcement was 30%.
3. Taking into account the mutual influence of building foundations and plate of Load-bearing floor can significantly change the expected deformations of the plate and Foundations. For the presented example, the change in the values of plate deformations was 88.56%.

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