Modeling of foundation slabs of buildings on complex foundations

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Abstract. The paper considers the problem of calculating the strength of foundation slabs under seismic and wind loads. As an example, a numerical model of a hotel building to be built on bulk islands is presented. The calculation of the foundation slab model is performed using the STARK ES software package. The results of the calculation are analyzed and recommendations for strengthening the foundation are given.

1 Introduction

Construction is being carried out in more and more difficult areas: with increased wind, snow and seismic loads, with difficult soils, etc. At today's pace of construction development it is necessary to keep abreast of developments. In a very limited time the variety of forms and types of buildings erected has increased several times. Recently, more and more unique buildings have begun to be erected on complex bases, such as bulk islands.

Modeling such structures involves a great deal of scientific work necessary to minimize the risk of building collapse, as well as to extend the life of buildings [1-4].

The study of foundations, as one of the main load-bearing structures of the building requires increased attention. A correct and detailed calculation of the foundation can often save a lot of money during the construction.

This paper considers the problem of calculating the foundation slab of a hotel building located on a bulk island, in order to identify weaknesses in buildings with complex foundations.

2 Foundation calculation

2.1 The raw data

The building is located on the dried land of the Caspian Sea. The construction site is located on a 160m x 80m plot, oriented to the east-west and north-west directions. The hotel building is a 29-story crescent-shaped tower 150.7 m high with a 4-story podium structure and 2 basement levels. The hotel is connected to the shoreline via a bridge and a tunnel. The total area is about 120.000 m^2.

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The building is designed according to the scheme of the frame-braced frame. The main load-bearing structures: columns and floor beams, stiffening cores, floor slabs and basement structures are designed from monolithic reinforced concrete; steel columns and beams for the top of the hotel building.
The structural stability system consists of stiffening cores running from the foundation slab to the top of the building. The stiffening cores house eight elevators, three of them panoramic and two for maintenance. The cores also provide access to the stairs.
The cores consist of walls that transmit vertical and horizontal forces to the foundation. In addition to the walls, the slabs are supported by vertical and inclined columns.
The main cores (17.40 m x 14.40 m) form a rectangular shape. The thickness of the outer walls of 800 mm, the inner walls of 300 mm.
The foundation of the building is a solid monolithic slab, resting on a pile foundation. The thickness of the slab 2650 mm, 2900 mm under the towers and 750 mm, 1000 mm and 2350 mm for the rest of the building.
The piles have a diameter of 1.5 m under the foundations of the towers and 2.0 m under the podium/basement.
The roof of the podium consists of a steel structure and its cladding, glass facade and is circular in shape.
The towers are connected by a 90 m steel truss. The truss supports the slabs and connects the two stiffening cores. At the junction the height of the truss is 7.6 m, at the center it is 20.45m.

2.2 Calculation model

In order to assess the reliability of the structural solutions adopted in the project, a verification calculation of the spatial model of the structure for the design loads and impacts was performed. The calculation was performed using the STARK ES software package.
This software package was chosen due to the fact that it is able to work with models that include a large number of elements, while not requiring huge computing power. Also, STARK ES offers convenient principles for working with the finite element mesh, which is a huge advantage with such an object size. Another feature of the program is the large number of utilities, "helper" programs, which greatly simplify the process of model creation [5].
The spatial shell-and-string model is used as the calculation model, in which the load-bearing columns, beams and truss elements are represented by rod elements of a general form, while the cover shell, floor slabs and walls are represented by elements of a flat shell (Fig. 1).
The main feature of the building is its location - a bulk sand island, which has been accounted for by a non-linear model of the soils of the building base. The foundation of the building is a pile foundation, the piles are 1500 mm to 2000 mm in diameter and up to 76.1 m long. They were modeled with rods to fully convey their work in the ground [6].

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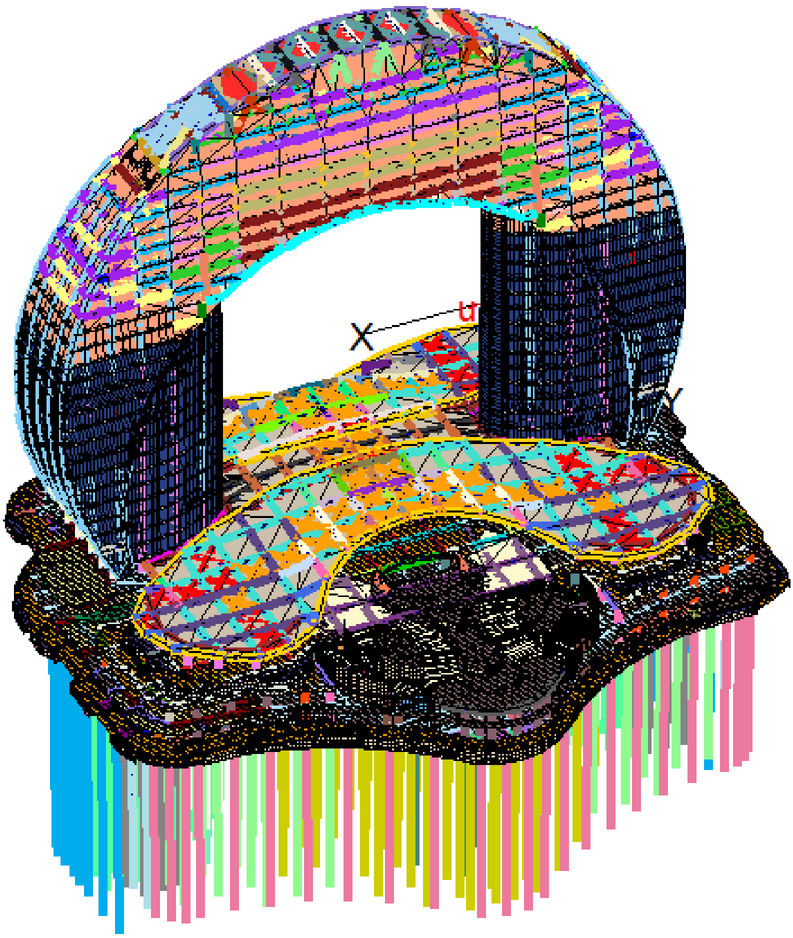

Fig. 1. Overall model

2.3 Design loads

Since the structure has an increased level of responsibility, the values of reliability coefficients are as follows [7-9]:

– in the calculation of forces and stresses (according to the first group of limiting states) in the building structures, foundations and foundations of the building, is assumed to be γ_n=1,1;
– in determining the displacements (in the second group of limiting states) of structures and deformations of the foundation, is assumed to be γ_n= 1,0;
– in the calculation of emergency impacts ("progressive" failure) and seismic impacts is assumed equal to γ_n=1,0.

Uniformly distributed temporary loads on the floor slabs are assumed in accordance with the purpose of the premises. Load capacity factors γ_f and load combination factors Ψi are assumed in accordance with the requirements.

The following loads and influences are taken into account in the calculation of the structure:

- vertical constant loads from the own weight of the load-bearing and enclosing structures of the building;
- long-term loads from the engineering equipment;
- temperature loads;
- snow load;
- average and pulsating components of wind loads (type of terrain A);
- seismic impact for the eighth grade area.

2.3.1 Snow loads

Snow district I - the calculated value of the weight of the snow cover per 1 m^2 of the horizontal surface is 0.8 kPa.
In the calculation model, the application of the snow load is made with a uniform load on the entire surface of the building cover. Snow bags are taken into account in accordance with the norms.

2.3.2 Wimd loads

The normative value of the average component of the wind load at height z above the ground:

$$w_m = w_0 k c \tag{1}$$

Wind region VI. Type of terrain A.
Normative value of wind pressure is $w_0 = 0.73$ kN/m^2.

2.3.3 Seismic loads

The building is located in an earthquake-prone area, so the calculation of resistance to such loads is extremely important. Many papers are devoted to the problem of modeling earthquake-resistant buildings [10-16].
Seismicity of the construction site is assumed to be 8 points (recurrence of 1000 years). Ground class according to seismic properties - III.
The vector of seismic forces on the i-th form of vibration in the j-th direction of the progressive seismic action is determined by the formula:

$$\{\mathbf{S}_{ij}\} = I_d \cdot [M]\{\eta_{ij}\}\beta_i, \tag{2}$$

[M] – matrix of the structure masses, calculated taking into account the design vertical loads on the structure and the coefficients of combination of loads;
$\{\boldsymbol{\eta}_{ij}\}$ – vector of coefficients of the form of oscillations;
β_i – dynamism coefficient corresponding to the period of oscillation of the form i (Fig.2).

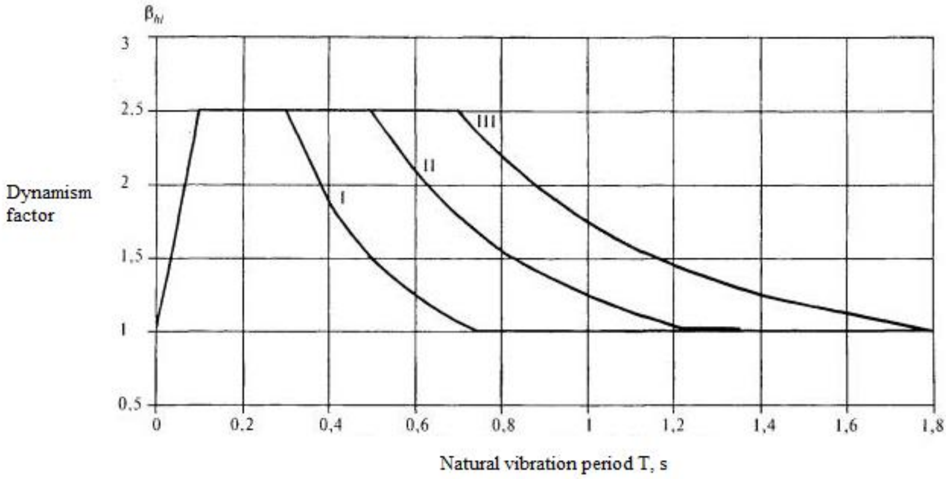

Fig. 2. Dependence of the dynamism coefficient value on the soil category

In determining the intensity of the seismic effect, appropriate coefficients are taken into account.
I_d - calculated intensity of seismic impact:

$$I_d = k_1 \cdot k_2 \cdot k_3 \cdot k_\psi\ k_q \cdot a_0\ g \quad [m/s^2], \tag{3}$$

where
k_1 – coefficient, taking into account the degree of responsibility of buildings and structures. Due to the increased level of responsibility of the building, the coefficient is assumed to be 1.1;
k_2 – coefficient, taking into account the structural solutions of buildings and structures. Since the building is a structure with a reinforced concrete frame with various connections, the coefficient is taken equal to 0.3;
k_3 - coefficient, taking into account the height of buildings and determined by the formula:

$$k_3 = 1+0,02\ (n-5) = 1,25; \qquad 1,0 \le k_3 \le 1.25 \tag{4}$$

here n = 32 is the number of floors;
k_ψ – coefficient that takes into account the energy dissipation capability of buildings. It is taken equal to 1.2, as the building is a frame building and the filling of its walls does not affect the energy dissipation;
k_q – coefficient of soil conditions is taken equal to 1.3, because the building stands on medium density water-saturated sands;
a_0 – normative seismic coefficient, the value of which should be taken equal to 0.25 for the seismicity of the area of 8 points.
As a result, the value of intensity of seismic effect is obtained as follows
I_d = 1.61 [m/s^2].

2.3.4 Scheme of application of some loads to the calculation scheme

A loads scheme on the building structure from living quarters is shown in Fig. 3. Also flat elements with zero thickness were added to the model (Fig. 4) in order to set the wind load on them. With these elements, the STARK ES software package correctly accounts for the eccentricity of the applied load, which allows for a more accurate transfer of the load to the building structure.

It is worth mentioning that the software package takes into account the possible eccentricity of the load in any flat element load application.

The seismic load was applied with the help of internal utilities of the program, which allowed to exclude the human factor, as well as to approach the issue of modeling accuracy in a deeper way.

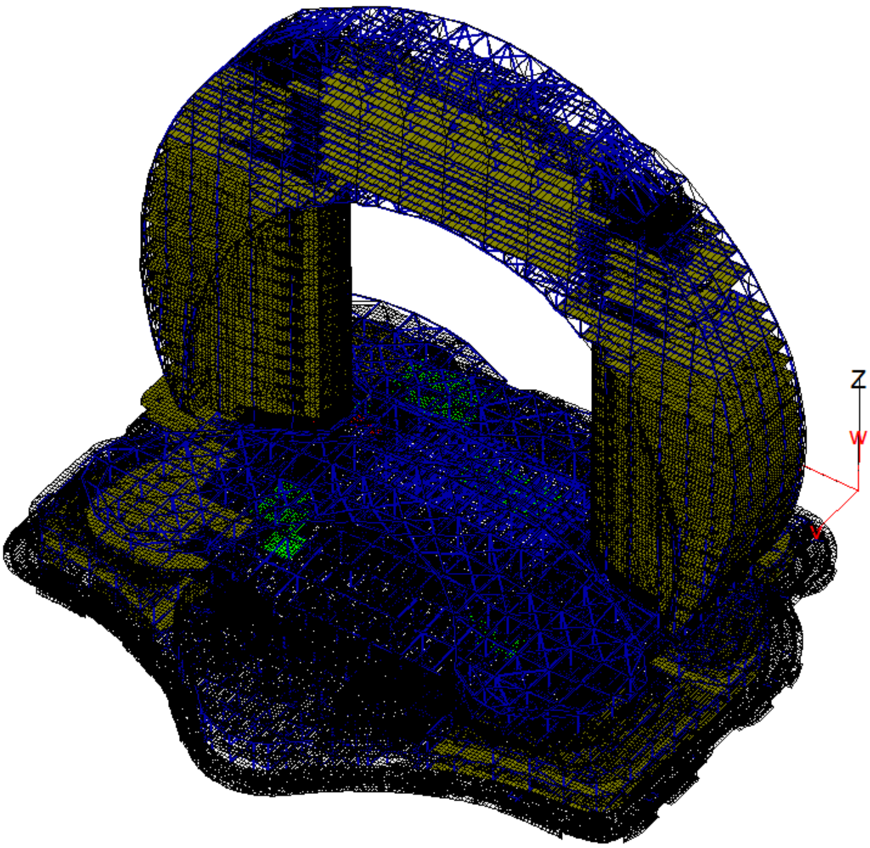

Fig. 3. Loads from living quarters

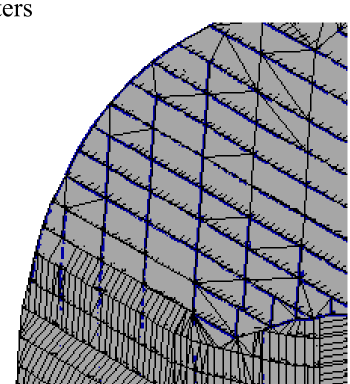

Fig. 4. Fragment of a building with flat elements

2.3.5 Foundation settlement

The foundation settlement was estimated for the main combinations of the full values of the regulatory loads.

The foundation slab was modeled using flat shell elements. The piles were created using rods, and the ground was set using a nonlinear formulation. This way of representing the elements of the structure allows the most accurate modeling of the actual joint operation of the structure. Also, as mentioned above, all kinds of eccentricities associated with the loads were taken into account, which increased the accuracy of the results obtained.

The maximum value of the relative difference of settlement from the main combinations of loads is s/L (the maximum length of the building)=0.00027, which in practice turns out to be an admissible value; however, the structural calculation and the selection of reinforcement has shown that it is insufficient (Fig. 5).

The calculation also shows that it is necessary to increase the number of longitudinal reinforcement, especially in the places where the columns are installed.

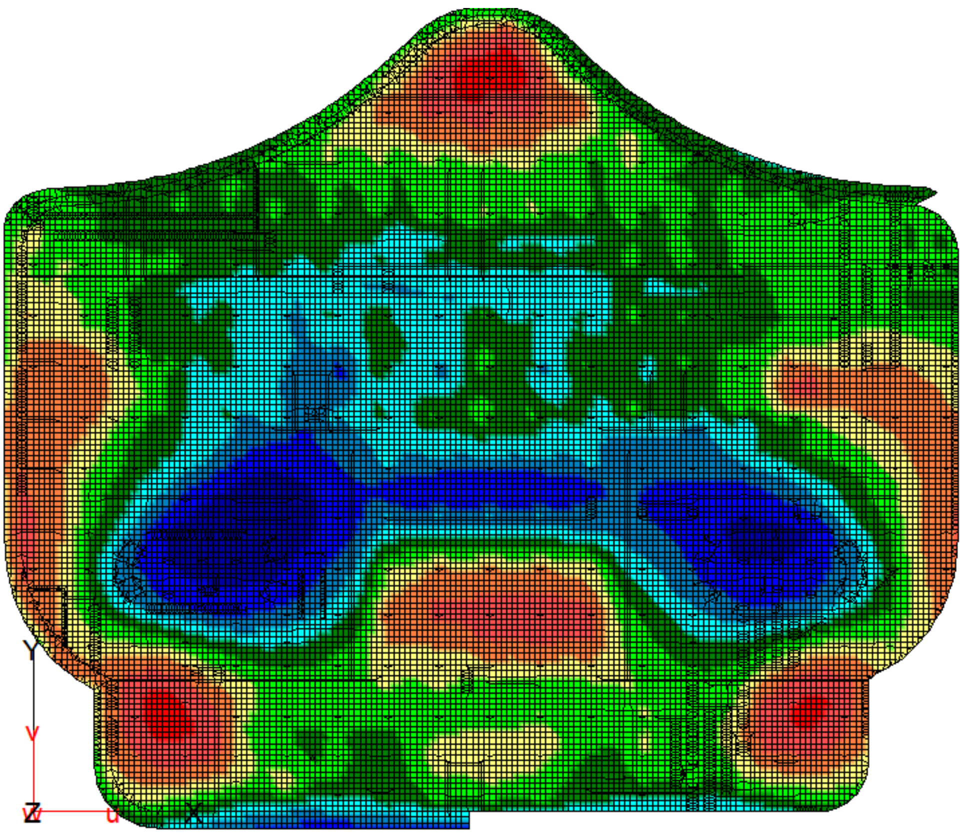

Fig. 5. Structure foundation settlement

3 Results and conclusions

The calculation of the foundation slab of the hotel building is performed. Reinforcement of the foundation slab with a thickness of 750 mm is shown.
The results of the calculation show that, although the foundation settlement is less than the permissible values, but the designed amount of reinforcement is not enough to provide the necessary conditions for the operation of the building.
The solution to this problem appears to be either an increase in the amount of reinforcement, or a reduction in the number of floors of the building, as a consequence of the load on the foundation slab, which will reduce the amount of reinforcement needed to fully operate the building in all conditions.

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