Calculating the Strengthening of Construction Structures Before the Reconstruction of the Building

A. N. Neverov, P. S. Truntov, E. S. Ketsko, and V. I. Rimshin

Abstract At present, are many buildings of various purposes are in operation. Many of these buildings are in unsatisfactory condition after 15–20 years of use and need to be repaired. In addition, due to changes in process flow and structural load, it is also necessary to strengthen the building structure during renovation. It is of great significance to strengthen of the building structure, because the further technical condition of the building or building depends on timely repair. In the design of reinforced building structure, an important stage is to evaluate the technical condition and suitability of each component of the building. The emphasis this work is devoted to the process of designing and calculating the foundation slab, reinforced using the method of one-way build-up. The building has six floors, with an overall dimension of 63 × 66 m. The spatial rigidity of the building is provided longitudinal and cross walls, columns, slabs and roofs, as well as the foundation. The «LIRA-SAPR» and «STATICA» software complexes were used for constructive calculations (checking the carrying capacity of the design elements). This article introduces the calculation scheme of strengthening structure and reviews the calculation method. The results are analyzed, and the general conclusions about the calculation and design of building structural strengthening are obtained.

Keywords Gain calculation · Bearing capacity · Reconstruction · Limiting states · Serviceability

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1 Introduction

The completion and usage of buildings and structures is always accompanied by the occurrence of various kinds of defects and damage to building structures. To ensure mechanical safety and durability of structures, it is necessary to repair and restore load-bearing structures, which in turn can significantly increase the service life of buildings and structures as a whole [1–5].

However, the need to improve the reliability of buildings and structures arises not only when various defects and damage to structures appear. This work considers the adjustment of design solutions caused by a change in planning solutions, a change in the installation scheme of technological equipment, as well as the device of pits for collecting water in the foundation slab [6–9].

Taking into account the changes introduced for new planning solutions, calculations of load-bearing structures were performed, and the existing design solutions were also corrected.

Within the framework of the study, a six-storey building with dimensions in plan 63 × 66 m was considered. The maximum height is 23.8 m. The building is divided into three blocks. The building frame is made of monolithic reinforced concrete with a slab foundation on a natural base, consisting of a grid of columns with a pitch of 4.7 ÷ 6.3 m and floor slabs [10–15].

Floor slabs are made with a thickness of 0.25 m. Foundation slab is made of monolithic reinforced concrete of class B30, F150, W6 and 700 mm thick. The columns are rigidly embedded in the foundation and interfloor ceilings, made with sections of 0.5 × 0.5 m and 0.4 × 0.4 m.

2 Materials and Methods

The calculation of the building together with the base was carried out in the LIRA-SAPR software package. The modeling of the structural elements of the building was carried out as follows:

- walls, floors, foundation slab are modeled using lamellar finite elements;
- columns and beams are modeled with bar finite elements;
- the decrease in the modulus of elasticity of reinforced concrete structures is taken into account;
- the stiffness characteristics of the foundation (variable in terms of the bed coefficient $C1$) were determined using the Soil module, taking into account the determination of settlement by the method of linearly deformable half-space. The results of engineering and geological surveys were taken as the initial data for determining the stiffness characteristics of the foundation;
- the reinforcement that directly affects the distribution of forces in the design scheme is taken into account explicitly, meaning that it is performed either by

modeling the corresponding added structural elements, or by changing the sections of existing elements;
- for structural calculations (checking the bearing capacity of structural elements) the software complexes LIRA-SAPR and STATICA were used.

To strengthen the foundation slab, two calculations were performed: the calculation of the reinforced foundation slab for punching and the calculation of the reinforced foundation slab along normal sections.

The STATICA software package was used when calculating a reinforced foundation slab for punching. Within the framework of the calculation, the most loaded (one which had the greatest deficit in bearing capacity according to the results of the verification calculation) support zone of the foundation slab was considered [16–22].

The software package performs the calculation taking into account the action of a concentrated force and bending moments in two mutually perpendicular planes. The calculation results must satisfy the condition:

$$\frac{F}{F_{ult}} + \frac{M_x}{M_{x,ult}} + \frac{M_y}{M_{y,ult}} \le 1, \tag{1}$$

where F, M_x, M_y are the concentrated force and bending moments in the directions of the X and Y axes, taken into account when calculating the punching shear from an external load.

Where F_{ult}, $M_{x,ult}$, $M_{y,ult}$ are the limiting concentrated forces and bending moments in the directions of the X and Y axes, which can be perceived by concrete in the design cross section when they act separately.

The limiting concentrated force F_{ult} is determined by the formula:

$$F_{ult} = R_{bt} \cdot A_b, \tag{2}$$

where A_b is the area of the calculated cross-section, R_{bt} is the design resistance of concrete to axial tension.

$M_{x,ult}$ and $M_{y,ult}$ are calculated based on the following formulas:

$$\begin{aligned} M_{x,ult} &= R_{bt} \cdot W_x \cdot h_0, \\ M_{y,ult} &= R_{bt} \cdot W_y \cdot h_0, \end{aligned} \tag{3}$$

where W_x and W_y are the values of the moments of resistance of the design contour of concrete when punching in the directions of mutually perpendicular axes X and Y,

h_0 is the reduced working height of the section equal to $0.5(h_{0x} + h_{0y})$ where h_{0x} and h_{0y} are the working height of the section for longitudinal reinforcement located in the corresponding axes.

When calculating the reinforced foundation slab along normal sections, the LIRA-SAPR software package was used.

3 Calculations and Results

When calculating the punching shear reinforcement of the foundation slab, the following provisions and assumptions were taken:

- the calculation takes into account the build-up layer above the foundation slab;
- an increase in the load transfer circuit due to the supporting elements of the metal cage is not taken into account in the margin (given the complex nature of the pressure transfer through the corners, reinforced with ribs);
- soil rebound when calculating for punching into the stock is not taken into account (considering the possible variability of characteristics);
- concrete reinforcement class is taken over the concrete of the existing foundation slab.

Calculation scheme. Column section dimensions—0.5 × 0.5 m, slab thickness —1.0 m, working height of the slab section $h_{0x} = h_{0y} = 0.94$ m.

Punching force from the acting load—F = 3127 kN, moment relative to the X-axis—$M_x = 12.0$ kN·m.

The calculation uses heavy concrete of class B30, transverse reinforcement A500.

The calculation result is shown in Fig. 1.

Considering the increase in the thickness of the slab the results of the calculation of the most loaded support zone of the foundation slab for punching show that the adopted reinforcement provides the bearing capacity of the support zone without transverse reinforcement (which would be impossible to install in the actually existing foundation slab).

The deficiency of reinforcement revealed during the verification calculation was primarily related to the lower longitudinal reinforcement of the foundation slab. It is technically impossible to increase the bottom reinforcement of the foundation slab in the existing building; as a reinforcement, a build-up layer of concrete was adopted, which is involved in joint work with the existing foundation slab. By significantly increasing the working section height, the amount of reinforcement required to absorb the bending moment is reduced.

Figure 2 shows a fragment of the performed verification calculation.

The change in the required reinforcement in the areas with a deficit was analyzed in the process of selecting the thickness of the concrete layer to be built up. In this

Ultimate forces in concrete	Fb,ult [кН]	Mbx,ult [кНм]	Mby,ult [кНм]	
	5603.9	2689.9	2689.9	
Strength state condition	F / F_{ult} +	$M_x / M_{x,ult}$ +	$M_y / M_{y,ult}$ =	
	0.5580 +	0.0045 +	0.0000 =	0.562 <= 1

Fig. 1 The result of the punching shear design for the support zone of the foundation slab. Fragment of the protocol from the PC "STATIC"

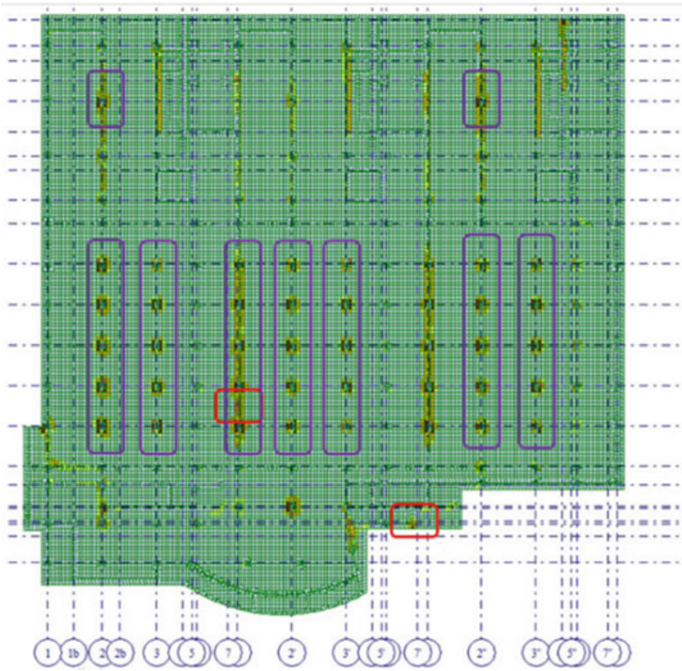

Fig. 2 Lower reinforcement of the foundation slab along the X-axis, cm^2/p.m. Areas with a bearing capacity deficit (up to 50%) are marked with red frames

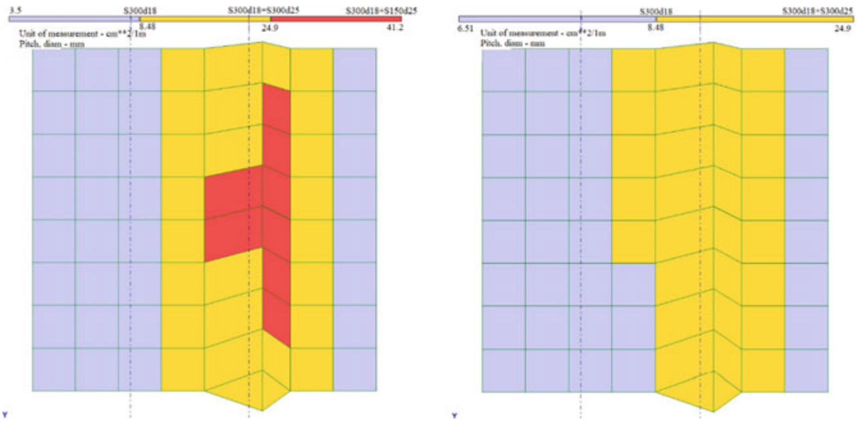

Fig. 3 Section of the foundation slab before and after reinforcement. The area with the required reinforcement exceeding the design reinforcement is highlighted in red on the reinforcement mosaic

case, the class of concrete is adopted for the concrete of the existing foundation slab. Figure 3 shows the calculation results for the most loaded area with the existing thickness of the foundation slab and after building up an additional layer of concrete, respectively. The required reinforcement does not exceed the design one in the presence of reinforcement.

The results of calculating the normal sections of the foundation slab, taking into account the reinforcement in the form of a built-up concrete layer, using the example of the most loaded sections, show the efficiency of the adopted reinforcement option.

4 Conclusions

The use of the STATICA and LIRA-SAPR software complexes made it possible to complete the project to strengthen the foundation slab and to provide it with the required characteristics.

Based on the results of calculating the reinforcement of the foundation slab, a number of adjustments were made to the structural scheme of the building. When reinforcing the foundation slab, the thickness of the layer to be built up is 0.3 m (total thickness, taking into account the foundation slab, 1.0 m). The concrete class of the reinforcement elements is accepted as B40, which is higher than the concrete class used in the reinforcement calculations. Reinforcement of the built-up concrete layer was made with reinforcement Ø18 mm with a step of 0.3 × 0.3 m. To ensure the joint work of the reinforcement with the existing foundation slab, it is necessary to prepare the surface of the slab in advance, to perform the gluing of transverse reinforcement.

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