Method for measuring deflections of monolithic floors in conditions of poor visibility of the structure

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Abstract. The article shows the method of testing for determining deflections in the slab covering the basement of a residential complex under construction with underground parking. The features of the construction of this section of the building and the reasons for conducting additional research of the erected structures are described. A description of the structures of the studied part of the building, their defects and damages acquired during construction is given. The article describes the methodology and methods used to determine deflections from the control load in conditions of limited visibility due to the presence of mounted engineering systems, as well as restrictions on access to the structure due to the presence of reinforcement elements on its surface. Features of measurements and advantages of combined research methods to ensure the reliability and speed of analysis of the results are described. Based on the results of the research, this article draws conclusions about the possibility of using Express methods for assessing the stress-strain state of building structures, using the example of a residential building with underground parking that has been erected and is being put into operation.

1. Introduction
When commissioning buildings, it is often necessary to perform preliminary tests of critical structures [1,2]. These tests using traditional methods can significantly increase the construction time, as they may require time to set up the test equipment itself and analyze the results obtained. To speed up production processes during testing, this paper proposes a simplified measurement method based on a combination of preliminary calculations and the use of high-precision laser measuring devices. It should be noted that often the installation of test beacons or devices on the test structure itself is prevented by various engineering systems installed on it, cable trays, and other devices that prevent access to the structure itself.

As an example of solving this problem, consider the floor slab of the underground part of the parking lot of one of the residential buildings under construction.

The thickness of the floor slab of the underground parking of a residential building under construction is 400 mm. The actual compressive strength of concrete corresponds to the class B30 (design concrete class B25)[3]. Reinforcement of the coating plate according to the executive documentation and the act for hidden work correspond to the project. During the construction of the building, a tower crane was used, for which a hole was provided in this floor slab. After the construction of the residential part of the building is completed, the tower crane is dismantled. In the future, the hole in the parking structure will be concreted, which is provided for by the project [4].
After removing the formwork and loading the plate with calculated loads (without short-term loads from machines), deflections up to 86 mm and cracks up to 0.6 mm appeared. This led to the need to strengthen the damaged plate with composite materials (carbon fiber sheets, lamellas) with additional mechanical fastening on the supports [5-7]. To do this, the damaged plate was reinforced with composite materials (carbon fiber sheets) with additional mechanical anchoring on the supports.

A general view of the coating structures in the reinforcement zone using carbon fiber slats is shown in Fig. 1.

![General view of the coating structures in the reinforcement zone using carbon fiber slats.](image)

**Figure 1.** General view of the coating structures in the reinforcement zone using carbon fiber slats.

Due to the high responsibility of the purpose of the building, it was decided to conduct additional tests of the reinforced coating plate. Testing of the section of the coating plate with a control load was carried out equivalent to the impact on the coating of a fire truck (the span of the plate was located above the roadway area) in order to determine deflections in accordance with regulatory documents.

2. **Materials and methods**

   As a result of visual inspection of the floor structure, it was found that the process of measuring deflections is difficult due to the fact that reinforcing elements are installed on the lower surface of the slab (direct access to the structure is limited), as well as engineering equipment (ventilation channels, cable trays, lighting devices, etc.). These circumstances make it difficult to take readings. As a result, the commission decided to perform complete studies using several types of measurements based on pre-performed calculations using a calculation complex based on the finite element method.

   Additional loading of the slab section was supposed to be carried out in one stage with a control load equivalent to the weight of a fire truck with an axle load of 21 tons (it is allowed to reduce the axle load by 30%). Load endurance - not less than 0.5 hours.

   Before loading, the actual deflections of the coating plate are fixed with markers applied to the surface of the plate in accordance with the drawing "Scheme for installing deformation marks on the lower surface of the monolithic slab structure". Markers are applied according to a pre-made marking corresponding to the location of the deformation marks specified by the customer (in places of maximum deformations-the center of the overlap structure). A plumb line or level can be used to fix the vertical position of markers.
Fixing the deflection values of the coating plate is performed using geodesic devices or other measuring devices with an accuracy of at least 1 mm.

The load for testing the section of the floor structure was selected based on the analysis of the design documentation, completed surveys, verification calculations and safety of the constructed floor structure.

![Diagram of installation of signs of deformation on the lower surface of a monolithic floor slab](image)

**Figure 2.** Diagram of installation of signs of deformation on the lower surface of a monolithic floor slab

To clarify the accepted load for testing, design data on the composition of the lawn used were used. Based on the analysis of project documentation and surveys, it was found that the thickness of the roof layers reaches about 2 meters. The load transmitted through the coating layers can be transmitted with an increased area distribution corresponding to the size of the pressure pyramid from the extreme points of force transfer. It was also taken into account that the measurement accuracy should not be less than 1 mm, which corresponds to the error of measuring instruments. Thus, according to approximate calculations, the approximate weight of the cargo was set, which was about 50 tons. To ensure the above load parameters, a four-axle dump truck was selected (SCANIA P440) with overall dimensions in plan (along the axes of the extreme wheels) of 1.83x6.15 meters, with a full load of sand. According to the technical characteristics of the dump truck, when fully loaded with sand of normal humidity, it can create a load of about 50 tons. In this case, the load on the monolithic slab
from the action of the dump truck can be considered uniform, since the distance between the axes of the machine is 1.35-2.8 m and the load is transmitted through a layer of soil 2 meters thick.

At the same time, taking into account the height of the coating layers (about 2m), as well as the pressure pyramid from the 4 axles of the car, the area of the transmitted load will be 6.0x10.15m²=60.9m². Thus, the evenly distributed load from the action of a dump truck with sand on the coating plate on a plot of 60.9 m² will be 50000/60.9=821kgs/m².

The placement of the dump truck was carried out according to a pre-made marking on the surface of the upper layers of the coating, which ensures that the load is placed exactly in the center of the span of the coating plate (Fig.3).

Loading of the floor structure was performed in 2 stages. The first stage of taking readings was performed from the load that makes up the own weight of the structures. The second stage of taking readings was carried out after installing the dump truck, according to the completed marking for at least 0.5 hours.

During the tests, deflections of the structure were recorded by markers applied to the lower surface of the structure, in accordance with the marking and numbering of markers. The markers were deposited on the pre-made markup, according to the previously performed measurements of the room. To fix the verticality of the marker application, a plumb line was used (for the method of measurement with a laser rangefinder).

The values of structural deflections were recorded using two methods:
1. By the method of trigonometric leveling of accuracy class II (accuracy class according to GOST 24846-2012 "Soils. Methods for measuring deformations of the base of buildings and structures"), twice in the forward and reverse directions according to the established deformation marks. The average square error in determining vertical movements in accordance with class II accuracy is 2.0 mm. Trigonometric leveling was performed with the Sokkia FX-101 electronic total station.

2. Using the Leica DISTO D210 laser rangefinder with a measurement accuracy of up to 1 mm.

3. Results
During the tests, the maximum deflections of the coating plate in the middle and edges of the span on the test area were determined, according to the completed marking. To verify the data obtained, an additional verification calculation was performed for similar load combinations for stages 1 and 2. This calculation takes into account the effect of strengthening the overlap structure with external carbon fiber reinforcement. As a result of the calculation, summary data were obtained, which are shown in the table below (Table 1).

| Number of the measurement point | The value of the difference by measuring with a total station, mm | Difference values based on the results of laser rangefinder measurement, mm | Values of the difference based on the results of the verification calculation, mm |
|--------------------------------|---------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1                              | 1                                                             | 0                                                                         | 0.009                                                                        |
| 3                              | 1                                                             | 2                                                                         | 0.04                                                                         |
| 4                              | 1                                                             | 2                                                                         | 0.047                                                                        |
| 5                              | 1                                                             | 1                                                                         | 0.05                                                                         |
| 7                              | 0                                                             | 0                                                                         | 0.012                                                                        |
| 8                              | 0                                                             | 0                                                                         | 0.038                                                                        |
| 10                             | 1                                                             | 1                                                                         | 0.207                                                                        |
| 11                             | 1                                                             | 2                                                                         | 0.303                                                                        |
| 12                             | 1                                                             | 2                                                                         | 0.237                                                                        |
| 14                             | 0                                                             | 0                                                                         | 0.059                                                                        |
| 15                             | 0                                                             | 0                                                                         | 0.101                                                                        |
| 17                             | 2                                                             | 2                                                                         | 0.564                                                                        |
| 18                             | 2                                                             | 2                                                                         | 0.632                                                                        |
| 19                             | 2                                                             | 2                                                                         | 0.547                                                                        |
| 21                             | 0                                                             | 0                                                                         | 0.145                                                                        |
| 22                             | 0                                                             | 0                                                                         | 0.207                                                                        |
| 24                             | 2                                                             | 2                                                                         | 1.109                                                                        |
| 25                             | 1                                                             | 2                                                                         | 1.274                                                                        |
| 26                             | 1                                                             | 0                                                                         | 1.102                                                                        |
| 28                             | 1                                                             | 0                                                                         | 0.204                                                                        |
| 29                             | 0                                                             | 0                                                                         | 0.255                                                                        |
| 31                             | 1                                                             | 1                                                                         | 1.686                                                                        |
| 32                             | 2                                                             | 2                                                                         | 1.98                                                                         |
| 33                             | 2                                                             | 1                                                                         | 1.71                                                                         |
| 35                             | 0                                                             | 0                                                                         | 0.254                                                                        |
| 36                             | 0                                                             | 0                                                                         | 0.261                                                                        |
| 38                             | 1                                                             | 2                                                                         | 1.827                                                                        |
| 39                             | 1                                                             | 2                                                                         | 2.13                                                                         |
4. Conclusion
In the course of this research work, a complex of observations of deflections of the monolithic structure of the parking overlap of a residential building was performed during trial tests in conditions that are limited for viewing due to the presence of installed engineering systems, as well as the presence of its reinforcement with carbon fiber on the lower surface. This research package included preliminary calculations of the coating plate structure for selecting the size and intensity of the load and the joint use of two measuring instruments for fixing deflections. Based on the study, the following main conclusions can be drawn for the design under study:

1. deflections in the center of the span of a monolithic slab (made with external reinforcement using carbon fiber) from a load intensity of 821 kgf/m², equivalent to the weight of a fire truck with an axle load of 21 t, on an area of 60.9 m² reach 2 mm, which corresponds to the calculated deflections;

2. the results of tests of a monolithic parking floor with a test load showed that the slab works according to the project without forming hinges in the parking area of the tower crane. The strength of the monolithic ceiling of the parking lot, taking into account carbon fiber reinforcement, is sufficient to perceive real loads and loads from fire equipment;

3. in cases of difficult review of extended floor structures, it is advisable to use combined measurement methods based on pre-performed calculations to avoid accidental measurement errors caused by difficulties in visual review of marks for laser control.

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