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STUDY OF THE INFLUENCE OF DEFECTS ON THE STRENGTH OF FLOOR ELEMENTS OF FRAME STRUCTURAL SYSTEMS

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Annotation. Reinforced concrete as a structural material has a number of characteristic properties that depend on the type of stress-strain state and create certain difficulties in the development of mechanical and mathematical models and algorithms for their implementation. Poor concrete compaction is most often encountered in areas with the highest concentrations of reinforcement or embedded parts. Even in the early stages of deformation, physical nonlinearity manifests itself, consisting of the lack of a proportional relationship between stresses and strains, heterogeneity, anisotropy, and other specific properties. With increasing load, the integral rigidity of the sections decreases, internal forces are redistributed between sections of the structure during structural changes in the materials, and displacements increase. Therefore, for any calculation method, a method for accounting for the physical nonlinearity of concrete and reinforcement deformation is important. This article presents the results of a study of the influence of defects on the stress-strain state of reinforced concrete bending elements of frame structural systems.

Keywords: defects, deformation, stress-strain state, load, frame, structure.

Introduction. During the construction and operation of various buildings and structures, damage and collapse may occur. Analysis of the results of surveys of structural failures and emergency situations at construction sites revealed that problems primarily originated during the fabrication stage or during construction. The primary causes of accidents were related to deviations from the design during construction and common construction defects, which significantly impact the stress-strain state of the elements. Furthermore, a significant proportion of accidents are due to defects acquired during operation.

Therefore, research aimed at developing a methodology for accounting for defects in reinforced concrete structures is a pressing scientific and technical issue. The purpose of this dissertation is to study the influence of defects on the stress-strain state of reinforced concrete flexural elements of frame structural systems.

To achieve this goal, the following experimental research objectives were set:

- determining the stress-strain state of complexly designed sections, symmetrical about the vertical axis, at all loading stages, taking into account the actual concrete stress-strain diagram;
- identifying the key patterns in the influence of changes in cover values, reduction in concrete strength, and longitudinal reinforcement area on the strength and stiffness of reinforced concrete flexural elements from design parameters.

An examination of the survey results in cases of failure of load-bearing building structures or the occurrence of emergency situations at construction sites revealed that problems arose primarily at the stage of fabrication of the structures or during the construction process. The main causes of accidents (in some sources, up to 60%) were associated with deviations from the design during fabrication and with ordinary construction defects [1-3].

The main defects of reinforced concrete structures include [4]:

- reduced concrete strength relative to the design value due to various reasons;
- deviation from the design dimensions of the structure;
- incorrect area and grade of working reinforcement;
- incorrect reinforcement placement.

In modern construction, concrete is typically produced centrally in factories and delivered to the construction site by truck. The hydration reaction of cement begins immediately after mixing with water. Prolonged mixing of concrete reduces the quality of the concrete by breaking the newly formed bonds of the cement adhesive. The maximum transport time for concrete mix depends on the outside temperature and the activity of the cement used in the concrete, and ranges from forty-five minutes to two hours. If transporting concrete by truck mixer takes more than three hours, the concrete may never set at all. Such a mixture will no longer be concrete, but rather a simple mixture of crushed stone covered with a hardened layer of cement mortar.

GOST 18105-86 permits non-destructive testing during the construction of monolithic structures. However, even in this section, the standard contains a number of problematic or poorly substantiated provisions that fail to take into account the specifics of modern monolithic buildings. For example, such an important requirement as mandatory testing of the concrete strength of each column is missing. Also, unjustifiably, restrictions have been introduced on the use of elastic rebound, impact pulse, and plastic deformation methods for testing the concrete strength of monolithic buildings. Restrictions on the application of these methods are rational for massive structures; however, their use is entirely acceptable for monolithic buildings [5].

Poor concrete compaction is most often encountered in areas with the highest concentrations of reinforcement or embedded parts. [6] notes that this defect, along with insufficient thickness of the concrete protective layer, should be assessed primarily as a deterioration in the protection of the reinforcement from corrosion and a deterioration in the appearance of the structure, while its impact on load-bearing capacity is questionable.

In addition to random variability, there is systematic variation in concrete strength within structures. This phenomenon has long been known for vertically cast structures, and is taken into account in design using appropriate service factor coefficients [7]. According to experimental studies, the average reduction in concrete strength in the upper portions of vertically cast columns is 10-12%. During the construction, repair, or reconstruction of buildings, new openings for utility lines are often created in floors and roofs, which can negatively impact their load-bearing capacity and deformability [8, 9].

Damage to reinforced concrete structures from mechanical impacts during operation occurs from accidental impacts and spalling, which is done to attach various elements to the reinforced concrete structure. Damage in the compressed zone leads to a reduction in the load-bearing capacity of the structure. Spalling in the tension zone does not affect the load-bearing capacity, but reduces rigidity and crack resistance [10-12].

Materials and methods of the study. The tested floor section is a 200 mm-thick monolithic beamless floor designed from heavy-duty concrete of design class B25. The slab rests on monolithic columns measuring 400x400mm with a span of 7.2 m along axes B-B and 6.0m along axes 3- 4. In the middle of the slab, along axis 3, there are rectangular openings with dimensions ranging from 140x140mm to 400x400mm for utility lines. After the building frame was erected, openings with diameters ranging from 100mm to 320mm were made in the floor due to apartment remodeling.

The floor is reinforced with hot-rolled grade A400 steel rebar with diameters ranging from 12 to 32 mm. Flat welded cages are installed at the column and exterior wall supports. The upper, lower, and additional reinforcement of the test section are shown in Figures 1 and 2, respectively. The cage design is shown in Figure 3.

The floor slab is designed for a standard useful load of 3.0 kPa, while the dead load of the supporting structures is 5.0 kPa. At the time of testing, the floor slab had no substructure. Prior to testing, a visual inspection of the floor structure revealed cracks between non-design openings on the bottom edge of the slab. These cracks do not significantly affect its rigidity.

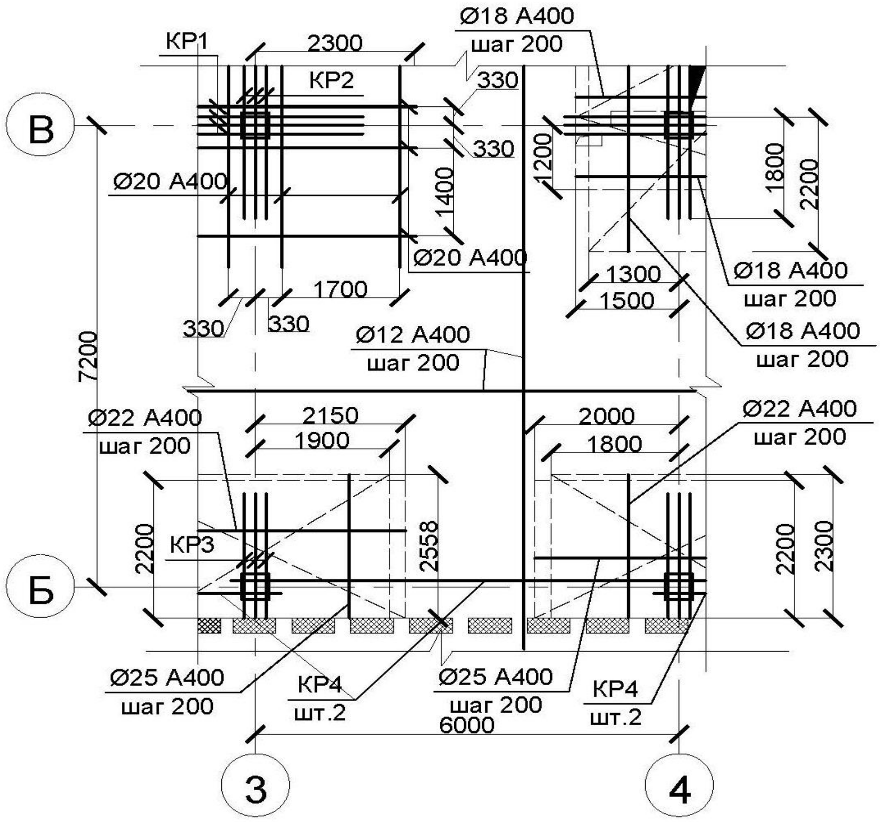

Figure 1 – Upper reinforcement of the tested floor fragment

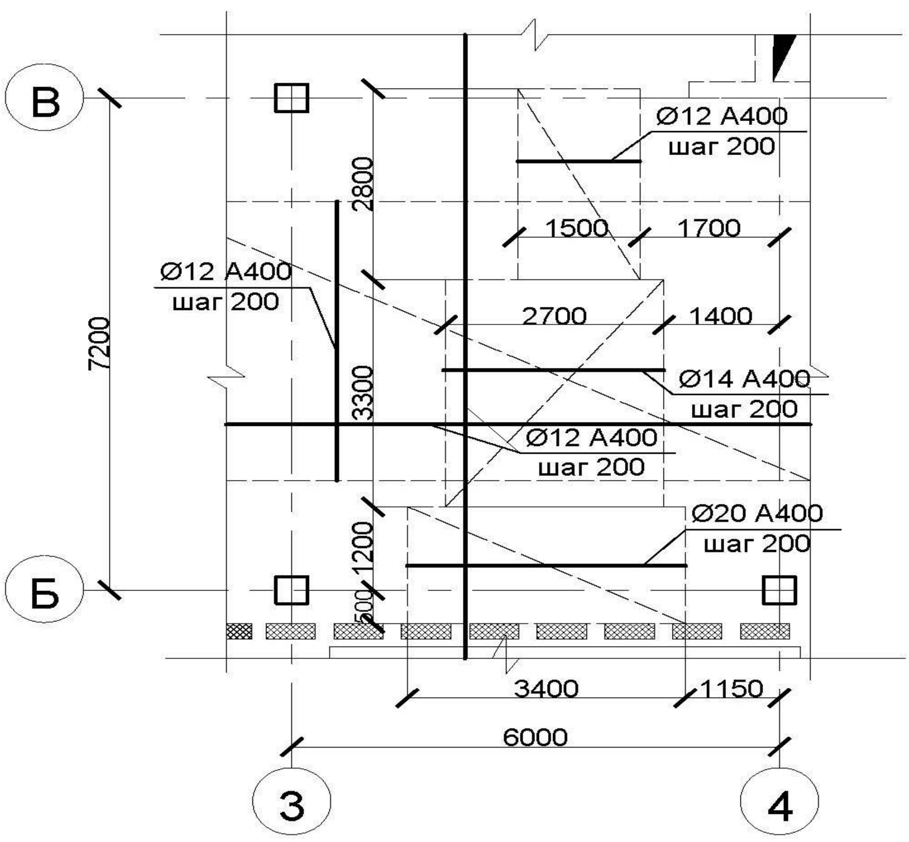

Figure 2 – Bottom reinforcement of the tested floor fragment

At the time of testing the floor section, the building had external and internal walls erected. A minimum gap of 50 mm was provided between the walls and the slab in the test and adjacent spans, eliminating their influence on the free deflection of the structure.

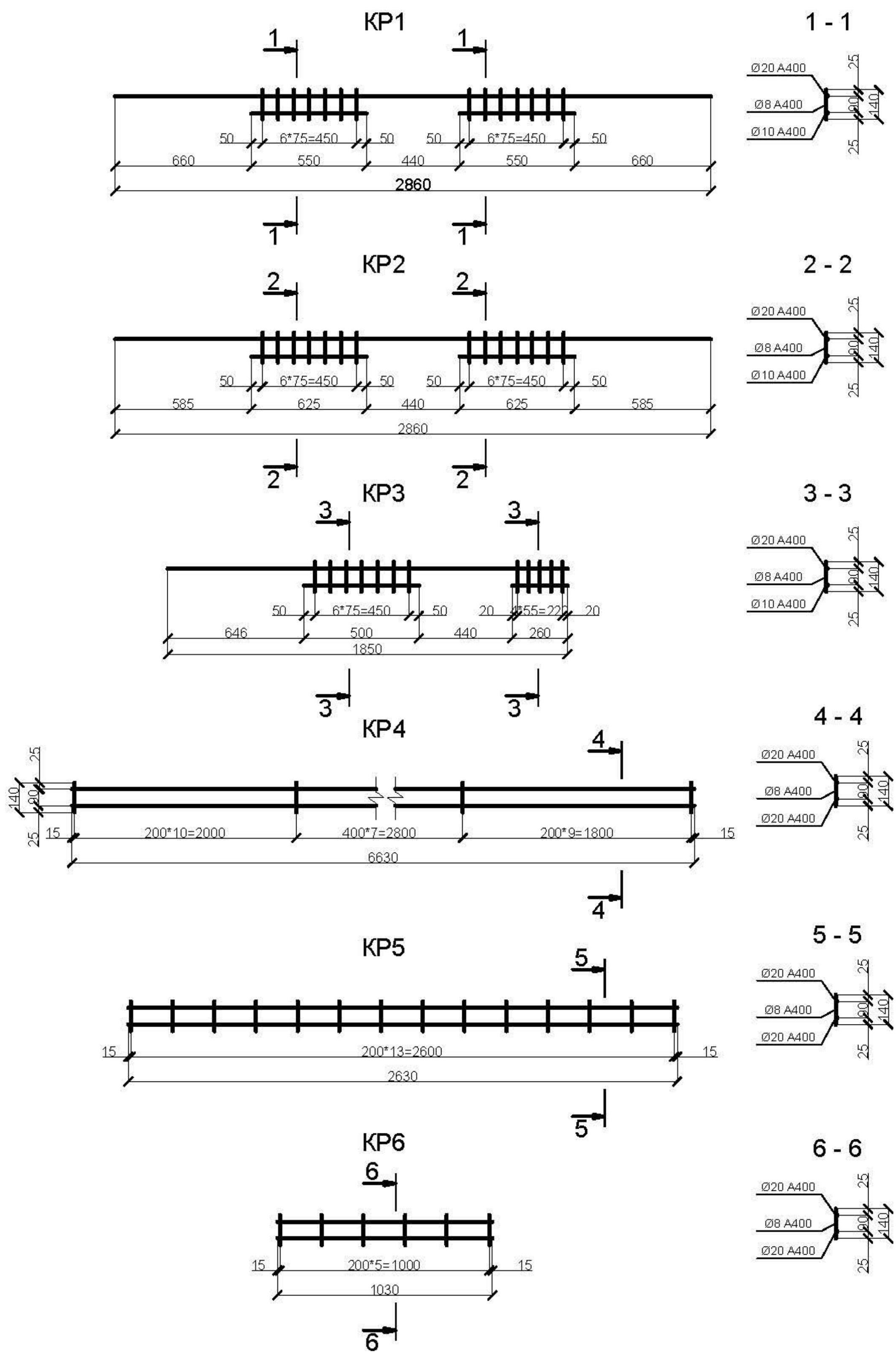

Figure 3 – Wireframes KP1, KP2, KP3, KP4, KP5, KP6

To prevent possible failure of the tested slab fragment and its fall onto the underlying floor, which could cause a progressive collapse of the entire building, a safety system of posts and beams was installed under the floor. During the tests, a uniformly distributed load was simulated using piece weights — facing ceramic stones with an average mass of 5 kg, which were placed with equal concentrated forces equivalent to the adopted loading step of a uniformly distributed load from the edges to the center of the slab [13, 14]. Loading was carried out in steps equal to 10% of the standard load. The loading diagram and the general view of the loading are shown in Figures 4 and 5, respectively. To measure deflections, ICh-10MN dial indicators with a division value of 0 were used. The devices were attached to the existing walls. At each loading stage, the floor was kept under load for at least 10 minutes, during which time readings were taken from all installed instruments, a visual inspection of the structures was carried out, and the width of the cracks and the distances between them were measured.

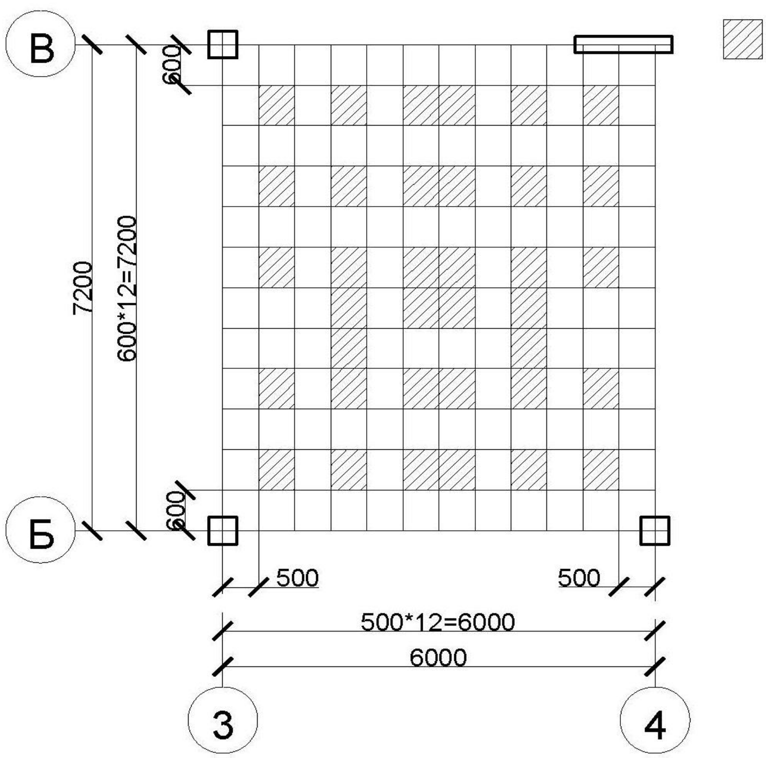

Figure 4 – The scheme of loading the overlap fragment

Results and Discussion. The experimental load-deflection relationships are shown in Figure 5.

In the initial stages of loading, the relationship between deflection and external load is virtually linear. At a load of approximately 0.75 times the standard load, its nature changes due to the nonlinear properties of concrete and the appearance of cracks, resulting in a distortion of the load-deflection relationship. At a live load equal to the standard load of 3.0 kPa, the maximum deflection was 2.74 mm, not exceeding 10% of the maximum permissible deflection.

The experimental cracking moment was recorded during visual testing of a floor fragment using an MPB-2 microscope and from indicator readings during data processing. During loading, the first cracks appeared at a live load of 2.25 kPa, with an opening width of 0.05 mm in the direction of the letter axes.

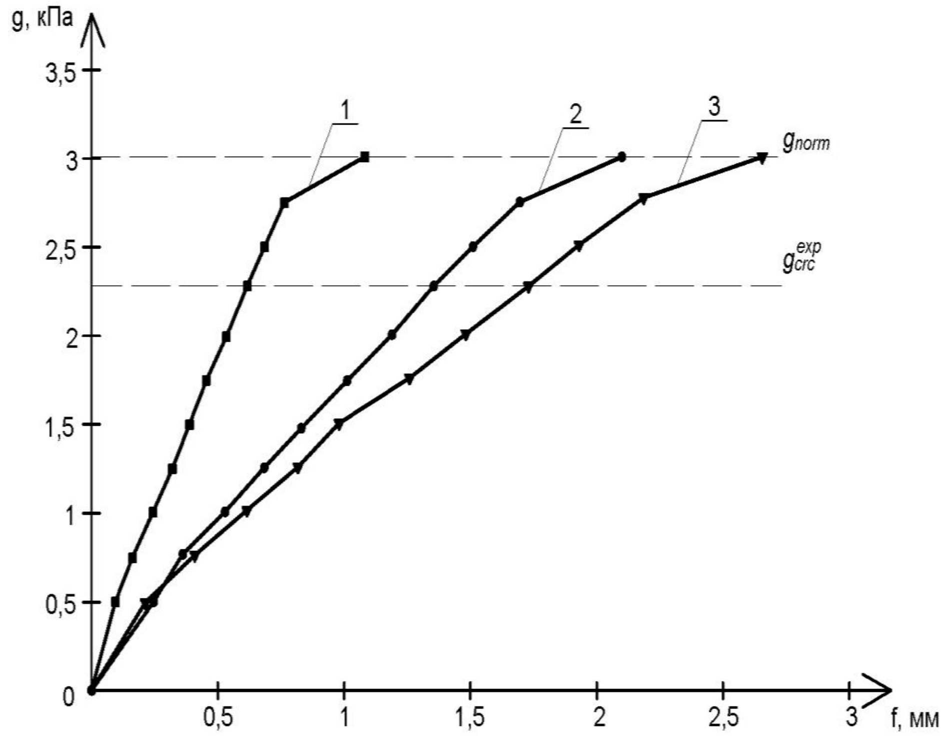

Figure 5 – Graph of deflection from external load in the middle of span 3-4;
1) deflection at a distance of 200 mm from axis B;
2) deflection at a distance of 2000 mm from axis B;
3) deflection in the middle of the span

As the load increased, the number of cracks in this zone increased, and the cracks spread to adjacent spans 2-3 and 4-5. The maximum crack width under a live load of 3.0 kPa was 0.125 mm, not exceeding the maximum permissible value. The average distance between cracks was approximately 200 mm, corresponding to the spacing of the longitudinal reinforcement. The crack pattern is shown in Figure 6.

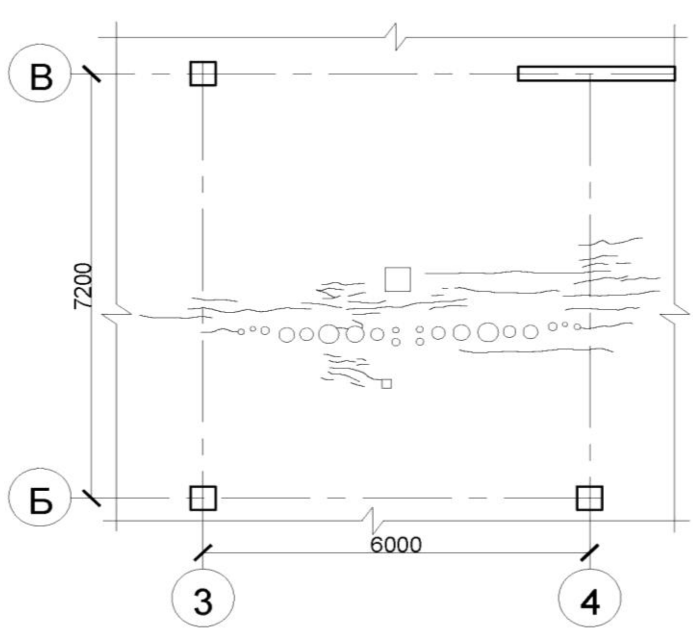

Figure 6 – The layout of the cracks

After installing non-design openings, the stress-strain state of the floor began to approach that of the beam slab. Therefore, the floor deflections were calculated using the proposed method and compared with the experimental deflections and those determined using the Lira 9.6 software package.

The floor slab calculation using the proposed method was performed for a strip of 1.0 m gross width, located along the digital axes in the middle of the slab. The width along the length of the slab varied depending on the openings within the calculated strip. The area of the longitudinal working reinforcement was assumed to be the design value (Figures 1,2). Modeling of a monolithic reinforced concrete floor was carried out using nonlinear finite elements in the Lira 9.6 software package, which allows one to consider various design situations in terms of geometry, reinforcement and support conditions of floors and to calculate deflections with sufficient accuracy under different load effects [15].

Standard material properties were used in the calculations. The calculations took into account physical and geometric nonlinearity. The concrete stress-strain diagram was chosen as a nonlinear one from the list provided in the computational package for heavy-duty concrete class B25. Reinforcement was adopted in accordance with the design.

The calculation model represents a floor slab of a technical floor. The finite element mesh spacing is set at 0.4 meters. The mesh is refined at the locations of openings. The junction with the column was modeled by assigning ties in all directions. The entire floor is subjected to a dead load of 5 kPa, and the test fragment in axes B-C and 3-4 is also subjected to a standard live load of 3 kPa. A uniformly distributed strip load is applied along the contour of the openings, compensating for the load removed across the slab area.

The isofields of displacements along the z-axis of the test fragment due to its own weight are shown in Figure 7, and those due to the live load are shown in Figure 8. A comparison of the experimental and calculated displacements obtained in the LIRA software package and using the proposed method revealed satisfactory agreement: the underestimation of the deflection due to the live load is 8.36% and 10.91%, respectively.

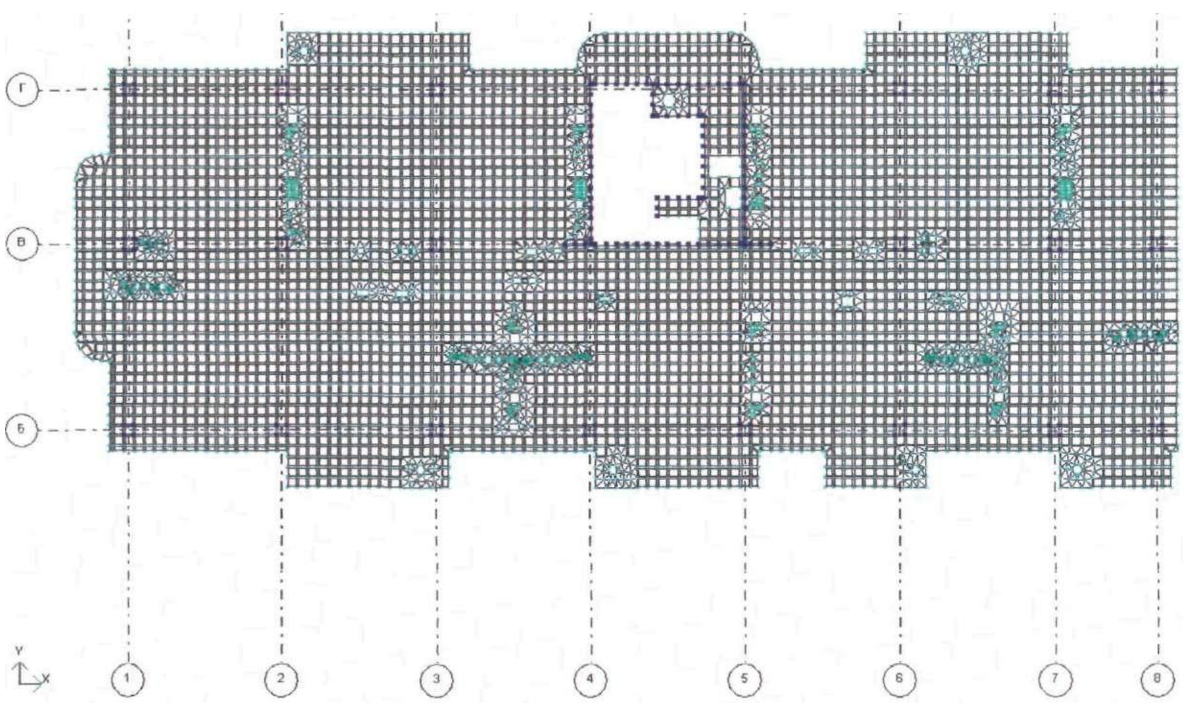

Figure 7 – Finite Element Model of a Floor Slab

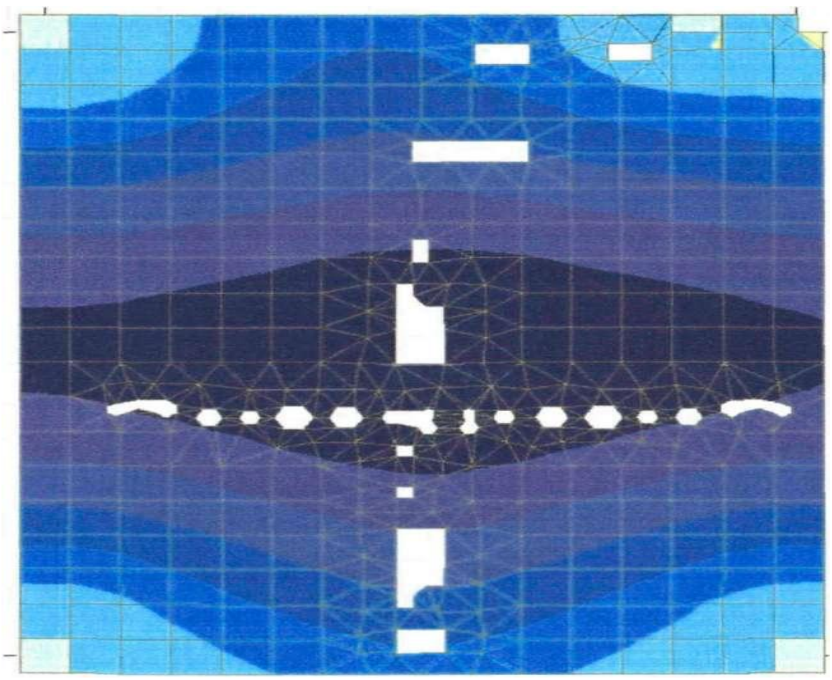

Figure 8 – Isofields of displacements along the Z axis of a fragment of the floor due to its own weight

An analysis of the experimental and theoretical deflections calculated in the LIRA 9.6 software package and using the proposed method showed that the calculation using the proposed method has a slightly larger error than that in the LIRA software package. Considering that the calculation using the proposed method is less labor-intensive than that in the LIRA software package, it can be used for approximate calculations of the deflections of reinforced concrete floor slabs.

To determine the impact of both design and non-design openings, a reduction in cylindrical stiffness in the direction of the numerical and letter axes of up to 40% was simulated. The calculation showed that the openings make the slab more flexible, leading to increased deflections in the span, but the ultimate limit state for deformation and crack resistance does not occur. This is explained by the fact that with an increase in the opening area, the slab's design model changes, and its operation approaches a cantilever model.

It is also worth noting that in the area of the openings above the columns, the support moments increase slightly, while the span moments decrease, which is consistent with the results of the mathematical modeling.

The conducted numerical analysis showed that the adopted design solution for the monolithic reinforced concrete floor has high spatial rigidity and crack resistance.

Conclusion. In accordance with the objectives set in this study, the following results were obtained:

1. During loading, the first cracks appeared at a temporary load of 2.25 kPa, with a crack width of 0.05 mm in the direction of the letter axes.

2. At all stages of loading, the relationship between deflections and external load was practically linear, and at a temporary load equal to the standard value of 3.0 kPa, the maximum deflection was 2.74 mm, which does not exceed 10% of the maximum permissible deflection.

3. The maximum crack width at a temporary load of 3.0 kPa was 0.125 mm, which did not exceed the maximum permissible crack width for short-term loading—0.4 mm.

4. A decrease in bending rigidity in the direction of the digital and letter axes to 40% leads to an increase in deflections in the span, but the ultimate state for deformation and crack resistance does not occur.

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ҚАҢҚАЛЫҚ ҚҰРЫЛЫМДЫҚ ЖҮЙЕЛЕРДІҢ ЖАБЫН ЭЛЕМЕНТТЕРІНІҢ БЕРІКТІГІНЕ АҚАУЛАРДЫҢ ӘСЕРІН ЗЕРТТЕУ

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Андатпа. Темірбетон құрылымдық материал ретінде кернеу-деформация күйінің түріне байланысты бірқатар сипаттамалық қасиеттерге ие және оларды жүзеге асырудың механикалық және математикалық модельдері мен алгоритмдерін әзірлеуде белгілі бір қиындықтар туғызады. Бетонның нашар тығыздалуы көбінесе арматураның немесе ендірілген бөлшектердің концентрациясы жоғары жерлерде кездеседі. Деформацияның алғашқы кезеңдерінде де физикалық сызықтық еместік көрінеді, ол кернеулер мен деформациялар арасындағы пропорционалды байланыстың болмауынан, гетерогенділіктен, анизотропиядан және басқа да нақты қасиеттерден тұрады. Жүктеменің артуымен қималардың интегралдық қаттылығы төмендейді, материалдардағы құрылымдық өзгерістер кезінде ішкі күштер құрылымның қималары арасында қайта бөлінеді және ығысулар артады. Сондықтан кез келген есептеу әдісі үшін бетонның физикалық сызықтық еместігін және арматура деформациясын есепке алу әдісі маңызды. Бұл мақалада қаңқалы құрылымдық жүйелердің темірбетон иілу элементтерінің кернеулі-деформацияланған күйіне ақаулардың әсерін зерттеу нәтижелері келтірілген.

Тірек сөздер: ақаулар, деформация, кернеулі-деформацияланған күйі, жүктеме, қаңқа, құрастырылымдары.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ДЕФЕКТОВ НА ПРОЧНОСТЬ ЭЛЕМЕНТОВ ПЕРЕКРЫТИЙ КАРКАСНЫХ КОНСТРУКТИВНЫХ СИСТЕМ

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Аннотация. Железобетон как конструкционный материал отличается рядом характерных особенностей, зависящих от вида напряжённо-деформированного состояния и создающих определенные трудности при разработке механико-математических моделей и алгоритмов для их реализации. Плохое уплотнение бетона чаще всего наблюдается в местах с наибольшей концентрацией арматуры или закладных деталей. Уже на ранних стадиях деформирования проявляется физическая нелинейность, заключающаяся в отсутствии пропорциональной связи между напряжениями и деформациями, неоднородность, анизотропия и другие специфические свойства. При увеличении нагрузки уменьшается интегральная жесткость сечений, происходит перераспределение внутренних усилий между участками конструкции при структурных изменениях материалов и увеличиваются перемещения, поэтому для любого метода расчета важное значение имеет способ учета физической нелинейности деформирования бетона и арматуры. В статье приведены результаты исследования влияния дефектов на напряженно-деформированное состояние железобетонных изгибаемых элементов перекрытий каркасных конструктивных систем.

Ключевые слова: дефекты, деформация, напряжённо-деформированное состояние, нагрузка, каркас, конструкция.