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# EVALUATION OF FIRE IMPACTED RAISED SLABS OF RESIDENTIAL BUILDING IN LVIV AND THEIR REINFORCEMENT

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**The research and analysis of technical conditions, deflections, and bearing capacity of subjected to fire impact reinforced concrete slabs of raised "panel per room" typical design model 1-480a of a five-storey residential building in Lviv are present.**

**A study of the technical condition of floor structures in the area of high temperatures. In the area of intense fire a decrease in the bearing capacity and rigidity of the shelf of the tent floor slab under the action of high temperatures was found.**

**Due to the fire impact, the thin plate of raised panel slabs completely loses load-bearing capacity, with large sagging deflections, caused by the plastic elongation of the wire reinforcement due to the action of high temperature.**

**The developed design of the reinforcement of the riced plate slab is considered.**

**Keywords: fire impact, technical condition, reinforced concrete, raised slab panel, reinforcement, strengthening.**

## Introductions

The degree of damage to reinforced concrete structures after a fire impact can be characterized by the amount of reduction in its rigidity and bearing capacity as a result of the high-temperature reduction of the physical and mechanical characteristics of concrete and reinforcement and subsequent loss of integrity.

Determining the load-bearing capacity of structures affected by fire, developing methods of restoration, and strengthening their load-bearing capacity is an actual problem both from the technical point of view of ensuring safety, reliability and economic efficiency as well as from the point of view of preserving the architectural space.

Many researchers in Ukraine (Klymenko, 2004; Hladyshev D., Hladyshev H., 2012; Vikhot et al., 2020; Chervynskyi et al., 2014; Khachaturian, 2010; Mazheika, 2010; Savytskyi et al., 2019; Shebanin, Bohza, 2015) and abroad (Banaszek et al. 2017; Sarja, 2003; Sarja, 2004) are working in this area. In addition, there are also studies in the direction of the influence of high-temperature influences on the technical condition of structures (Shnal, 2002; Otrosh, 2016; Otrosh, 2018; Hladyshev D., Hladyshev H., 2022; Maladyka, Shkarabura, 2017).

Inspection of the technical condition of structures after a fire is necessary for deciding on the further operation of the entire building and is one of the components of fire safety systems of buildings.

The intensity of burning within the area of the fire divides it into different zones of thermal influence, accordingly, the damage to the structures is different. Therefore, it is impossible to apply any one typical solution to strengthen damaged structures, that is, the approach in each specific case must be individual.

The research purposes are: to carry out a comprehensive analysis of the technical condition of the load-bearing structures of the floor slab of a residential building exposed to fire; based on the analysis, to develop an effective design for strengthening the floor slab under the condition of preserving the functional purpose of the premises.

## Materials and Methods

Accidental action of high-temperature fires cause a significant decrease in the technical parameters and conditions of load-bearing reinforced concrete structures. These actions primarily lead to the loss of load-bearing capacity and rigidity of reinforced concrete structures of floor slabs. The loss of their rigidity is shown by significant excessive deflections. In connection with the measurement of a significant number of points within small premises, for example, in apartments of a housing stock, the traditional use of geodetic tools is problematic. In this regard, the use of laser rotary levels is proposed, which will significantly speed up measurements in unfavorable post-fire conditions of premises.

## Results and discussion

A fire broke out in a five-story residential building in Lviv, in one of the apartments on the fourth floor. The fire started at night and lasted for an hour and a half before its liquidation, which is recorded in the fire report. The study was carried out based on an appeal from the LKP management to the authors regarding the determination of the technical condition of building structures within the fire zone.

This study involves the following works:

- dimensions of premises in the area of the fire zone and above the fire zone (two apartments);
- measurements and research of construction structures on the fire site and above the fire zone to identify these structures according to typical series;
- photo recording of the state of construction structures;
- analysis of damage to building structures in and above the fire zone;
- definition of categories of the technical condition of building structures according to the requirements of Code Guidance (Nastanova shchodo obstezhennia budivel i sporud dlia vyznachennia ta otsinky yikh tekhnichnoho stanu, DSTU, 2016);
- general conclusions with recommendations for strengthening;
- verification calculations of reinforcement elements of damaged building structures;
- development of constructive solutions and recommendations for strengthening damaged structures.

**Measuring works.** According to the architectural and planning decision, the building is a sectional type, residential, five-story with a basement. According to the constructive solution, the slab is a large precast panel-type structure, with a single-row per room layout of the facade. The building was commissioned in the 1970s. The building project structural design and executive documentation were not provided by the customer, but the floor plans were available (Fig. 1).

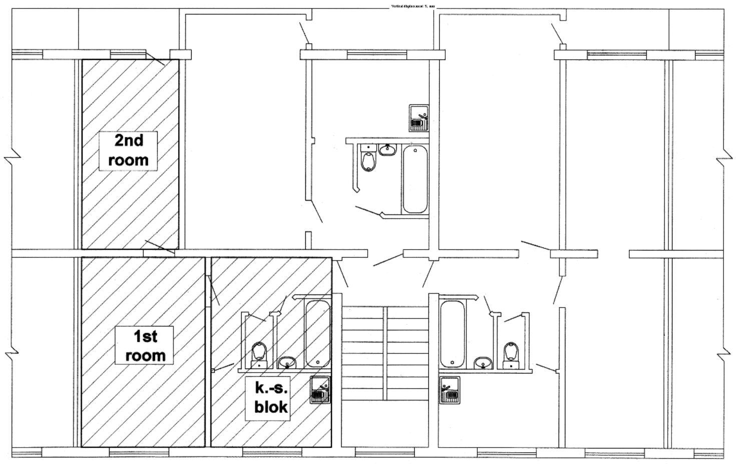


*Fig. 1. The plan of the fourth floor with the designation of the premises that were in the fire zone*

All the necessary work on determining the geometric parameters of the premises and structural elements in the zone and above the fire zone was done.

Geometrical parameters of the examined premises:

– plan dimensions of the kitchen-sanitary block – 3.05×4.84 m, the first room – 3.12×4.84 m, the second room – 2.45×4.82 m; the height of all rooms is 2.56 m.
– The structural elements parameters:
– the longitudinal outer walls are single-layer expanded clay concrete ($\gamma$=13 kN/m$^3$) 3.19×2.79 m, 350 mm thick;
– the longitudinal internal walls are reinforced concrete wall panels measuring 4.385×2.79 m, 220 mm thick;
– partitions within the apartment are gypsum concrete on a wooden frame of the "room size" type, 70 mm thick;
– the partitions with the adjacent apartment are double gypsum concrete on a wooden frame of the "room size" type, with a total thickness of 150 mm;
– the floor slab is made from the raised "room size" reinforced concrete panels 5.04 m×3.18 m and 5.04×2.58 m, 220 mm thick (Fig. 2).

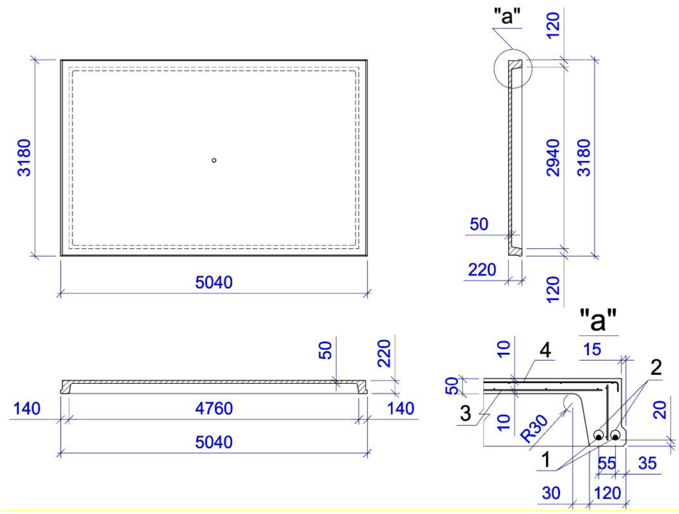


*Fig. 2. Design features of the raised floor slab panel:*
*1 – prestressed reinforcement; 2 – spiral ; 3, 4 – welded grids*

Photographs of the facade of the building and its internal rooms, which were affected by the fire, are shown in Fig. 3–10.

*Fig. 3. The window of the first room of apartment No. 160 on the fourth floor where the fire started*

*Fig. 4. The condition of the first room in the fire zone. View from the outer wall of the main facade of the building*

*Fig. 5. The condition of the second room in the fire zone. View from the inner wall*

*Fig. 6. The condition of the second room in the fire zone. View from the outer wall*

*Fig. 7. The condition of the door frame in the partition, which was located in the fire zone*

*Fig. 8. State of constructions of the kitchen and sanitary block in the fire zone*

*Fig. 9. View of the central part of the flange of the raised panel of the floor slab above the first room. Deflection (f=70 mm) of the flange with the formation of two cracks in it with an opening width of 2–3 mm, located in the middle of the longitudinal and transverse spans*

*Fig. 10. View of the floor in the room above the fire zone. Deflection of the floor in the first room above the fire zone*

**Survey of bearing structures.** On the basis of a visual survey, the main attention was paid to the structures of the floor slabs. The identification of belonging to the serial type of these slabs was carried out based on geometric parameters, identified specific features of their reinforcement and determined strength characteristics of concrete. The strength of concrete was determined by a non-destructive method based on its surface hardness using a spring machine A-1 of the "Khmelnytskprombud" type. The determined concrete class of reinforced concrete raised slabs of floors not exposed to fire specified as C18/20.

The electromagnetic meter of the cover layer thickness IZS-10N was applied to determine the locations and parameters of the reinforcements. In addition, destructive sounding was also used in several separate places. The bottom tensioned zone of the flange of the raised floor plate is reinforced by welded mesh ∅3 B-1, step 170 mm in two directions. The general principle of reinforcement is shown in fig. 2.

Based on the determined concrete reinforcement and strength parameters data, the slabs were identified as the 1960s "panel per room" typical design, model #1-480a.

A significant decrease in the rigidity of the flange of the raised floor slab (which was only subjected to a constant load) in the fire zone above the first room (Figs. 9, 10) recorded during the visual inspection led to the determination of the actual deflection of this slab.

Deflections of floor slabs in two rooms were measured using a laser rotary level. Measurement data and floor plate deflections are presented in Figs. 11–14.

The measured deflection of the flange is $f$=77 mm with the formation of a significant number of cracks of small width and two cracks with a maximum opening width of 2–3 mm, which are located in the middle of the longitudinal and transverse spans.

Significant cracking is associated with the effect of high-temperature heat flow, in which, with a 10 mm thickness of the cover layer, the stress in the reinforcing wire mesh with a wire diameter of 3 mm went into the plastic stage. The steel wire mesh was significantly elongated, which was manifested by the maximum deflection of the shelf of the raised plate.

The resulting actual deflection $f$ for the span $L_0$=3180-150×2=2880 mm exceeds the limit $f_u$=$L_0$/150=2880/150=19.2 mm by 77/19.2=4.01 times according to the standard (Systema zabezpechennia nadiinosti ta bezpeky budivelnykh obiektiv. Prohyny ta peremishchennia, DSTU, 2006).

Longitudinal ribs plates have actual deflections $f$=18.3mm and $f$=17.3mm, which do not exceed the limit value $f_u$=$L$/200=4670/200=23.75 mm according to the code (Systema zabezpechennia nadiinosti ta bezpeky budivelnykh obiektiv. Prohyny ta peremishchennia, DSTU, 2006). In the survey area, damages were detected in the raised panel slabs above the first and second rooms, which were associated with the effect of elevated temperature, which in various ways reduced their design load-bearing capacity and stiffness. Due to the intensity of the high temperatures in the first room, defects and damage occur in the shelf of the raised slab of the floor, which reduces the durability of the shelf of the raised slab due to the broken bond between the reinforcement and concrete.

**Assessment of categories of technical condition of structures**. The identification of the categories of the technical condition of the floor slabs was carried out based on their inspection, detected damage, verification calculations and compliance with the standards (Systema zabezpechennia nadiinosti ta bezpeky budivelnykh obiektiv. Prohyny ta peremishchennia, DSTU, 2006). When classifying with the selection of individual elements of the raised panel, ribs and flanges have different categories of technical conditions:

– the category of technical condition of the flange plates above the first room was assigned to the 4th category – emergency.

– the category of technical condition of the longitudinal ribs of the floor slab above the first room of the apartment was assigned to the 2nd – satisfactory.

– the category of the technical condition of the flange and longitudinal ribs of the raised floor slab above the second room was classified as 2nd – satisfactory.

According to the technical condition, the raised slab of the floor above the first room was to be strengthened, and the floor structure above this slab was to be levelled (Fig. 10). Complete replacement of the defective flange plate will lead to greater costs and inconvenience for the residents of the apartment on the next floor, which is located directly above the fire zone.

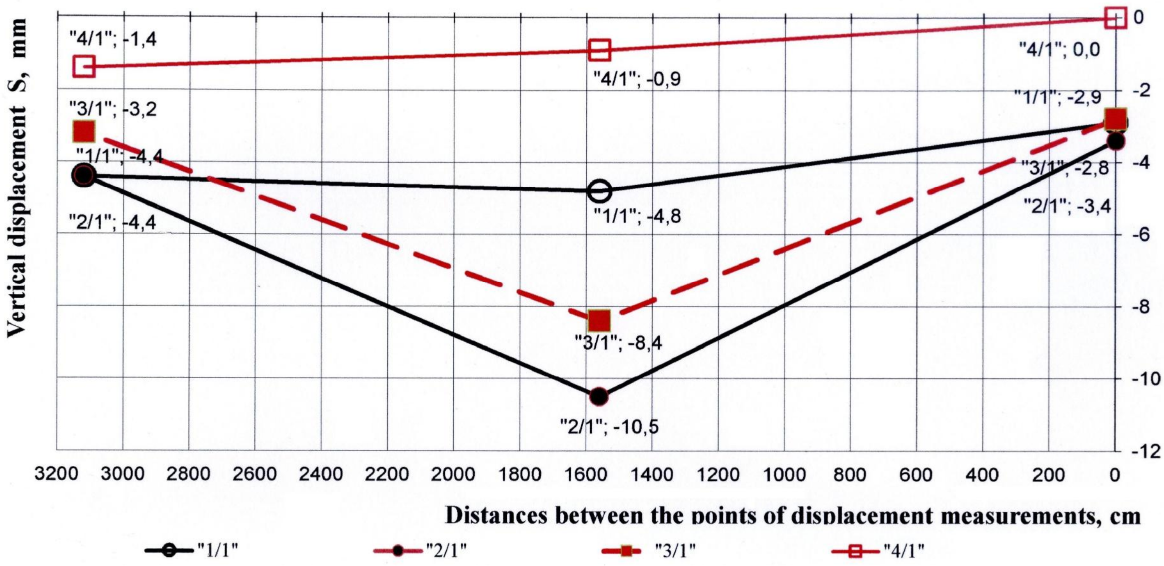


*Fig. 11. Nonuniform excessive vertical deformations (sags) across the floor slab panel above the first room + installation inaccuracy (the support of the slab on the middle wall is 3 cm lower than on the outer wall)*

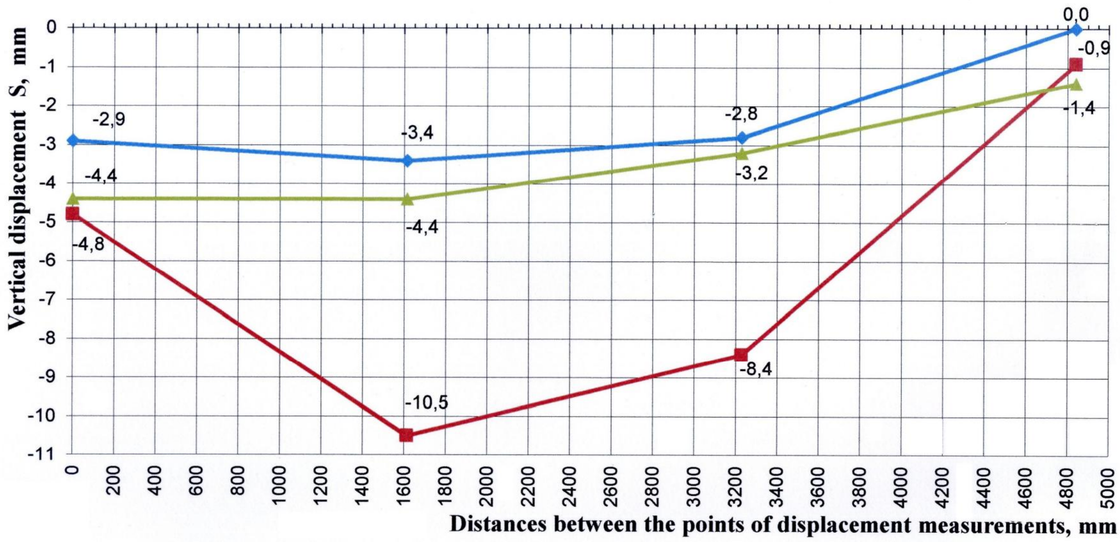


*Fig. 12. Nonuniform excessive vertical deformations (sags) along the floor slab panel above the first room + installation inaccuracy (the support of the slab on the middle wall is 3 cm lower than on the outer wall)*

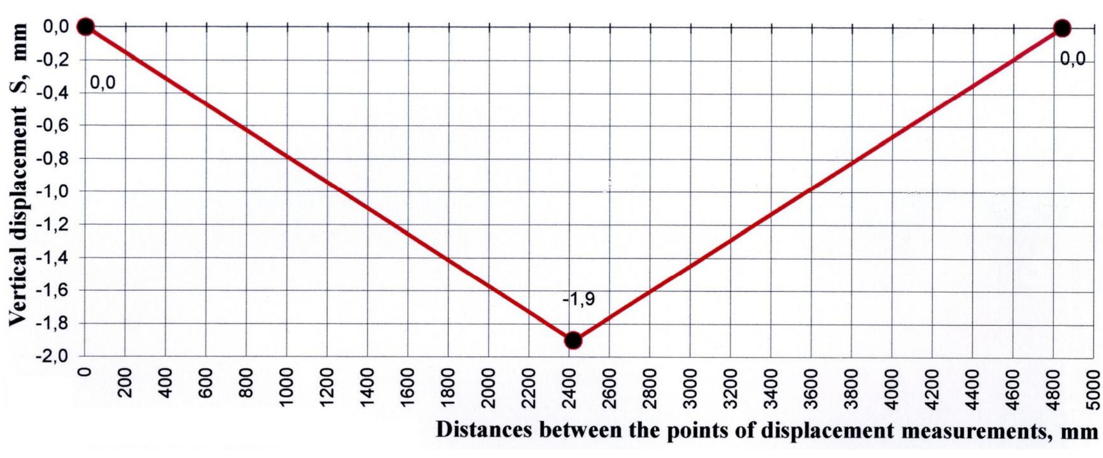


*Fig. 13. Nonuniform excessive vertical deformations (sags) along the floor slab panel above the second room*

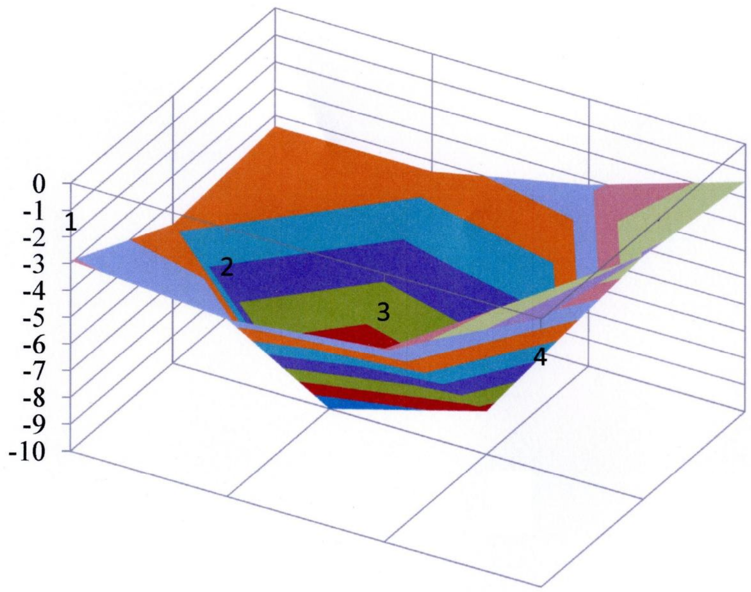


*Fig. 14. Surface of the factual displacements (effect of high-temperature +effect of installation inaccuracy) of the floor panel slab in the first room*

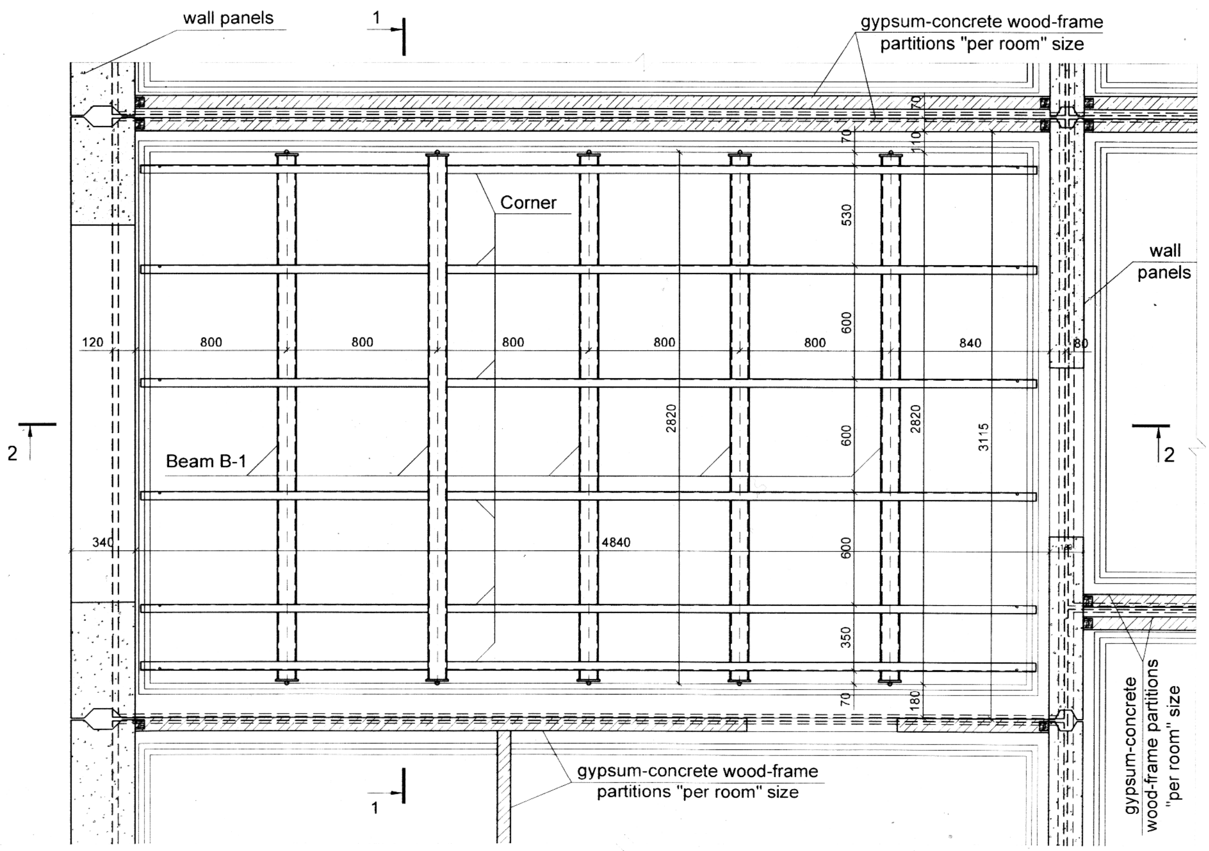


*Fig. 15. The construction of the reinforcement of the floor slab raised panel. Plan view*

**Structural solutions for strengthening the flange of the raised panel of the floor slab.**

For the design of the structural solution for strengthening the load-bearing structures, the following work was done: calculation of loads, the strengthening elements analysis and verification calculations. The maximum design load was 600 kg/m$^2$, including the load from the self-weight of the plate shelf, the repair concrete reinforced screed to compensate for the deflection of the plate shelf, the weight of the floor and the live load (Systema zabezpechennia nadiinosti ta bezpeky budivelnykh obiektiv. Navantazhennia i vividy, DBN, 2006).

The reinforcement is designed in compliance with the requirements of the code (Remont i pidsylennia nesuchykh i ohorodzhuvalnykh budivelnykh konstruktsii ta osnov budivel i sporud, DSTU, 2016). This design structural solution (Figs. 15, 16) consisted in placing additional beams under the slab flange, suspending and pulling these elements up to the longitudinal ribs of the floor slab. To create a horizontal surface during the installation of a suspended ceiling (from the corresponding layer of plasterboard sheets), rolled metal angles were used, which were attached to the reinforcement beams. As a result, the height of the room decreased by 170 mm, but this solution allowed to use of this room for its original functional purpose.

Obviously, after strengthening finishing works are also necessary: installation of a suspended ceiling in the first room, replacement of parquet flooring, restoration of gypsum-concrete partitions, replacement of windows and doors, etc.

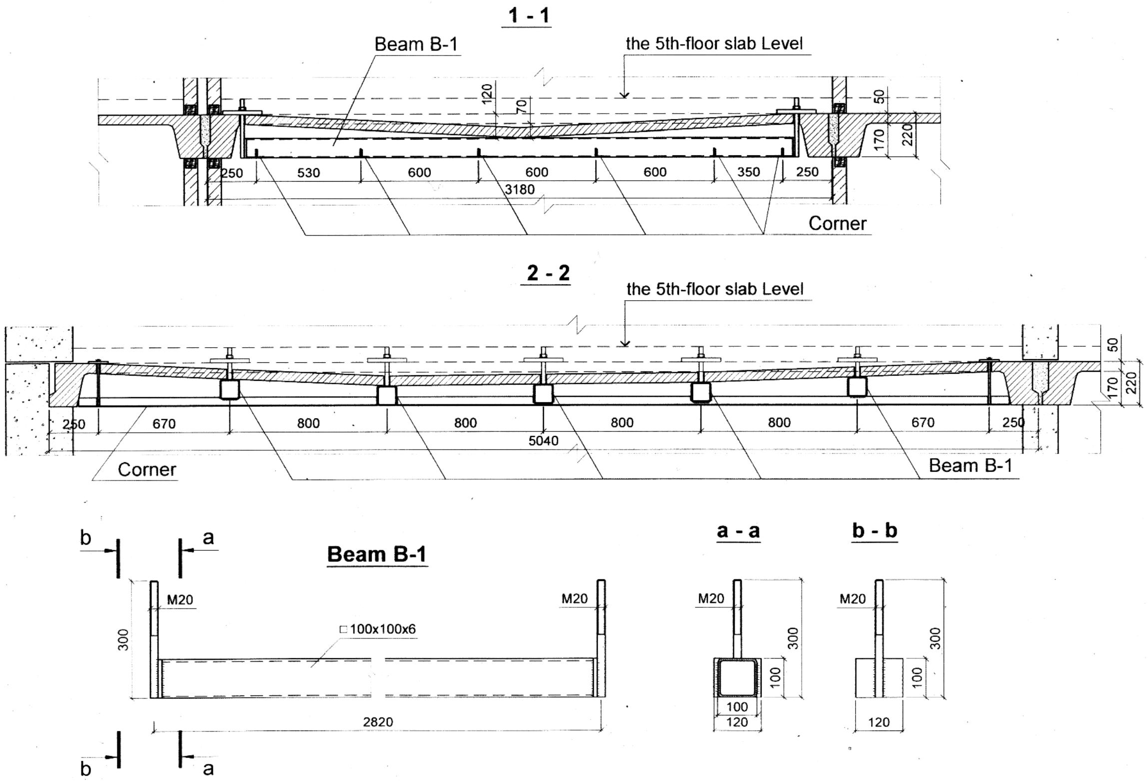


*Fig. 16. The construction of the reinforcement of the floor slab raised panel. Sections*

## Conclusions

The parameters of the structural elements were determined, which made as possible to identify the design series of used slab panel elements.

A significant rigidity decrease in the panel flange of the floor slab above the first room in the fire zone was investigated and the categories of technical conditions of structural elements of the floor slab are specified.

Reinforcement and repair of the structural elements of the floor were developed and designed, which ensures reliable further operation of the premises according to their original functional purpose.

The survey of the technical condition of the bearing floor structures in the area of high temperatures caused by an intense fire in a closed room was carried out.

The parameters and characteristics of the structural elements were determined, which made as possible to identify the typical design model of used riced panel slab elements.

In the zone of intense fire, a critical decrease in the load-bearing capacity and rigidity of the flange of the riced RC panel slab was found.

Based on the analysis of the deflections of the elements of the riced RC panel slab, it is possible to precisely specify the areas with the greatest temperature impact.

It has been investigated that, as a result of a fire, the load-bearing capacity of the flange of the riced RC panels of slabs was completely or partially lost, which is manifested in the increase of their deflections due to plastic deformations of the reinforcements. Thermal deflections of the plate significantly exceed deflections, cause of the force loads cases.

The loss of load-bearing capacity of the longitudinal ribs of the riced panels is significantly less, their load-bearing capacity can be restored.

Based on the analysis of the performed survey and calculations of the load-bearing capacity of the elements, the possibility and expediency of slab reinforcement were carried out, and an effective constructive solution of reinforcement was developed.

The proposed constructive solution for strengthening the floor panel allows the further use of the room according to its original functional purpose.

## Prospects for further research

The conducted studies show that the use of a laser rotary level to measure the deflections of reinforced concrete floor slabs in difficult post-fire conditions allows for quick and reliable measurements, and, based on them, to evaluate and identify the technical condition of the structures of the load-bearing slabs and, if necessary, to carry out their reinforcement.

It seems possible and important to further develop express methods for determining the epicenters of fires based on the analysis of the increments of deflections of floor slabs and their maximum. In turn, this will allow to effectively and quickly assess the technical condition of load-bearing floor slabs exposed to fire, and therefore to have a quick reliable assessment of the risks of destruction, identification and development of measures to prevent further destruction of load-bearing structures after a fire.

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## ДОСЛІДЖЕННЯ ТА ПІДСИЛЕННЯ ПІДДАНИХ ВПЛИВУ ПОЖЕЖІ ЗАЛІЗОБЕТОННОГО ШАТРОВОГО ПЕРЕКРИТТЯ ЖИТЛОВОГО БУДИНКУ У М. ЛЬВОВІ



Подано результати дослідження технічного стану шатрової залізобетонної плити перекриття за типовою серією 1-480А після пожежі в межах квартири на четвертому поверсі п'ятиповерхової житлової будівлі у Львові. Будівля була здана в експлуатацію у 70-х роках минулого століття. Весь

цей час шатрові плити перекриттів експлуатували у неагресивному середовищі з пониженою вологістю. Пожежа, яка сталась в одній із квартир, тривала півтори години до її ліквідації.

Виконано дослідження технічного стану конструкцій перекриття в зоні дії високих температур. У зоні інтенсивної пожежі виявили критичне зниження несучої здатності та жорсткості полички шатрової плити перекриття під дією високих температур.

За аналізом зміни фактичних прогинів поличок шатрових плит перекриттів у кімнатах квартири можна чітко відслідковувати ділянки з найбільшим впливом температур.

Досліджено, що внаслідок пожежі в першу чергу повністю або частково втрачають свою несучу спроможність полички шатрових залізобетонних панелей перекриття, що проявляється у збільшенні їхніх прогинів унаслідок пластичних деформацій аматури. Значні температурні прогини плити значно перевищують розрахункові від дії повних силових експлуатаційних навантажень. Втрата несучої здатності поздовжніх ребер шатрових панелей є відчутно меншою, їхня несуча здатність може бути відновлена.

На основі аналізу результатів виконаного обстеження та розрахунків несучої здатності елементів проведено аналіз можливості та доцільності підсилення, розроблено ефективне конструктивне вирішення конструкції підсилення, яке також представлене у статті.

Запропоноване конструктивне вирішення підсилення панелі перекриття дозволяє подальше використання приміщення за його початковим функціональним призначенням, що підтверджено тривалим терміном функціонування приміщень після підсилення.

**Ключові слова: вплив пожежі, технічний стан, залізобетон, шатрова панель, армування, підсилення.**