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ASSESSMENT AND REPAIR OF RC STRUCTURE DAMAGED IN A FIRE - CASE STUDY

Abstract: The load-bearing reinforced concrete structure of the last six floors was severely damaged in the fire that occurred on the 12th floor of the 54 m tall building in Novi Sad in April 2000. This paper gives a short description of the damages to the basic structural elements and an assessment of the condition of the load-bearing structure from the 8th to the 13th floors and offers a conclusion concerning the adequate repair measures needed to obtain the load-bearing capacity and stability of the building. It also presents the details of the repair of the basic load-bearing elements of the RC structure and the rehabilitation and strengthening measures.

Key words: fire, concrete, RC structure, high building, damages, repair

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1. INTRODUCTION

In April 2000, a fire spread in the building of the Novi Sad Open University (Fig. 1 and 2). It broke out on the 12th floor and rapidly spread over the last six floors of the building. Due to the fire, which lasted for approximately six hours and was mainly extinguished with water, the load-bearing structure of the building was damaged and the facade, the interior and the installations were completely destroyed on floors caught by fire.

Figure 1. The 9th floor in fire

Figure 2. The view of the building after fire

The unfavorable structure of the building (non-existence of vertical fire resistant separating walls, non-insulated installation openings and staircases, etc.), a large amount of flammable materials in the building and the remarkably strong wind (13 – 15 m/s) enabled the quick spreading and instant development of the fire along both horizontal and vertical lines. The fire destroyed six floors (8th to 13th), the total area of which was approximately 2.400 m^2.

2. BASIC DATA ON THE BUILDING

The building of the Novi Sad Open University was constructed in 1966. The building consists of the basement, ground floor, mezzanine and 13 floors. The dimensions of the basis (Fig. 3) of the building are approx. 30x15 m, and the height is 54 m. The height of the floors is as follows: basement – 2.6m, ground floor – 6.0 m, first floor – 6.0 m, floors from 2 to 13 – 3.5 m (cross-section on Fig. 4).

The structure of the building consists of a RC skeleton with an arrangement of columns at the distance of 6 m in both the longitudinal and transversal direction and RC walls in the staircase area.

Figure 3. The plan of a standard floor

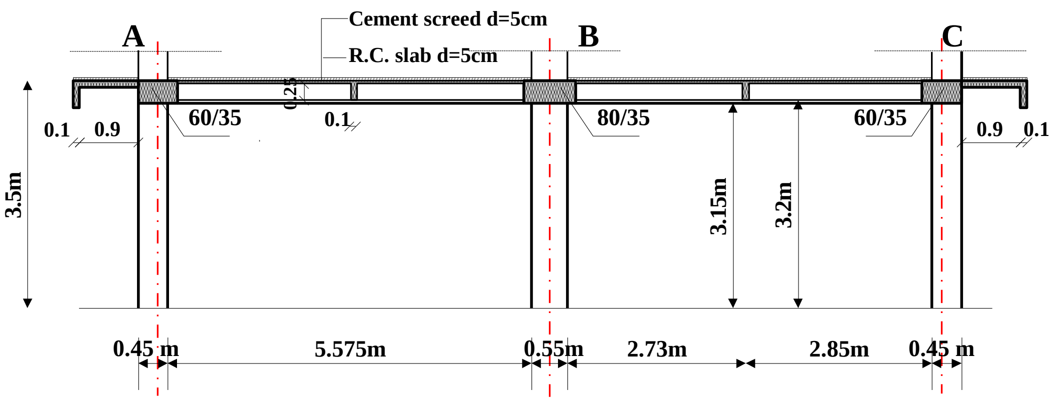


Figure 4. Cross-section of a standard floor

The basic elements of the load-bearing structure are:

- RC columns rectangular in cross-section, whose largest dimensions are in the basement, i.e. 50x90cm and 50x76cm; the smallest are the dimensions on the 13th floor, i.e. 35x40cm and 35x35cm.
- RC longitudinal beams, 6m in span, with a rectangular cross-section of variable dimensions, from the floors 8 to 11 - 80x35cm and 60x35cm, and on the 12th floor - 35x45cm.
- RC transversal beams, 6m in span, with a rectangular cross-section, 35cm high and of variable width, 44cm – 38cm from the 8th to the 12th floor.

- RC walls constructed along the whole height of the building in the staircase and elevator area, with the constant thickness of 30cm.
- RC walls of the basement and ground floor.
- RC pan-joist structure, a 5cm thick slab; the dimensions o the ribs are 10x25cm with a 60cm axial distance between the ribs.
- Solid RC slab over the basement and the mezzanine.
- RC facade beams, with dimensions of 10x32cm.
- RC two-flight stairs, built along the whole height of the building, with a 10cm thick slab.
- Piles and connective foundation beams.

The bearing steel structure of the facade of the building is connected to the RC structure. It is built on three sides of the building, from the third floor up to the top.

The partition-walls from the 3rd to the 12th floor are light partitions, consisting of a wooden frame wainscoted with chipboards. The columns are wainscoted with the same material. The lowered floor system consists of perforated boards on a wooden structure. The interior of the facade parapet is wainscoted with pressed chipboard. On the highest, 13th floor, the suspended ceiling is made of mortar on a wire lath. On this floor the columns are covered with marble plates set in mortar.

3. THE ASSESSMENT OF THE STRUCTURE AFTER THE FIRE

In order to assess the degree of damage to the bearing structure and facade of the building, as well as the kind and scope of repair work, the following records were made and tests carried out:

- Subsequent testing of the quality of built-in materials (concrete and reinforcement).
- Detailed survey of the RC structure and steel facade structure.
- Control calculation of the structure.

The subsequent testing of the concrete compressive strength was carried out using destructive and non-destructive methods. The number and the arrangement of the measuring spots were chosen with the aim of assessing the possible changes in the mechanical characteristics of the concrete caused by the fire. For that purpose, tests were carried out on the RC elements directly exposed to fire, as well as on the structural elements that were not exposed to fire or were protected by marble plates and/or mortar.

On each floor caught by fire, all the elements of the RC structure were surveyed in detail, with the focus on the following:

- Defects resulting from flaws in the construction phase;
- Damages caused by the fire.

3.1. The condition of the structural elements from the 8th to the12th floor

This section of the paper presents only the conclusions of the condition of the structure after the fire and the photographs of the typical damages to the individual structural elements. A detailed description of the conditions of the structure after the fire and all the results of the testing are presented in an previous paper [3], [5].

The general view of the characteristic floor after the fire and cleaning of residues of interior is presented in Fig. 5.

Figure 5. The view of the damaged structure on the 8th floor after the fire and clearing

The conclusions about the condition of the RC structure after fire were:

- Concrete compressive strength for columns, beams and curtain walls was ca. 30 MPa.
- Concrete compressive strength for the ribbed ceiling was ca. 20 MPa.
- The reinforcing steel had the mechanical characteristics corresponding to those of quality of mild reinforcement GA 240/360.
- The decrease in concrete strength (31-34%) and the preservation of the mechanical characteristics of the reinforcing steel confirm the theoretical insights on the change of the properties of these materials when exposed to fire.
- The reinforced concrete structure has been built with numerous faults (concrete honeycombing, uneven, frequently insufficient protective concrete layers, imperfections, irregularly breaks and continuation in concreting).
- All reinforced concrete columns were damaged in the fire (characteristic view in Fig. 6). The concrete cover, approx. 4 cm thick, is crumbled, dilapidated and cracked. In the interior of concrete, at the depth up to 12 cm, there are cracks which point to the separation of the outer layer from the sound core of concrete. The edges of columns are separated or fallen off up to longitudinal reinforcement. Bond between concrete and reinforcement has been impaired.
- All longitudinal and transversal reinforced concrete beams were damaged due to the fire (characteristic view in Fig. 7). The surface concrete layer from the lower side was dilapidated and broken off (thickness of this layer was approx. 5cm). The edges were cracked or broken off along the whole height, and longitudinal

reinforcement was bared. There are vertical cracks on the sides of approx. 0.5 mm of width, and horizontal cracks at the joints of transversal beams and slab. Adhesion between concrete and rebars in the lower zone has been impaired.

- The pan-joist structure was the most severely damaged element of the load-bearing structure due to its small dimensions and unfavorable position in relation to the fire (characteristic view in Fig. 8 and 9). The lower parts of ribs up to 15 cm in height were broken off, while the remaining parts were cracked and dilapidated. The reinforcement was bared along the whole length of the ribs, and adhesion between it and concrete was impaired. There were slanting or vertical cracks at the points of swaying of reinforcement bars from the lower into the upper zone and horizontal cracks at the joint with the plate. The slab was 5 cm thick and had net-like cracks on the lower side. The 3 cm thick cover was dilapidated, crumbled and fallen off, especially at places of uneven changes in dimensions and breaks of concreting, where the damage affects the slab in its whole thickness.
- The reinforced walls in the axis 11 are damaged from the side which was not mortared, and which was directly exposed to fire. The concrete cover, approx. 4 cm thick, was dilapidated, crumbled and falls off, especially at the places of concrete honeycombing. There were net-like and vertical cracks. Reinforcement was partially bared.

Figure 6. Typical view of the column after fire

Figure 7. The characteristic view of the longitudinal beam after fire

3.2. The condition of the structural elements of the 13th floor

- The concrete compressive strength in the columns was ca. 60 MPa.
- The concrete compressive strength in the curtain wall in axis 11 was ca. 30 MPa.
- The columns have not been damaged by the fire. Some of them suffered only isolated surface damage.
- The curtain wall in axis 11 has been damaged only on the side of axis 10 in the same way as the walls on the lower floors.
- The beams and the ribbed ceiling have not been damaged.

Figure 8 and 9. The characteristic view of the pan-joist structure after fire

3.3. The condition of the façade steel elements

- The characteristic damage of steel façade elements was buckling due to restrained elongation. It was concluded that all façade steel elements from 8th to the 12th floor had been destroyed in fire.

After the analysis of all gathered data, it was concluded that the registered damages of the load-bearing RC structure from the 8th to the 12th floor jeopardized the stability and the load-bearing capacity of this part of the building. However, it was concluded that damaged structure could be repaired.

4. REHABILITATION AND STRENGTHENING OF MAIN STRUCTURE ELEMENTS

This chapter presents the chosen repair measures, which were selected according to the degree and the type of the damage and the type of the element of the RC bearing structure [4], [7].

4.1.1. RC Columns

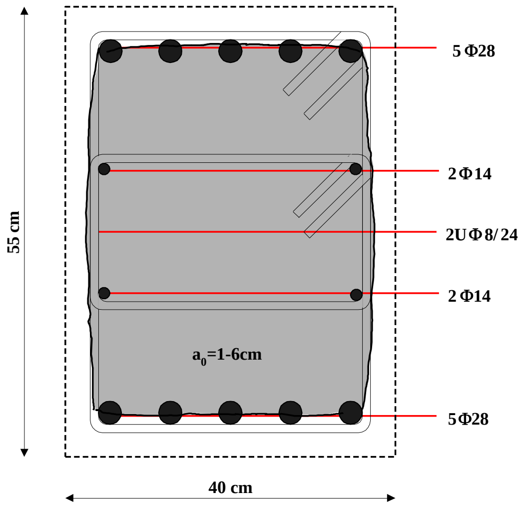
In the choice of the repair measures for the RC columns on the 8th to 13 the floor, the presence of cracks in the column interior and the condition of the exterior concrete coat have been taken into consideration. Also, the replacement of the damaged concrete cover and the strengthening of the columns by adding a new longitudinal and transversal reinforcement were foreseen.

The repair measures consist of:

- The removal of damaged, dilapidated and cracked parts of concrete up to the sound concrete and uncovering the main reinforcement (Fig. 10, 11),

- The placing of additional vertical reinforcement bars ∅ 14mm and stirrups ∅8mm/10cm (Fig. 12 and 13),
- Connecting the new bars with existing reinforcement by direct welding and additional steel plates (Fig. 12),
- Coating of the surface of the existing concrete and reinforcement of columns with the material for improving the bond between old and new concrete,
- Applying a new concrete cover with polymer modified concrete of class C40/50 in two phases through holes in the formwork from the upper slab (Fig. 14, 15 and 16).

By this method of rehabilitation and strengthening of damaged columns, existing cross-section dimensions were increased by 10cm.



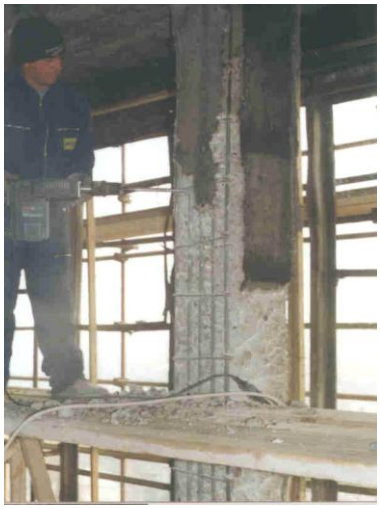
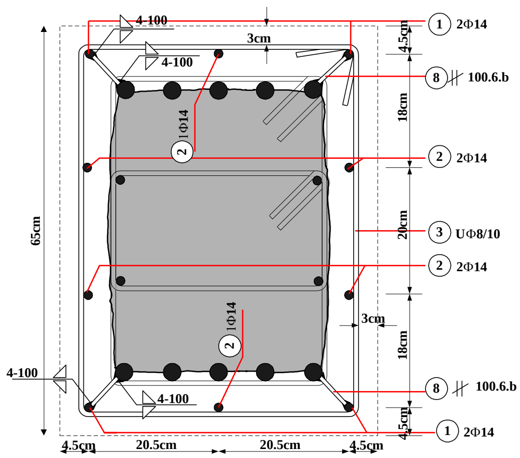


Figure 10 and 11. Removal of the damaged concrete layer from the column



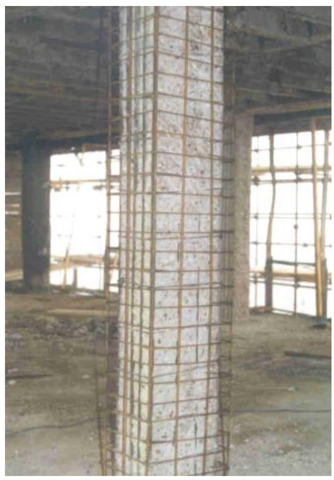


Figure 12. The placing of the new column reinforcement

Fig 14. Placing of the new layer on the column

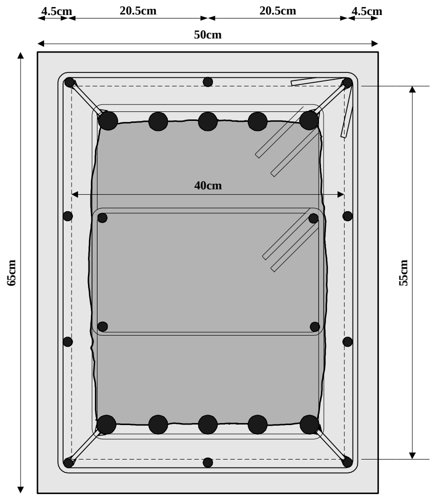


Figure 15 and 16. The repaired column

4.1.2. RC Beams

Since the damages of the RC beams due to the fire occurred only in the concrete cover, the reinforcement was not been damaged, these elements were repaired by replacing the damaged concrete cover.

The rehabilitation of RC beams consisted of:

- The removal of damaged, dilapidated and cracked concrete cover from bottom and side surfaces (up to the sound concrete and partial uncovering the main longitudinal reinforcement and stirrups (Fig. 17 and 18),
- placing of the new cover by pouring self-leveling repair mortar through hollows in the slab (Fig. 19 and 20),
- The upper part on the side surfaces of these beams was repaired by a manual application of polymer modified cement mortar (Fig.21).

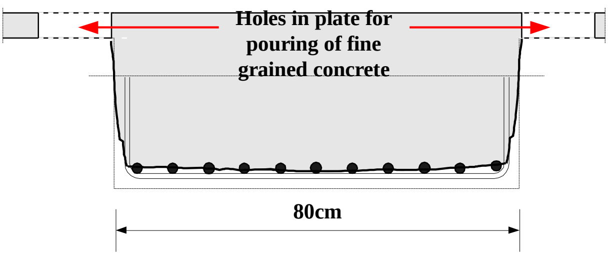


Figure 17 and 18. Removal of the damaged concrete cover and drilling a slab opening

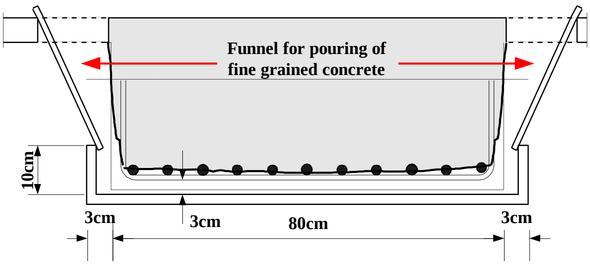


Figure 19. Placing of new cover on the down part of the beam

Figure 20. View of the new protective cover on the down part of the beam

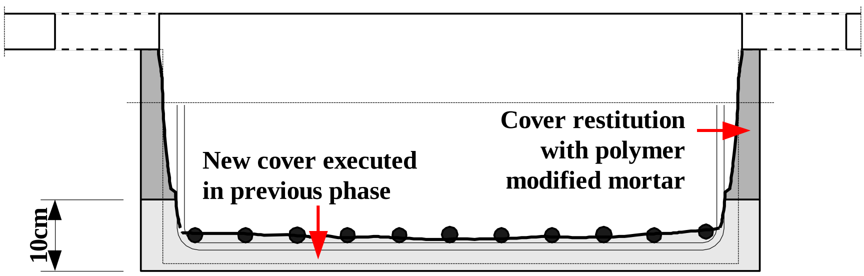


Figure 21. Applying the new protective cover on the side surfaces of the beam

4.1.3. Pan-joist Structure

RC pan-joist structure was the most damaged element of the structure. The required repair and reinforcement of the plate floor structure with the preservation of the same construction system would demand hiring a large number of construction workers who would have to repair manually almost all the ribs and most of the slab. Therefore, the repair measures where the existing floor structure is substituted without removing it, i.e., the building of new RC beams along the 1/3 of the span and a 6cm tick slab over the existing one (Fig. 22) was chosen as a solution. Figures 23 and 24 show the transversal and typical cross-sections of the new beams with the arrangement of the reinforcement.

The order of repair works is shown below:

- The removal of damaged, dilapidated and cracked parts of concrete from the ribs and the bottom surface of the slab and removal of screed;
- Supporting of the existing pan-joist structure ribs;
- Removal of parts of the slab for the execution new RC beams (Fig. 25 and 26);

- installing of new beam reinforcement by anchoring in the existing longitudinal beams and placing the mesh reinforcement for the new slab (Fig. 27);
- Concreting of the new beams and the slab with concrete of class C30/37 (Fig 28.)

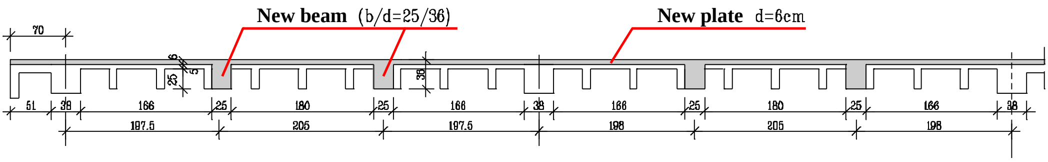


Figure 22. The arrangement of the new RC beams and the slab in the existing floor structure

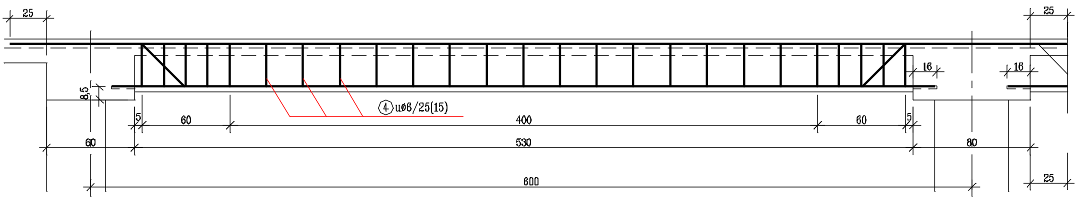


Figure 23. The new beam reinforcement plan: longitudinal cross-section

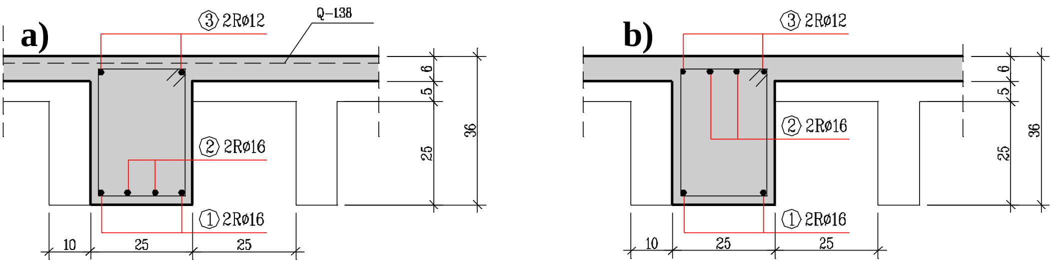


Figure 24. The new beam reinforcement plan: transversal cross-sections: a) in the span; b) in the support zone

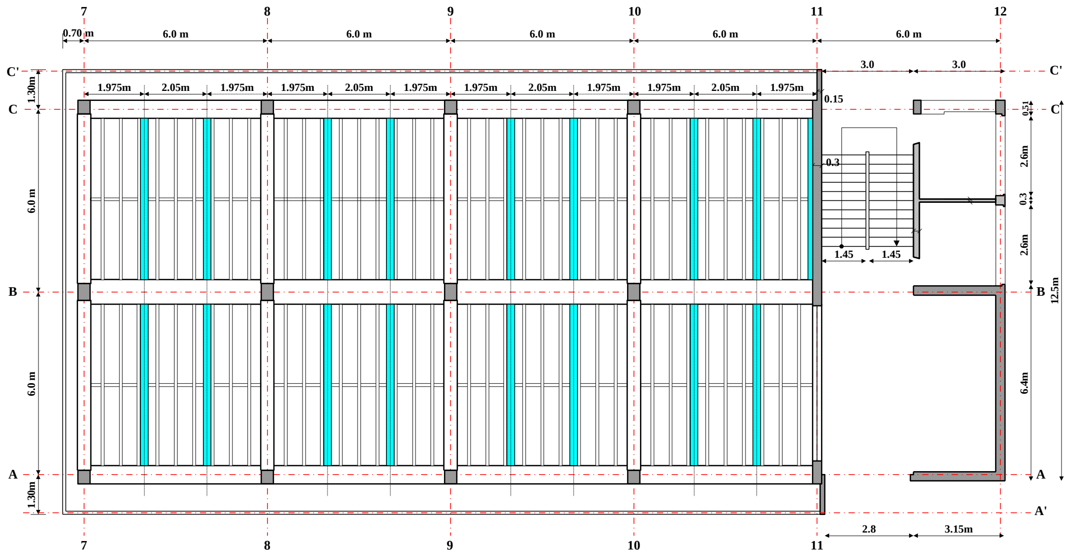


Figure 25. Disposition of the new beams in the existing slab

Figure 26. The reinforcement of the new beam

Figure 27. The wire-mesh reinforcement in the slab

Figure 28. Concreting of the new slab

The repair of the damaged structure was successfully finished in March 2001.

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