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ASSESSMENT AND REPAIR OF THE BEARING STRUCTURE OF THE GRADISKA CULTURAL CENTRE AFTER FIRE

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Subject review
The paper briefly presents the specificity of evaluation and repair of fire-damaged reinforced concrete structures through one case study. Analysed building is the "Cubrilovic" Cultural Center in Gradiska, Bosnia and Herzegovina, that was severely damaged by fire in 2005. Reinforced concrete structure as a classic skeletal structure stiffened with RC walls for seismic actions, was built with many defects which contributed to progressive appearance and spreading of damage characteristic for fire. Real condition of the structure was assessed on the basis of analyses of all field and laboratory test results. On the basis of control design of structure with increased imposed load and decreased concrete strength class it was identified that in certain structure elements there is a lack of built-in reinforcement and that the cross-sections of elements are insufficient. Repair solutions for the damaged structure elements due to the fire are briefly described and only characteristic repair details and a few original solutions for the strengthening of the existing structure are shown in the paper.

Keywords: *assessment, damage, fire, RC structures, repair, strengthening*

Procjena stanja i sanacija nosive konstrukcije doma kulture u Gradiški nakon požara

Pregledni članak
U radu su ukratko prikazane specifičnosti procjene stanja i sanacije armiranobetonskih konstrukcija oštećenih požarom, kroz jednu studiju slučaja. Analizirani objekat je dom kulture "Čubrilović" u Gradiški u Bosni i Hercegovini, u kome je izbio požar krajem 2005. godine. Armiranobetonska konstrukcija, kao klasična skeletna konstrukcija s AB zidovima kao seizmičkim ukrućenjima, bila je izvedena s puno defekata koji su doprinijeli bržem pojavljivanju i većoj propagaciji oštećenja karakterističnih za požar. Na osnovu analize svih rezultata ispitivanja na terenu i u laboratoriji i podataka prikupljenih detaljnim vizuelnim pregledom, procijenjeno je stvarno stanje konstrukcije objekta. Na osnovu proračuna konstrukcije s povećanim korisnim opterećenjem i sa smanjenom markom betona, utvrđeno je da u pojedinim elementima konstrukcije nedostaje određena količina armature ili su dimenzije tih elemenata nedovoljne. U radu su ukratko opisana sanacijska rješenja za elemente konstrukcije oštećene požarom, a detaljnije su prikazani samo karakteristični detalji sanacije i neke originalne tehnike ojačavanja postojeće AB konstrukcije.

Ključne riječi: *AB konstrukcija, ojačanje, oštećenje, požar, procjena stanja, sanacija*

1 Introduction

In modern construction, growing attention is paid to measures for the protection of facilities from accidental destructive actions such as fires, explosions, earthquakes, etc. Statistical data on the damages caused only by fire are rather alarming. Over 5 000 000 fires break out in the world annually, with 40 000 to 50 000 of casualties. In most Balkan countries, the annual damage caused by fire exceeds 2 % of gross national income [1].

Figure 1 View of the front facade of the building after fire

The real assessment of the structure condition after fire demands expertise in the behaviour of the concrete and the reinforcement when exposed to rising temperatures, as well as significant experience in the recognition of the form and extent of damages and distinguishing them from similar damages which are caused by other.

Figure 2 Severely damaged RC slab after fire

Among the large number of concrete structures which the authors of this paper have analyzed and repaired after fire, this case study has been chosen, on the basis of which it is possible to gain insight into the methodology for the assessment of the damaged RC structures. At the same time, this example is a good base to show some of the characteristic damages of reinforced concrete structures which occur in fire [2]. Certain possibilities for their repair are also proposed, as well as a few specific strengthening solutions [3].

2 General information about the fire and building

In 2005, a fire broke out at the "Cubrilovic" Cultural Centre in Gradiska. The fire caught all floors and was extinguished after 4,5 hours. During the fire, installations and the interior of the building as well as the timber roof structure were completely destroyed, while the bearing reinforced concrete structure was partially damaged (Figs. 1 and 2).

The "Cubrilovic" Cultural Centre in Gradiska was built in 1977. The part that was caught by fire is an independent structural entity that is separated by expansion joint from the movie theatre and "Simpo" furniture store. It consists of four stories (basement, ground floor, 1st and 2nd floor), and the dimensions at the base are 30 by 30 m. The Cultural Centre itself, taking the space between axis H-N and 1-7, is schematically represented in Fig. 3.

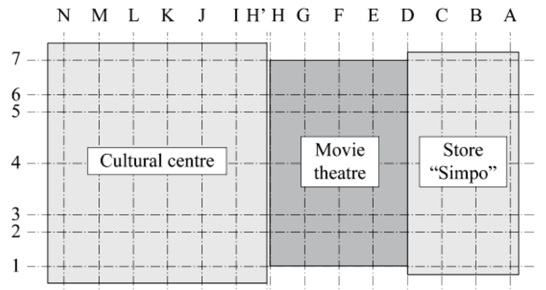

Figure 3 Disposition of building parts and adopted marks of the axis

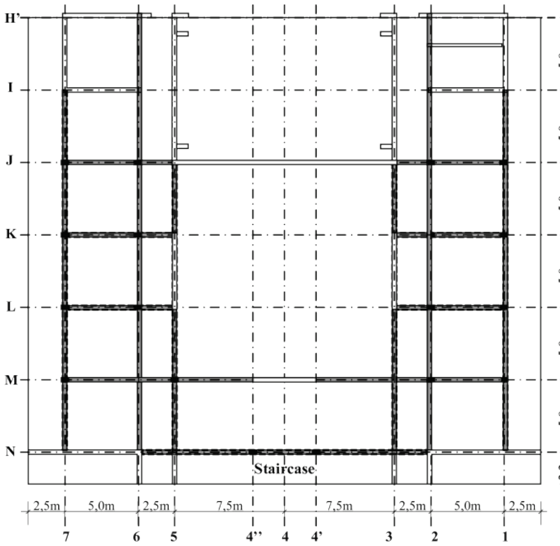

Figure 4 Base of ground floor

Structure of the object is the classic skeletal structure with RC walls as seismic stiffening. Basic elements of the load-bearing structure that was caught by fire are:

- RC columns, 30 × 50 cm,
- RC walls, width 20 and 30 cm,
- RC partitions, width 10 cm,
- RC beams, spanning 5 and 2,5 m (30 × 50 cm),
- RC beams, spanning 15 m (30 × 110 cm), and
- RC full slabs, 12, 13, 14 and 16 cm thick (continually two-way slabs, continual one-way slabs and cantilever slabs).

In order to locate the position of individual elements of the structure, the axis markings are shown on the base of the ground floor (Fig. 4).

Main staircase is of reinforced concrete and was made as an elbowed one-way slab. Final supports are RC walls, and middle support is a cantilever beam. Auxiliary staircase is made as a double RC staircase with a half-landing.

Designed concrete class for all elements of the bearing RC structure is C30/37. For reinforcing of the bearing structure ribbed reinforcement 400/500, mild reinforcement 240/360 and welded wire-mesh reinforcement 500/560, were used.

3 Checking the dimensions and built in reinforcement

From technical design documentation on the building, only some graphical documentation was found, while the static calculation and details on reinforcement were not available during the survey of the object and preparing of the repair design. By checking the dimensions of characteristic elements of the structure, it was concluded that the bearing structure was done according to the available documents. Since there were no data about the reinforcement involved, its arrangement and amount in characteristic section of the structure elements was ascertained via chase cutting. Figs. 5 and 6 show the examples of reinforcement arrangement in the characteristic elements.

Figure 5 RC beam M/3-4' above the first floor

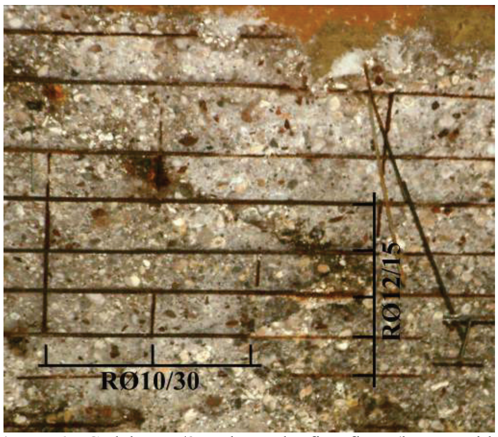

Figure 6 RC slab K-L/3-5 above the first floor (bottom side)

After chase cutting, while checking all the elements of the structure, the following data were collected:

- All slabs have ribbed reinforcement with different arrangement (R∅10/15, R∅10/20, R∅12/15 and R∅10/30), depending on the static system of the slabs.
- All columns have ribbed reinforcement (4R∅19).
- Beams above ground floor have mild reinforcement, and above 1st and 2nd floor, ribbed reinforcement.
- Stirrups are from mild or ribbed reinforcement ∅8. The distance between the stirrups is unequal.
- Walls are reinforced with ribbed reinforcement in the field and at the edges with combined ribbed and mild reinforcement.

4 Quality of the concrete

In order to ascertain the quality of the concrete used in the load bearing RC structure and to ascertain the thickness of the concrete damaged in the fire, 35 cores were taken out (24 cores from the part of the building caught by fire, and 11 from the part that did not burn). Cutting drill equipment and samples prepared for the testing are presented in Figs. 7 and 8. Testing results are presented in Tab. 1 (part of the building caught by fire is coloured).

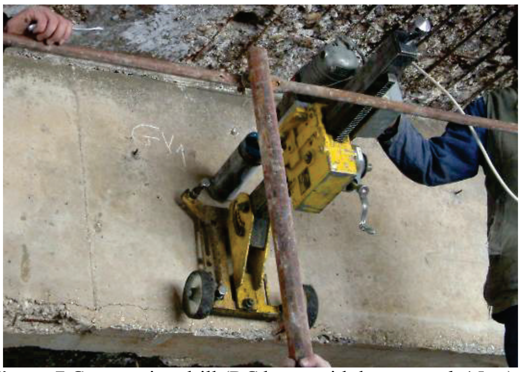

Figure 7 Core cutting drill (RC beam with long span l=15 m)

Figure 8 View of a part of cores, prepared for testing

Based on the result of the analysis of the concrete compressive strength, the following conclusions have been made [2]:

- In both sets of the results there are large differences in individual strength, within a single element of the structure, which shows the variations in the concrete quality, which are primarily the consequence of internal defects in the concrete structure caused by poor adhesion of cement stone and large grains of aggregate (Fig. 9).
- Individual compressive strengths smaller than 20 MPa were gained on the concrete cores with defective and damaged structure.
- There is no significant difference in compressive strength between the part of the object being caught in the fire and the part that has not burned if cores with defective and damaged structure are excluded.
- All average values of concrete compressive strength in the part of the object that was caught by the fire are above 25 MPa, which proves that there is a "healthy" concrete core in the structure.

Table 1 Single and mean values of concrete compressive strength

Floor	Concrete compressive strength / MPa				
	Columns	Walls	Small beams	Large beams	Slab
I	39,0	37,7	16,6*	47,7	44,4
	55,0	31,5	34,7	39,0	23,5
	15,2*	45,8	27,1	43,3	25,8
	-	15,2*	28,2	-	-
Average	36,4	32,6	26,7	43,3	31,2
II	-	-	55,1	43,8	51,1
	-	-	-	46,6	65,1
	-	-	-	60,4	64,0
Average	-	-	55,1	50,3	60,1
I	41,5	39,7	-	42,3	-
	45,2	56,2	-	24,4	-
	31,4	-	-	22,4	-
	44,1	-	-	47,0	-
	-	-	-	47,0	-
Average	40,6	48,0	-	36,6	-

* Concrete cores with defective and damaged structure (large grains separated from the concrete mass or internal fissures)

Figure 9 View of a plane fracture of concrete core

5 Visual inspection

All elements of the load bearing RC structure (columns, beams, walls, slabs and staircase) were inspected in detail on every floor. During this detailed survey, characteristic defects and damage were recorded. For identification of the examined structural elements, adopted system of marking axes was used (Fig. 2). The results of the visual inspection were systematized and presented according to the elements of the structure.

5.1 Columns

RC columns had no protective layer from non-combustible material (mortar, plaster), the surface of the concrete was only treated with the finishing decorative coating in several layers. Because of that, the columns were directly exposed to the high temperatures and open flame, especially the inner rows of columns. There were numerous wirings (Fig. 10) and anchors for the fixation of partition walls. In these places, the damage done to the concrete by the fire was more intense.

By analysing the results of the visual inspection of 60 reinforced concrete columns (20 on each floor), which were directly exposed to the fire, it was concluded that:

- On 8 columns no visible damage from the destructive influence of the fire was recorded.
- A change in colour in the surface layer of the concrete was recorded on about 40 % of the total number of columns. The pink colour of the concrete shows that the temperature of that layer was above 300 °C. The thickness of this layer is about 1 cm.
- Thin net-like fissures in the surface layer of concrete are recorded on about 30 % of the total number of columns. It is presumed that the percentage is greater due to the decorative layer which made it more difficult to examine the surface of some columns.
- Vertical fissures and cracks near the edges of the columns (along the main reinforcement) are recorded on about 20 % of the total number of columns. The main reason for this damage is impaired adhesion between the concrete and the reinforcement due to the two-sided effect of high temperatures. The cracks are located 10 cm from the edge of the column and the cracked part of the concrete is easily removed from the rest of the concrete (Fig. 11).
- Dilapidated longitudinal edges of the columns were recorded on about 60 % of all columns (due to the effect of high temperatures on the porous edges).
- Cracking, separation and falling of concrete along the edges of columns was recorded on about 20 % of all columns. The cause of this is the same as for the vertical cracks (usually on the same columns).
- Cracking, separation and falling of concrete at the places of wirings and anchor for partition walls, was recorded on 20 % of the total number of columns.
- Horizontal fissures were recorded on about 10% of the total number of columns. They are not the consequence of fire but the small thickness of the protective concrete layer, and they are located at the place of stirrups.

Figure 10 RC column M/3 (ground floor)

Figure 11 RC column K/2 (first floor)

After the analysis of the appearance of the concrete cores that were taken out, and the character of their failure mode, it was concluded that some columns contain fissures in the concrete mass, the consequence of mass defects in the concrete structure and local exceeding of concrete tensile strength. This local damage in the concrete mass occurred due to poor adhesion between the cement stone and the large grains of aggregate, which was additionally damaged by concrete stress caused by the fire. Poor adhesion is primarily the consequence of using quarry aggregate with clay film on the grain surface. The characteristic view of RC columns after the fire is shown in Figs. 10 and 11.

5.2 Beams

RC beams also had no protection layer from non-combustible materials, but only a finishing decorative layer. Due to that, they were directly exposed to high temperatures and open flame.

In beams spanning 5 and 2,5 m, there are numerous wirings, the heating and burning of which caused the surrounding concrete to burn through, and the local deformations of reinforcement (Fig. 12). At the places where anchors for partition walls were placed, local mechanical damage showed up during removal of the load bearing structure of partition walls. This kind of damage is most noticeable at five places on the longitudinal edge of the beam.

Figure 12 RC beam above the first floor (J-K/2)

By analyzing the results of the visual inspection of 156 reinforced concrete beams (ground floor, 1st and 2nd floor) which were exposed to the fire, it was concluded that:

- 15 beams have no visible damage from the destructive influence of the fire.
- Change of the concrete colour in the surface area (concrete burned through) was recorded on about 30 % of the total number of beams. The pink colour of the concrete/aggregate shows that the temperature of the concrete in that layer was above 300 °C. The thickness of this layer varies from 1 to 3cm. In this area, the concrete had reduced mechanical characteristics.
- Thin net-like fissures in the surface layer of concrete were recorded on less than 10 % of beams.
- Dilapidated longitudinal edges of the beams were recorded on about 70 % of all beams. They arose from the effect of high temperature in the edge zone of the beams. On about 20 % of all beams, dilapidated concrete on bottom beam side was registered (characteristic for the beams with high quantity of reinforcement in lower zone).
- Cracking, separation and falling of concrete along the free longitudinal edges (along the main reinforcement) was recorded on about 30 % of the

total number of beams. This damage is characteristic for the beams with 15m span, where the lower edges are dilapidated and cracked in the layer as high as 10cm along the entire length of the beam. The cracked part of the concrete is easily separated from the rest of the concrete (Fig. 13).
- Concrete is burned through and falling around the wirings. This damage was recorded on beams with smaller span (2,5 and 5 m). The damage described is especially noticeable on the places of installation boxes and at the place of longitudinal installations.
- Small thickness of the protective layer. This defect was recorded on about 60 % of the total number of beams. A thin protective layer is characteristic for the bottom side of the beam where stirrups can mostly be seen.
- Reinforcement corrosion was recorded on about 10% of the beams, mostly at the stirrups without the protective concrete layer. It is characteristic for the peripheral beams in the structure and the beams above the 2^{nd} floor.

On the outer sides of peripheral beams above the 1^{st} and 2^{nd} floor, surface damage was recorded, in the form of cracks, crumbling of cement stone and separation of the aggregate grains due to the effects of frost. Beams on the 2^{nd} floor have marks of water leaking and influence of weathering over many months of exposure, due to the damaged roof. In the inner structure of concrete built in the RC beams, the same local defects and cracks have been noticed as in the RC columns.

Figure 13 RC beam above the first floor (K/3-5, span of beam 15 m)

5.3 Slabs

Reinforced concrete slabs originally had only a finishing decorative layer from the bottom side, and later a lowered ceiling was done, mostly from combustible materials. All the slabs contain numerous wirings, placed without a regular arrangement, whose heating and combusting made the surrounding concrete burn through, so that the fire damage to the concrete, at these places, is of higher degree. Due to high temperatures in those zones, there is also a local deformation of the reinforcement. On the bottom surface of the slabs there are also defects from the period when the structure was built (concrete honeycombing, linear segregation with de-levelling, insufficient thickness of the protective layer of the concrete, visible reinforcement and inappropriately performed breaking and continuations of concreting) that added to the damage caused by the fire and weather. All slabs show marks of water leaking, with sediment products of calcium-hydroxide wash-out and salt due to many months of exposure to rain and snow that enter through the damaged roof. Leaking of water from the roof and white sediments of washing out products are most noticeable on the slabs above the second floor. Due to occasional presence of moisture, some reinforcement bars have started to corrode. Upper surfaces of the slabs were protected via the cement screed and mineral wool, so they showed no damage from the fire.

By analyzing the results of visual inspection of 94 RC slabs (above ground floor, 1^{st} and 2^{nd} floor), from the bottom side, that were exposed to multiple effects of the fire, it has been concluded that:
- Five slabs did not show visible fire damage.
- Thin net-like fissures in the surface layer of the concrete were recorded in about 20 % of the total number of slabs.
- Surface layer of concrete that is burnt through, dilapidated or fallen off was recorded in about 60 % of the total number of slabs. The thickness of this layer is 1 ÷ 5 cm. At the places where wiring is set, the concrete has burned through deeper. The described damage is also more pronounced at the places of defects, especially at concrete honeycombing and breaking of concreting. On slabs with smaller span this damage is local and exists in several places. On slabs with the span of 15 m (J-M/3-5) the described damage has caught most of the downside surface of the slab, and white, broken grains of the aggregate were recorded, apart from the change in colour of the concrete. For these slabs, falling off of concrete up to and behind the reinforcement is characteristic.
- Longitudinal, transverse and slanting fissures and cracks were recorded in about 60 % of the total number of slabs. On most recorded fissures, marks and products of water leaking are noticeable. A number of fissures are located at the area of wiring in the slab. On cantilever slabs (1-1’ and 7-7’) transverse fissures are characteristic, probably located at places where there was a break in applying of the concrete layer. On square slabs, spanning 5 m, fissures appear in both ways, and on some there are also diagonal fissures. On slabs spanning 15 m, longitudinal fissures are characteristic (at the third and in the middle of the span). They are located at places of badly performed breaking and continuations of concreting. The width of the fissures is from 0,1 to 0,3 mm.
- A small protection layer (bared – visible reinforcement) was recorded on about 35 % of the total number of slabs.
- Surface reinforcement corrosion was recorded on about 10 % of slabs.

Poor adhesion between the aggregate and the cement stone is characteristic for the concrete built-in in reinforced concrete slabs, as well as the concrete built-in in other elements of the structure. Characteristic appearance of the bottom side of RC slabs after the fire can be seen in Figs. 14 and 15.

Figure 14 RC slab above the first floor (K-L-M/3-5)

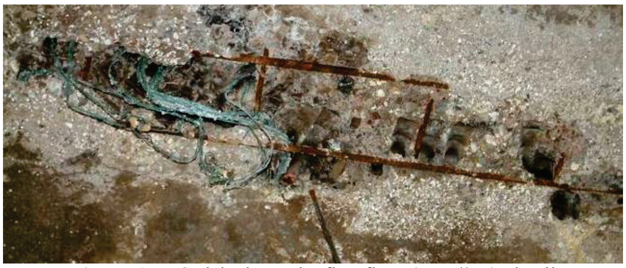

Figure 15 RC slab above the first floor (L-M/3-5), detail

5.4 Reinforced concrete walls

RC walls are 30 cm thick and have two types of finishing. RC walls in axis N had the "sandwich" layer of combustible materials (wood-based panels on a wooden substructure with thermo isolation). This finishing of RC walls was mostly damaged during the fire (Fig. 16). The rest of the RC walls only had the finishing decorative coat. At the places of electric wiring local burning-through of the adjacent concrete was recorded.

Figure 16 RC wall N/6-7 (ground floor)

By analyzing the results of the visual inspection of 44 reinforced concrete walls it was concluded that:

- 12 RC walls do not show any visible damage from the destructive influence of the fire.
- The most damaged walls were K-L/3 and K-L/5.
- Porous, dilapidated edges and the chipped parts of concrete at the edges of walls or around openings in walls were recorded only on 30 % of all RC walls.
- The surface layer of concrete that is dilapidated and burnt through, with colour change and reduced mechanical characteristics was recorded on about 10 % of the total number of RC walls. The damage is local, goes 2 cm deep, and the plane of the breaking goes through the grains of the aggregate.
- Net-like fissures on the concrete surface exist on about 20 % of all inspected RC walls. These are thin fissures, 0,1 to 0,2 mm in width. They could be the consequence of concrete shrinking also.
- Local concrete burn-through around the electric installations in the walls exists on about 20 % of the total number of walls.
- Thin (insufficient) depth of concrete protective layer exists on about 10 % of the total number of RC walls, and together with honeycombing represents the most evident defects.
- Shearing cracks and breaking off concrete parts in the corners of RC walls in N axis at the RC beams support. The cracks have existed before the fire.

6 Assessment of the structure

Based on the analysis of all the test results, both on the field and in the laboratory, and the data gathered through visual inspection, it has been concluded that:

- Reinforced concrete structure was done with many defects (honeycombing, unequal and often not sufficient protective layer of concrete, irregularly done break of concreting). The mentioned defects have all contributed to the faster appearance and greater propagation of damage due to the fire.
- Principle of wiring guidance through the bearing elements of RC structure, which was applied on this building, caused significant damage to the surrounding concrete and reinforcement during the fire. These defects were especially pronounced on beams spanning 2,5 and 5 m and RC slabs.
- Due to great variations in the concrete compressive strength, it has been suggested that for the control calculation of the structure, for all the bearing elements, in the repair project, lower concrete class has to be used (C25 instead of C30). This would partially include the defects in the concrete structure, mostly poor adhesion between the large grained aggregate and the cement stone.
- The built-in reinforcements in the bearing elements of RC structure have mechanical characteristics corresponding to the quality of mild reinforcement (240/360) and the ribbed reinforcement (400/500).
- During the fire, installations and the interior of the object as well as the wooden roof structure were completely devastated, while the bearing RC structure was partially damaged (see Chapter 5).

The degree and the character of the damage done to the elements of the bearing reinforced concrete structure, caught in the fire, is such that the entire load bearing capacity of the structure has decreased, but the global stability of the structure has not been jeopardized. It was concluded that with the appropriate repair and strengthening measures, this part of the structure can be brought to a designed state of load bearing capacity and stability.

7 Repair and strengthening of the structure

A static calculation of the structure was done with imposed load, which was defined based on the new functions of certain rooms in the building and with the decreased concrete strength class (C25/30). The horizontal wind force and earthquake activity of the intensity VIII according to MCS scale was also included in the calculation. In that analysis, the building was treated as category I and the calculation parameters have been taken from a past earthquake period of 500 years.

Based on the calculation of the structure with the increased imposed load and decreased concrete strength class, it was determined that in certain elements of the structure (one way continuous slabs, 15 m span beams, cantilever slabs, etc.) some of the reinforcement is lacking or the dimensions of those elements are insufficient. Moreover, due to the change in the function of certain parts of the building, some new structure elements were designed, and it was necessary to work out their connection with the existing structure. Certain structure elements underwent a change in terms of the static system (e.g. the cantilever slab was transformed into the slab of the gallery, supported on two ends).

The repair solution entails determining the construction work procedure, the type of repair material as well as all the required details for the repair of the damaged elements of the RC structure. Apart from that, the reinforcing details are provided as well as the method of connecting the newly-designed structure elements with the existing structure [3].

What follows is a brief description of the repair solutions for the damaged elements of the structure, and only the characteristic details of repair work and strengthening of the existing RC structure are shown, as well as some details on the connection of the newly-designed structure elements to the existing structure.

Figure 17 Preparing of RC columns for confinement

7.1 Repair of RC columns

As a basic repair method, after removing the crumbly and cracked parts of the concrete, "confinement" of the RC columns with additional stirrups ∅8/25 cm and local reprofiling with fibre reinforced repair mortar (to the designed cross-section), was chosen (Figs. 17 and 18).

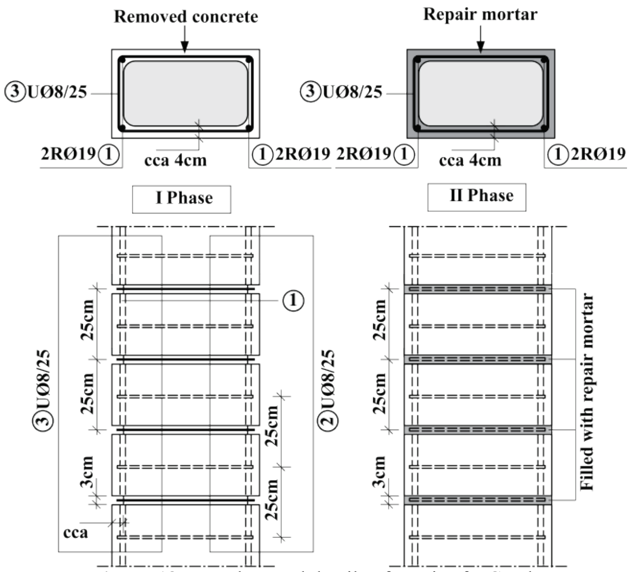

Figure 18 Procedure and details of repair of RC columns

During the preparation of the RC columns for repair, it was observed that, while cutting grips for the new stirrups, bigger bits of the surrounding concrete were falling off as well. For that reason, the authors of this paper decided at the site, to do a classic repair of the columns by jacketing (additional vertical bars and stirrups and applying an additional concrete layer (Fig. 19).

Figure 19 Classic way of repair of RC columns, by jacketing

7.2 Repair of RC beams

Local surface repair with fibre reinforced repair mortar, after removing the crumbly and cracked parts of the concrete, was supposed for the less damaged beams (5 m and 2,5 m span) (Figs. 20 and 21).

Strengthening of support zones of RC beams (5 m and 2,5 m span), for which it was determined by calculation that they lack reinforcement to sustain a hogging bending moment (due to the lack of reinforcement in the upper area, steel plates are added, 12

× 200 cm, 15 mm thick, which are connected to the existing construction with M16 bolts).

Figure 20 RC beam prepared for reparation

Figure 21 View of columns and beams after repair

This solution was proposed due to the impossibility of achieving continuity of additional reinforcement in the upper area at place of the column or RC wall, which goes through two floors (Fig. 22).

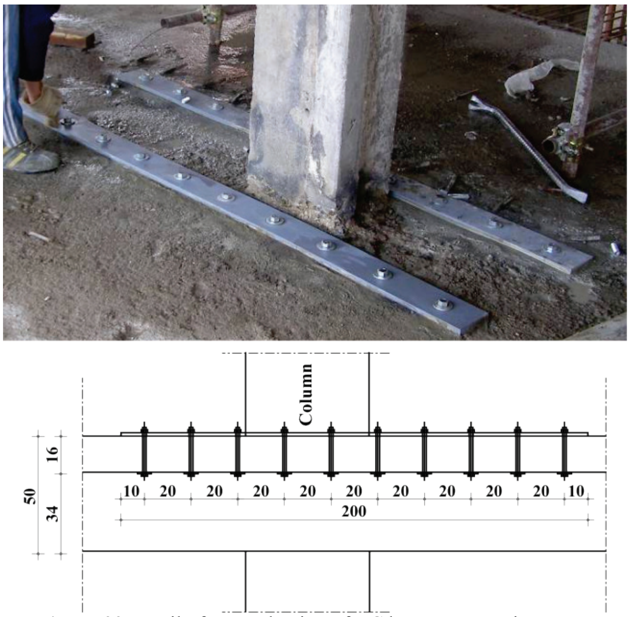

Figure 22 Detail of strengthening of RC beams supporting zones

Strengthening of the RC beams with 15 m span was done by adding new reinforcement and a new concrete on the bottom side of the beams (Fig. 23).

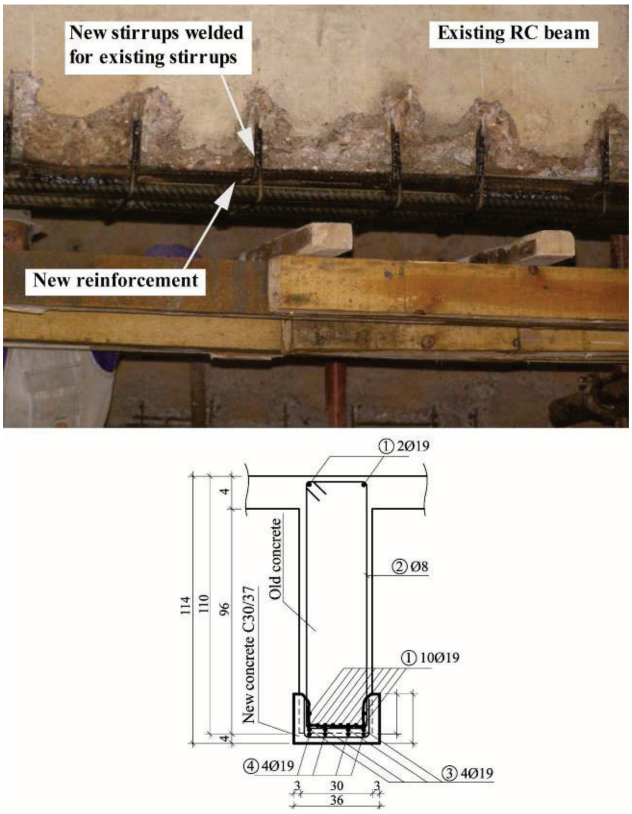

Figure 23 Strengthening of RC beams (L=15 m)

7.3 Repair of RC slabs

Strengthening of two-way RC slabs (5 × 5 m and 5 × 2,5 m) was executed by adding new reinforcement and a new concrete layer on the bottom side of the slab.

Strengthening of the continuous RC slabs was done by adding new reinforcement and a new protective layer of concrete on the bottom side of the slab, (Figs. 24 and 25). The new concrete layer was done as a shotcrete. Strengthening in supporting zones was also done by adding new reinforcement and a new protective layer of concrete on the upper side of the slab. It refers only to the slabs for which it was established by calculation that they lack reinforcement due to bending moments.

Fig. 26 shows a characteristic detail which served to solve the anchorage problem of the additional reinforcement in RC wall zone, and Fig. 27 execution of the strengthening.

Figure 24 Repair of RC slab
(additional reinforcement and executing of new concrete layer)

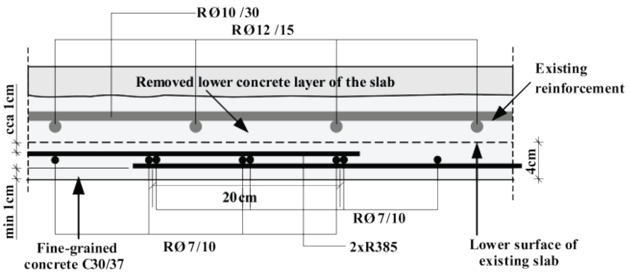

Figure 25 A detail of strengthening of RC slabs (additional reinforcement and new concrete layer)

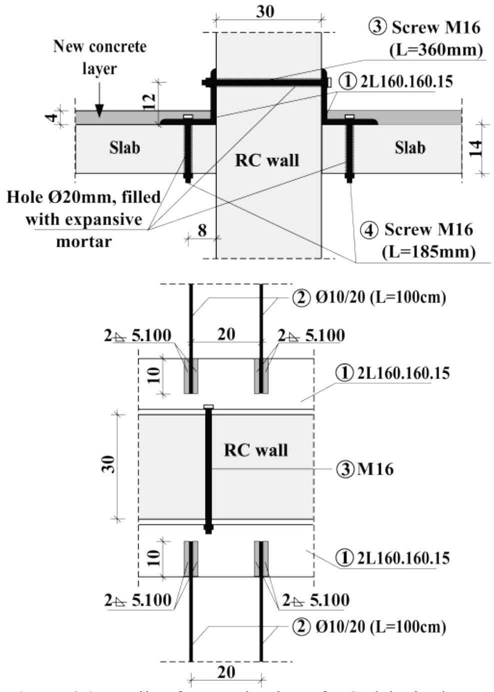

Figure 26 Details of strengthening of RC slabs in the zone of existing RC wall

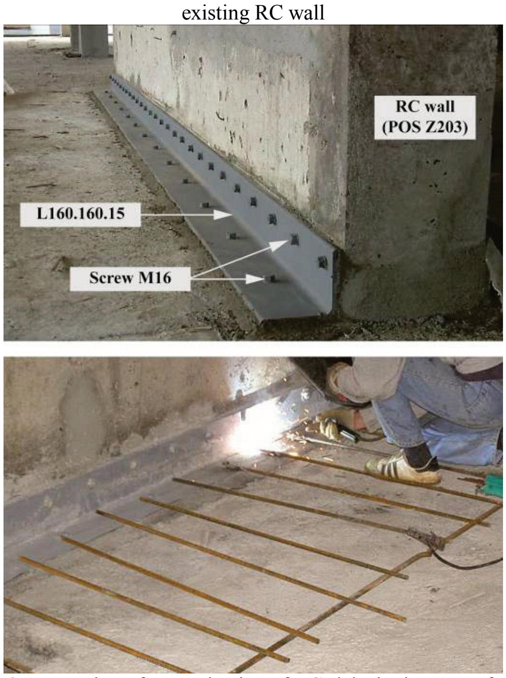

Figure 27 Execution of strengthening of RC slabs in the zone of existing RC wall

Strengthening of cantilever slabs was executed by increasing the critical cross-section, i.e. by adding new concrete in supporting zones (Figs. 28 and 29).

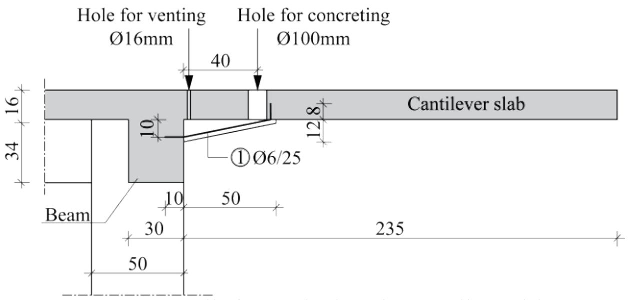

Figure 28 Detail of strengthening of RC cantilever slabs

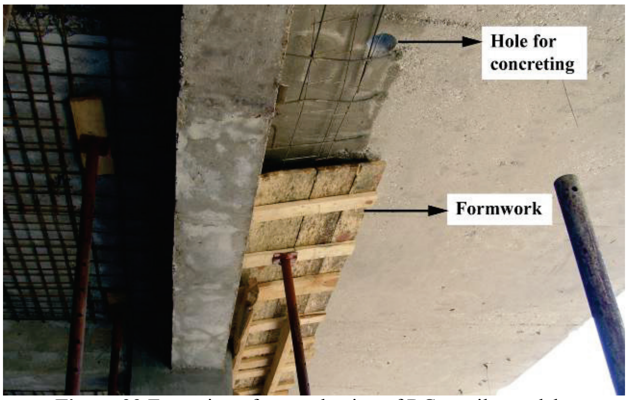

Figure 29 Execution of strengthening of RC cantilever slabs

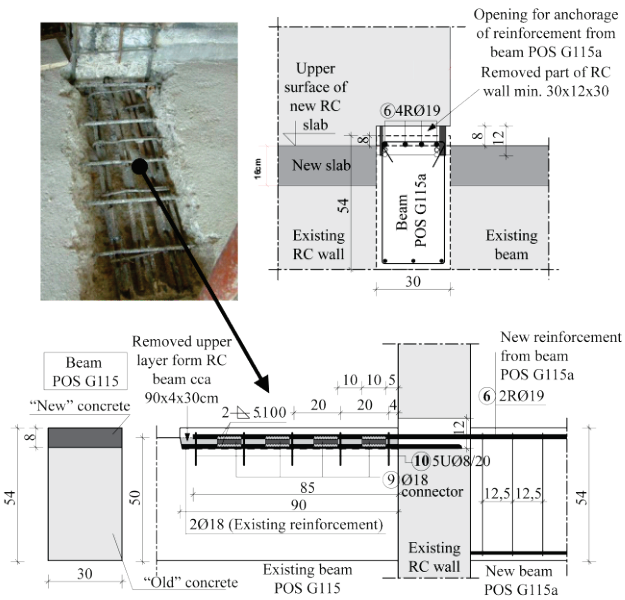

Figure 30 Detail of connection of a new RC cantilever beam with existing structure

7.4 New elements

As part of the adapting the building to the new function, the following new elements were designed:

- Reinforced concrete cantilever beam (POS G115a and POS G116a, b/d=30/54 cm), which supports the slabs of the small galleries. Fig. 30 shows the solution of connection between the newly-designed cantilever beam – POS G115a and the existing structure (beam POS G115 and RC wall Z104).
- Reinforced concrete slab of the large gallery (POS P101, d=16 cm), by extending and transforming the existing cantilever slab to one-way slab (Fig. 31),
- Reinforced concrete slabs of the small galleries (POS P116 and POS P117, d=16 cm),

- Reinforced concrete beam with a span of 15 m (POS G114, *b*/*d*=25/107 cm), which supports the slabs of the big gallery and the small galleries.

Figure 31 Extending and transforming the existing cantilever slab to one-way slab

Apart from that, the repair project entails the demolition and removal of the main cantilever staircase on the ground and first floor. During execution of the repair works, this idea was transformed to changing of cantilever system of the existing staircase by adding new columns and strengthening existing beams (Fig. 32).

Figure 32 Changed static system of existing cantilever staircase (new RC columns and strengthened beams)

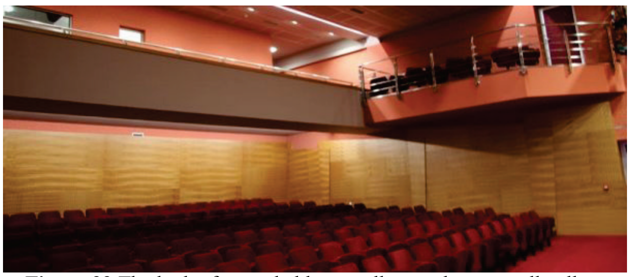

Figure 33 The look of extended large gallery and new small gallery

Prior to the start of the repair and strengthening of the damaged structure elements and demolition and removal of some structure elements, all the layers above the floor structures were removed (thermal insulation, cement screed, light concrete slope layer, waterproofing, tiles and granite tiles) and certain elements were strutted.

Figure 34 The appearance of the building facade after rehabilitation

The repair work of the Cultural Centre was done by company "Arting Invest" from Gradiska and was successfully completed during 2007 (Figs. 33 and 34).

8 Conclusion

Concrete structures completely demolished by fire are rare in practice. Most of the facilities with RC structure have been repaired and used again, even those which have been exposed to great fires. Therefore, the real assessment of the type and extent of damages on RC structures and the selection of adequate repair measures are especially significant. Authors of this paper show through this case-study what are the characteristic damages of RC structures due to the fire, how they are influenced by previously existing defects and how the structure could be successfully repaired. In addition, some original techniques of strengthening are briefly presented, with which bearing capacity of the existing structure could be even increased.

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9 References

[1] Krnjetin, S. Preventive measures for fire protection. DDOR Novi Sad and Faculty of Technical Sciences (in serbian), Novi Sad, 1996.

[2] Radonjanin, V.; Malešev, M.; Folic, R. Elaboration on the assessment of the load bearing structure of "Cubrilovic" Cultural Centre - Gradiska, after fire (in serbian), FTN – Institute of Civil Engineering, Novi Sad, 2006, p. 169.

[3] Radonjanin, V.; Malešev, M.; Folić, R. Repair project of the Bearing Structure of the "Cubrilovic" Cultural Centre in Gradiska after fire (in serbian), Consultant: P. Pavlović, FTN – Institute of Civil Engineering, Novi Sad, 2006, p. 72.

[4] Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire, CEN, November 2002.

[5] Buchanan, A. H. Structural design for fire safety. John Wiley&Sons LTD, London, 2002.

[6] Folic, R.; Radonjanin, V.; Malesev, M. The assessment of the Structure of Novi Sad Open University Damaged in

Fire. // Construction and Building Materials. 16, 7(2002), pp. 427-440.

[7] Peker, K.; Pekmezci, B. Damage analysis for a fire exposed industrial building. // Structural Engineering International (IABSE). 13, 4(2003), pp. 245-248.

[8] Radonjanin, V.; Malešev, M.; Pavlović, P.; Folić, R. The Assessment of a warehouse RC structure damaged in an explosion. // Structural faults & Repair / Editor M. Forde. London: Engineering technics press, 2003.

[9] Folic, R.; Radonjanin, V.; Malešev, M. Evaluation and repair of reinforced concrete multi-story frame structures subjected to high temperatures. // Workshop "Extreme Loadings, Aging and Durability of Concrete Structures" / Montreal: Hydro-Quebec, McGill University and Laboratoire de Beton, 2004, p. 25.

[10] Radonjanin, V.; Folić, R.; Malešev, M. Investigation, Evaluation and Repair of Reinforced Concrete Structures Damaged in Fire. // Workshop "Extreme Loadings, Aging and Durability of Concrete Structures" / Montreal: Hydro-Quebec, McGill University and Laboratoire de Beton, 2004, p. 35.

[11] Radonjanin, V.; Malešev, M.; Folic, R. Assessment and Repair of RC Structure Damaged in Fire - Case Study. // 1st International Conference on Innovative Materials and Technologies for Construction and Restoration / Editors Antonio La Tegola & Antonio Nanni. Lecce: Liguori, (2004), pp. 664-678.

[12] Repairability of fire damaged structures: CIB W 14 Report, 1989.

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