Repair of RC structure of road-pedestrian bridge over Lepenica river in Kragujevac*

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ABSTRACT

The paper gives an overview of the repair solution of the RC structure of the bridge over the Lepenica River in Kragujevac with a detailed description of the adopted solution for the repair/strengthening of the main RC girders. All necessary parameters (degree of environment aggressiveness, classes of exposure, the thickness of the concrete cover, principles and methods of repair, etc.) for the proper selection of products (materials) and the techniques of repair, were defined according to the Regulations on technical standards for concrete structures exposed to aggressive environments, EN 206, EC 1992-1-1 and standard EN 1504..

1 introduction

After 60 years of service a severe damage of the reinforced concrete bridge have been occurred. The main causes that have led to significant damage appearance are: direct exposure to weathering, a numerous defects originating from the period of bridge construction, poorly solved bridge drainage system and lack of maintenance. By the survey of the bridge load-bearing structure and in-situ testing of built-in materials it was concluded that the designed load-bearing capacity and durability of the bridge can be restored by appropriate repair measures.

2 Basic data on the bridge structure

The road-pedestrian bridge is a RC structure, a static system of a continuous girder on three-span continuous beam (23.5m+28.2m+23.5m), with total length of 75.20m. The superstructure consists of: 3 main longitudinal and 13 cross girders, bridge deck and cantilever slabs. The main longitudinal girders are located in the axes "A", "B", and "C" at a distance of 3m from each other (Fig. 1). The height of the main longitudinal girders in the axes "A" and "C" is 140cm, and in the axis "B" is 145cm. In the zone of middle supports (above the river pillars) the main longitudinal girders in the axes "A" and "C" are 190cm high, and the girder in the axis "B" is 195cm (due to the transverse slope of the pavement). The width of the main longitudinal girders is constant - 40cm.

Cross girders were constructed at quarters of each span. The width of those girders is 25cm, and their height is 125cm.

The thickness of the bridge deck is 17cm. The slope of the deck is 2% to both sides. Along with the bridge deck,

1.5m wide cantilever pedestrian paths were constructed on both sides, with variable height from 25cm to 10cm.

The elements of substructures are: 2 RC pillars and 2 abutments. The abutments are constructed as massive elements, 8m long and of variable width from 4.30m to 1.95m at the top. Both river pillars are constructed as RC panels, 80cm thick, with variable width (maximum 6.40m). The height of the river pillars is 10.40m. The wing walls are constructed as hanging RC wings (tied to the abutments).

Three supports of the main girders are roller supports, and the fourth one on the abutment in the axis "3" is pin support. The roller support on the abutment in axis "0" is built of reinforced concrete in the form of a pendulum, while the supports on the river pillars are built of crossed reinforcement.

The foundation of the bridge was derived on a single stepped footings made of plain concrete. The dimensions of the foundations under the river pillars are 400x700cm in the base (height 270cm) and under the abutments 515x800cm (height 160cm).

3 Assessment of the bridge structures

The process of assessment of the load-bearing RC structure and other elements of the bridge included:

- review and analysis of available bridge documentation,
- control of the dimensions of the bridge and the basic elements of the load-bearing structure,
- detailed visual inspection with registration and classification of characteristic defects and damages of the load-bearing structure elements,

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Figure 1. The base and longitudinal cross section of the bridge with the adopted axis labels

- subsequent determination of the quality of the built-in concrete;
- determining the depth of the concrete carbonation,
- checking the arrangement of built-in reinforcement in main and transverse girders,
- geodetic survey of the bridge and
- control calculation of the load-bearing capacity of the bridge.

The aim of all these activities was to obtain a sufficient number of reliable data for an realistic assessment of the condition of the bridge structure in terms of its load-bearing capacity, stability, serviceability and durability [1], [3].

Based on the obtained results of the current condition of the bridge the following conclusions were derived:

- The load-bearing structure of the bridge corresponds to the designed values of the bridge in terms of shape and dimensions.
- The assessed class of compressive strength of built-in concrete in the tested RC elements of the bridge structure corresponds to the designed one.
- The type and arrangement of the installed reinforcement in the tested structure elements correspond to the details of the reinforcement from the project.

- The control calculation confirmed the load-bearing capacity and stability of the bridge except in the upper zone of the bridge deck, where approximately 5% of reinforcement is missing.

- The reinforcement lost its passive protection due to the concrete carbonation and the insufficient thickness of the concrete cover.

- The stability of the bridge is not endangered.

- The load-bearing capacity of the two main longitudinal girders (in axes "A" and "C") is reduced due to heavy corrosion of reinforcement and loss of adhesion between reinforcement and concrete, thus reducing the load-bearing capacity of the bridge as a whole (Fig 2 and 3).

- The durability of the bridge is reduced due to numerous defects, such as the insufficient thickness of the concrete cover, improper reinforcement arrangement, honeycombing, etc., as well as carbonation, damages of the concrete in the form of cracked and fallen parts of concrete and improper drainage of atmospheric water from the bridge.

- The serviceability of the bridge is partially endangered on pedestrian paths due to deep damages in asphalt concrete and precast RC slabs, and on the pavement slab, because of the reduced load-bearing capacity of the superstructure.

Figure 2. Severe corrosion of reinforcement, broken stirrups, longitudinal girder in axis "A"

Figure 3. Severe corrosion of reinforcement, broken stirrups, deep spalling off of concrete, longitudinal girder in axis "C"

4 Repair design

In order to ensure the designed load-bearing capacity, serviceability, and durability of the bridge, the following repair solutions [2], [4] were proposed:

- general reprofiling of abutments,
- local reprofiling and surface protection of river pillars,
- replacement of bearings (3 pendulums) on the abutment in the "0" axis,
- repair and strengthening of the main RC longitudinal girders in axes "A" and "C", new protective layer and surface protection,
- structural repair of the main RC longitudinal girder in the "B" axis and new protective layer,
- local reprofiling and surface protection of transverse girders,
- local reprofiling, application of a new protective layer or application of a protective coating on the underside of the RC slab;
- structural repair of the top side of the RC slab,
- removal of edge RC girders of pedestrian path and construction of new edge girders and slabs of pedestrian path,

– other works (drains and atmospheric sewers, waterproof membrane, ...)

Here are presented repair solutions for main structural elements: longitudinal RC girders, replacement of bearings and repair of RC slab.

The appearance of main cross sections is presented in Figures 4 and 5.

4.1 Main longitudinal girders

The repair method of the main edge girders in axes A and C includes cleaning and protection of the reinforcement bars affected by moderate or surface corrosion (principle 7, method 7.2), replacement of main reinforcement bars and stirrups affected by strong corrosion (principle 4, method 4.1), execution of a new protective layer of concrete (principle 4, method 4.4 and principle 7, method 7.1), reinforcement with CFRP composites (principle 4, method 4.3), and application of a protective coating which additionally prevents the penetration of water, CO₂, chloride and other aggressive substances into the concrete interior (principle 1, method 1.3).

Figure 4. Main cross section of bridge before repair

Figure 5. Main cross section of bridge according to repair design

Depending on the degree of damage, the repair solutions of main girders are divided into two groups:

- Girders in axes A and C on which the following procedures are applied: repair of reinforcement affected by moderate or surface corrosion, replacement of rods of main reinforcement and stirrups affected by strong corrosion, execution of a new protective layer of concrete, strengthening with CFRP strips and application of protective coating.
- Girders in the B axis on which the following procedures are applied: repair of reinforcement affected by moderate or surface corrosion, construction of a new protective layer of concrete and strengthening with CFRP strips.

Taking into account extent of damage and position of damaged zone, four different repair solutions are designed (Figure 6).

4.1.1 D2/D4: Repair of reinforcement bars affected by moderate or surface corrosion and construction of a new protective layer

Local repair of corroded bars is applied at the places of visible corrosion of reinforcement and stirrups and at the places of cracks along corroded bars of reinforcement, and includes the following operations:

- Marking of zones for repair of corroded reinforcement bars on the sides, while for the lower side it is planned to

remove the protective layer of concrete over the entire surface.

- Removal of the existing protective layer of concrete on the underside of the girder and locally, around the corroded reinforcement bars on the underside and on the sides, including areas with cracked concrete. The depth of the removed layer of concrete depends on the preservation of the adhesion between the reinforcement and the concrete and on the degree of corrosion of the reinforcement (Figure 7).
- Preparation of the complete concrete surface of the sides by dry sandblasting to obtain base for a new protective layer (cleaning and removal of smaller loose grains, dust deposits, biological deposits and other impurities), which provides the necessary roughness of the concrete surface and cleaning visible parts reinforcement from corrosion.
- Washing of prepared surfaces.
- Coating of "exposed" reinforcement bars to ensure better adhesion, which at the same time protects the reinforcement from corrosion.
- Setting the formwork to perform a new protective layer.
- Pouring of self-compacting concrete (SCC, two-fraction $D_{\max} = 8$ mm) or applying of repair mortar (Figure 8).
- Curing of concrete.

Figure 6.. Repair solutions for longitudinal and transverse girders

Figure 7. Removal of the existing protective layer of concrete: a) removed layer of concrete if the reinforcement bar is partially affected by the corrosion process, and the adhesion is preserved; b) removed layer of concrete if the reinforcement bar is affected by the corrosion process along the entire circumference, and the adhesion with the concrete is disturbed

Figure 8. New protective concrete cover

4.1.2 D1: Replacement of bars of the main reinforcement and stirrups affected by strong corrosion and execution of a new protective layer

Replacement of corroded bars is applied in places of strong corrosion of reinforcement and significant reduction of cross section (Figure 9).

Replacement of corroded reinforcement bars includes the following operations:

- Marking of zones for replacement of corroded reinforcement bars. The zones should be of regular geometric shape and be at least 50 cm wider on both sides in relation to the damaged zone.
- Removal of concrete around the corroded reinforcement bars in the first row in order to release them and in height up to the first "healthy" reinforcement bar. "Healthy" rods should be stripped to $\approx 1/3$ of the cross-sectional circumference. Concrete removal is performed by manual chipping or by pneumatic hammers. The depth of the removed layer of concrete depends on the number of bars affected by strong corrosion and is at least 5 cm in the zone of middle bars and 8 cm in the zone of corner bars.
- Removing concrete around the stirrups, to cut and weld to continue the stirrups. Concrete is removed at a length equal to the length of the corroded part of the stirrup increased by 20 cm or at a length of at least 20 cm from the

upper edge of the removed concrete (if the stirrups have not corroded).

- Preparation of the remaining vertical concrete surfaces of the beams by dry sandblasting
- Cutting of corroded reinforcement bars and stirrups around the longitudinal reinforcement, in the replacement zone. When cutting the reinforcement that continues, at least 50 cm of free "healthy" reinforcement remains on both sides of the damaged zone. The stirrups are cut along the entire length on which the concrete was removed.
- Cleaning of the remaining visible parts of the reinforcement by dry or wet sandblasting.
- Washing of prepared surfaces.
- Continuation of reinforcement bars with garters made of rolled L profile or reinforcement bars and installation of new stirrup parts by overlapping with single-sided welding.
- Coating of "exposed" reinforcement bars to ensure better adhesion, which at the same time protects the reinforcement from corrosion.
- Setting three-sided formwork to the lower surface of the pedestrian cantilever slab. The formwork is placed in such way to ensure the continuity of the cross-section with the zones where the structural repair was not performed.
- Concreting of the new protective layer and the missing parts of the section with concrete under pressure.
- Curing of concrete.

Figure 9. Repair solution D1 – replacing existing corroded reinforcement

4.1.3 D3: Strengthening with CFRP strips

Strengthening with CFRP strips includes both zones, with strong corrosion and zones in which the load-bearing capacity with the existing reinforcement is not satisfied (according to static calculation). Detail of strengthening is given in Figure 10.

When placing CFRP, the following technical requirements are prescribed:

- Proof of achieved concrete compressive strength ($f_c \geq 30 \text{ MPa}$);
- Determination of bond strength / adhesion for concrete surface (Pull-off method, $f_{ath} \geq 1.5 \text{ MPa}$);
- Control of flatness / roughness of surfaces;
- Dew point control (surface temperature must be higher than dew point temperature increased by 3°C);
- Surface humidity control (surface humidity must not exceed 4%);
- Outdoor temperature ($10^\circ \text{C} - 35^\circ \text{C}$);
- Principle of applying CFRP (preparation for gluing, applying glue and gluing) should be done according to the manufacturer's instructions;
- Control of performed works;

– Control of empty spaces in the glue. Gaps in the middle reinforcement zones can be injected with epoxy resin under low pressure, while in the case of gaps at the ends, the strips must be removed and re-glued.

4.2 Replacement of bearings

For the purpose of replacing the existing "pendulum" bearings with new, elastomeric ones, it is planned to raise the structure by $\sim 10 \text{ mm}$ at the column location S0 (Figure 11).

Lifting is performed by placing the press under the supporting transverse girder, in the phase after repairing the lower zone of the main girders, but before concreting the additional layer of the RC slab from the top side. The presses are placed next to the main girders, outside the zones of the new support so that the procedure of repair of the bearing surfaces and replacement of the bearing can be executed.

After lifting, the structure rests on temporary supports. Edge presses required for lifting must have a capacity of at least 350t, while the required capacity of medium presses is at least 120t.

Figure 10. Repair slution D3 – replacing existing corroded reinforcement

Figure 11. Replacing of existing pendulum bearings

Figure 12. Repair solution of top side of RC slab

After the formation of new bearing blocks and the repair of the lower zone of the beam, the construction is lowered down on the new elastomeric bearings.

4.3 RC slab

4.3.1 Repair solution of top side of bridge deck

The method of repairing of top side of the bridge deck (Figure 12) includes the installation of anchors for ensuring composite action of new and old concrete (principle 4, method 4.2) and execution of a new concrete layer (principle 4, method 4.4).

These repair solution is applied to the entire top surface of the slab and includes the following operations:

- Preparation of the complete concrete surface by sandblasting for the application of bonding primer (cleaning and removal of smaller loose grains, dust deposits and other impurities), which also provides the necessary roughness of the concrete surface.
 - Drilling holes with a diameter of Ø18, cleaning, dusting and pouring the mass to ensure adhesion between the anchors and the old concrete.
 - Installation of Ø14 (B500B) concrete steel adhesion anchors in the prepared holes.
 - Washing the top surface of the slab
 - Installation of additional reinforcement.
 - Applying a bonding primer immediately before concreting (if the coating is polymer-based)
- Concreting of the additional concrete layer ($D_{max} = 16\text{mm}$).

4.3.2 SP1 and SP2: Repair solution of bottom side of bridge deck

The method of repairing the RC bridge deck from the bottom includes: local repair of corroded reinforcement bars (principle 7, method 7.2), surface impregnation to prevent general corrosion of reinforcement (principle 11, method 11.3) and application of a protective coating which partially compensates the insufficient thickness of the concrete protection layer (principle 1, method 1.2) and execution of a new protective layer (principle 7, method 7.1).

Depending on the degree of damage to the lower surface of the slab, two groups of repair procedures are defined:

- SP1 is applied on slab areas that lack a protective layer, and has only local corrosion of reinforcement, erosion of concrete and concrete honeycombs and includes local repair of corroded reinforcement bars, surface impregnation and application of a protective coating
- Procedure SP2 is applied to slab areas that lack a protective layer, but have severe corrosion of reinforcement and other types of damage and includes the repair of

corroded reinforcement bars and the execution of a new protective layer.

The position of the slab areas according to the repair solution is given on Figure 13.

5 Conclusion

Development of repair design was iterative, as there were several factors to consider. The investor had two requests that limited possible repair solutions. The first one was ensuring that one-half of the bridge would be available for pedestrian use during repair works. The other one was related to the fact that there is an active railway track below the bridge and because of that, it was not possible to significantly change the height of the main girders and to use supporting scaffolding.

Also, repair design for main girders according to solution D3 implies phase execution, in terms of sequential remove and replace of corroded reinforcement, due to significant reduction of the load-bearing capacity of their cross-section.

Project information

Investor: Municipal Administration Kragujevac,

Designer: Joint venture (JV): Project Biro Utiber Ltd. (Leader), Faculty of Technical Sciences, Department of Civil Engineering and Geodesy, Novi Sad (Partner), CPL Ltd. (Partner)

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Figure 13. Areas with different repair solution for bottom side of RC slab

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