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STRUCTURAL ASSESSMENT AND RETROFITTING MEASURES FOR REINFORCED CONCRETE STADIUM STANDS

Summary: This paper presents an assessment of the condition of the reinforced concrete structure of the stadium grandstands after many years of service and proposes recommendations to ensure its safe continued operation. The research focuses on deterioration of concrete and reinforcement in elements of the primary and secondary structural systems, including areas that were previously inaccessible for inspection during the facility's operation. New structural calculation models were developed to compare the obtained results with the values given in the original design documentation. Based on the analyses and inspections performed, recommendations are provided for eliminating the identified deficiencies and for establishing appropriate monitoring of the reinforced concrete structure during its future service life. After rehabilitation, the structure has remained in operation with continuous monitoring of its behavior and structural performance.

Keywords: reinforced concrete structure, damage, corrosion, rehabilitation, strengthening

PROCENA STANJA ARMIRANOBETONSKE KONSTRUKCIJE TRIBINA SA PREDLOGOM MERA ZA SANACIJU

Rezime: U radu je opisano stanje armiranobetonske konstrukcije tribina atletskog stadiona nakon upotrebnog veka od 50 godina i predložene mere za sigurnu dalju eksploataciju. Prikazana su uočena oštećenja na betonu i armaturi delova primarne i sekundarne konstrukcije, nedostupnih pregledu u toku upotrebe objekta. Predstavljeni su novi proračunski modeli oformljeni radi upoređivanja rezultata sa vrednostima iz osnovne projektne dokumentacije. Komentarisane su razlike između važeće i tehničke regulative iz perioda projektovanja i izvođenja objekta. Predstavljeni su zaključci i predlog aktivnosti potrebnih za otklanjanje uočenih problema i za monitoring armiranobetonske konstrukcije u daljem upotrebnom periodu. Sanirana armiranobetonska konstrukcija je već nekoliko godina u eksploataciji uz stalno praćenje ponašanja.

Ključne reči: armiranobetonska konstrukcija, oštećenje, korozija, sanacija, ojačanje

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1. INTRODUCTION

The athletics stadium of the "Ibar" Sports Center in Kraljevo was designed in 1970 and constructed two years later. In addition to a natural grass playing field and an athletics track, the facility includes a single spectator stand with a seating capacity of 1,000. Auxiliary spaces and support facilities are located beneath the grandstand structure (Figure 1).

Figure 1: Former appearance of the athletics stadium in Kraljevo

Following several decades of service, a comprehensive reconstruction of the stadium was initiated. During this process, deterioration of the grandstand structure was identified, primarily in the form of reinforcement corrosion and concrete damage, necessitating a more detailed assessment of the condition of the reinforced concrete load-bearing structure.

The assessment of the structural system and the observed damage was based on the available original design documentation [1],[2]. All data used in the analysis were obtained from the existing project documentation and from on-site inspections of the structure. Particular consideration was given to the fact that, at the time of the design and construction of the facility, the regulations and standards currently governing the design and analysis of reinforced concrete structures and structural elements were not yet in force.

2. DESCRIPTION OF THE EXISTING CONDITION

From a structural perspective, the stadium grandstand consists of a monolithic reinforced concrete frame structure (Figure 2).

The retaining walls in contact with the soil are constructed of reinforced concrete with thicknesses ranging from 25 cm to 35 cm. The reinforced concrete columns have cross-sectional dimensions of 30 × 60 cm and 60 × 60 cm. The primary beams have cross-sectional dimensions of 30 × 80 cm. The seating support beams have dimensions of 15 × 46 cm and are spaced at 80 cm center-to-center, supporting reinforced concrete slabs with a thickness of 6 cm. The spatial frame structure is founded on isolated footings, while strip foundations are provided for the reinforced concrete retaining walls.

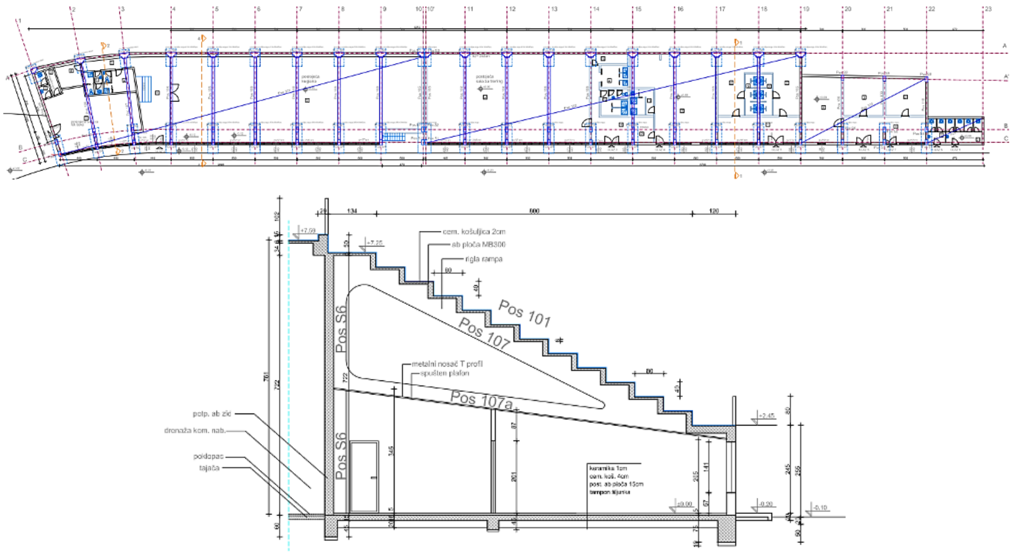


Figure 2: Structural layout of a section of the grandstand structure of the athletics stadium in Kraljevo

Following many years of service, the condition of the grandstand structure indicated the need for reconstruction. After the removal of the suspended ceilings beneath the grandstands, reinforcement corrosion and concrete deterioration were observed in both the primary and secondary reinforced concrete structural elements. These structural components had not been accessible or visible during the service life of the facility.

Significant portions of the load-bearing structure beneath the grandstands were found to have insufficient concrete cover, with both transverse and longitudinal reinforcement visibly exposed and undergoing active corrosion. Concrete spalling was also observed (Figures 3 and 4), most likely resulting from reinforcement corrosion and repeated freeze–thaw cycles.


Figures 3 and 4: Damages to the reinforced concrete grandstand structure

The extent of deterioration observed in the structural elements varied significantly. The reinforced concrete seat-support beams and reinforced concrete grandstand seating slabs exhibited both moderate and severe deterioration of the concrete and reinforcing steel, including complete rupture of reinforcing bars in certain cross-sections as a consequence of advanced corrosion. The columns, primary reinforced concrete beams, and reinforced concrete walls were characterized by moderate to minor deterioration of the same type.

In addition to the detachment of the plaster finish applied to the reinforced concrete structural elements of the grandstands, traces of water infiltration indicated deterioration and the absence of an effective waterproofing system (Figure 5).

Figure 5: Damage to the reinforced concrete grandstand structure

3. STRUCTURAL ANALYSIS

The structural analysis was performed using the software package for static and dynamic analysis of spatial structures, *Tower 7* (© Radimpex, Belgrade), based on a three-dimensional computational model of the structure (Figure 6). The structural system was assumed to be non-sway. The effective buckling length factors were determined separately and specified during the design verification of the columns. The ends of the frame members were assumed to be laterally restrained. The computational model was developed in full accordance with the original design documentation [1],[2] and the dimensions of the as-built structure.

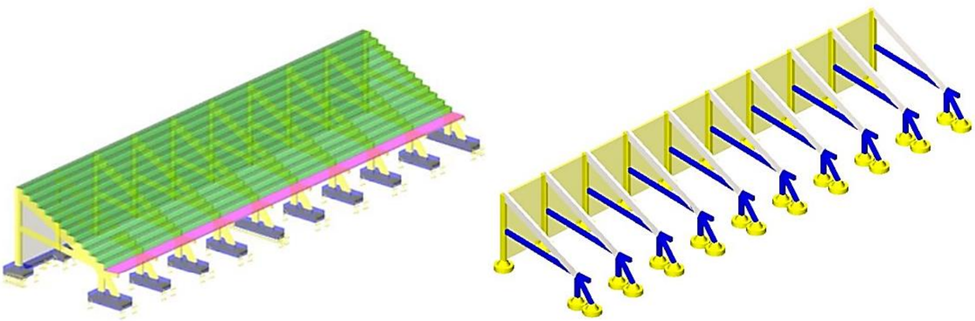


Figure 6: Isometric view of the computational model of the grandstand structure

The original structural design considered variable imposed loads (6.5 kN/m²) and active earth pressure, in accordance with the regulations in force at the time of design.

However, variable surcharge loads acting on the soil adjacent to the structure, seismic actions, and thermal effects were not included in the original design documentation. The considered actions were incorporated into the present verification analysis in accordance with the applicable design codes and standards in force at the time of the assessment (2019) [4–6]. Furthermore, the assessment was additionally performed with reference to the provisions of design codes and standards that were not mandatory at that time but were considered relevant supplementary guidelines for the evaluation of the structural performance [7–10].

At the request of the occupant of the space beneath the grandstands (the bowling alley), a modification of the geometry of one of the beams within the transverse frame located along Axis 5 was also considered (Figure 7).

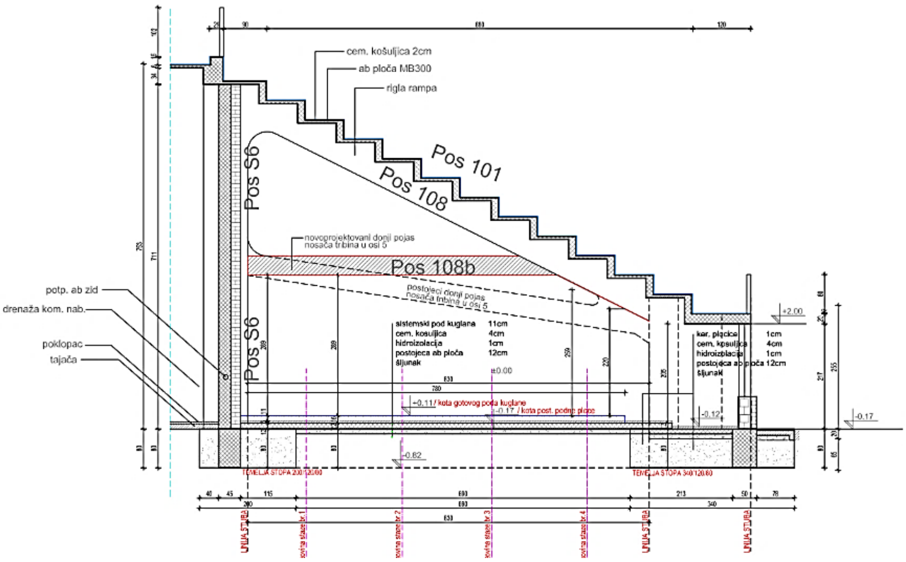


Figure 7: Modification of the geometry of the reinforced concrete beam within the transverse frame

The structural assessment included nine computational models encompassing all structural elements under different service stages, loading conditions, and structural configurations. This approach was adopted to enable a comprehensive comparison with the results obtained from the original design calculations.

Based on the analysis of the results obtained from the structural verification analyses of all models, the following conclusions were drawn:

- The existing structural system was neither designed nor constructed to resist seismic actions or the surcharge loads imposed by vehicular traffic on the roadway located in the immediate vicinity of the structure.
- The existing structural elements have been adversely affected by reinforcement corrosion and concrete deterioration.
- Rehabilitation of all damaged structural elements is required, together with strengthening of the reinforced concrete structural members to ensure adequate resistance to seismic actions and traffic-induced loading from the adjacent roadway.
- The strengthening of the existing structural elements should be carried out in accordance with the recommendations provided.

4. STRUCTURAL RETROFITTING MEASURES

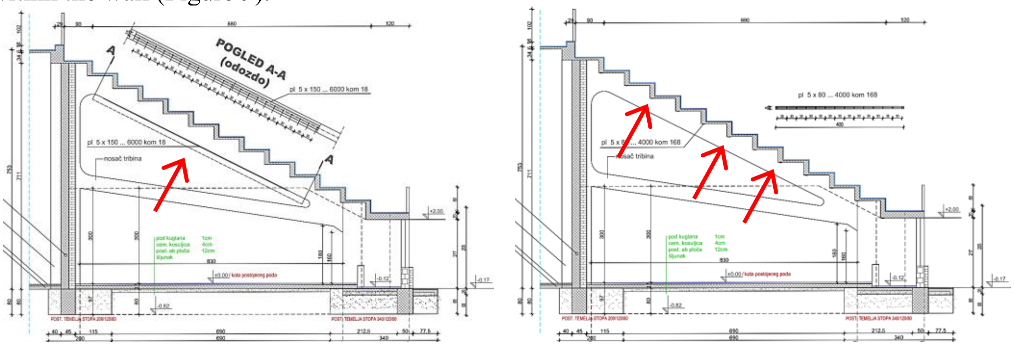
To ensure that the existing reinforced concrete structure can safely resist the actions prescribed by current regulations and standards, a comprehensive rehabilitation program was proposed. The program includes the repair of existing concrete and reinforcement deterioration, as well as the strengthening of all structural elements of the stadium grandstands, in accordance with the results of the structural verification analysis and the recommendations provided for the execution of rehabilitation and strengthening works.

4.1. STRUCTURAL REPAIR MEASURES

The condition of the deteriorated concrete and corroded reinforcement required remedial intervention involving the removal of all damaged concrete and existing plaster finishes, followed by the cleaning of reinforcement bars affected by corrosion. After thorough cleaning, the reinforcement of the structural elements was treated with a corrosion protection system. Subsequently, all reinforced concrete elements were restored to their original design geometry through the application of suitable repair mortars. In addition, the installation of a new waterproofing system for the beams and seating slabs of the grandstands was specified.

4.2. STRUCTURAL STRENGTHENING MEASURES

The strengthening of the reinforced concrete structural elements was carried out using steel plates. In accordance with the results of the structural verification analysis, all beam elements were strengthened by applying steel strips only to the lower tension zone within the span (Figures 8a and 8b). Strengthening of the reinforced concrete retaining wall was performed by applying steel strips on the interior side of the sub-stand spaces, in the zones of maximum internal actions within the wall (Figure 9).



(a) (b)

Figure 8: Strengthening of ramp stringers (a) and strengthening of seat-support beams of the grandstand (b)

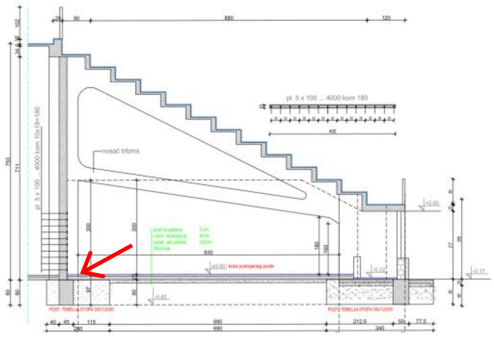


Figure 9: Strengthening of the reinforced concrete retaining wall

The arrangement and dimensions of the epoxy-bonded steel plates were defined to achieve the required enhancement of the flexural load-carrying capacity of the reinforced concrete members. Since the strengthening intervention for the beams and walls was designed to be implemented within a single region only, the ultimate limit state verification was conducted by applying a linear elastic analysis with limited redistribution of bending moments. Furthermore, the mechanical properties of the steel plates were selected to be consistent with those of the existing reinforcing steel, which represents a favorable condition regarding the structural compatibility of the strengthened members. The improvement in the flexural resistance of the reinforced concrete members achieved through the application of epoxy-bonded steel plates also contributed positively to the serviceability limit state verification. The calculated stress levels, crack widths, and deformation values obtained from the control model incorporating the simulated strengthening remained within the specified admissible ranges.

In order to achieve the full effectiveness of strengthening reinforced concrete members using steel plates, it is essential to ensure the initial conditions related to the physico-mechanical properties of the existing concrete. Accordingly, measurements of concrete moisture content and pull-off testing were performed. Following confirmation of the applicability of the selected strengthening technique, a strengthening procedure for the considered structural elements was proposed in accordance with the performed design calculations and the recommended execution sequence. In this case, an epoxy adhesive, also serving as a repair mortar, manufactured by a reputable producer was selected, as its mechanical and bonding properties ensure adequate composite action between the existing concrete substrate and the steel plates. Full compliance with the manufacturer's technical recommendations for the application of the epoxy adhesive was required, including the presence of the manufacturer's technical representative during the initial stage of implementation.

The recommended sequence of strengthening procedures is as follows:

- Marking of the steel plate positions in accordance with the rehabilitation design layout.
- Surface preparation of the marked concrete areas using appropriate abrasive techniques.
- Marking and drilling of holes in the steel plates in accordance with the rehabilitation design.
- Application of anticorrosive protection coating to one side and all edge surfaces of the steel plates.
- Surface treatment of the bonding side of the steel plates using suitable abrasive methods.
- Positioning of the steel plates at the designed locations and drilling of corresponding holes in the reinforced concrete.
- Trial installation of the steel plates followed by their removal.
- Application of epoxy adhesive "Sikadur 31" (or equivalent approved product) to the steel plates.
- Installation and fixing of the steel plates at the prepared locations.
- Temporary shoring of the structural element, ensuring the introduction of a slight pre-camber (counter-deflection) until the adhesive achieves full curing.
- Continuous monitoring of the structural response (including potential cracking and deformations) during load redistribution.
- Establishment of a plan for periodic inspection and monitoring of the structural behaviour of the facility.

4.3. RECONSTRUCTION OF ONE TRANSVERSE FRAME

Reconstruction works on the grandstands also included a modification of the geometry of one transverse frame. The lower inclined beam of the frame was removed and subsequently replaced with a horizontal beam. This intervention was carried out at the request of the user of the sub-stand space in order to increase the clear height in this area.

The procedure involved the removal of concrete from the existing beam while retaining the existing reinforcement and a portion of the concrete in the region of one support, in order to ensure a rigid connection. The new beam was constructed by adapting the configuration of the existing reinforcement bars, supplemented with additional reinforcement where required, followed by concreting (Figure 10).

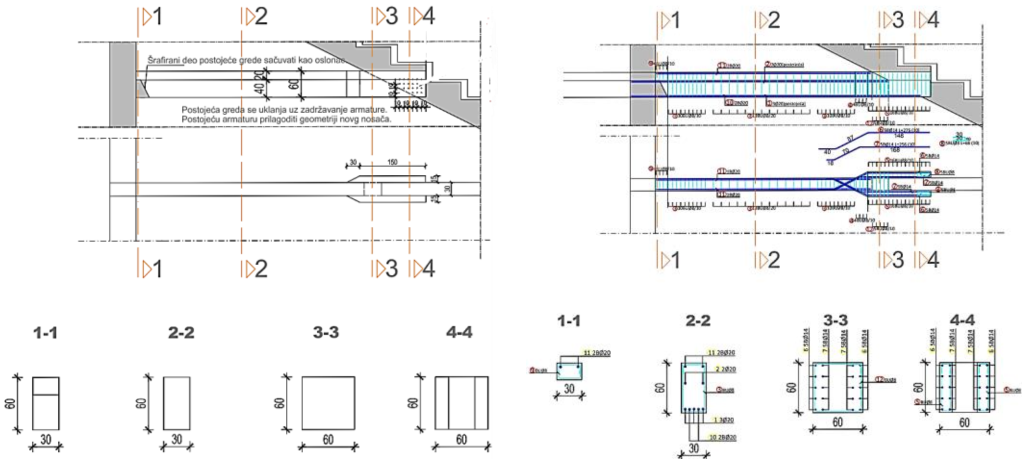


Figure 10: New beam of a transverse frame

5. CONCLUSION

This paper presents a methodology that, rationally and cost-effectively, enables both the repair and subsequent strengthening of an existing monolithic reinforced concrete structure using steel plates. The construction period of the facility (1970–1972) justified a structural verification analysis due to differences between the regulations applicable at the time of design and construction and those currently in force.

The strengthening of all reinforced concrete beams and the retaining wall was executed exclusively from the sub-stand space, which represents a simpler and economically more favourable approach. The applied rehabilitation procedures fully eliminated the observed deterioration of concrete and reinforcement within the grandstand structure. Based on the proposed plan and programme for periodic inspection and monitoring of the structural performance of the facility, the user conducted visual inspections of the structure at six-month intervals following the completion of the grandstand reconstruction works in 2021. The reinforced concrete elements were monitored with the aim of detecting any potential signs of deterioration, including the occurrence and development of cracks and deformations, as well as increased moisture content and corrosion-induced staining associated with the reinforcing steel. The grandstands of the athletics stadium have remained in service for five years without any newly detected signs of deterioration.

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