



SEISMIC RETROFITTING OF THE GROMOVI BRIDGE IN SISAK

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Abstract

The Gromovi bridge is one of the main road transport links between the city of Sisak and the Banovina region. The length of the bridge's superstructure is more than 600 meters, making this steel-concrete bridge the longest bridge in Sisak-Moslavina County. It consists of three parts: the northern and southern reinforced concrete access viaducts and the central steel superstructure above the Kupa River. A strong earthquake, which occurred on December 29, 2020, in the Petrinja area, measuring 6.4 on the Richter scale, caused major damage and deformation of the structural elements of the bridge. The earthquake caused spalling and break-off of the concrete on the bridge piers, where cracks also appeared, which were particularly noticeable in the inner corners at the junction of the head beams and piers. On the surface of the bridge's pedestrian walkway, transverse cracks were visible across the full width of the pavement, while the bridge expansion joints were damaged and deformed, and the steel profiles were displaced and damaged. In addition, part of the bridge structure sank approximately 15 cm. Cracks appeared in the ground, parallel to the bank of the Kupa River, through which sand was visibly emerging. Settlement of the foundation soil occurred in those parts, especially around piers on the west side of the bridge. Based on a visual inspection by specialists, it was concluded that the earthquake caused significant damage to the bridge structure, affecting its load-bearing capacity, usability and safety. This paper presents rehabilitation works as part of the seismic retrofit of the Gromovi bridge, which included strengthening of the existing structure and geotechnical ground improvement. All rehabilitation works were carried out based on the conducted investigation works and the corresponding rehabilitation design documents.

Keywords: reconstruction, improvement of the foundation soil, strengthening of foundations, strengthening of bridge pillars

1 Introduction

Bridges located in seismically active areas are susceptible to displacements and vibrations caused by ground acceleration during an earthquake [1]. This paper presents the reconstruction of the Gromovi Bridge, which is a steel-concrete composite bridge situated in Sisak-Moslavina County on the state road DC37 in the Republic of Croatia. The primary cause of the bridge damage was the strong earthquake in the Petrinja area whose seismic activity led to deformations and damage of structural elements, as well as settlement of the foundation soil [2].

2 Bridge description

The Gromovi Bridge in Sisak provides a roadway crossing of the Kupa River. It is located on state road DC37, Section 1, at chainage km 0+126. The total length of the superstructure is 618.64 m. The superstructure consists of three parts: a reinforced concrete northern approach viaduct, a central steel box-girder superstructure, and a reinforced concrete southern approach viaduct. The superstructure of the approach viaducts is composed of 20 prestressed reinforced concrete girders interconnected by a monolithic deck slab. The substructure consists of 23 reinforced concrete piers, each composed of inclined columns and a pier cap with cantilevers, as well as four reinforced concrete abutments. Two single abutments with vertical wing walls are located at the beginning and at the end of the bridge, while two double abutments founded on piles are located at the transitions between the reinforced concrete approach viaducts and the steel superstructure [2]. For labeled structural elements of the bridge, you can refer to figure 1. The piers of the approach viaducts are founded on shallow spread footings at a depth of approximately 2.5 m. Each footing consists of a 50.0 cm-thick base slab and an inclined truncated pyramid with a height of 150.0 cm. The central steel box-girder superstructure is supported by two pairs of reinforced concrete piers, each with a thickness of 175.0 cm, founded on pile foundations [2].

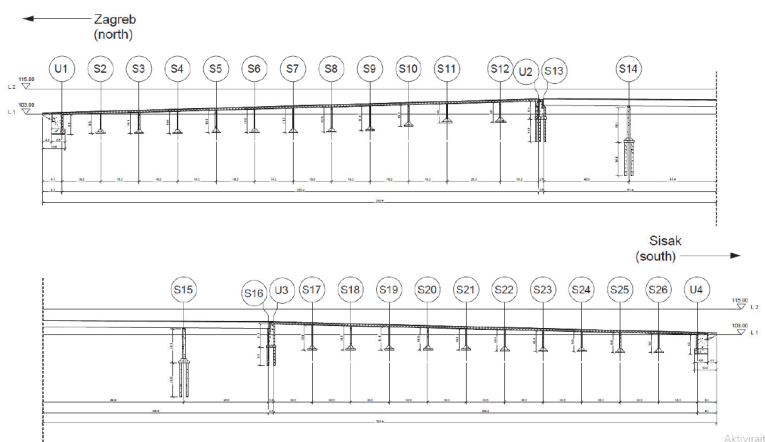


Figure 1 Overview of the Gromovi Bridge with labelled structural elements [2]

The width of the bridge is 19.50 m and consists of a carriageway with four traffic lanes, two 1.0 m-wide bicycle lanes, and two 1.75 m-wide pedestrian walkways. In the cross-section, the carriageway is designed with a 2% transverse slope from the center of the bridge toward the edges, while the pedestrian walkways slope 2% toward the carriageway. In the longitudinal profile, the superstructure exhibits a convex curvature, with the central portion sloping downward toward the approach viaducts. According to the plan layout, the central span and the southern viaduct are constructed along a straight alignment, whereas the northern viaduct follows a slight horizontal curvature [2].

3 A visual inspection of the bridge

A visual inspection of the bridge and investigative works were carried out in January 2021 to determine the appropriate reconstruction solution for the bridge. The expert engineering team performed a visual inspection of the foundations and foundation soil around the piers and abutments on the left bank of the Kupa River, as well as a visual inspection of the bridge superstructure.

The inspection revealed damage to the expansion joint at the connection between the central span and the northern approach viaduct at abutment U2. A partial distortion of the steel profiles of the expansion joint was revealed, and the seal insert was cracked along its entire length [2]. At the same locations on the structure, separation of the expansion joint in the steel railing on the pedestrian walkway and localized deformation of the railing were observed. As a result of seismic activity, at several locations on the bridge superstructure, the connection between the pedestrian walkway and the concrete curb detached, and cracks appeared in the elements. Additionally, on the second pier of the eastern approach viaduct, which connects to the Gromovi Bridge, the seismic counterweight was damaged, showing visible cracks and material spalling. The steel profiles of the expansion joint at the connection between the central span and the southern approach viaduct at abutment U3 were deformed, damaged, and partially displaced from their original positions. Concrete delamination and spalling were observed on the majority of the previously repaired piers, along with the formation of cracks at the connections between pier caps and columns and at the edges of the columns. As the earthquake halted the bridge repair works, the protective concrete layer on piers S10 and S11, which remained unrepaired, suffered spalling, exposing advanced corrosion of the reinforcement [2]. Seismic forces caused the formation of cracks in the soil on the northern riverbank near the bridge viaduct. The cracks were parallel to the Kupa River, and sand was observed emerging from the fissures. These phenomena can be seen in figure 2 and figure 3. [2] The presence of sand indicates soil liquefaction, which led to settlement of the foundation soil and it affected piers S2 to S6 of the northern viaduct [2, 3].



Figure 2 Seismic-induced soil crack between piers S5 and S6 [2]



Figure 3 Sand extrusion from a soil crack near pier S4 [2]

Observing the western side of the northern viaduct, a level difference in the viaduct superstructure was noted (figure 4). Geodetic leveling measurements were conducted to compare the current state of the structure with a leveling survey carried out before the earthquake. Since the absolute displacement could not be determined due to the lack of a permanent reference point, the maximum relative vertical displacement of the leveling line between abutment U2 and pier S6 was measured at 17.7 cm [2, 3]. The geodetically determined displacement of 17.7 cm significantly exceeds the limit value specified in Eurocode 7, where the total settlement of a statically executed structure must not exceed 10.0 cm [3]. Accordingly, reference points (benchmarks) are installed on abutment U1 and piers S2 to S5, allowing spatial geodetic monitoring of potential further displacements at two points on each element in the event of future earthquakes or high water levels of the Kupa River [2]. The benchmarks are installed 1.0 m above the foundation and 1.0 m below the pier cap [3]. Analysis of the measurements over a period of approximately 3.5 months showed that the largest settlement on the northern side of the bridge occurred beneath the right foundation of pier S5, measuring 0.81 cm, while the largest settlement on the left side was observed beneath the left foundation of pier S21, measuring 0.24 cm [3].



Figure 4 Differential settlement of the AB span of the northern viaduct resulting from pier settlement (S2–S6) due to seismic ground movement [2]

Based on a specialist visual inspection, it was concluded that the Gromovi Bridge suffered significant damage during the seismic activity, which affected the load-bearing capacity and usability of the structure, as well as traffic safety. After determining the condition of the structure, it was deemed necessary to carry out the reconstruction of the bridge as soon as possible [2].

4 Investigative works

An inspection was conducted to verify the compliance of reinforcement works with the execution design, detect the actual condition of concrete joints, and inspect horizontal cracks at the top of the columns [2]. Prior to testing the compressive strength of the column concrete according to HRN EN 12390-3, concrete samples in the form of 100 mm diameter cylinders were drilled using a diamond core drill in accordance with HRN EN 12504-1. Carbonation testing of concrete was performed by applying a 1% phenolphthalein solution to the sample surface in accordance with HRN EN 14630. The concentration of acid-soluble chloride ions was determined using the RCT method, tensile strength of concrete was tested using the pull-off method according to HRN EN 1542, and the position and depth of reinforcement in the concrete were determined using a rebar locator [4].

After the investigative works were carried out, it was concluded that the bridge was not constructed entirely in accordance with the execution design. The reinforcement works do not match the positions specified in the construction drawings, the bearings were not installed, and the concrete joint was not executed according to professional standards. The concrete in the columns was poorly placed, showing visible signs of segregation, and exhibiting insufficient compressive strength and quality compared to the specified values [2]. The greatest depth of carbonation was recorded at abutment U4, where the average penetration depth was 31 mm, and this element also has the highest risk of corrosion according to the RCT method. Potential corrosion may occur on column S5 and its corresponding cap. The lowest tensile strength of the concrete, measured by the pull-off method, was recorded at abutment U1, amounting to 0.6 N/mm², while in columns S5 and S6 it was 1.4 N/mm² and 0.8 N/mm², respectively [4]. It was concluded that the reconstruction of the columns is necessary in order to increase their durability and load-bearing capacity against seismic forces. It was proposed that the cracks at the joint between the columns and the caps be injected with epoxy resins. The hinged connection between the foundation and the column was to be fixed in order to reduce bending moments from horizontal forces at the joint between the column and the cap [2].

5 Applied reconstruction methods

After the investigative works and a specialized visual inspection of the structure were carried out, a calculation of the mechanical resistance and stability was performed, and a reconstruction solution for the Gromovi bridge structure was proposed. The work included the replacement of damaged steel transition devices, reinforcement of the foundation soil, widening of the pier foundations, and strengthening of the piers [2].

5.1 Improvement of the foundation soil

Improvement of the foundation soil was achieved through the installation of soilcrete columns using the jet grouting method. A total of 28 soilcrete columns were constructed for each foundation, with diameters of 60 and 80 cm, depending on the geotechnical characteristics of the soil, and arranged at center-to-center spacings of 80, 90, and 100 cm. The soilcrete columns intended to be structurally connected to the foundation reinforcement were executed so that the reinforcing bars protruded at least 2.0 m above the lowest level of the foundation footing. Upon completion of the soilcrete columns, mechanical trimming of the soilcrete column heads was carried out in order to level them to the lowest elevation of the foundation footing [2]. Jet grouting of the foundation steps was carried out to improve the bearing soil, in order to minimize the potential for soil liquefaction beneath the bridge foundations, homogenize the subsoil conditions, and reduce the risk of differential settlement. The intervention enabled a plan-wise enlargement of the bridge foundations and ensured the capacity of the foundations to resist tensile (uplift) forces [3].

5.2 Widening of pier foundation

Reinforced concrete collars with a height of 1.0 m were constructed around the existing foundations, providing an extension of 0.5 m from the edge of the existing foundation, as well as a 0.5 m layer above the footing and around the truncated pyramid (figure 5). The damaged concrete layer was removed using hydro-demolition, while the existing reinforcement was coated with a protective anti-corrosion treatment and any deteriorated bars were replaced. Bonding between the new and existing concrete was achieved by anchoring Ø12 mm reinforcement bars at 30 cm spacing into pre-drilled Ø16 mm holes, 20 cm deep, previously filled with epoxy resin [2].

5.3 Strengthening of bridge piers

Hydro-demolition was used to remove a 2-3 cm-thick layer of concrete from the piers up to 4.0 m above the foundation level. The existing reinforcement was coated with an anti-corrosion treatment, and any damaged bars were replaced as required. A 20 cm-thick reinforced concrete overlay was constructed around the existing piers, forming a rigid connection between the pier and its foundation (figure 5). The longitudinal reinforcement of the jacket was anchored into the existing foundation using pre-drilled holes filled with epoxy resin. The anchorage length of the $\varnothing 20$ mm longitudinal bars was 100.0 cm. This intervention resulted in a change of the structural system, replacing a pinned connection with a fixed connection [2].



Figure 5 Widening and strengthening of bridge piers

5.4 Replacement of expansion joints

After the removal of the existing expansion joints and anchoring beams, the widened joint gaps were filled with repair mortar, and new expansion joints with the same specifications as the removed ones were installed. The expansion joints were placed across the full width of the bridge at the level of the final wearing course of the pavement [2].

6 Conclusion

This paper presents the reconstruction of the steel-concrete Gromovi Bridge, located on state road DC 37 in the city of Sisak, which carries the roadway over the Kupa River. The bridge was damaged as a result of the destructive 2020 earthquake, whose epicenter was in the Petrinja area, at an aerial distance of 9 km from Sisak. Prior to the earthquake, the central steel span of the bridge had been repaired, and the majority of rehabilitation works on the southern and northern viaducts had been completed. The earthquake caused new damage and raised concerns regarding the load-bearing capacity and usability of the structure. It has been shown that, when detailed inspections of the structure are performed and an execution project for the repair of the resulting damage is prepared, even the most demanding works can be successfully executed, and the structure of significant urban importance can be returned to service. It should be emphasized that the successful and high-quality execution of the works requires the selection of a company with the appropriate specialization.

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