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*Original Article*

# Structural Condition Assessment and Strengthening of the Reinforced Concrete Arch Bridge

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***Abstract*** *- This paper presents the results of an advanced inspection, structural assessment, and development of rehabilitation and strengthening strategies for Concrete Bridge No. 44, located on National Road N2, Prishtina - Blacë. The primary objective of this study is to identify effective methods for restoring load-bearing capacity and improving the operational safety of the bridge, in compliance with contemporary design standards as prescribed by the Eurocodes, considering the current degradation state of its structural elements and the critical importance of this infrastructure within the national road network. The assessment methodology involved systematic visual inspections, non-destructive testing, and numerically modeled structural analyses to evaluate the existing performance of the main load-bearing beams, columns, and other key components. Based on the collected data, modular and phased intervention proposals have been developed, allowing for the prioritized implementation of repair measures according to the severity of identified deficiencies and the functional priorities of the bridge. The results of this study provide both practical and scientific contributions to the planning of interventions on existing structures built in previous decades, combining modern rehabilitation engineering approaches with international standards of structural design and safety control.*

***Keywords*** *- Concrete bridges, Reinforced concrete, Prestressed concrete, Load-bearing capacity, Durability, Maintenance.*

## 1. Introduction

A bridge in the engineering sense is defined as a structure that connects the body of the road on both sides and enables it to cross valleys, lakes, rivers, whether natural or artificial, and allows water, etc., to pass underneath (in open space). Bridges occupy a special place in transport infrastructure due to their direct connection to other places [1] and are a very important component of transport networks [2]. The construction, operation, maintenance, etc., of a bridge as an engineering structure requires and is closely related to the geological environment in which it is built. Therefore, the profile where the construction of the bridge is planned is required to be stable (solid rock) on which the foundations are supported - the load-bearing system of the bridge itself and the transport vehicles that will pass through it. The location of the bridge on stable rocks is also related to the lifespan of the bridge, because, as we point out [3, 4], bridge restoration is also challenging and costly [5-7]. There are two important parameters for which optimization of bridge restoration would be appropriate - network stability and cost. This requires a different perspective in modeling extreme natural events and includes models for the interaction between individual components (e.g., bridges) and the network as a whole [8]. It is believed that the bridge for which the structural condition assessment was made and presented in this study was built in 1967, which results in an age of 58 years, and which belongs to the group of engineering works (objects) with a lifespan of up to 60 years according to a geological-engineering categorization.

It consists of a reinforced concrete arch structure with 12 continuous superstructure spans, supported by 2 abutments, 10 pairs of piers, and 1 pair of arch crowns. The total length of the bridge is approximately 140 meters, with a width of 9.5 meters. The central span of the arch is approximately 85 meters, positioned symmetrically along the bridge axis. The bed consists of three layers of asphalt with a total thickness of approximately 7 cm, where the lower and middle layers are separated by a 0.5 mm metal plate. Between the asphalt and the concrete, a layer of mortar with a welded reinforcing mesh of 3 mm is applied, with a thickness of approximately 3 cm. Drainage from atmospheric water is ensured through gutters and outlets located along the sidewalks. The sidewalks, surrounded by natural stone, are raised approximately 150 mm above the road level. The safety barriers consist of steel tubes with three longitudinal rails positioned at 0.3 m, 0.6 m, and 0.9 m above the pavement level, fixed every 2 meters to the end beams. The monolithic superstructure includes two main longitudinal beams, transverse beams, and an extended deck slab that serves as the pavement. The substructure consists of the supports, 2 pairs of foundation piers directly driven into

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the ground, 2 pairs of piers sharing common foundations with the arch, and 6 pairs supported directly on the arch. The foundations, as seen, are driven directly into the ground (rock). Expansion joints are installed in both supports. The bridge is supported by concrete piers placed under each main longitudinal beam.

## 2. Study Area

The bridge is located approximately 55 km south of Prishtinë, near the border with North Macedonia. It serves as a critical section of the national N2 road, ensuring road connectivity between Kosovo and North Macedonia. The bridge carries traffic over two lanes, each 3.75 meters wide, along with two sidewalks, each 0.9 meters wide. The structure spans across a deep valley, encountering challenging geotechnical and geometrical site conditions.

Due to its strategic position, the bridge represents a key node for international transportation and regional economic development. The surrounding area is characterized by hilly and mountainous terrain with significant slopes, while the bridge foundations are designed to adapt to the particular geological conditions of the site (Figure 1). The location of the bridge is illustrated on the map below, with the arches and six pairs of columns supported on the arches. Expansion joints are provided at each abutment at the bridge ends. The bridge is supported by rocking concrete bearings located beneath each longitudinal main girder at the abutments. These bearings rest in basins constructed as part of the abutments.

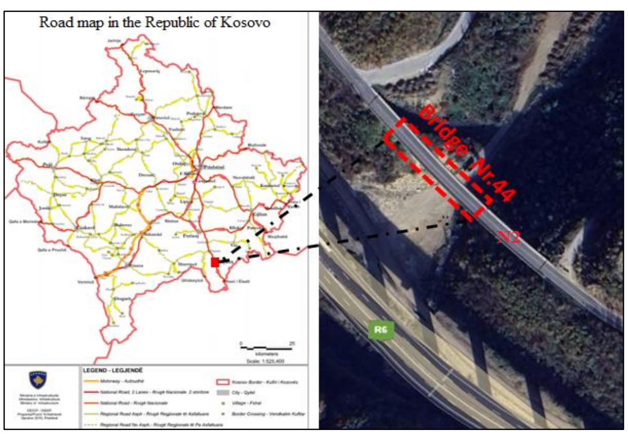



**Fig. 1 Position of bridge No. 44**

(Source: http://mi-ks.net/repository/docs/ and Google Earth, modified by the authors)

## 3. Results and Discussion

The bridge is believed to have been originally constructed in 1967. It is a reinforced concrete arch structure comprising 12 continuous spans in the superstructure. The superstructure is supported by two abutments, ten pairs of columns, and one pair of arch crowns, with an overall length of approximately 140 meters. The bridge width is approximately 9.5 meters. The main arch span measures about 85 meters and is symmetrically positioned within the bridge. The pavement consists of three layers of asphalt with a total thickness of approximately 7 cm, as determined from extracted core samples. The lower and middle asphalt layers are separated by a 0.5 mm metallic plate. Between the asphalt and the structural concrete, a mortar layer reinforced with a 3 mm welded mesh has been cast, with an approximate thickness of 3 cm. Drainage is provided via gutters and outlets located along the sidewalks. The sidewalks, edged with natural stone curbs, are elevated roughly 150 mm above the roadway level. Guardrails consist of steel pipes with three longitudinal rails positioned at 0.3 m, 0.6 m, and 0.9 m above the sidewalk level, welded to vertical posts embedded every 2 meters into the edge beams. The monolithic superstructure includes two longitudinal main girders with transverse girders and a deck slab extended as cantilevered wings over the main girders to form sidewalks. The monolithic substructure comprises two abutments, two pairs of columns closest to the abutments founded directly on the ground, and two pairs of columns founded on common. The structure is likely founded directly on soil or rock.

### *3.1. Railings and Sidewalks*

The paint coating is in very poor condition, with widespread rust and severe corrosion, especially at the posts fixed into the edge beams. Many steel profiles are deformed, broken, or missing due to traffic impacts. Some natural stone curbs are eroded by freeze-thaw cycles, and the asphalt pavement shows holes and vegetation growth. The concrete cover over edge beams is insufficient, exposing reinforcement and causing concrete spalling, particularly behind guard rail posts impacted by traffic.

### *3.2. Pavement and Mortar Layer*

The gutters and outlets are clogged and unclean. The asphalt pavement on and approaching the bridge shows heavy cracking and rutting, especially in the southbound and northbound lanes. The deck lacks waterproofing. Core samples reveal a pavement composed of three asphalt layers totaling 70 mm over a 30 mm reinforced mortar layer, which lacks proper bonding to the structural concrete. Minor water leakage through the deck was observed.

### *3.3. Superstructure*

The monolithic reinforced concrete superstructure shows insufficient concrete cover with some exposed reinforcement. Cold joints and poorly poured concrete with exposed aggregate and reinforcement are present, notably on the underside of main girders. Transverse cracks, likely due to shrinkage, are observed across deck sections and wings. Minor vertical cracks due to loading are visible in the main girders. Material tests indicate homogeneous concrete of reasonable quality with a compressive strength of 52 MPa, carbonation depth of 10–20 mm, and negligible chloride content. The load-bearing capacity is estimated to be reduced by approximately 20%.

### *3.4. Substructure*

The reinforced concrete substructure, including abutments, columns, and arches, exhibits insufficient concrete cover and exposed reinforcement, especially severe under the arches. Cold joints and poorly placed concrete with open stones and exposed reinforcement cause spalling due to corrosion. Abutment walls show surface erosion, water leakage from bearing basins, and moss growth. Load capacity is estimated to be reduced by 20% [9].

### *3.5. Retaining Walls*

Small retaining walls display surface erosion and concrete spalling, with slight horizontal movement noted at the southwest wall.

### *3.6. Foundations and Surrounding Terrain*

The foundation soil appears adequate, but slope stability in the valley is compromised by waste dumping, causing permanent instability and landslides. At the bridge's northwestern end, waste accumulation under and against the structure likely induced a moment crack in a column due to transverse loading and pressure [9].

### *3.7. Accessories*

Expansion joints at the abutments are functional but leak into the rocking concrete bearing basins. The rocking concrete bearings themselves are in acceptable condition; however, their basins are filled with concrete debris, scaffolding material, gravel, and sediment from water leaking through expansion joints. Drainage from the basins is impaired due to leakage through abutment walls. Based on these findings, specialized interventions are required to restore load-bearing capacity and improve the long-term durability and stability of the bridge structure in accordance with modern standards.

## 4. Load Capacity Assessment

### *4.1. Codes and Standards for Bridge Assessment*

The load capacity assessment has been performed in accordance with the Eurocodes:

- Eurocode 1: Basis of design and actions on structures
  Part 3: Traffic loads on bridges
- Eurocode 2: Design of concrete structures
  Part 1-1: General rules and rules for buildings
  Part 2: Concrete bridges

All calculations are carried out based on the *Ultimate Limit State (ULS)* design approach [10].

### *4.2. Lane Configuration*

According to Eurocode, the carriageway is divided into notional traffic lanes, typically 3 meters wide. The number of lanes depends on the total width of the carriageway.
The designation and arrangement of notional lanes follow these principles:

- The lane numbering is not necessarily related to their physical positions on the bridge.
- For each verification, the number of loaded lanes, their positioning on the carriageway, and their numbering are selected to produce the most unfavorable loading effects.
- The lane producing the most critical effect is designated Lane 1, followed by Lane 2, Lane 3, etc.

### *4.3. Traffic Load Models*

According to Eurocode 1, characteristic values for vertical traffic loads are applied in the ultimate limit state. Specifically, *Load Model 1* is used for both global and local verifications, representing the combined effects of heavy vehicles and passenger cars.

Load Model 1 includes two components:

- Concentrated Tandem Axle Loads (Double Axle System)
  Each tandem system consists of two axles, with each axle carrying a load of $\alpha_Q Q_k$. Only one tandem system is applied per lane, and only complete tandems are considered. Each tandem is positioned in the most unfavorable location within its respective lane to maximize the load effect. Each axle in the tandem system has two identical wheels, with each wheel carrying. 0,5 $\alpha_Q \cdot Q_k$ . The contact area for each wheel is assumed to be square with a side length of 0.40 m.
  A maximum of three lanes may be loaded with tandem systems simultaneously.
- Uniformly Distributed Loads (UDL)
  The UDL has a load intensity of $\alpha_q q_k$ , of per square meter. These loads are applied only in the unfavorable regions of the influence area, both longitudinally and transversely.
  The characteristic values are: $q_k = 9\ {kN}/{m^2}$ for Lane 1 and $q_k = 2.5\ {kN}/{m^2}$ for the remaining lanes.

The adjustment factors **α** are assumed equal to 1. Dynamic amplification effects are already incorporated into the specified $Q_{ik}$ and $q_{ik},$ values (Table 1) [11].

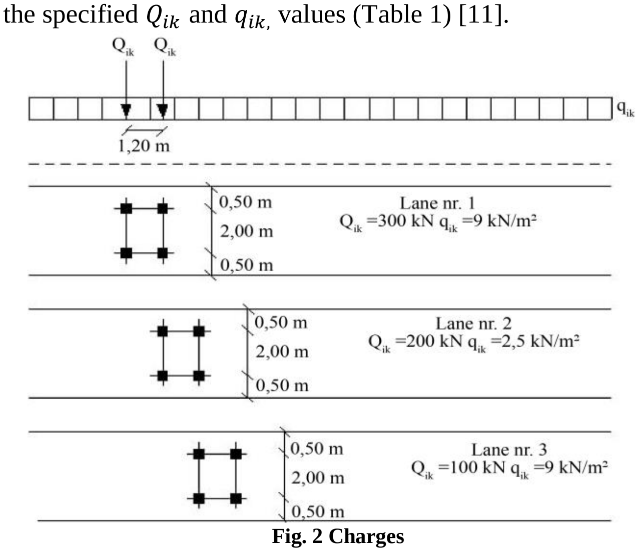


**Fig. 2 Charges**

**Table 1. Results of the loads**

| Location | Tandem system | UDL system |
|---|---|---|
| | Axle loads $Q_{ik}$ (kN) | $q_{ik}$ (kN/m²) |
| **Lane number 1** | 300 | 9 |
| **Lane number 2** | 200 | 2.5 |
| **Lane number 3** | 100 | 2.5 |
| **Other lanes** | 0 | 2.5 |
| **Remaining area** | 0 | 2.5 |

According to Eurocode 1, the following load combinations shall be considered for the load-bearing capacity assessment:

Superstructure:

1.35·Dead load + 1.35·Traffic load;

Substructure:

1.35·Dead load + 1.35·Traffic load + 0.5 · Braking force;

### *4.4. Materials*

According to Eurocode 2, Part 2, Concrete Bridges, the following material safety factors shall be used:

- Concrete: 1.50
- Reinforcement: 1.15

A factor α for sustained compression shall also be taken into account. Generally, α, it may be assumed to be 0.85.

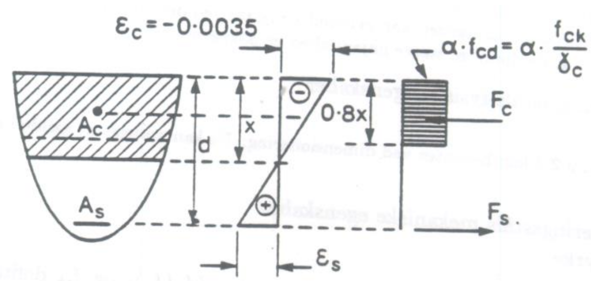



**Fig. 3 Rectangular diagram showing α.**

The geometry and material data are based on existing information derived from the original drawings and static calculations. The geometrical parameters are detailed in the drawings provided in Appendix B**,** and are summarized as follows:

- Carriageway width: 7.5 m
- Deck width: 9.4 m
- Number of notional lanes: 2
- Arch span: 84.6 m
- Arch rise (height): 19.7 m

The bridge deck comprises 12 spans, of which 8 spans are supported directly by the arch structure. The cross-section of the deck is constructed as two longitudinal T-beams.

Based on the original drawings and design calculations, the following material strength parameters are applied:

- Concrete Strength: Cubic compressive strength of 30 MPa, corresponding to a characteristic cylinder strength of 24 MPa.
- Reinforcement Steel: St. 37, used as the primary reinforcement for most structural elements, with a characteristic yield strength of 225 MPa.

Considering the applied load combinations, geometric parameters, and material strengths, the utilization ratios (capacity ratios) have been calculated for the main span, adjacent spans, and the arch structure.

The load-bearing capacity of both the superstructure and arch has been adjusted according to the actual condition assessments described in Section 4.2 (Table 2).

**Table 2. Results of the loads**

| Span No. | Utility Ratio (Eurocode) |
|---|---|
| **Longitudinal T-beams at mid span** | 1.3 |
| **Longitudinal T-beam at support** | 0.7 |
| **Cross beam, support** | 0.8 |
| **Cross beam, mid span** | 0,6 |
| **Deck** | 1.0 |
| **Arch** | 1.4 |

The Utilization Ratio (U) is defined as:

$$U = {}^{M_T}/_{M_U} \quad (1)$$

Where:

- $M_U$ - Total load effect (resultant moment or force from applied loads)
- $M_T$ - Ultimate capacity (resistance capacity of the element)

Materials - According to Eurocode 2, Part 2, Concrete Bridges, the following material safety factors shall be used:

- Concrete: 1.50;
- Reinforcement: 1.15;

A factor α for sustained compression shall also be taken into account. Generally, α, it may be assumed to be 0.85 (Figures 4-6)

In order to determine the appropriate traffic restrictions to be implemented during the period prior to the completion of the strengthening works, supplementary load capacity analyses have been performed, taking into account the current traffic conditions.

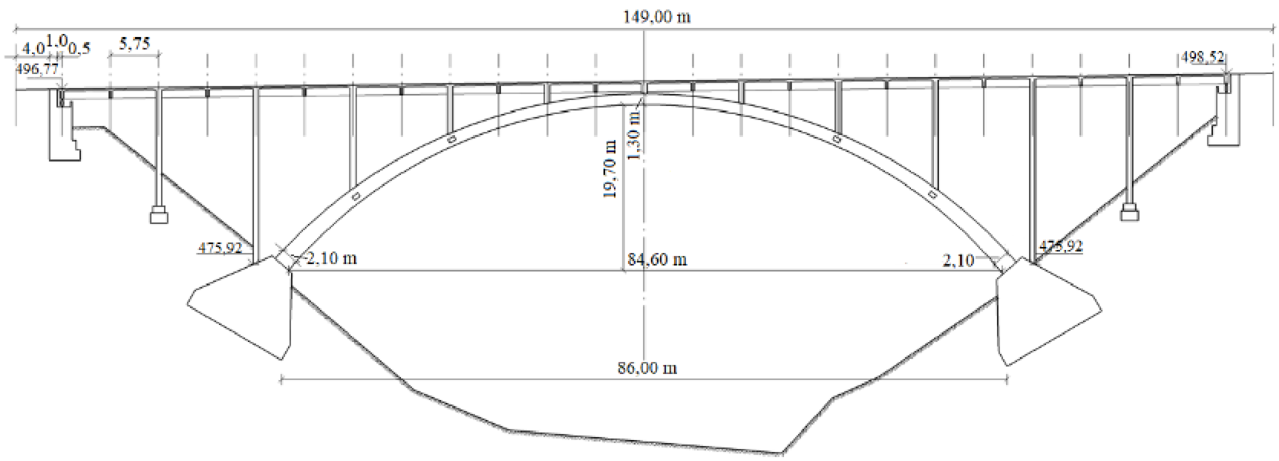



**Fig. 4 Longitudinal section of the bridge**

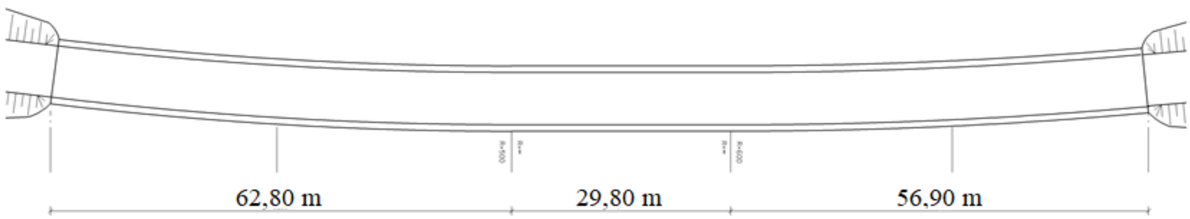



**Fig. 5 Bridge foundation**

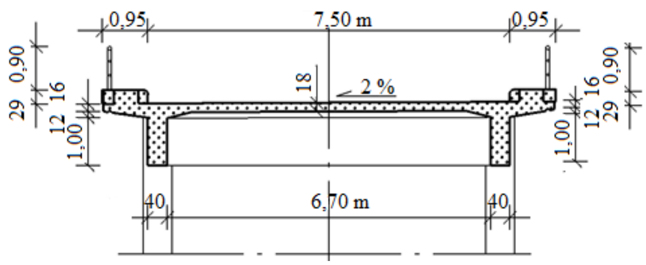
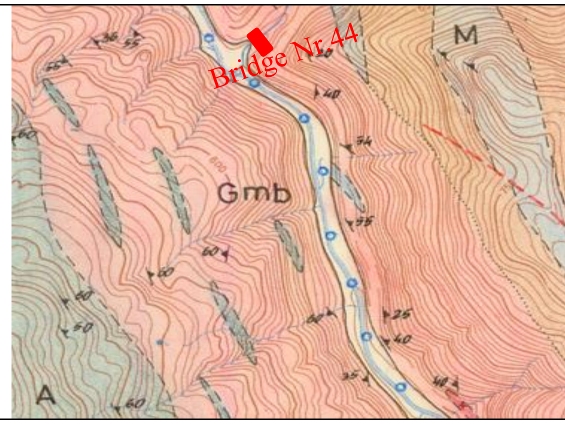



**Fig. 6 Cross-section of the bridge**

**Table 3. Data from the bridge inspection**

| Category | Road bridge | |
|---|---|---|
| Coordinates | 42°12'49" and 21°15'23" |  |
| Road location | Ferizaj - Hani i Elezit<br>Main Road N2 | |
| Superstructure type | Multi-span, continual concrete structural slab | |
| Total spans | 9 | |
| Length (m) | 149 | |
| Total Width (m) | 9.6 | |
| Road Width (m) | 7.6 | |

| | | |
|---|---|---|
| **Geology Paleozoic (source: geological map 1:25 000, Kaçanik sheet)** | Description<br>Gmb Gneiss;<br>A Amphibolite, amphibolite schist;<br>M Marble, calcschist; |  |

**Description**

| **Approaches** | | **level 0 (good) to 3 (high severity)** |
|---|---|---|
| **Asphalt pavement** | YES | 1 |
| **Embankment** | | |
| **Guard rail** | YES | 1 |

| **Abutments** | | **level 0 (good) to 3 (high severity)** |
|---|---|---|
| **Type** | Full height | 0 |
| **Joint with the deck** | NO | |
| **Bearings and pedestal** | No visible | |
| **Backwall** | Yes, reinforced concrete cast in situ | 0 |
| **Wingwalls** | Yes, reinforced concrete cast in situ | 0 |

| **Pier** | | **level 0 (good) to 3 (high severity)** |
|---|---|---|
| **Pier columns** | Arch beam and columns R. C. cast in situ | 0 |
| **Cap beam** | Yes, reinforced concrete cast in situ | 0 |
| **Pedestals** | Yes, reinforced concrete cast in situ | 0 |
| **Bearings** | Yes, reinforced concrete cast in situ | 0 |

| **Superstructure** | | **level 0 (good) to 3 (high severity)** |
|---|---|---|
| **Primary member** | Trans. And longitudinal beams | 0 |
| **Deck structural** | Reinforced concrete plate | 0 |
| **Joints** | YES | 0 |

| **Deck elements** | | ***level 0 (good) to 3 (high severity)*** |
|---|---|---|
| **Wearing surface** | Asphalt | 1 |
| **Sidewalk** | YES, both sides 1,00 | 1 |
| **Guard rails** | NO | |
| **Parapets** | YES | 1 |

## 5. Conclusion

The bridge inspection represents a comprehensive structural assessment of a reinforced concrete arch bridge, originally built in 1967, which serves as a key element in the regional and international road network connecting the Republic of Kosovo with North Macedonia. The bridge study integrates detailed visual inspections, material testing, and load capacity analysis carried out in accordance with Eurocode specifications. The assessment revealed numerous damaged elements affecting both the bridge superstructure and the substructure. The superstructure showed an insufficient concrete protection layer; as a result of this insufficient layer, there was also significant corrosion of the reinforcement, cracks caused by excessive truck loading, especially with gravel, poor quality concrete, and poor compaction in some structural parts of the bridge. Similarly, there is visible damage to the concrete in the substructures, especially at the connection of the arches and the supports, where advanced degradation of the material, significant corrosion of the reinforcement, and loss of concrete bearing capacity due to exposure to long-term non-drainage of atmospheric water from the bridge structure are clearly visible.

The network of pipes for the removal of atmospheric water shows poor functionality, contributing to the entry of moisture into the structural parts of the bridge, which has even led to the acceleration of corrosion and the accumulation of sediments within the bearing parts. The connections of the main joints show signs of leakage, further worsening the bearing capacity processes.

The load-bearing capacity calculations show that several key structural elements exceed the safe use rates, with utilization ratios of 1.3 for the longitudinal T-beams in the middle of the span and 1.4 for the arch structure, indicating a significant reduction in the safety margins of the supporting structure. In addition, we have also observed geotechnical instability in the slopes around the bridge foundations, mainly caused by uncontrolled waste disposal, which poses an increasing risk to the stability of the foundations, especially at the northwestern end of the bridge structure.

Based on these findings, the current condition of the bridge does not ensure the safe development of traffic or sufficient stability under normal loads. Immediate implementation of preventive measures is required, including temporary traffic restrictions, structural reinforcement, repair of damaged elements, restoration and functionality of drainage, and stabilization of the slopes around the bridge foundations.

Comprehensive rehabilitation and reconstruction are recommended to extend the useful life of the bridge and restore its full functionality in accordance with current Eurocode standards, ensuring its long-term role as a vital infrastructure asset within the regional and international transport corridor.

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