COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES,
STANDARDIZATION AT A EUROPEAN LEVEL

TU1406 WG4 Final report Appendix A17

Bridge Case study

KA0040 bridge over Motnišnica river - Slovenia

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1. GENERAL DATA ON THE BRIDGE

1.1. GENERAL DESCRIPTION

The inspected bridge is a single span vehicle road in-situ concrete girder bridge. It crosses Motnišnica river in the municipality of Kamnik. Total length of the bridge is 10.8 meters. There are 2 lanes over the bridge. On each side of the bridge there is a curb with a width of 0.68 meters. Carriageway width between the curbs is 4.95 meters. Maximal abutment height is 2.85 meters. The bridge crosses the river with a skew angle of 52 degrees.

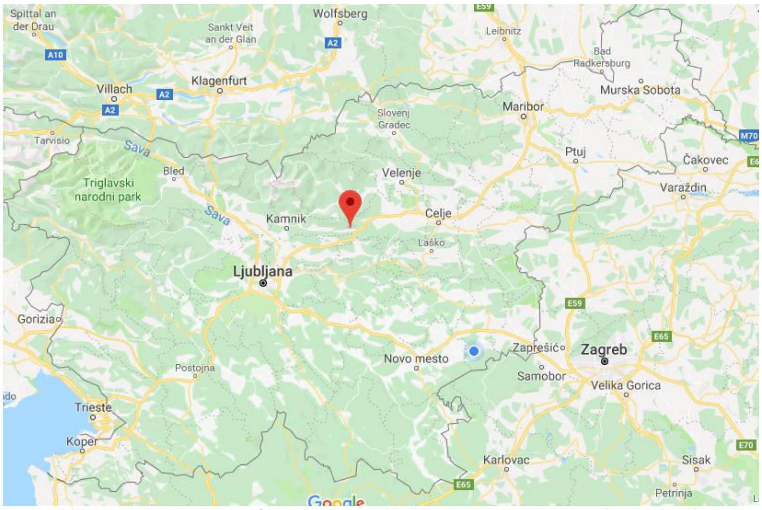


Fig. 01 Location of the bridge (bridge marked in red symbol)

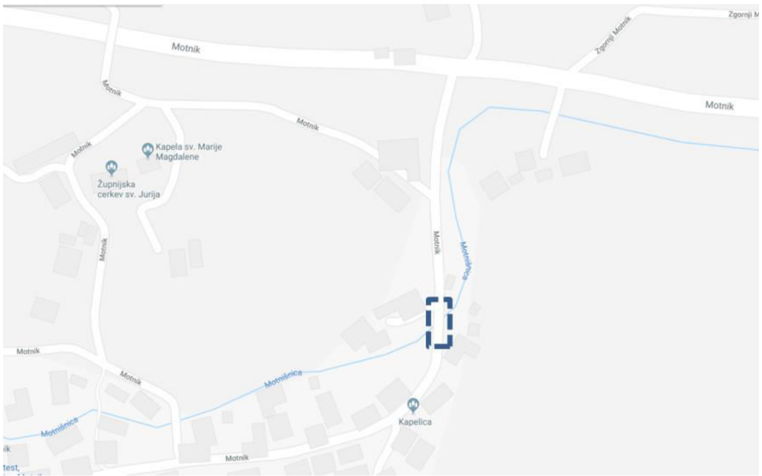


Fig. 02 Map of the bridge area (bridge marked in blue rectangular)

Fig. 03 General photo of the bridge

Fig. 04 Elevation photo of the bridge

Fig. 05 Over the deck photo of the bridge

1.2. TRAFFIC INFORMATION

No traffic information is available for this bridge.

1.3. FOUNDATION

From the inspection it was seen that the foundation under abutment walls is made of in-situ concrete. Due to absence of original plans, type of the foundations cannot be described more in detail.

1.4. SUBSTRUCTURE

Considered bridge is a single span bridge, therefore substructure represents cast in situ reinforced concrete abutments on each side. On each side of the abutments reinforced concrete walls serve as a slope protection.

1.5. SUPERSTRUCTURE

The deck of the bridge consists of 6 10.8 meters long cast in situ girders, supported by gravity abutments on both sides. Longitudinal girders are connected to each other with two transverse girders, approximately at the third of the span from the abutments, on each side. Reinforced concrete slab is connected rigidly onto the girders.

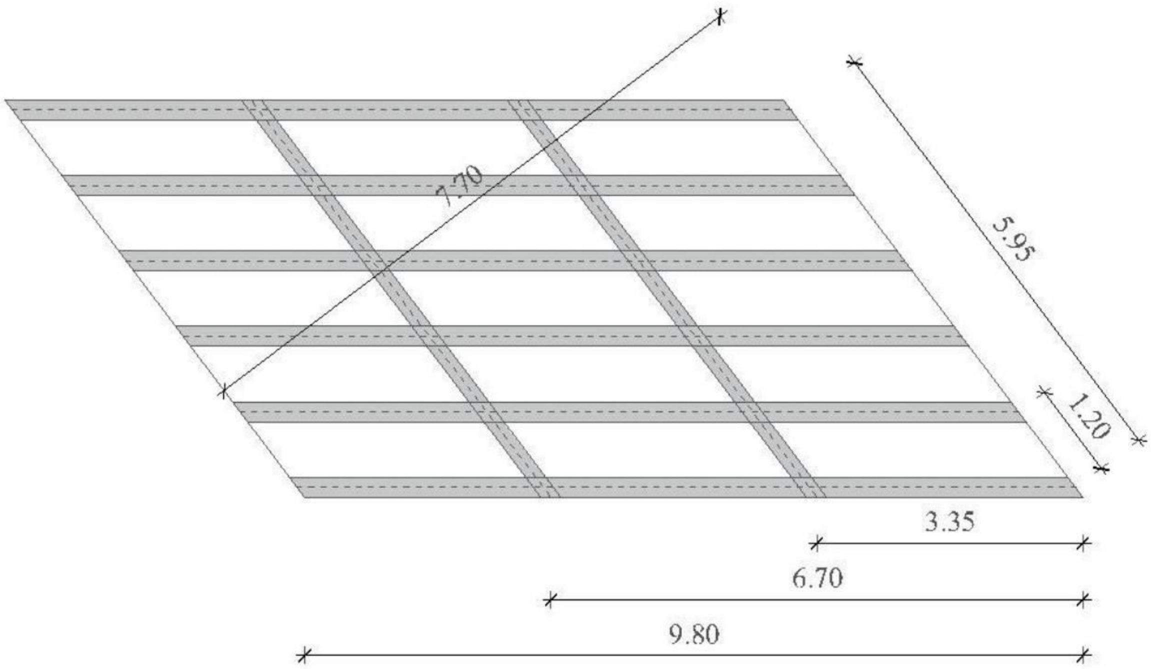


Fig. 06 Plan view of the superstructure, showing raster of longitudinal and transverse girders

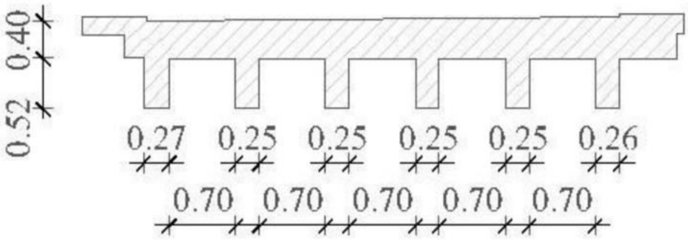


Fig. 07 Superstructure cross section

1.6. ACCESSORIES

On each side of the bridge there is a safety railing mounted on the curb, made of galvanized steel. Asphalt paving is covering the superstructure. Joints are not visible due to pavement that is blocking the view.

1.7. LOAD CAPACITY

Safety assessment of the considered bridge was performed in 2016. Analysis was performed in SAP2000 software considering elastic beam elements. Conservatively, hinge supports were taken into account in the analysis. Numerical model of the bridge is shown on Fig 08 and Fig 09 Cross section of the considered beam is shown on Fig 10, where data from in-situ measurements were used. Amount and position of longitudinal reinforcement (hot rolled beam) was determined by profometer, as described later.

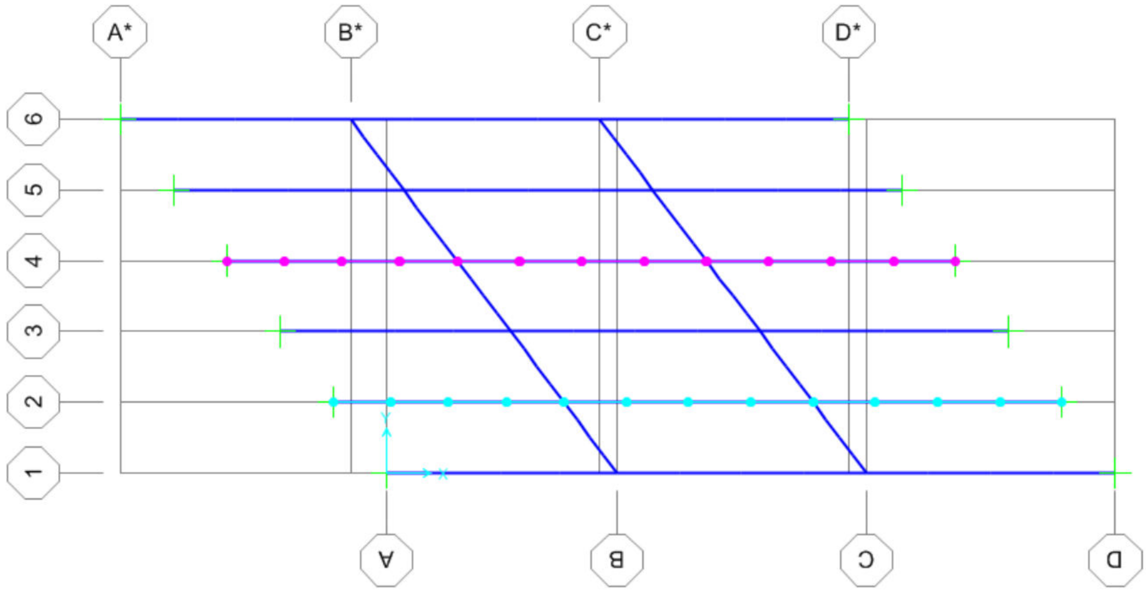


Fig. 08 Numerical model of the bridge in plan view

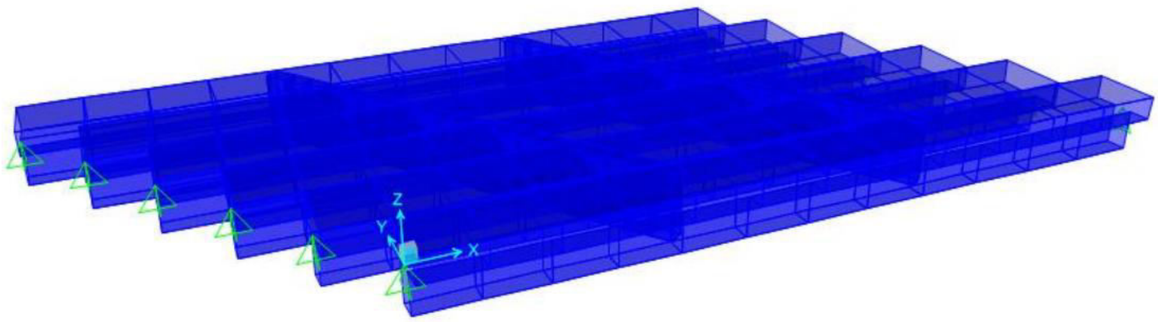


Fig. 09 Numerical model of the bridge in 3D view with extruded beam elements

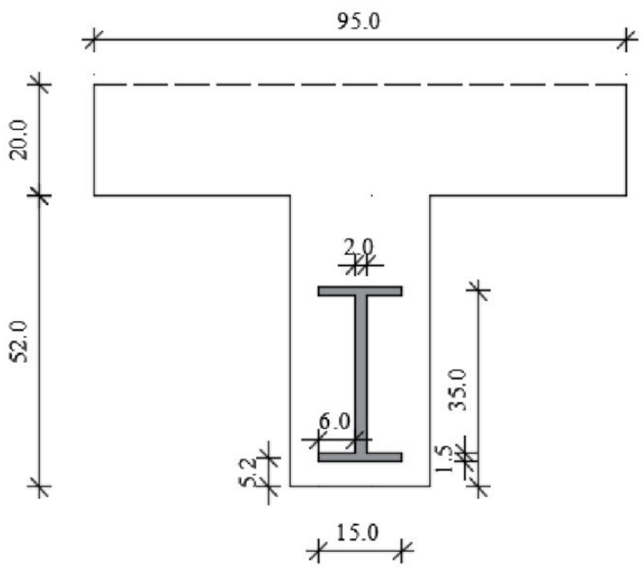


Fig. 10 Longitudinal beam cross section

Material characteristics were conservatively assumed in the analysis, therefore concrete with compressive strength of 20 MPa and steel beam with yield strength of 220 MPa were used. Material models are shown on Fig 11.

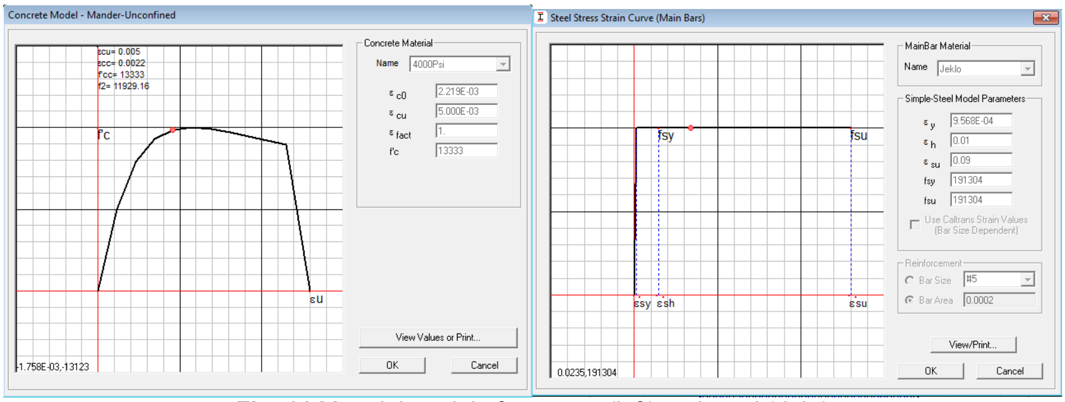


Fig. 11 Material model of concrete (left) and steel (right)

Value of bending resistance moment was calculated as 754 kNm. Bending resistance of the considered cross section as determined by *SAP2000* software is shown on Fig 12. Shear resistance of considered cross section was calculated as 722 kN, taking EC3-1 recommendations into account, where only contribution of the beam web to the shear resistance was considered.

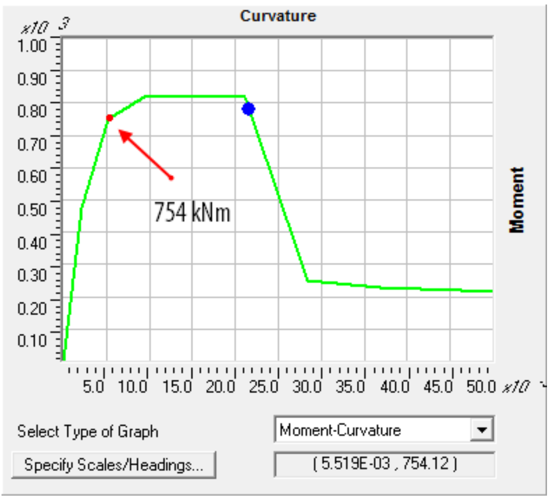


Fig. 12 Bending resistance of the considered cross section

Traffic load as shown in Fig 13 was considered, where concentrated loads represent moving loads. Beside traffic load, own weight of the girders and superstructure was taken into account.

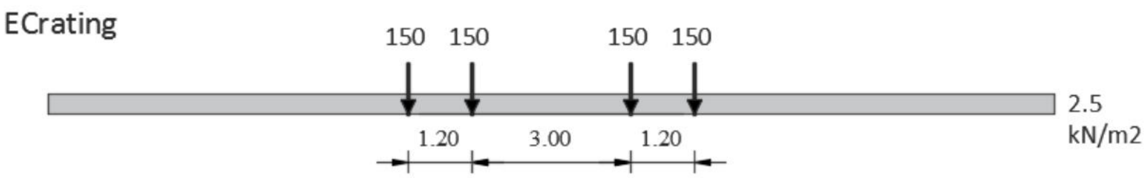


Fig. 13 Traffic loading

Results of the safety assessment are shown in Table 01, where γ_S represents dead load safety factor, $\gamma_P$traffic load safety factor, k_d dynamic factor and ϕ represents load capacity reduction factor.

Table 01 Load, Load capacity and Rating Factor values

	γ_S	γ_S	k_d	ϕ	Load Capacity [kNm, kN]	Dead Load [kNm, kN]	Traffic Load [kNm, kN]	Traffic Load, dyn [kNm, kN]	Rating Factor
M (midspan)	1,2	1,6	1,23	0,88	754	165	227,7	280,071	1,04
V (support)	1,2	1,6	1,23	0,88	722	70,3	173	212,79	1,62

Both values of rating factor, shown in Table 01 are higher than 0,95 therefore it can be assumed that according to Žnidarič & Moses (1997), Žnidarič (2010) and ARCHES report D10 (2009)), the considered bridge <u>in next 6 years</u> meets the criteria for sufficient safety.

1.8. CONDITION RATING OF THE BRIDGE

According to the Slovenian bridge condition rating system, the rating of the considered bridge is shown in the following. The condition rating of the bridge is performed in a quantitative form. Final assessment code is given in Table 02. Bridge condition is calculated as a sum of individual elements damage rating:

$$R = \sum RF_i$$

Table 02 Slovenian bridge condition rating system

Condition class	Definition	Condition rating R
5	Very good	0 < R < 5
4	Good	1 < R < 15
3	Satisfactory	10 < R < 30
2	Bad	20 < R < 50
1	Critical	R > 40

Individual elements damage rating is calculated as follows:

$$RF = B \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4$$

Where individual factors mean:

- B - type of damage, in the range of 1 to 5
- K_1 - importance of the defect for the particular element (0.3, 0.7, 1.0)
- K_2 - damage level (0.4, 0.6, 0.8, 1.0) corresponding to (I, II, III, IV)
- K_3 - damage extend (0.5, 0.8, 1.0) corresponding to (A, B, C)
- K_4 - seriousness (threat) of the damage to the element (1, 3, 5, 10)

Rating of the supporting structure is 13,96, meaning that cracks in the abutments should be investigated in detail and that safety assessment of the bridge is necessary.

Rating of the superstructure is 4,5 due to numerous structural damages, such as reinforcement exposure, corrosion, concrete spalling, etc.

Rating of the carriageway is 0,62, representing relatively good upper part of the bridge.

Rating of the accessories is 0,45 due to damaged railing and overgrowth on the deck, at the contact with the curb.

Rating of the whole bridge is 19,53 representing the overall condition of the bridge as bad.

1.9. VULNERABLE ZONES

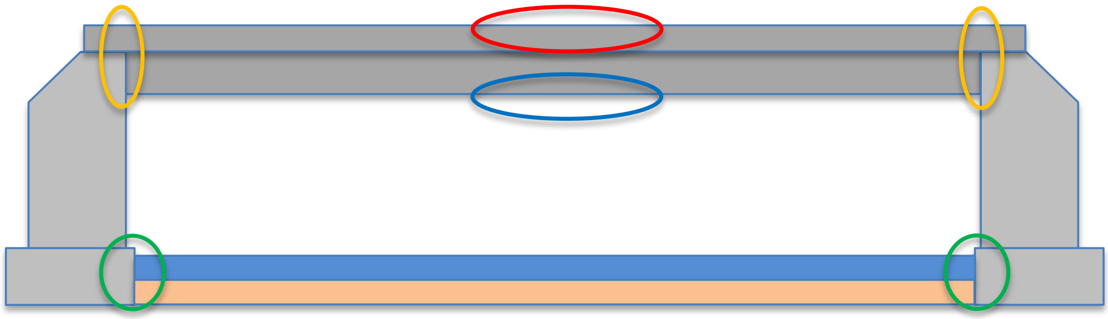


Fig. 14 Vulnerable zones – Side view (Red = compression zone – high sagging moments , Blue = tensile zone – high sagging moments, Orange= high shear forces zone, Green = area possibly exposed to scour)

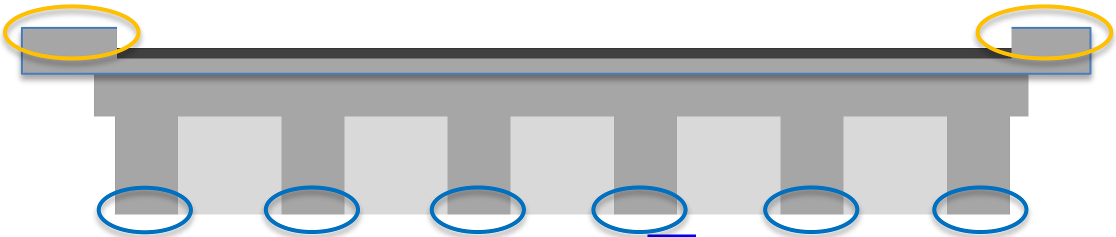


Fig. 15 Vulnerable zones –Typical cross section of the bridge (Blue = tensile zone – high sagging moments, Orange= Slab edge)

2. TECHNICAL CONDITION

2.1. COLLECTION OF DEFECTS

The main types of defects discovered on the bridge inspection are:

1. Obstacles in the riverbed
2. Erosion under the abutment foundations
3. Discharge of deck drainage wedges on the vertical surface of the abutments
4. Crack in the abutments at the contact with slope protection wall due to overloading
5. Longitudinal cracks on the lower half of the girders
6. Transverse and longitudinal reinforcement exposure and corrosion in the girders
7. Damaged and corroded safety railing

The defects on the main members are presented on the sketches below.

Fig. 09 Erosion under the abutment foundations

Fig. Discharge of deck drainage wedges on the vertical surface of the abutments

Fig. 18 Crack in the abutments at the contact with slope protection wall due to overloading

Fig. 19 Damaged pedestrian handrail (up) and corroded railing (below)

2.2. DEFECTS OF THE MAIN STRUCTURAL ELEMENTS

Due to erosion under the abutment foundations, foundations are inclined from original position. The width of the crack between the abutment and the foundations is approximately 3 cm.

Fig. 20 Obstacles in the riverbed

Fig. 21 Crack between abutment and foundations (1)

Fig. 22 Crack between the abutment and the foundations (2)

Fig. 23 Longitudinal cracks on the lower half of the longitudinal girders

Fig. 24 Leakage in the longitudinal and transverse girders

Fig. 25 Transverse and longitudinal reinforcement exposure and corrosion in the longitudinal girders

3. POTENTIAL FAILURE MODE OF THE BRIDGE

In accordance with current condition of the bridge following failure modes are considered:

Ultimate limit state:

- Failure due to sagging bending moment in girders
- Failure due to shear forces in girders
- Inclination of the abutments due to settlements of the foundations
- Rigid body movement of the superstructure due to abutment foundations settlement/scouring
- Rigid body movement of the superstructure due to seismic loading

Serviceability limit state:

- Asphalt pavement failure due to unevenness at the locations of the abutments
- Excessive deflections in the superstructure due to settlements of the foundations
- Falling from the bridge due to damaged railing

4. NDT TESTING

4.1. PROFOMETER

While performing safety assessment of the bridge in 2016, structural elements of the bridge and reinforcement were measured. These data was taken it into account in numerical model. It was found out that unlike ordinary longitudinal and shear reinforcement in girders, inside the longitudinal girders there is an I shaped hot rolled section, as shown in Fig. 26. Because there were no original building plans from the bridge, this was proven by Profometer, rebar locator device, which detects the presence of the reinforcement up to 10 centimeter deep in the concrete. Because the investigation did not provide accurate data about the location and amount of reinforcement, concrete cover was removed and therefore dimension of hot rolled steel beam was measured.

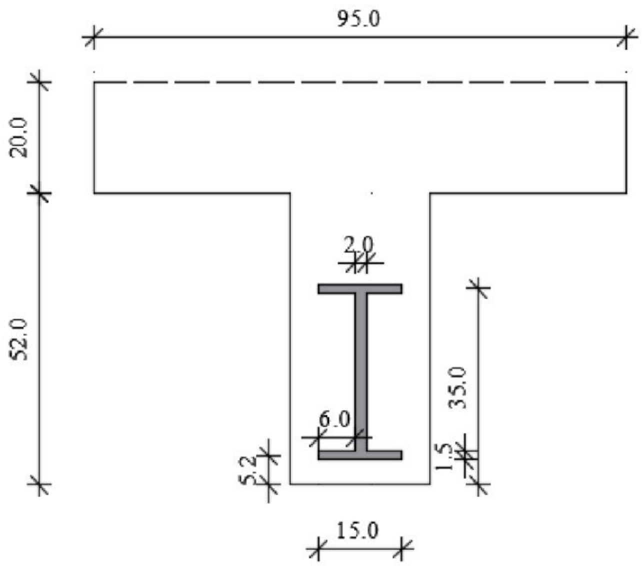


Fig. 26 Longitudinal beam cross section

4.2. FIG. 27 DETERMINATION OF REINFORCEMENT AMOUNT AND POSITIONMATERIAL TESTING

Material testing was not performed on the considered bridge.

4.3. DYNAMIC TESTING OF THE BRIDGE

Dynamic testing was not performed on the considered bridge.

4.4. LOAD TESTING

Load testing was not performed on the considered bridge.

5. KEY PERFORMANCE INDICATORS AND QC PLAN

In the following two life time cycle approaches are shown to evaluate the life time costs, reliability, availability and safety of the bridge in the following 120 years.

At first, the referenced approach is analyzed, where none rehabilitation works, except basic repairs such as pavement replacement, are considered. Critical elements of the bridge will therefore deteriorate until their collapse. When the collapse of the element occurs, this part is replaced or rehabilitated.

Secondly, preventative approach is considered, where a major rehabilitation works are performed at the beginning. In the following, bridge is inspected and interventions are performed in time intervals throughout the life cycle of the bridge in order to prevent the overall collapse of the structure.

5.1. CURRENT STATE EVALUATION

In accordance with current state of the described structure following KPIs are considered:

Structure type	Group	Component	Material	Design & Construction	Failure mode	Location/ Position	Damage /Observation	Damage process	KPI	Performance Indicator component level		Performance value		Estimated failure time [years]
												R	**S**	
GB	Structural elements	Abutments	Reinforced concrete	/	Inclination due to settlement of the foundations	At the contact with foundations	Horizontal cracking	Corrosion	Reliability (Structure safety)	4.5	**4.5**	**4.5**	**3.0**	**2**
						In the middle part of the element	Diagonal cracking	Corrosion		4.0				**2**
						At the contact with wing walls	Vertical cracking	Corrosion		4.0				**2**
						At the contact with girders	Leakage	Leaching	(Symptom)	(2.0)				
		Longitudinal girders	Reinforced concrete	/	Bending	High sagging area	Longitudinal cracking	Corrosion	Reliability	2.0	**2.0**			**20**
					Bending	High sagging area	Leakage	Leaching	(Symptom)	(2.0)				
					Shear failure	High shear area	Leakage	Leaching	(Symptom)	(2.0)				
		Transverse girders	Reinforced concrete	/	Shear failure	Entire element	Spalling	Corrosion	Reliability	2.0	**2.0**			**30**
		Deck slab	Reinforced concrete	/	Bending	Middle part	Leakage	Leaching	(Symptom)	(2.0)				
	Equipment	Railing	Steel	/	Falling of the deck	Railing	Corrosion of structural steel	Corrosion	Safety (Life and limb)	2.0	2.0			**30**
		Pedestrian Handrail	Steel	/	Falling of the deck	Handrail anchoring	Broken	Impact	Safety (Life and limb)	3.0	3.0			**5**
		Pavement	Asphalt	/	Pavement deterioration	At the contact with the curb	Vegetation	Pavement deterioration	Safety (Life and limb)	2.5	2.5			**10**

5.2. REFERENCED APPROACH

In the reference approach it was assumed that the bridge doesn't have major repairs until estimated failure of an element occurs and which has to be than repaired. This approach considers estimated failure of bridge elements as shown in previous section. Development of the existing structure defects and estimated failure times are described as follows:

The current (initial) state of the bridge is evaluated as:

- Reliability: 3
- Availability: 1
- Safety: 3

It is assumed that after 2 years traffic restrictions except for the cars are applied in order to lower the intensity of decay of the abutments, therefore level of the availability is reduced.

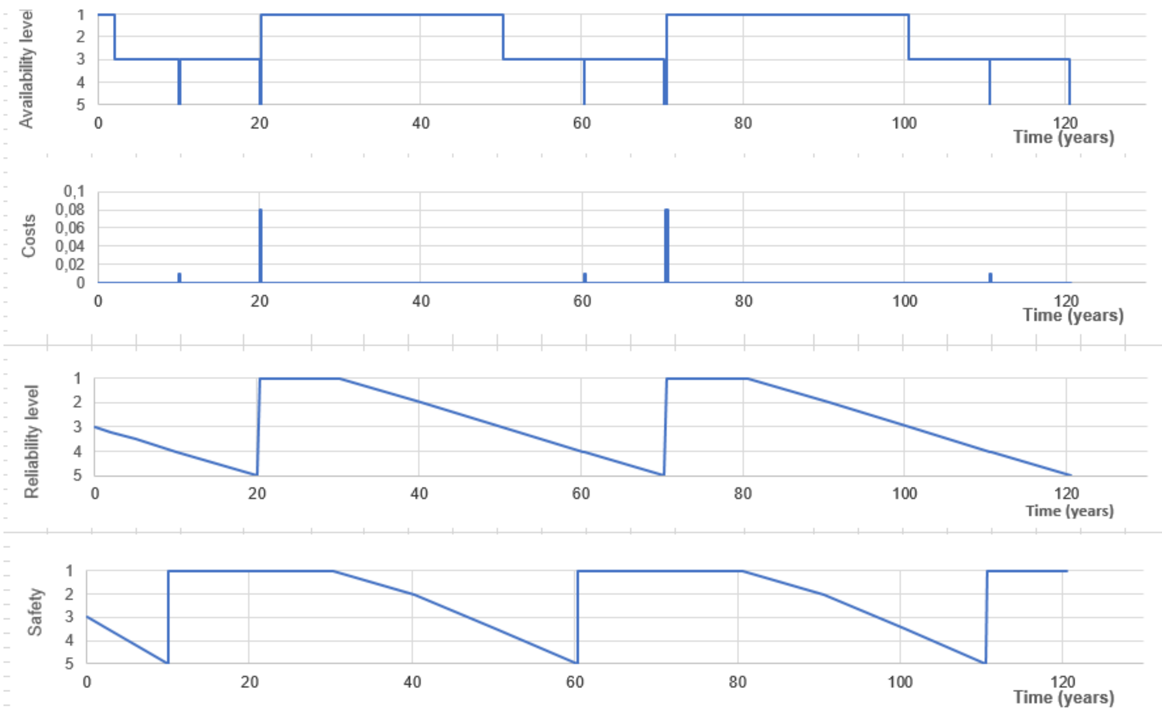
Damaged pedestrian handrail and safety railing are replaced during pavement repair after 10 years, what increases the level of safety up to 1. It is assumed that urgent pavement repairs costs approximately 10000 €.

It is assumed that failure of the bridge occurs in 20 years due to corrosion in high sagging area in the longitudinal girders as well as due to inclination of the abutments, which can't carry loads from (restricted) traffic.

After failure, the existing bridge is completely renovated or new bridge is built instead for projected lifespan of 50 years. With a value of 1200 €/m^2 it was assumed that new bridge costs approximately 80000 €.

In the first 10 years after major renovation no reduction in reliability and safety is expected. After 10 years, erosion processes under abutments begin, what causes drop in reliability of the bridge to the value of 2 after 20 years of renovation. Due to the lack of major repairs, bridge decays intensively and therefore heavy traffic restriction is applied 30 years after renovation. Drop in reliability level from value of 2 at 20 years after renovation to the value of 5 in 50 years (when the bridge reaches its projected lifespan) is assumed as linear. After 10 years, beside reliability, safety begins to drop too due to damaged handrail and railing – it is assumed that between 10 and 20 years safety level drops from 1 to 2. Furthermore, from 20 years to 40 years safety levels falls from 2 to 5 due to intense pavement decay and corrosion processes. After 40 years major pavement repairs are performed, what increases the level of safety to the value of 1.

After 50 years the bridge is completely renovated/new bridge is built and therefore last cycle repeats.



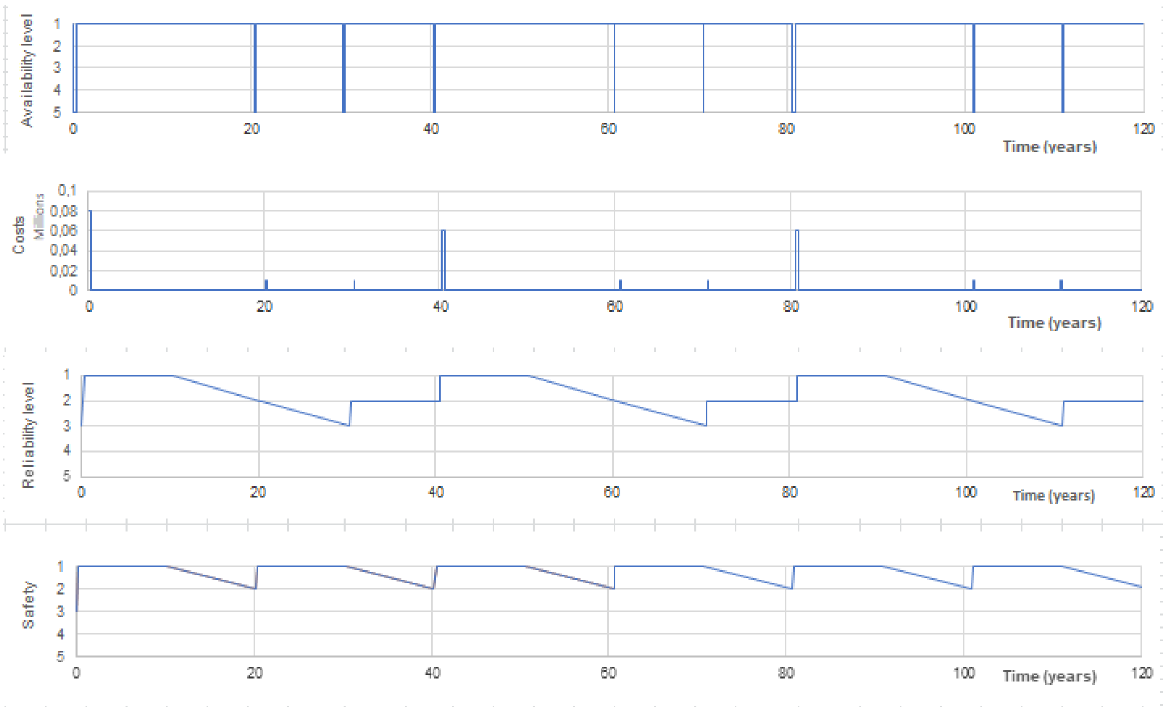
5.3. PREVENTIVE/CORRECTIVE APPROACH

In the preventive approach it was assumed that there is immediate renovation of the bridge at the beginning, what raises the level of reliability and safety to the level of 1 for the time of 10 years.

After 10 years, no change in the level of reliability and safety is expected. Between 10 and 30 years, pavement and safety equipment starts to decay intensively, therefore pavement, handrail and railing is replaced after 30 years, what raises up the level of safety back to 1 for 10 years. It is assumed that pavement and safety equipment repairs costs are approximately 10.000 €.

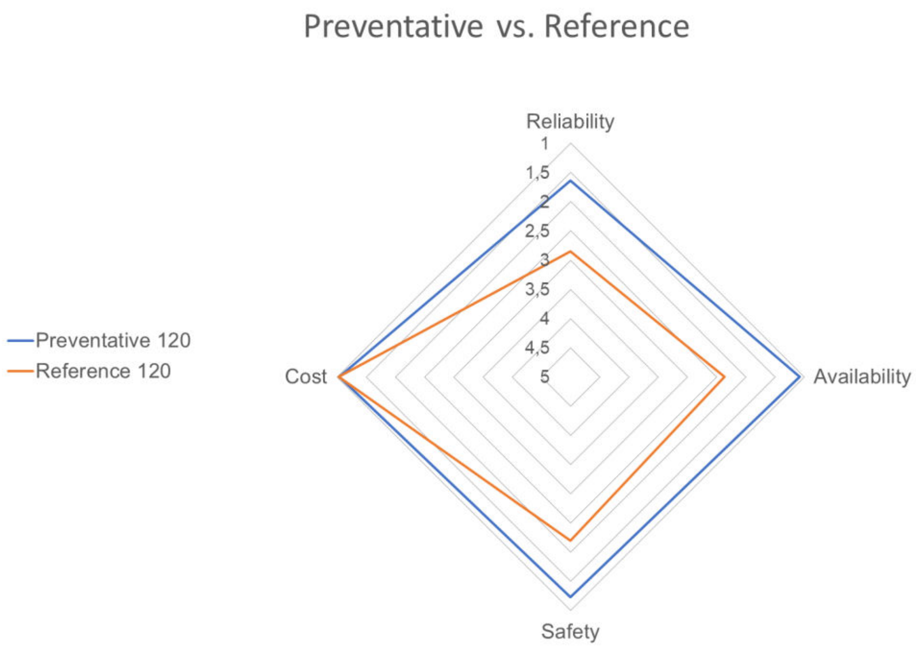
Between 10 and 30 years level of reliability drops from 1 to 3 due to erosion processes. In the reference approach it was assumed that after 30 years, due to lack of major repairs, bridge decays intensively and therefore heavy traffic restriction is applied. In order to avoid this restriction, intervention at this time is performed, where abutments are rehabilitated. It is assumed that abutments rehabilitation costs are approximately 10.000 €. This raises up the level of reliability from 3 to 2. This level remains constant for the following 10 years.

10 years after pavement and safety equipment repairs (30 years after major renovation), level of safety begins to drop and reaches level of 2 after 20 years. At this point major rehabilitation of the bridge is performed, what raises the level of reliability and safety to the 1. Comparing to the reference approach this costs are lower (approximately 60.000 €) due to already rehabilitated abutments in the last intervention.



5.4. COMPARISON OF THE APPROACHES

A comparison of the considered approaches is shown in the following “spider” diagram. As expected, preventative approach is more appropriate for the considered bridge. Except cost indicator, all other indicators, such as reliability, safety and availability, show more favorable results comparing to the reference approach.



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