TU1406

COST ACTION

TU1406 WG4 Final report Appendix A1

Bridge Case study: Girder Bridge in Dobříš - Czech Republic

WG4

TECHNICAL REPORT
PREPARATION OF A CASE STUDY

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1. GENERAL DATA ON THE BRDGE

The inspected bridge is a one-span concrete structure built in 1983. The bridge carries the highway D4 across the local road III/10226 close to Dobříš town. General views of the bridge are presented below.

Figure 1. *The view under the bridge*

Figure 2. *Side view of the bridge (right side)*

Figure 3. *A view along the road in the Prague direction*

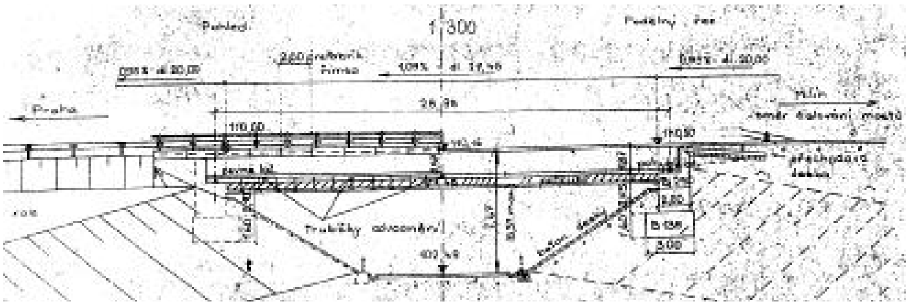


Figure 4. *Elevation of the bridge*

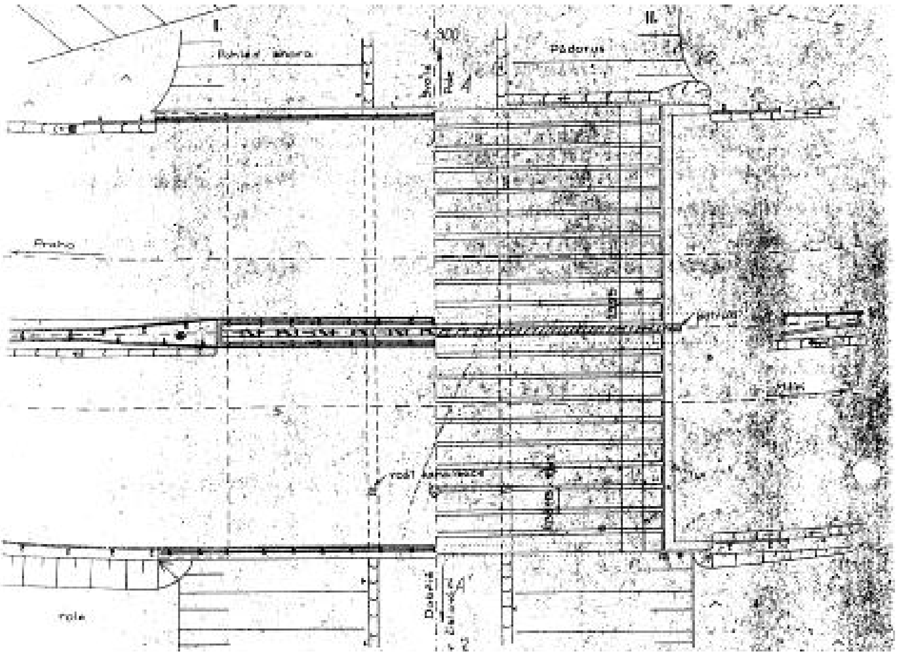


Figure 5. *The plan of the bridge*

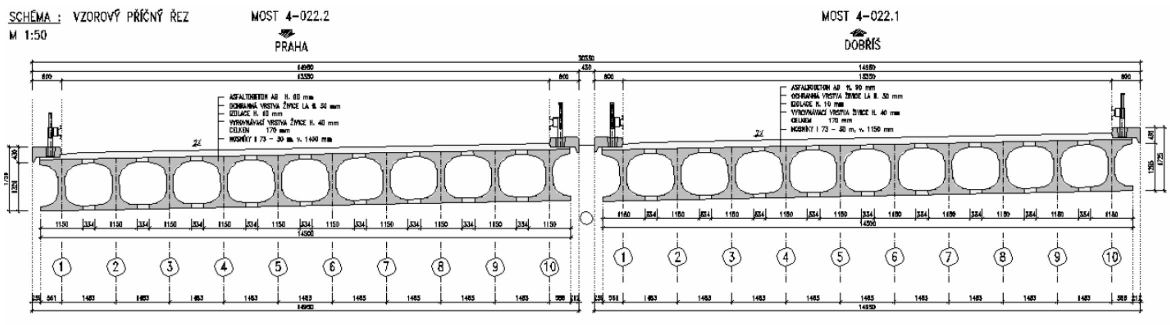


Figure 6. *General cross section of the bridge*

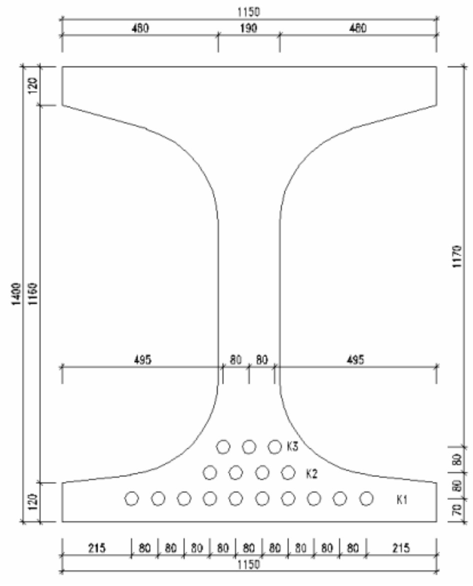


Figure 7. *Cross section of the I73 girder*

1.1. TRAFFIC INFORMATION

The last information about the traffic are from the last counting in 2010.
Number of cars / 24h: 20306
Number of heavy cars / 24h: 3868

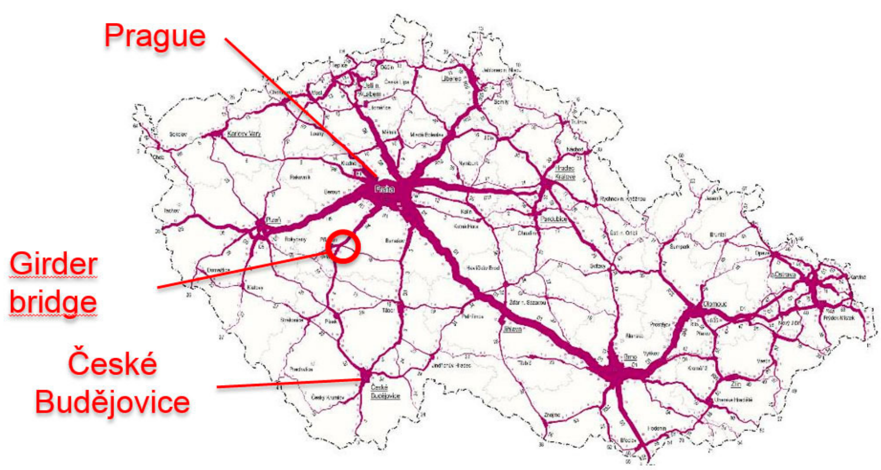


Figure 8. *Location of the bridge on the map of traffic intensity*

1.2. FOUNDATION

Foundations are inaccessible, and there are no existing precise drawings, showing them. According to to the sketches from BMS we expect there are pad foundations.

1.3. SUBSTRUCTURE

Substructure is formed by the abutments from the concrete.

1.4. SUPERSTRUCTURE

The superstructure is divided to two parts, there is a independent superstructure for each traffic direction. Each superstructure is formed by 10 precast and prestressed I73 girders. Each girder is supported on steel bearings, one fixed and one movable.

1.5. ACCESSORIES

There is asphalt pavement on the bridge. The walkway is made from concrete and equipped with steel crash barrier integrated with steel railing. The drainage is done on the bridge sides and water is drained out of the structure.

1.6. LOAD CAPACITY

The load capacity of the bridge is considered as:

- Normal capacity of the unlimited number of vehicles: Vn = 24 t
- The capacity of the one single vehicle on the bridge: Vr = 53 t
- Exceptional capacity for the heavy special transport: Ve =292 t
- Critical member is a side beam and its bending capacity.

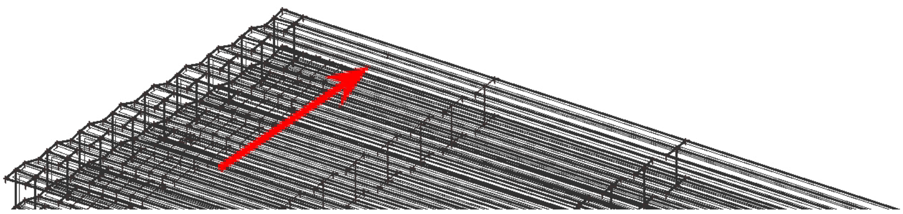


Figure 9. *The view on the numerical model for the load capacity calculation – shell model.*

1.7. RATING OF THE BRIDGE

According to the Czech rating system, the status is V (bad) for the superstructure and IV (satisfactory) for the substructure, on the scale between I (excellent) and VII (emergency). The availability is of the grade 2 (available with limitations) on the scale between 1 (available) and 5 (Unavailable).

2. TECHNICAL CONDITION

2.1. COLLECTION OF DEFECTS

The types of defects discovered on the analysed bridge are:

- Concrete deterioration and the reinforcement corrosion of both abutments
- Concrete deterioration and the reinforcement corrosion of main girders.
- Defects of expansion joints
- Waterproofing defects,
- Deterioration of the concrete parapets (ASR)
- Bearings damage

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

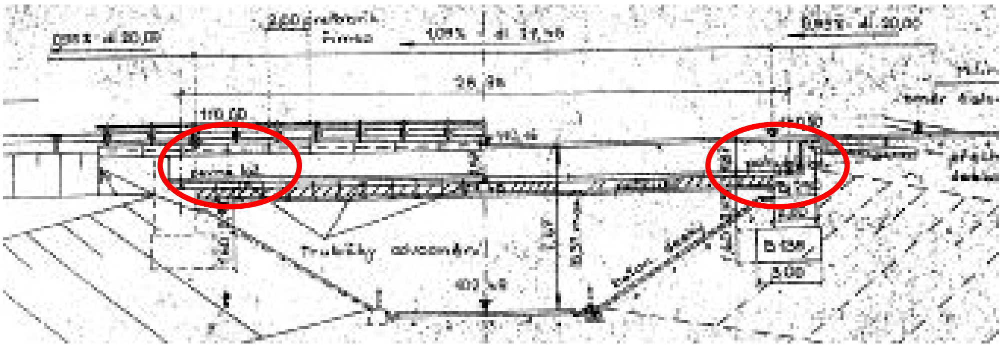


__Figure 10.__ The location of the most deteriorated parts, due to the water leaking

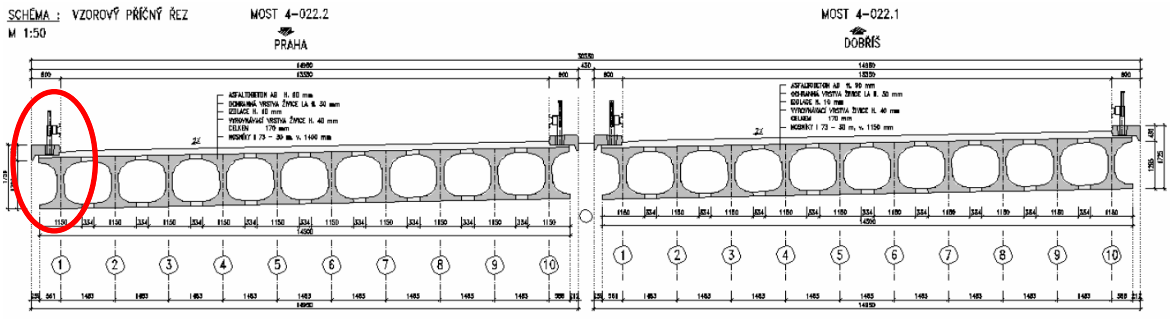


__Figure 11.__ The location of the most deteriorated beam

2.2. DEFECTS OF THE MAIN STRUCTURAL ELEMENTS

2.2.1. CONCRETE DETERIORATION AND THE REINFORCEMENT CORROSION OF BOTH ABUTMENTS

__Figure 12.__ Deterioration of the abutment – concrete spalling, reinforcement corrosion

Figure 13. *Deterioration of the abutment under the bearing, bearing corrosion*

2.2.2. CONCRETE DETERIORATION AND THE REINFORCEMENT CORROSION OF MAIN GIRDERS.

Figure 14. *The water leaking through the expansion joint, crack between precast and in-situ casted concrete of the main girder*

Figure 15. *The corrosion of the reinforcement and prestressing cables at the end of the side girder*

Figure 16. *The corrosion of the reinforcement and concrete deterioration of the side main girder.*

Figure 17. *The poor quality of the side main girder*

Figure 18. *The view inside the main girders*

2.2.3. DEFECTS OF EXPANSION JOINTS

Figure 19. *The defects in the expansion joints and pavement nearby*

2.2.4. WATERPROOFING DEFECTS

Figure 20. *The water leaking because of the expansion joint failure*

Figure 21. *The water leaking because of the waterproofing and expansion joint failure*

2.2.5. DETERIORATION OF THE CONCRETE PARAPETS (ASR)

Figure 22. *ASR reaction on the concrete parapets*

Figure 23. *Poor concrete of the parapets, safety barrier secured by timber*

2.2.6. BEARINGS DAMAGE AND CORROSION

Figure 24. *The significant corrosion of the bearings*

3. POTENTIAL FAILURE MODE OF THE BRIDGE

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

- Failure of the edge girder, because of the concrete degradation and reinforcement corrosion, that will influence the prestressing cables and/or prestressing anchors, leading to the girder failure.
- This is the most probable scenario, as the leakage to the anchoring area can lead to the corrosion of the prestressing reinforcement close to the anchor.
- Failure of the bearings, because of the heavy corrosion – but this will take a long time, and the consequences are not critical.
- Loss of stability of the abutment under the edge bearing, the local pressure into the deteriorated concrete will lead to the local girder failure (slip of the girder, the failure will result in the large deformation, not to the global collapse).

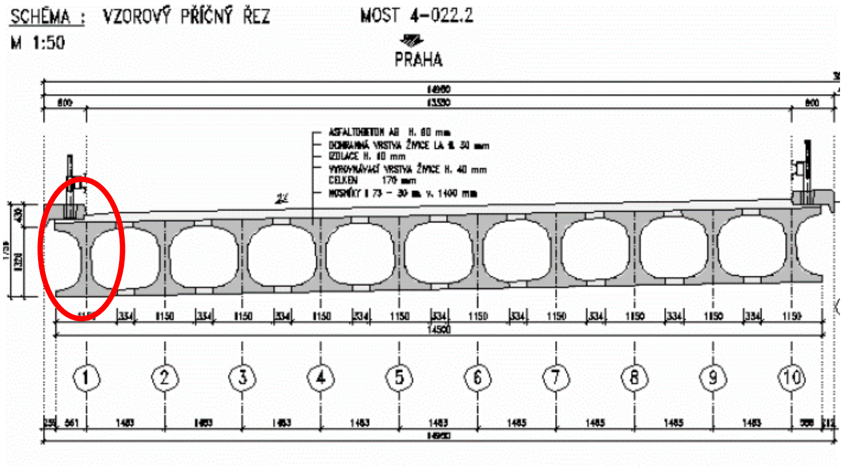


__Figure 25.__ The location of the most critical place – the edge girder

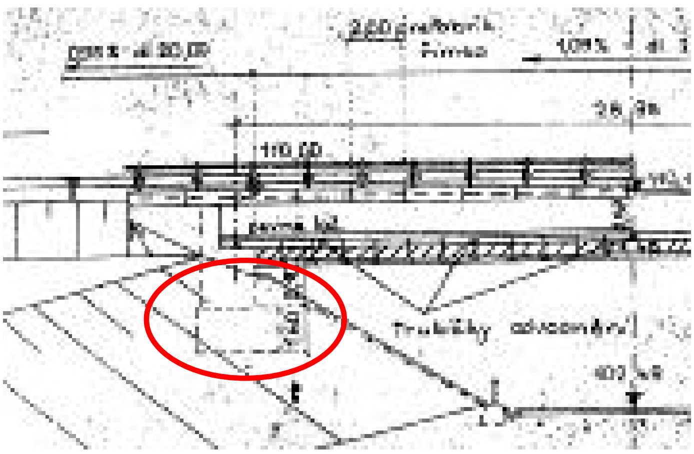


__Figure 26.__ The location of the abutment and possible failure scenario

4. MATERIAL TESTING

4.1. COMPRESSIVE CONCRETE STRENGTH TEST RESULTS

The received results of the tests are given below.

Specimen	Unit weight [kg.m-3]	Force [kN]	Compressive strength [MPa]
Main girder 1	**2377**	552	**77,6**
Main girder 2	**2384**	487	**69,0**
Main girder 3	**2386**	515	**75,0**
Main girder 4	**2374**	478	**70,0**
Abutment 1	**2280**	45,5	**36,7**
Abutment 2	**2277**	50,8	**40,8**
Abutment 3	**2276**	48,3	**38,7**
Abutment 4	**2278**	66,9	**53,6**

The concrete can be considered as a C60/75 for the girders, C30/37 for the abutments.

4.2. ALKALI – SILICA REACTION

The Rhodamin method was used to identify the existence of the silica gel. The ASR was found on the concrete of the parapets.

Figure 27. *Typical signs of the ASR*

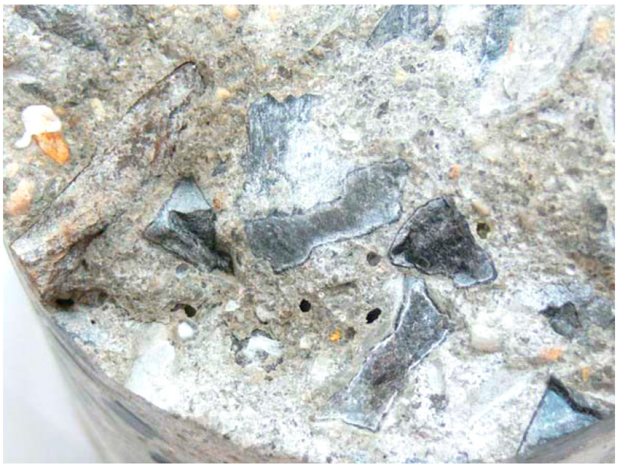


Figure 28. *Specimens with ASR signs*

4.3. CARBONATION

The next test was focused on the carbonation of the concrete. The depth is 8,6 mm on the main girders (5-11mm), and 26,7 mm on the abutment (11-46mm). The parapet shows 36,7mm (37-45mm).

4.4. FREEZING RESISTANCE

All samples were exposed to the 75 freezing cycles. The results show, that the concrete of the superstructure can resist to 75 cycles. The concrete of the abutment is much worse, it was fully damaged only after 25 cycles.

5. KEY PERFORMANCE INDICATORS

Key performance indicators are provided in accordance with best practice knowledge of the research team and experiences with bridge inspection in Czech Republic. The indicators are evaluated and failure modes of the bridge are estimated.

Furthermore, two life time cycle approaches are shown to evaluate the life time costs, reliability, availability and safety of considered arch bridge in following 100 years.

First Referenced approach consider a lack of any repairs of bridge except of very basic ones on the pavement and crash barrier. The bridge defects are developed till bridge failure and whole bridge is replaced with new structure.

Second Preventative approach consider set of repairs during life time cycle to prevent further defect development and overall damage to the structure.

The life time costs consider every year maintenance costs, pavement replacement costs every 20 years, bridge repair every 40 years and other costs described in following sections depending on considered approach.

5.1. CURRENT STATE EVALUATION

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

Structure	Component	Material	Design and Con-strution	Failure Mode	Vurnerable Zone	Symptoms	KPI	Performance Indicator		Estimated Failure Time
Pre-stressed Girder Bridge	Edge Main Girder	Prestressed Concrete	1983	Global Failure	Bottom flange and Prestressing cables	Reinforcement cor-rosion deterioration	Reliability (structure safety)	3	3	20 years
	Edge Main Girder	Prestressed Concrete	1983	Global Failure	Anchors of Pre-stressing cables	Leakage, crack in the anchor zone		3		20 years
	Bearings	Steel	1983	Bearing Failure	Bearing	Corrosion		2		40 years
	Abutments	Reinforced Concrete	1983	Loss of stability under the edge bearing	Bearing block	Concrete deterio-ration		3		20 years
	Steel Para-pets	Steel	1983	Corrosion and Collapse	Bottom section of parapet	Reinforcement deterioration	Safety	3	3	10 years
	Pavement at EJ	Asphalt	1983	Serviceability and Failure	Expansion joint	Asphalt deteriora-tion, cracks		3		5 years
	Parapets	Reinforced Concrete	1983	Parapet degra-dation	Top surface	Crack & ASR		3		10 years

The estimated failure time is assumed according to research team experience with concrete structures in Czech Republic and estimated progress of the defects. It is however safe assumption under severe conditions.

5.2. RELIABILITY VERIFICATION

The load capacity of the bridge is considered as:

- Normal capacity of the unlimited number of vehicles: V_n = 24 t
- The capacity of the one single vehicle on the bridge: V_r = 53 t
- Exceptional capacity for the heavy special transport: V_e =292 t

Critical member is a side beam and its bending capacity. This load capacity was calculated as a heaviest vehicle, that can cross the bridge, based on following material and load safety factors:

γ_S = 1,15 – for prestressing steel
γ_G = 1,35 – Safety factor for dead load
γ_Q = 1,35 – Safety factor for live load

Those load factors are given in the Czech load capacity code for existing bridges.

For the prestressing steel, we do not have the exact data. However, we can writhe the material factor as:

$$\gamma_S = \frac{f_{yk}}{f_{yd}} = e^{\left(-k_n \cdot V_{fy}\right)} \Big/ e^{\left(-\alpha_R \cdot \beta \cdot V_{Rx}\right)}$$

Where the variability index can be written as:

$$V_{Ry} = \sqrt{V^2{}_{fy} + V^2{}_{geo} + V^2{}_{\zeta}}$$

We can assume, that variability for prestressing steel according to the literature is V_{fy}= 0,05, variability of the geometry is small, as it is precasted member, V_{geo} = 0,02, model uncertainty variability is V_{ζ} = 0,05. Then we can get:

$$V_{Ry} = \sqrt{V_{fy}^2 + V_{geo}^2 + V_{\zeta}^2} = \sqrt{0,05^2 + 0,02V^2 + 0,05^2} = 0,073$$

Then, following the above formula, we can write:

γ_S = *exp (-1,64 · 0,05) /exp (-0,8 · 3,8 · 0,073) = 1,15*
Which is the same as the used value in the analysis, for β = 3,8.

For the dead load, as the geometry was not measured, we can assume for dominant load α_E= -0,7, and variability V_G = 0,1. Then, we take the factor of the model uncertainty as γ_{Sd} = 1,05. We can write:

$\gamma_G=(1 - \alpha_E \cdot \beta_t \cdot V_G) \cdot \gamma_{SD}= (1 + 0,7 \cdot 3,8 \cdot) \cdot 1,5 = 1,329$

Or to get 1,35
$\gamma_G=(1 - \alpha_E \cdot \beta_t \cdot V_G) \cdot \gamma_{SD}= (1 + 0,7 \cdot 4,1 \cdot 0,1) \cdot 1,05 = 1,35$
So for the dead load, β = 4,1.

If we assume the live load, and we assume the variability of the model uncertainties $V_{\theta E}$=0,1, we can get the β = 3,5.

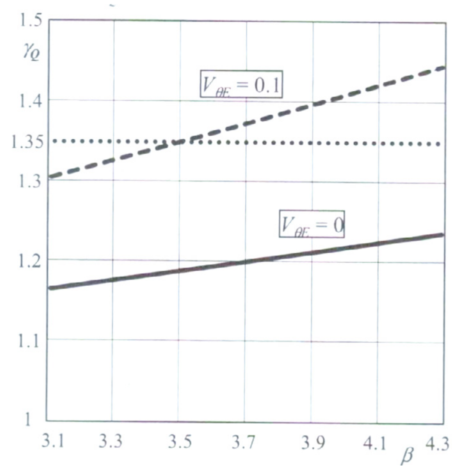


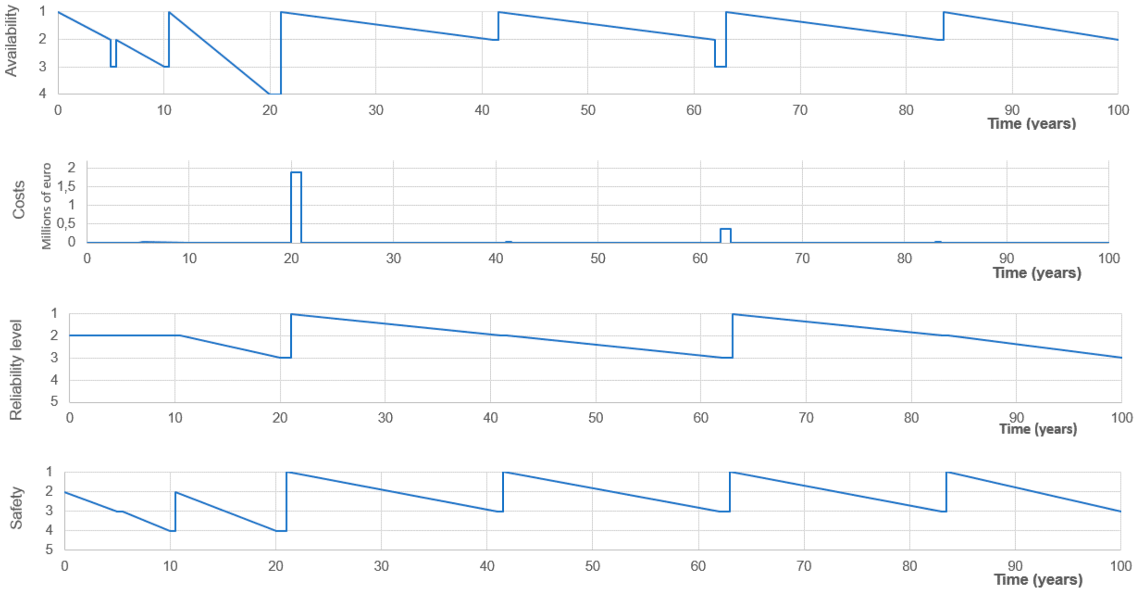
Figure 29. *The relation between β and γ_Q*

Based on previous calculations, and application of the standard safety factors, we can conclude that the smallest β was calculated for the live load impact. So we are on the safe side, if we take this β for the whole bridge. For more precise load capacity verification, the slightly smaller load factors for the dead load can be taken, if we take β = 3,5 and thus slightly increase the load capacity.

5.3. REFERENCED APPROACH

Lack of any major repairs of superstructure and accessories except of basic pavement repairs leads to the defects development up to the bridge failure. In accordance with previous section, the existing structure defects, development and estimated failure times are assumed as follows:

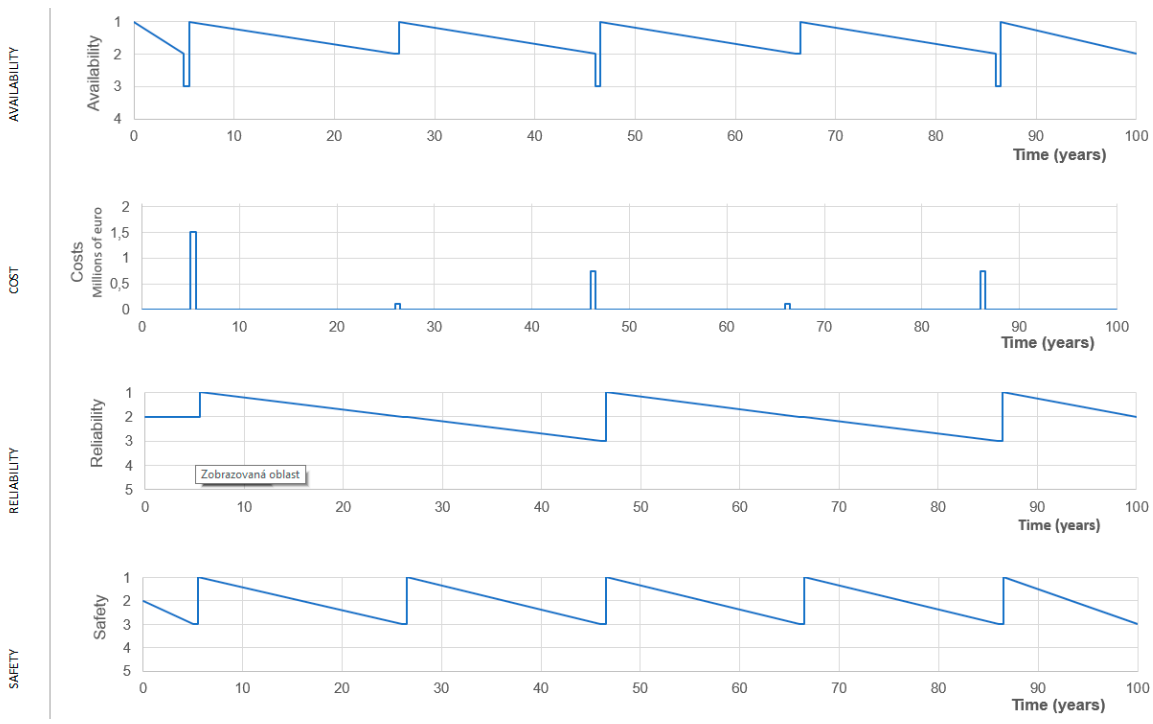
- Pavement failure in five years due to crack development at the EJ location, sweating and deformation in five years (as noted the pavement layer shall be repaired).
- Then the pavement will be repaired. But only the pavement, not the waterproofing. The cost is estimated as 40t Euro/bridge. It will temporarily decrease the availability.
- Concrete parapets collapse (meaning the unstable crash barrier, which is no more safe) in 10 years. At this time, the installation of the temporary concrete crash barrier is assumed. It means decrease of availability & safety, as the bridge is narrower. The cost is estimated as 50t Euro/bridge
- Loss of the stability of the abutment under the bearing, or more likely failure of the prestressing cables in 20 years (bridge failure and replacement with new structure).
- The drop of the availability, bridge will be closed. But the adjacent bridge will carry one traffic lane in each driving direction, so the traffic will be only slowed and traffic jams can be expected.
- The cost of the repair is 1 900 000 Euro.
- Preventative approach on the new bridge (pavement replacement every 20 years and bridge repair every 40 years).
- The repair will be done by halves of the bridge, so temporarily the availability is decreased. The cost of the pavement repair is 110 000 Euro, cost of the complex repair (pavement, crash barrier, railing, parapets) is 300 000 Euro.



5.4. PREVENTATIVE APPROACH

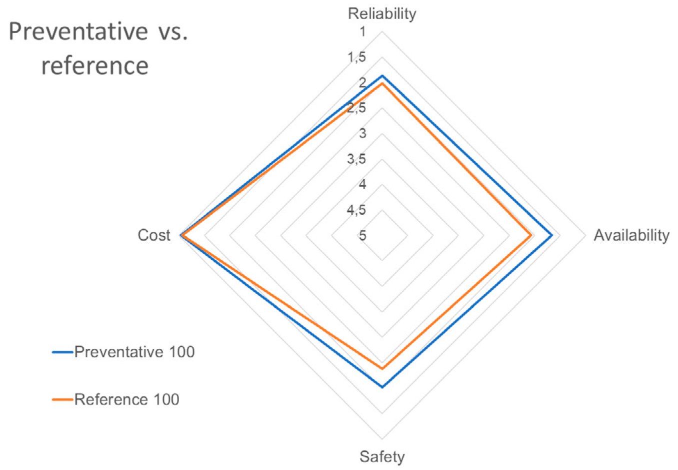
First the bridge repair shall be designed and done in 5 years. The whole bridge structure and accessories repair is considered. The life time cycle is considered as follows:

- pavement failure in five years due to crack development, sweating and deformation in five years (shall be repaired). The whole bridge and accessories repair is considered in the same time.
- The new concrete deck will be laid on the top of prestressed girders, side beam will be replaced by a new one. Cost is considered as 1 500 000 Euro.
- The drop of the availability, bridge will be closed. But the adjacent bridge will carry one traffic lane in each driving direction, so the traffic will be only slowed and traffic jams can be expected.
- In following years, the preventative approach on the repaired bridge is assumed (pavement replacement every 20 years and bridge repair every 40 years). Cost 40000 Euro or 750 000 Euro respectively (cost are increased, because of expected repair works on the renovated concrete).
- The repair will be done by halves of the bridge, so temporarily the availability is decreased.



5.5. COMPARISON OF THE APPROACHES

A comparison of the two considered approaches is shown in following “spider” diagram:



According to the carried-out analysis the preventative approach is more appropriate for the arch bridge - the indicators shows more favourable results for all aspects – safety, reliability, availability. Only the costs are almost comparable - the reason is the normalization of the costs based on the interest rate 2%.

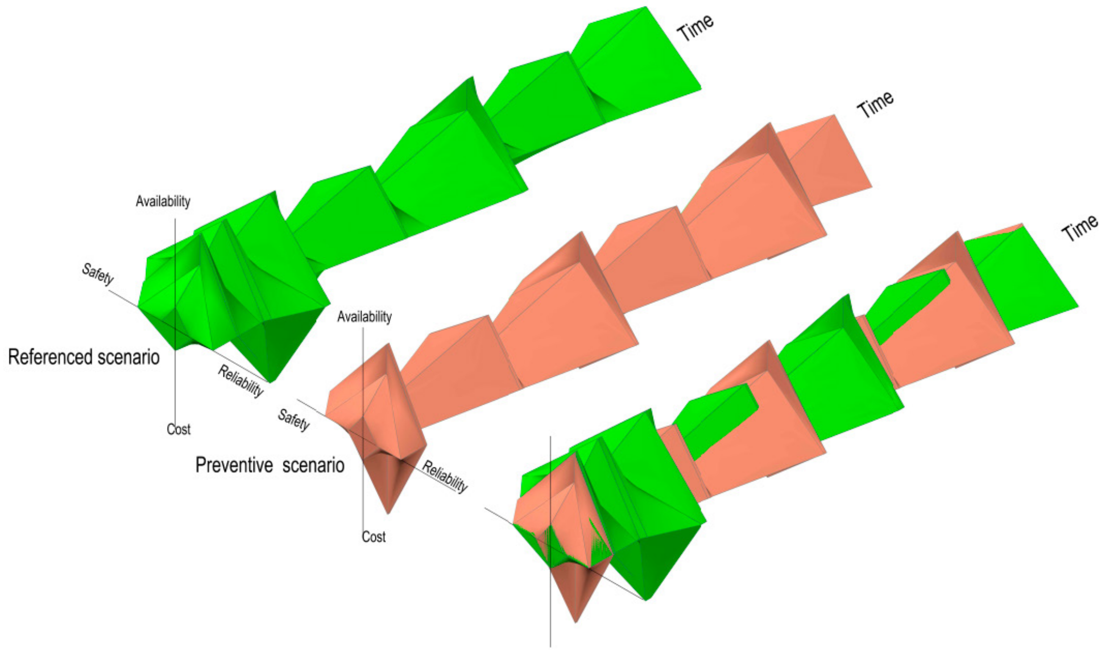


Figure 30. *The comparison of the safety, reliability, availability and cost in time and volume comparison*

Informatively, we can also compare the Referenced and Preventive scenario in the 3D spider graph, separately and in one image together for the whole period of 100 years. The comparison can be done on the comparison of the volume of the normalized graph (unitless), as an averaging tool. Then we have:

- Referenced scenario - 180
- Preventive scenario - 146

This means, that preventive scenario is generally closer to the best “1” grade, which means it is more appropriate here.

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