Tailor Made Concrete Structures – Walraven & Stoelhorst (eds)

Case study: LCC analysis for Krk Bridge

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ABSTRACT: The Krk Bridge (constructed between 1976–1980) connects the mainland and the island of Krk, and consists of two arches including one of the largest conventionally reinforced concrete arch span in the world. During more than 25 years of service the bridge was exposed to very aggressive environment which caused corrosion problems. Therefore, structures of both arches are being repaired intensively during last 10 years. In this paper approximate costs of the maintenance and repair works performed during last 3 decades on the small and big arch of the Krk bridge are analysed. The actual costs are compared to the estimated costs of the life cycle management, if outer layer of carbon steel reinforcement had been replaced with stainless steel.

1 INTRODUCTION

The Krk Bridge connects the mainland and the island of Krk passing over the small island Sv.Marko, and consists of two arches including one of the largest reinforced concrete arch span in the world (390 m, no prestressing nor steel pieces). Total length of the bridge is 1310 m, which includes 96 m of road over the island Sv.Marko, Figure 1. The bridge was constructed in the period from 1976 until 1980.

During more than 25 years of service the bridge was exposed to strong winds (gale and sirocco) which rised the salt water and spread it all over the bridge substructure. High salinity of the water (3.5%) combined with the wind accelerated the penetration of chlorides into the bridge elements, columns and the arches, provoking the corrosion in the reinforcing bars as well as microcracking, spalling and deterioration of the concrete cover, Figures 2A and B. Therefore, structures of both arches are being repaired intensively during last 10 years. (Beslac 2003)

Figure 1. View form the mainland towards the island Krk.

2 REPAIR AND MAINTENANCE COSTS

Maintenance and repair works, and their approximate costs are shown in Table 1, and graphically in Figure 3 and Table 1.

Figure 4 presents the life cycle cost (LCC) analysis for the Krk bridge in graphical form. This shows two scenarios (a) 30% and (b) 50% of the carbon steel is replaced by the far more expensive stainless steel.

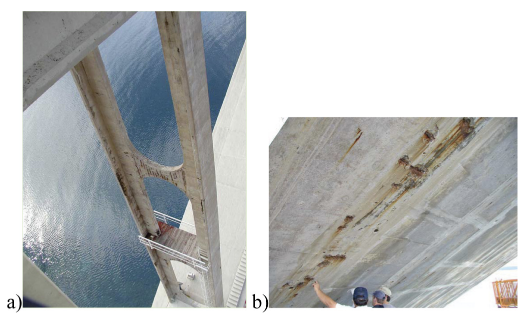

Figure 2. Cracking due to corrosion on a) column, b) lower part of the Big arch.

Table 1. Overview of repair and maintenance works on Krk bridge.

Year	Inspection	Repair	Cost (%)
1976–1980	execution		100
1980–1999	geodetic survey		0,12
1980		rectification of Small Arch	
1981	first visual inspection		
1982		rectification of Big Arch for 63 mm	0,20
1983		rectification of Big Arch for 93 mm	
1985	"Recommendations for inspection and maintenance of Krk bridge"		0,20
1986	first detailed inspection (visual, on-site + laboratory testing)		
1987–1993		• complete change of head beams and support joints on Columns C4 to C19, C28 • on columns C4, C12 and C13 construction of special dillatation (THORMA JOINT)	8,00
1988–1991		• protection of lower parts of arches and supports with coatings (cca 4500 m^2) • repair of upper surfaces, feet and supports of Small Arch	3,00
1900	production of specially designed movable scaffold for bridge inspection		0,20
1993	second detailed inspection (visual, on-site + laboratory testing)		0,10
1996	dynamical testing of Big Arch		0,04
1998–2001	dynamical testing of Small and Big Arch		0,04
1999	detailed inspection of Small Arch		0,02
1999–2001		• repair of columns C27, C28, C29, C30, C31	4,00
2001–2003	detailed inspections of Big Arch		0,04
2001–2002	installation of sensors (optic fibers) for monitoring of deformations on columns C20 and C26	• repair of columns C20 to C26 • repair of Small Arch up to 15 m.a.s.l.	5,00
2004–2005		• repair of head beams on C29, C30, C31 • design project of Cathodic Protection of submerged parts of the Big Arch	3,00
2005		tender for repair and protection of the whole structure of Big Arch	1,00
2005–2010		• estimation of future repair costs of the remained parts of the bridge	20

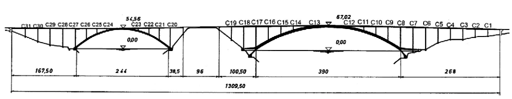

Figure 3. Schematic drawing of the Krk bridge with column labels.

Cost analyses for the selective use of stainless steel are based on the data given in Table 2. Total cost of the bridge was 50 mil. US$. (Stojadinovic 1981, Sram 1981).

From Figure 4 it is obvious thus the selective replacement of carbon steel by stainless steel would

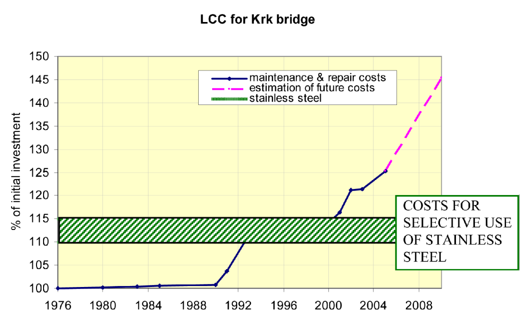

Figure 4. Life cycle costs for Krk bridge.

Table 2. Cost calculations for selective use of stainless steel.

Steel type	Carbon (Price in 1980: 350 $/ton)	Stainless (Price in 1980: 3500 $/ton)	% to the total cost	Original construction cost %
Scenario 1	100%	–	–	–
Amount	4415 ton	–	–	–
Price	1.5 mil. US$	–	–	–
	1.5 mil. US$		3.1	100
Scenario 2	70%	30%	–	
Amount	3091 ton	1324 ton	–	
Price	1.1 mil. US$	4.6 mil. US$		
	5.7 mil. US$		11.4	108.4
Scenario 3	50%	50%		
Amount	2028 ton	2028 ton	–	
Price	0.8 mil. US$	7.7 mil. US$		
	8.5 mil. US$		17	113.9

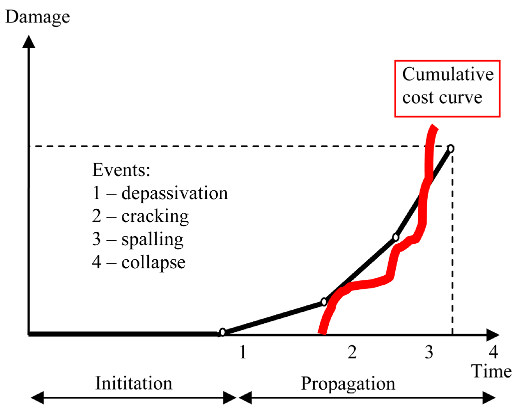

Figure 5. Service limit states in comparison with cumulative life cycle costs.

have produced a lower overall life cycle cost. (fib 2007, Matthews 2007).

Figure 5 shows schematically a hypothetical relationship between service life limit states (Duracrete 2000) and life cycle cost which is incurred, illustrating the significant increase in the cost of undertaking repairs as the structure deteriorates to a greater degree.

3 CONCLUSION

With this case study it has been demonstrated that by adopting proactive management of structures, rather than a reactive approach, it is possible to save money in the longer term. LCC analysis of concrete structures should be used during design phase in order to ensure the best choice of suitable materials, technologies and maintenance techniques.

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