An overview of Krk Bridge repairs

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ABSTRACT: Krk Bridge is still the biggest reinforced concrete arch bridge with the longest concrete arch span in the world (390 m) and in spite of the designed concrete cover of only 2.5 cm is still, after 30 years of use in a very aggressive marine environment, in good condition. The paper is trying to explain it by the description of some measures undertaken during the execution and 20 years of its repair and protection. Important things in the execution were composition of concrete, specified and achieved concrete quality and in the maintenance proper testing of the concrete and reinforcement, choice of repair systems, materials and technologies of application and their optimal application in properly chosen time on properly chosen positions of the structure. Some other interested things (positive and negative) of execution, testing and repair are described as well, like slipforming of the thin and high columns, design and construction of multipurpose, complex moveable scaffolding for bridge monitoring and maintenance, sea shells attack of under water reinforced concrete foundation elements, asphalt reconstruction without surface demolition and cleaning of very thin concrete slab (11-13 cm), etc.

1 INTRODUCTION

Krk Bridge is connecting Croatian main land and the biggest Adriatic island Krk with two reinforced concrete arch bridges with arch spans 244 and 390 m (Fig.1). The second one is still the longest in the world in this type of the bridge.

Figure 1 : Krk Bridge.

It was executed in the period from 1976 to 1980 and opened for traffic in July 1980, what means that it is in use 30 years and that its main parts like foundation elements and lower parts of the arches are in a very aggressive marine environment over 30 years.

The dangerous influences on its durability are:

(1) Too thin designed concrete cover (of only 2.5 cm);

(2) Relatively high salinity of the Adriatic Sea (approximately 3.5 %);

(3) Local marine environment with the very frequent changes of very strong southern and northern winds which are blowing and carrying sea spray during several winter months and posing it on the structure;

(4)The winter drops of temperature below freezing point which varies from 10 to 15 times.

But in spite of that, reinforced concrete structure of the Krk Bridge is still in a good condition. The main surface reinforcement is still in the initiation or in the beginning of the propagation period. There are several reasons or applied measures for it (in the execution and in the maintenance as well), which we are trying to explain and emphasize in this paper.

2 EXECUTION MEASURES

First of all concrete was specified in the design in a relatively high quality for that time. The compressive strength classes (related to the standard cube sample 20x20x20 cm) were as follows:

(1) C50 – arches and mine girders;
(2) C45 – horizontal foundation struts;
(3) C40 – inclined foundation elements in the sea, perpendicular girders and slabs;
(4) C35 – columns.

Fortunately all concrete was produced and reinforced concrete structure was executed in the same highest concreter class C 50 with w/c ratio 0.36, what means in the concrete without capillary pores. The average compressive strength achieved in the production quality control was 55.6 MPa. The present compressive strength of concrete estimated lately on a number of cores from the structure corresponds with class C 60/75.

This decision was especially important for the thin and relatively high columns (Fig. 2) which were unfortunately executed by slipforming, the technology which is because of known deficiencies absolutely inconvenient for such elements in such aggressive environment.

Figure 2 : View on thin and relatively high columns executed by slipforminig.

And fortunately again the chosen cement for the concrete was PC 20z-45 with the addition of 20 % of blast furnace slag which was transported from near 400 km distanced factories in Split and not at that time dominant pure Portland cement PC 45 from abut 200 km nearest factories in Istria. No one knows now how it happened but it was great benefit. More than ten years later it was experimentally discovered that the chlorides ingress in the concrete with cement with the addition of slag is very retarded (Mehta, 1988).

What concerns to the thin designed concrete cover the designers and the executers where explaining lately that it was designed so because it had been planned to protect the whole concrete structure. Some parts had been even protected, some one with epoxy and some one with brittle polymer cement mortar (Thoroseal). Epoxy as it is known was not physically compatible with concrete and Thoroseal as porous brittle coat even increased surface chloride concentration and penetration in concrete (Fig.3).

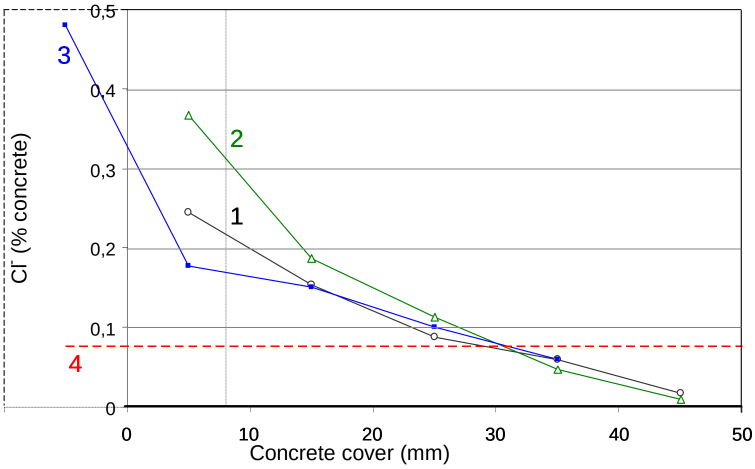

Figure 3 : Diagrams of chloride ingress in concrete and firstly applied protective systems tested in 2008: 1 – in non protected concrete executed 1978, 2 – in concrete protected with Thoroseal 1980, 3 – in repair mortar + polymer cement coat applied 1989, 4 – threshold value (Beslac et al., 2008).

3 MAINTENANCE MEASURES

Maintenance works of the reinforced concrete structure of Krk Bridge started immediately after opening for traffic. The missing applications of epoxy and brittle polymer cement coatings were mentioned before.

The first general monitoring and restricted testing were performed in the years 1985 and 1986. Testing was restricted because the main part of the structure was not accessible. The conclusion was that the whole reinforced concrete structure must be protected. The first very common specifications for its designing and execution were performed and the first bidding announced in 1988. All protection products, systems and technologies known at that time were possible. There were a number of offers and systems but no one satisfied already mentioned very common specifications. Therefore it was decide and offered to the producers of the systems to make trial surfaces on the foundation strut on Snt. Marko, the mostly exposed position on the bridge. More than 20 systems were tested at that very beginning and more than 10 later on. Only two or three of them were partly satisfactory. Some of them that have being forced for the application made the reinforcement protection even worse (Fig.4). The reinforcement corrosion was accelerated, what is understandable because we removed 1 to 2 cm of very good concrete cover and replaced it with more porous mortar. At that time there were not chloride impermeable coats.

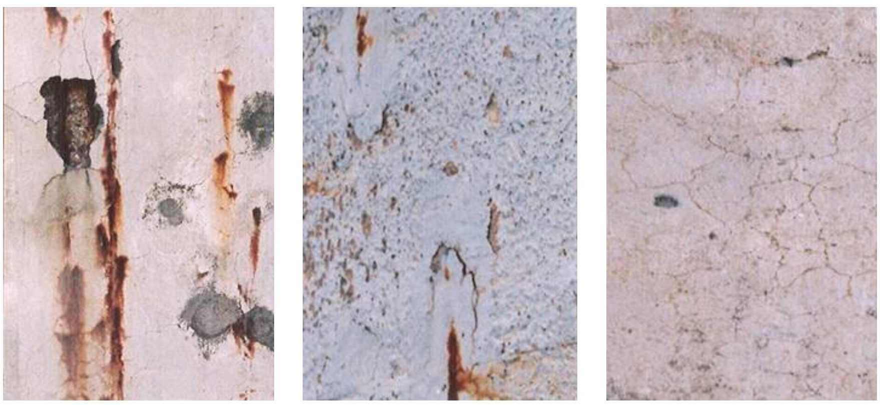

Figure 4 : Some of the poor trial protective systems offered for the protection of Krk Bridge after 20 years of service.

Some parts of the bridge near the sea level were protected with best of those systems but they did not solve the problem. They helped only by the absorption of chlorides in the added mortar and prolongation of their penetration in the concrete (Fig.3).

At the same that time the state of the underwater foundation elements of big arch were examined as well. It was estimated that their surface was covered by sea flora and fauna and concrete cover was damaged by the sea shell Rocellaria Dubia dwellings about 10 mm in diameter and 25 mm deep (Fig.5). Their greatest density was 4000 unites per m^2 at the depth 5 m below sea level. Then years later it was increased for 10 percents. The reparation of this concrete cover is not solved yet. The cathodic protection of the elements was designed but not executed yet.

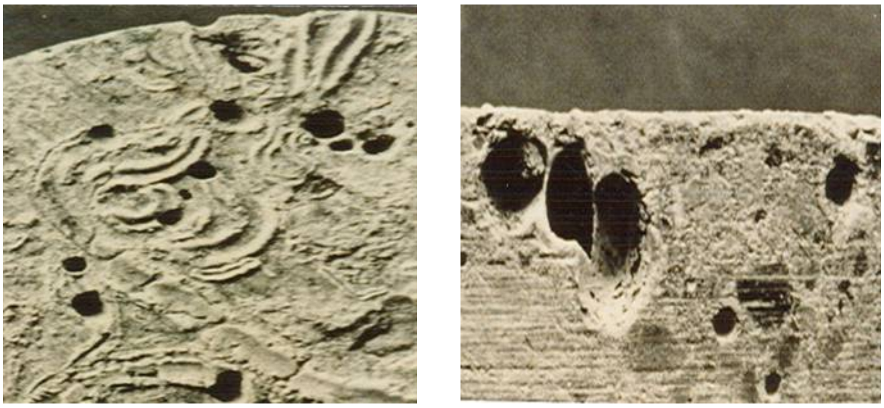

Figure 5 : The dwellings of the sea shell Rocellaria Dubia in the concrete cover of the underwater foundation elements.

The problem of the monitoring and repair and protection of non accessible parts of the bridge structure was solved in the year 1990 by the very complex multipurpose moveable scaffolding (Fig.6) constructed for this purpose and paid about 45000 USD.

Figure 6 : Multipurpose moveable scaffolding for the maintenance of Krk Bridge.

From that time monitoring, repair and protection of the whole concrete bridge structure started, firstly the mostly attached columns and lower parts of the arches and later on the rest of the concrete structure. As it was the time of improved technology of the protection of reinforced concrete by the pure polymer coats impermeable for chloride ingress it was designed as it follows:

For columns and lower parts of the arches:

(1)concrete cover must be partly or totally (dependent on the chloride concentration) hydrodemolished by the water pressure 2500 Bar;

(2) hydro demolished concrete cover must be impregnated with penetration reinforcement corrosion inhibitor;

(3) hydro demolished concrete cover must be renewed by high quality cement mortar, 1 or 2 cm thicker, with 50 MPa compressive strength and 2,0 MPa adhesion to concrete substrate;

(4)repair mortar and concrete must be protected by pure polymer coat 1,2 mm thick with the adhesion to mortar 0,8 MPa and capillary absorption below 0,01 $kg/m^2/h^{0,5}$.

For upper parts of the structure (with lower chloride ingress): concrete surface must be washed by water pressure of 1500 Bar, impregnated by penetration reinforcement corrosion inhibitor and protected by pure polymer coat like in before case.

Nearly all columns and lower parts of the arches have being already protected. The efficiency of the system has being tested after 7 years of use and found satisfactory (Fig.7). There are even some redistribution of chlorides rested in concrete.

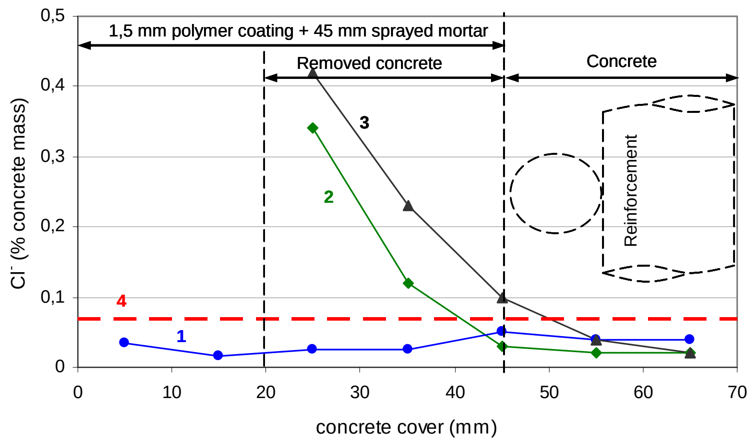

Figure 7 : Chloride ingress in the present protective system after 7 years (1) and in concrete after 10 years (2) and 20 years (3); (4) is threshold value for Krk Bridge.

Special problem of the maintenance of Krk Bridge was reconstruction of asphalt layer which has not being repaired from the beginning of it cycle life. The depth of concrete slab of only 11 to 13 cm was not allowed to remove it in the full depth and clean the concrete by surface hydro demolition. It was successfully removed up to the firstly executed hydroisolated layer made of fine sand mastix covered with new liquide hydroisolation pored in sity and 4+3 cm of asphalt concrete (Fig.8).

Figure 8 : Reconstruction of the asphalt layer.

4 CONCLUSIONS

Design and execution of Krk Bridge were very sensitive and brave job. Its maintenance during last 30 years in the above mentioned very aggressive environment was not much easier.

Contrary it was very challenging. Thanks to some good decisions in the design and execution, maintenance is keeping it still in a good condition in spite of some mistakes made in the design, execution and use as well. We surely will try to do the same in the future.

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