Hydrophobe VII *7th International Conference on*
Water Repellent Treatment and Protective Surface Technology for Building Materials
A.Elena Charola and J. Delgado Rodrigues, Editors
LNEC (Laboratório Nacional de Engenharia Civil), Lisbon: 2014 (235-240)

Life cycle cost analysis on impregnated bridge edge beams

Otto During
CBI Swedish Cement and Concrete Research Institute
Stockholm, Sweden, otto.during@cbi.se

Katarina Malaga
CBI Swedish Cement and Concrete Research Institute
Stockholm, Sweden, katarina.malaga@cbi.se

SUMMARY: The aim of this study is to perform a life cycle cost analysis (LCC), where the economic cost of extending service life by the impregnation of bridge edge beams is compared to the reparation of an edge beam. Earlier economic analyses on bridge edge beams have shown that there is no clear economic benefit to impregnate the edge beams. However, results from this study pointed out that in most cases there is a clear economic benefit to impregnate the bridge edge beams even if it has to be repeated every 15 years.

KEY-WORDS: LCC, impregnation, concrete, edge beams, maintenance

INTRODUCTION

On a yearly basis, the road authorities of the Nordic countries allocate vast budgets on the hydrophobic surface protection of reinforced concrete structures, e.g., bridges, in order to reduce the risk for chloride induced corrosion caused by the extensive use of de-icing salts during harsh winters. Despite this, there is no consensus concerning effectiveness of the impregnation and its impact on the financial benefits of the maintenance process. On behalf of the Swedish Road Administration, CBI has performed an LCC study on the economic validity of impregnating bridge edge beams. The study includes a literature review, interviews with contractors and the road administration staff. The calculations are performed using an LCC including community costs.

LIFE-CYCLE COST ANALYSIS

Edge beam replacement and water repellent (WR) impregnation have been compared in this analysis and no other possible alternatives have been considered, i.e., the use of stainless steel reinforcement. Traffic delays are limited to the range of 50 to 2000 hours/m of edge beam. The discount rate is only estimated at 3.5% [1]. The costs of edge beam replacement(s) are calculated between 610 and 1780 €/m of edge beam. WR impregnation costs varied between 22 and 44 €/m of edge beam (e.b.).

The total cost (Ct) for a new edge beam on a new bridge is calculated for a service life of 120 years and amounts to the sum of costs for impregnation [Ci], the cost of traffic delays [Cd] and the cost of replacing the beam [Cr]. The present value of a future cost is calculated using Equation 1:

Present value = Cost in today's value / (1.035^{years})   Eq. 1

Functional unit

All costs are calculated per meter of edge beam (€/m e.b.)

Impregnation

Cost for impregnation (Ci)

With the help of the answers from various contractors to questionnaires, it was found that the impregnation cost lies between 5.50 - 55 € /m e.b. Accordingly, in this study, we applied 22 € /m e.b. and performed a sensitivity check using 44 € /m e.b.

Frequency of impregnation

According to the contractors, impregnation of a structure is performed every 10 or 20 years. In this study, the average value corresponding to 15 years was used.

The enquired contractors gave varied information concerning the optimum time for the first impregnation after bridge construction time. The answers indicated that some contractors did the impregnation directly after the construction and some up to five years after the structure was built. It was therefore assumed that the first impregnation was effectuated 6 months after casting to allot the concrete sufficient curing time and thereby reduce its moisture content (internal relative humidity).

The effects of impregnation

The effects of impregnation on concrete were taken from a previous study [2].. Impregnation of a dense concrete structure, w/c ratio 0.40 with only slight cracks and successful casting of the edge beam, gives a 70% decrease in chloride penetration. The impregnation of a structure (w/c greater than 0.40) results in an estimated 95% reduction of chloride penetration.

Edge beam replacement

Cost for edge beam replacement (Cr) can be estimated according to two possible alternatives (Fig. 1):

Alternative 1 Cr = 610 €/m e.b.   (suggested by contractor) [3].

Alternative 2 Cr = 1780 €/m e.b. (suggested by Swedish Road Administration) [4]

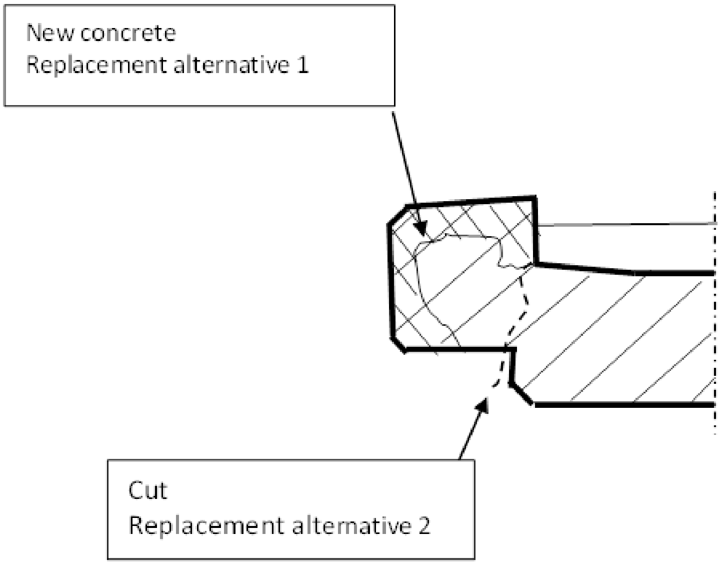

Figure 1. Edge beam replacement.

Edge beam service life

In practice, new edge beams have a longer service life than old edge beams due to enhanced concrete quality in new constructions. According to the current Swedish requirements for quality of concrete, valid since 1994, the w/c ratio must not exceed 0.40. Prior to that, the requirements from 1979 allowed w/c below 0.45. Before 1979, many bridges in Sweden were built with a concrete having a low resistance to aggressive environments. Today the road administration schedules replacement for edge beams every 50 years for new bridges, which could be a slightly pessimistic approach due to previous failure experiences. In this study, however, for non-impregnated structures with w/c 0.40, a default lifetime of 60 years was selected, which is slightly longer than the normally scheduled time by the road administration. A sensitive check was carried out for a service life of 90 years.

Cost of traffic delays (Cd)

The cost for a traffic delay calculated per car is € 16 for a long term analysis. Replacement of edge beams requires that one traffic lane is closed for a month (30 days). The busiest road in Stockholm has four lanes in one direction. A 50 meter long edge beam replacement is estimated to affect 20,000 cars/day, losing 10 minutes/car, corresponding to a loss of time of 2,000 hours/meter edge beam which gives a total cost of 32,000 € /m e.b. The impregnation is carried out at night and provides only small delays in traffic. The estimated delay is 1 hour per impregnated meter edge beam which corresponds to a cost of 16 €/m e.b.

Environmental costs (Ce)

The cost of 1 kg of CO_2 is assessed at 0.16 €/kg CO_2 according to The Swedish Road Administration [1]. A traffic delay of 1 hour is expected to cause an increased fuel consumption of 0.5 l gasoline. CO_2 emissions from 1 l of fuel amounts to 2.36 kg that corresponds to the climate impact 0.5 * 2.36 = 1.18 kg CO_2/ hour by direct emissions from a vehicle. This gives a cost of 0.19 €/hour which is only a little more than one percent of the cost of the delay. The effect is therefore considered insignificant.

Scenarios for a new bridge through Stockholm

Edge beam replacements:

- Edge beam/bridge length : 50 m
- Lanes in one direction : 4
- Time for Edge Beam replacement : 30 days
- Designed service life for the bridge : 120 years
- Designed service life for the edge beam: 60 years
- Delay : 2000 hours/m e.b.
- Type of replacement : Alternative 1

Edge beam impregnation:

- Year of impregnation : 0, 15, 30,45,60,75,90,105
- Designed service life for the bridge : 120 years
- Delay : 1 hour /m e.b., impregnation
- Specific cost for impregnation : € 22 /m e.b., impregnation

Sensitivity check

- Edge beam replacement after 90 years.
- Edge beam replacement type 2.
- Only 20 % of edge beams have to be replaced. (This calculation is a large scale approach where one of five bridges need beam edge replacements during the bridge service life.)
- Specific cost of impregnation is doubled to 44 €/m e.b., impregnation.

RESULTS

The variable that is most important for the outcome, which is both difficult to determine and could differ for different projects, is the traffic delay caused by the bridge replacement. Therefore, the delay for bridge edge beams replacement has been shown as a variable in Figure 2. For the chosen example of Stockholm, the calculated reference delay is 2000 hours/m e.b. and it is very clear that the impregnation alternatives have lower costs than any of the replacement alternatives. There is an economic advantage of impregnation even if there is only a 20% risk of damages leading to the beam replacement in a period of 60 or 90 years. Even if the delay for bridge edge replacement is overestimated four times and the real delay is 500 hours/m e.b., there is still a clear economic advantage for the impregnation alternative. The diagram can be used for bridges in small cities. The calculated delay for a bridge edge beam replacement is 250 hours/m e.b. for a small city. The diagram shows that there is still an economic advantage for most cases. The only case where this theory is not valid is when a 20% risk for edge beam replacement occurs after 60 years, where the cost for impregnation would be higher.

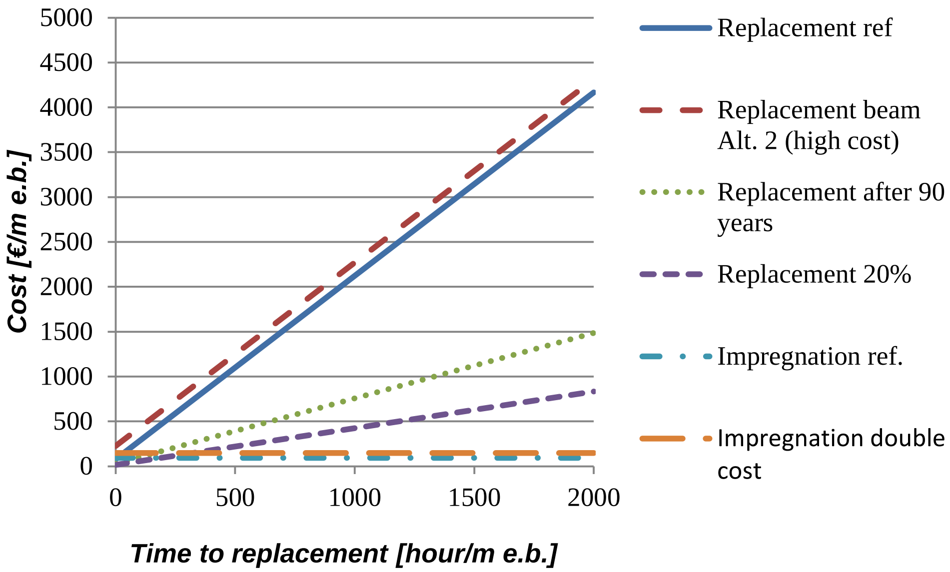

Figure 2. Increase of cost due to maintenance delay.

DISCUSSION

The objective of the study was to highlight the importance of long term planning for a society with a functioning infrastructure. The investments which need to be carried out in the future estimated via a life cycle cost analysis shows very low costs. A cost of a million euros (€1,000,000) for 90 years into the future, with a depreciation rate of 3.5%, corresponds to a present value of €45,000. However, in this study, the future cost for delays is so high that it is the dominating cost.

The application and knowledge of delay costs is not new, but it is mostly ignored when we, in the concrete industry, compare the costs of different maintenance alternatives. Organizations with responsibility for maintaining often look at the budget when they do an investment cost analysis but the link between the maintenance budget and delay costs is very weak. For the implementation of this type of calculation, a more comprehensive picture of a sustainable infrastructure and how it interacts with the rest of the society is needed. Programs supporting sustainable development are essential to highlight these types of studies.

It should be noted that the costs for delays are still underestimated in this study since the delay costs for goods and heavy traffic are not included.

The frequency of the impregnation (15 year) is higher than required if good conditions for impregnation could be guaranteed. The high frequency of impregnation could be motivated by the fact that in practice the weather and concrete conditions are normally not optimal for impregnation.

REFERENCES

[1] THE SWEDISH ROAD ADMINISTRATION. 2012. *Socio-economic principles and calculation values for the transport sector*. TRV68384

[2] SELANDER, A. 2010. *Hydrophobic impregnation of concrete – effects on concrete properties.* Doctoral Thesis, Chair of Structural Design and Bridges, Department of Structural Engineering, School of Architecture and the Built Environment, Royal Institute of Technology, Stockholm. TRITA-BKN Bulletin No. 104.

[3] LUNDGREN, D. 2013. *Costs for beam edge replacement alt 1*. Internal report. CBI Betonginstitutet.

[4] MAGLICA, A. 2013. *Costs for beam edge replacement alt 2*. Internal report. The Swedish Road Administration.