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# Comparative Life-Cycle Analysis of Two Repair Measures for Chloride Contaminated Concrete Structures

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## 1 Introduction

Chloride-induced corrosion require maintenance actions as major reason for structures deterioration. The standard (EN 1504-9) provides several repair principles for chloride-contaminated concrete structures with the aim to stop and to prevent reinforcement corrosion. The demand of maintenance and repair of reinforced concrete structures will increase tremendously in the upcoming year. We need a further look on their sustainability to support the decision-making of choosing an adequate repair principles and corresponding repair method. The aim is to evaluate the category indicators when applying cathodic protection and concrete replacement as repair measure.

## 2 Case Study

The objective of the life-cycle assessment of two different repair measure is to support future decision-making for the most sustainable repair measure. Secondly, the study aims to identify missing data we need to collect in future to enable comprehensive sustainability analysis of repair measures.

The functional unit for the sustainability assessment of repair measures is a very common constructive element: one square meter of reinforced concrete plate. This plate could be e.g. part of a bridge superstructure or part of a multi-storey car park. Consequently, the functional unit is exposed to chlorides from de-icing salts in combination with cyclic wetting and drying. The designed service life was 75 years with a target reliability index of 0.5. First, a probabilistic service life prediction assists the decision making to estimate when and how often the functional unit needs repair actions. Even though, the durability design of the functional unit complies with the standards the target reliability of $\beta = 0.5$ is reached after around 40 years.

The most common repair measures of chloride-contaminated concrete are based on the Principles 7 and 10 (EN 1504-9). Therefore, the life-cycle assessment includes one repair method from both principles: (i) 7.2: substitution of the chloride-contaminated concrete and (ii) 10.1: application of an electric potential

The installation of the CP systems with ribbon anodes takes place earlier in a service life than the replacement of the chloride-contaminated concrete. The reason for that is that the CP system can only be applied when the corrosion damage is not in an advanced stage showing cracks and spalling of the concrete cover. Therefore, the timing of the CP installation is set when the reliability index is 1.3 (corrosion probability 10 %) after 11 years. Every 20 years, in total for two times, all electronic components will be renewed. In contrast, the time of the concrete replacement corresponds to the time when the target reliability is reached after 40 years. It is assumed that the new concrete shows the same chloride penetration resistance as the former one. Therefore, the repair measure takes place only once until the end of the designed service life of the structure.

The software package SimaPro (Version 8.4.0.0) with the underlying databases of ecoinvent (Version 3) supported the evaluation of this LCA study using the CML-IA baseline method. In all three categories, the cathodic protection system shows greater impact on the environment than the concrete replacement measure considering a service life of 75 years. The greatest difference between both repair measures is in the global warming potential. Here, the impact of the CP systems is more than twice the level of the concrete replacement. The reason for this difference is the impact of the replacement (production and disposal) of the electronic components for the cathodic protection system with a value of 158 kgCO2eq. The highest impact on the global warming potential within the concrete replacement has the removal of the old concrete using ultra-high water pressure jetting with a value of rd. 62 kgCO2eq.

The same dependencies apply for the abiotic depletion. Here, the impact of the CP systems is much greater due to the production of the electronic components with a value of 586 MJ. Again, the ultra-high water pressure jetting during concrete removal has major impact on the abiotic depletion of the concrete replacement. The difference between both repair measures is less pronounced considering the ozone layer depletion.

# 3 Conclusions

The following conclusions can be drawn from this specific comparative LCA of the concrete repair measures concrete replacement and cathodic protection.

- The environmental impact of the cathodic protection system is greater than the impact of the concrete replacement when comparing the category indicators global warming potential, abiotic depletion and ozone layer depletion.
- Even though, the concrete replacement consumes much higher quantity of energy-intensive concrete it is not necessarily the repair measures with the greatest impact on the environment.
- The high environmental impact of the cathodic protection system is the result of its demand of multiple electronic components.
- The service life of the electronic components is the determining factor of the sustainability of the cathodic protection system.

More generally, more field data on the durability of concrete replacement is required to enable reliable assumptions on repair intervals.

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