# ABSTRACT

Title: Service Life Prediction and Economic Evaluation of Concrete Treated by a Compound Penetrant in Marine and Severe Cold Environment

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[Abstract]

At present, many infrastructures face the phenomenon of ageing year by year, and more and more infrastructures need to be maintained and updated. How to effectively and economically prolong the service life of concrete in harsh service environments is a significant issue facing our engineers today. It is also the obligatory social responsibility of our professionals. This thesis studies the maintenance effect of a group of composite penetrants applied to the concrete surface. First, through indoor experiments, the influence of impregnants on the performance of concrete was studied. Secondly, through the follow-up study of the actual project, Tomakomai Dam, for nearly 20 years, the dynamic evaluation of the application of this group of composite impregnants in the cold ocean environment was carried out. Moreover, its life span and economy are estimated.

This set of composite impregnation is composed of two impregnants: a sodium silicate solution applied on the surface of the concrete as the bottom layer and a silane solution applied on the sodium silicate solution as the upper layer.

① Concrete surface water absorption, air permeability, pH, surface micro-pore size distributions, and the anti-salt freezing-thawing properties of concrete after applying the impregnating agents were conducted indoor experiments. The results show that: Compared with the untreated groups after applied the impregnants, the concrete surface: The surface water absorption is significantly reduced by 60.97%;

② The air permeability is almost unaffected. When the concrete surface water content decreases slightly, there is even a slight tendency to increase;

③ pH increases at the time of testing (390 days after the test block is formed, about 330 days after the impregnant is applied) ;

④ The distribution of the pores in size range of 400-1000nm in the surface layer (0-10mm) is significantly reduced in the $12^{th}$ year;

The composite impregnants can make the concrete surface denser and form a hydrophobic film on the surface of the concrete. The hydrophobic film has water-blocking and air-permeable properties. The dosage of composite impregnant was studied, and a reasonable dosage of penetrant was proposed according to the quality conditions of concrete: the water absorption of concrete is low before treatment (surface water coefficient is ≤ 0.12

(ml/m$^2$/s)). When the quality is good, the dosage can be 50% of the recommended dosage.

In the 3rd, 12th and 20th years after the construction of Tomakomai, core samples from the part of Tomakomai project treated with impregnant and the comparison part where the impregnant is not applied were taken. The samples were delivered to the laboratory for the following experiments: carbonization depth determination, chloride ion diffusion, pH measurement, concrete surface micropore size measurement (MIP), freeze-thaw and freeze-thaw experiments after retreated. Based on the data from the above tests, the life expectancy of Tomakomai was calculated, the selection and economic of maintenance plans and was analyzed.

Through deterministic calculation method, probability and reliability method and Monte Carlo method, the life of Tomakomai dike under carbonization, chloride erosion and freeze-thaw cycles was calculated, respectively. The results show that:

① In the marine environment, applying this set of impregnants on the concrete surface will shorten its life by about 70% under carbonization erosion. However, the progress of concrete carbonization is slow. When the concrete cover thickness reaches 50mm, the carbonization life of the treatment concrete can reach up to 170 years which is generally longer than the concrete designed target life.

② The impregnants can effectively reduce the corrosion of chloride ions and extend the life of concrete in this situation to 1.1-3.5 times the group without treatment.

③ In the 20th year, the alkalinity of the treated concrete surface is lower than that of the untreated group, and It is consistent with the conclusion that the concrete life is shortened by applying penetrants under the carbonization environment.

④ In the cold ocean environment, concrete life is determined by the deterioration of the salt-freezing-thawing. Therefore, although the impregnating agents on the concrete surface will lose part of the carbonization life, it is helpful to extend the concrete life in the salt-freezing-thawing erosion environment and finally extend the actual concrete service life.

⑤ The calculation also shows that the construction quality related to the thickness of the concrete protective layer has a significant impact on the life of the concrete. If the construction quality improves, the probability of the concrete cover construction deviation of 10mm is reduced from 15% to 5%; the guaranteed rate is increased from 85% to 95%, the life under chloride ion attack can be extended by 10%, and the concrete carbonization life will be significantly improved. When the concrete cover is more than 20mm (30mm in the treatment groups), when the guaranteed rate is increased by 10%, the total carbonization life of the concrete can be prolonged by an average of 37 years. The untreated groups are slightly longer than the treatment groups.

⑥ Different impregnating agents should be used for concrete under different service environments. As far as the conclusions of this article are concerned: Impregnant used in this study significantly improve the resistance of concrete to chloride corrosion and freeze-thaw deterioration, but it is not conducive to the resistance to carbonization. Therefore, they are not suitable for the dry and warm environment easily corroded by carbon dioxide.

⑦ The pore size larger than 1000 nm distribution of the concrete surface layer is small at the 12th year. However, It increased a lot in the 20th year with the passage of service years, indicating that the effect of the impregnants is gradually weaker by year.

⑧ The re-application of the compound impregnants can delay the appearance time of concrete rapid scaling for about 20 to 65 cycles under salt-freezing-thawing (ASTM-C 672) erosion in indoor experiments.

⑨ The use of composite penetrant maintenance before the scaling depth reaches 2.5 mm can effectively reduce the life cycle cost by at least 50%. Fortheinfrastructures treated with composite penetrant in the construction year, the secondary maintenance time should be ≤33 years. For the infrastructures without maintenance in the construction year, the maintenance interval should be ≤17 years. The impregnant can make the concrete "freeze age" for 17 years.

⑩ The calculation also shows that the construction quality related to the thickness of the concrete protective layer has a significant impact on the life of the concrete. If the construction quality improves, the probability of the concrete cover construction deviation of 10mm is reduced from 15% to 5%; the guaranteed rate is increased from 85% to 95%. At this time, the concrete carbonization life will be significantly improved. When the concrete cover is more than 20mm (30mm in the treatment groups), when the guaranteed rate is increased by 10%, the total carbonization life of the concrete can be prolonged by an average of 37 years. The untreated groups are slightly longer than the treatment groups.

Among the three concrete life calculation methods, the Monte Carlo method is recommended. This method not only considers the random distribution characteristics of the calculated parameters and the failure probability of the material but also has a high degree of computerization, and the calculation speed and calculation accuracy are also more excellent than the other two methods.

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