# A STUDY ON APPLICATION OF DEEP LEARNING ALGORITHM FOR THE PREDICTION OF CARBONATION RATE COEFFICIENT OF THE UNDERGROUND CONCRETE STRUCTURES

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論　文　名：A STUDY ON APPLICATION OF DEEP LEARNING ALGORITHM FOR THE PREDICTION OF CARBONATION RATE COEFFICIENT OF THE UNDERGROUND CONCRETE STRUCTURES

( 地下コンクリート構造物の中性化速度係数の予測に対するディープラーニングアルゴリズムの適用に関する研究)

区　　分　　：甲

# 論 文 内 容 の 要 旨

The Power Cable Tunnel (PCT) and Utility Tunnel (UT) are important non-transport infrastructures installed underground to accommodate electricity, water and sewerage, gas, and telecommunications facilities. Most of the PCT and UT are Reinforced Concrete (RC) structures, and their deterioration is intensified due to the increase in duration of use. As a result, the repair and reinforcement costs have been increasing rapidly, which leads to difficulties in maintenance. In general, carbonation of concrete is known to be a major cause of durability deterioration for the PCT and UT. The rate of carbonation should be predicted using a reliable model that considers the materials and mix proportions of concrete and the environmental conditions under which the structure is in service. However, there is an insufficient data on that, and it is difficult to accurately present carbonation prediction models for each structure. This study aims to develop a model that predicts the carbonation depth on the existing underground RC structures, such as the PCT and UT, which have been aging in Korea for maintenance. This dissertation consists of a total of 9 chapters.

**Chapter 1** explains the background of this research, problem statement, research objective and limitation, research contribution and novelty, and dissertation outline.

**Chapter 2** describes the carbonation mechanism and the carbonation influencing factors which are summarized by reviewing various types of literature related to carbonation of concrete. In addition, a lot of techniques for the prediction of concrete carbonation and carbonation prediction models proposed were reviewed.

**Chapter 3** provides status of data collection on the carbonation. The results of Non-Destructive Testing (NDT) such as concrete carbonation test and concrete rebound hardness test are extracted from the precision safety diagnosis. Total span lengths on the existing underground structures to be collected for this study are 143 km for the PCT and 104 km for the UT. In addition, environmental characteristics such as temperature, humidity, and $CO_2$ concentration during normal operation of the PCT and UT were investigated. The environmental characteristics of the PCT and UT depend on the local as well as the performance of ventilation system of underground structures. Therefore, it is clarified that consideration of regional characteristics is necessary when predicting the carbonation rate of underground structures.

**Chapter 4** provides data analysis and probabilistic approach to carbonation rate of the PCT and UT. The carbonation rate coefficient of the PCT and UT were in the range of 0.017 ~ 5.774 mm/√year and

0.080 ~ 11.612 mm/√year, respectively. The analysis of probability for carbonation by region of the PCT showed that at 50 % and 95 % of the Cumulative Distribution Function (CDF) $F(x)$, the carbonation rate coefficient was in the range of 0.249 ~ 2.195 mm/√year and 0.485 ~ 4.123 mm/√year, respectively. For the UT, the ranges were 1.000 ~ 3.233 mm/√year at 50 % of the CDF $F(x)$ and 1.532 ~ 6.589 mm/√year at 95 % of the CDF $F(x)$. As a result of the analysis of the carbonation status, it was found that the carbonation depth dispersion is large enough to be difficult to characterize the pattern, unlike the test result of the limited laboratory.

**Chapter 5** describes the uncertainty measurement for the probability distribution of carbonation rate coefficients of the PCT and UT by region estimated using the principle of maximum entropy that is a method of maximizing and quantifying uncertainty based on this given information. As a result of measuring the uncertainty of carbonation rate coefficient due to entropy, in order to improve the reliability of the statistical estimation, it could be necessary to supplement the randomness on the probability distribution of carbonation rate coefficient for the PCT in Incheon and the UT in Busan.

**Chapter 6** proposes multiple linear regression models for predicting the carbonation rate coefficients of the PCT and UT. The multiple regression analysis was used to quantitatively analyze the relationship between the variables and the carbonation rate coefficient to find out how the selected characteristic variables influence the carbonation rate coefficients of the PCT and UT. The adjusted coefficient of determination ($R_a^2$) of the multiple linear regression model is 67.03 %. The explanatory powers of the multiple linear regression models presented for the estimation of carbonation rate coefficients of underground structures were found to vary by structure and region.

**Chapter 7** presents the Deep Neural Network (DNN) model for prediction of carbonation rate coefficients on the PCT and UT. The DNN model considering the features such as structures classification, region classification, construction type, measurement location, member parts of structures, and concrete strength of the PCT and UT using deep learning algorithm was developed to predict the carbonation rate coefficient of underground structures. The DNN model with more explanatory power was developed by using nonlinear coupling between input characteristics for carbonation rate coefficient prediction. Sensitivity analysis depending on hyper-parameter such as batch size, epoch condition, and optimizer was performed. In the optimal DNN model for prediction of carbonation rate coefficient of underground structures, the explanatory power of $R^2$ is 82.48 %.

**Chapter 8** examines the validity of the prediction results before the practical application of the developed carbonation rate coefficient prediction DNN model. Additionally, the plan was established to apply the DNN model developed for the prediction of the carbonation rate coefficient of underground structures. In order to predict the carbonation rate coefficient of underground structures such as PCT and UT, the predicted performances of the proposed model and the existing specification model were compared. As a result of predicting carbonation rate coefficient by prediction model, the DNN model's explanatory power on the PCT was 72.17 ~ 86.26 % according to region and on the UT was 76.53 ~ 91.95 % by region, showing significant regression performance.

**Chapter 9** conveys a summary of the study, overview of contributions and conclusions, and recommendation for research work in the future are presented.