

박스형 전력구의 콘크리트 탄산화에 의한 잔존수명 예측

Estimation of Carbonation and Service Life of Box Culvert for Power Transmission Line

우 상 균¹⁾ 이 윤^{2)*} 이 성 태³⁾
Woo, Sang Kyun Lee, Yun Yi, Seong Tae

Abstract

The construction of underground structures such as box culverts for electric power transmission is increasing more and more, and the life extension of these structures is very important. Carbonation-induced corrosion in concrete may often occur in a high carbon dioxide environment. In this study, the risk of carbonation of two concrete box culverts in an urban area was evaluated by measuring the carbonation rate and concrete cover depth. Then, the carbonation-free service life at the depth of the steel was calculated, based on in situ information, by the Monte Carlo simulation. The service life of box culvert due to carbonation was estimated over 250 years via Monte Carlo simulation.

Keywords : Monte Carlo simulation, Box culvert, Carbonation, Service life, Concrete cover

1. INTRODUCTION

Box culverts for electrical power transmission began to be constructed in the mid-1970s in Korea and are increasing in numbers recently due to power demand growth and underground installation of transmission lines. The amount of related maintenance work also continues to increase because of the increasing usage life of the constructed box culverts. Corrosion of steel due to carbonation usually occurs particularly in an urban area which has a high level of carbon dioxide, emitted from vehicles and industrial factories. Carbonation can be defined as the chemical reaction between carbon dioxide present in the air and cement hydration products such as mainly calcium hydroxide and the CSH gel phase, which results in the formation of calcium carbonate. Thus, the risk of carbonation is more severe in urban or/and industrial area. Carbonation of concrete itself does not do harm in view of the performance of structure, adversely a marginal enhancement of the

compressive strength was observed. However, when carbonation reaches at the depth of the steel, the high alkalinity of the concrete pore solution is neutralized and hydration products are dissolved then to lower the buffering capacity of hydrations against a pH fall. At this moment, the passivation layer on the steel surface, which otherwise would protect the steel embedment from a corrosive environment, is destroyed, and steel is directly exposed to oxygen and water, eventually to corrode

2. METHODOLOGY

2.1 Description of Carbonation Process

The limit state function is useful to render the risk/resistance of concrete carbonation, as being expressed into two parts: the resistance to carbonation and the carbonation risk, as given in Eq. (1).

$$g(t) = R(t) - S(t) \quad (1)$$

1) Senior Researcher, Korea Electric Power Research Institute (KEPRI)
2) Assistant Professor, Civil Engineering, Daejeon University
3) Professor, Civil and Environmental Engineering, Inha Technical College

* Corresponding author : yunis@dju.ac.kr 042-280-2525

• 본 논문에 대한 토의를 2012년 8월 31일까지 학회로 보내주시면 2012년 9월호에 토론결과를 게재하겠습니다.

where $R(t)$ and $S(t)$ denote the carbonation resistance (concrete cover depth), and the carbonation risk (carbonation depth) with time.

The carbonation depth is usually calculated as a function of time, as given in Eq. (2), with the carbonation coefficient encompassing the concrete quality and the environmental conditions.

$$x(t) = K\sqrt{t} \quad (2)$$

where $x(t)$ is the depth of carbonation, K for the carbonation coefficient and t for time of exposure to the atmosphere.

2.2 Monte Carlo Simulation

The safety factor method and the Monte Carlo simulation are representative techniques in modelling the risk of carbonation. However, for the safety factor method in predicting the risk of carbonation, the safety factor was not rationally determined with the reliability index in previous studies. The safety factor has been usually derived from an engineering judgment rather than calculated from in situ information, in order to compensate for the variance of the parametric values such as carbonation rate and concrete cover depth, which might happen arising from the difference in construction environments and construction quality. The safety factor has been conventionally regarded as being 1.2 in some standards and guidelines. Furthermore, the distribution type for the parametric values, although the carbonation rate and concrete cover depth are obtained from the corresponding in situ examination, is always determined to the normal distribution only, possibly leading to an error in calculating the safety factor. Thus, it can be said that the carbonation-free service life predicted by the safety factor method might be less convincing. The Monte Carlo simulation requires a number of empirical measurements from a field in terms of the average value and the standard deviation of the parametric values, in order to

validate its probabilistic prediction.

Unlike the safety factor method, the carbonation resistance and risk factors are not required, when the probabilistic method is used, to consider the variance of the experimental information including the carbonation depth and concrete cover depth. Instead, the simulated deviation of the parametric values is taken into account in determining the carbonation resistance and risk. In the present study, the Monte Carlo simulation technique, as a probabilistic way, was used to assess the carbonation risk. For the simulation, mean value and standard deviation of the parametric values (i.e. carbonation depth and concrete cover depth) were obtained from underground field investigation. Then, 100,000 of random samples for the parametric value were generated by the Monte Carlo simulation. The probability for carbonation to reach the depth of the steel can be calculated from the 100,000 random trials and is defined as the ratio of the number of carbonation, calculated by Eq. (1), at the depth of the steel to the number of total trials, as given in Eq. (3).

$$P_t = n(g(t) < 0) / N \quad (3)$$

where P_t is the probability of carbonation at the depth of the steel and $n(g(t) < 0)$ denotes the number of carbonation at the depth of the steel out of N trials (100,000 trials in this study).

3. FIELD AND INDOOR INVESTIGATION

Two concrete box culverts in Kayang and Kwacheon in Seoul, as typically shown in Fig. 1, were examined for carbonation after 18 and 16 years, respectively. The concentration of carbon dioxide in the box culvert reached 508 ppm in Kayang and 629 ppm in Kwacheon, respectively.

Prior to measuring the carbonation depth, the concrete cover depth to the steel was measured using an ultrasonic cover meter in 84 points. After measuring the cover depth, 84 concrete core specimens



(a) in Kayang



(b) in Kwacheon

Fig. 1 Typical Box Culvert for Power Transmission

were drilled out for durability test including carbonation depth investigation. In order to avoid further carbonation of the core specimen in later experiment, each specimen was sealed with plastic wrap up to indoor test. By splitting cylinder specimen in the laboratory, carbonation depth was measured in each specimen.

The measurement was done with a phenolphthalein pH indicator (i.e. <10 in the pH) to determine the carbonation depth. The carbonated concrete parts were not changed in color, whereas the sound ones turned purple by the indicator, as shown in Fig. 2.

In this study, box culvert for power transmission in the metropolis was examined in terms of the risk of carbonation. Carbonation depth was examined with 17 core specimens using phenolphthalein indicator.

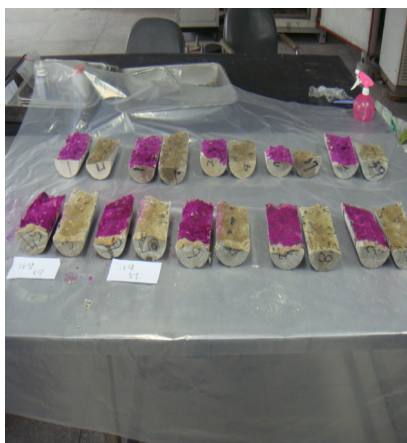


Fig. 2 Carbonation Test with Phenolphthalein

The concrete cover depth and carbonation depth measured are given in Figs. 3 and 4, respectively

The concrete cover depth measured ranged from 80 to 170 mm in Kayang, from 20 to 130 mm in Kwacheon, respectively. The distribution of the concrete cover depth was best fitted to the lognormal distribution, determined by the goodness-of-fit tests. The average of the measured cover depth was 118.9 mm in Kayang and 72.9 mm in Kwacheon, respectively. The standard deviation was high, ranging from 22 to 32 mm, meaning that the quality of construction for concrete cover was not good in many parts of the box culvert in casting concrete.

The distribution of carbonation depth was best fitted to the lognormal distribution likewise cover depth, and ranged from 2 to 38 mm. Carbonation depth on average accounted for 19.6 mm and 14.2 mm for Kayang and Kwacheon box culvert, respectively.

The distribution of carbonation rate was best fitted to the lognormal distribution likewise cover depth, and ranged from 0.5 to 10 mm/year^{0.5}. Carbonation rate on average accounted for 4.6 and 3.5mm/year^{0.5} for Kayang and Kwacheon box culvert, respectively.

4. Estimation of Service Life

The service life due to carbonation was calculated by the Monte Carlo simulation. Probability of corrosion

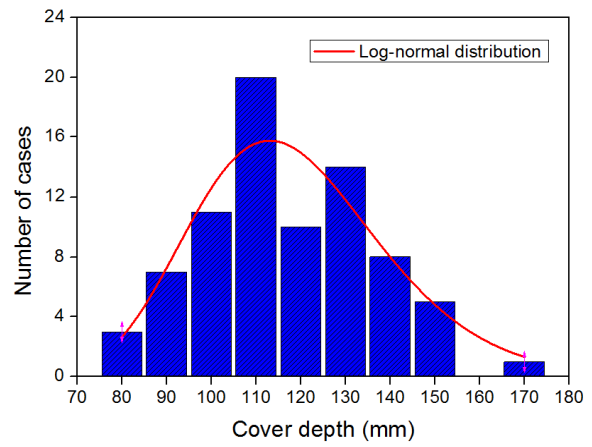
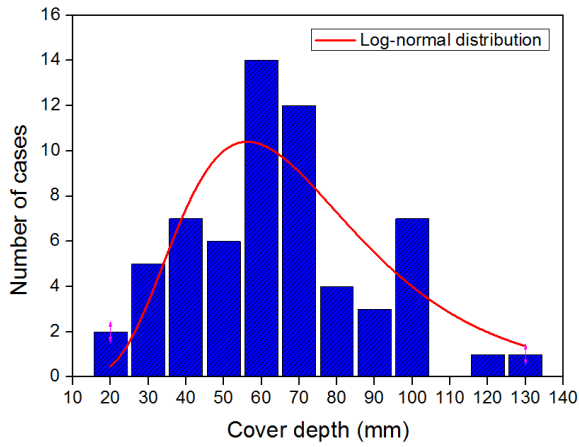


Fig. 3 Concrete Cover Depth Distributions

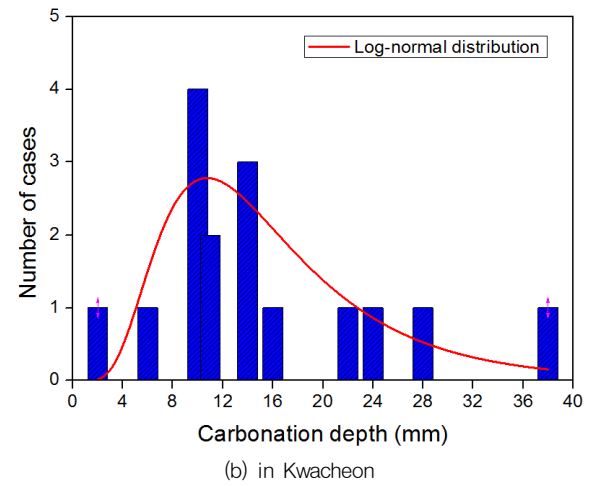
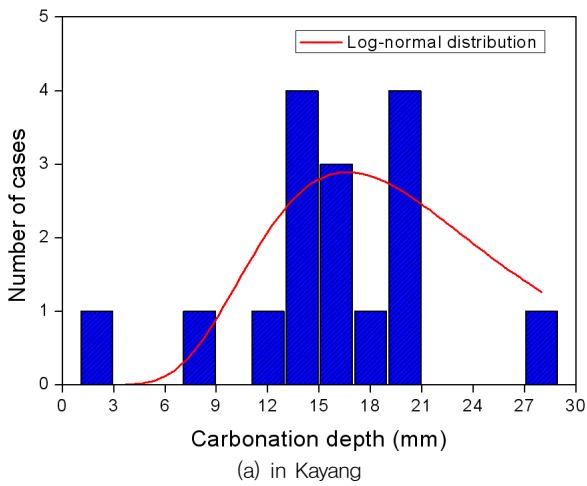


Fig. 4 Carbonation Depth Distributions

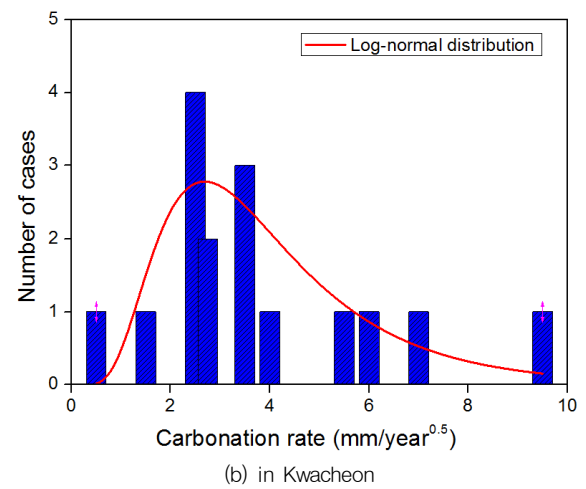
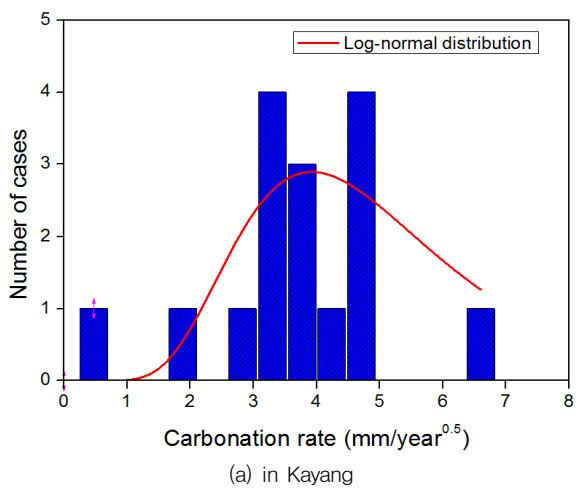


Fig. 5 Carbonation Rate Distributions

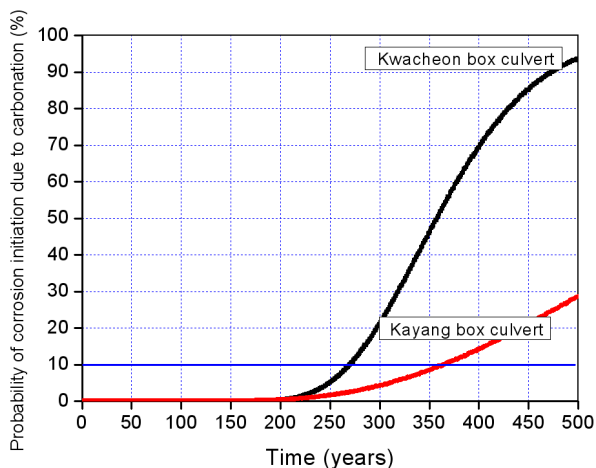


Fig. 6 Probability of Service Life Due to Carbonation Estimated by Monte Carlo Simulation

was dotted with an increment of 1 year of time as shown in Fig. 6. The variation in the concrete cover depth and the rate of carbonation was taken into account by producing 100,000 samples considering the lognormal distributions of the parametric values.

The service life of box culverts accounted for about 360 and 270 years for Kayang and Kwacheon box culverts, respectively, assuming that the limit state for carbonation at the depth of the steel is regarded as 10% of probability which is usually determined by engineers' preference. Despite of rapid carbonation rate of Kayang box culvert, it was seen that the service life of Kayang box culvert was about 90 years longer than Kwacheon box culvert due to the large cover depth up to 120 mm.

5. Conclusions

The research results of this study are as follows.

- (1) In this study, the risk of carbonation of two concrete box culverts in an urban area was evaluated by measuring the carbonation rate and concrete cover depth. Then, the carbonation-free service life at the depth of the steel was calculated, based on in situ information, by the Monte Carlo simulation. The service life

of box culvert due to carbonation was estimated over 250 years via Monte Carlo simulation. The service life of box culvert due to carbonation was estimated over 250 years via Monte Carlo simulation.

- (2) The distribution of the concrete cover depth and carbonation depth was best fitted to the lognormal distribution by the goodness-of-fit tests.
- (3) The service life of box culverts accounted for about 360 and 270 years for Kayang and Kwacheon box culverts, respectively, assuming that the limit state for carbonation at the depth of the steel is regarded as 10% of probability of steel corrosion.
- (4) It was seen that the service life of Kayang box culvert was about 90 years longer than Kwacheon box culvert due to the large cover depth up to 120 mm despite of rapid carbonation rate of Kayang box culvert.

Acknowledgments

This work (20101620100140) was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy.

References

1. ACI Committee 222, "Corrosion of metals in concrete", Manual of concrete practice, part 3, Detroit(USA): American Concrete Institute, 1994.
2. Aron B, Sidney D, Neal SB, "Steel corrosion in concrete", E&FN SPON, 1997, pp.120-35.
3. Klemm WA, Berger RL, "Accelerated curing of cementitious systems by carbon dioxide: part I, Portland cement", Cem Concr Res 1972, vol. 2, No. 5, pp.567-76.

(접수일자 : 2012년 4월 27일)
 (수정일자 : 2012년 6월 11일)
 (심사완료일자 : 2012년 6월 14일)

요 지

박스형 전력구와 같은 지하구조물의 건설은 점점 증가하고 있는 추세이며, 지상구조물에 비해 보수 및 재시공이 어려운 지하구조물의 수명 연장은 매우 중요한 문제로 대두되고 있다. 콘크리트 구조물에서 이산화탄소에 노출된 환경에서 발생하는 탄산화는 콘크리트 내부의 철근을 부식시켜 수명을 저하시키는 요인이 된다. 이 연구에서는 도심지의 두 박스형 전력구에 대한 탄산화 깊이를 측정하여 탄산화에 의한 내구성을 평가하고, 탄산화 측정결과를 바탕으로 몬테카를로 시뮬레이션 기법을 통해 철근의 부식 시기를 예측하였다. 탄산화에 의한 기존 도심지의 두 박스형 전력구의 사용수명은 250년 이상으로 예측되었다.

핵심 용어 : 몬테카를로 시뮬레이션 기법, 박스형 전력구, 탄산화, 사용 수명, 콘크리트 피복
