PRACTICAL APPLICATION OF A MODEL IN THE PREDICTION OF CONCRETE CARBONATION IN REAL-LIFE STRUCTURES

Kanazawa Institute of Technology, Student Member, ○Zulu Wanzi Alphacy
Kanazawa Institute of Technology, JSCE Member, Shinichi Miyazato

1. INTRODUCTION

Carbonation-induced corrosion has started to attract attention in the 21st century due to the increase in global temperatures and CO_2 concentration in the atmosphere [1] and it has become one of the critical problems that affect the durability of RC structures [2] most especially in areas away from the coast. In this study, a model was used to make predictions that were in turn compared to actual measurements done on real-life RC structures for its practical application and engineering accuracy.

2. METHODOLOGY AND ANALYSIS

To ascertain a meta model's practical application and engineering accuracy, data from literature [1] [3] on concrete carbonation of real-life RC structures, RC design standards and specifications (IS 456l:2000, EN1992-1:2004, BS8500-1:2006, EVS/EN206-1, NBR 6118, ACI 211.1-91 and JGJ-2011) including climatic/environmental conditions shown in Tables 1 and 2 in locations of real-life RC structures were used. Based on a new meta-model, whose details are given in [4], Eq. (1) was applied to predict carbonation coefficients using values in Table 2.

$$K = \sqrt{\frac{2Dco_{2.}[co_{2.}]external}{a}} \tag{1}$$

where K is carbonation coefficient ($m/s^{0.5}$), $Dco_{2.}$ is CO_2 diffusion coefficient (m^2/s), $[co_{2.}]external$ is CO_2 concentration in the air (kg/m^3) and a is amount of CO_2 required for complete carbonation (kg/m^3).

While Eq. (2), based on the most widely used relationship between carbonation depth (C_t) and concrete age(t), carbonation coefficients, K [1]were obtained using actual data measurements on real-life structures. Actual data measurements for RC structures in Brazil shown in table 3, were used to estimate the average carbonation coefficient which was then compared with that obtained from a meta-model. The above procedure was applied in comparing the values of carbonation coefficients obtained using equations (1) and (2) in this study.

$$C_t = K\sqrt{t} \tag{2}$$

where K is carbonation coefficient ($mm/year^{0.5}$).

Table 1 Environmental conditions and location of real-life structures under study [1] [3] [5].

Country - city	Temperature (°c)	Relative humidity (%)	Climate type	Coordinates
South Africa-Johannesburg	17	58	Tropical/subtropical	26.20S, 28.04E
India-Bhopal	26	57	Tropical/subtropical	23.16N, 77.26E
China-Taipei	23	77	Tropical/subtropical	25.11 N, 121.59E
South Korea-Seoul	17	67	Temperate	37.53N, 127.03E
Switzerland-Blenio	15	74	Temperate Alpine	46.45N, 8.95E
Estonia-Tallinn	7	83	Temperate	59.44N, 24.75E
Brazil-Brasilia	21	63	Tropical (wet/dry)	15.79S, 47.88W
Bangladesh-Dhaka	27	71	Tropical/subtropical	23.42N,90.22E

Table 2 Values adopted in meta-model coefficient prediction [3][6].

Country-city	Real life structure	a (kg/m^3)	$Dco_{2.}$ (m^2/s)	$[co_{2.}]external$ (kg/m^3)	Meta model K ($mm/year^{0.5}$)
South Africa-Johannesburg	Skyscraper/Building	115.37	$3.46x10^{-8}$	5.98E-04	3.28
	Bridges				
India-Bhopal	Concrete Structures	111.77	$4.43x10^{-8}$	6.60E-04	5.64
China-Taipei	Chon-Ching viaduct	105.69	$4.66x10^{-8}$	6.47E-04	3.58
	Wann-fwu bridge				
South Korea-Seoul	Train Bridge – sound concrete	115.37	$2.15x10^{-8}$	5.78E-04	2.60
Switzerland-Blenio	Main Building	108.16	$3.18x10^{-8}$	6.14E-04	3.37
	Gymnasium				
Estonia-Tallinn	Bridge Abutments	100.95	$6.0x10^{-9}$	4.07E-04	1.24
Brazil-Brasilia	Building Columns	109.96	$6.90x10^{-8}$	6.17E-04	4.93
Bangladesh-Dhaka	Various RC Structures	109.96	$4.58x10^{-8}$	6.42E-04	4.07

Keywords: Concrete, Carbonation Coefficient, Model Prediction, Measured Value, Worldwide
Contact Information: 7-1 Ohgigaoka, Nonoichi, Ishikawa 921-8501 Tel: 076-248-1100

© Japan Society of Civil Engineers

Table 3 Actual data measurement for RC buildings in Brasilia, Brazil[3].

Name of structure	Age t (years)	Concrete cover (mm)	Mean carbonation depth C_t, (mm)	Carbonation rate K ($mm/yr^{0.5}$)
AC- Aguas Claras Building	8	25 - 30	11	3.89
CK- Colina building	10		19	6.01
FS - Health school building	22		35	7.46
FA- Applied studies building	25		19	3.80
NC- Novacap building	33		20	3.48
EM - Monumental axle building	35		32	5.41
Average value				**5.01**

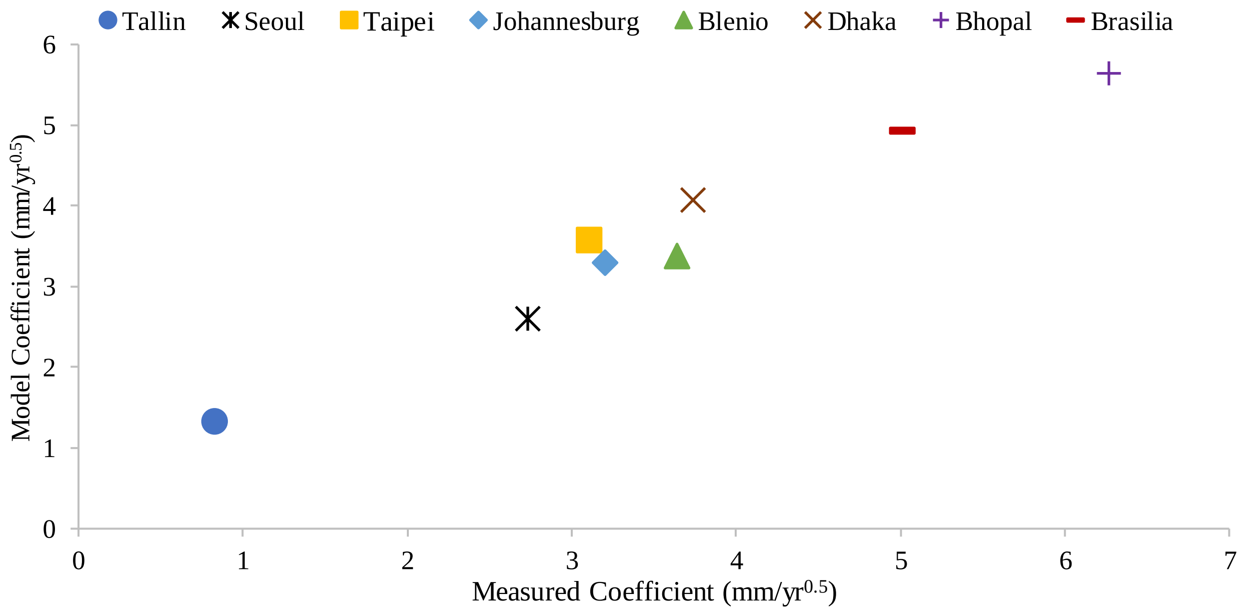

Fig.1 Carbonation coefficients comparison

In this study, ordinary Portland cement type CEM I, conforming to EN 197 standards, was used in model carbonation predictions and for uniform comparisons, measured data reported to have come from cracked/construction joint areas and structures containing slag in the cement used were not considered.

3. RESULTS

The results in figure 1, generally show a well-comparable trend of the coefficient values, with cities located in tropical/subtropical recording higher coefficients. The highest coefficients were in Bhopal city and the lowest in Tallinn city due to the higher temperature and CO_2 concentration in Bhopal. It was further observed that the difference in coefficient values between the measured and model are all less than 1$mm/yr^{0.5}$, with the highest in Bhopal at 0.62$mm/yr^{0.5}$, while the lowest was in Brasilia at 0.07$mm/yr^{0.5}$. This indicates a good agreement that the model predictions regarding concrete carbonation are reasonably accurate/reliable.

Based on the above comparison, the mode can be said to be within engineering accuracy and can practically be applied in the life cycle design and maintenance planning of reinforced concrete structures, particularly in inland tropical regions where carbonation is the most significant degradation mechanism.

REFERENCES

[1] T. U. Mohammed, M. N. Islam, A. Hasnat, and J. M. Khatib, 'Carbonation Coefficient of Concrete in Dhaka City Recycling of Finer Material Separated from Returned Concrete View project Effect of Impact loads on structures View project', 2013, Accessed: Dec. 08, 2022. [Online]. Available: http://www.claisse.info/Proceedings.htm
[2] Y. Zhou *et al.*, 'Carbonation-Induced and Chloride-Induced Corrosion in Reinforced Concrete Structures, 2014, doi: 10.1061/(ASCE)MT.1943-5533.0001209.
[3] S. O. Ekolu, 'Model for natural carbonation prediction (NCP): Practical application worldwide to real life functioning concrete structures', *Eng Struct*, vol. 224, Dec. 2020, doi: 10.1016/j.engstruct.2020.111126.
[4] V. L. Ta, S. Bonnet, T. Senga Kiesse, and A. Ventura, 'A new meta-model to calculate carbonation front depth within concrete structures', *Constr Build Mater*, vol. 129, pp. 172–181, Dec. 2016, doi: 10.1016/j.conbuildmat.2016.10.103.
[5] 'World Temperatures — Weather Around The World'. https://www.timeanddate.com/weather/ (accessed Mar. 15, 2023).
[6] 'Japan Meteorological Agency'. https://www.data.jma.go.jp/ghg/kanshi/co2map/co2map_e.html?yr (accessed Mar. 15, 2023).