Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Carbonation Coefficient of Concrete in Dhaka City

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ABSTRACT

Corrosion of steel bars in concrete is one of the major reasons for deterioration of concrete structures in Bangladesh. It is due to the use of low strength concrete for construction as well as poor quality control of materials during construction. A high carbonation rate of concrete is expected for concrete structures in Bangladesh that leads to corrosion over the steel bars in concrete in a short period of service life and subsequently results in early deterioration of concrete structures. No detailed studies have been conducted to estimate carbonation of concrete in Bangladesh. Therefore, this study has been planned to determine carbonation rate of concrete structures in Dhaka city.

For evaluation of carbonation depth in structural elements, such as beam, slab, and columns of real structures seventy buildings from Dhaka city were selected for investigation. The age of the structures was varied from 1 year to 79 years. Based on the relationship between carbonation depth and age of the structures, carbonation coefficient was determined for different structural elements. More carbonation depth was found in outdoor exposure condition compared to the indoor exposure condition. More carbonation rate was also found for slab compared to beams and columns.

Keywords: Coefficient of Carbonation, Carbonation, Concrete, Corrosion, Steel Bar.

INTRODUCTION

Carbonation induced corrosion is a major concern for durability of reinforced concrete structures in Bangladesh. Dhaka, one of the mega cities of the world, observed a very fast growth of urban population in recent time. As a result, CO_2 concentration is increased in air of Dhaka city. Recent study done by Ahmmed et al, 2010 showed that the concentration of CO_2 in air is exceeded 500 ppm in Dhaka city. The global warming phenomenon due to the increase in temperature and CO_2 concentration has been regarded as one of the most critical environmental problems in the 21st century (Yoon et al, 2007). Carbonation in concrete is a reaction between CO_2 in the atmosphere and calcium hydroxide in concrete, which is a major product of hydration of portland cement. The gaseous CO_2 does not react with calcium hydroxide, so the presence of water is essential; carbonation does not progress at the surface of concrete in contact with water containing dissolved CO_2 at very low or very high relative humidity. Indeed, the relative humidity of ambient air is a major factor influencing carbonation. The rate of carbonation is highest in the range of relative humidity of 50 to 70% (Neville, 2003). It was also found that higher rate of temperature also enhance the rate of carbonation (Moslehuddin, 1996). The monthly relative humidity and temperature chart of Dhaka city is shown in Figure 1. Based on the relative humidity and temperature variation data, it is understood that the rate of carbonation of concrete structures in Dhaka city will be very high. Spalling of cover concrete due to carbonation induced corrosion is found in many structures as shown in Figure 2.

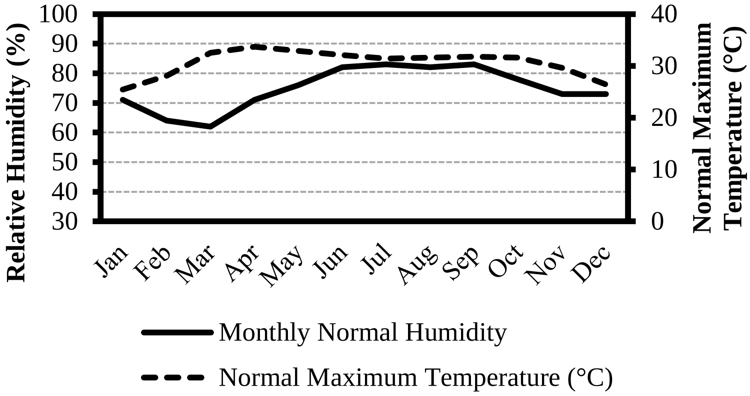

Figure 1. Monthly relative humidity and temperature of Dhaka city
(www.bmd.gov.bd)

Figure 2. Corrosion of steel due to carbonation: structures in Dhaka city

As per authors' literature survey, no study has been conducted yet on carbonation of concrete in Bangladesh. Therefore, to understand the rate of carbonation of concrete structures in Dhaka city, a comprehensive study has been planned. Carbonation depths of structural elements, such as, slab, beam, column, stair, sun shade, shear wall were measured. Seventy concrete structures of age from 1 year to 79 years were investigated. Carbonation coefficient was estimated based on these data and will be very useful for durability based design of concrete structures. The results will also be helpful to assess the current situation of the concrete structure in Dhaka city and to improve the present durability design consideration.

EXPERIMENTAL INVESTIGATIONS

Carbonation depth measurements were taken from 70 different concrete structures in Dhaka city. Measurements were taken from different structural members, such as, slab, beam, column, stair, sun shade, shear wall, etc. Stair case, sun shade, and shear wall categorized as other structural member as shown in Figure 3. Exposure conditions were grouped as indoor and outdoor. Member which is in open air condition and exposed to sun and rain is categorized as outdoor exposure condition. On the other hand, member which is not situated in open air condition and does not exposed to sun and rain is categorized as indoor exposure condition.

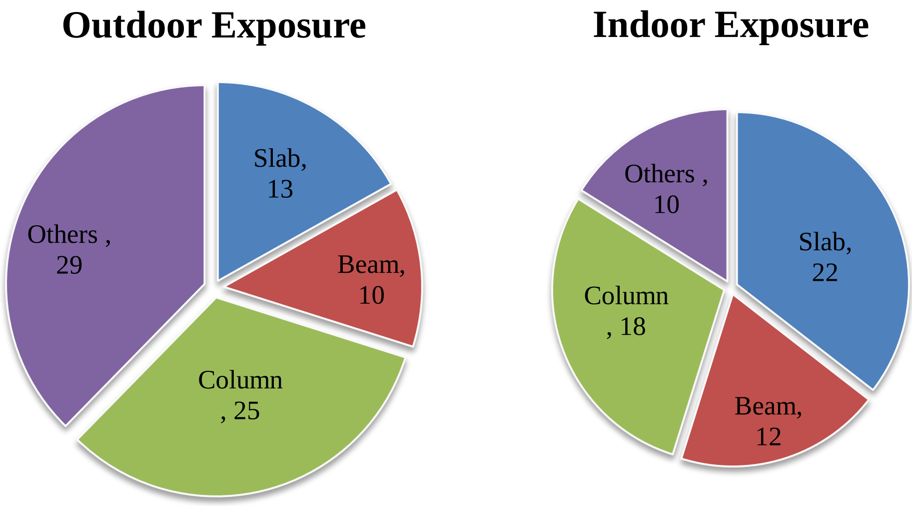

Figure 3. Structural members tested for carbonation

Detecting Carbonation

The ways to determine the carbonation depth of concrete are shown in Figure 4. Freshly fractured concrete surfaces perpendicular to the external concrete surface (as shown in Figure 4 (a)) were sprinkled by a phenolphthalein indicator. In the basic region (non-carbonated region), the indicator changes its color into a pink shade as shown in Figure 5. Carbonated portion showed no color. The line between the colorless and pink surface marks the carbonation depth. If it is not possible to break a part of structural elements, phenolphthalein solution is sprayed over concrete dust sample (as shown in Figure 6) collected by a concrete drill (Neville, 2003). In this research work, both methods were used to determine the carbonation depth.

Determination of pH of Concrete

Concrete samples were powdered manually to evaluate the pH of carbonated concrete and non-carbonated concrete. 15 g of powder concrete sample and 15 g of distilled water were mixed together for 5 min and pH of the solution was measured by a digital pH meter.

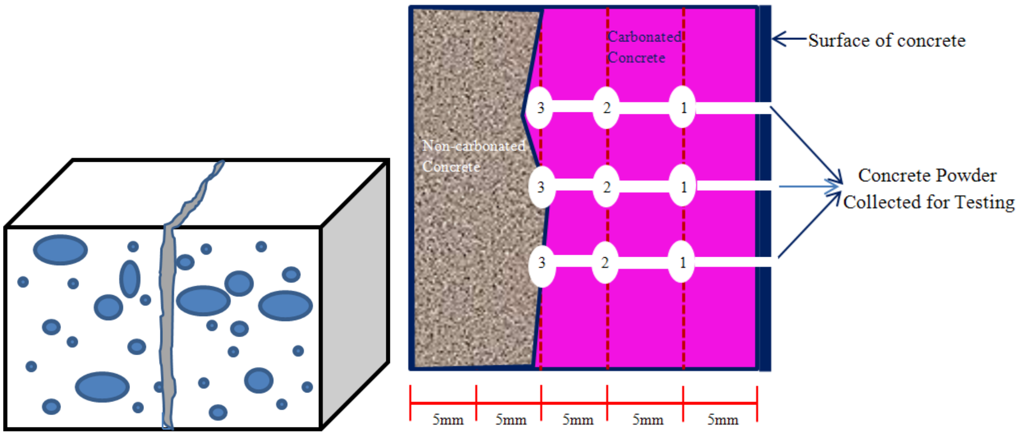

Figure 4. Sample collection procedure (a) fracture sample (left), (b) powder sample collected by drill (right)

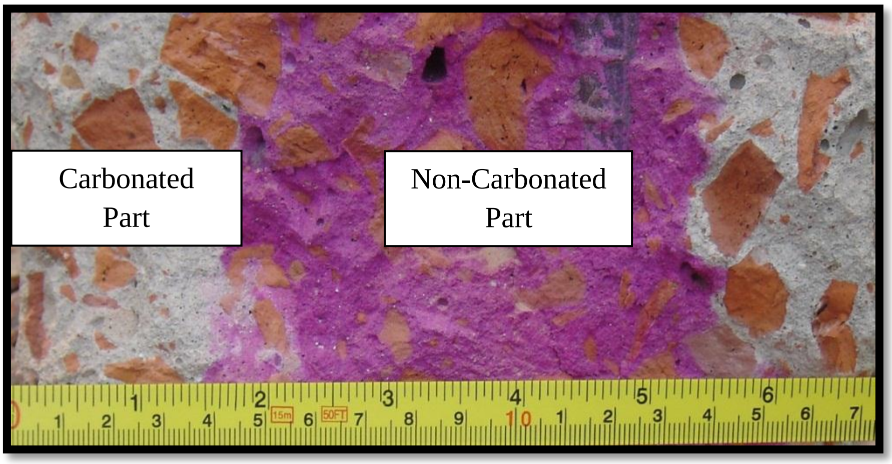

Figure 5. Measurement of carbonation depth: freshly fractured surface

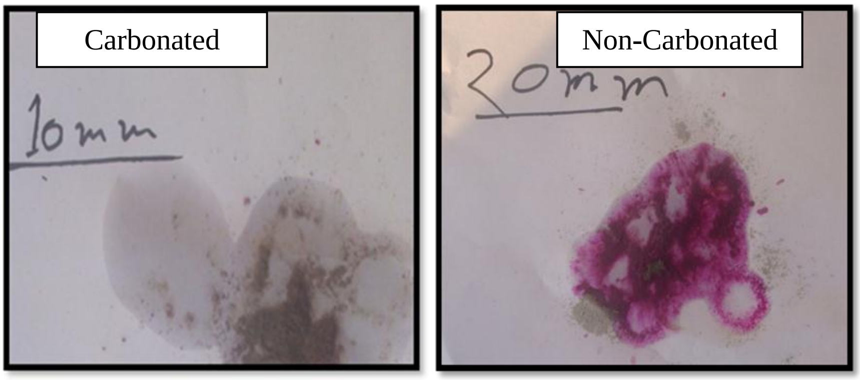

Figure 6. Measurement of carbonation depth: powder samples

RESULTS AND DISCUSSION

Coefficient of Carbonation

There are several models that describe the relationship between carbonation depth (C_t) and concrete age (t). The most widely used one is given below:

$$C_t = K\sqrt{t} \quad (1)$$

where K is the carbonation coefficient.

Monteiro et al, 2012 investigated around 47 samples from existing concrete structures of age up to 99 years and found the value of K = 3.76 mm/year$^{0.5}$ for moderately humid exposure condition. Khaiat and Haque, 1997 studied about 50 buildings situated 0.5 to 18 km from the coast of Kuwait. The results of this investigation indicated that coastal structures in hot exposure of Kuwait result in higher carbonation depth than the near coastal structures.

Variation of carbonation depth with age of structure for different structural elements, such as, slab, beam, column, and other elements in indoor and outdoor exposure conditions are shown in Figure 7 and Figure 8 respectively. In indoor exposure, carbonation coefficient is found to be 3.83, 3.13, 3.54, and 3.22 for slab, beam, column, and others, respectively. The values in outdoor exposure condition are 4.12, 4.03, 3.90, and 4.13 for slab, beam, column, and others, respectively. Relatively, a higher rate of carbonation was found for slab elements. It is because lower grade of concrete is used for slab construction compared to beam and column.

Relationship between carbonation depth of concrete and the age of structure is shown in Figure 9 for indoor and outdoor exposure condition irrespective of the structural elements. The coefficient of carbonation is found to be 3.36 for indoor exposure condition and 4.16 for outdoor exposure condition. Higher carbonation rate is found in outdoor exposure condition. It is because deterioration of concrete initiates at the exposed concrete surface due to fluctuation in temperature, ingress of moisture and penetration of damaging species into concrete. Irrespective of the exposure conditions and structural elements, the average carbonation coefficient is found to be 3.75 as shown in Figure 10. Carbonation coefficients are summarized in Table 1 for various structural elements and various exposure conditions. A higher value of carbonation coefficient is found due to poor quality of construction work as well as favorable carbonation environment in Dhaka city.

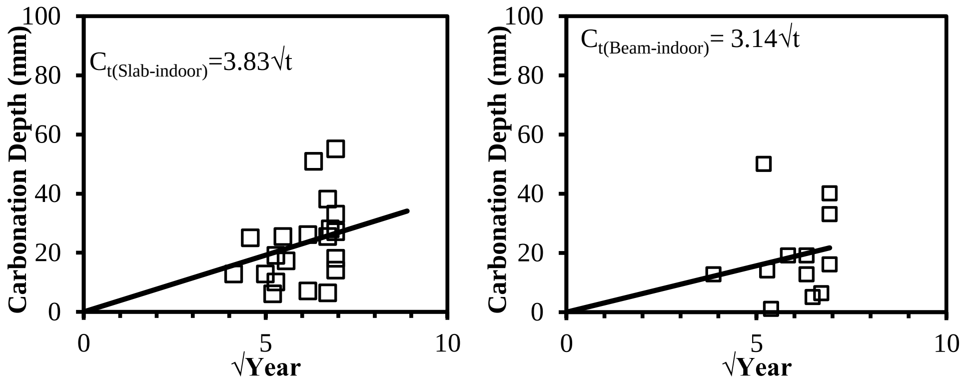

Figure 7(a). Relationship between depth of carbonation and age of structure for indoor exposure condition

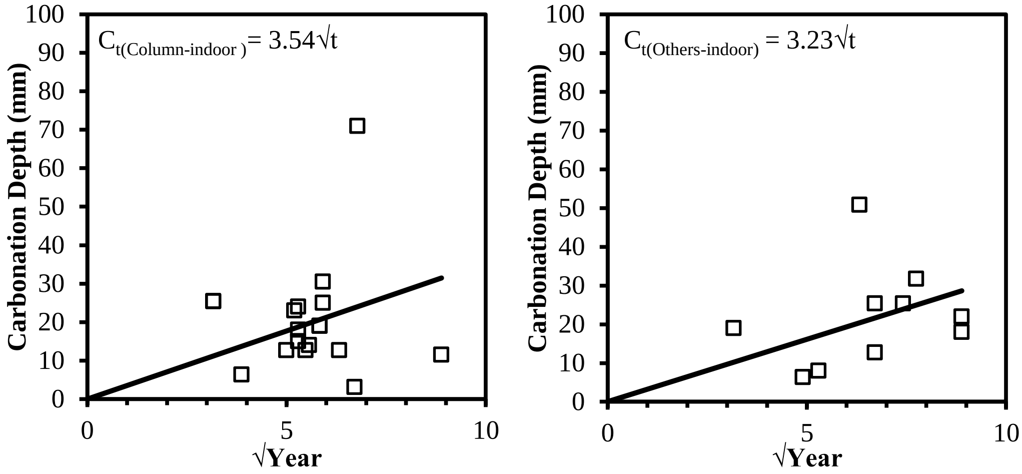

Figure 7(b). Relationship between depth of carbonation and age of structure for indoor exposure condition

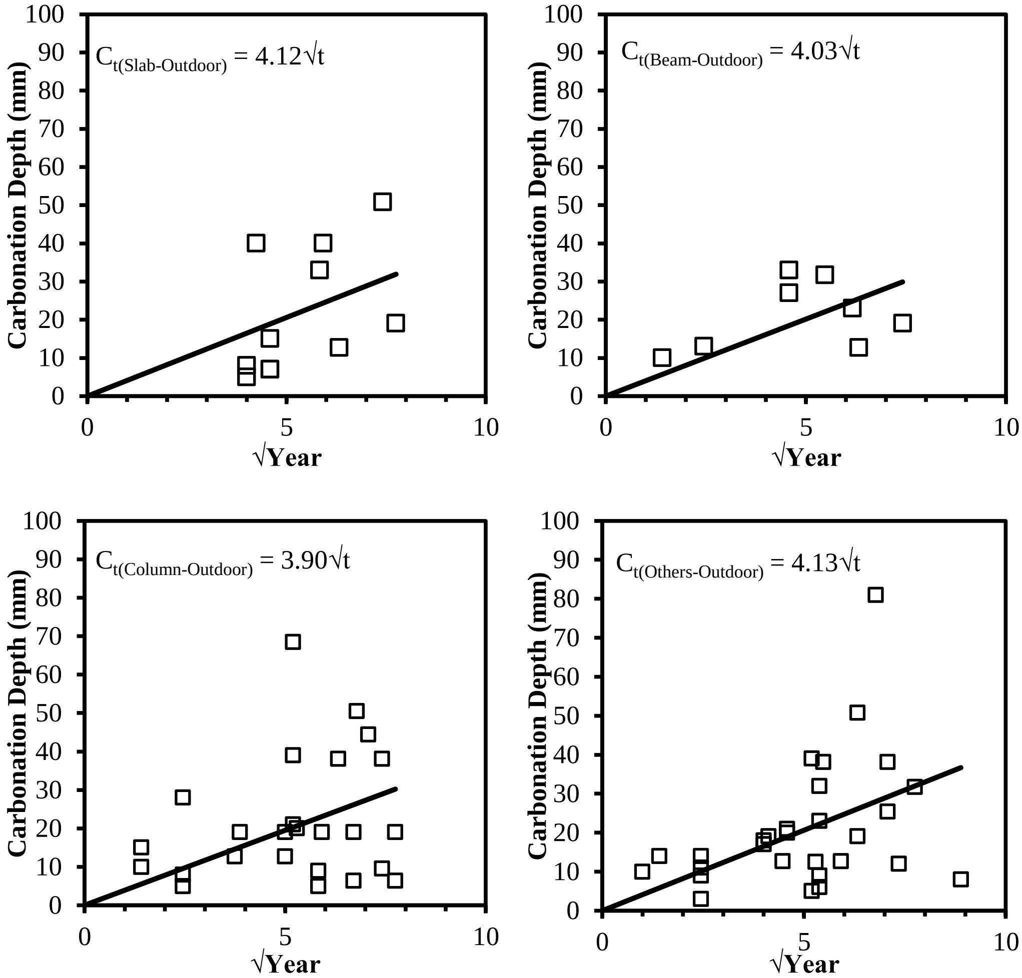

Figure 8. Relationship between depth of carbonation and age of structure for outdoor exposure condition

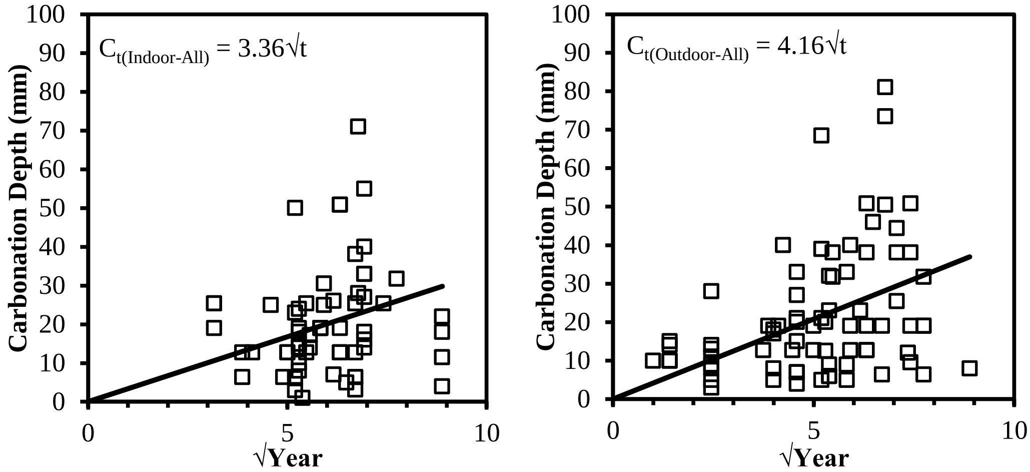

Figure 9. Relationship between depth of carbonation and age of structure for indoor exposure condition (left) and outdoor exposure condition (right)

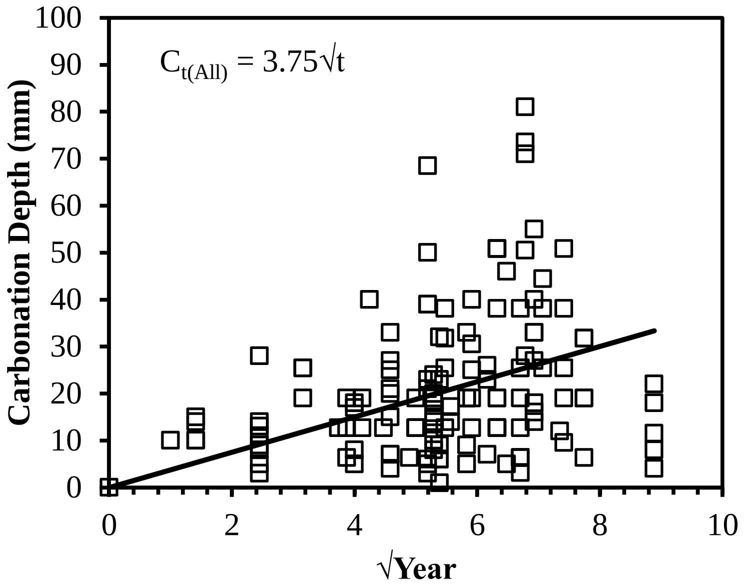

Figure 10. Relationship between depth of carbonation and age of structure

Table 1. Coefficient of Carbonation of Different Structural Members

Structural Element	Coefficient of Carbonation (K)		
	Outdoor Exposure	Outdoor Exposure	Average
Slab	4.12	3.83	3.98
Beam	4.03	3.14	3.59
Column	3.9	3.54	3.72
Others	4.13	3.23	3.68
Average	4.16	3.36	-
All-indoor and outdoor exposure	3.75		

Time to Initiate Corrosion

For specified concrete cover as per ACI 318-11, the time to initiate corrosion of different structural elements are calculated and summarized in Table 2. Here, carbonation coefficient is assumed to be 3.75 (as per Figure 10). It is found that, after 26 years of exposure, corrosion of steel bars in slab will be started. From the field investigations, it was also found that corrosion of steel bars in slab was started earlier compared to the other structural members. Steel bars embedded in slab was corroded earlier than the steel bar embedded in other structural members due to the less cover as well as the use of lower quality concrete in slab compared to the other structural members. Photograph of spalling of cover from slab were also published in daily newspaper as shown in Figure 11.

pH of Concrete

pH of concrete at the carbonated region and no-carbonated region is shown in Figure 12. The pH value of concrete is varied from 8.2 to 10.4 in the carbonated region and 9 to 12.5 for noncarbonated region.

Table 2. Time to Initiate Corrosion

Structural Element Type	Clear cover (mm) (ACI 318-11)	Average Carbonation Coefficient	Time to Initiate Corrosion- Year
Slab	19	3.75	26
Beam	37.5		100
Column	37.5		100

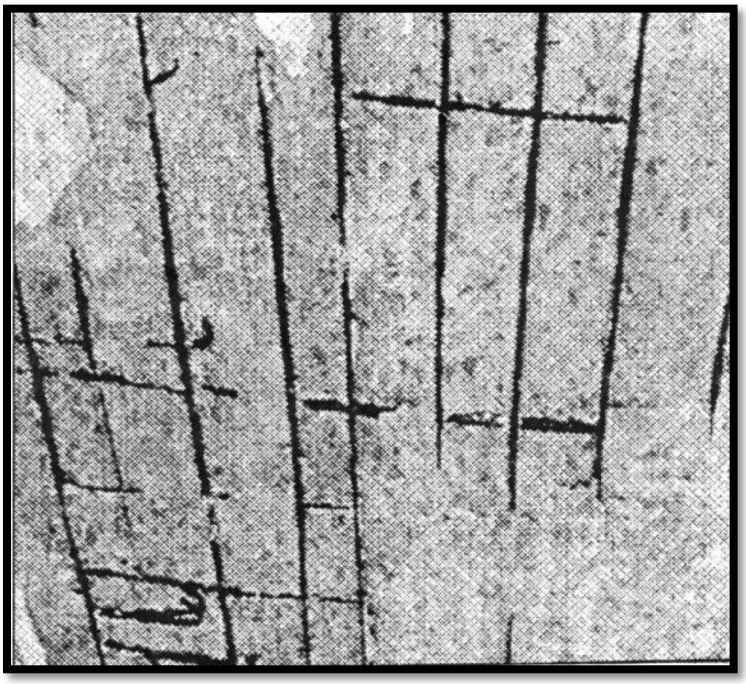

Figure 11. Spalling of cover concrete from slab (The Daily Ittefaq, 16th April, 2007)

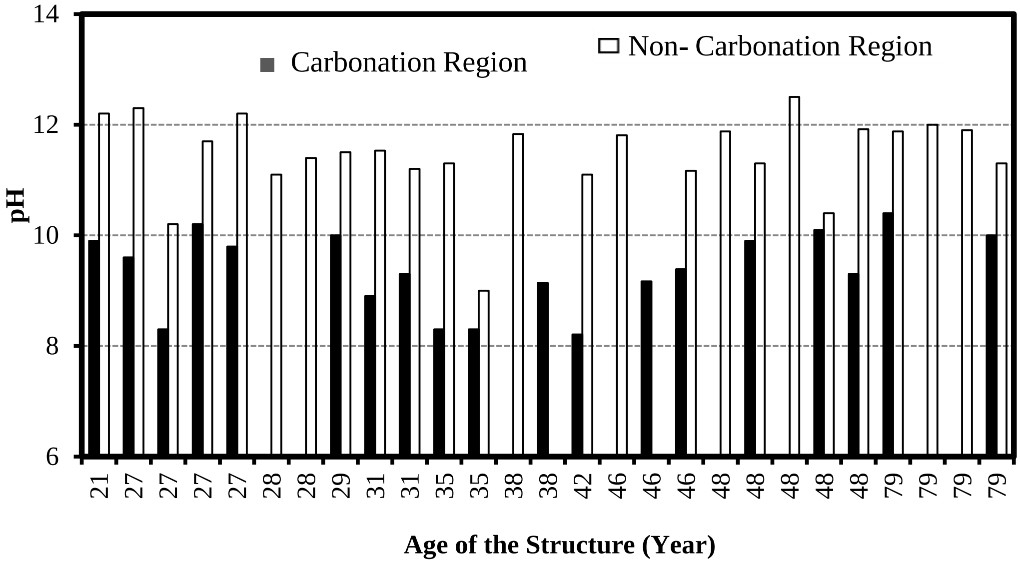

Figure 12. pH of concrete at carbonated and noncarbonated zone

CONCLUSIONS

Based on the field and laboratory investigations on carbonation of concrete in Dhaka city, the following conclusions are made:

1. Irrespective of the structural elements, carbonation coefficient is found to be 3.36 for indoor exposure condition and 4.16 for outdoor exposure condition. Overall carbonation coefficient, irrespective of indoor and outdoor exposure conditions and structural elements is found to be 3.75. It is observed that, concrete exposed in outdoor exposure shows more carbonation than indoor exposure conditions. Relatively, a higher rate of carbonation is found in slab compared to the other structural members.

2. The average pH value in carbonated zone is found to be 9.45 and in noncarbonated zone over 11.5. Lower pH values in concrete cause corrosion of steel in concrete.

3. To enhance durability, it is necessary to increase clear cover of slab concrete. Higher grade of concrete is also to be used as in beams, and columns.

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