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Carbonation depth and compressive strength of pedestrian bridge concrete structures in Mueang Nakhon Pathom environment

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Abstract

This study is an investigation on the carbonation of pedestrian bridge structures in community area Nakhon Pathom province by nondestructive testing methods. Compressive strength and carbonation depth of pedestrian bridge structures in 16 projects were measured. The results indicated that the compressive strength of pedestrian bridge structures was larger than the design specification. The rate of carbonation of pedestrian bridge structures in community area Nakhon Pathom province was higher than that of the pedestrian bridge structures in the suburb area. The carbonation depth of concrete having higher compressive strength was lower than of concrete having lower compressive strength. The suggest that it is necessary to limit the carbonation depth of concrete to an acceptable level in the severe environmental conditions prevailing in Mueang Nakhon Pathom. Finally, the results of the survey have yielded realistic values of a carbonation coefficient which can be used to predict the carbonation depth of structures built with compressive strength different concrete in Mueang Nakhon Pathom environment.

Keywords: carbonation depth, Schmidt hammer, compressive strength, Mueang Nakhon Pathom, pedestrian bridge

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1. Introduction

Concrete is commonly used in construction. The concrete may have deteriorated due to the durability of concrete structures. In the Mueang Nakhon Pathom, it is the combination of carbon dioxide geology and the extreme climate which makes the environment potentially more aggressive to concrete than anywhere. Especially in areas with heavy traffic are exposed to high amounts of carbon dioxide. The carbon dioxide will reaction with the calcium hydroxide in the cement paste. Causes calcium carbonate to the equation (1).

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (1)$$

Such a reaction carbonation. This causes a decrease in the alkaline of concrete. As a result, corrosion of steel.

Research in the past found that the incidence of carbonation in concrete depending on several factors. For example, the concentration of carbon dioxide, relative humidity at 50-75 percent take effect high carbonation [1]. The type of binder, such as replace cement with fly ash caused high carbonation [2, 3] and the water binder ratio (w/b) in concrete at higher rates caused high carbonation [4]. For buildings with similar mix design properties, the carbonation depth increased with the elevation, and from West-to-East orientation for the conditions of the tropical marine climate [5].

Although the majority of reinforced concrete structures in the community. Such as community housing, roads, and pedestrian bridge. These structures are exposed to carbon dioxide in large quantities as well. It causes the deterioration of reinforced concrete structures such as carbonation. In addition, the design of reinforced concrete structures has no regard for the impact on the location. The structure of the construction affects the carbonation. The data primarily from accelerated test laboratory. No database of real structure. Therefore, this is a study of the impact of such an effect on the carbonation of concrete structures. As well as the remaining lifetime of the project. By study the condition of the real structure of the bridge structure in the community area Nakhon Pathom.

Study area

In this study were to assess the damage and deterioration of the pedestrian bridge. The inspection, non-destructive testing of concrete structures using instruments and apparatus for testing and drilling sample for a concrete chemical testing laboratory for carbonation depth for in this study were collected from

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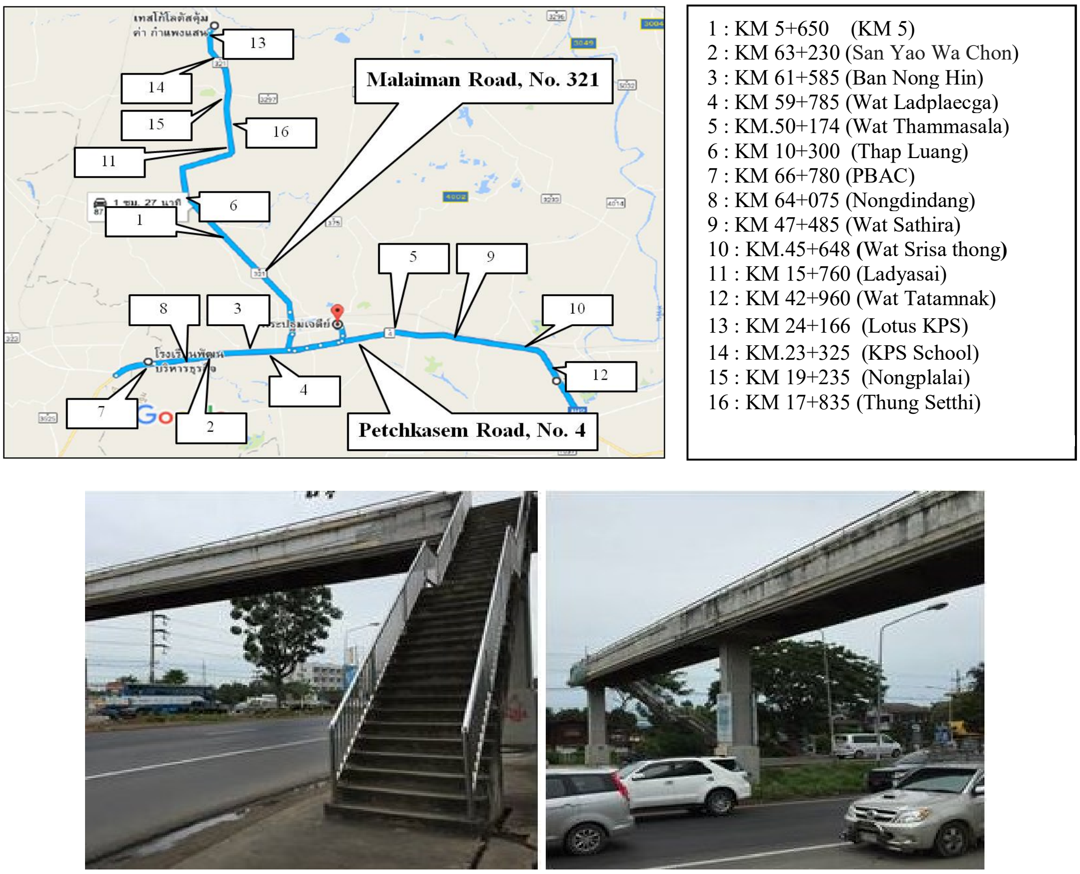

Figure 1 Locations of sites

the drilling of reinforced concrete bridge structure is exposed to an environment with high amounts of carbon dioxide. By age of structures range from 12-22 years. Altogether 16 pedestrian bridge in the community Nakhon Pathom. Many of the pedestrian bridge surveyed are located at a somewhat similar distance (see Table 1). It was necessary to have a fairly large sample size and to include the effect of differing construction practices etc. The majority of the pedestrian bridge included in this survey were constructed in the period from 1993 to 2003. Recent study done by Warinlai and Krammart, showed that the concentration of carbon dioxide in air is exceeded 600 ppm in Mueang Nakhon Pathom [6]. Figure 1 shows a map with the location of a pedestrian bridge in the province of Nakhon Pathom in this research.

2. Methods

2.1 Determine the compressive strength of the pedestrian bridges

In the study the carbonation of pedestrian bridge structures in the community Nakhon Pathom. It measures the total reflection of the concrete with a Schmidt hammer. The compressive strength of concrete was determined according to ASTM C805-02 [7]. By used to measure the compressive strength and consistency of the compressive strength of the structure position close to the coring sample (see Figure 2). By one position keep the reflection of the concrete 36 values. The measurement reflects the time required is approximately 25 millimeters. The one pedestrian bridge keep six positions. The total values equal to 216 values.

2.2 Sample to test the carbonation depth

The test carbonation of the pedestrian bridge is located in Nakhon Pathom province by coring the concrete samples with a drill head drills hole saw diameter of about 5-6 centimeter from the pillar of a pedestrian bridge at an altitude of 1.50 to 2.50 meters. The coring samples collected all six samples per one pedestrian bridge.

2.3 Carbonation depth measurement

For the carbonation tests of the pedestrian bridge is located in Nakhon Pathom province, carbonation depth was measured in the laboratory. The carbonation depth was assessed by split the concrete coring and spraying the split specimens uniformly with 1% of phenolphthalein in solution is colorless and used as an acid-base indicator [8] (see Figure 3). The color of the solution changes into purple when pH is higher than the range of approximately nine. The carbonation portion is uncolored and non-carbonation portion is purple. The carbonation depth was measured with a vernier caliper to the nearest 1 millimeter in Figure 4. The results are included in Tables 2-5.

Figure 2 Measurement the reflectance of concrete with Schmidt hammer

Figure 3 Spraying with a phenolphthalein solution to concrete sample

Figure 4 Carbonation depth

Table 1 Features of the pedestrian bridges (Nakhon Pathom)

Structure no.	Position	Distance from Mueang (km)	Age (year)	Latitude	Longitude
1. KM 5	Mueang Nakhon Pathom	9	15	13°51'25"	100°00'47"
2. San Yao Wa Chon	Mueang Nakhon Pathom	10	14	13°48'06"	99°59'49"
3. Ban Nong Hin	Mueang Nakhon Pathom	8	12	13°48'41"	100°00′43"
4. Wat Ladplaecga	Mueang Nakhon Pathom	6	12	13°48'14″	100°01'43"
5. Wat Thammasala	Mueang Nakhon Pathom	8	17	13°48'46"	100°06'59"
6. Thap Luang	Mueang Nakhon Pathom	14	15	13°53'19"	99°59'08"
7. PBAC	Mueang Nakhon Pathom	13	15	13°47'48"	99°57'55"
8. Nongdindang	Mueang Nakhon Pathom	11	16	13°47'58"	99°59'21"
9. Wat sathira	Nakhon Chai Si	11	14	13°48'31"	100°08'27"
10. Wat srisa thong	Nakhon Chai Si	11	17	13°48'23"	100°09'13"
11. Ladyasai	Kamphaeng Saen	18	15	13°54'36"	99°58'50"
12. Wat Tatamnak	Nakhon Chai Si	19	22	13°47'17"	100°10′20"
13. Lotus KPS	Kamphaeng Saen	29	15	13°59'34″	99°59'43"
14. KPS School	Kamphaeng Saen	27	15	13°59'07"	99°59'41"
15. Nongplalai	Kamphaeng Saen	25	15	13°57'03"	100°00′14″
16. Thung Setthi	Kamphaeng Saen	23	15	13°56'17"	100°00′13"

Table 2 Carbonation depth and compressive strength of cores taken from pedestrian bridge (6-10 km from Mueang Nakhon Pathom)

Structure no.	Position	Distance from Mueang (km)	Age (year)	Strength (ksc)	Carbonation depth (mm)	Expected depth of carbonation in 20 years (mm)	Expected time to carbonate 30 mm cover (year)
1. KM 5	Mueang Nakhon Pathom	9	15	356	18.80	21.53	39
2. San Yao Wa Chon	Mueang Nakhon Pathom	10	14	213	60.00	71.93	3
3. Ban Nong Hin	Mueang Nakhon Pathom	8	12	217	37.80	49.14	7
4. Wat Ladplaecga	Mueang Nakhon Pathom	6	12	235	34.50	44.85	9
5. Wat Thammasala	Mueang Nakhon Pathom	8	17	295	18.30	19.70	46

Table 3 Carbonation depth and compressive strength of cores taken from pedestrian bridge (11-15 km from Mueang Nakhon Pathom)

Structure no.	Position	Distance from Mueang (km)	Age (year)	Strength (ksc)	Carbonation depth (mm)	Expected depth of carbonation in 20 years (mm)	Expected time to carbonate 30 mm cover (year)
6.Thap Luang	Mueang Nakhon Pathom	14	15	400	16.20	18.71	51
7. PBAC	Mueang Nakhon Pathom	13	15	274	31.60	36.49	14
8. Nongdindang	Mueang Nakhon Pathom	11	16	219	39.30	43.71	9
9. Wat sathira	Nakhon Chai Si	11	14	322	21.70	25.71	27
10. Wat srisa thong	Nakhon Chai Si	11	17	343	17.40	18.74	51

Table 4 Carbonation depth and compressive strength of cores taken from pedestrian bridge (16-20 km from Mueang Nakhon Pathom)

Structure no.	Position	Distance from Mueang (km)	Age (year)	Strength (ksc)	Carbonation depth (mm)	Expected depth of carbonation in 20 years (mm)	Expected time to carbonate 30 mm cover (year)
11. Ladyasai	Kamphaeng Saen	18	15	325	25.50	29.20	21
12. Wat Tatamnak	Nakhon Chaisi	19	22	315	24.50	23.14	34

Table 5 Carbonation depth and compressive strength of cores taken from pedestrian bridge (21-30 km from Mueang Nakhon Pathom)

Structure no.	Position	Distance from Mueang (km)	Age (year)	Strength (ksc)	Carbonation depth (mm)	Expected depth of carbonation in 20 years (mm)	Expected time to carbonate 30 mm cover (year)
13. Lotus KPS	Kamphaeng Saen	29	15	332	18.70	21.42	39
14. KPS School	Kamphaeng Saen	27	15	389	20.50	23.48	33
15. Nongplalai	Kamphaeng Saen	25	15	356	19.20	21.99	37
16. Thung Setthi	Kamphaeng Saen	23	15	359	14.00	16.03	70

Table 6 Variation of depth of carbonation with distance from the Mueang Nakhon Pathom

Distance from Mueang (km)	Average strength (ksc)	Average carbonation depth (mm)
6-10	263	33.88
11-15	312	25.24
16-20	320	25.00
21-30	359	18.10

3. Results and discussion

The results reflected the concrete with a Schmidt hammer of the pedestrian bridge in the Nakhon Pathom province 16 pedestrian bridge. The reflection of the Schmidt hammer used to estimate the compressive strength of concrete by the relationship of Equation (2) [9].

$$f_c' = -176.4 + (12.446 \times RN) \quad (2)$$

where f_c' is the compressive strength of concrete, ksc, RN is reflecting the Schmidt hammer.

The results of the compressive strength 16 pedestrian bridges are between 213-400 ksc. As shown in Tables 2-5. Which found that the average compressive strength is higher than the standard design of the highway is 210 ksc [10]. (see St. no. 2, 3, 4 and 8) only 4 out 16 pedestrian bridge surveyed have been built with concrete compressive strength less than 240 ksc. All these four pedestrian bridges are located within 11 km from the Mueang Nakhon Pathom and can be classified as near Mueang Nakhon Pathom locations. From a climatic and exposure point of view, all these four pedestrian bridges are located in a very severe regime. Four out of 16 pedestrian bridges have been built with a concrete compressive strength of between 200-250 ksc i.e. 25.00% of the pedestrian bridges surveyed. One out of 16 pedestrian bridges have been built with a concrete compressive strength of between 250-300 ksc i.e. 12.50% of the pedestrian bridges surveyed. Nine out of 16 pedestrian bridges have been built with a concrete compressive strength of between 300-350 ksc i.e. 31.25% of the pedestrian bridges surveyed. One out of 16 pedestrian bridges have been built with a concrete compressive strength of between 350 - 400 ksc i.e. 31.25% of the pedestrian bridges surveyed. The carbon dioxide exposure conditions are very severe and no structure should be built with a concrete compressive strength of less than 210 ksc, so if designing for durability of the pedestrian bridges surveyed represents compliance as regards concrete compressive strength.

3.1 Carbonation depth

Tables 2-5 shows the results of phase carbonation depth average of the 16 pedestrian bridges. Showed that carbonation depth average of the pedestrian bridges that is between 14-60 mm. The pedestrian bridges are located in the Mueang Nakhon Pathom (6-10 km from Mueang Nakhon Pathom) promising carbonation depth over the located in the metropolitan area to another. (11-15 km from Mueang Nakhon Pathom), (16-20 km from Mueang Nakhon Pathom) and (21-30 km from Mueang Nakhon Pathom).

This is because 1) A lifetime of difference. 2) An environment that is different in Mueang Nakhon Pathom, a location adjacent to the shopping center. A community the volume of traffic the concentration of carbon dioxide than in other metropolitan areas. 3) The quality of the concrete used in the construction of each section may be different.

However, the age of the structure and carbonation depth to calculate the carbonation coefficient from equation (3) [2, 11, 12].

$$d = k\sqrt{t} \quad (3)$$

where d is the tested carbonation depth (mm), t is the time in this project about the life of the structure (month), k is the carbonation coefficient (mm / month$^{1/2}$)

Table 6 includes the variation of average carbonation depth of the pedestrian bridges with their distance from the Mueang Nakhon Pathom. The average compressive strength of these structures as determined from Tables 2-5 is different, i.e. 263, 312, 320 and 359 ksc, respectively. It can be assumed that the average quality of the concrete used in these Nakhon Pathom structures is different. With this assumption, it seems that Mueang Nakhon Pathom structures (6-10 km)

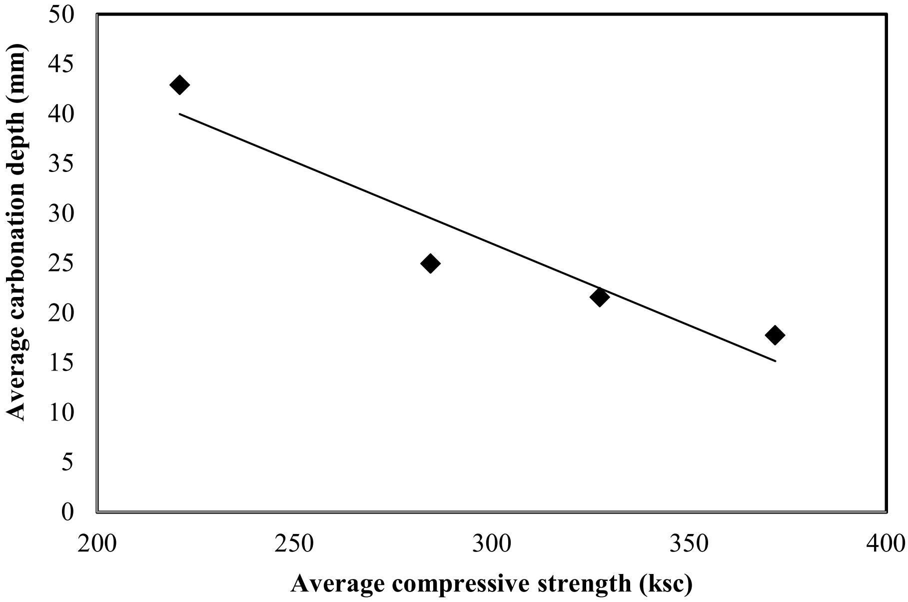

Figure 5 Variation of carbonation depth for concretes structures

carbonation depth the most, 33.88 mm, and then those located within 11-15 km from the Mueang Nakhon Pathom with a carbonation depth of 25.24 mm. The structures located within 16-20 km seem to have carbonated the least, 25.00 mm. In the pedestrian bridges 21-30 km from the Mueang Nakhon Pathom, the carbonation depth seems to have decreased again to 18.10 mm. While the highest carbonation depth of Mueang Nakhon Pathom pedestrian bridges can be attributed to both high temperature and sufficiently high ambient humidity, the decrease in this value for pedestrian bridges located within 11-15, 16-20 and 21-30 km from the Mueang Nakhon Pathom can be due to decreasing carbon dioxide and humidity with an increasing distance from the Mueang Nakhon Pathom.

As mentioned earlier, the 16 pedestrian bridges surveyed have been constructed using 200-250 ksc, 250-300 ksc, 300-350 ksc and 350-400 ksc concretes. The average values of the compressive strength of these four grades of concrete of 221, 284, 327 and 372 ksc, respectively, have been plotted against the corresponding average depth of carbonation of 42.90, 24.95, 21.56 and 17.74 mm in Figure 5. The figure suggests, amongst other factors, that the carbonation depth of concrete structures is a linear function of the compressive strength of the concrete. Accordingly, the best safeguard against the passivation of reinforcement, where rate and total carbonation depth is expected to be high, is to use higher strength and better quality concrete. The maximum carbonation depth of 60 mm observed in this investigation occurred in a column of a pedestrian bridges which was only 14-years-old (see St. no. 2, Table 2). The compressive strength of the concrete used was only 213 ksc in this Mueang Nakhon Pathom pedestrian bridges. A compressive strength of 213 ksc is simply inadequate for a Mueang Nakhon Pathom pedestrian bridges which are exposed to the ingress of another carbon dioxide as well. In addition, there are two other pedestrian bridges (see St. no. 2 and 8), where even lower compressive strength concrete of about 217 and 219 ksc have been utilized. The carbonation depth, however, in both of these pedestrian bridges is only 37.80 and 39.30 mm after 12 and 11 years of exposure, respectively. Although the compressive strength of 217 and 219 MPa is undesirably low, the possible reason for the much lower depth of carbonation of these pedestrian bridges is their distance from the Mueang Nakhon Pathom, of 8 and 11 km, respectively.

3.2 Predicted carbonation depth

The depth of carbonation can be predicted by using, $d = k\sqrt{t}$ where d is the carbonation depth in mm; t is the age of the concrete in a month and k is the carbonation coefficient, whose value depends on both concrete strength and storage condition. These predictions are only indicative, as k would vary for different combinations of concrete quality and exposure conditions.

The pedestrian bridges surveyed in this investigation were between 12 and 22 years old. It was desirable to predict the carbonation depth of these pedestrian bridges, say, at the age of 20 years. In addition, it would be interesting to know how long it would take for the pedestrian bridges surveyed to carbonate 30 mm. This information can be used to predict the design life of a structure, assuming that carbonation was the only mechanism of deterioration. Accordingly, the above equation was used to determine the k values for all the 16 pedestrian bridges, knowing both their age and the measured carbonation depth at a given age. It is envisaged that the k values, thus calculated, are much more reliable as the measured carbonation depth

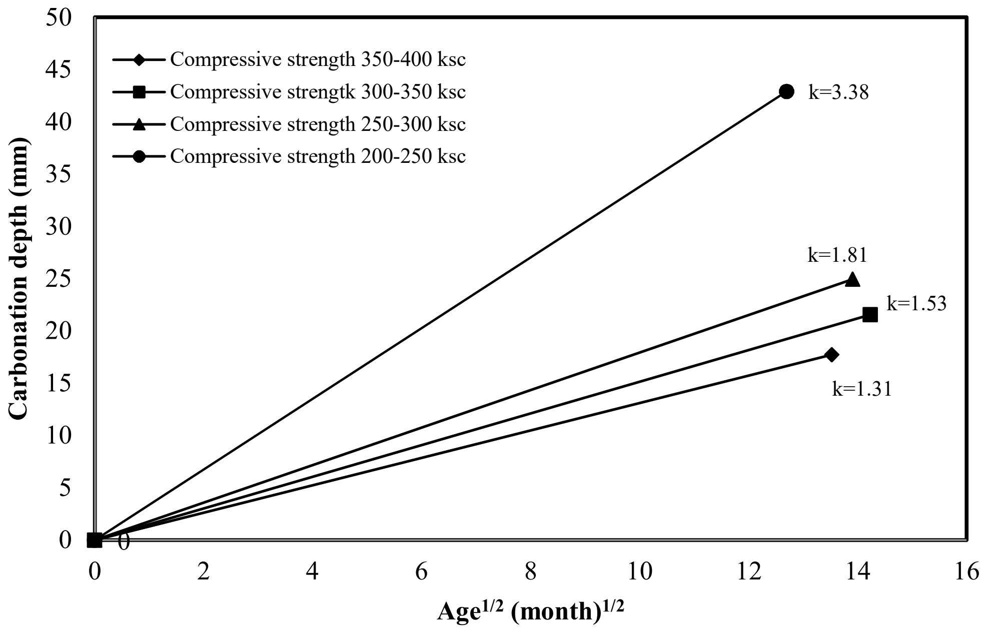

Figure 6 Variation of carbonation coefficient for concretes structures

Table 7 Average values of carbonation coefficient for structures surveyed

Strength range (ksc)	Average strength (ksc)	Carbonation coefficient (k)	Carbonation depth after 25 year (mm)
350-400	372	1.31	22.72
300-350	327	1.53	26.47
250-300	284	1.81	31.35
200-250	221	3.38	58.54

have adequately incorporated the effect of both concrete quality and the exposure regime. Accordingly, the predictions based on these k values are likely to be more reliable. The expected carbonation depth after 20 years and the expected time to carbonate 30 mm cover concrete are included in Tables 2-5. According to these predictions, structures number 2, 3, 4 and 8 are likely to carbonate to the depth that steel passivation may be a possibility in 20 years. It is worth noting that an adequate strength (200-250 ksc) may not be adequate in some cases, as regards depth of carbonation, because of demanding exposure conditions. These predictions suggest that it is safer to use a 250 ksc good quality concrete in Mueang Nakhon Pathom regions so that damaging species like salts, moisture, and carbon dioxide cannot penetrate the concrete easily.

As mentioned earlier, the structures surveyed were grouped in the (350-400 ksc), (300-350 ksc), (250-300) and (200-250 ksc) ranges. The average values of the compressive strength of the structures falling in these categories and the corresponding average of the k values calculated are included in Table 7. These k values have then been used to predict the 25 year carbonation depth of the structures built using the compressive strength of between 350-400 ksc, 300-350 ksc, 250-300 and 200-250 ksc concrete (see Table 7). These predicted values suggest, correctly, that the lower the concrete strength the higher the depth of carbonation. Finally, the k values which are more realistic for the Mueang Nakhon Pathom exposure conditions of Thailand (Figure 6).

4. Conclusions

4.1 The results indicated that the compressive strength of pedestrian bridge structures was larger than the design specification.

4.2 The rate of carbonation of pedestrian bridge structures in community area Nakhon Pathom province was higher than that of the pedestrian bridge structures in the suburb area.

4.3 Carbonation depth of concrete having higher compressive strength was lower than of concrete having lower compressive strength.

4.4 The results suggest that it is necessary to limit the carbonation depth of concrete to an acceptable level in the severe environmental conditions prevailing in Mueang Nakhon Pathom.

4.5 The results of the survey have yielded realistic values of a carbonation coefficient which can be used to predict the carbonation depth of structures built with compressive strength different concrete in Mueang Nakhon Pathom environment.

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