THE DURABILITY AND REPAIR PROBLEMS OF REINFORCED CONCRETE COLUMNAR STRUCTURES

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Abstract

In the paper an attempt is made to assess the durability of nine thirty-four years old reinforced concrete columnar structures. To assess the durability the durability model is used, suggesting determination of the structure wear based on the progress of carbonatization of concrete cover. On the basis of proper inspection the method of repair of analysed structures was proposed.

Streszczenie

W artykule podjęto próbę oszacowania trwałości dziewięciu trzydziestoczteroletnich, żelbetowych konstrukcji słupowych. Do oceny trwałości wykorzystano model trwałości, proponując ustalenie zużycia badanej konstrukcji na podstawie badania postępu karbonatyzacji otuliny betonowej. Na podstawie przeprowadzonych badań własnych została zaproponowana metoda naprawy analizowanych konstrukcji żelbetowych.

Keywords: **Durability; Reinforced concrete; Columnar structures; Carbonatization; Concrete cover; Repair.**

1. INTRODUCTION

Durability is one of the basic requirements for hardened concrete. The definition of the durability of concrete structures is given in [8]; according to this definition the required durability of the structure is preserved if the construction performs its functions regarding usage, carrying capacity and stability in planned utilization time, with no distinct reduction in utilization features or unexpected maintenance costs. After some years of utilization of the construction, even if no external manifestation indicating any menace to the construction is present, it is recommended to test the remaining utilization period. Such assessment can protect the owner of the facility from excessive expenses related with the maintenance of the construction, e.g. its repair. The paper is an attempt to determine the durability of thirty-four year old column constructions in the plant where prefabricated concrete elements are produced. Subject to the test was a structure shielded against precipitation (columns in production hall) as well as a construction exposed to external climatic conditions (columns of storage ground for finished products). General view of analyzed structures is presented in fig. 1a) and 1b).

2. THE MAIN CONCRETE DESTRUCTIVE FACTORS

Concrete is a heterogeneous and porous material. Its spatial structure is created by aggregate surrounded with hydration products in colloidal state C-S-H and hydrate consolidated to different degree. Micro-structure model of cement paste is showed in fig. 2

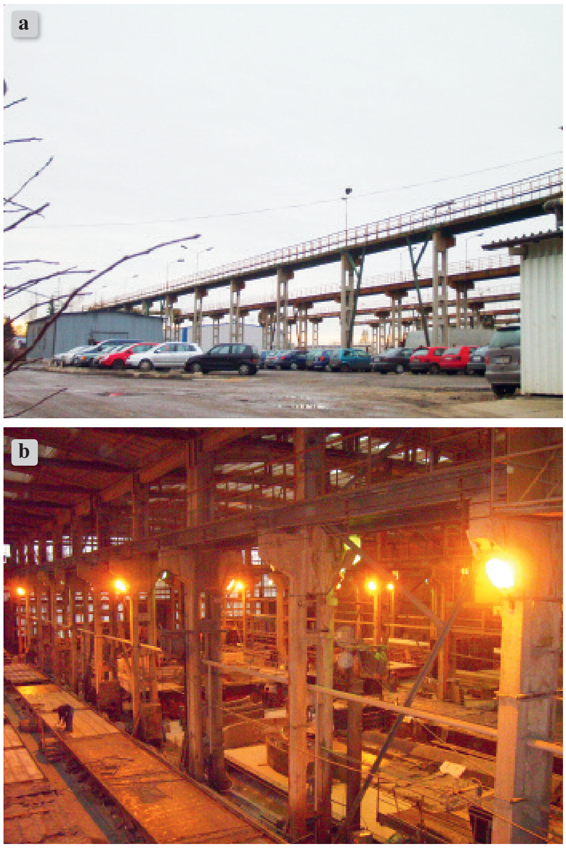

Figure 1.
General view of analyzed structures: a)storage area, b) hall

System of pores in hardened cement – paste favours the flow of liquid and of gases through concrete. This movement can take place as a result of:

– differential pressure,

– differential concentrations(diffusion),

– absorption.

One of the reasons for concrete corrosion is carbonatisation. This process consists in diffusion of CO_2 inside of concrete, and then in reaction of CO_2 from hydrated cement – $Ca(OH)_2$, which takes place as a result result of hydrolysis alite, thus creating $CaCO_3$.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (2.1)$$

The formed calcium carbonate is harder soluble than $Ca(OH)_2$, it crystallizes in pores where the reaction takes place. As an effect of the carbonatisation, apart from $CaCO_3$, also hydrated oxides of aluminium, silicon and irons are formed from $Ca(OH)_2$, [3]. When $Ca(OH)_2$ is subjected to exhaustion, there exists a possibility of occurrence of carbonatisation of hydrated calcium silicate, C-S-H. When it starts, not only does it increase the content of $CaCO_3$, but simultaneously creates siliceous gel, which makes easy further carbonatisation accumulating in pores [4]. Whole process lowers alkalinity of concrete.

Under influence of carbonic acid $CaCO_3$ changes and in further phase it is a very easily soluable and sour calcium carbonate $Ca(HCO_3)_2$, which is washed out by surrounding water.

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2 \qquad (2.2)$$

When concrete cover undergoes carbonatisation, and the front of lowering pH reaches the steel, we speak about loss of protective properties of concrete cover, possibly as a consequence of corrosion. We can then speak about wear of concrete cover. This process is strongly connected with service life of a structure. The lifetime of the structure can be divided into 3 stages. First stage embraces the state, when this steel is protected against aggressive activity with concrete cover, but due to aggressive environment neutralization of concrete takes place. In second stage steel arms begin to corrode, because the concrete cover loses its protective function. Corrosion of steel causes enlargement of volume of armature, which in consequence causes cracks in concrete cover and its abandonment. In third stage rods corrode until reaching the limits of carrying capacities (fig. 3).

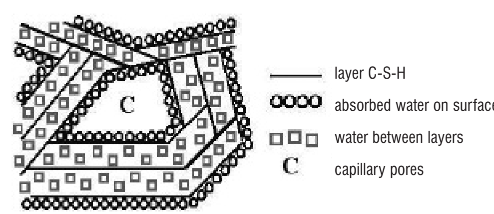

Figure 2.
The model of cement paste microstructure (phase C-S-H), according to T.C. Powers [2, 4]

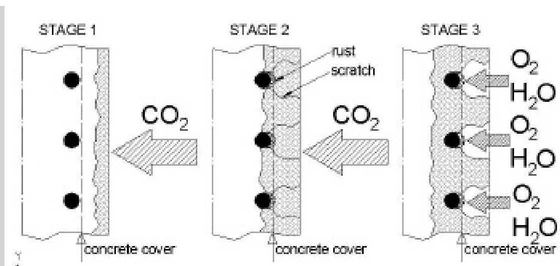

Figure 3.
Stages of deterioration of reinforced concrete resulting from environment influences [1]

3. ASSESSING THE DURABILITY OF COLUMNAR STRUCTURES

3.1. Preliminary assumptions

To assess durability of the analyzed facilities the model has been presented in paper [6].The structure's durability, in other words the time of using the structure or time of structure useful usability is the time random variable according to Sitnik [5]: from the date of putting the structure into operation up to achievement of terminal state of its property. The substance of such considerations is presented in fig. 4.

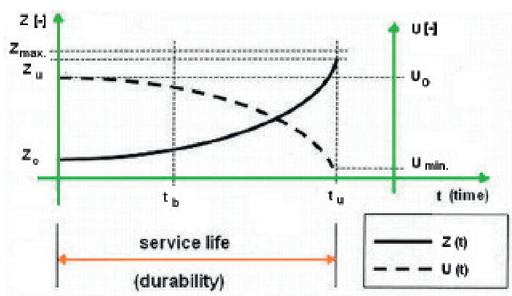

Figure 4.
Waste curves Z(t) and usability U(t) of the building structure [6]

The meaning of the symbols is following: Z_{max} – maximum waste; Z_u – waste after lapse of time tu; Z_o – initial waste; U_o – initial value of useful usability; U_{min} – minimum useful usability; t_b – time when the structure is under examination [years]; t_u – structure's durability [years].

The mathematical model of waste kinetics for a building structure may be described

in the following way [6]:

$$Z(t) = Z_o + \beta_{tn} \tag{3.1}$$

where: Z_o – initial waste; β – kinetic parameter; t – time; n – structure's deterioration factor.

Let's also assume that for $t = t_o = 0$ $Z = Z_o$,; for $t = t_b$ $Z = Z_b$; for t = tu $Z = Z_u$.

If we put these values in equation (3.1) we obtain [6]:

$$Z_b = Z_o + \beta t_b^n \tag{3.2}$$

$$Z_u = Z_o + \beta t_u^n \tag{3.3}$$

If we mark β coefficient from equation (3.2) and put in (3.3), after adequate transformations we obtain the following relation [6]:

$$t_u = t_b \left(\frac{Z_u - Z_o}{Z_b - Z_o} \right)^{\frac{1}{n}} \tag{3.4}$$

Taking the following assumptions [6]:

$$U(t) = Z_{max} - Z(t) \tag{3.5}$$

and $$Z_{max} = 1 \tag{3.6}$$

equation (3.4) we obtain:

$$t_u = t_b \left(\frac{U_o}{U_o - U_b} \right)^{\frac{1}{n}} \tag{3.7}$$

Equation (3.7) is the mathematic model of building structure durability. From this formula we can obtain the remaining time of structure using:

$$t_{pu} = t_u - t_b = t_b \left[\left(\frac{U_o}{U_o - U_b} \right)^{\frac{1}{n}} - 1 \right] \tag{3.8}$$

and values of useful usability of building structure at any time $t_b \le t_u$:

$$U_b = U_o \left[1 - \left(\frac{t_b}{t_u} \right)^n \right] \tag{3.9}$$

Let's see that the remaining time of structure using can be calculated from equation (3.4), as well:

$$t_{pu} = t_u - t_b = t_b \left[\left(\frac{Z_u - Z_o}{Z_b - Z_o} \right)^{\frac{1}{n}} - 1 \right] \tag{3.10}$$

The values t_u, t_{pu} and U_b, given from equations (3.4) or (3.7), (3.8) or (3.10) and (3.9) respectively, will be reliable only if the deterioration factor is definied precisely. The value of deterioration factor depends on material's structure resistance to destructive influence of aggressive weather.

In addition to this, for the purpose of the analysis, it was assumed that the wear of the construction would be determined based on testing progress of concrete cover carbonatization. The wear was determined based on the following relations [7]:

$$z = \frac{(pH_{max} - pH_{bad})}{pH_{max}} \tag{3.11}$$

$$z_{max} = \frac{(pH_{max} - pH_{min\,bad})}{pH_{max}} \tag{3.12}$$

Using proposed equations (3.11) and (3.12), wear degree Z_b, appearing in formula (3.4), was determined based on the relation:

$$z_b = \frac{z}{z_{\max}} \tag{3.13}$$

The wear on the border of steel was tested, in this case 1.5 cm from the surface of the structure.

3.2. Description of the tests

Applying the above mentioned durability model one needed to identify precisely ”n”, that is the deterioration factor, appearing in formula (3.4). The resistance of tested columns was determined by means of sclerometric method for testing the concrete resistance to compression using Schmidt’s hammer of N type. Successively, 9 samples were obtained from the structure. They were marked with numbers from 1 to 9. The samples from 1 to 6 originate from the weather conditions (columns of storage area for prefabricated elements). The following drawing presents the location of the samples. After having executed micro bore-holes on tested column facilities using core drilling rig (fig. 5), carbonatization test was performed on cut samples.

Different laboratory techniques are used to determine carbonatization depth for example chemical analysis, structural X-ray analysis, spectroscopy in infra-red radiation and analysis termogravimetry. The most popular method of research of progressive carbonatisation is spraying phenolphthalein solution in thinned liquor on fresh fracture of concrete. Progress of carbonatization was tested by spraying phenolphthalein solution in dilute alcohol on fresh concrete fracture and by using reagents in upper part of pH scale: pH = 8.3 to pH = 14.0. Tests of pH reaction of pore liquid were carried out on micro bore-holes of 50 mm diameter (fig. 6). While investigating progress of carbonatisation we find out that at pH≥ 12 concrete cover keeps its own protective proprieties, at pH within the limits of < 10.5; 12) the concrete cover also still keeps the protective proprieties, however decrease in pH takes place. At pH within the limits of < 9; 10.5) concrete cover loses its own protective proprieties, and at pH lower than 9 neutralization of concrete takes place. When pH equal 8.3 then a full wear of concrete cover take place.

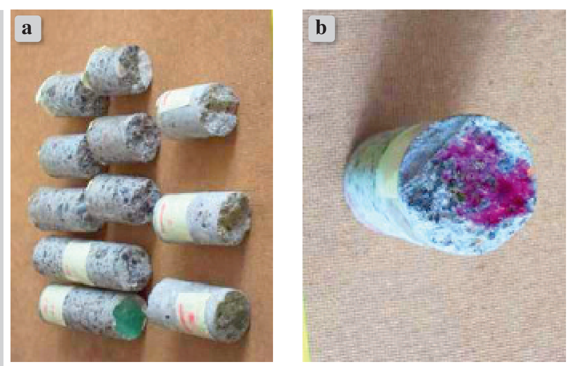

Figure 5.
Samples of micro bore-holes taken from tested columns: a) general view, b) phenolphthalein solution coloration

3.3. Research results

Tests of pore liquid pH reaction were carried out on micro bore-holes from production hall columns (samples from no. 1 to 6) and on samples taken from

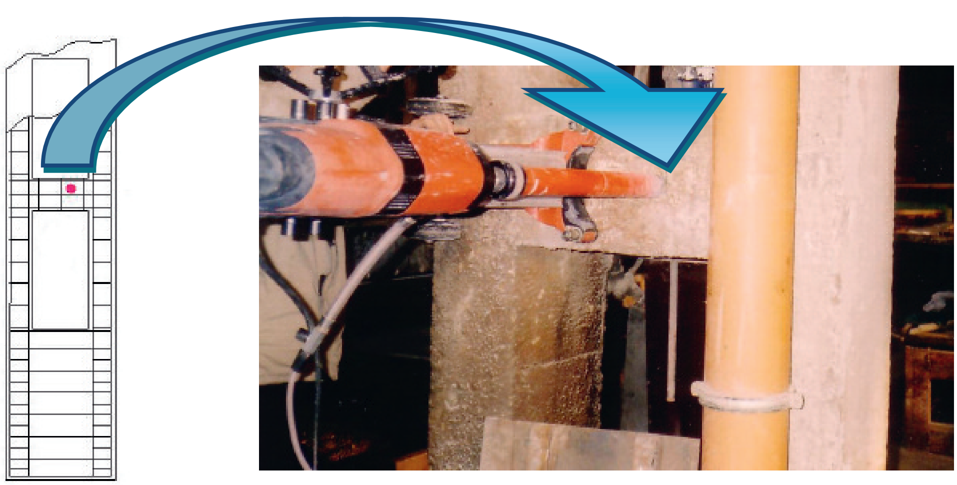

Figure 6.
Execution of bore-hole (concrete sample)

columns of prefabricates storage room (samples from no. 7 to 9).

Durability of columns was calculated using auxiliary model (3.4) according to [6]. At first wear on the ground of progress of concrete carbonatisation process was marked, then deterioration parameter was counted. The results enabled estimation of durability of reinforced concrete column structure using the above mentioned model.

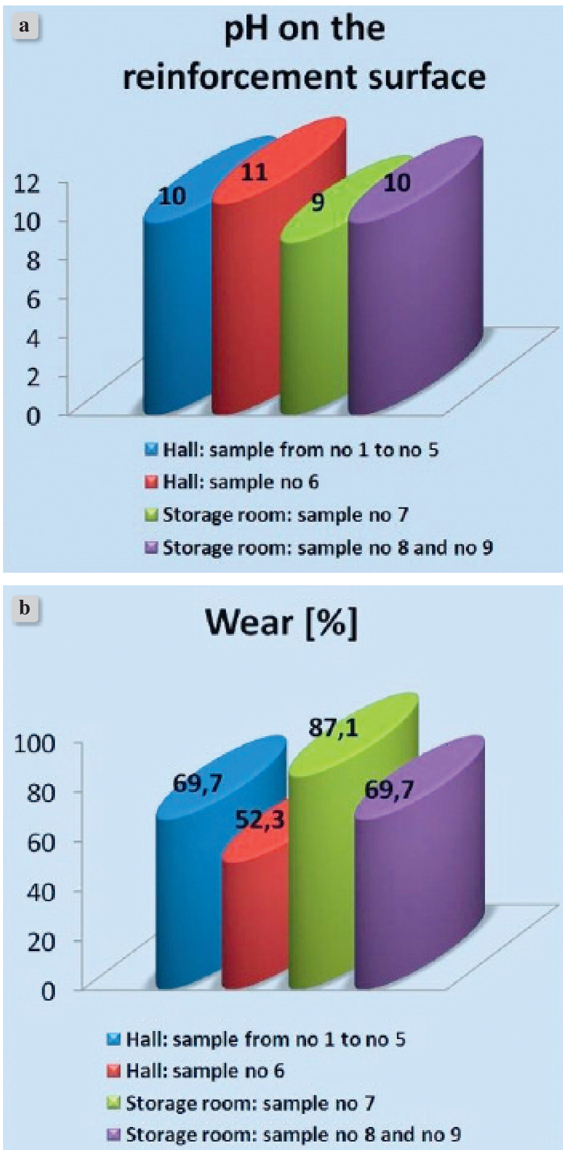

Figure 7.
a) progress of concrete carbonatization on the surface of reinforcement, b) waste of reinforced concrete columnar structures

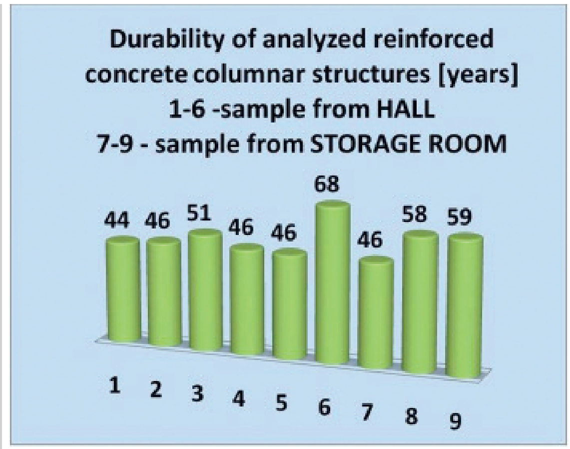

Figure 8.
Forecast of service life of analyzed reinforced concrete columns

4. ANALYSIS OF THE RESULTS OF COLUMNAR STRUCTURES DURABILITY TEST

In case of sample No. 7 (storage area) research result is pH 9. In this structure the concrete cover lost its protective proprieties and its complete neutralization may take place in near future. In case of sample No. 6 (hall) research result is pH 11. In this case the concrete cover still maintains its protective proprieties for steel reinforcement. In near future the wear of the showed column (sample) No. 1(hall) will be predicted. Durability of No. 1(hall) is estimated to be 44 years. The remaining wear time of this structure is only 10 years. Reinforced concrete column in the hall, from which sample no. 6 was obtained, showed the greatest durability. Anticipated wear time of this structure amounts to 68 years. However, this column was protected in the place of sample taking, which limited the access of aggressive environment elements to the interior of the structure. Results of durability obtained from measurements performed on columns in storage area turned out to be more favorable than those obtained in the hall. This results from greater endurance of columns in the storage area. Carbonization of concrete is a process during which one can describe function of hyperbolical type showing asymptote, corresponding with terminal range of carbonization in most cases. It was noticed that in low-cut samples from structure No. 2 (hall) and 3 (hall), based on the pH graphs on depths, progress of carbonization in concrete cover – was considerably quicker than that in the remaining samples. Excessive concrete cover quickly lost its protective proprieties in the face steel. Comparing investigated objects No 2 (hall) and 3 (hall) with other ones, we can find out that the reason for obtaining worse result of carbonization progress is the fact, that the objects were protected not enough, as covering painting coat was damaged to large extent, as compared with remaining objects.

5. THE METHOD OF THE REINFORCED CONCRETE COLUMNAR STRUCTURES REPAIR

In many cases concrete cover of analyzed columnar structures has lost its protective properties and if in the near future any rehabilitation treatments were not taken then its total neutralization could occur very fast. In single cases of columns in the storage area cracking of concrete cover could be visible and also its defects exposing corroded reinforcement (Fig. 9a).

The great importance has early discovery of the process of excessively fast degradation of the whole layer of concrete cover before lose its protective properties towards reinforcement. A single treatment of spreading protective covers on concrete surfaces may be used. Additional protective measures may always cause slowing down of devastation processes in such a way that during the use of structures, reinforcement corrosion does not occur.

Projecting corroded reinforcement should be cleaned and decline of concrete cover should be completed in order to prevent further spreading of reinforced corrosion resulting in structure's weakening. After recommendations following actions were taken. A cracked concrete cover was removed, road cleaned from rust. Next roads were painted with anticorrosive paint. Then concrete and rods surface were covered with remedy primer which increases adherence and intensifies absorbable, excessively absorbent concrete surfaces. The defects were leveled with fast hardening mortar for repairing concrete or reinforced concrete foundations. The last action was grounding of the whole column with remedy primer. This remedy primer thanks to its ability to penetrate strongly penetrates into concrete, strengthening and protecting it against damp (Fig. 9b).

Figure 9.
Reinforced concrete columnar structures: a) corroded concrete reinforcement, b) after renovation

6. CONCLUSIONS

Estimation was made of the existing durability of reinforced concrete structure based on the research of progressive carbonatization of concrete cover.

In most cases this carbonatisation decides about durability of reinforced concrete structure. It is so because the content of CO_2 is from 10 to 100 times greater than that of other sour gases, such as SO_2 or HCl. Average durability of columns in the hall amounts to 50 years, and average durability of columns in the storage area amounts to about 54 years. The tested columns are classified into the category of buildings of average durability. Most of industrial buildings belong to this category. The remaining time of wear amounts to about 20 years. In many cases the concrete cover lost its protective proprieties and if no rehabilitation actions are taken in the near future, the whole cleading will be neutralized soon.

Appropriate early detection of degradation process of concrete cover before all layer concrete cover will lose protective proprieties for reinforcement has large meaning. One can use simple intervention means consisting in putting protective coats on surfaces of concrete. Additional protection can always contribute to slowing down the processes of deterioration to such degree, that in the period of use the structure would not undergo corrosion of steel. There are two cases in which carbonatisation may take place. The first case is when precipitation influences the surface of the concrete, temporarily moistening it. This is the case of concrete columns found in the storage area. The second case occurs when surface of concrete is protected against falls, e.g. in the interior of a room, which is the case of the columns found in the hall. In investigated case progressive carbonatization was greater in structure exposed to weather conditions. Lower porosity of columns was found in the storage area. It can be supposed that grains of cement which don't hydrate during hydration process, now under the influence of water from atmospherical falls can start continue further hydration, which in consequence leads to rise durable structures of hydrated calcium silicates (C-S-H), which caused higher tightness of concrete. Less porosity and lowered pH of columns in storage is a result of reaction of calcium hydroxide with diffused carbon dioxide, because in consequence soluable calcium carbonate, which crystallizes in pores is created with difficultly.

Obtained results show technical state and may be the foundation for starting rehabilitation treatment allowing to extend the remaining service life. On the basis of carried out research, a method of analyzed columnar structures repair was proposed, which is already executed.

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