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CASE STUDY REGARDING THE INFLUENCE OF THE OPERATING ENVIRONMENT ON THE DEGRADATION STATE OF AN INDUSTRIAL BUILDING

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Abstract: *The operating environment, by aggressive agents contained, causes diverse manifestations of the structural degradation state on constructions elements, with negative effects on the operational reliability. Identifying the causes of degradation, the manifestation forms and the effects produced represents an important phase in the evaluation process of the technical condition of a building.*
In this context, the paper represents a detailed description of the investigation process made on an existing industrial building, for which the environmental factors, due to the technological flow, are an important cause for structural elements degradation.
Following the investigation process, defining elements regarding geometrical and mechanical characteristics are given and used in the building's structural analysis and designed rehabilitation solutions.

Key words: *degradation, chemical corrosion, reinforced concrete, structural rehabilitation, metal coating, concrete coating, reinforcement.*

1. Introduction

1.1. General Considerations

Buildings, no matter their destination, being the goods with the most lasting use period, have to fulfill, during their lifespan, some technical requirements regarding: structural resistance, stability, fire resistance, operational safety, durability, etc.

The fulfillment of these basic technical requirements is influenced by the materials the building elements are composed of, respectively by their mechanical characteristics, design manner, execution manner, maintenance and protection manner regarding the destructive action of the external environment and not lastly by their manner and conditions of operation.

Many times the buildings operation environment produces, due to the containing aggressive agents, different forms of structural degradation, with negative effects on the operational durability and safety of the building, so that the identification of the degradation causes, of manifestation forms and the effects on the structural elements, represent

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an important stage in the assessment process of the technical state of a building [2]. In this context, the paper represents a detailed description of the investigation process carried on an existing industrial building, for which the environment factors, due to the technological flow, represent an important degradation cause of the component structural elements.

1.2. Identification Data for the Investigated Building

The building segment, respectively the section "Surface treatments" subject to investigation regarding the determination of the degradation level of the structural elements as a result of environment conditions, is part of an industrial building type "ground floor hall", with 3 openings of 24.0*m* and 10 bays of 12.0*m*, respectively 6.0*m*, being situated between A - B axis of the industrial hall (Figure 1).

The resistance structure is composed of prefabricated reinforced concrete pillars, embedded in sleeve foundations, having a section of 70 x 70*cm* within A and D axis where they are disposed at distances of 6,0*m*, respectively 80 x 80*cm* within B and C axis where they are disposed at distances of 12.0 *m*. The structural elements of the roof are composed of transversal and longitudinal metal beams type "trussed roof", with an opening of 24.0*m* respectively 12.0*m*. The surface elements of the roof are coffer type of 1.50 x 6.00*m*, mounted at the superior bloom level of the transversal metal beams.

Within section "Surface treatments" subject to investigation, there were and are used by choice during the operational process development, chemical substances such as: nitric acid, chlorine hydride and sulfuric acid.

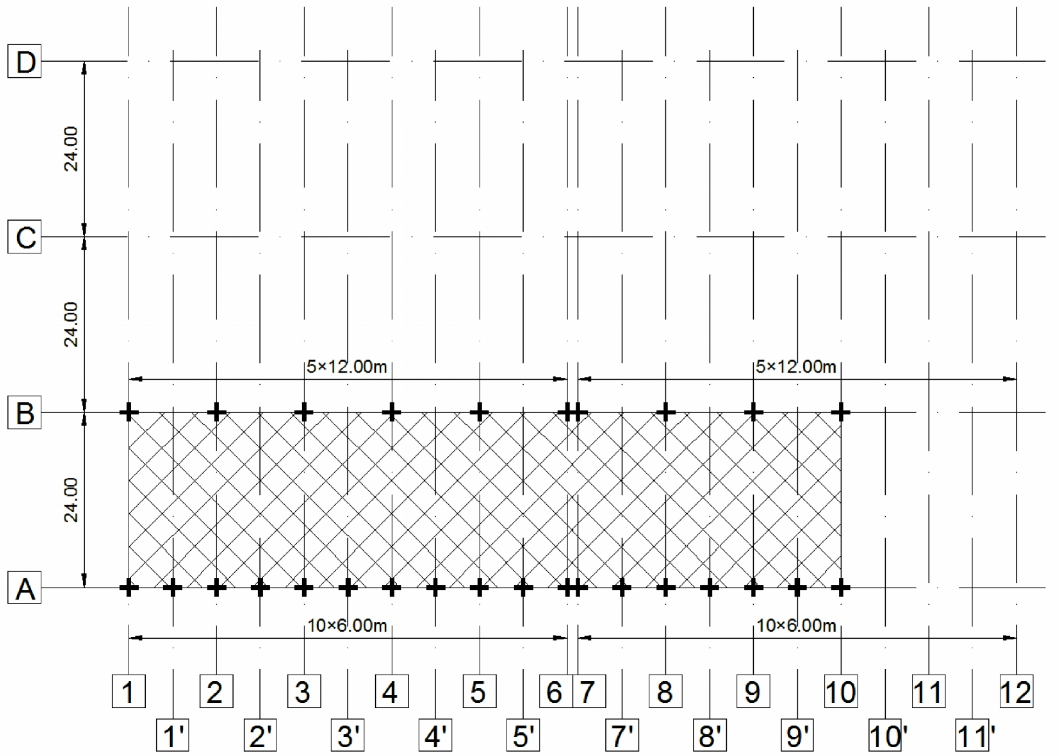

Fig. 1. *Ground floor plan*

2. The Assessment of the Building Degradation State

2.1. Investigation Methods

During the first stage of the building degradation state investigation, the assessment of the depreciation level of the physical – mechanical characteristics of the reinforced concrete structural elements has been had in view, adopting the following investigations methods:

- visual inspection of the degraded areas;
- verifying by measurements the geometrical dimensions of the structural elements;
- non-destructive tests;
- destructive tests carried on concrete cores extracted from the concrete pillars;
- lab analysis;
- local uncovering.

2.2. Causes and Manifestation Forms of the Degradation State

The investigation of the degradation state through the methods mentioned above, have highlighted the following depreciation forms:

2.2.1. Degradations on Reinforced Concrete Pillars

For these structural elements, on site investigations have highlighted:

- indents of the edges caused by accidental mechanical shocks, revealing here and there the reinforcement, without determining sectional reductions – Figure 2;
- segregations here and there of the concrete, as a result of inappropriate compaction in the moment of pre-casting on site – Figure 2;
- the cover concrete layer is insufficient in some areas (0.5÷1*cm*) – Figure 3;

Fig. 2. *Highlight the indents and concrete segregation – A4 pillar in A axis*

Fig. 3. *Highlight the insufficient cover concrete layer – A7 pillar in A axis*

- degradation through concrete carbonation, the detaching of the superficial concrete layer and local sectional reduction, the uncovering of the casing favoring its corrosion process; these degradations are produced at the inferior section of the pillars, predominant for pillars within A axis – Figure 4 and 5;
- visible cracks of the concrete in the direction of the clamps as a result of plastic slump after casting and the insufficient thickness of the covering concrete layer;

Fig. 4. *Highlight the degradation through concrete carbonation; reinforcement corrosion – A2 pillar in A axis*

Fig. 5. *Highlight the degradation through concrete carbonation – B5 pillar in B axis*

- blank sound when knocking the concrete with a hammer afferent to the inferior section of the pillars in B axis, especially towards the section near the one investigated.

As it was highlighted above, the causes of degradations are due as a result of an accidental mechanical shock, execution defects, plastic slump of fresh concrete, concrete carbonation through CO_2 action, chemical corrosion of concrete and electrochemical of the reinforcement, phenomenon emphasized by the presence of chlorine ions.

The degradation phenomenon of concrete and reinforcement has been ascertained to be more reduced for B axis pillars, but more accentuated for the A axis pillars, area where during the investigations, the presence of a moisture environment at the floor level and around the pillars has been noticed.

The emphasized degradation state of the A axis pillars, respectively in their inferior area, has been produced by the following mechanism:

– in time carbonation of concrete and the destruction of the protective film of the reinforcement;
– oxygen inflow through formed cracks and eventually through the pores caused by the flawed casting of the concrete;
– water inflow through cracks, casting pores and capillary pores;
– reinforcement corrosion and the concrete superficial layer expulsion.

If due to the technological process an atmosphere loaded with sulfur ions has resulted or sulfuric acid leaks at the floor level have been noticed, their/its presence in contact with the concrete forms products with volume increase, such as calcium sulfate (volume increase 124%), respectively hydrous calcium aluminium sulfate (ettringite), with volume increase of 227%, which favored the concrete expansion and expulsion.

2.2.2. Degradation on Roof Coffers

For these structural elements on site investigations have highlighted here and there the presence of some local detachments of the reinforcement protective layer and the appearance of some rust stains, especially in the fins area, as well as exfoliated sections of the finish layers applied in time.

2.3. Experimental and Theoretical Data Processing and Interpreting, for the Building Section Subject to Investigation

On site measurements, non-destructive determinations through combined method, destructive tests on extracted cores on the spot, as well as laboratory tests [3], have highlighted a reduction on the concrete section and on the reinforcement at the pillars inferior level, mainly on A axis, a reduction of concrete class, for all the pillars on A and B axis, as well as a content of chemical agents, superior to the one provided by standards.

2.3.1. Tests Using the Combined Non-destructive Method (with N type Schmidt sclerometer [5] and impulse ultrasonic method [4])

This combined nondestructive method has been applied because the precision of determining the resistance is usually superior to the simple non-destructive methods. For each element of concrete on which tests have been carried on, three sections have been taken into consideration, respectively three points for each section. The devices used for this method were: a type N Schmidt sclerometer and an ultrasonic MATEST device. The results for two of the concrete pillars on which tests have been carried on are indicated in Table 1.

The results of the tests for combined non-destructive method within the building section subject to investigation – Calculation table of the equivalent resistance for pillar A2 and A3.

Table 1

S	Np	Time *[μs]*	Thickness *[cm]*	Speed *[m/s]*	Rebound indices	Ref. strength *[N/mm²]*	Equiv. strength *[N/mm²]*
a	1	186.3	72.00	3865	33 34 34 35 35 35 35 36 36 37	19.8 →	**17.8**
	2	187.6	72.00	3838			
	3	186.8	72.00	3854			
	→			3852	35 →		
b	1	187.0	72.00	3850	34 34 33 35 35 35 35 37 36 37	20.0 →	**18.0**
	2	185.7	72.00	3877			
	3	186.4	72.00	3863			
	→			3863	35.1 →		
c	1	188.0	72.00	3830	33 33 33 35 35 35 35 36 36 36	19.3 →	**17.4**
	2	186.5	72.00	3861			
	3	187.1	72.00	3848			
	→			3846	34.7 →		

After analyzing the results in the above table, it has been ascertained that the equivalent compression strengths have values between 17.4 and 18.0 N/mm^2, equivalent strengths which come under the concrete class C12/15, inferior to concrete class C18/22,5 considered 40 years ago when the elements were executed.

2.3.2. Destructive Tests Carried on Cores Extracted from Site, on the building section subject to investigation – tests carried on cores extracted from three elements, respectively pillar A1, A2 and A3 – Table 2.

The destructive tests results carried on cores extracted on site Table 2

Core ind.	Place	d *[cm]*	h *[cm]*	Breakout force *[N]*	Section area *[mm²]*	Compression strength *[N/mm²]*	Equiv. compression strength obtained after correction coefficient is applied *[N/mm²]*
C1	pillar A1	8.0	8.0	65000	5024	12.94	**16.2**
C2	pillar A4	6.5	6.5	40000	3317	12.06	**16.1**
C3	pillar A5	6.5	6.5	37000	3317	11.40	**15.2**

After analyzing the results obtained on the extracted cores, results indicated in the above table, it has been ascertained that according to the practice code CP 012/1-2007, the equivalent compression strengths obtained, come under concrete class C12/15, inferior to concrete class C18/22,5 considered 40 years ago when the elements were executed.

2.3.3. Laboratory Chemical Results

Laboratory test results - chemical analysis Table 3

Crt. no.	Test name	Expression	Determined value	Value according to STAS 3349/1-83
1	pH value at 20^0C	-	6,8	4,5
2	soluble chlorides	mg Cl^-/Kg	1780	3000
3	superficial sulphates	mg $SO^{2-}{}_4$/ Kg	3250	5000
4	total sulphates	mg $SO^{2-}{}_4$/ Kg	7890	5000

After the laboratory chemical analysis, a total content of sulphates has been ascertained, superior to the one considered by the specialty standard, concentration which partially favored the degradation of the concrete elements.

2.3.4. Theoretical Determination of the Average Depth of Concrete Carbonation, by the following calculation formula [1], [6], [7].

$$\bar{x} = \frac{150 \cdot c \cdot k \cdot d}{f_c}(t)^{1/2} \quad (1)$$

in which:

f_c - concrete compression strength (N/mm^2);

t – CO_2 and / or chloride ions time of action;

c – coeficient depending by the type of cement;

k – coeficient of environmental conditions;

d – coefficient that takes into account the influence of CO2 and chloride ions concentration.

As a result on applying the above calculation formula, considering a concrete class C18/22,5, used at the moment of execution of the concrete elements, respectively 40 years ago, an average depth of carbonation of 2.15cm resulted.

2.4. Experimental and Theoretical Data Processing and Interpretation, Carried on for the Building Section near to the One Investigated, where There Are Normal Conditions of Operation

Within the section near to the one investigated, respectively within the section situated between B - C axis of the industrial hall, where a normal operation process is being carried on, without using chemical agents, only destructive tests have been carried on, on cores extracted from three elements, respectively pillar C1, C2 and C3, and the results of these tests are indicated in Table 4.

After analyzing the results obtained on the extracted cores, results indicated in the above table, it has been ascertained that according to the practice code CP 012/1-2007, the equivalent resistances on compression obtained come under concrete class C16/20, in relative to concrete class C18/22,5 considered 40 years ago respectively when executing the elements.

The results of destructive tests on cores extracted on site in the section near to the one investigate d, with a normal operation process Table 4

Core ind.	**Place**	**d** *[cm]*	**h** *[cm]*	**Breakout force** *[N]*	**Section area** *[mm^2]*	**Compression strength** *[N/mm^2]*	**Equiv. compression strength obtained after correction coefficient is applied** *[N/mm^2]*
C1	pillar C1	8.0	8.0	65000	5024	16.9	**21.1**
C2	pillar C2	6.5	6.5	40000	3317	16.1	**20.9**
C3	pillar C3	6.5	6.5	37000	3317	15.4	**19.4**

2.4.1. Theoretical Determination of the Average Depth of Concrete Carbonation, using the above relation (1).

As a result on applying the above calculation formula, considering a concrete class C18/22,5, used at the moment of execution the concrete elements, respectively 40 years ago, without chemical agents contained, an average depth of carbonation of 1.56 cm resulted.

3.Conclusions

As a result of data analysis and interpretation obtained as a result of experimental and theoretical tests, the following have been ascertained:

– a more emphasized decrease of the concrete class for structural elements within the section ”Surface treatments” subject to investigation, with approximately 25%, in comparison to the next section where a normal production process is being carried on, without chemical agents – Figure 6, 8;

– a carbonation average depth for concrete elements situated within ” Surface treatment” section subject to investigation, with approximately 40 % higher, in comparison with the section next to it where a normal operation process is under development, without a content of chemical agents – Figure 7.

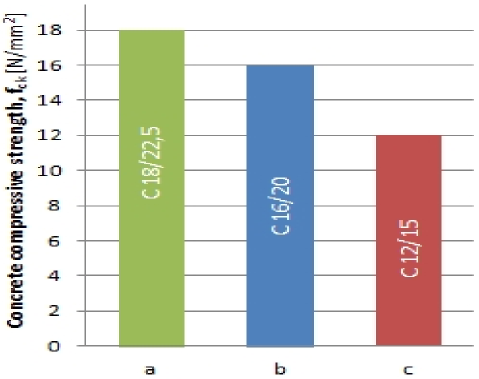

Fig. 6. *Operating conditions influence over the concrete class:*
a. at execution date (1975);
b. normal operating conditions (2015);
c. special operating conditions (2015).

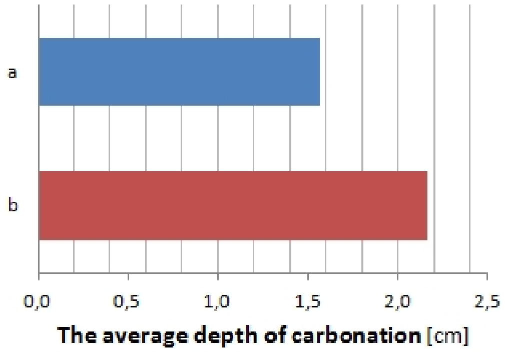

Fig. 7. *Operating conditions influence over average carbonation depth (in 40 years):*
a. normal operating conditions;
b. special operating conditions.

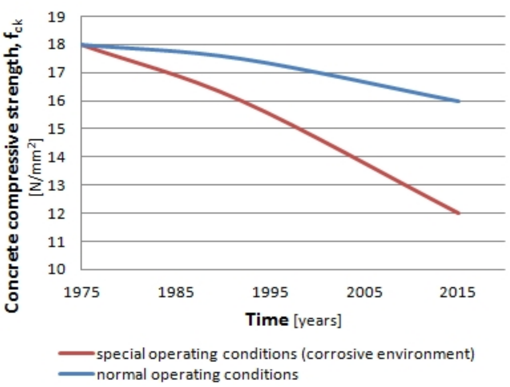

Fig. 8. *Operating conditions influence in time over concrete compressive strength*

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