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ASPECTS REGARDING DIAGNOSIS AND REHABILITATION OF AN INDUSTRIAL REINFORCED CONCRETE STRUCTURE

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Abstract: *Chemical corrosion is the main cause of degradation of reinforced concrete structures with extended operating system in an aggressive chemical environment. As a result of chemical action a significant number of industrial buildings developed and operated in the chemical industry before 1989 suffered pronounced degradation state. The paper treats theoretical and practical aspects related to procedures for investigation, diagnosis and rehabilitation of a concrete structure from dyes platform "COLOROM" Codlea. Rehabilitation solution proposed leads to the restoration of damaged structure capacity to a level 130% higher than that of the undamaged state.*

Key words: *chemical corrosion, structural rehabilitation, state of degradation, short concrete console, rigid concrete shirt.*

1. Introduction

1.1. General

Aggressive operating environment on buildings from "COLOROM" Codlea Platform and "CELOHART S.A." Zărneşti put his imprint on the state of structural components.

Technological processes carried out in production sections caused significant structural degradation due to the increase in air concentration of Cl^{-}, SO_4^{2-} ions, the leakage of water loaded with chemicals and prolonged action of CO_2.

Corrosive chemical agents depend on the nature of chemical substances or components participating or resulting from manufacturing.

Several buildings from Codlea and Zărneşti chemical platform of dyes and paper were surveyed. Their structural elements degradation, presented in various forms is:

• S.C. COLOROM S.A. CODLEA (dye-stuffs industry):
- ACID 'I' section;
- "INTERMEDIARIES B1" section;

• S.C. CELOHART S.A. Zărneşti (cellulose and paper industry):
- SULPHUR storage.

Following studies and investigations [2] have made proposals for solutions to rehabilitate the damaged structural elements due to chemical action.

An example of applying the coating solution for the rehabilitation of degraded components in a shirt stiff concrete is

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"Hall of production "INTERMEDIARIES B1" from COLOROM platform - Codlea, elements which are detailed in this paper.

1.2. Aspects of Chemical Corrosion Behavior of Industrial Structures Investigated Components

"Acid I" section

The building is situated on the chemical platform of SC COLOROM S.A. CODLEA, near a group of buildings housing major technological flows with chemical releases.

Building structure is made of transverse precast concrete frames, longitudinal linked through precast beams. Beams on the boundary pillars are through short consoles. Closing walls and divisions are made of brick. The all-cast slab over the first floor rest on prefab frame beams and the roof is made of precast coffer (1.5x 9.0 m) rested on longitudinal and central beams.

Flooring on the first and second floor is clad with antacid brick. First floor is provided with drainage channels to collect acid water from the manufacturing process.

In some parts, degraded antacid plywood encourages direct concrete contact with acid water.

Studies and observations on the issues investigated revealed the following:

- Concrete surface layer leaching out to a thickness of between 2 and 3 cm;

Fig. 1. *"Acid I" Section - Series B, axis 5, +5.50 m elevation, console and beam frame*

- Unveiling transverse reinforcing bars and its surface corrosion (Figure 1);
- Reduced thickness of concrete reinforcing bars cover layer;
- Non-uniform distance between the stirrups;
- Lack of basic measures of protection of concrete against chemical corrosion;
- Poor maintenance of the building.

"Intermediaries B1" section

"Intermediaries B1" production department is a two stories reinforced concrete frames structure building.

Prefabricated frame columns have section 50 x 50 cm at the first floor and 40 x 40 cm at the second floor and are provided with consoles for resting prefabricated slab beams. Intermediate, at +4.80 m elevation, there is an all-cast concrete floor and the roof is made of prefabricated coffers. Building foundations are of glass type, and the walls for closures and divisions are made of brick with vertical holes.

Degradation survey presented in Figure 2 revealed the following:

• For columns and consoles:

- Corroded reinforced concrete bars cover, with opened cracks at approximate (2.5…3) cm distance from the edge;
- Cracked concrete layer is slightly off when striking with a hammer;
- Local detachment of the concrete cover, with the highlight of corroded reinforcing bars;
- The unveiling of the aggregate grain from bonded side and highlighting the area of "rough" concrete;
- Leaching out of protective concrete on a thick from (2…6) cm;
- Corroded longitudinal and stirrup reinforcing bars, reducing their section with approx. 30% for columns and about (10…15)% for consoles.

• For slab at +4.80 m elevation:

- Sections with protected concrete from slab's intrados exfoliated (Figure 2);

Fig. 2. *"Intermediaries B" Section - Floor degradation at +4.80 m elevation, series B-C, axis 4-5*

Fig. 3. *"Sulfur storage" hall overview*

- Corroded floor ribs with longitudinal cracks in the concrete cover at a distance of approximate (2…3) cm from the edge (Figure 2);
- Protection concrete separated on parts from the beams and unveiling of reinforcing bars (Figure 2);
- Corroded reinforcing bars from degraded or fallen protection concrete areas and highlight the section bars reduction with approximate (20…30)%;
- Protective concrete leaching out on (2…4) cm thickness;
- Most affected areas are those around production tanks crossing holes.

• For roof's floor:

- Corroded concrete from coffer's slab intrados, with visible mesh of reinforcement;
- Coffers with strong damaged ribs by cutting of longitudinal reinforcing bars and reduction in certain areas of the rib section in proportion of 50%;
- Corrosion of reinforced concrete beams and attic;
- Concrete roof elements leaching out, on a thickness of (2…7) cm.

Sulfur deposit

The building has one floor, with precast reinforced concrete frame structure. Frame's columns are provided with two short brackets, one is to insure rolling beams suspension at an intermediate level and the other (at the end) assure the connection bond column - frame beam at roof level (Figure 3). Frame beam from roof level is a reinforced concrete girder.

Outdoor enclosures are made of brick alternating with glazed spaces.

At the structural level there is a pronounced degradation of the frame columns and brackets for roof girders support.

Investigations on these elements revealed the following aspects (Figure 4):

- Concrete leaching out on a (1-5) cm thickness range;
- Carbonation products erosion from the surface layer of concrete and highlighting (unveiling) aggregated granules (Figures 2 and 3);
- Presence of surface and in-depth cracks on columns and consoles faces, specific to sulfating corrosion (Figure 4);
- Cracks orientation towards disposition direction of reinforcing bars;
- Local detachment of the reinforcing bars cover;
- Unveiled reinforcing bars corrosion;
- Insufficient thickness of concrete reinforcing bars cover;
- Use of metal spacers for maintaining the position of reinforcing bars instead of plastic or cement mortar;
- Excessive moisture in the concrete columns due to water seepage from the roof;

Fig. 4. *"Sulfur storage" - Column and bracket, series A, axis 2*

- Lack of concrete protection against corrosion.

1.3. Analyze the Degradation of Structural Elements Investigated

Process of investigating the damaged items consisted of (Tables 1-3):
- Visual inspection of degraded areas;
- Photographing studied areas;
- Laboratory chemical analysis (with determinations result made on samples taken on the spot presented below);

"Acid I" Section Table 1

Nr.	Name	Expression	Determinant	Classification according to STAS 3349/1-83
1	*pH* indicator at 20 °C	-	7.8	4.5
2	Sulphates superficial layer	mg SO_4^{2-}/Kg	4260	5000
3	Total sulphate	mg SO_4^{2-}/Kg	5100	5000
4	Free CO_2	mg CO_2/dm^3	70	90

"Intermediaries B1" section Table 2

Nr.	Name	Expression	Determinant	Classification according to STAS 3349/1-83
1	*pH* indicator at 20 °C	-	6.8	4.5
2	Soluble chlorides	mg Cl^-/Kg	560	3000
3	Sulphates superficial layer	mg SO_4^{2-}/Kg	2578	5000
4	Total sulphates	mg SO_4^{2-}/Kg	9255	5000

"Sulfur" storage Table 3

Nr.	Name	Expression	Determinant	Classification according to STAS 3349/1-83
1	*pH* indicator at 20 °C	-	6.4	4.5
2	Sulphates superficial layer	mg SO_4^{2-}/Kg	12443	5000
3	Total sulphate	mg SO_4^{2-}/Kg	23150	5000
4	Free CO_2	mg CO_2/dm^3	82	90

- Treatment with phenolphthalein solution determines the depth of carbonation;
- Comment on the state of concrete reinforcement and degraded areas;
- Finding the geometric dimensions of the reinforced concrete consoles.

Investigative methods used revealed the chemical corrosion of concrete from consoles, because:

a) The action of SO_4^{2-} ions;
b) The action of Cl^- ions;
c) Action of CO_2 and electrochemical corrosion of reinforcing bars due to;
d) The action of oxygen and/or chlorine.

1.4. Ultrasonic Nondestructive Testing Method on the Structural Elements Investigated

To research the state of degradation of the presented elements, non-destructive tests were performed, using ultrasound on a total of 12 items.

The choice of sections, number of determinations, working way and results interpretation was done according to C25-1985 [3] and other specialized technical publications [1].

By this method were investigated a total of three consoles for each object in the study.

For consoles tested by ultrasonic method [4], obtained results indicate following classes of concrete:

• C8/10, for "Sulfur" deposit;
• C12/15, for "Intermediaries B1";
• C16/20, for "Acid I" section.

Concrete classes obtained, related to the expected ones, indicate advanced degradation process for consoles belonging to "Sulfur" deposit and "Intermediaries B1".

Degradation is lower for consoles owned by "Acid I" section.

2. Experimental Study on Structural Rehabilitation of "Intermediaries B1" Building

2.1. General

Study of resistance capacity of reinforced concrete elements, which have acquired a certain amount of degradation as a result of destructive actions, is a concern for many specialists in this field.

This is because most reinforced concrete industrial structures (especially in our country) are aged and the costs of demolition and replacement with the same or another type of structure are large, often reasonless or exceed the financial possibilities of the belonging units.

Experimental study contains a practical solution for the rehabilitation of degraded short consoles by coating them in a shirt stiff concrete.

Has opted for this solution because it is used frequently in rehabilitation of degraded industrial structures practice and are few studies on the degree of recovery of items bearing capacity strengthened through this method.

It was also found that these solutions [2] are competitive in that:

- To restore the safe bearing capacity in service;
- Is reasonably easily achieved with relatively simple means and technologies;
- Does not require special materials, difficult to be procured;
- Do not involve providing staff worker with a special skill;
- With appropriate safeguards, providing an enhanced element long life;
- Ensure a good working speed;
- They require only local dismantling production space;
- Arrangements can be made in building service;
- Are relatively inexpensive compared to other solutions.

2.2. Description of Experimental Elements

Short consoles used for experimental study are made of concrete reinforced longitudinally with bars and transversally with stirrups. To establish the geometric dimensions and longitudinal and transverse reinforcement area, a 20 tf service load was considered over the console.

Initial experimental models were made in the polygon for prefabricated elements from Zada SA Codlea construction unit and have been tested in reinforced and prestressed concrete laboratory from Technical University of Cluj-Napoca, Faculty of Construction.

The test stand was equipped with a metallic frame made of modules assembled together with metal screws, in order to adapt it to the shape and geometric dimensions of the experimental models.

Transmission load on the console was made in increments of 1-5 tf to load value of 5tf and 5tf after this value, using a 120 tf hydraulic press, driven by a central high-pressure pump (300 atm.), type INCERC Bucharest.

Registration strains were done with comparators mounted in four characteristic sections and for reading opening cracks a Brinell magnifier was used.

The initial and strengthening experimental models was made from C16/20 concrete class, OB37 steel for stirrups and PC52 steel for longitudinal reinforcing bar from columns and from cross consoles. Geometrical dimensions of the experimental brackets were based on general rules of composition. Transverse reinforcing bars were obtained according to expression (1):

$$A_{eo} \geq \frac{1}{3} \cdot \frac{Q \cdot l_c}{0.8 \cdot h_0 \cdot R_a} \cong \frac{Q \cdot l_c}{2.5 \cdot h_0 \cdot R_a}, \quad (1)$$

and longitudinal reinforcement related to the maximum of the bending moment from fixed support between console and column, according to expression (2):

$$A_a = \frac{p}{100} \cdot b \cdot h_0, \quad (2)$$

where:

Q - the shear load;

l_c - the span of shear;

h_0 - effective depth;

R_a - the resistance calculation of reinforcing bars;

p - percentage of reinforcing;

b - the width of reinforced concrete section.

2.3. Practical Way to Conduct the Experimental Program

Experimental program was conducted in three work phases, content of each stage are described below:

- **Work stage number 1:** test all experimental models, in which three elements to break and three elements to a 30 tf load.

- **Work stage 2:** strengthen the three elements tested up to 30 tf initially, by covering with a reinforced concrete layer.

The 8 cm thick reinforced concrete coat includes both console and column area to which is bounded.

After prior preparation of experimental models surface (by roughened and washing with running water) - models tested in the first phase up to 30 tf load - the reinforcing bar case was introduced and fixed in position through metallic spacers, then formwork and C16/20 concrete class pouring was made.

Strengthening experimental models and their tests were also made in reinforced and prestressed concrete laboratory from Construction Faculty of Cluj-Napoca.

- **Work stage 3:** breaking attempt for experimental models strengthened in stage 2.

2.3.1. Consoles tested to failure

For consoles, CS 1-1, CS 1-2, CS 1-3 (tested to failure), their breakdown has occurred at a force of 48 tf for consoles CS 1-2, CS 1-3 and 50 tf for CS 1-1 console.

Cracks appearing and development (Figure 5) show that they occur in number from two to three, which then spreads into new crack, smaller in terms of length and opening.

2.3.2. Consoles tested up to 30 tf

For the consoles made in second series (CS 2-1; CS 2-2, CS 2-3, CS 3-3), maximum load was limited to 30 tf ascertaining, in this test too, the appearance on the side of the console, a number of one, two or three cracks.

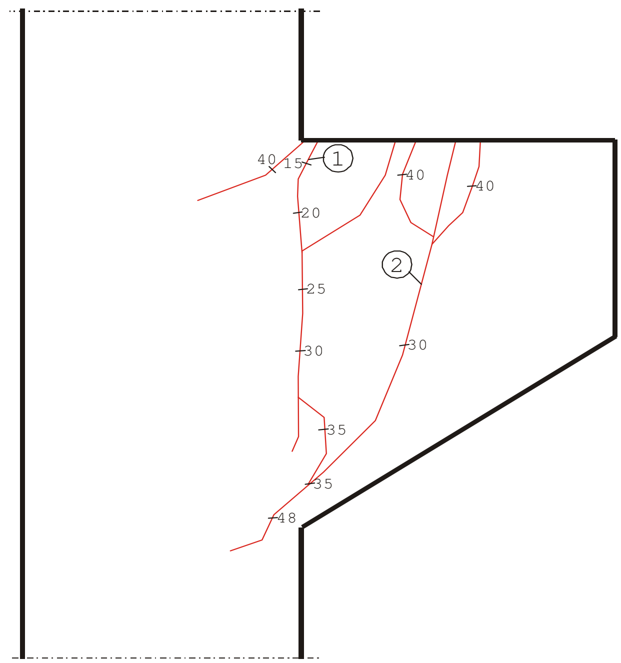

Fig. 5. *CS-1 console mapping cracks*

The first cracks appear, in all cases, at the joint point with the column, under a load of 15 tf.

Second crack occurred at a strength test value of 25 tf console, except CS 2-1 and CS 2-2, at which cracks occurred in 30 tf and 20 tf, respectively. Crack is observed for all three consoles to load 30 tf.

Second crack is usually located between the first and the third and is less developed than those, not going beyond the top half of the height of the console.

The third crack starts under the metal plate support or adjacent to it, reaching an angle of about 45^0 at a distance of approx. (1…34) cm from the lower corner of the console-column junction. The map for CS 2-1 console cracks appearance and development is shown in Figure 6.

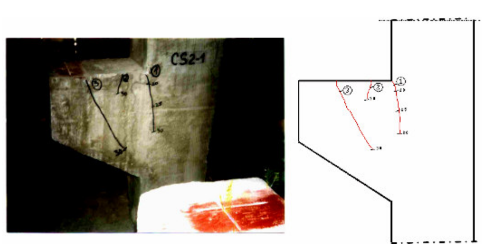

Fig. 6. *CS 2-1 console mapping cracks*

2.3.3. Reaction to vertical loads for consoles rehabilitated by coating

After passing the period of 28 days from consolidation by coating, experimental items were tested to failure.

The experimental program was conducted similar to tested stage one. Strains registration was ensured in this case with comparators and cracks open reading with Brinell magnifier.

- Presence on the side of the console of a 4 to 5 main breaks;
- First crack appears in the console-column junction for all consoles, at a vertical load of 30 tf for CS 2-1; 20 tf for CS 2-2 and 25 tf for CS 2-3;
- Other cracks are inclined (about 45°),

start under or adjacent to the support plate and develop the height of the console;

- Console failure occurred at a vertical load of 69 tf for CS 2-2 and 70 tf for CS 2-1, CS 2-3, by opening and cracks spreading and crushing concrete from the main column supporting the console (Figure 7).

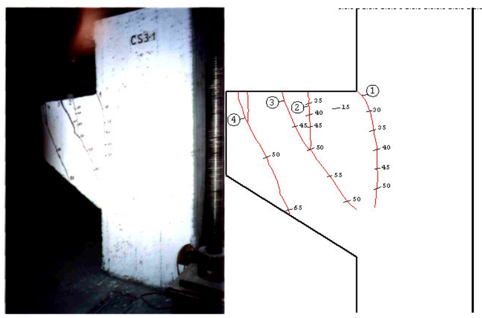

Fig. 7. *CS 2-1 console mapping cracks* (*consolidated*)

3. Conclusions

The issues presented on the mechanism of failure of brackets, highlights the role that coating concrete plays in developing transverse deformations of compressed diagonal. This is due to confinement effect that newly created coated concrete produce it on the degraded element, preventing the pronounced opening of fissures and ensuring growth of rehabilitated console ductility. Following distribution of critical load on experimental consoles unconsolidated and consolidated, tested to failure, the following information result:

• Critical load, obtained on a number of elements have similar values, ranging from (48-50) tf for the original console and between (69-70) tf for the enhanced version "coated reinforced concrete".

• Roughness degree of concrete surface (before consolidation), does not carry out any significant influence over strengthening capacity of considered element.

Regarding the recovery of bearing capacity (denoted by "n_{RCP}") for damaged and strengthened consoles, the following values resulted:

• Consolidation option "stiff concrete coat":

$$n_{\mathrm{RCP}} = \frac{\text{Ultimate load (average) strenghted elements}}{\text{Ultimate load (average) unstrenghted elements}} = \frac{69.7\ \text{tf}}{49.3\ \text{tf}} \approx 1.41 .$$

The high level of recovery of bearing capacity and ductile nature of failure components, recommend method of building raised in the paper as competitive, both in technical-economical, as well as technological aspects. This solution was applied for rehabilitation of building structures in reinforced concrete frames of industrial production hall "Intermediate B1". Rehabilitation solution for consoles, columns and beams, consisted in making an 8 cm thick concrete coat, molded by conventional methods. Concrete coat thickness has been established for reasons of resistance and reinforcing bars concrete cover recovery.

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