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AGGRESSIVE INFLUENCES OF WATER FROM WASTEWATER TREATMENT PLANTS ON REINFORCED CONCRETE MEMBERS

BY

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Abstract. The impact of wastewater within water treatment plants on the reinforced concrete members is studied. Structural members exposed to wastewater environment are susceptible to different forms of chemical attack. Usually, concrete is resistant to most natural environments and many chemicals. Concrete is virtually the only material used for the construction of wastewater transportation and treatment facilities because of its ability to resist to corrosion caused by the highly aggressive contaminants in the wastewater stream as well as the chemicals added to treat these waste products. However concrete is sometimes exposed to substances that can attack it and cause deterioration. The corrosion of the concrete is generated by the interaction between biological and chemical processes. Reinforcement corrosion, a consequence of concrete damage, is a very important process because this represents a significant threat for the resistance and stability of structures. Because many times maintenance costs are disproportionately high, indicating a lack of adequate durability, the comprehension of the damaging processes is a key step in order to manufacture highly durable materials.

Key words: corrosion; concrete; reinforcement; sewage.

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1. Introduction

The extensive mechanical actions on constructions during the operation of the plant, the lengthy influence exerted by a series of climatic factors, (temperature variations and humidity, repeated freeze – than, etc.), as well as the aggressive action of various agents (natural or triggered by industrial processes), may significantly contribute to the deterioration of framework parameters. The outcomes arising from this situation are assessed by means of some quality indices among which the durability of buildings is of major importance. The notion of durability is defined as the length of time in which constructions maintain a satisfying external appearance, performing at the same time their functions, under normal environment conditions and without any exaggerated maintenance costs.

In particular, the durability of reinforced concrete structures expresses their quality to be used for a long period of time, especially because of the protective action on the reinforcing bars, thanks to the calcium hydroxide which influences the alkalinity of cement. Durability may be slightly diminished under the independent or simultaneous actions of extremely aggressive factors, deriving from the features of environment and/or from certain structural internal alterations within the cement mass. The attack of aggressive agents mainly targets the cement component which is the most sensitive of the artificial conglomerate known as concrete (Glasser *et al.*, 2008). Besides mechanical stress, which in some situations may be extremely dangerous, determining the concrete's crack and the damage of its bonding with the rebar, corrosion is the most important factor of durability decrease (Schneider & Chen, 2005).

2. Corrosion of Concrete

Concrete corrosion represents the process of concrete deterioration due to the aggressive influence of the environment and may be physical, chemical or biochemical. Physical corrosion has detrimental outcomes as it develops stresses within the concrete, being determined by various causes. The basic physical phenomena of corrosion are dissolution and expansion. The most hazardous physical phenomenon of concrete corrosion is that of solubilization, which the aggressive agents exercise on cement hydrates, in particular on calcium hydroxide. Chemical corrosion involves chemical reactions between the environment components and the newly created cement hydrates, reactions which are set apart by their character and by the nature of reaction products. This situation brings about the creation and the development of corrosion according to mechanisms, which may be

a) corrosion processes by decalcification / removal of calcium ions from the cement component;

b) corrosion processes through expansion.

In either natural or industrial contexts, the causes and, as a result, the mechanisms of the physical-chemical corrosion of concrete, do not manifest separately, irrespective of the type of the main mechanism. Therefore, it is necessary that the study of corrosion outcomes should be conducted taking into account the action of individual aggressive agents as well as the action of complex corrosive environments (Wang *et al.*, 2006). Detrimental chemical processes may also be engendered by microorganisms, such as bacteria, moss, algae, lichens, fungi, either through their secretions or though the alterations caused to some substances of the environment. Biochemical corrosion is specific to water engineering constructions, being quite common in pumping plants, sewers or domestic sewage pipes, and especially in wastewater treatment plants. Biochemical degradation of concrete is mainly determined by the presence of bacteria, microorganisms which are on the borderline between plants and animals, having a very intense metabolism. Depending on the value of the oxydo-reduction (their oxygen requirements), bacteria are classified as: aerobic and anaerobic.

Aerobic bacteria grow in oxygenated environments, oxygen being essential for them. These bacteria together with specific enzymes oxidize organic substances, hydrocarbons, proteins, detergents (frequently met in sewage), converting them into carbon dioxide, sulfur dioxide, calcium salts, potassium, magnesium, phosphorous, etc., in the intermediary stages also producing ammonia and hydrogen sulfide. During the next stage, sulfur dioxide and sulfur are oxidized to sulfates, which have a strongly adverse effect on concrete and reinforcing bars.

Sulfur is stored as nutritive material in the cells of aerobic bacteria and are oxidized as sulfuric acid, which is further neutralized by the salts of carbonic acid. Anaerobic bacteria grow in environments with less oxygen, or even without it; this element is produced by reducing organic or inorganic substances, following their decomposition (for example, sulfates are reduced to hydrogen sulfide, glucose to lactic or acetic acid). Among concrete damaging bacteria we may also include nitrifying bacilli. These ones convert ammonia compounds into nitrates. Algae and moss trigger concrete corrosion due to the humic acids resulted from their putrefaction, and due to the carbon dioxide released after the photosynthesis. Fungi engender a highly acid environment (pH = 1.9...2.8), through their gelatinous mycelia, which spread all over the concrete and penetrate deep within its core.

In conclusion, there are various causes of biochemical corrosion, depending on the nature of microorganisms and on the growing conditions, on the environment with propitious features, namely, the presence of humidity, of temperatures ranging between 0° and 80°C, a pH less than 10, sediment deposits, vegetal or animal wastes. Over time, the strength and behavior of concrete under either the natural or industrial aggressive chemical action is mainly provided by its compactness and, generally speaking, by its internal structure, which is successively influenced by the composition selected (type of cement and of aggregates, amount of water) and by the technology of placing.

3. Corrosion of Reinforcement

Theoretically, if a concrete structure was accurately designed and manufactured, the corrosion of the reinforcing bars should not occur. The cement component, on account of its alkaline nature, is able to provide a high level of protection against corrosive agents. Compact concrete with a high degree of permeability cuts down to minimum the penetration of oxygen, chlorine and carbon dioxide ions, factors which generate and accelerate the process of steel deterioration. However, the deficient manufacture and operation of constructions located in highly corrosive environments usually determines reinforcement corrosion. Because this represents a significant threat for the resistance and stability of structures, it is compulsory to examine the causes which triggered it and to undertake proper measures. Steel corrosion is a slow process of progressive degradation over time, following the development of some chemical or electrochemical reactions under the action of the environment.

In the chemical reactions triggered by dry gases or by liquid solutions which are bad conductors of electricity, it is created a mix of hydrated acids, with a much larger volume than that of non-oxidized steel. Electrochemical reactions occur when steel is in contact with liquid chemical substances which are conductors of electricity (electrolytes). Thus are created iron ions which may further combine with oxygen or with ions of hydroxyl, bringing about the corrosion of reinforcement by rust. Electrochemical processes involve the formation of a galvanic element which usually appears in the areas where reinforcing bars have unevenness or irregularities (soldered joints, coexistence of oxidized and non-oxidized areas, manufacture flaws). In the case of interaction with an aggressive environment (in a broad sense this may be the covering concrete, the cement paste for injection, the air, the soil, generally speaking any electrolytic solution which is able to come into contact with the reinforcement and corrode it), the corrosion of reinforced concrete elements mainly develops according to two patterns namely

a) direct destruction of the concrete layer covering the reinforcing bars, together with its exposure and corrosion;

b) reduction of electrolyte alkalinity (lying in the pores of the concrete which comes into contact with the reinforcement) or the penetration of corroding ions from the outside through the concrete layer. Thus a certain type of corrosion is generated, sometimes more accelerated than that of steel in direct contact with the environment.

The outcomes of corroding the reinforcement inserted in concrete consist in (Güneyisi *et al*., 2005)

a) shortening the cross section of the reinforcement;

b) splitting the concrete layer covering the rebar.

By reducing the size of the cross section, the load bearing capacity of the reinforcement drops proportionately, and the characteristics of deformation and fatigue resistance decrease by more than the reinforcement reduction (Chung *et al.*, 2008).

The accumulation of rust on the reinforcement exterior boosts its volume, as rust has a much higher volume than steel (theoretically up to six times bigger). Therefore, cracks parallel to the reinforcement may appear within the concrete under the action of splitting forces caused by the fact that the surrounding concrete prevents the steel to expand its volume. If the covering layer is slim, it loosens and may cause the sudden break of the element, especially when the reinforcement-oriented cracks develop in the bar-fastening areas.

The corrosion which occurs in environments without big amounts of oxygen available, determines the creation of corrosion products whose volume is only 1/2...2 times higher than that of steel. Such a corrosive process is slowly developing and, in special cases, the corrosion products may scatter in the wholes and pores of concrete, without triggering the cracks and split-up of the conglomerate. In such rare situations the reinforcing bars can become much corroded, without any warning which might indicate the possible break. In the case of our study such a situation is encountered within the sludge fermentation tanks. The above mentioned phenomena may occur if the watertight and protection layers of concrete are deteriorated after extensive use.

4. The Complexity of Corrosion Phenomenon

The extremely strong aggressiveness of liquid or gas environments with which various facilities of the sewage treatment plant come into contact and in which harmful substances like the ones aforementioned were identified, requires the comprehension of the damaging processes which are occurring in order to manufacture highly durable materials. Taking into account the multitude and diversity of chemical compounds, the physical-chemical and biochemical phenomena which can cause concrete and reinforcement destruction, are not thoroughly known. The mechanisms based on which the chemical reactions occur between concrete components and aggressive agents, may be explained only for certain substances and in a separate manner, without taking into account the aggravating aspect, resulting from the cumulated action of two or more corrosive factors. In most cases there are no accurate data about the concentration of aggressive agents from the atmosphere deposited on the external sides of the construction elements as condensation, and about the weather conditions in various periods of the year.

In addition, conclusive data regarding the presence and concentration of some concrete and reinforcement damaging chemical compounds from wastewater are seldom provided when periodic measurements are performed. Their effect is assessed statistically, in order to increase their representative character, but this activity involves a large volume of work and a long period of time for gathering all data. Even in this type of context, one cannot rule out inherent uncertainties which corrupt the accuracy of results.

We should also consider the subjective influences caused by the technical condition of measuring instruments and of installations generating emanations or pollutant leaks which may lead to the increase of the concentration level. Furthermore, the level of professional training and the degree of diligence of operators involved in the manufacturing processes and of those who perform field measurements may vary to a great extent. Therefore, taking into consideration all these aspects and the features of corrosive processes in open areas under the influence of climatic factors, the endeavours to formulate exaggerate speculations concerning the processes and mechanisms which, for now, are not completely clarified, seem futile (Neville, 2004).

The current stage of understanding complex phenomena which occur is really useful for the accurate assessment of the effects of water, vapours and gases on structural elements. In addition, it is very significant to identify design, installation and manufacture flaws (which are able to trigger and favour the propagation of corrosive processes), to diminish as much as possible the negative outcomes of the deficient construction design. The concentration of aggressive gas from the atmosphere and their actions on construction elements vary depending on climatic conditions and on their location in relation to the gas release source. Water under the shape of mist as well as various types of precipitations determine the formation of acid solution with different concentrations, whose fine drops are carried by drafts and splashed on the objects met on the way.

Being heavier than air, sulfur dioxide and hydrogen sulfide fall down and settle in the areas between constructions and in lower areas, where the possibility of removal is more difficult. Water accumulation on the horizontal side of the concrete elements by pooling for a long period of time, the effects of repeated freeze – than, washing of available sides by rainwater, the action of wind and snow storm carrying ice particles on the concrete directly exposed to bad weather conditions, all represent factors which accelerated the dynamics of corrosive processes. According to the type and location of the element within the structure, the corrosion process was intensified by certain physical-chemical phenomena. Thus, on the horizontal sides of boards and beams, the film of aggressive solution moves towards the points of drop creation which are in the micro-areas of low height. Here, under the effect of gravitational force, when the film has a certain thickness, superficial stress is overcome by creating drops, which detach from the support area.

Then, the forces of superficial strain are balanced, until the width of the solution film increases up to the point when a new drop is formed. Therefore, the film of aggressive substance develops an oscillating movement in the micro-areas of lower height, constantly washing these surfaces. The motion of molecules of the aggressive solution enhances the reaction with cement compounds. The mentioned aspects may represent a satisfactory explanation of the serious deterioration of most plane elements. On the vertical sides of pillars and walls occurs the phenomenon of concrete washing with chemically aggressive solutions, so that the intensity of the damaging impact increases in the lower areas being further accentuated by the tendency to gather liquid in these areas. On account of the lower temperatures in certain periods of the year, the condensation affects the superficial layers. This way, although dry gases have a small effect on construction materials, by dissolving them through the condensation layer, aggressive solutions are formed which easily penetrate the permeable texture of concrete.

The framework of most facilities being manufactured from precast elements and its structural design favoured the appearance and extension of some deterioration processes. By carefully examining the areas where the wall elements of the settling tanks were joined, it was observed that in some areas the monolith concrete cracked and was dislocated, thus exposing the reinforcing bars to the direct contact with the environment conditions and to the attack of corrosive agents from the atmosphere. The continuity areas of precast elements, no matter how appropriately manufactured, represent the most sensitive parts of a framework when acted upon by the corrosive agents. Initially, in the joining areas between wall strips pre-cracks appear where the end of the precast element comes into contact with the freshly poured concrete. Afterwards, these ones develop to cracks following the contraction phenomenon.

The lack of continuity between the two materials is determined by the presence of some carbonated layers of concrete and of impurities on the outer layer of the precast, and, especially, by the concrete contraction which acts destructively on the tendency to make intimate contacts between the two types of concrete. The structural flaws from the joining area are greatly augmented by the outcome of soldering reinforcement and metal fittings, which, by heating damage the concrete to a certain depth, agglomerating the contact surface with inadhesive products. Due to the reinforcement concentration and to the need to provide their continuity by soldering or overlapping, adverse strains are exerted on the concrete and steel conglomerate. The discontinuity and heterogeneity of materials in the joining area determines big differences of potential, thus creating propitious conditions for the appearance and development of electrochemical corrosion of reinforcement. The phenomenon occurs on favourable ground due to the neutralization of the protective alkaline environment by the carbon hydroxide from the air.

The alternating movements triggered by earthquakes have a significant detrimental impact on joints. These motions are able to speed up the initial phase of concrete micro-cracks and to cause cracks in the joining area and in its surrounding area, enabling humidity and corrosive agents’ penetration to the reinforcement. The above mentioned aspects explain the nature and the scope of degradation in the articulation areas of precast elements, especially those of walls.

5. Conclusions

In theory, based on a complex study of causes and effects related to the occurrence of corroding processes, we may forecast the impact of chemical attack on buildings and on the environment. Such an approach of the durability issue becomes possible provided that the development of damaging processes over time should be known and the interaction as well as the influence of various factors is taken into account. Moreover, there should be the possibility of tracking the evolution of aggressiveness in order to maintain it within certain limits, both from a qualitative and a quantitative point of view.

As long as the mechanisms of causing and developing damaging processes are known, hypothetically the effects of certain aggressive environments light be anticipated and the selection and planning of proper protection measures are facilitated.

In real condition of operating technological installations and networks, usually the maximum concentration of corrosive substances is exceeded, and humidity and air temperature vary within wide enough limits. Quite often, the intensity of corrosive processes is hard to forecast and to manage, especially when the aggressive actions go much beyond the initially set parameters. The multitude and the complexity of diffused chemical agents, both inside manufacture halls and on industrial platforms, the interference of phenomena which trigger concrete and reinforcement deterioration, as well as the diversity of contextual conditions for these processes, encumber the explanation of real mechanisms behind the corrosive attack.

In conclusion, the issue of constructions damage tends to become a current preoccupation of growing significance, from a technical and economic perspective. Therefore, it is necessary to change the orientation of the design process in order to elaborate some efficient solutions for protection (Bassuoni & Nehdi, 2007) as well as the direction of maintenance and periodic repair activities which have a significant role in the reduction of effects caused by corrosion, so that operational safety is not jeopardized.

In the case of new buildings, the introduction of a new approach is obviously necessary while for existing buildings it is compulsory to conduct a study on the actual state of alteration after long operating times.

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INFLUENȚE AGRESIVE ALE APELOR UZATE DIN STAȚIILE DE EPURARE ASUPRA ELEMENTELOR DIN BETON ARMAT

(Rezumat)

Se prezintă rezultatele unui studiu al impactului apelor uzate din cadrul stațiilor de epurare asupra elementelor din beton armat. Elementele structurale aflate în contact cu apele uzate sunt supuse unor atacuri chimice variate. În mod uzual betonul este un material cu rezistență ridicată la atacul multor agenți chimici agresivi şi în majoritatea mediilor naturale. În aceste condiții betonul este cel mai recomandat material pentru structuri utilizate în transportul şi tratarea apelor uzate, în condițiile în care rezistența sa naturală îi conferă protecție atât la agenții agresivi existenți în apele uzate cât şi la substanțele chimice utilizate în procesul de epurare. Cu toate acestea, anumite substanțe pot afecta integritatea structurală a betonului, procesul de degradare al acestuia având la bază combinații de procese chimice şi biologice. Coroziunea armăturii, ce apare ca urmare a degradării stratului de acoperire cu beton, constituie un proces important în condițiile în care aceasta reprezintă o amenințare serioasă la rezistența şi stabilitatea structurilor. În condițiile în care, de multe ori, costurile de întreținere ale structurilor de beton sunt foarte mari, elementele având o durabilitate redusă, înțelegerea proceselor de degradare reprezintă un pas important în vederea realizării de materiale cu durabilitate foarte ridicată.