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Investigation of different reinfocement corrosion causes in sewage environment-A case study

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Abstract

Concrete is commonly used in construction of sewage treatment plant elements. Concrete structures in wastewater collection and treatment facilities are subjected to microbiological corrosion, resulting in huge economic losses. In this article, concrete structures of a sewage treatment plant have been studied for assessment the level of damage by comprehensive set of experiments included visual inspection, compressive strength determination, electrical resistivity, half cell potential method, carbonation depth and chloride content measurement.

The reinforcement corrosion has occurred widely in different parts of plant. The first reason that could be imaginable for reinforcement corrosion is sulfate compound attack, however investigations revealed that other factors like chloride penetration and carbonation seriously affected reinforcement; in fact, a complex attack has occurred on structures which leads to concrete deterioration and reinforcement corrosion after less than a decade of operation.

Key words: concrete, durability, sewage treatment plant, sulfate attack, reinforcement corrosion, chloride diffusion

1-Introduction

The degradation of concrete in sewage environment by biogenic sulfuric acid attack is an important challenge in many cities around the world. Unfortunately some of these structures deteriorate after less than 10 years (EPA 1991). Parker (1945) has investigated on the microbial corrosion process in sewer environment. In anaerobic condition of slime layer beneath water level, sulfide-reducing bacteria (SRB), reduce sulfate ions present in the stream to sulfide ions (O'Connell et al 2010, Monteny et al 2000). Then these components use sulfate of wastewater to gain oxygen and release sulfur ions, sulfur ions react with H_2 dissolved in wastewater to form H_2S (Hewayde et al 2006). H_2S would be release to atmosphere above water level during pH reduction or turbulence (Monteny et al 2000, Saricimen et al 2003). Right above water level, there are aerobic conditions on concrete surface which sulfur-oxidizing bacteria like species Thiobacillus exist; the production of metabolism of these bacteria is sulfuric acid. Roberts et al 2002 state that when the pH of concrete surface is reduced to 9, these bacteria could colonize. The pH reduction occurred by concrete carbonation or the reaction of H_2S which is a weak acid by concrete (Jana and Lewis 2005, Roberts et al 2002, Davis et al 1998 and Silva and Rosowsky 2008). Sulfuric acid reacts with cement matrix, the first step is reaction between acid and calcium hydroxide ($Ca(OH)_2$).

$$Ca(OH)_2+H_2SO_4 \rightarrow CaSO_4+2H_2O \quad (1)$$

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Subsequently it is hydrated to form gypsum (CaSO4.2H20). The gypsum would react with the calcium aluminate hydrate (C_3A) to form ettringite which is expansive (O'Connell et al 2010):

$$3CaSO_4.2H_2)+3CaO.Al_2O_3+26H_2O \rightarrow (CaO)_3.(Al_2O_3).(CaSO_4).32H_2O \quad (2)$$

These two products are expansive and cause crack occurrence as well as increasing porosity and capillary absorption (Silva and Rosowsky 2008). By increasing the porosity, migration of other ions such as sulfate and chloride become faster and easier, thus, the rate of corrosion rises. Carbonation occurrence also could accelerate the deterioration of structures. Reaching these aggressive agents to the embedded steel in concrete, results in pH reduction near reinforcement allowing corrosion to start (Mehta 2006).
In this study the level of damage in concrete structures of Ahwaz treatment plant in Iran was assessed by a set of tests including half-cell potential method, determination of compressive strength of concrete and water absorption, chloride ions diffusion, carbonation test and electrical resistivity. These tests were performed in three different parts of sewage plant: entrance channel primary sedimentary tank and aeration tank. Former is working since 1993 and two latter had been working from 1993 to 2000.

2. Investigations

2.1. Exposure condition

Ahwaz is a large city located in warm area of south of Iran. According to 54 years Iran Meteorological organization statistic the average temperature in summer is 36°C and average relative humidity during these years is 43%. The chemical analysis of sewage during two year is presented in table 1.

Table 1. Chemical analysis of waste water during 2 years

Factor	2008				2009			
	spring and summer		fall and winter		spring and summer		fall and winter	
	inlet	outlet	inlet	outlet	inlet	outlet	inlet	outlet
pH	7.3	7.1	7.35	7.2	7.4	7.2	7.25	7.2
Ammonium (mg/L)	25.7	1.52	29.3	9.4	28	3.5	31.4	10.36
Sulfate (mg/L)	1250	1135	1044	842	1152	965	881	700
Chloride (mg/L)	959	862	993	852	1233	1008	1086	991

2.2. Materials

Using XRD test, the main component of aggregates is quartz. Also these aggregate are natural and rounded. Type 5 cement was been used based on local data. The cement to water ratio is unknown because of poor quality control during construction.

2.3. Method

2.3.1. Visual inspection: The main aim of visual inspection is to provide primary information about the structure condition. This gives the idea about the extension of deterioration and also helps in finding the best places for doing tests. Therefore, detailed visual inspection was performed before any test.

2.3.2. Compressive strength and water absorption: The concrete was drilled to get some cores in order to determine the compressive strength of concrete as well as water absorption. The compressive strength of concrete was determined in accordance with ASTM C39.

One of the concrete properties that are directly related to the quality of concrete is water absorption; this test could provide useful information relating to the pore structure, permeation characteristics and durability of concrete (Parrot 1992). Concrete cores were divided into two parts, affected and unaffected parts. Indeed, the affected part is the surface concrete which was affected by aggressive agents and it could be detected visually. The inner part is almost intact and looks sound. This easy work could help in comparison between transportation properties of affected and unaffected parts of concrete.

2.3.3. Electrical resistivity: Electrical resistivity method appears to be a useful and inexpensive technique for determination the rate of corrosion in concrete. The electrical resistivity of concrete is a function of moisture electrolyte content and porosity (Shekarchi et al 2009); This has an important role on the rate of corrosion of reinforcement. After initiation the corrosion, electrical resistivity and oxygen permeability of concrete are the main factors determining the corrosion rate (Costa and Appleton 2002). According to ACI 222, when the electrical resistivity is below 5, the rate of corrosion is very high. In the present study four point electrical resistivity of concrete surface was measured. Before doing the test, concrete surface was moisturized quietly to saturate it.

2.3.4. Half-cell potential method: One of the electrochemical methods used to evaluate the corrosion activity of the steel reinforcement is half-cell potential mapping; In this project, half-cell potentials were measured versus silver/silver chloride electrode which is stable and easily prepared. The ASTM C876-91 standard guide for interpretation of the half-cell potential measurements is given relative to standard copper/copper sulfate electrode. Using equation 3, these amounts could be converted to silver/silver chloride reference (Leelalerkiet et al 2004)

$$E_{cu}=E_{Ag}-120-1.1\times(25-T) \quad (3)$$

In which T is the ambient temperature. Table 2 presents corrosion probability criteria for silver/silver chloride electrode.

Table 2. Evaluation of corrosion activity versus silver/silver chloride electrode

Potential versus	Interpretation
EAg> -83 mV	More than 90% probability that no corrosion is occurring
-233 mV <EAg< -83 mV	Corrosion activity is uncertain
EAg < -233 mV	More than 90% probability that corrosion is occurring

2.3.5. Carbonation test: Carbonation depth measurement is an easy way for determining the depth of deterioration. When the CH is depleted from concrete by some mechanisms, then the pH would be reduced in concrete. For doing the test, a hole was made in concrete and then 1% phenolphthalein was sprayed to that part. The colorless depth is in fact carbonated part and that measured value was recorded as carbonation depth.

2.3.6. Chloride diffusion profile: In order to investigate the chloride penetration depth, some powder sample was taken from six different depths of concrete. The chloride content by percent weight of concrete was measured in different depths in accordance with ASTM C114.

3. Results and discussion

3.1. Visual inspection

3.1.1. Entrance channel: This part has been in contact with aggressive agents for longer period in compare with two other assessed parts. After revealing the signs of deterioration, a polymer liner was applied to the walls of channel in order to stop the process of deterioration. However the damaged concrete had not been removed before doing this repair work. Thus, an empty space was formed between concrete and the repair liner which contains enough oxygen and moisture for extension the rate of corrosion. Deep vertical and horizontal cracks, cement paste decomposition, efflorescence formation, spalling of concrete and also severe reinforcement corrosion was some signs of failure of structures in entrance channel (Fig 1.a). It is noteworthy that this observation are related to the backside walls of channel which were more in contact with sulfate and chloride rich soil of city.

3.1.2. Primary sedimentary and aeration tank: The severity of deterioration above water level was more than submerged areas. That is the result of existence of suitable condition for bacterial activity. The crack occurrence, reinforcement corrosion, cement paste decomposition and efflorescence formation are signs of deterioration in this two tanks (Fig 1.b and 1.c). The warm climate of Ahwaz and poor quality of concrete could be reasons for acceleration of corrosion. In some places in aeration tank, reinforcement was completely exposed (fig 1.d).

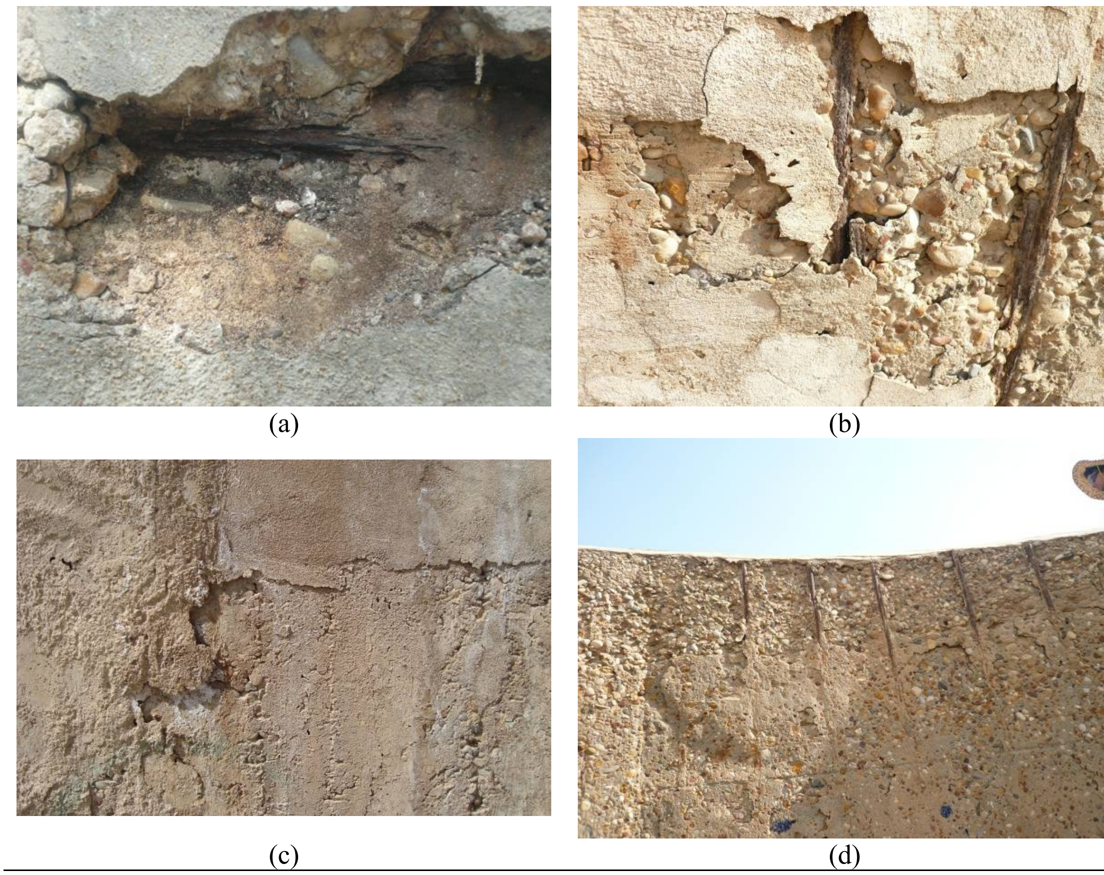


Figure 1. signs of deterioration a)Entrance channel, b and d)Aeration tank, c)Primary sedimentary tank

3.2. Compressive strength and water absorption

The average compressive strength are 19.2, 28.5 and 21.7 MPa in entrance channel, primary sedimentary tank and aeration tank, respectively. The test was performed after removing the corroded part of cores. This low compressive strength is not suitable for such an aggressive environment. The water absorption test was performed on both corroded surface concrete and base unaffected core part. The average water absorption of specimens was 4.3% with standard deviation of 1.04% which shows the high porosity of base concrete. Interestingly, the half-hour water absorptions of surface concrete which are affected by aggressive agents were twice base concrete (average 4.3% surface concrete and 2.1% for base concrete). This proves the higher porosity and capillary absorption in outer depth of concrete. Also, the higher porosity facilitates transportation of other ions like chloride to concrete.

3.3. Electrical resistivity

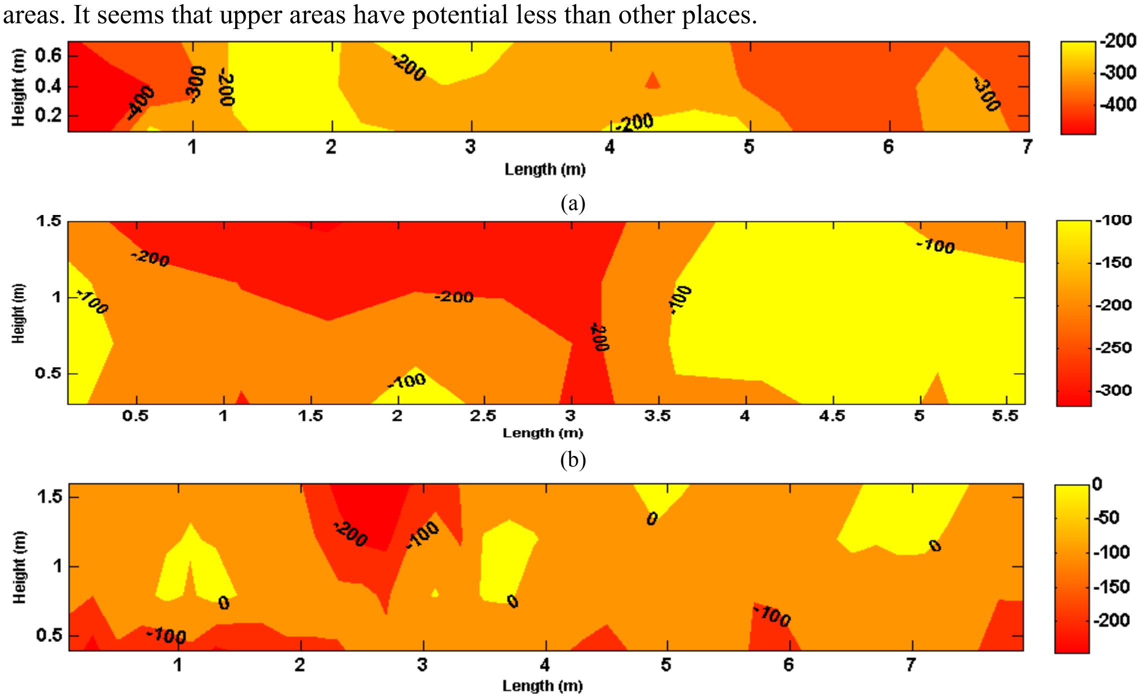
Four point electrical resistivity measurements were performed in three parts of sewage treatment plant. In entrance channel, the test was done after removing repair liner. The result of electrical resistivity measurements are presented in table 3. The low values of electrical resistivity in most areas specially damaged parts state the probability of high rate of corrosion. In some cases, this amount is high because of variety of concrete quality in different parts of structures, some parts are sound and no corrosion sign is visible, furthermore surface moisture and carbonation occurrence could affect these values.

Table 3. Electrical resistivity in different parts of structures

Location	Electrical resistivity (KΩ-Cm)									
	Test No 1	Test No 2	Test No 3	Test No 4	Test No 5	Test No 6	Test No 7	Test No 8	Min	Max
Entrance channel	4	5	4	2	6	7	7	4	2	7
Primary sedimentary tank	4	7	5	7	22	3	23		3	23
Aeration tank	4	2	10	4					2	10

3.4. Half-cell potential method

Half-cell potential contour are shown in Fig.2. This indicates that entrance channel has extensive corrosion. In large areas the potential is less than -233 which implies the probability of corrosion is greater than 90%. The situation in primary sedimentary and aeration tanks is better in compare with entrance channel. In most areas the corrosion activity is uncertain. However, this could not be attributed to whole parts of these two tanks and it is related to tested areas. It seems that upper areas have potential less than other places.



(c)

Figure 2. half-cell potential contours in a) Entrance channel b)Primary sedimentary tank c)Aeration tank

3.5. Carbonation test

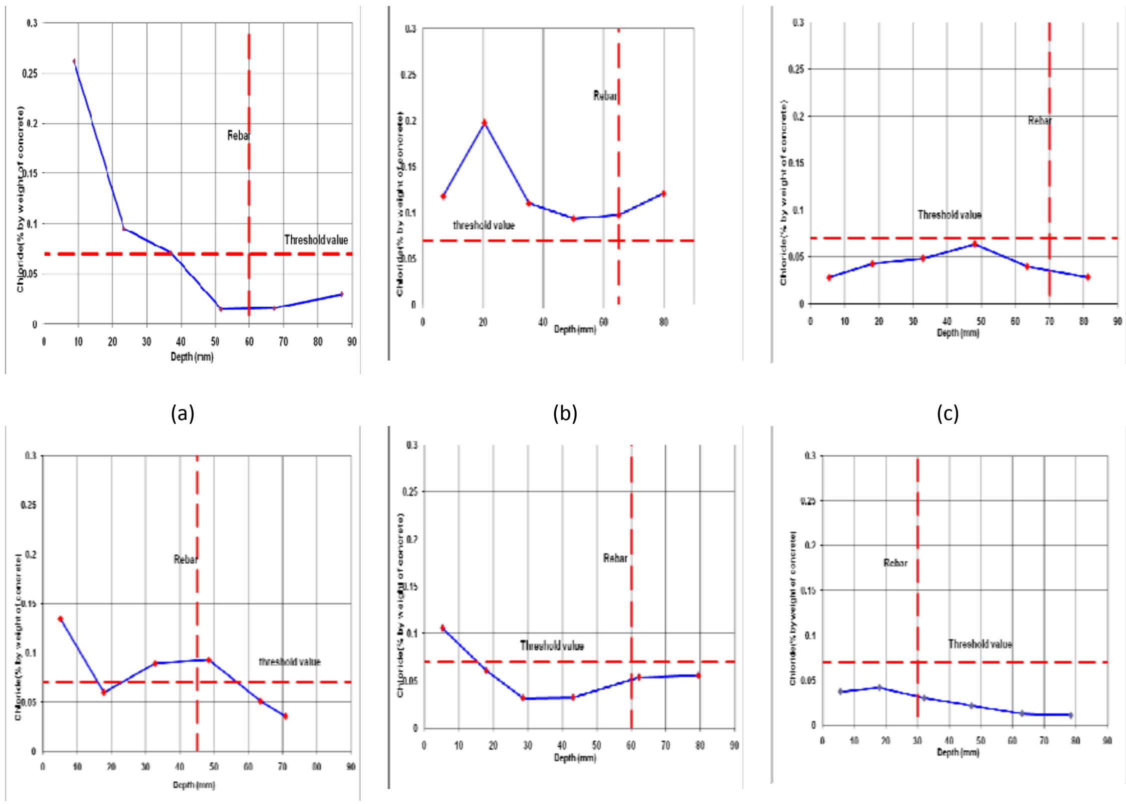
The result of carbonation depth measurement is presented in table 4. The carbonated depth of concrete is high in most area of structures. The average is 59 mm with standard deviation of 16 mm. This value is more than concrete cover of reinforcement, therefore carbonation could be one of the most important reasons for severe reinforcement corrosion in these structures. The carbonation occurrence also could increase the porosity of concrete by consumption of CH providing easier way for penetration of other aggressive agents.

Table 4. Carbonation depth result

test number	location	Carbonation depth (mm)
1	Entrance channel	45
2		53
3		90
4		55
5		45
6		40
7	Primary sedimentary tank	55
8		80
9		55
10		59
11		80
12		77
13	Aeration tank	65
14		37
15		55

3.6. Chloride diffusion profiles

Chloride diffusion profiles of concrete in six different points are shown in Fig 3. As mentioned in table 1, the chloride content of sewage is not so high (around 1000 ppm). Despite this medium value, the chloride penetration in some areas of structures is considerable. 0.07% chloride by weight of concrete was selected as threshold value which initiation of corrosion occurs. However it is not certain value and depends on many parameters. The chloride profiles of entrance channel were from backside walls which are in contact with soil (Fig 3.a, 3.b). But other profiles have been taken from areas that are in direct contact with sewage. The chloride content in concrete of entrance channel is high, visual inspection revealed severe reinforcement corrosion in those walls. The chloride content of concrete is less in primary sedimentary and aeration tanks comparing to entrance channel. However, it is considerable. The profile Fig 3.c is from the area that concrete quality is better than other parts according to visual inspection and compressive strength test. The least amount of chloride is in aeration tank Fig 3.e and Fig 3.f). The complex attack on concrete such as sulfate and sulfuric acid and carbonation made the concrete surface porous which in turn provide easier way for chloride ions to penetrate into concrete and accelerate the reinforcement corrosion beside other corrosion reasons.



(a) (b) (c)

(d) (e) (f)

Figure 3. Chloride diffusion profiles in entrance channel (a,b), primary sedimentary tank (c,d), aeration tank (e,f)

4. Conclusion

The present article investigates the different causes of deterioration of structure in a sewage treatment plant. It seems that a complex attack including sulfate attack, chloride penetration, carbonation etc has occurred in sewage system. In addition, the hot climate of city makes the corrosion process faster. Based on test result:

- The rate of deterioration above water level is more than submerged areas. The reasons could be bacterial activities above water level, oxygen availability and wet and drying cycles.
- Considerable depth of concrete was affected by aggressive agents result in increasing the porosity and capillary absorption, thus, penetration of other ions became faster and easier.
- As a result of increasing in concrete porosity, chloride ions easily penetrate into concrete depth and cause reinforcement corrosion.
- In most places, carbonated depth is more than concrete cover of reinforcement; Thus an important reason for reinforcement corrosion could be carbonation of concrete.
- For repair of structures, it is proposed that the deteriorated depth of concrete must be removed, corroded rebar should be replaced. After that, a compatible and durable concrete with sufficient thickness should be casted. Applying an effective coating on finished surface could increase the life cycle time.

5-Acknowledgements

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