The Deterioration of Concrete in Wastewater Treatment Plants

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ABSTRACT

Loss of serviceability over time is the simplest definition of deterioration. Concrete deterioration can be a result of the interaction of several factors that affect the structure of concrete in terms of durability. Wastewater treatment plant concretes must resist all the natural factors and operational impacts without the need of major maintenance and repair. For this reason high quality and durable concretes should be designed. The compressive strength, durability of concrete and the corrosion in reinforcement steel bars; might be affected due to the harmless effect of acidic wastewater with the passing time.

This thesis states the harmful effects of the wastewater on concrete durability and the properties of concrete which is suitable for wastewater treatment plant purposes were studied. The most recently built wastewater plants Gazimağusa plant, Baquba-Iraq plant and EMU campus plant have been investigated. In addition, some laboratory experiments have been performed for EMU campus wastewater treatment plant.

At the end of this study it can be concluded that, high durable concrete should be produced in order to prevent its deterioration either at early stages or to extend its lifetime service.

Keywords: Wastewater Treatment Plant, Corrosion, Permeability, Microorganism, Durable Concrete

ÖZ

Hasar, en basit bağlamda herhangi bir yapı elemanının zaman aşımına bağlı olarak işlevini yitirmesi olarak tanımlanabilir. Betonda oluşan hasar, birçok faktöre bağlı olarak betonun yapısını dayanıklılık açısından etkilemektedir. Arıtma tesislerinde kullanılacak olan betonun, bütün doğal faktörlere ve çalışma anında oluşan çarpmaların şiddetine çok fazla bakım ve tamirat gerektirmeden direnç gösterebilmesi gerekmektedir. Bu sebeple, arıtma tesisi beton tasarımı yapılırken yüksek kalite ve dayanıklılık ön planda tutulmalıdır. Beton basınç dayanımı, dayanıklılığı ve de beton içerisindeki çelik donatıların bütünlüğü geçen zamanla birlikte pis su atıklarındaki asitin etkisi altında zarara uğrayabilirler.

Bu tez çalışmasında; pis su atıklarının betonun dayanıklılığı üzerindeki zararlı etkileri ve de bu amaç için kullanılacak betonda olması gereken özelikler araştırılmıştır. Yakın geçmişte inşaa edilmiş olan Gazimağusa ve Baquba-Irak arıtma tesisleri ile Doğu Akdeniz Üniversitesi (DAÜ) arıtma tesisi incelenmiştir. Buna ek olarak, DAÜ kampüsü arıtma tesisinde bazı laboratuvar deneyleri de gerçekleştirilmiştir.

Bu çalışmanın neticesinde; arıtma tesisi betonunun hem erken yaşlarda hem de uzun süre içerisinde hasara uğramaması için yüksek dayanıklılıkta üretilmesi getektiği sonucuna varılmıştır.

Anahtar Kelimeler: Arıtma Tesisi, Beton, Mikroorganizma, Geçirimlilik, Dayanıklılık, Paslanma

To my lovely father and mother,

for their endless love and encouragement.

To my dear wife, sons Mohamed and Ali,

darling daughter (Tuqa) who have always loved me and fill my life happiness.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ASOM:	Acidophilus Sulphur-Oxidizing Micro-organisms
ASTM:	American Society for Testing and Materials
DAÜ	Doğu Akdeniz Üniversitesi
EMU :	Eastern Mediterranean University
GGBS :	Ground Granulated Blast Furnace Slag
SSD:	Saturated Surface Dry
TS.EN:	Turkish Standard Institution
w/c :	Water to cement ratio
WWTP:	Wastewater Treatment Plant

Chapter 1

INTRODUCTION

1.1 Wastewater Treatment Plants

Wastewater or sludge treatment processes or operating systems are used to reduce or remove objectionable properties in wastewater and save the human life from pollution. These processes should be completed before the final disposal of wastewater in order to reduce diseases that may occur from the pathogenic organism in the sewage and prevent infections from surrounding the surface and ground water.

Nowadays, concrete is the main material used in wastewater treatment plant construction. However, the presence of micro-organisms in wastewater results with in the deterioration of concrete and corrosion of the reinforcement steel bars. Therefore, durability of the concrete used for wastewater treatment plant should be very high in order to prevent or reduce the severe effect of the acidic wastewater. The factors that determine durability of concrete includes the type of concrete ingredients used and their ratios, the permeability and pH value of the concrete, the amount of acidophilus sulphur-oxidizing microorganisms and sulphuric acid present in wastewater and environmental conditions. Every year, a lot of money is being spent on the maintenance and repair of the concrete structures of wastewater plants all over the world.

1.2 Objective

The aim of this study is to explore the influences of wastewater on concrete durability and to determine the properties of concrete which is suitable for wastewater treatment plant. For this purpose, the most recently built Gazimağusa and Baquba-Iraq wastewater treatment plants; and also EMU campus wastewater treatment plant has been investigated. In addition, some in-situ laboratory experiments have been carried out only for the EMU campus WWTP. Core concrete specimens were taken for compressive strength and permeability tests. At the same time, the corrosion rates for the reinforcement structural steel bars were measured.

1.3 Organization

The present chapter (Chapter 1) includes the general information about the wastewater treatment plant, the objective and scope of this study. Chapter 2 includes the summary of the literature review about the elemental effects on the concrete durability in WWTP environment. The General details of mix designs, concrete quality test results and insulation materials carried out for Gazimağusa WWTP, Baquba- Iraq and EMU campus WWTP are stated in Chapter 3. Chapter 4, investigates and explains the physical, environmental and operational impacts on concrete durability characteristics standard for EMU campus and Gazimağusa WWTP. Chapter 5 includes the experimental study results and discussions held about the EMU campus WWTP. Finally Chapter 6 concludes and makes recommendations, for better concrete structures in the future for the WWTP plant projects

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Chapter 2

LITREATURE REVIEW

2.1 Introduction

It is globally believed that considerable amount of money is dedicated to the treatment of water and sewer systems. Besides, the degree to which waste water affects the quality of concrete and steel bars in reinforced concrete cannot be overstated. In additions, concrete permeability is highly influenced by the acid which exists in the waste water. In the following chapter, prominent factors that affect the quality of concrete during its lifetime, in respect to the exposure to waste water, are presented and summarized.

The most important factors to be mentioned are type of concrete, ingredients and the attributed ratios, permeability and pH value of concrete, acidophilus sulphur-oxidizing microorganisms and sulphuric acid. On the other hand, measures to be taken in order to minimize the adverse effects of the aforesaid factors are discussed. Concrete quality assurance, maintenance cost minimization and increases in the concrete life-span are mainly highlighted.

2.2 Wastewater Effect on Concrete Performance

Concrete quality can be altered to a great extent when exposed to wastewater and the process during which concrete performance is reduced is comparatively sophisticated as several elements such as pH value, microorganisms, sulphuric acid, Hydrogen Sulfide and gradients of concrete are involved. A combination of these factors can have a devastating effect on the performance and lifespan of concrete. Sulfuric acid for instance, forms from hydrogen sulphide as the result of the chemical reaction triggered by thiobacillus thiooxidans microorganisms. The reaction of the aforesaid chemicals' ions with concrete, affects concrete porosity to a great extent, weaken the structure of concrete and leads to the formation of calcium sulphate.

2.2.1 Effect of pH Value on Concrete Durability

The value of pH in concrete, or in the wastewater to which concrete is exposed, influences the quality of the components of reinforced concrete, namely steel bars and concrete itself. It is discussed by Islander, R. and Devinny, J. (1991), that the degradation of concrete cover occurs as pH value in concrete decreases from 13 to 9, as it affects concrete permeability and steel bars are get destroyed in a rather short time. Degraded concrete at pH 5, makes a quicker and easier exposure of steel bars to microorganisms present in wastewater (Islander, R. and Devinny, J. 1991). A similar conclusion is drawn by Shi, C. and Stegemann, J.A. (2000) regarding an environment with lower than 9 value for pH in concrete. They concluded that concrete parts solves quicker in a pH 5 environment than pH 3, as amalgamate of lime and high alumina concrete in presence of wastewater leads to the formation of gypsum.

Jahani, F. et al, (2001), demonstrated that reinforced concrete with comparatively thin cover on steel bars, in an environment with moderate pH level, corrodes faster as the result of soluble oxidized iron. The penetration of wastewater in concrete, reduced the pH level until the iron oxide is dissolved, they explained. Parande, K. et al (2005) discussed that one of the main reasons of internal corrosion of steel bars in wastewater treatment plants is conventional acid attacks which is caused by lower levels of pH value that leads to sulphate attack which is attributed to the direct discharge of industrial waste in sewer systems.

2.2.2 Effect of Acidophilus Sulphur-Oxidizing Micro-organisms (ASOM) on Concrete Deterioration

There are several researches published on the effect of ASOM on concrete deterioration. Acidophilus Sulphur-Oxidizing Microorganisms produce acid to a considerable level that the corrosion of steel bars process of reinforced steel bars is speed up. The sulphuric acid then spreads from the corroded area which can cause more damage to the structure of concrete, concludes (Davis, L.J., et al, 1988). In case of wastewater treatment plants, Montenya, J. et al, (2000), demonstrated similar results. Considering the same types of plants as case study, Jahani, F, (2001), discussed that the corrosion of steel bars process is the result of the transformation of hydrogen sulphide to sulphuric acid by bacteria which exist on the surface of concrete. During this process, the ions of sulphide and hydrogen penetrates concrete and a chemical reaction between sulphuric acid and concrete ingredients forms sulphate and ettringite, claimed (Jahani, F, 2001).

De. J, et al, (2002) claimed that there is a microbiological sequence developed by ASOM and NSOM which effect on concrete detriment is devastating. A recent investigation by Hewayde, E. et al, (20070, suggests that SRB type of bacteria and microorganisms that exist in the mud layer of sewer system produce sulphate and sulphuric acid consequently that corrodes reinforced steel bars to a great extent.

Aforementioned bacteria claimed to use the sulphide as a source of oxygen and speed up the chemical reaction process.

2.2.3 Effect of Sulphuric Acid on Concrete Deterioration

Chen, H. G. et al, (2001), performed an empirical investigation on the unsatisfactory resistance of concrete specimen. They concluded that in the presence of sulphate acid, the accelerating effect of sulphide on the concrete is noticeable. Montenya, J. et al, (2001), highlighted the damaging effect of sulphuric acid that is discharged into the sewer system on concrete. They claimed that the main reason behind the existence of such substances in the sewer system is disposure of industrial waste and the reaction of free lime in concrete with acid which can form gypsum.

2.2.4 The Hydrogen Sulphide (H_2S) Effect on Concrete Durability

Sulphate and hydrogen ions reaction in concrete pores stimulates the reaction with cement elements Jahani, F. et al, (2001) concludes. Their study demonstrated that the reaction forms calcium sulphate and ettringite which reduces the durability characteristics of materials. In another similar study by Vincke, E. (2002), it was claimed that sulphuric acid or sulphate attacks are responsible for one fifth of concrete deterioration in sewage systems. Parande et al. (2005), explained the role of sulphate in corrosion of steel bars as the process said to be initiated when sulphates in the sewer transforms to sulphur. Besides, the most important accelerating element in damaging concrete pipes concluded to be hydrogen sulphide (H_2S).

This specific element was acknowledged to be damaging to sewer pipe systems initially in 1920 and the effect mentioned to be as much as 150 millimeters, which is nearly half the thickness of a normal sewer pipe, in 10 years' time horizon (Hewayde, E. et al, 2007). In a similar investigation, Zhang et al. (2008) discussed that different types of damages in sewer systems are attributed to hydrogen sulphide diffusion.

2.3 Effect of Concrete Constituents and w/c Ratio on Concrete Durability

It is not to say that concrete durability is dependent on concrete permeability and in this respect, water cement ratio of concrete mixes plays a significant role. The effect of w/c ratio on concrete mixes is discussed by several researches and it is generally believed that an increase in w/c ratio leads to a rise in porosity level of concrete as the result of cohesive deficiency between aggregates and cement paste. According to a study by Ahmed, S. (2003), mentioned several factors affecting the concrete reinforcement corrosion level such as concrete quality, water cement ratio, cement content, defects in the concrete components, and cracks on the surface of the concrete. De Belie, N. (2004), proposed a production technique for concrete pipes, following which the durability of pipes is increased. His focused on waster cement ratio and the degree to which the water is absorbed during concrete formation. Concerning the w/c ratio, Fernandes, I et al (2012), found that in order to obtain a concrete mix relatively resistant to different degradation mechanisms a low cement content and w/c ratio below 0.4 should be used. The minimum values admitted in the design for class C35/45 was of 51/55 MPa compressive strength and the w/b ratio should be lower than 0.40–0.44

Considering corrosion of steel bars, most of the investigations highlighted cementious matrix and mainly the water cement ratio. However, there has been several works published on the effect of aggregates and their significant role in reinforced concrete corrosion. Chen et al, (2001) concluded that the existence of aggregates in concrete reduces the damage which may have been occurred to the concrete during its life span. Ahmed, S. (2003), on the other hand, performed an experimental study on the size and type of aggregates and discussed that concrete uniformity, reinforcement corrosion and chemical reaction level is under effect of the size and types of aggregates used in the production process.

2.4 The Correlation between the Permeablity and Durablility of the Concrete

The durability of concrete basically depends on the permeability of the concrete. Therefore, the permeability of concrete can be used as an indirect rapid estimation factor to examine its durability (Xinying et al, 2002). According to Choinska et al, (2007) concrete with high permeability results in the rapid penetration of gases, liquids and other destructive materials such as chlorides and sulphates. This is the main cause of rapid corrosion of the reinforced steel bars and sulphate attack which leads to concrete deterioration and increase of the micro cracks. Similarly Figueiras, H, et al, 2009 and Hoseini, M, et al, (2009), concluded that The permeability of concrete is one of the most important factor in order to achieve a durable concrete with a life span service. The growth of cracks, due to high permeability, accelerates the penetration of water or destructive chemical ions into the concrete, which leads to deterioration. The increase of permeability due to regular crack growth accelerates penetration of water or destructive chemical ions into the concrete and therefore facilitates deterioration (Yia, S, 2009). In another similar study of Desmettre and Charron (2012), it is defined that, the durability issues such as; concrete deteriorations are due to the ingress of water and detrimental agents into the concrete. This results in the speedy chemical deterioration of the concrete and corrosion of the reinforced steel bars. In another study by Chahal et al, (2012), it is explained that; the corrosion of steel bars process is fundamentally caused by the penetration of chloride ions into the structure of concrete due to high permeability.

2.5 The Effect of Environmental Conditions of the Concrete in WWTP

The effects of environment temperature and humidity on concrete deterioration and corrosion of reinforced steel bars are discussed in the following sections.

2.5.1 Effect of Environmental Temperature within the Level of Cracks of the Reinforced Concrete

Hussain. J and Ishida.T (2010), in their practical study searched out that; reinforced concrete buildings exposed to tough environment conditions such as severe chloride attack merging with high temperature; results in the accelerated corrosion of reinforcement steel bars and deterioration of the concrete material. They expressed that, the chloride and the temperature is an electrochemical thermodynamic phenomena representing one of the important factors which has an effect on the corrosion of process of the steel bars. A more detailed study was conducted by Alhozaimy, et al, (2011), they explored that; the corroding factors are less when the environmental temperature is around 30^{o} C. However, when the temperature reaches up to 40^{o} C the corroding products become complex and massive. This implies that the corrosion of steel bars rate increase within the temperature interval of 30^{o} C to 40^{o} C.

In a recent study performed by Deus, et al (2012), it is demonstrated that; the interconnection of the temperature and the potential corrosion of the passive stainless steel bars embedded in concrete is very high. The potential corrosion increase was observed in the course of different temperature variations. Similarly, Chang and Shan Hung, (2012), explained that; the internal temperature is a key indicator when evaluating materials and structures deterioration. For example, temperature and the variation of water content in concrete pores significantly affect the corrosion rate of reinforced steel bars.

2.5.2 The Effect of Humidity on Concrete Durability

Humidity has an immediate and considerable effect on concrete durability. According to Hussein, R. and Ishida, T. (2009), the limitation of oxygen diffusion under high relative humidity conditions, has an influence on the corrosion rate of the steel by blocking the pores of concrete with wet and reducing the contact required for the flow of oxygen to the steel bar’s surface. In a recent study done by Alhozaimy, et al, (2011), it was expressed that; the amount of corrosion of steel bars decreases as a result of chloride concentration at high temperature condition of 50 C and high relative humidity of 85%. Chang, and Shan Hung, (2012), pointed out that the intensive humidity rate among 80%–95% within the environment and the presence of chloride and sulphate expose concrete structures to deterioration and eventually reduce their life span service. It is also defined that; if the relative humidity is sustained at 80% and the surrounding temperature of the reinforced concrete has increased; there will be an increase in the rate of steel bar corrosion.

Table 2.1: The Effect of Relative Humidity on the Corrosion of Steel Bar in Concrete

Relative Humidity (%)	Remarks	Corrosion Risk
Concrete submerged in water	Capillaries filled with calcium hydroxide solution. Oxygen must diffuse through solution-filled capillaries to steel.	No-corrosion to small risk.
90 - 95	Pores filled with pore solution through which oxygen must diffuse.	Small to medium risk.
60- 90	Pores only partially filled. Water and oxygen reach steel easily.	Great risk.
below 60	No or very little solution in pores.	No risk.

Chapter 3

GAZİMAĞUSA, EMU CAMPUS AND BAQUBA-IRAQ WASTEWATER TREATMENT PLANT CONSTRUCTION METHODS AND SPECIFICATIONS

3.1 Introduction

The design capacity of wastewater treatment plant (WWTP) depends on many factors such as the region population and the amount of corresponding domestic wastewater flow. The wastewater flow may rise from three different sources, domestic, industrial and institutional. It has been assumed that about 80% of consumable drinking water is discharged directly as wastewater. Regardless of the size and capacity of the system, we have to cast the corresponding units with high durable concrete. For this purpose, we should ask how we can produce durable concrete or what are the factors that make the concrete durable?

Concrete durability relies on many factors, such as a good mix design, high quality of the materials used, quality control procedures, necessary maintenance and the environmental conditions to which the concrete is subjected to during its lifespan. Nowadays, plain and reinforced concrete is used as the main material to build the wastewater treatment plants (WWTP). This make the researchers work harder in order to find out the best specifications and standards for the production of high durable concrete.

In this chapter general information about Gazimağusa-Cyprus, Baquba-Iraq and limited information about EMU campus-Gazimağusa WWTP is stated. General information about Gazimağusa city treatment plant are clarified such as; the city of Gazimağusa, WWTP site location, water demand and wastewater production with all the specifications, mix designs, concrete test result and insulation materials used. Mentioning about Baquba-Iraq WWTP, different types of mix designs were prepared to be used in this project, the admixtures used and the test result will be explained. Unfortunately, for the EMU campus WWTP, the data about the mix design and the concrete test result could not be obtained.

3.2 Gazimağusa Wastewater Treatment Plant

The following sections explain the site location and design details of Gazimağusa WWTP.

3.2.1 General Data of Gazimağusa City

Many factors have been taken into consideration while designing Gazimağusa WWTP. The first one is the prediction of the population and the corresponding amount of domestic wastewater flow during the WWTP life span. Table 3.1 shows the population estimations provided by a consultant to help form a design.

Table 3.1: Available Population Projections and Corresponding Domestic WW Flow for Gazimağusa WWTP

Scenario	**Parameter**	**Year**			
		2010	2015	2020	2025
Base Scenario	inhabitants	48.140	50.629	53.247	56.000
	Growth rate	1,01%	1,01%	1,01%	1,01%
Average Domestic Wastewater flow	m^3/d	4.539	4.774	5.020	5.280

3.2.2 Site Location and Design Details

The site of WWTP is located about 5 km west of the city of Gazimağusa, 61 km east of the city of Nicosia. The surrounding areas are used as farmlands. The access to the site is via a public road which is mainly a gravel road. The WWTP site covers an area of 9.5 hectares. According to the design outcome, 2.2 hectares mustbe reserved for the construction of the new WWTP. The following figures 3.1 and 3.2 shows the project area layout and some unite of the WWTP. The Conceptual designs have been prepared within the project scope and financed by the European commission.

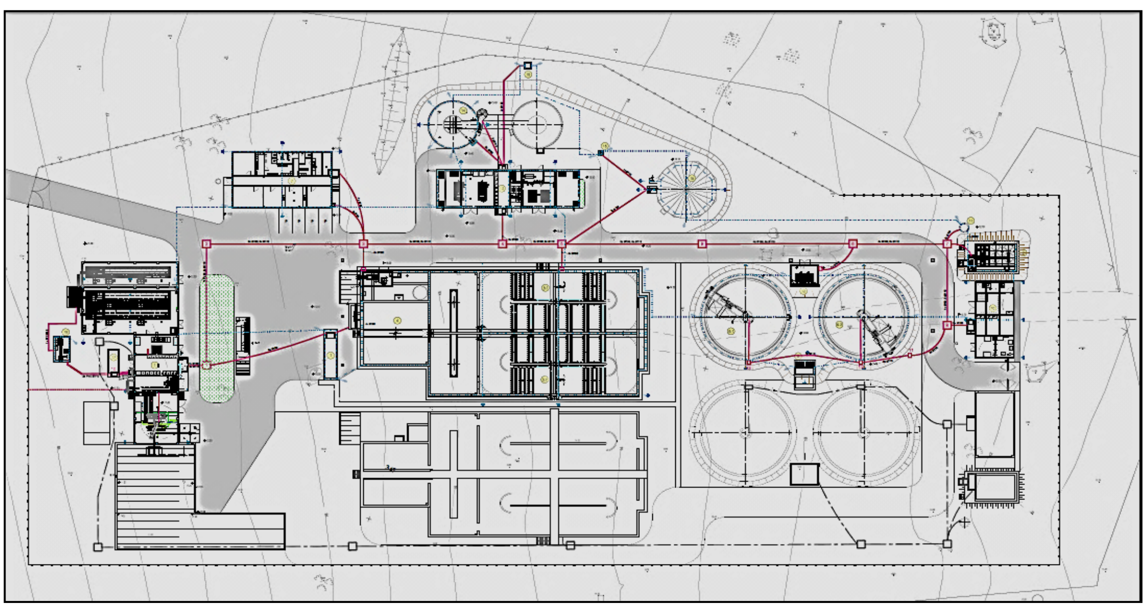

Figure 3.1: Layout of Gazimağusa WWTP

Figure 3.2: Unit Treatement Tanks of Gazimağusa WWTP

3.2.3 Water Demand and Wastewater Production

To obtain reliable information about the water demand, the consultant has referred to the stated documents above and further information received from the Gazimağusa municipality. Finally the agreed rate of potable water consumption for the Gazimağusa residential area is 120 litres per capita per day and 100 litres per capita per day in the rural areas. No further data was obtained concerning the percentage used by individual consumer groups (domestic / industrial / institutional).

Furthermore, it has been assumed that about 80 % of the consuming drinking water is discharged directly into the wastewater collection system.

Table 3.2: Relationship between Water Consumption and Wastewater Discharge

	Unit	**Unit**
Drinking Water Consumption	[l/c/d]	120
Wastewater discharge (80 %)	[l/c/d]	80
Waste water flow	[l/c/d]	96

According to the retrieved information and discussions made with all relevant stakeholders, the Consultant has used the values in the Table 3.2 as the design values for all further calculations. Taking the difference between urban and rural consumers within the coverage area into consideration, the scheduled domestic waste water production will be 5,280 m^3/d averages for the year 2025.

3.2.5 Design of Concrete Mix Constituent Proportions

The mix designs for Gazimağusa WWTP have been prepared by Inşaat mühendlseri Odası/Mehmet Göze (Asi) by Emek inşaat company. Mix designs were according to eight different types of concretes which are; C14, C16, C18, C20, C25, C30, C35, and C40 as it is stated in Table 3.3. The water cement ratio was kept as 0.45 within these mix designs. All mixes were designed according to the specifications prepared for Gazimağusa WWTP project which has been provided in (appendix 1).

Table 3.3: Concrete Mix Design for Gazimağusa WWTP

Concrete class	**Sand**	**Aggregate**			**Water (lt)**	**Cement (kg)**	**Additives (kg)**
	0-5mm	5-12mm	12-19mm	19-25mm			
C14	1250	300	290	120	120	200	1
C16	1230	300	290	120	120	220	1,5
C18	1130	350	320	120	125	240	1,5
C20	1100	350	320	120	125	280	1,5
C25	1000	380	350	140	135	300	1,5
C30	980	380	350	140	135	300	1,5
C35	950	380	350	150	155	340	1,5
C40	930	380	350	150	165	360	1,5

3.2.6 Concrete Compressive Strength Laboratory Test Results

In Gazimağusa WWTP three different concrete types were used. C40 type concrete was used for the structural elements exposed to wastewater such as the apron, foundation and slab concretes. C40 concrete type was produced according to the mix design given in Table 3.3. Test results for the compressive strength have been shown in Table 3.4. All the mechanical test results on account of compressive strength were examined according to the standard TSEN 206.1 Table 3.5.

Table 3.4: Compressive Strength Test Results of C40

Sampling Data	**Test Data**	**Average (Day)**	**Dimensions (cm)**	**Maximum Load (kN)**	**Compressive strength (N/mm^2)**	**Weight (kg)**	**Density (kg/m^3)**	**Details**
5/2/2010	15/2/2010	10	15x15x15	1096.10	48.72	8.285	2455	C40
5/2/2010	15/2/2010	10	15x15x15	1076.27	47.83	8.325	2467	C40

Table 3.5: TSEN 206-1/April 2002

28 Days Comperssive Strength kgf/cm^2 (N/mm^2)						
	Cylinder ϕ15 cm h=30 cm			Cube 15x15x15 cm		
Concrete class	Minimum Charistristic Compressive Strenght (Fck)	Average Compressive Strenght (Fcm)	Minimum acceptable result (any single sample) Compressive Strenght	Minimum Charistristic Compressive Strenght (Fck)	Average Compressive Strenght (Fcm)	Minimum acceptable result (any single sample) of Compressive Strenght
C8/10	80 (8)	129(12)	40(4)	100(10)	140(14)	60(5)
C12/15	120(12)	160(16)	80(8)	150(15)	190(19)	110(11)
C16/20	200(20)	200(20)	120(12)	200(20)	240(24)	160(16)
C20/25	160(16)	240(24)	160(12)	250(25)	290(29)	210(21)
C25/30	200(20)	290(29)	210(21)	300(30)	340(34)	260(26)
C30/37	300(230)	340(34)	260(26)	370(37)	410(41)	330(31)
C35/45	350(35)	390(39)	310(31)	450(45)	490(49)	410(41)

C30 concrete was designed for the concrete structural elements which are not exposed to wastewater or sludge such as Aeration tank, septic delivery ramp base concrete and floor unit concretes. C30 concrete type was produced according to the mix design given in Table 3.3. Test results for the compressive strength of C30 type concrete are shown in Table 3.5. All the mechanical test results on account of compressive strength was examined according to the standard TSEN 206.1 in Table 3.5

Table 3.5: Compressive Strength Test Result of C30 and C35

Sampling Data	**Test Data**	**Average (Day)**	**Dimensions (cm)**	**Maximum Load (kN)**	**Compressive strength (N/mm^2)**	**Weight (kg)**	**Density (kg/m^3)**	**Details**
13/1/2010	26/1/2010	13	15x15x15	923.13	41.03	8.140	2412	C35
13/1/2010	26/1/2010	13	15x15x15	901.97	40.09	8.100	2400	C30

The third type of concrete was C20. C20 was designed for screed and massive concrete fill under the foundations. It is used as Aeration tank corner fillet concrete, fencing concrete, and aeration tank septic delivery ramp lean concrete purposes. C20 concrete type was produced according to the mix design given in Table 3.3. All the mechanical test results on account of compressive strength was examined according to the standard TSEN 206.1 (appendix 1).

3.2.7 Cements Type

Sulphate resisting SRC 42.5 R cement type was used in this project. The Cement analysis report was prepared by DÇ Denizli çimento Sanayii T.A.Ş according to TS 10157 - Sulphate Resisting Cement, (appendix 4).

3.2.9 Quality of Water for Concrete

Water used in mixing and curing concrete and mortar should be fresh and free from sediment and dissolved or suspended matters which may be harmful and should comply with the requirements of BS 3148 or any other relevant Standard.

3.2.10 Admixture Materials for the Concrete

In Gazimağusa WWTP, Superplasticizer type chemical admixture has been used. Substantial improvement has been achieved in the workability without having to increase the amount of water. All the specification and standard for these materials are provided in appendix 3.

3.3 Concrete Works for Baquba-Iraq WWTP Project

Baquba-Iraq WWTP is an Iraqi project in the middle of Iraq. This plant serves 250,000 people. The project was designed by the Germany Company in 1979; however the construction started in 2008 due to the war.

Figure 3.4: Digester Tank in Baquba-Iraq WWTP

3.3.1 Mix Design Calculations and Concrete Properties

Baquba-Iraq WWTP contains four types of mix design, which was prepared sequentially by the Consulting Engineering-University of Baghdad, Scientific and Engineering Consultant – University of Technology and Consulting Engineering-Dyala University. Two concrete mix designs were prepared by the Consulting Engineering-University of Baghdad according to Building Research Establishment Method are as AX 38.7 MPa and BX 33.4 MPa compressive strengths 28-days. All the mix designs and test result information are available in Table 3.5 and Table 3.6.

Table 3.5: Concrete Mix Design for Baquba-Iraq WWTP

Main target compressive Strength MPa	**Cement kg/m^3**	**Sand kg/m^3**	**Gravel kg/m^3**	**Water lt/m^3**	**Additives lt/m^3**
AX 38.7	470	710	1005	190	4.5
BX 33.4	425	750	1005	190	4

Table 3.6: Compressive Strength Test Result for Mix Design

Main Target Compressive Strength MPa	**Data of casting**	**Data of Testing**	**Compressive strength (7 days) MPa**
AX 38.7	7/9/2009	14/9/2009	36
			35.6
			35.6
BX 33.4	7/9/2009	14/9/2009	31.6
			32
			31.1

The third mix calculations and test results prepared by the Dyala University according to Building Research Establishment Method for 28-day target compressive strength at least 38.7 MPa. For more details see Table 3.7 and Table 3.8.

Table 3.7: Third Concrete Mix Design for Baquba-Iraq WWTP.

Main target compressive Strength (MPa)	**Cement kg/m^3**	**Sand kg/m^3**	**Gravel kg/m^3**	**Water lt/m^3**	**Additives lt/m^3**
AX 38.7	550	645	957	225	4-6

Table 3.8: Compressive Strength Test Result for Mix design

Main target Compressive Strength MPa	**Data of casting**	**Data of Testing**	**Compressive strength (7 days) MPa**
AX 38.7	20/4/2010	27/10/2010	43.4
			39.5
			39.2

According to Building Research Establishment method the final mix design is prepared by the consultant engineering – University of Technology for 28-days target compressive strength 38.7 MPa. All the mix design calculations and test results are available in Table 3.9 and Table 3.10.

Table 3.9: Final Concrete Mix Design for Baquba-Iraq WWTP.

Main target compressive Strength MPa	**Cement kg/m^3**	**Sand kg/m^3**	**Gravel kg/m^3**	**Water lt/m^3**	**Additives lt/m^3**
AX 38.7	450	670	1025	190	6

Table 3.10: Compressive Strength Test Result for Mix Design

Main target compressive Strength MPa	Data of casting	Data of Testing	Compressive Strength (7 days) MPa
AX 38.7	2/6/2009	9/6/2009	36.2
			35.8
			36.9
	30/6/2009	30/6/2009	43.6
			44.4
			43.9

3.3.2 Concrete Type and Test Results

In the Baquba-Iraq WWTP, AX type concrete was used for the structure, which exposes to wastewater or sludge such as, inlet pump station, outlet structure apron and slab concrete and outlet structure foundation concrete. The AX concrete type was used as specified in the standard and according to the specification presented within the project. The mix design calculation prepared by the college of engineering- University of Baghdad is as given in Table 3.6.

The second concrete type which is BX was used in places not exposed to wastewater or sludge such as; aeration tank, septic delivery ramp base concrete and access stair case concrete and drying beds. It was used in accordance with the standards and specifications presented for the project within the technical and mix design. All the mechanical test result in terms of compressive strength satisfied according to the Iraq standard.

3.3.3 Type of Cement

Sulphate resistance cement type was used in this project. According to Iraq standards, the cement chemical analysis was prepared by the Consulting Engineering Bureau - Dyala University

3.4 Comparison of Mix Designs for Gazimağusa WWTP and Baquba WWTP

- The compressive strength for Gazimağusa WWTP is C40-C30-C25, while for Baquba-Iraq WWP the compressive strength is AX 38.7-BX 33.7.
- The Water cement ratio for Gazimağusa WWTP is 0.45, while for Baquba-Iraq WWTP the ratio is ranging between 0.31-0.41.
- Superplasticizer has been used in both projects.
- Sulfate-resistant type of cement has been used in both projects.
- The Maximum aggregate size for Gazimağusa WWTP is 25mm, while for Baquba-Iraq WWP this measure is 19mm.
- Crushed limestone aggregate were used for Gazimağusa wastewater treatment plant, while for Baquba-Iraq WWP, natural rivers type aggregate has been used.
- Tap water has been used as the type of water to produce the concrete.

Chapter 4

THE CONCRETE PROBLEMS IN GAZİMAĞUSA AND EMU CAMPUS WASTEWATER TREATMENT PLANTS

4.1 Introduction

Loss of serviceability over time is the simplest definition of deterioration. Concrete deterioration can be a result of the interaction of several factors that affect the structure of concrete in terms of durability. Many studies have categorized these factors into three types; physical, environmental and operational. These factors have a direct effect on the durability of concrete in wastewater treatment plants. Abrasion of the concrete surfaces, the chemical reaction of wastewater with concrete, microbiological activities of wastewater, and seasonal freeze and thaw cycles of concrete create destructive forces which can significantly deteriorate the concrete and therefore reduce its life service.

The life span of the sanitary plant is thirty years at the minimum according to the design standards internationally accepted. For this reason, the wastewater treatment concrete plants must resist all the environmental factors and operational impacts without the need of major maintenances and repairs throughout this period. Therefore, high quality and durable concretes should be produced for the WWTP projects.

This chapter investigates the physical, environmental and operational effects on the concrete's durability that occurs during the construction period and/or its lifetime service within the EMU campus WWTP and Gazimağusa WWTP. According to the investigations made over the wastewater treatment plants mentioned above, the following items can be criticized.

4.2 Gazimağusa Wastewater Treatment Plant Concrete Problems

In the previous chapter (Chapter 3); the specifications and standards used within different mix designs, the quality control test results and admixtures used for the construction of wastewater treatment plants were explained. The Effects of wastewater on the efficiency of the concrete will be discussed as an environmental factor and one of the existing problems. There has not been any progressing damage observed in the Gazimağusa WWTP since it has been in use for one and a half years. However, the initiations of some corrosion of steel bars and damage problems have been detected. Their definitions and causes are provided in the following sections.

4.2.1 Workmanship Problems

Figure 4.1 and 4.2 shows the initiation of corrosion in the stop logs and pipes which are produced by iron. In order to protect these parts from corrosion, they should be isolated by using epoxy or such like materials. On the other hand, as it can be observed from Figure 4.1, concrete surface is not smooth due to the existing small holes and pores. This may increase the rate of penetration of the wastewater into the concrete. In Figure 4.3 shows the poor workmanship, where the nails are kept inside the concrete. Since the H_2S gas is very effective in this area after a few years of time, the concrete will deteriorate and the steel bars will suffer from corrosion.

Figure 4.1: Bump Concrete and Rusting of the Steel.

Figure 4.2: Rust Layer on the Secondary Tank

Figure 4.3: Workmanship Problems

4.2.2 Microbiological Problems

Microbiological problems have the greatest effect on concrete deterioration especially in wastewater treatment plants. The effect of micro-organism can be observed in the main lagoon which is the first unit for the wastewater treatment process. In these sewer systems, the bacteria create a sulphur cycle, which can lead to the formation of sulphuric acid. The formation of this sulphuric acid is the main cause for the further expansion of the corrosion of steel bars process (Figure 4.4 and 4.5).

Figure 4.4: The Effect of Microorganism on Concrete Surface in Main Lagoon

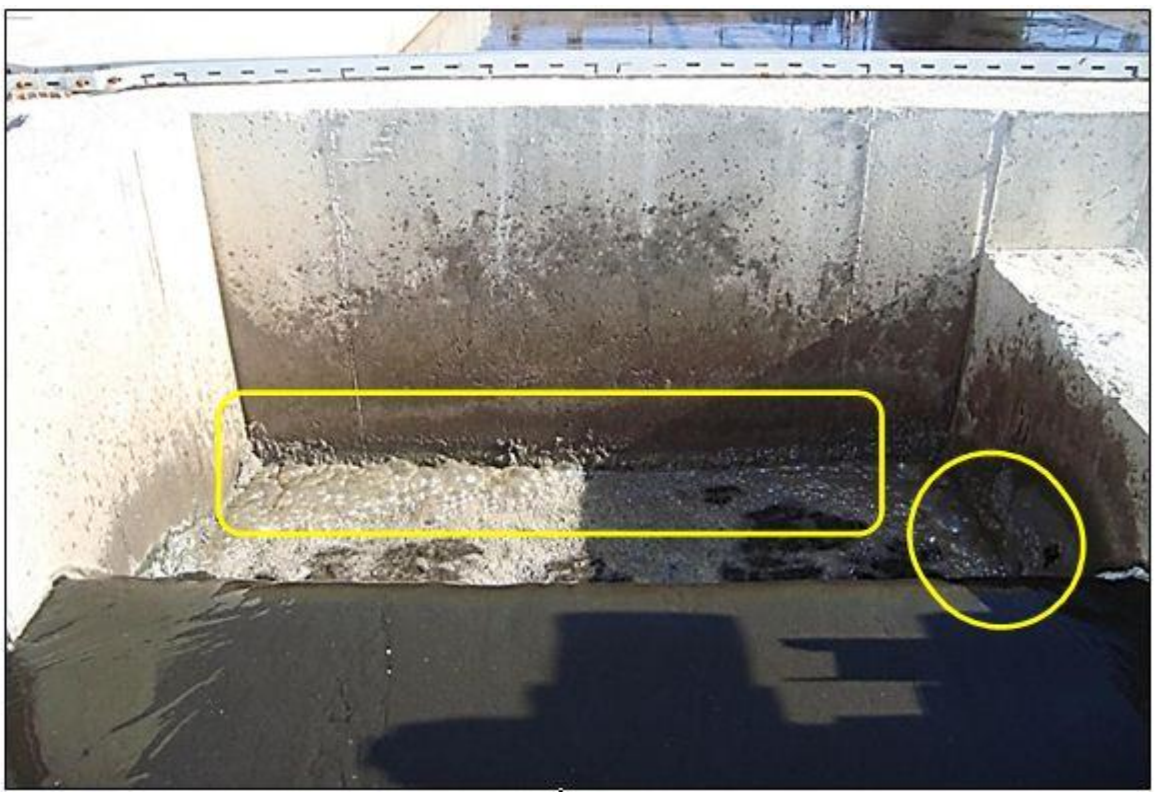

Figure 4.5: The Effect of Microorganism on Concrete Surface in Main Lagoon

4.2.2 Plastic Shrinkage and Settlement Cracks

The plastic shrinkage and settlement cracks have direct influence on the concrete degradation and therefore activate the corrosion of steel bars process by penetrating the liquids or gases inside the concrete. Figure 4.6 shows the plastic shrinkage cracks observed on the top of the aeration bridge tank.

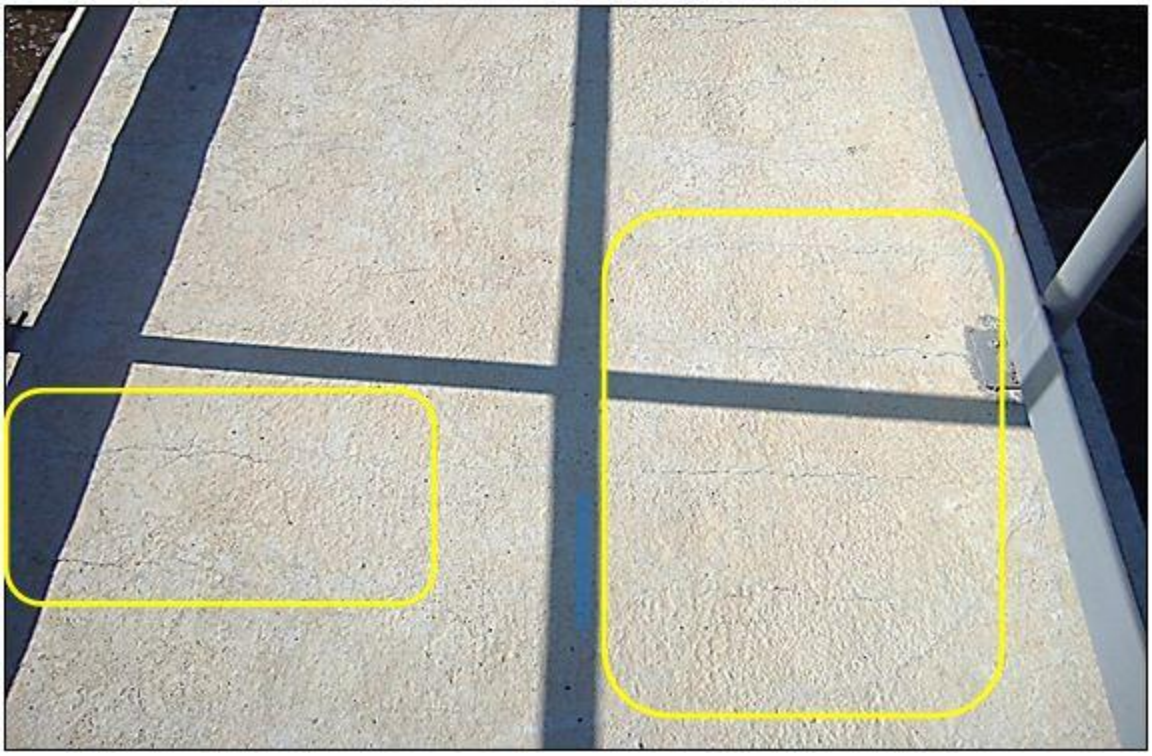

Figure 4.6: Plastic Shrinkage Crack Problem over the Aeration Bridge Tank

4.3 EMU Campus WWTP Concrete Problems

EMU campus WWTP has been constructed fifteen years ago. However, in 2008 new parts were added to increase its operation capacity. This section explains and discusses the important durability problems and their causes. The main reasons of these problems rely on the inadequate workmanship and concrete quality, and also the harmful effect of wastewater on concrete durability.

4.3.1 Carbonation Problem

The chemical reaction between carbon dioxide (CO_2) and cement paste products generates a chemical process which leads to corrosion of steel bars. This effect results in the degradation of concrete and corrosion of the reinforcement steel bars as shown in Figure 4.7.

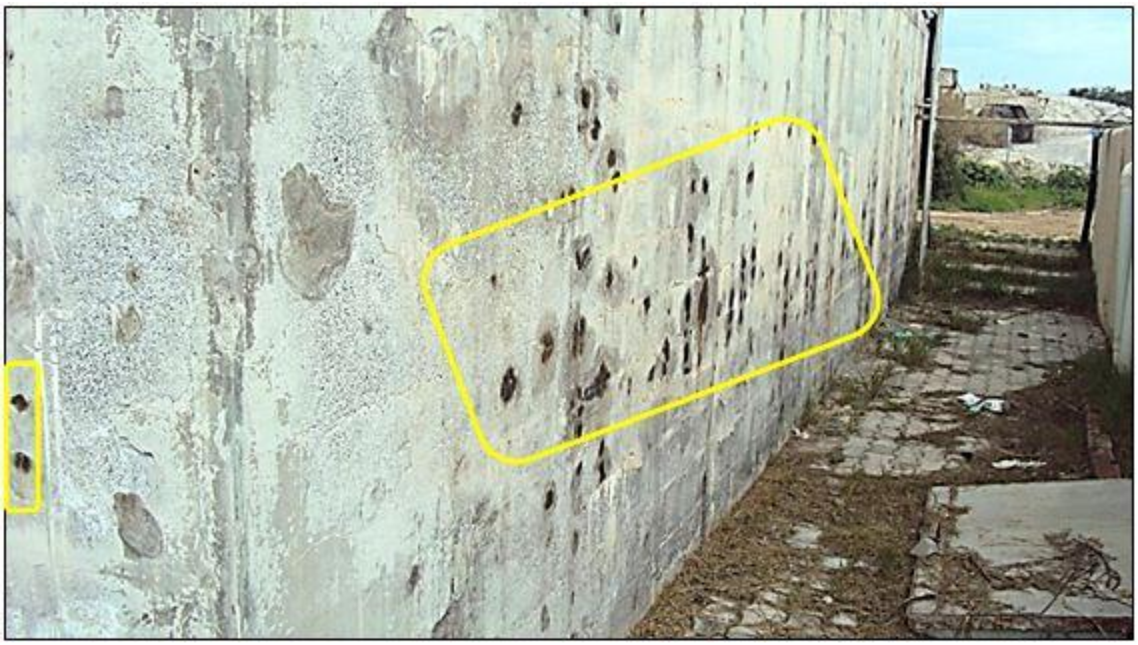

Figure 4.7: Carbonation Problem at EMU Campus WWTP.

4.3.2 Thickness of the Concrete Cover

The thickness of the concrete cover is one of the main factor that affect the rate of penetration of chloride ions, and the incursion of carbon dioxide into the concrete to reach the level of the steel bar. When the thickness of the concrete cover is adequate, chlorides and carbon dioxide takes more time to reach to the surface of the steel bar. As it can be displayed in Figure 4.8, the cover thickness of the concrete is very small and therefore corroded within the past fifteen years.

Figure 4.8: Cover Problem at the EMU Campus WWTP.

4.3.3 Permeability Problem

Permeability of concrete is one of the most important factor that must be taken into account during the design and implementation stages of a durable concrete. EMU campus WWTP concrete is very permeable to water and gas. This situation accelerated the corrosion of steel bars process as shown in the figure below.

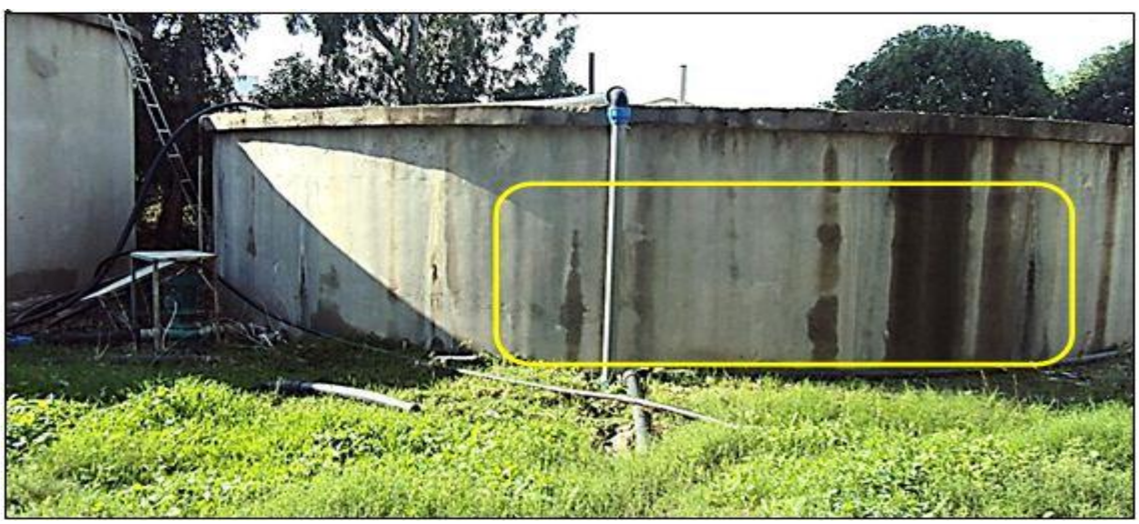

Figure 4.9: Permeability Problem at the EMU Campus WWTP.

4.3.4 Workmanship Problems

Many problems are represented as the workmanship problem within the EMU campus wastewater WWTP such as cold joint cracks, segregation, and lack of maintenance. The joint occurred during casting led to surface separation and helps to push moisture and oxygen inside concrete. This contributes to the corrosion of the steel bars. This problem can be displayed in Figure 4.10.

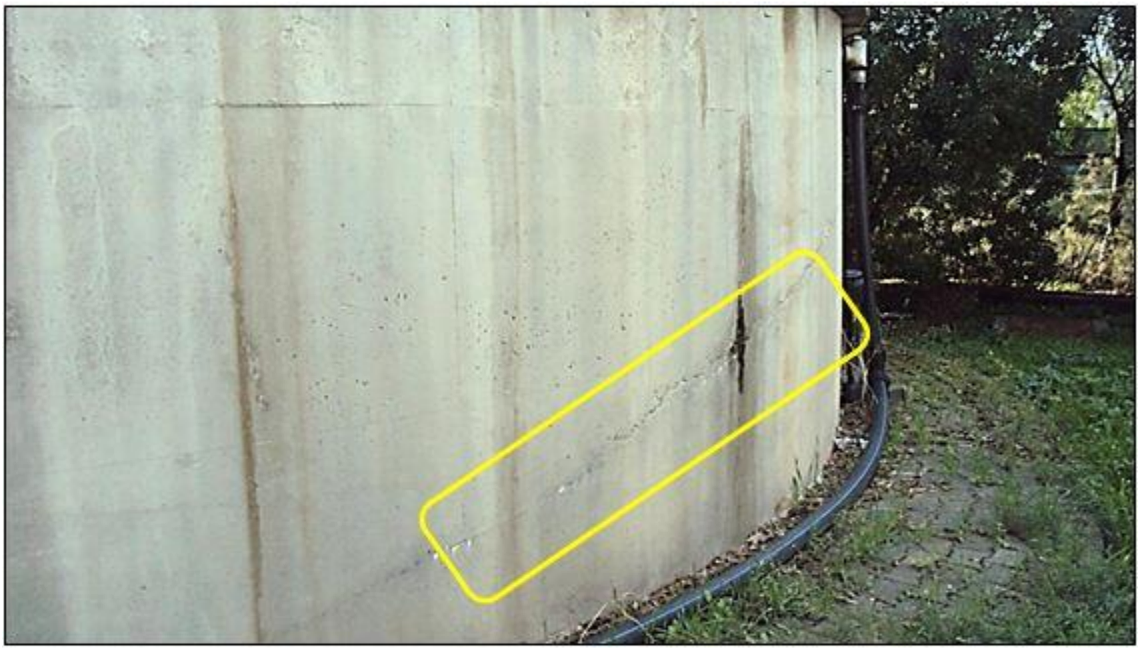

Figure 4.10: Cold Joint Effect on Durability in EMU Campus WWTP.

4.3.5 External Sulphate Attack Problem

This is the most common type of problem that occurs when the water contains dissolved sulphate due to bacteria and penetrates into the concrete. This reaction leads to changes in the composition and microstructure of the concrete. These changes commonly include; extensive cracking due to expansion, loss of bond between the cement paste and its aggregates, alteration of paste composition. The effect of these changes is the overall loss of concrete strength and durability. These changes can be seen in Figures 4.11 and 4.12.

Figure 4.11: Sulphate Problem in the EMU Campus WWTP

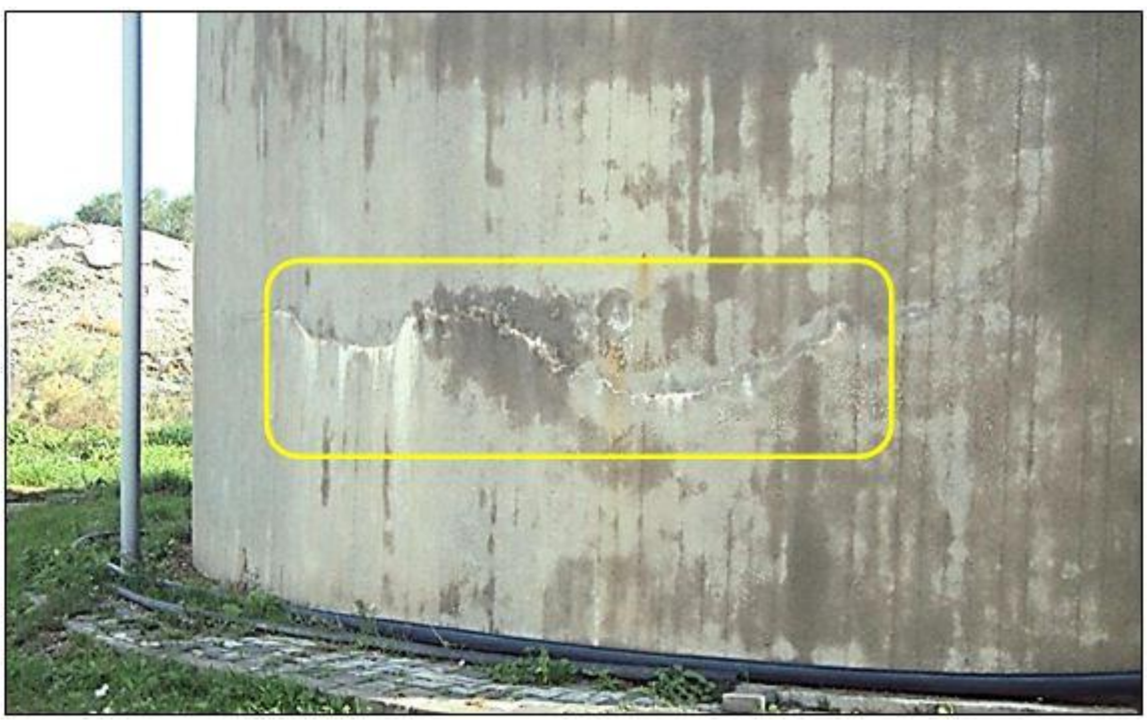

Figure 4.12: Formation of Gypsum Problem in the EMU Campus WWTP

4.3.6 Lack of Maintenance and Repairing of Concrete Cracks

In this plant there are some important types of cracks caused due to the mistakes while casting. Implementing agencies or supervisors do not draw the required attention to these cracks. These cracks cause the easy access of the oxygen and moisture as well as the harmful gaseseventually leading to the corrosion of reinforcment steel bars and deterioration of the concrete. The following two WWTP units, named as Unit-1 and Unit-2 are subjected to some insute and laboratory experiments to determine the degree of the corrosion, which has occured in the reinforcement steel bars and also the quality of the concrete. The main structural difference between the two is the lack of plaster procecess for unit-1.

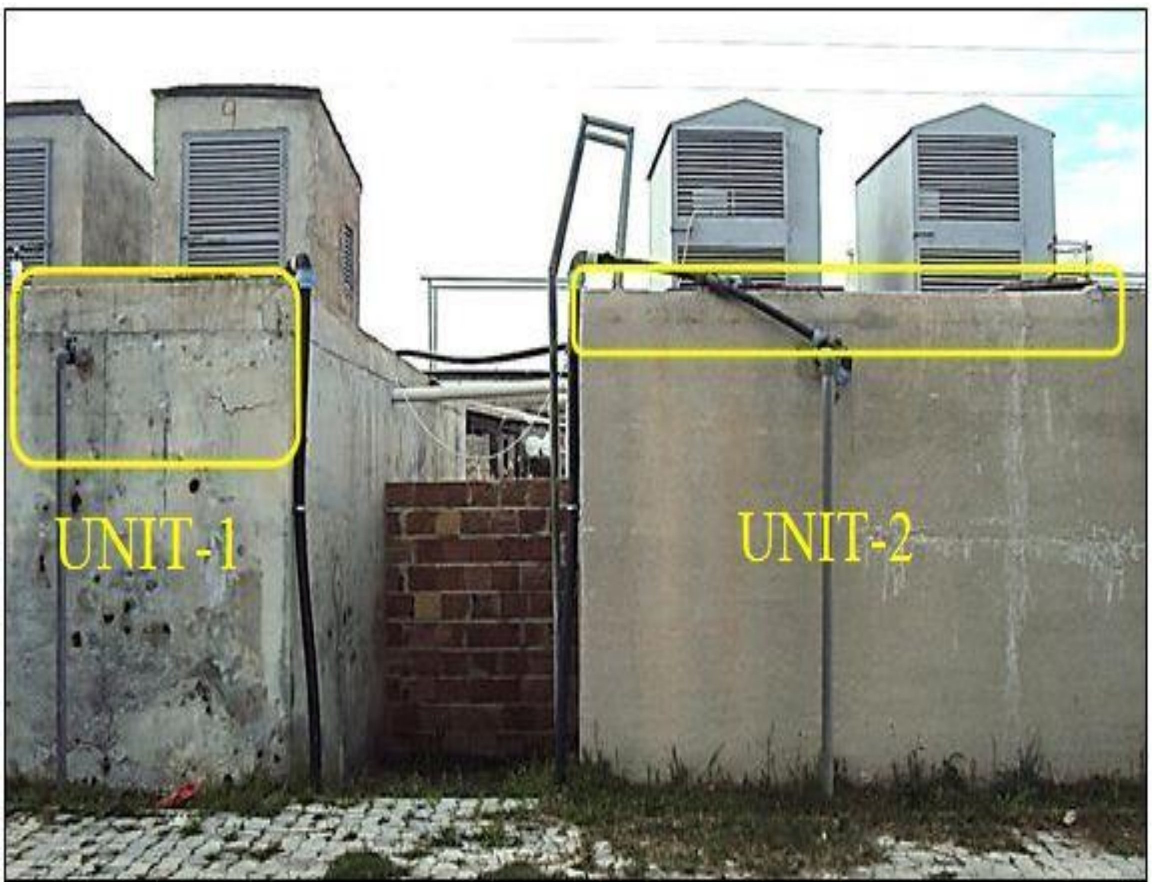

Figure 4.13: Lack of Repairing the Cracks in the EMU Campus WWTP

Chapter 5

EXPERIMENTAL WORKS

5.1 Introduction

The main target of this study is to find out the effect of different factors on the concrete's durability within wastewater plants. The compressive strength, permeability and degree of corrosion in the reinforced steel bars of the concrete might be affected due to the harmless effect of the acidic wastewater during the life span of the plants. Therefore some in-situ and laboratory experiments have been performed for EMU campus sanitary plant. For this purpose, core concrete specimens were taken from different dimensions to measure the compressive strength and permeability and some in-situ readings were made to measure the percentage of corrosion for reinforced steel bars. All experiments were done according to ASTM standards.

5.2 Core Sampling and Standards

According to ASTM C42/C42M-13 named as "Standard Test Method for obtaining and Testing Drilled Cores and Sawed Beams of Concrete", eight core samples were taken from two units of the EMU campus wastewater treatment plant. To determine the actual compressive strength a total of five core samples were taken either from unit-1 or unit-2. On the other hand, three more core samples were taken only from unit-1 for permeability measurements. Figure 5.1-Figure 5.4 shows the stages in which core samples were taken.

Figure 5.1: Determination of Core Sample Location

Figure 5.2: Sampling Core Operation

Figure 5.3: Sample Core Drilled

Figure 5.4: Sampled Core Cutting Process for Test.

5.2.2 Discussion on Concrete Core Samples Qualities-Visual Inspection

The actual compressive strength test results and visual inspections of the core samples were performed according to the "Concrete Society Technical Report No.11-Core Testing for Strength" standard. As the standard notifies, the visual examinations were conducted before trimming and capping the core samples. In Figures 5.3 and 5.4, the difference between the structure of concrete for unit-1 and unit-2 are clearly visible.

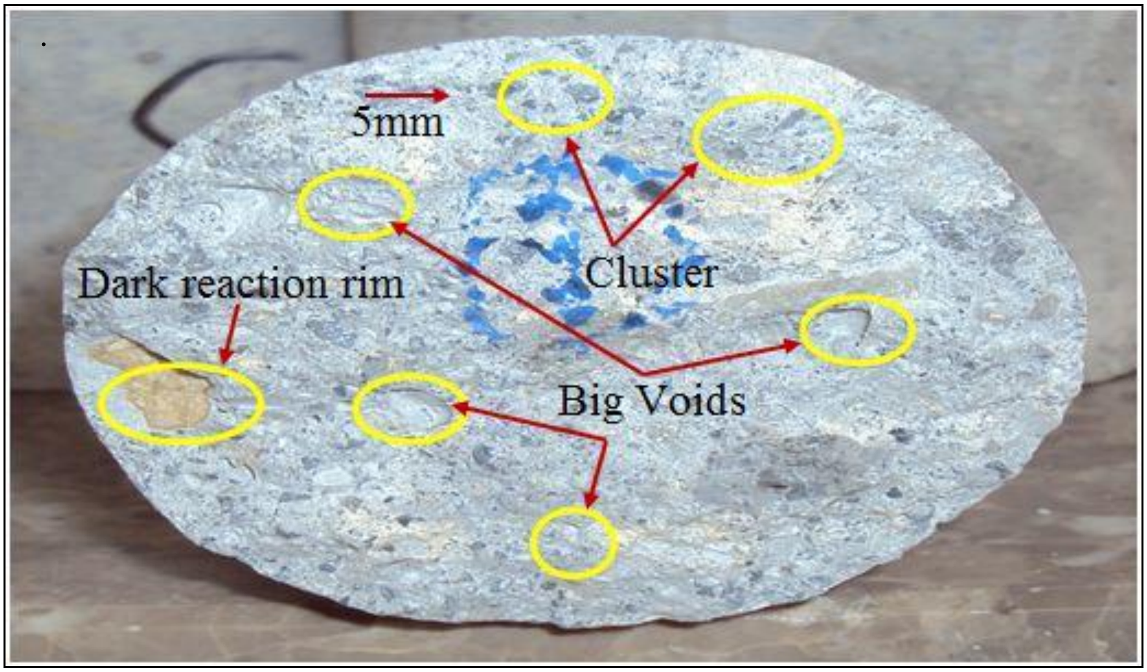

Figure 5.3: Sample of Unit-1 Concrete (No.3)

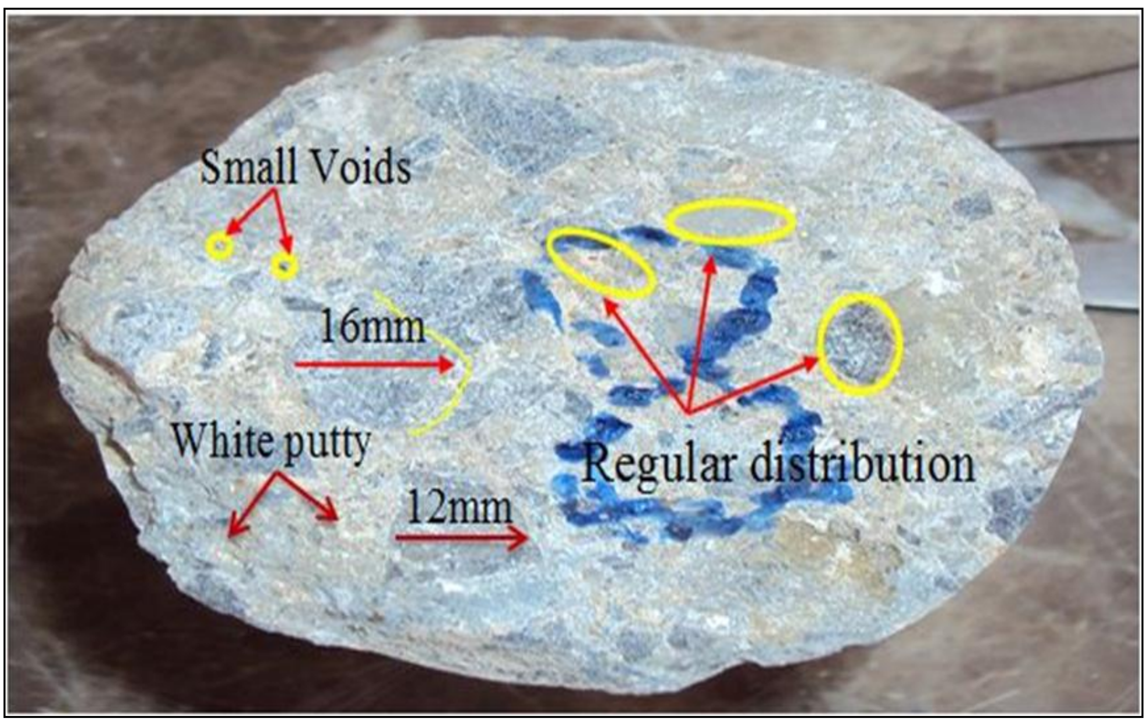

Figure 5.4: Sample of Unit-2 Concrete (No.8)

According to the visual inspection of unit-1 and unit-2, it is very clear that unit-1 is much more deteriorated than unit 2. Both units can be discussed and compared as below:

1- For unit-1 irregular shape coarse aggregates maximum size was measured as 5mm with a non-homogenous distribution, however for unit-2 the irregular shape coarse aggregates have a maximum size of 16mm with homogenous distribution. The maximum aggregate size for the both is below the standard limits which are among the values of (20-25) mm.
2- The cement paste mixture has a gray color for both units.
3- The concrete of unit-1 has high porosity due to weak compaction, general composition is not regular, the amount of coarse aggregate to mortar is low and abrasion exists on the surface. On the other hand, the concrete of unit-2 has low porosity due to good compaction, general composition is regular with no segregation, the amount of coarse aggregate to mortar is normal and less abrasion on the surface was observed.
4- The cover of reinforcement steel bars for unit-1 was observed to be 3 cm and for unit 2 as 5-6 cm. Both are below the standard which is given as 7 cm.

5.4 Preparation of the Core Samples for Compressive Strength Test

After finishing the cutting process as shown in Figure 5.5, the capping operations were done for the five samples to prepare them for the compressive strength test. After the capping process, the concrete specimens were cured for two days in a water tank as shown in Figure 5.6.

Figure 5.5: Capping Specimens

Figure 5.6: Curing Process of Specimens

5.4.1 Discussion of Compressive Strength Test Results

During this study, the compressive strength experiments were carried out according to ASTM C39/C39M – 11. The actual compressive strength results were obtained from five specimens which are as follows; C1, C2 and C3 taken from unit-1 and C7 and C8 taken from unit-2. All the results were adjusted according to Concrete Society Technical Report No.11-Core Testing for Strength. Table 5.1 demonstrates all the actual compressive strength test results

Table 5.1 Core Sample Compressive Strength Test Result

No	Sample Name	Dimensions (mm)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	C1	65x81.5	22.25	24.14
2	C2	65x82	25.89	
3	C3	65x82	23. 96	
4	C7	65x83	51.52	46.83
5	C8	65x82	41.15	

Figure 5.7: Compressive Strength Tests

According to the TS-EN 206.1 standard given in Table 3.5; the actual compressive strength test result of unit-1, with an average value of 24.4 MPa, corresponds to C20 type concrete. However, according to the average value obtained for unit-2, which is 46.83 MPa, corresponds to C40 type concrete.

5.4.2 Discussion of Permeability Test Results

For this research, the permeability tests were carried out on three samples taken from unit-1. The test was implemented according to ASTM C1202. The vacuuming process of these samples, before testing, is show in Figure 5.8.

Figure 5.8: Vacuuming Apparatus

After installing the machine, the test was launched to find the change (coulombs) passing through the specimen. Readings were taken every five minutes as disclosed in appendix 5.

Figure 5.9: Recording of Permeability Values

Figure 5.10: High Permeable Concrete

Table 5.2 Permeability Test Result

No	**Sample Name**	**Coulombs (C)**	**Standard ASTM C1202**
1	P1	19191	>4,000 High / 2,000–4,000 Moderate 1,000–2,000 Low/100–1,000 Very Low <100 Negligible
2	P2	16770	
3	P3	16886	

As it can be observed in Table 5.2, all values recorded from the three samples of unit-1 are greater than 4,000. This means that the concrete of unit-1 is highly permeable.

5.5.1 Corrosion Potential Percentage

According to ASTM C876-80, the measurements for the potential corrosion were carried out by drawing a grid with 10*10 cm dimension as shown in Figures 5.11 and 5.12. The area of corrosion and their percentage can be obtained using this method. This test was applied to two different points of unit-1. One reading is taken from the top of the concrete wall and the other reading is taken from the bottom which is in direct contact with the wastewater.

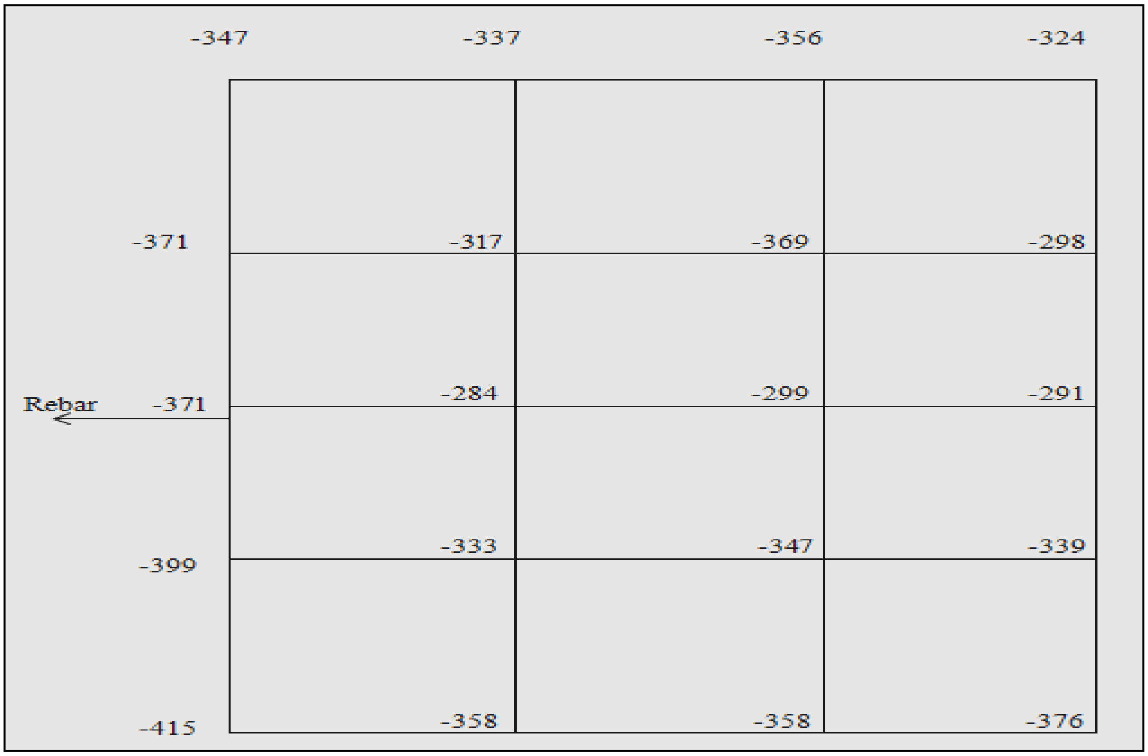

Figure 5.11: Potential Corrosion Percentage Readings- Direct Contact with Wastewater

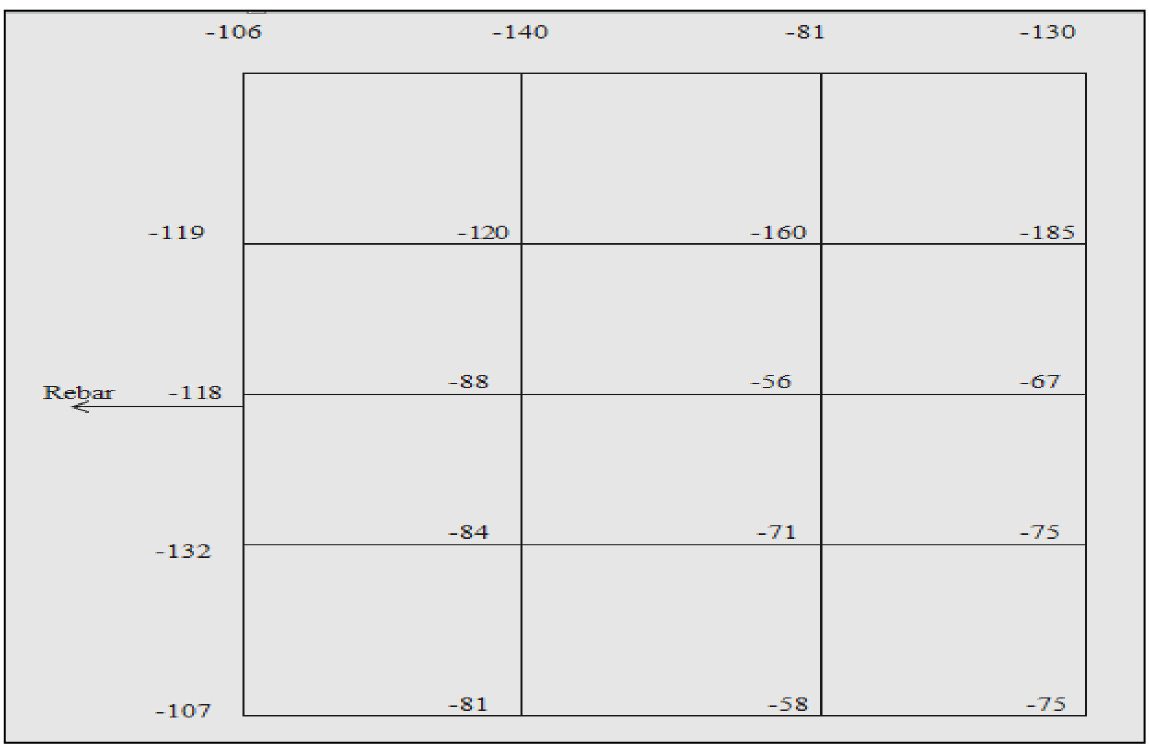

Figure 5.12: Potential Corrosion Percentage Readings-No Contact with Wastewater

Figure 5.13: Potential Corrosion Measurement Process.

If the test results are compared; an extreme difference exists between the corrosion percentage results for the reinforcement steel bars of the concrete which are in direct contact with the wastewater than the corrosion reading taken from the top of the wall. The corrosion result for the first case is 95%, while for the others, which are not in direct contact with the wastewater, it is only 5%.

Chapter 6

CONCLUSIONS

According to the literature review research, the data obtained from the three different WWTP and some experimental test results, the following conclusions were gathered.

1) High durable concrete should be produced for wastewater treatment plant construction. To achieve this; the following steps could be followed:

- Concrete type should be at least C40,
- Cement amount should be at least 300 kg/m3
- Water to cement ratio must be between 30%-40%,
- Well-graded coarse aggregates should be within the range 5mm-20mm,
- Silica fume or blast furnace slag can be used as the mineral admixture.
- Tap water should be used in mixing the concrete.
- Super plasticizer type chemical admixture should be used.

2) Proper casting, vibration, and curing methods should be followed,

3) Quality control tests of the concrete should be performed,

4) Concrete surfaces should be well isolated to protect the concrete from deterioration and the steel bars from corrosion.

5) Preventive maintenance should be followed in wastewater treatment plants to increase the life time service of the plant.

6) According to the experimental study performed in the EMU campus WWTP for unit-1 and unit-2, the following conclusions were carried out:

- Depending on the actual compressive strength test results; the type of concrete used for unit-1 is C20 and for unit-2, the concrete type is C40.
- The unit-1 concrete was found as highly permeable.
- 95% of corrosion was discovered in the steel bars within the concrete which is directly exposed to the wastewater. However the corrosion rate is only 5% for the steel bars within the concrete which is not in a direct contact with the wastewater. These results were gathered from unit-1 which is not plastered.

7) According to the visual observations of unit-1 and unit-2 concretes, it is very clear that unit-1 is much more deteriorated than unit-2.

8) The direct contact of the wastewater with concrete results in serious damage on both the concrete and the structure of the steel bars.

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APPENDICES

Appendix 1: Concrete Compressive StrengthTest Report

EASTERN MEDITERRANEAN UNIVERSITY
Department of Civil Engineering
MATERIALS OF CONSTRUCTION LABORATORY

Project No : B28/2011
Subject : Compressive strength of Concrete
Request for test : Emek İnşaat Şti. Ltd.

Date:17/10/2011

REPORT

The test results of concrete samples (Construction of waste water treatment plant of the town of Famagosta) brought to the Materials of Construction Laboratory are given in Table 1 below.
Table 2 shows requirements of TS-EN206-1 April 2002 standard.

Table 1: Test results.

No	Date of Cast	Date of Test	Age (Days)	Weight (Kg)	Unit Weight (Kg/m^3)	Ultimate Load (kN)	Compressive Strength (N/mm^2)	Concrete Class	Note
1	27.07.11	26.08.11	30	8.030	2379	1055	46.9	C30/37	Emergency generator found
2	27.07.11	26.08.11	30	8.010	2373	1113	49.5	C30/37	Emergency generator found
3	27.07.11	26.08.11	30	7.926	2348	967	43.0	C30/37	Emergency generator found
4	27.07.11	26.08.11	30	8.065	2384	1215	54.0	C40/50	Distribution Chamber Wall
5	27.07.11	26.08.11	30	8.105	2401	1267	56.3	C40/50	Distribution Chamber Wall
6	27.07.11	26.08.11	30	8.005	2372	1269	56.4	C40/50	Distribution Chamber Wall
7	08.08.11	26.08.11	18	8.045	2384	1073	47.7	C30/37	Lime dosing station fond. Conc
8	08.08.11	26.08.11	18	8.025	2378	957	42.5	C30/37	Lime dosing station fond. Conc
9	08.08.11	26.08.11	18	7.940	2353	1049	46.6	C30/37	Lime dosing station fond. Conc
10	18.08.11	26.08.11	8	7.765	2301	809	36.0	C30/37	Gas flare base conc.
11	18.08.11	26.08.11	8	7.960	2359	850	37.8	C30/37	Gas flare base conc.
12	18.08.11	26.08.11	8	8.015	2375	867	38.5	C30/37	Gas flare base conc.
13	18.08.11	26.08.11	8	7.965	2360	668	29.7	C30/37	Aeration tank corner conc.
14	18.08.11	26.08.11	8	7.685	2277	673	29.9	C30/37	Aeration tank corner conc.
15	18.08.11	26.08.11	8	7.765	2298	733	32.6	C30/37	Aeration tank corner conc.
16	18.08.11	26.08.11	8	7.615	2256	685	30.4	C30/37	Sludge pumping st. and final treat. Screed
17	18.08.11	26.08.11	8	7.600	2252	701	31.2	C30/37	Sludge pumping st. and final treat. Screed
18	18.08.11	26.08.11	8	7.585	2247	629	28.0	C30/37	Sludge pumping st. and final treat. Screed
19	08.08.11	15.09.11	38	8.135	2410	1053	46.8	C30/37	Lime dosing station fond. Conc.
20	08.08.11	15.09.11	38	8.060	2388	967	43.0	C30/37	Lime dosing station fond. Conc.
21	08.08.11	15.09.11	38	7.990	2367	1128	50.1	C30/37	Lime dosing station fond. Conc.
22	03.08.11	15.09.11	43	8.060	2388	787	35.0	C20/25	Lime dosing station lean conc.
23	03.08.11	15.09.11	43	7.935	2351	772	34.3	C20/25	Lime dosing station lean conc.
24	03.08.11	15.09.11	43	8.035	2381	747	33.2	C20/25	Lime dosing station lean conc.
25	18.08.11	15.09.11	28	7.675	2274	1004	44.6	C30/37	Aeration tank corner conc.
26	18.08.11	15.09.11	28	7.670	2273	972	43.2	C30/37	Aeration tank corner conc.
27	18.08.11	15.09.11	28	7.580	2246	970	43.1	C30/37	Aeration tank corner conc.
28	18.08.11	15.09.11	28	8.090	2397	968	43.0	C30/37	Gas flare base conc.
29	18.08.11	15.09.11	28	8.045	2384	927	41.2	C30/37	Gas flare base conc.
30	18.08.11	15.09.11	28	7.990	2367	961	42.7	C30/37	Gas flare base conc.
31	18.08.11	15.09.11	28	7.665	2271	1004	44.6	C30/37	Sludge pumping st. and final treat. Screed
32	18.08.11	15.09.11	28	7.465	2212	986	43.8	C30/37	Sludge pumping st. and final treat. Screed
33	18.08.11	15.09.11	28	7.635	2262	972	43.2	C30/37	Sludge pumping st. and final treat. Screed

1/2

Appendix 2: Isolation Material for Repair

Pattex **CF 900**

Henkel

A Brand like a Friend

Technical information

Reaction resin mortar, vinyl-ester-based
styrene-free

CONCRETE / SOLID STONE

USAGE

1. AREAS OF APPLICATION
   - Heavy load-carrying attachments in solid stone, concrete, porous concrete and light concrete
   - Suitable for attachment points close to the edge, since anchoring is free of expansion forces
   - Also suitable as repair mortar or adhesive mortar for concrete components
   - Attachment of anchor rods, threaded collars, reinforcement bars, profiles etc.

2. BENEFITS
   - Can be used in various solid stones
   - Cartridge can be used up to the end of the validity date by replacing the static mixer or resealing cartridge with the sealing cap
   - Water-impermeable joint, i.e. no water can penetrate into the hole at the side of the adhesive compound
   - Galvanised steel, stainless steel, high-corrosion-resistant steel

3. PROPERTIES
   - For use with special application gun and static mixers
   - Temperature resistant up to 80 °C; for short periods up to 120 °C
   - Application temperature of the cartridge should be at least 20 °C
   - High chemical resistance
   - Storage temperature from 5 °C up to max. 25 °C
   - Storage life: 12 months

- ETA-05/0133
- ETA-05/0134
- ETA-05/0135

USAGE INSTRUCTIONS

UNDERSURFACE: Concrete, solid stone

1. Drill hole with percussion drill
2. Clean drill hole (blow out: 4x, brush out: 4x, blow out: 4x)
3. Screw mixer to cartridge
4. Squeeze out and discard approx. 10 cm of compound before use
5. Starting from the back end, fill hole completely with mortar
6. Push anchor up to base of hole whilst turning it slightly
7. Visual check of mortar filling
8. Observe hardening time
9. Install component, apply torque

Appendix 3: Admixture Materials

Product Data Sheet
Edition: 11.10.2007
Revision no: 2
Identification No
01 01 01 01 100 0 000001
Sikament® FFN Plus

Construction

Sikament® FFN Plus

Superplasticizer concrete admixture

Product Description	Sikament® FFN Plus is a substantial water reducing agent for promoting high, early and ultimate strengths or as a highly effective superplasticizer for production of free flowing concrete.
Uses	■ Floor slabs, foundations, ceilings, walls, beams and columns ■ Slender components with densely packed reinforcement ■ Precast concrete elements ■ Prestressed concrete productions ■ Bridge and cantilevered structures ■ Areas of concrete where formwork must be removed quickly or early load will be applied ■ In cold weather concreting where high early strength is desired
Characteristics / Advantages	Sikament® FFN Plus provides following properties As a superplasticizer ■ Substantial improvement in workability without increased water or risk of segregation ■ Improved concrete density and surface finished ■ Improved workability so reduced vibration and labour costs As a high range water reducer ■ Very high water reduction ■ Increased early and ultimate strengths compared with concrete producing without admixture, depend on admixture dosage and concrete mix design ■ Lower water cement ratios provide decreased permeability and increased durability ■ Increases frost and water resistant properties of concrete because of reduced water content and low permeability ■ Reduced rate of carbonation of the concrete ■ Reduced shrinkage and creep ■ Provides economic solutions by improving early and ultimate strengths Sikament® FFN Plus does not contain chlorides or other ingredients promoting corrosion of steel reinforcement. It is therefore suitable for reinforced and prestressed steel.

Tests

Approval / Standards	Conforms to the requirements of TS EN 934-2 tables 3.1 and 3.2.

Sika®

1

Sikament® FFN Plus

Appendix 4: Chemical Analysis of Cement

CEMENT ANALYSIS REPORT

Report Date	Report No.
12.04.2010	35

Type of Cement	Standard Nr.	Vessel / B-L Quantity / Destination	Date of Sampling
Sulfate Resisting Cement SRC 42,5 R	TS 10157- Sulfate Resisting Cement (TS 10157-SDÇ 42,5 R)	M/V ASU ATUN - 635 mTon - CYPRUS	02.04.2010

Chemical and Mineralogycal Analysis (%)	Result of Analysis	Value of Standard		Standard / Method
		Turkish Standard Nr. TS 10157	Euro. Standard Nr.	
SiO_2	18,70			TS EN 196-2 , XRF
Al_2O_3	3,91			TS EN 196-2 , XRF
Fe_2O_3	4,18			TS EN 196-2 , XRF
CaO	64,09			TS EN 196-2 , XRF
MgO	1,39			TS EN 196-2 , XRF
SO_3	2,60	Max. 4,0 (%)		TS EN 196-2 , XRF
Na_2O	0,27			TS EN 196-21 , XRF
K_2O	0,88			TS EN 196-21 , XRF
Cl	0,0177	Max. 0,100 (%)		TS EN 196-21 , XRF
Loss on Ignition (LOI)	4,87	Max. 5,0 (%)		TS EN 196-2
Insoluble Resudie (IR)	0,31	Max. 5,0 (%)		TS EN 196-2
Na_2OEq. (Na_2O + 0,658 K_2O)	0,85			Calculated
Free CaO	3,15			TS 687 (Acidimetric)
Minor Additional Constituents	0,00			TS 10157
Clinker	100,00	Min. 100 (%)		TS 10157
Tri Calcium Silicate (C_3S)	50,61			Calculated By Bogue Eq.
Di Calcium Silicate (C_2S)	13,18			Calculated By Bogue Eq.
Tri Calcium Aluminate (C_3A)	3,29	Max. 5,0 (%)		Calculated By Bogue Eq.
Tetra Calcium Alumino Ferrite (C_4AF)	12,72			Calculated By Bogue Eq.
$2C_3A + C_4AF$	19,30	Max. 25,0 (%)		Calculated by Bogue Eq.

Physical and Mechanical Analysis		Result of Analysis	Value of Standard		Standard / Method
			Turkish Standard Nr. TS 10157	Euro. Standard Nr.	
Spesific Gravity (gr/cm^3)		3,12			TS EN 196-6
Spesific Surface (cm^2/gr)		4019			TS EN 196-6
Setting Time	Initial (minute)	170	Min. 60,0		TS EN 196-3
Soundness (mm)		0	Max.10,0		TS EN 196-3
Compressive Strength (MPa)	2 Days	24,2	Min. 20,0		TS EN 196-1
	7 Days	37,4			
	28 Days		Min. 42,5 - Max. 62,5		TS EN 196-1

Controlled By	Approved By
Hakan BERBER	Sinal ÖZEL

Appendix 5: Permeability Measurements Details

Ver.	Firmware	1.0	
Test	to	ASTM	C1202
Id	Test:	40300	
Id	Sample:	1	
Integration	int.:	5min	
Time:	13:20:12		
Date:	12/04/2013		
***	CELL	1	***
V:	60.0		
mA:	297		
T.:	f		
C:	89		
***	CELL	1	***
V:	60.0		
mA:	310		
T.:	Ef		
C:	181		
***	CELL	1	***
V:	60.0		
mA:	329		
T.:	[illegible]		
C:	279		
***	CELL	1	***
V:	60.0		
mA:	343		
T.:	f		
C:	381		
***	CELL	1	***
V:	60.0		
mA:	359		
T.:	f		
C:	488		
***	CELL	1	***
V:	60.0		
mA:	370		
T.:	f		
C:	598		
***	CELL	1	***
V:	60.0		
mA:	379		
T.:	f		
C:	711		
***	CELL	1	***
V:	60.0		
mA:	390		
T.:	pf		
C:	828		
***	CELL	1	***
***	CELL	1	***
V:	60.0		
mA:	416		
T.:	f		
C:	1072		
***	CELL	1	***
V:	60.0		
mA:	425		
T.:	f		
C:	1199		
***	CELL	1	***
V:	60.0		
mA:	439		
T.:	f		
C:	1330		
***	CELL	1	***
V:	60.0		
mA:	453		
T.:	f		
C:	1465		
***	CELL	1	***
V:	60.0		
mA:	467		

mA:	394		
T.:	1f		
C:	10879		
***	CELL	1	***
V:	60.0		
mA:	385		
T.:	Df		
C:	19191		
Permeability	Class:		
**	High	**	
Time:	19:22:39		
Date:	12/04/2013		

Appendix 5: Permeability Measurements Details (cont.)

Ver.	Firmware		1.0
Test	to		ASTM C1202
Id	Test:		40300
Id	Sample:		2
Integration	int:		5min
Time:		19:48:06	
Date:		13/04/2013	
***	CELL		1 ***
V:	60.0		
mA:		314	
T.:	f		
C:		94	
***	CELL		1 ***
V:	60.0		
mA:		322	
T.:	f		
C:		190	
***	CELL		1 ***
V:	60.0		
mA:		337	
T.:	of		
C:		291	
***	CELL		1 ***
V:	60.0		
mA:		350	
T.:	Bf		
C:		395	
***	CELL		1 ***
V:	60.0		
mA:		366	
T.:	f		
C:		504	
***	CELL		1 ***
V:	60.0		
mA:		377	
T.:	jf		
C:		617	
***	CELL		1 ***
V:	60.0		
mA:		389	
T.:	f		
C:		733	
***	CELL		1 ***
V:	60.0		
mA:		401	
T.:	<f		
C:		853	
***	CELL		1 ***
***	CELL		1 ***
V:	60.0		
mA:		429	
T.:	f		
C:		1105	
***	CELL		1 ***
V:	60.0		
mA:		440	
T.:	!f		
C:		1237	
***	CELL		1 ***
V:	60.0		
mA:		456	
T.:	Jf		
C:		1373	
***	CELL		1 ***
V:	60.0		
mA:		469	
T.:	f		
C:		1513	
***	CELL		1 ***
V:	60.0		

***	CELL		1 ***
V:	60.0		
mA:		362	
T.:	>f		
C:		8991	
***	CELL		1 ***
V:	60.0		
mA:		360	
T.:	f		
C:		16770	
Permeability	Class:		
**	High		**
Time:		01:50:33	
Date:		13/04/2013	

Appendix 5: Permeability Measurements Details (cont.)

Ver.	Firmware		1.0
Test	to		ASTM C1202
Id	Test:		40300
Id	Sample:		3
Integration	int.:		5min
Time:		10:13:34	
Date:		15/04/2013	
***	CELL		1 ***
V:	60.0		
mA:		294	
T.:	f		
C:		88	
***	CELL		1 ***
V:	60.0		
mA:		307	
T.:	f		
C:		180	
***	CELL		1 ***
V:	60.0		
mA:		321	
T.:	f		
C:		276	
***	CELL		1 ***
V:	60.0		
mA:		335	
T.:	f		
C:		376	
***	CELL		1 ***
V:	60.0		
mA:		347	
T.:	f		
C:		480	
***	CELL		1 ***
V:	60.0		
mA:		358	
T.:	f		
C:		587	
***	CELL		1 ***
V:	60.0		
mA:		371	
T.:	f		
C:		698	
***	CELL		1 ***
V:	60.0		
mA:		379	
T.:	)f		
C:		811	
***	CELL		1 ***
***	CELL		1 ***
V:	60.0		
mA:		402	
T.:	|f		
C:		1049	
***	CELL		1 ***
V:	60.0		
mA:		416	
T.:	f		
C:		1173	
***	CELL		1 ***
V:	60.0		
mA:		421	
T.:	Cf		
C:		1299	
***	CELL		1 ***
V:	60.0		
mA:		435	
T.:	f		
C:		1429	
***	CELL		1 ***
V:	60.0		

V:	60.0		
mA:		367	
T.:	f		
C:		9216	
***	CELL		1 ***
V:	60.0		
mA:		355	
T.:	f		
C:		16886	
Permeability	Class:		
**	High		**
Time:		16:13:43	
Date:		15/04/2013	