STRUCTURAL CONCRETE IN AGGRESSIVE ENVIRONMENTS :

A CASE STUDY OF THE FEDERAL SUPERPHOSPATE FERTILIZER COMPANY LIMITED, KADUNA

BY

UNDE, RICHARD TERFA
B. ENG. (CIVIL) A.B.U.

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
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DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA,
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I ECLARATION

I hereby declare that the work in this dissertation was carried out by me under the supervision of S.S Letcha and A.J. Akpan.

No part of this dissertation has been presented in any previous application for a higher degree. All sources of information are acknowledged by means of references.

.....

UNDE, RICHARD TERFA.

CERTIFICATION

This dissertation entitled "STRUCTURAL CONCRETE IN AGGRESSIVE ENVIRONMENT; A CASE STUDY OF THE FEDERAL SUPERPHOSPHATE FERTILIZER COMPANY LIMITED, KADUNA", by Unde, Richard Terfa meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

.....

S.S. Letcha

Chairman

Supervisory Committee

.....

A.J Akpan M.N.S.E

Member

Supervisory Committee

.....

Prof. O. Adebisi, Head

Civil Engineering Department

.....

Dean, Postgraduate School

Date:....31.7.97

AHMADU BELLO UNIVERSITY, ZARIA,

NIGERIA.

DEDICATIOn

This work is deservedly dedicated to my dad,

J. A. Unde,

who naketh while we clothe.

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CONTENTS

Title		Page
Declaration		ii
Certification		iii
Dedication		iv
Acknowledgements		v
Table of Contents		vi
List of Figures		x
List of Tables		xi
List of Plates		xiii
List of Notations		xiv
Synopsis		xvi
CHAPTER ONE		
1.1	General Introduction	1
1.2	Justification of Research	2
1.3	Objectives of Research	3
1.4	Scope	4
1.5	Methodology.	4
CHAPTER TWO		
2.0	LITERATURE REVIEW	6
2.1	Introduction	6
2.2	Concrete in Chemically Aggressive Environments	7
2.2.1	Sulphate Attack on Concrete	8
2.2.2	Acid Attack on Concrete	17
2.2.3	Gas Attack on Concrete	20
2.2.4	Chlorine/Seawater Attack on Concrete	20

2.3	Concrete in Physically Aggressive Environments	22
2.4	Concrete in Biologically Aggressive Environments	23

CHAPTER THREE

3.0	SITE ASSESSMENT	24
3.1	Introduction	24
3.2	Background Information on Case Study Site	24
3.3	Production Processes	28
3.3.1	Superphosphate Production	28
3.3.2	Chemistry of the Superphosphate Production	28
3.3.3	Sulphuric Acid Production	29
3.3.4	Chemistry of the Sulphuric Acid Production	29
3.4	Site Inspection	29
3.4.1	Documentary Evidences	29
3.4.2	Equipment for Site Inspection	33
3.4.3	Procedure for Site Inspection	33
3.4.4	Site Observations	34
3.5	In-situ Testings	36
3.5.1	Equipment for In-situ Testing	37
3.5.2	Procedure for In-situ Testing	38

CHAPTER SEVEN

7.0	CONCLUSION AND RECOMMENDATIONS	83
7.1	Summary of Condusions	83
7.1.1	Literature Review	83
7.1.2	Visual observations and Experimental Studies	84
7.2	Recommendations	85
	APPENDICES	86
	BIBLIOGRAPHY	96

LIST OF FIGURES

2.1 Strength of 1:3 Mortar Bars Stored in a 0.15 Molar solution of Na_2SO_4

2.2 Dimensional Changes of Mortars made with Portland Cement

3.1 Case study site plan

4.1 Cube Compressive Strength of Concrete made with Ordinary Portland Cement

4.2 Basic Volume Fraction of Cement for Different Workabilities.

4.3 Corrections to Basic Volume Fraction of Cement

4.4 Recommended Volume Fraction of Coarse Aggregate

5.1 Case Study Site Plan Showing Sampling Locations

6.1 Case Study Site Plan Showing a Summary of Damages Based on Visual Observations.

LIST OF TABLES

Table No	
4.1	Physical Properties of Cement Employed
4.2	Chemical Composition of the Cement Employed
4.3	Workability Requirements
4.4	Sieve Analysis Result
4.5	Aggregate Grading Parameters
4.6	Solids Fraction of Loose Coarse Aggregate
5.1	In-situ (Pundit) Test Result
5.2	In-situ (Pundit) Test Result
5.3	In-situ (Pundit) Test Result
5.4	In-situ (Pundit) Test Result
5.5	Chemical Composition by weight of Soil Samples
5.6	PH Results for soil samples
5.7	Results of Control Specimens
5.8	7 Days Immersion Test Results For the Uncoated Specimen
5.9	14 Days Immersion Test Results For the Uncoated Specimen
5.10	21 Days Immersion Test Results For the Uncoated Specimen
5.11	28 Days Immersion Test Results For the Uncoated Specimen
5.12	7 Days Immersion Test Results For the Bitumen Coated Specimen
5.13	14 Days Immersion Test Results For the Bitumen Coated Specimen
5.14.	21 Days Immersion Test Results For the Bitumen Coated Specimen

5.15 28 Days Immersion Test Results For the Bitumen Coated Specimen

LIST OF PLATES

Plate No.		Page
1.	Cube Before Immersion and after 28 days of Immersion in Sulphuric Acid.	91
2.	Bitumen Coated Cube after 28 Days of Immersion ir Sulphuric Acid.	92
3.	Devastation of Concrete Acid Tank Foundation at the Sulphuric Acid Plants Also Showing Corroded Steel Pipes.	93
4.	Devastation of Concrete and Corrossion of Steel Pipes Near the Stark Equipment at the Sulphuric Acid Plant.	94
5.	Devastation of Concrete Wall at the Acidulation Plant.	95

LIST OF NOTATIONS

a.	Volume fraction of coarse aggregate
b.	Volume fraction of fine aggregate
c.	Volume fraction of cement
Db.	Equivalent mean diameter of fine aggregate
fcm.	Target mean strength
fcu.	Required characteristic strength
Ga	Grading modulus for coarse aggregate
Gb	Grading modulus for fine aggregate
S	Standard deviation
W	Volume fraction of water
Mi	Initial acid molarity
Mf	Final acid molarity
Vi	Initial acid volume
Vf	Final volume of acid + dilution water
O_2	Oxygen
S	Sulphur
Ca	Calcium
Cl	Chlorine
CO_2	Carbon dioxide
C_3A	Tricalcium aluminate
C_4AF	Tetracalcium aluminoferrite
HF	Hydrogen flouride
HI	Hydrogen iodide
H_2O	Water
PO_4	Phosphate
P_2O_5	Phosphorous pentaoxide
SO_3	Sulphite

SO_4	Sulphate
SiO_2	Silicon dioxide
$Bacl_2$	Barium chloride
$Ca(OH)_2$	Calcium hydroxide
$CaSO_4$	Calcium sulphate
Fe_2O_3	Iron II oxide
Al_2O_3	Aluminium trioxide
Hcl	Hydrochloric acid
HNO_3	Nitric acid
H_2SO_4	Sulphuric acid
$KMnO_4$	Pottasium permanganate
KSCN	Pottasium tiocyanide
$MgSO_4$	Magnesium sulphate
HPO_3	Phosphoric acid
NaOH	Sodium hydroxide
Na_2SO_4	Sodium sulphate
NH_4cl	Ammonium chloride
NH_4OH	Ammonium hydroxide
$(NH4)_2SO_4$	Ammonium sulphate
$Ca(H_2PO_4)_2$	Soluble phosphate (fertilizer).
$Ca_5F(PO_4)_3$	Phosphate rock
$CaSO_4.2H_2O$	Gypsum
$3CaO.2SiO_2$	Tricalcium silicate
$3CaO.Al_2O_3.12H_2O$	Hydrated calcium aluminate
$3C_3O.Al_2O_3.3C_3So_4.31h_2O$	Calcium sulphoaluminate (ettringite)

SYNOPSIS

This dissertation presents details of the study of how aggressive environments affect concrete durability with particular reference to the structural concrete at the Federal Superphosphate Fertilizer Company Limited, Kaduna, and the acidic (H_2SO_4) environment to which it is exposed by virtue of the production processes.

It has been established from available literature that there exist three types of aggressive environments in relation to concrete durability. These are chemical, physical and biological with the degree of aggressivity decreasing in that order. It has further been established that the durability of concrete is affected more adversely under hot weather conditions than cold weather conditions in a chemically aggressive environment. This is by virtue of the fact that the devastation reaction like most chemical reactions is accelerated by high temperatures.

In the experimental investigation, chemical analysis of soil samples from selected locations at the case study site together with the observed nature of the devastation have diagnosed the sulphuric acid rich environment as the main cause of the devastation. Non - destructive testing using the pundit tester has ascertained the severe devastation the structure has undergone with the structural concrete having a residual compressive strength of about one - quarter the initial strength.

In simulating the site conditions, the ages of total immersion in sulphuric acid (46 .31% concentration) of concrete cubes ($40N/mm^2$) was varied for 7, 14, 21 and 28 days. It was found that the losses in weight, density and strength of both the

uncoated and bitumen coated concretes took place rapidly initially but at later ages diminished progressively as a result of the reduced cement surface the acid can attack. It was also found that the loses in weight, density and compressive strength of a bitumen coated concrete subjected to sulphuric acid attack took place more slowly in comparison with an uncoated concrete initially. However, this trend reversed at later ages as a result of the dissolved bitumen increasing the acidity of the attacking medium.

Overall, it was found that the structural concretes in the tested areas at the case study site have become structually unsafe.

CHAPTER ONE

1.1 GENERAL INTRODUCTION

Structural concrete is today, one of the principal construction materials that has gained world wide usage. As a construction material, it has done creditably well yet instances abound where it has failed to achieve the desired durability performance. Most of the works done by early researchers have always attributed this non attainment of desired performance to poor workmanship, its constituent materials and the proportion in which they are mixed without giving due consideration to the type of environment in which the concrete has been mixed, placed, cured and is subsequently expected to function.

Perhaps not so obvious but of a more severe nature is the devastation concrete suffers when put to use in an aggressive environment. This is particularly so for concrete in acidic, sulphate, chloride and marine polluted environments. Because of the chemically biased nature of the devastation these environments make concrete undergo, they are referred to as chemically aggressive environments as far as concrete durability is concerned. The devastation is a consequence of the reaction produced between the chemical radicals prevalent in such an environment and the products of cement hydration in concrete.

The last three decades in Nigeria as indeed most of the developing nations of the world has witnessed a proliferation of industrial activities. Most of these industries are either wholly chemically biased in their products or use one form of chemical or the other in production. The fact that such chemicals very

often come in contact with the structural concrete need not be over - emphasized. It is a well known fact too, that high temperatures accelerate the rate of many chemical reactions. This is true for both the hydration reaction of cement in structural concrete and for the reaction of the chemicals which attack concrete.

The case study site of this research; The Federal Superphosphate Fertilizer Company Limited, Kaduna, is one of such industrial complexes in which the structural concrete is in contact with an environment that is chemically polluted. Handling of the constituents of the fertilizer and the fertilizer itself within the factory premises often results in spillage. During the rainy seasons, this spilled fertilizer gets dissolved and the dissolved solution percolates into the ground and with time, seeps into the structural concrete. A mere visual inspection of the case study site reveals devastating attributes such as cracks, discolourations, displacements, pop-outs, exudations, dissolved cement etc that are usually associated with structural concrete when put to use in an environment that is chemically aggressive. It therefore, came as no surprise when some time back, some newspapers reported that the Federal Superphosphate Fertilizer Company Limited, Kaduna, was being confronted by serious civil engineering (structural) problems.

1.2 JUSTIFICATION OF RESEARCH

As stated above, Nigeria as indeed most of the developing nations of the world fall into the hot - dry climate where the climatic conditions make the devastation of structural concrete

in chemically aggressive environments most severe as a result of the high temperatures which accelerate the devastation reaction. Hot - dry climates are characterized by aridity, high day - time summer temperatures and frequently by high wind velocities. The maximum summer temperatures are in the region of 40^{0}c- 50^{0}c, while the minimum may be around 15^{0}c - 25^{0} c. The relative humidity fluctuates with the air temperature ranging from approximately 20% - 30% in the afternoon and from approximately 30% - 50% at night[36]. Hot - dry regions are found in the sub-tropical regions of Africa, the Middle East, Central and Western Asia, North - Western and Southern America. However, despite the severity of the problem in these regions, it is probably least understood in these regions which encompass most of the developing nations of the world with their characteristic lack of resources and technical expertise. Therefore, a thorough understanding of the problem with the aim of checking it in Nigeria which by implication can be extended to any of the nations in the hot dry climatic regions of the world becomes more important than ever before. This has to be so if industrial structural concrete that is prone to come into contact with a chemically aggressive environment is to attain it's desired life span.

1.3 OBJECTIVES OF RESEARCH

This research has as its main objective, the assessment of the durability of structural concrete in a chemically polluted environment.

The ancillary objectives include:

(i) A chemical analysis of the soil at the case study site for possible identification of the corrosion radicals present in the environment.

(ii) Examination by simulations in the laboratory of equivalent aggressive environments. This will facilitate comparison with the control specimens.

(iii) Assessing the probable future of the structural concrete at the case study site.

(iv) Codification of results and publication in engineering journals for knowledge dispensation.

1.4 SCOPE

It is a widely recognized fact that concrete compressive strength is the singular most important yardstick of concrete durability. Concrete is also known to be weak in tension. To make up for this weakness, it is usual to reinforce the concrete in the tension zone. Existing literatures have established that the tensile strength of concrete is only about ten percent of its compressive strength. From the above, the reason for the preference of concrete compressive strength and not concrete tensile strength as an index of concrete durability need not be over - emphasized. In the light of this therefore, the durability assessment of concrete is restricted to concrete compressive strength in this research.

1.5 METHODOLOGY

For the purpose of strength assessment as an index of durability, non destructive testing techniques will be employed.

The corrosion radicals present at the case study site will be identified using the quantitative technique of chemical analysis.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The durability of concrete is defined as[1] its resistance to deteriorating influences which may through inadvertence or ignorance reside in the concrete itself, or which are inherent in the environment to which it is exposed. Though strength is usually considered as the yardstick to judge concrete quality, when concrete is exposed to aggressive environments its performance is dependent to a greater extent on its durability against the environmental conditions than on its strength property.

Lea[19] and Neville[25] have identified three types of environments as being potentially aggressive to concrete. These are the chemical, physical and biological with the degree of aggressivity decreasing in that order.

It is known that aggressive environments are more common in hot-arid regions than cold regions. Thus, concrete structures exposed to such environments are liable to deterioration and may never fulfil their designed life. High temperatures coupled with these environments make concrete structures even more vulnerable to deterioration with time[25]. Therefore, a knowledge of durability is of great practical significance so that adequate measures can be taken to minimize the deterioration of concrete structures in such environments.

It has been observed that the deterioration of concrete is very rarely due to one isolated cause[19]. Therefore it is

difficult to hold a single factor as being responsible for concrete deterioration in a given situation. It is however possible to identify the factor that plays a domineering role in the deterioration.

As stated above, the potentially aggressive environments to concrete are the chemical, physical and biological. This chapter is devoted to the review of influences of these varied environments on concrete durability being the main theme of this project. Some precautionary measures as well as methods of maintaining designed durability are also discussed.

2 2 *CONCRETE IN CHEMICALLY AGGRESSIVE ENVIRONMENTS*

The resistance of concrete to attack by chemical agents is generally lower than to other forms of attack[25]. This is quite fortunate since only a small proportion of the concrete used in practice is exposed to serious chemical attack. Chemical attack is generally common only to industrial structural concrete where as a result of negligence or inadvertence, potentially aggressive chemicals are bound to come in contact with the structural concrete.

Dry concrete is generally immune to attack by dry chemicals[16, 19]. It is also highly resistant to many chemicals in solution. However, a considerable number of chemicals in solution will attack concrete[28]. When concrete is attacked by a chemical solution, the rate and extent of deterioration generally depends on the nature and concentration of substance in the solution in contact with the concrete, the temperature and

pressure of the solution , and importantly, on the quality of the concrete as measured primarily but not solely by its permeability.

The more common forms of chemical attack are the action of sulphates, chlorides, seawater, acids and gases on concrete. The effect of these on concrete durability will be considered hereafter.

2.2.1 *SULPHATE ATTACK ON CONCRETE*

Solid sulphates do not attack concrete but when present in solution, they can react with the hardened cement paste[25]. Sulphate solutions which have shown appreciable deterioration effects on concrete are those of ammonia, aluminum, calcium, cobalt, copper, iron, magnesium, nickel, potassium, sodium and zinc[28]. However, of this lot, the calcium, sodium and magnesium sulphates are the most common and occur naturally in many parts of the world as alkali soils. Therefore, attack takes place if concrete slabs, foundations and other structures are laid in contact with such sulphate bearing soils and ground water. Concrete is also prone to attack from sulphate in industries where the use of sulphates is employed. The use of ammonium sulphate in the ammonia fertilizer industry readily comes to the mind.

The sulphate surrounding concrete reacts with the products of cement hydration in the concrete and forms compounds which are known to have a greater volume than the compounds they replace[2, 16, 19, 25]. This means that the reaction with sulphate leads to expansion and disruption of concrete.

Concrete attacked by sulphate has a characteristic whitish appearance. The damage usually starts at edges and corners and is followed by progressive cracking and spalling which reduces the concrete to a friable or even soft state[25].

Various investigators[2, 16, 19, 23, 25] have convergent views on the chemistry and mechanism behind the deterioration of concrete in a sulphate infested environment. For brevity, the chemistry and mechanism behind the deterioration of concrete in calcium, sodium and magnesium sulphates will be presented. A consideration of the influences these sulphate exert on concrete is an almost exhaustive representation of the influence of sulphates on concrete[19] because all the other sulphates react with concrete in very much the same way as one of these three.

Sodium sulphate can attack concrete by reacting with the free calcium hydroxide and the hydrated calcium aluminate to form gypsum and the calcium sulphoaluminate also called the ettringite respectively. The reaction between sodium sulphate and the free calcium hydroxide in set cement can be formulated as follows[19]:

$$Ca(oH)_2 + Na_2\ SO_4.10H_2O \rightarrow CaSO_4.2H_2O + 2NaOH + 8H_2O \quad - (1)$$

The extent to which the reaction (1) proceeds depends on the condition. In flowing water with a constant supply of sodium sulphate and removal of sodium hydroxide, it will eventually proceed to completion. If however, the sodium hydroxide accumulates, an equilibrium is reached depending on the sodium sulphate concentration[13]. Test conducted by Lea[19] are in agreement with the above assertion. The test results showed that with 5 per cent sodium sulphate solution, only about one - third

of the sulphur trioxide is deposited as calcium sulphate when equilibrium is reached and with 2 per cent sodium sulphate only about one-fifth.

Sodium sulphate can also attack concrete by reacting with the hydrated calcium aluminate. The chemistry of the attack is thus[19]:

$2(3CaO.Al_2O_3.12H_2O) + 3(Na_2SO_4.10H_2O) \rightarrow$

$3CaOAl_2O_3.31H_2O + 2Al(OH)_3 + 6NaOH + 17H_2O$ - (2)

Calcium sulphate however, does not react with the free calcium hydroxide in set cement[25]. It attacks concrete by reacting with the hydrated calcium aluminate in the set cement. The chemistry of the reaction is as follows[19]:

$3CaO.Al_2O_3.12H_2O + 3(CaSO_4.2H_2O) + 13H_2O \rightarrow$

$3CaO.Al_2O.3CaSO_4.31H_2O$ - (3).

In the reaction (1) the conversion of calcium hydroxide to gypsum more than doubles the solid volume, the respective molecular volumes of calcium hydroxide and gypsum being 33.2 and 74.3 cc. The combination of the hydrated calcium aluminate and gypsum to form calcium sulphoalumina the ettringite is accompanied by a rather smaller increase in solid volume. This reaction accounts for the expansion and disruption of concrete and mortars when attacked by these sulphates[2, 15].

The alkali sulphates do not attack the hydrated calcium silicate to any appreciable extent[19] because they are more insoluble than the calcium sulphate and the alkali silicates that would result. The calcium hydroxide liberated in the setting of tri-and dicalcium silicates reacts according to the reaction (1) above. Thus, in sodium sulphate solution, crystals of gypsum are

soon formed from tricalcium silicate but with dicalcium silicate the reaction proceeds much more slowly corresponding with the very slow rate at which this compound splits of calcium hydroxide in water.

Magnesium sulphate has a far more reaching action than other sulphates and decomposes the hydrated calcium silicates in addition to reacting with the free calcium hydroxide and the hydrated calcium aluminate in the set cement. The reaction of magnesium sulphate and the calcium hydroxide occurs in exactly the same way as the reaction of (1) above.

Magnesium sulphate has initially a similar action to that of the other sulphates on the hydrated calcium aluminates, and calcium sulphoaluminate (ettringite) is first formed together with magnesium hydroxide. The calcium sulphoalminate is itself however unstable in the presence of magnesium sulphate solution[19], and by the continued action of this salt, it is ultimately decomposed again to form gypsum, hydrated alumina and magnesium hydroxide, This action must be attributed to the PH value of the saturated magnesium hydroxide solution being below that required to stabilize calcium sulphoaluminate. It can be seen to occur if calciumsulphoaluminate is placed in a magnesium sulphate solution, when crystals of gypsum gradually form. The external skin of cement mortars which have been exposed for a fairly long period to the action of magnesium sulphate solution sometimes appears quite free from calcium sulphoaluminate crystals, while gypsum is present in large amounts. In the interior of the mortar, where access of the solution has been much slower, both calcium sulhoaluminate and gypsum are formed.

If tri- or dicalcium silicate is placed in a magnesium sulphate solution, the formation of gypsum crystals occurs rapidly. The reaction between the tricalcium silicate hydrate and magnesium sulphate can be formed as follows[19]:

$3CaO.2SiO_2.aq + MgSO_4.7H_2O \rightarrow CaSO_4.2H_2O + Mg(OH)_2 + SiO_2.aq$ - (4)

Because of the very low solubility of magnesium hydroxide, the above reaction proceeds to completion[31] so that under certain conditions, the attack by magnesium sulphate is more severe than by other sulphate. Lea[19] agrees with the above assertion but says there is more to it than just the low solubility of the magnesium hydroxide. According to him, the reasons why the above action proceed completely while with sodium sulphate, it does not occur is to be found in the low solubility of magnesium hydroxide and the resulting low PH value of its saturated solution. It is soluble only to the extent of about 0.01gm per litre and its saturated solution has a PH value of about 10.5. This is lower than the PH required to stabilize the hydrated calcium silicate. The silicate liberates lime to the solution to establish its equilibrium PH but when magnesium sulphate is present, the lime reacts with it forming magnesium hydroxide and calcium sulphate. The former at once separates from solution reducing the PH value to 10.5 again; more lime passes into solution by decomposition of a further part of the hydrated calcium silicate to re-establish the PH and so the action proceeds. The calcium sulphate accumulates in solution until it becomes saturated and crystals of gypsum then separate out.

There is evidence that the above equation is not the end of

the above reaction (4), for Steopoe[32] has found that magnesium hydroxide and the silica gel can react very slowly to form a hydrated magnesium silicate. This seem to be confirmed by Cole[7] by the finding in a deteriorated concrete seawall of a soft white material which proved to have a composition approximating to $4MgO.SiO_2.8.5H_2O$. This hydrated magnesium silica appears to have no binding power in contrast to the silica gel[19], and its formation represents therefore, a final stage in the detoriation of concrete attacked by magnesium sulphate solution.

An assessment of the probable severity of attack of sulphates on concrete is primarily based either on a determination of the percentage of sulphates (as SO_3) present in the soil, or a determination of the quantity of sulphates (as SO_3) present in the ground water. The analysis should also indicate the metal radicals present in conjunction with the sulphate and the PH value of the soil or ground water[23].

The best assessment of Sulphate influence on concrete is by long time exposure. However situation arise in which results are needed in weeks or even days. For this reason, a number of accelerated test techniques have been advocated. This basically involves increasing the concentration of the sulphate attacking medium or/and lowering the quality of the concrete [2, 19, 23, 25].

Tests conducted by Mcmillan *et al*[21] in Canada on 1.6 sand mortar, stored in sodium sulphate solution showed an expansion of about 0.01 percent after four weeks. Tests on 1.3 mortar bars immersed in a 0.15 mortar solution of sodium sulphate showed an appreciable decrease in tensile strength as the time in the solution increases as shown in figure 2.1, Neville[25]. It can be

seen from the graph that there is an initial increase in strength which can be attributed to the filling of the concrete voids by crystals which increase the density and hence the strength. But the growth and expansion of the crystals are limited by the sizes of the voids, and this will lead to the formation of internal stresses which ultimately leads to the reduction in strength.

Yan Aardt[33] who investigated dimensional changes of 1:3 mortar (Portland Cement: sand) in an aggressive environment of sulphate rich brine solutions found that expansion takes place as the time in the solution increases, as shown in figure 2.2. From this figure, it can be seen that different sulphate solutions cause dimensional changes by the same amount in different times, ammonium sulphate causes appreciable expansion after a very short period of the time.

Fig 2.1: Strength of 1:3 Mortar Bars Stored in a 0.15 Molar Solution of Na_2SO_4

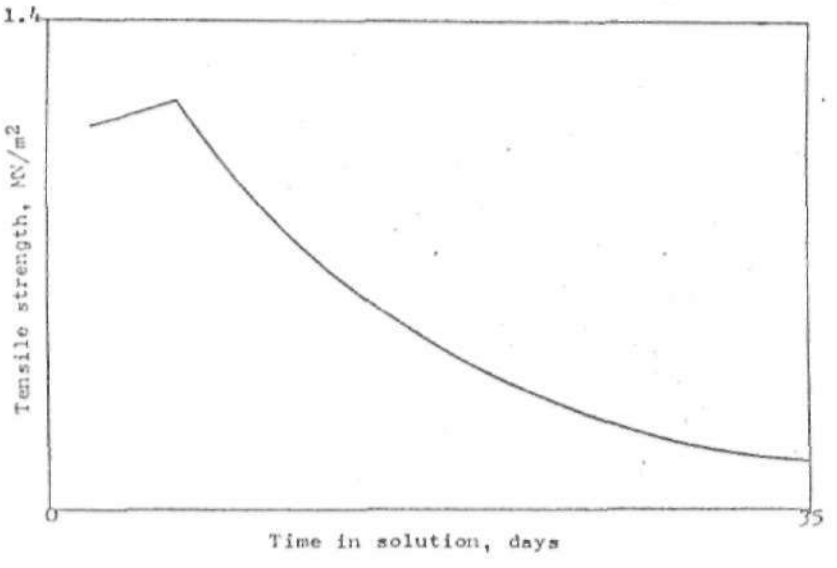
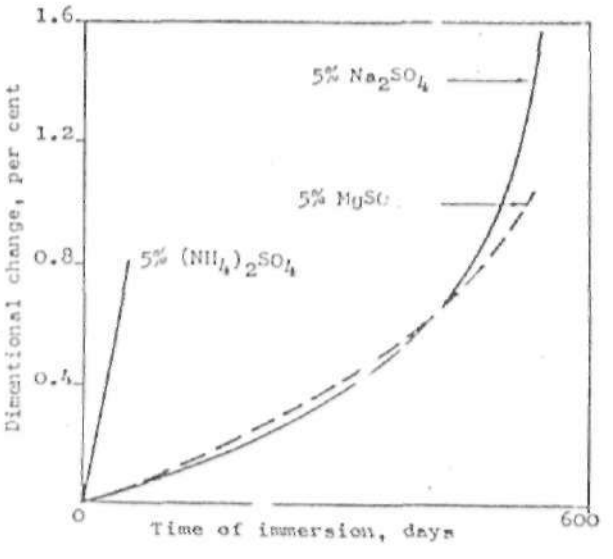


Fig 2.2: Dimensional Changes of Mortars Made with Portland Cement.



1:3 Portland Cement: sand
78 days water curing before immersion in aggressive solution.

The rate of sulphate attack increases as the strength of the solution increases. However, Lea[19] found that beyond a concentration of about 0.5 percent magnesium sulphate or 1 percent of sodium sulphate the rate of increase in the intensity of the attack starts diminishing. It has also been established that the rate of sulphate attack depends on the continuity of its supply to concrete. Therefore, in designing structures particularly, foundations in sulphate rich clays, the movement of ground water has to be known so as to design the structure accordingly.

The vulnerability of concrete to sulphate attack can be reduced by the use of a cement low in tricalcium aluminate[25, 28] but with a higher tetracalcium aluminoferrite content. This would seem strange since the tetracalcium aluminoferrite should be capable of forming calcium sulphoaluminate and the corresponding sulphoferrite, producing expansion. The reason for this however, has been advanced by Cirilli[6] who found that when cements containing C_3A and C_4AF are hydrated in the presence of lime and calcium sulphate, the amount of calcium sulphate taken up corresponds to the complete formation of $3CaO.Al_2O_3.3CaSO_4.aq$ and $3CaO.Fe_2O_3.3CaSO_4.aq$, whatever the A/F ratio of the cement. If however, the cement was hydrated before being exposed to the calcium sulphate solution, the amount of sulphate taken up steadily deceased with deceasing A/F ratio. In this case, a solid solution can first be formed between tetracalcium aluminate and ferrite, the rate of attack of which by calcium sulphate decreases with decreasing A/F ratio. The tetracalcium ferrite is more resistant even than the solid solution and if any free

calcium aluminate is formed, it may be protected by films of the ferrite over it.

The resistance of concrete to sulphate attack can also be improved by the addition of pozzolanas[25, 28]. Pozzolanas have the effect of removing the free calcium hydroxide and rendering the alumina bearing phase inactive[25].

The resistance of concrete to sulphate attack is further enhanced by curing in steam under suitable conditions. Tests conducted by Lea[19] showed that curing below 100'C does not improve the resistance and may infact decrease it. However at 100'c or at even higher temperature under pressure, the resistance of the concrete to sulphate attack is very significantly improved.

2.2.2 ACID ATTACK ON CONCRETE

Concrete is chemically basic having a pH value of about 13, and therefore is attacked by acids which have a pH value of less than 7. Concrete is not resistant to strong solutions of acids (organic or inorganic) and will definitely suffer some deterioration by prolonged contact with acids[16]. Tests conducted by Neville[25] by exposing different types of portland cement to the aggressive action of acids are in agreement with the above assertion. The test results showed some deterioration within the first three months of exposure.

Acids attack concrete or cement mortars by dissolving part of the set cement. Acid attack on concrete or cement mortars does not lead to expansion as in sulphate solutions but progressively weakens the material by removing the cementing

constituents[19, 25]. A soft and mushy mass is all that ultimately remains of a concrete or cement mortar that has been subjected to the action of aggressive acidic media.

There are quite a good number of acids which when in contact with concrete will attack it. However, the more common inorganic acids include sulphuric, hydrochloric and nitric acids. The more common organic ones include acetic, lactic and formic acids.

In the case of the attack on concrete by an inorganic acid such as sulphuric acids, the free calcium hydroxide is partly leached from the concrete and partly converted to calcium sulphate and calcium sulphoaluminate[19]. The chemistry for the conversion of the sulphuric acid to calcium sulphate for instance, can do formulated as follow:[19]

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

When sulphuric acid attacks concrete, some of the sulphate radicals remain in the concrete and serve to identify the acid responsible for the attack. The concrete also exhibits a characteristic yellowish white colouration. Even with the acids which form very soluble salts, such as hydrochloric acid with which calcium chloride is formed, an appreciable amount of the acid radical may be found in the concrete owing to the formation of very complex salts like calcium chloroaluminate[19].

Acetic acid is the principal acid in vinegar. Lactic acid develops in sour milk and sour beer while formic acid develops from formaldehyde. These three organic acids attack concrete with a severity depending on concentration and temperature.

Various physical and chemical tests on the resistance of concrete to acids have been developed[19] but there are no standard

procedures. It is however, essential that tests are performed under realistic conditions as when a concentrated acid is used the cement dissolves rapidly and no assessment of their relative quality is possible. For this reason, care is required in interpreting the results of accelerated test. Tests conducted by Eisenbeck and reported by Lea[19] shows that a one percent solution of sulphuric, hydrochloric or nitric acids will corrode concrete deeply with a few months and much weaker solutions affect it more slowly.

In practice, attack on concrete by acids occurs at values of pH below about 6.5[29]. For values of pH between 3 and 6, the attack progresses at a rate approximately proportional to the square root of time. This indicates that the governing factor is diffusion through the residual layer of the low solubility products of reaction which remain after calcium hydroxide has been dissolved. Thus, it is not only pH but also the ability of ions to be transported that influences the progress of the attack[29]. The rate of attack also decreases when aggregates have become exposed because the vulnerable surface is smaller and the attacking medium has to travel around the particles of aggregate.[29]

Artificial surface treatment of concrete with bituminous paints, coal-tar pitch, rubber paints and epoxy resins to protect concrete against acid attack has been used successfully.[25] The degree of protection rendered by the various treatments varies but in all cases, it is essential that the protective coat produced by the treatment adheres well to the concrete and remains undamaged.

2.2.3 GAS ATTACK ON CONCRETE

Gases on their own, have negligible influence on the hardened concrete. However, under moist conditions, certain gases are dissolved in water and are then converted to acids which corrode concrete when in contact with it. Most chemical industrial operations involve one effluent or the other been given off. The more common of these effluents include, sulphur dioxide (SO_2), hydrogen fluoride, (HF), hydrogen bromide (HB), hydrogen iodide (HI) hydrogen chloride (Hcl), chlorine (cl) and carbon dioxide (CO_2).

Sulphur dioxide is converted to sulphurous acid by dissolving in water which in turn, reacts with the atmospheric oxygen to form sulphuric acid. Hydrogen fluoride dissolves in water to form hydrofluoric acid, hydrogen bromide yields hydrobromic acid, hydrogen iodide yields hydroiodic acid, hydrogen chloride and chlorine yield hydrochloric acid while carbon dioxide yields carbonic acid. All these acids adversely affect concrete.

2.2.4 CHLORINE/SEAWATER ATTACK ON CONCRETE

The main problem arising from the presence of chloride in hardened concrete is the increased risk of corrosion of reinforcement and migration of chloride to the surface of the concrete, spoiling the finished appearance. The most common chloride salt is sodium chloride, which is the principal constituent of seawater. Brackish waters can also be found well inland because of the presence of soluble salts in the surrounding rock and sand, and this is very common in arid

regions.[14]

When chloride salt solutions are in contact with concrete structures, penetration of the salt solution into the concrete through cracks results which leads to attack on the concrete and steel reinforcement. Carbon dioxide and moisture from the atmosphere penetrates into the concrete through the cracks and thereby starts carbonating the calcium hydroxide liberated during the setting of cement[14]. This results in a lowering of the alkalinity of the concrete, and the reinforcing steel consequently loses it's protection. In the presence of chloride and moisture, rusting of the steel occurs. It has been found that a volume increase of some four times occurs on rusting and serious spalling and disruption of the concrete results[24].

As has been pointed out, seawater contains chloride and sulphate salts. The action of concrete immersed in seawater is similar to that previously described for sulphate solutions (see section 2.2.1), but the reaction is not accompanied by expansion[25]. Lea[19] found that calcium sulphate and calcium sulphoaluminate (both products of cement hydration) are more soluble in a chloride solution than in water, and are thus leached out by seawater, while in the laboratory test they are left insitu and consequently cause expansion. Leas[19] assumption is based on the fact that the solubility of calcium sulphate in water which is 0.12 percent rises to 1.0 percent in saturated solutions of sodium chloride and calcium chloride. As a result of this, formation of calcium sulphoaluminate might be inhibited[4]. The concentration of chlorides in seawater is approximately 3.5 percent and this is far from the value of a

saturated solution[4].

The introduction into concrete of salts such as chlorides and sulphates may result in the production of a white efflorescence on the surface of the concrete[14]. Efflorescence is unsightly, but is rarely harmful to concrete. However, under repeated cycles of wetting and drying, crystallization of the salts can occur near the surface, and disruptive forces caused may disintegrate the concrete[23].

2.3 CONCRETE IN PHYSICALLY AGGRESSIVE ENVIRONMENTS

The main elements of physical aggression on concrete are the effects of high and low temperature, abrasion and erosion.

In hot climate regions, large changes in temperature is one of the major factors affecting durability of concrete. Due to the different coefficients of thermal expansion of the constituent materials of concrete, large temperature changes cause substantial stresses which result in cracking and hence deterioration of the concrete[33]. In hot arid areas diurnal changes in temperature may be up to $40^{0}C$[4]. In arid areas where evaporation of soluble salts in the soil which may affect buried concrete. In the temperate zones, alternate freezing and thawing is considered to be amongst the most destructive of the natural weathering conditions.

Abrasion of concrete results when the concrete surface is worn away by a rubbing or friction process e.g wheels on a concrete road. Erosion of concrete is the deterioration brought about by the abrasive action of fluids or solids in motion as in concrete under flowing water.

2.4 CONCRETE IN BIOLOGICALLY AGGRESSIVE ENVIRONMENTS

The main agents of biological aggression on concrete are the effects of aggressive bacteria, fungi and rock borers.

Concrete pipes used in sewerage scheme are often severely attacked by sulphuric acid produced by bacterial action in the sewers. It has been established that organic and inorganic sulphur compounds in the sewage are reduced by sulphur-reducing organisms to hydrogen sulphide[22]. Under suitable conditions, hydrogen sulphide is evolved from the sewage into the sewer atmosphere where it is converted on the walls and roof of the sewer to sulphuric acid by sulphuricoxidizing bacteria[33]. This form of attack is more severe in warm climate that in cold.

The fungi constitute a group of plant organism which with prolonged contact with concrete can destroy it. This is because in order to get inside the concrete, they produce considerable quantities of acids which dissolve the cement paste.

Several species of rock-boring mollusks, commonly called marine borers have been recognized. It has been reported that they can drill into concrete and thus damage it[12].

CHAPTER THREE

3.0 SITE ASSESSMENT

3.1 INTRODUCTION

This chapter presents details of the site inspection works carried out at the case study site - the Federal superphosphate Fertilizer company limited, Kaduna. This is however, preceded by a presentation of the documented evidences available on the case study site as they relate to this research. The chapter is rounded up by presentation of details of the in-situ testings carried out at the case study site.

3.2 BACKGROUND INFORMATION ON CASE STUDY SITE

The Federal Superphosphate Fertilizer company Limited was established on April, 21st, 1973 as a limited liability company by the Federal Government of Nigeria, through the Federal Ministry of Industries, which is the sole owner of the company. The company came upstream in 1976.

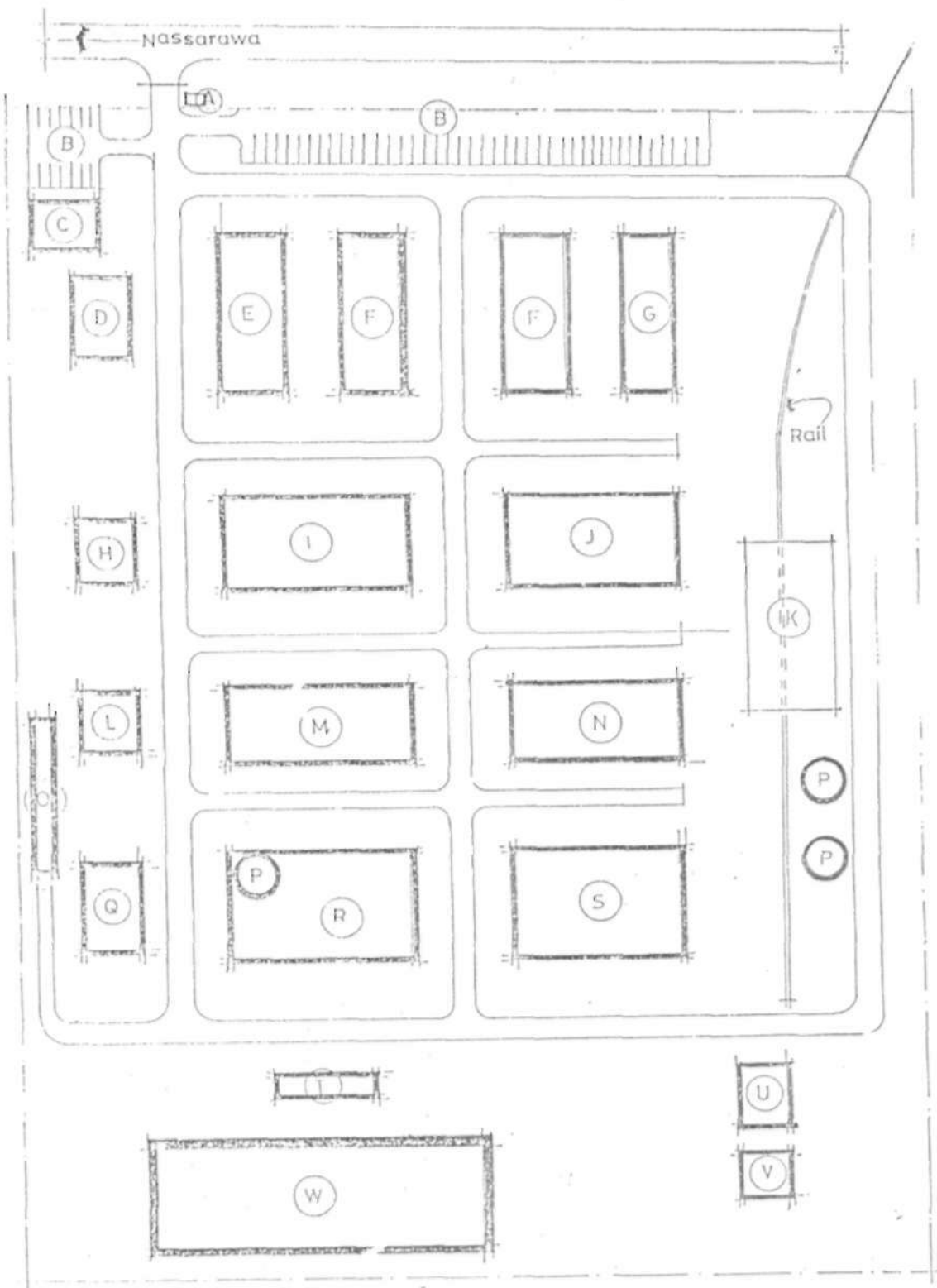
The company enjoys the monopoly of production of the phosphatic type of fertilizer in the country. The superphosphate fertilizer provides primarily phosphorous to the plants in the form of phosphoric anhydride or phosphorous pentaoxide (P_2O_5). Secondary nutrients provided to the plants include sulphur and calcium .

As used in the fertilizer trade, the term superphosphate refers to the material which result when either sulphuric or phosphoric acid or a mixture of both is caused to commingle intimately and thoroughly with phosphate rock. Common usage designates the product containing 16 to 21% Phosphoric anhydride

as single superphosphate, and the product containing 43 to 48% phosphoric anhydride as triple superphosphate. The Federal superphosphate Fertilizer company produces the single superphosphate type of fertilizer.

The factory comprises a 100,000 tons per annum superphosphate plant and a 42,000 ton's per year captive sulphuric acid plant. For both, the raw materials are imported. These are phosphate rock for the superphosphate production and sulphur for the sulphuric acid production.

Fig 3.1 SITE PLAN



KEY

A - - Main Gate

B - - Parking Space

C - - Administration Block

D - - Laboratory

E - - Curing House

F - - Granulation House

G - - Bagging House

H - - Electrical Department

I - - Acidulation plant/Grinding House/Waste Water Treatment Plant

J - - Storage House for Phosphate Rock

K - - Discharge shed for phosphate Rock

L - - Store

M - - Storage House for spare Parts/Utilities

N - - Warehouse

O - - Generator House

P - - Sulphuric Acid Tank

Q - - Maintenance Workshop

R - - Sulphuric Acid Plant

S - - Storage House for sulphur

T - - Toilets

U - - Carpentry Shed

V - - Rand D Section

W - - Water Reservoir

The phosphate rock is imported from Togo while the sulphur comes from Europe and U.S.A.

The company also operates a pilot plant that produces 100

tons per day of filter alum and a captive lime kiln of 6 tons per day capacity. The lime is used in effluent water treatment.

3.3 PRODUCTION PROCESSES

3.3.1 SUPERPHOSPHATE PRODUCTION

The production of the single superphosphate type of fertilizer involves four processes. These are the grinding, acidulation, granulation and bagging processes. The phosphate rock is ground at the grinding house so as to increase its surface area for reaction. It is then acidulated with sulphuric acid at the acidulation plant and then allowed to cure. The cured superphosphate is then taken to the granulation house where it is granulated to optimum sizes (1-4mm) for proper application to the soil. The granules are then moved to the bagging house where they are bagged and ready for transportation.

3.3.2 CHEMISTRY OF THE SUPERPHOSPHATE PRODUCTION

Phosphate rock is a complex material; the principal constituent is fluorapatite which contains phosphate, fluoride, carbonate, and other radicals bound together within a crystal lattice. It is attacked by the sulphuric acid to produce the single superphosphate. The reaction occurs in two stages as follows:

1. $Ca_5F(PO_4)_3 + H_2SO_4 + H_2O \rightarrow HPO_3 + CaSO_4.1/2\ H_2O + HF$
2. $Ca_5F(PO_4)_3 + HPO_3 \rightarrow Ca(H_2PO_4)_2 + HF$ (water soluble)

The first reaction yields gypsum that easily crystallizes, making the second diffusion - controlled, in which the HPO3 has to diffuse through the crystallized gypsum. Thus, the second reaction takes days.

3.3.3 SULPHURIC ACID PRODUCTION

Sulphuric acid is produced at the case study site by the contact process method of manufacture. It basically involves four stages. Firstly, the solid sulphur or brimstone is heated in the sulphur burning plant to produce sulphur gas. The sulphur gas reacts with atmospheric oxygen to produce sulphur dioxide. The sulphur dioxide undergoes further combustion to produce sulphite. Lastly, the sulphite is dissolved in water to produce the sulphuric acid.

3.3.4 CHEMISTRY OF THE SULPHURIC ACID PRODUCTION

As stated above, the production of sulphuric acid from sulphur or brimstone occurs in four stages. These stages can be formulated as follows:

(1) $S(s) \rightarrow S(s)$
(2) $S(g) + O_2(g) \rightarrow SO_2(g)$
(3) $SO_2(g) + 1/2\ O_2(g) \rightarrow SO_3(g)$
(4) $SO_3(g) + H_2O(g) \rightarrow H_2SO_4(l)$

3.4 SITE INSPECTION

3.4.1 DOCUMENTARY EVIDENCES

The documentary evidences presented in this section were obtained from the Civil Engineering/Maintenance Unit of the Federal Superphosphate Fertilizer Company Limited, Kaduna.

The case study site - the Federal Superphosphate Fertilizer Company, Kaduna, is located along the Nassarawa road within the Kakuri industrial area of Kaduna State. It is about 300m from the main entrance of the United Nigeria Textile Limited (UNTL) when Nassarawa bound. It is bounded to it's north by both the United Nigeria Textile Limited and Pyramid Engineering

Service Limited. To its east, it is bounded by both Ugo Foam and Leman industries and to its south by Nassarawa village.

The design and construction of the case study site was done by a Japanese Firm - the Hitachi Ship Building and Engineering Company Limited, Osaka, Japan. Construction work was started in 1973 and completed in 1976 the same year production started.

The foundations at the case study site are made up of reinforced concrete. The brick walls are reinforced and plastered with cement mortar. The roofing everywhere within the factory was done with asbestos roofing sheets. Most of these materials used in the construction viz the cement, brick, mortar, base course treating material, asbestors and the pipe linings were imported from Japan. The properties of these materials as supplied by Hitachi Ship Building and Engineering Company Limited are as follows.

ACID PROOF BRICKS:

CHEMICAL ANALYSIS;

SiO_2	-	more than 74%
Al_2O_3	-	more than 14%
Fe_2O_3	-	less than 2%
Other	-	less than 10%

PHYSICAL AND MECHANICAL PROPERTIES

	Standard	Miscellaneous	Miscellaneous Large
Water absorption (%)	< 0.2	< 0.5	< 2.0
Porosity (%)	< 0.5	< 2.0	< 5.0
Apparant density	> 2.2	> 2.2	> 2.2
Bending strength	> 400 (kg/cm^2)	> 300	> 200
Compression strength	> 2000 (kg/cm^2)	> 1500	> 1200
Test of corrossion (%) (JIS Powder Method)	< 0.2	< 0.2	< 0.2

ACID PROOF MORTARS
PHYSICAL AND MECHANICAL PROPERTIES

Water absorption (%)	< 0.6%
Porosity (%)	< 1.0
Bulk density	> 1.5
Bending strength (kg/cm^2)	> 300
Compression Strength (kg/cm^2)	> 900

BASE COURSE TREATMENT MATERIAL

There was no documented evidence to suggest whether bitumen or asphalt or some other different material entirely was used as the base course treatment material. However, the properties of the material are as follows:

Softening Point (°C)	> 100
Penetration (25°C,100g, 5,sec)	20 - 40
Penetration index	> 5.0
Evaporation (%)	< 1.0
Flash point (°C)	> 280
Contents soluble in Ccl_4 (%)	> 97
Embrittling temperature (°C)	< -15
Dooping length (mm)	< 8.0
Stability under heating	Acceptable.

Although records showed that acid proof cement imported from Japan was used for the entire construction, there was no documented record of the properties of the cement. There was also no documented evidence to suggest where the steel reinforcing

bars were got from. However, it is suspected that the reinforcements were procured locally in Nigeria. This suspicion is given credence by the fact that there is an abundance of steel in Nigeria whereas in Japan, the situation is one of near scarcity.

Documented evidence available has it that in 1980 when the structure was barely four years old, the first signs of deterioration were noticed. This occurred at the sulphuric acid and acidulation plants. The first ever repair/maintenance work to be carried out at the company as regards any structural element was done in 1981. This was at the sulphuric acid plant. The following year, repair/maintenance work was carried out at the acidulation plant. It is pertinent to mention that the sulphuric acid and acidulation plants are worst hit by the devastation as between 1981 when the first ever repair/maintenance work was carried out and the date of this research publication, no fewer than twelve major repair/maintenance works have been carried out at these plants. On the average, repair/maintenance works on these plants occur annually and usually during the month of March.

Next in line in order of decreasing number of repair/maintenance works is the granulation plant. Documented evidence has it that it has undergone four repair/maintenance operations since the factory came upstream. No other part of the company has undergone any significant repair/maintenance work as far as the records show. However, the records show that these parts have undergone some minor repair/maintenance as the need arises.

Repair/maintenance works have only been undertaken for the floors, walls and roofs. No repair/maintenance work has been undertaken for foundations. The repair/maintenance work for the flocrs and walls are carried out as follows.

For the floors, the concrete floor is dug and the soil beneath is removed and refilled with new laterite. A new floor is then recast to the level of the old floor.

For the walls, it is normal to chip the portion out and wash with lime. A new wall is then rebuilt.

During these repair/maintenance works, if a portion of a reinforcing bar has to be removed, it is cut out and replaced by a new one which is held in place by reinforcing links.

It is worth mentioning that a mixture of ordinary portland cement, bitumen R115/15, fine sand and carbon black (finely grounded charcoal) are used for the repair/maintenance works. This is because this mixture is said to have some degree of acid resistance.

3.4.2 EQUIPMENTS FOR SITE INSPECTION

The equipment used for the site inspection include magnifying glass (x20 lens power), a camera loaded with colour film and equipped with a flash gun and a record note book.

3.4.3 PROCEDURE FOR SITE INSPECTION

Site visits were undertaken several times during the months of February and March 1992. These site visits were all undertaken during the daytime when visibility is best. The magnifying glass was used to examine the deposits in cracks and

fissures. The camera was used to make comprehensive photographic records. A description of each photograph was recorded in the record note book. A detailed description of the observations at the site was also entered into the record note book.

3.4.4 SITE OBSERVATIONS

These results are based purely on visual observations during site inspection visits to the case study site with respect to the extent and severity of chemical devastation the structural complex has undergone.

It was observed that the sulphuric acid and acidulation plants were the worst affected. At the sulphuric acid plant, the extent and severity of devastation became so severe about five years ago to the point that further production of sulphuric acid had to be stopped. The sulphuric acid used in the production of the superphosphate fertilizer is now being procured from other manufacturers.

At the sulphuric acid plant, it was observed that the cement part of the foundations of the tanks and machinery has been seriously dissolved thus exposing the aggregates. What remained of these foundations in most cases was a soft and mushy mass with a yellowish colour. It was observed that this was particularly so for the outside edges of the foundations. The walls at the sulphuric acid plant also revealed cases of very serious cracking and spalling to the extent that in very many areas, the wall reinforcing rods were exposed. There were situations where the walls had been cracked so seriously as to result in displacements. All the pipes within and around the sulphuric acid

plant exhibited very serious rusting. The rusting was so severe that most of the pipes were observed to have been leaking while the sulphuric acid plant was still functional. As a result of this, it was observed that a lot more of the acid had come into contact with the structural elements than would have been the situation if the acid pipes were in good working condition. The stark (the means by which the excess acid fumes formed during acid production are channelled for safe disposal) was also found to be in bad working condition. Thus, while the sulphuric acid plant was still functional, quite a lot of these fumes got released into the atmosphere and in combination with moisture, resulted in the formation of sulphuric acid which attacks the structural elements.

At the acidulation plant, most of the acid pipes were found to be leaking as a result of the very serious corrossion (rusting) they have undergone. Cases where acid drips directly onto floors and walls were a common occurrence. Areas of floors subjected to these acidic conditions revealed situations in which the cement at such areas had been very seriously dissolved and thus exposing the aggregates. Areas of the walls which are in contact with the dripping acid water also revealed situations in which the wall plaster had been completely dissolved and the wall bricks beneath showing significant devastation. The leaking sulphuric acid and the hydrogen fluoride gas given off during the acidulation process and which in combination with moisture forms hydrofluoric acid were observed to be responsible for the devastation at the acidulation plant.

At the granulation plant, the devastation was observed to

be not as severe as at either the sulphuric acid or acidulation plants. It was observed that the cement part of the floor had been dissolved thus exposing the aggregates. The walls revealed fine cracking in some areas. The pipes at the granulation plant were observed to be also seriously corroded.

Other parts of the structural complex viz the administration building, clinic, welfare unit etc revealed a far lesser degree of devastation. In most of these areas, no devastation was observed and in the few instances where devastation was observed, it was just in the form of fine hair cracks.

The roofing everywhere within the structural complex was observed to have resisted the aggressive environment to a very high degree as the asbestos sheets were still in fairly good condition. However, almost everywhere within the plant, some corrossion of the roof has begun near the roofing nails about 1 cm radius around the nails.

See Plates 3, 4 and 5 showing conrete devastation within the factory.

3.5 IN-SITU TESTINGS

As mentioned earlier, concrete compressive strength is the singular most important yardstick of concrete durability. Thus, these in-situ testings were geared towards determining the residual strength of concrete elements within the structural complex at the case study site.

As can be discerned from the documentary evidences and site observations, the sulphuric and acidulation plants were worst hit by the devastation. Thus, these two areas were selected for these in-situ testings.

3.5.1 EQUIPMENT FOR IN-SITU TESTING

The equipment used for the in-situ testing was the ultrasonic pulse velocity (pundit) instrument. The pundit tester used derives its name from the initial letters of the full title of "Portable Ultrasonic Non-destructive Digital Indicating Tester". It is designed with site testing in mind so as to ensure adequate portability and to give a high degree of accuracy. It generates low frequency ultrasonic pulses and measures the time taken for them to pass from one transducer (emitting transducer Tx) to another (receiving transducer Rx) through the material. The pundit tester used for this examination is the 1988 CNS INSTRUMENT LONDON model with the following specifications.

Impedance :	Approximate 1 micro - ohm.
Transmitter:	Energising pulse 1000V peak, 1.5 microsec. pulse repetition
frequency:	Normal 100 pps and 3pps switch to 100 pps when the instrument is used with the analogue add-on unit.
Power supply:	mains 220 - 250V
Frequency range:	50 - 60 Hz
Display:	3 in line numerical indicator
Circuit:	Integrated circuit and silicon semiconductors.
Dimension:	180 x 110 x 160mm
Weight:	3kg
Ambient temperature range:	0^{0}c to 40^{0}c

3.5.2 PROCEDURE FOR IN-SITU TESTING

The indirect transmission mode was used in testing the foundations and floor slabs. The direct and semi-direct modes of transmission were not used anywhere during the course of the research.

CHAPTER FOUR

4.0 LABORATORY ASSESSMENT

4.1 INTRODUCTION

As outlined in chapter one, this research has as one of its objectives, the simulation as far as practicable, of an equivalent aggressive environment in the laboratory of the environment prevalent at the case study site with a view to:

i) Chemically examining soil samples for the radicals present and in what percentage they occur so as to determine to what extent these radicals might have contributed to the visible damages (diagnosis).

ii) Assisting in forecasting the possibility of further devastation in the structural concrete and the magnitude of any such further devastation (Prognosis).

To facilitate the above, four samples each from the sulphuric acid and acidulation plants were collected and analysed chemically. Based on the results obtained from these chemical analysis, a mock aggressive environment was formulated in the laboratory and concrete cubes ($150mm^3$) were immersed in these media while monitoring the effect these environments had on the concrete cubes.

4.2 SAMPLING

Almost inevitably, the limitation of access and economics will be deciding factors in the selection of sampling locations and the number of samples to be taken. This was particularly so for this research. Thus, four samples each from the sulphuric acid and acidulation plants where the devastation was most severe

were taken. The method employed in obtaining the samples involved cleaning the topsoil with a shovel and taking the soil beneath. The samples thus taken, were securely tied up in polytene bags and taken to the laboratory for analysis.

4.2.1 PREPARATION OF SAMPLES

The same method of preparation was used for all eight samples. The samples were very finely ground in a grinding crucible and sieved through the 75 μm sieve. The portion which passed through was made use of in the analysis. In order to achieve a representative sample, the coning and quartering method was employed.

4.2.2 ANALYTICAL TECHNIQUES.

In order to facilitate brevity, the analytical techniques employed in the chemical analysis of sample SA_1 together with the inherent calculations involved will be outlined hereafter.

CHEMICAL ANALYSIS OF SAMPLE SA_1

WEIGHINGS.

Weight of sample only = 1.00g

Weight of beaker only = 106.794g

Weight of sample + beaker = 107.794g

PERCENTAGE SILICATE (SiO_2)

TREATMENT

1g sample + 5ml each of nitric acid (HNO_3) and hydrochloric acid (Hcl) + 20ml of water (H_2O) were digested for 30 minutes.

The solution was filtered through a W40 filter paper while the filtrate was reserved for the determination of other radicals while the residue containing SiO_2 was ashed and weighed

Weight of crucible + ash = 15.329g

Weight of empty crucible = 14.9218g

Weight of ash only = 0.4072g

% SiO_2 = 0.4072 x 100

= 40.72%

PERCENTAGE IRON AND ALUMINUM OXIDES (Fe_2O_3 & Al_2O_3) R_2O_3

TREATMENT

25ml stock solution + ammonium chloride and ammonium hydroxide in small quantities were boiled and filtered. The residue which contained iron and aluminum oxides (R_2O_3) was ashed at 860°C.

Weight of crucible + ash = 17.9266g

Weight of empty crucible = 17.9267g

Weight of ash only = 0.0099g

% R_2O_3 = 0.0099 x 250 x 100

= 9.9%

PERCENTAGE IRON OXIDE (Fe_2O_3) TREATMENT

5ml stock solution + 5ml, 2m potasium tiocyanide (KSCN) was diluted with water (H_2O) to 250ml in a flask. Absorbance of solution was measured at 480mm.

Absorbance = 0.1 = 1.016 ppm FC

1.016/10 x 250/5 x 250/5 x 100/1 x 1.43 = 0.36%

PERCENTAGE ALUMINIUM OXIDE (Al_2O_3)

$\% Al_2O_3 = \% Al_2O_3 - \% Fe_2O_3$

$= 9.9 - 0.36$

$= 9.54\%$

PERCENTAGE CALCIUM OXIDE (CaO)

TREATMENT

Filtrate from R_2O_3 + 5ml ammonium okalate was boiled and filtered through the W40 filter paper. After cooling, the filtrate precipitated and the precipitate was dissolved in dilute sulphuric acid and titrated with 0.1 N potassium permanganate 4.

Final titration reading = 0.35ml

Initial titration reading = 0.00ml

1ml 0.1 M KMnO4 = 0.002004g Ca

% Ca = 0.002004 x 0.35 x 250/25 x 100/1 = 0.70%

PERCENTAGE SULPHATE (SO_4)

TREATMENT

25ml stock solution + 10ml barium chloride ($Bacl_2$) solution was digested for 30 minutes and filtered through a W42 paper and ashed at 860 degree Centigrade.

Weight of crucible + ash = 19.0520g

Weight of empty crucible = 17.9267g

Weight of ash only = 1.1253g

$\% SO_4$ = 1.1253 x 0.4115 x 100

= 0.4631

= 46.31%

PERCENTAGE PHOSPHATE (PO_4)

TREATMENT

25ml stock solution + dilute nitric acid (HNO_3) + 20ml, 4% ammonium molybolate solution was stirred and filtered through a W42 filter paper. It was then allowed to settle and a precipitate was formed. The precipitate was ashed at 86°C for one hour and then allowed to cool and then weighed.

Weight of crucible + ash = 17.9359g

Weight of empty crucible = 17.9396g

Weight of ash only = 0.0053g

% PO_4 = 0.0053 x 250/ x 100/1 x 0.05281

= 0.28%

DETERMINATION OF PH

PROCEDURE

5g of the ground sample was taken in a 100ml volume flask and filled to the mark with distilled water. The suspension was thoroughly shaken and filtered through a W40 filter paper. The filtrate was collected and the electrodes of a PH meter were dipped into it and the PH value of the sample was read from the cal brated scale.

DETERMINATION OF BASICITY

PROCEDURE

10ml portion of each sample that showed a low PH was t.trated with 0.1M sodium hydroxide using phenolphthalein and then repeated with methyl orange. The basicity was then calculated from the volume of NaOH required to neutralize the low PH sample.

4.3 LABORATORY SIMULATIONS

4.3.1 Discription of Materials Used

It is generally agreed that the quality and performance of concrete depends to some extent on the type and properties of it's constituent materials. Therefore, from the outset of this research, care was exercised in selecting suitable materials which were of the type and had the properties of the materials used at the case study site. However, there were very many instances where as a result of non availability or economics, such materials could not be procured and alternative materials had to be resorted to. Further care was exercised in ensuring that the quality of materials used remained consistent throughout the investigation.

CEMENT

In this research, because of time constraint, only one type of cement - the Ashaka brand ordinary portland cement produced in Bauchi, Nigeria was used, although it was recognized that the study would benefit from the use of other types of cement. Details of the physical and chemical characteristics of the

cement as supplied by the Associated Portland Cement Manufacturers Limited, are given in tables 4.1 and 4.2 respectively.

Table 4.1: Physical Properties of the Cement Employed

Property B.S. Test	
Fineness: Specific Surface, m^2/kg	331
Specific gravity	3.13
Setting time, min.	
initial	200
final	290
water, percent	27.0
Expansion: Le Chaterlier, mm	1.50
Compressive strength, N/mm^2	
(mix 1:2:5: 10.60 concrete, 100mm cubes)	
3 days	19.8
7 days	29.6
28 days	41.0

Table 4.2: Chemical Composition of the Cement Employed, per cent

C_aO	64.3
S_iO_2	20.5
Al_2O_3	5.3
Fe_2O_3	2.9
I.R.	0.22
M_nO_3	0.05
P_2O5_3	0.18
TiO_2	0.26
M_gO	1.20
SO_3	2.70
S	0
Free time	1.30
K_2O	0.26
Na_2O	0.40
Alkali	0.57
Ratio A/F	1.80
S/A + F	2.50
LOI	2.00
LSF	95
LCF	93
C_3S	54.4
C_2S	14.8
C_3A	9.1
C_4AF	8.8

AGGREGATE

The coarse aggregate that was used was irregular gravel which was retained on the 4.76 mm sieve but passed through the 19.05mm sieve.

The fine aggregate used was naturally occurring sand.

BITUMEN

The binder used was the penetration grade bitumen of penetration class 80/120.

ACID

The acid used was sulphuric acid of 98% concentration However, it was diluted to 46.31% before being employed for the experimental study. This was done to simulate the 46.31% concentration of sulphate for the worst case - sample SA_1

4.4 MIX DESIGN

As stated above, the suspected grade of concrete at the case study site was grad 40. In order to achieve this in the laboratory, a mix design was formulated. An outline of the mix design is as follows.

Characteristic cube strength	= 40N/mm^2 at 28 days
Type of work	= Simply reinforced section with vibration
Cement	= Ordinary Portland Cement.
Coarse aggregate	= Irregular gravel (19.05 - 4.76mm)
Fine aggregate	= Naturally occurring sand
Specific gravities for coarse, aggregate, fine aggregate and cement respectively	= 2.7, 2.6 and 3.14 .

DESIGN BY VOLUME

i) Durability (CP 110: PART 1) MINIMUM CEMENT CONTENT = 250Kg/m^3

ii) Strength fcm = fcu + BS

= 30 + 15 = 45N/mm^2

iii) From fig 4.1, c/w by volume = 0.66

iv) From workability table 4.3, - low workability appropriate

From fig 4.2, basic volume fraction of cement c = 9.7%

Table 4.3: Workability requirements

Type of Work	V - B (s)	Compacting factor	Slump (mm)	Workability
Heavily reinforced sections with vibration. Simply reinforced sections without vibration.	(3)	0.92	(25-100)	Medium
Simply reinforced sections with vibration. Mass concrete without vibration.	6	(0.86)	(10-50)	Low
Mass concrete and large sections with vibration. Road slabs vibrated using power-operated machines.	12	(0.80)	-	Very low

v) Table 4.4: SIEVE ANALYSIS

Bb 410 test										
Sieve(mm)	38.1	19.05	9.52	4.76	2.00	1.18	0.60	0.30	0.15	0.063
				% Passing						
Irregular gravel	100	79.81	20.19	4.12	0					
Natural occurring sand					100	89.00	69.24	25.38	8.42	4.21
				% Retained						
Irregular grave	20.19	59.62	16.07	4.12						
Natural occurring sand					11.00	19.76	48.86	16.96	4.21	4.21

vi) Using Table 4.5

Gravel (Ga)

20.19 x ¼ = 5.05

59.62 x 1/2 = 29.81

16.07 x 1 = 16.07

4.12 x 2 = 8.24

59.17

Sand (Gb)

11.00 x 2 = 22.00

19.76 x 4 = 79.04

43.86 x 8 = 350.88

16.96 x 16 = 271.36

4.21 x 32 = 134.72

4.21 x 63 = 265.23

1123.23

Sand (Db)

Sand (Db)

11.00 x 4 = 44.00

19.76 x 2 = 39.52

43.86 x 1 = 43.86

16.96 x 1/2 = 8.48

4.21 x ¼ = 1.05

4.21 x 1/8 = 0.53

137.44

Ga = $0.90 \times 59.17 \times 10^{-2} = 0.53\ mm^{-1}$

Gb = $0.90 \times 1123.23 \times 10^{-2} = 10.11\ mm^{-1}$

Db = $0.90 \times 137.44 \times 10^{-2} = 1.24\ mm^{-1}$

vii) From fig 4.3

(a) -

(b) -

(c) 3.6(0.53 - 0.46) = + 0.25

Corrected volume fraction C = 9.7 + 0.25

= 9.95%

Durability requirement = 250 kg/m^3

$$= \frac{250 \times 100}{3.14 \times 100}$$

= 7.8% (ok)

Therefore, volume fraction of

Cement C = 0.0995

≃ 0.1

viii From iv, c/w = 0.66

i.e 0.1 = 0.66

w

Therefore, volume fraction of water w = 0.152

Using (vi),

GaDb = 0.53 x 1.24

= 0.66

From table 4.6,

ab = 0.58

From fig 4.4. volume fraction of coarse aggregate

a = 0.482

ix) a + c + w = 0.482 + 0.1 + 0.152

= 0.734

Therefore, volume fraction of fine aggregate

= 1.0 - 0.734

= 0.266

x) The batch quantities are thus -

Water = 0.152 x 1000 = 152 Kgm^{-3}

Cement = 0.1 x 1000 x 3.14 = 312 Kgm^{-3}

band = 0.266 x 1000 x 2.6 = 691.6 Kgm^{-3}

Gravel = 0.482 x 1000 x 2.7 = 1301.4 Kgm^{-3}

2459 Kgm^{-3}

In the mix design just outlined, the parameters represent the following:

fcm - target mean strength

fcu - required characteristic strength

S - standard deviation

C - volume fraction of cement

w - volume fraction of water

a - volume fraction of coarse aggregate

Ga - grading modulus for coarse aggregate

Gb - grading modulus for fine aggregate

Db - equivalent mean diameter of fine aggregate

B - 1.64

b - volume fraction of fine aggregate

Table 4.5: Aggregate Grading Parameters[17]

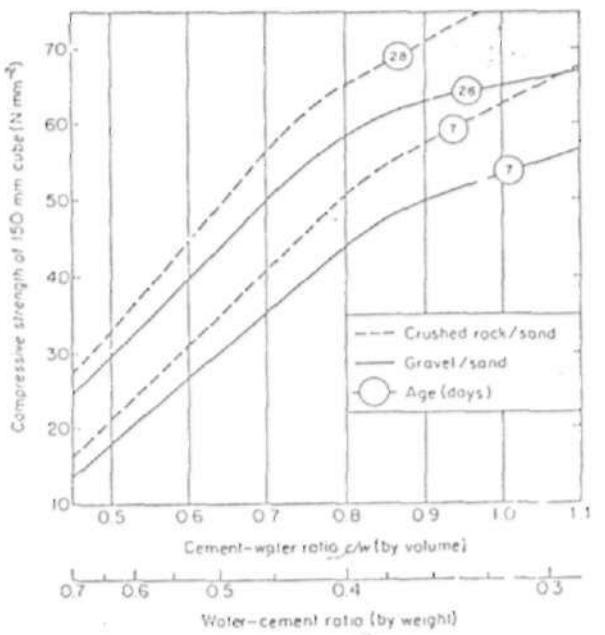
BS 410 test sieve (mm)	37.50	20.0	10.0	5.00	2.36	1.18	0.60	0.30	0.15	0.075
Grading modulus (× 0.90 mm^{-1})	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	16	32	63	
Equiv. mean diameter (× 0.90 mm)			8	4	2	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	

Table 4.6: Solids Fraction of Loose Coarse Aggregate[17]

Aggregate size	Solids fraction e_b	
	20 – 10 mm	20 – 5 mm
Irregular gravel	0.56	0.58
Crushed rock	0.46	0.48

Fig 4.1: Cube Compressive Strength Relationships for Concrete Made with Ordinary Portland Cement[17]

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'ig 4.2: Basic Volume of Cement for Different Workabilities, Based on Hughes (1971)[17]

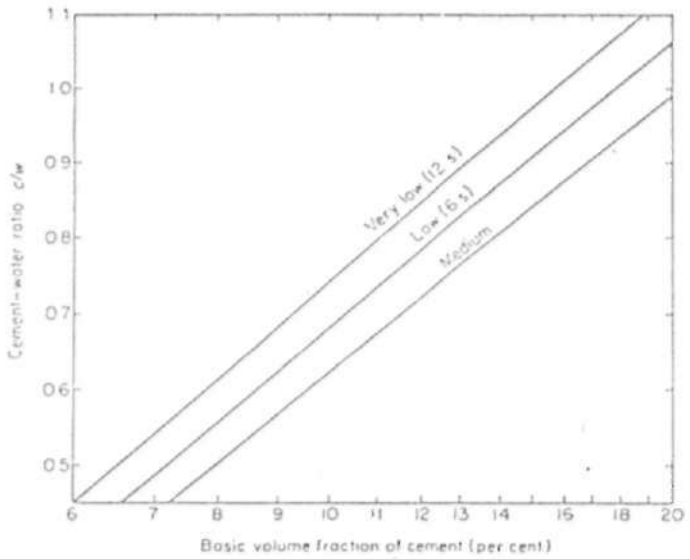


Fig 4.3: Corrections to Basic Volume Fractions of Cement[17]

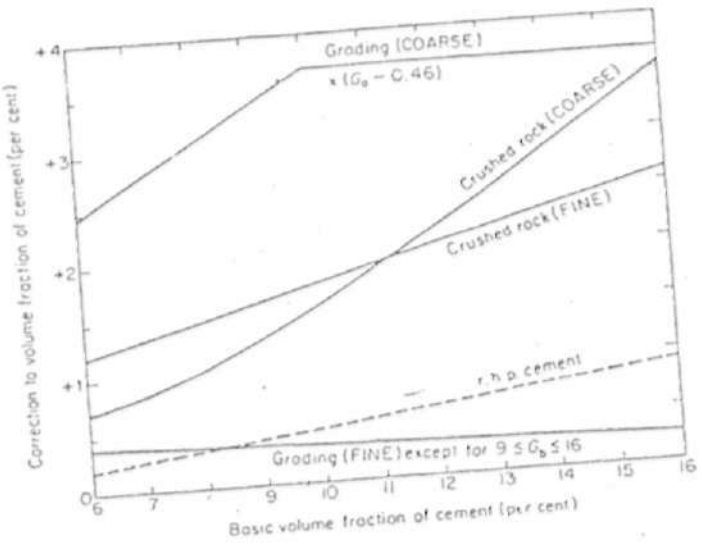
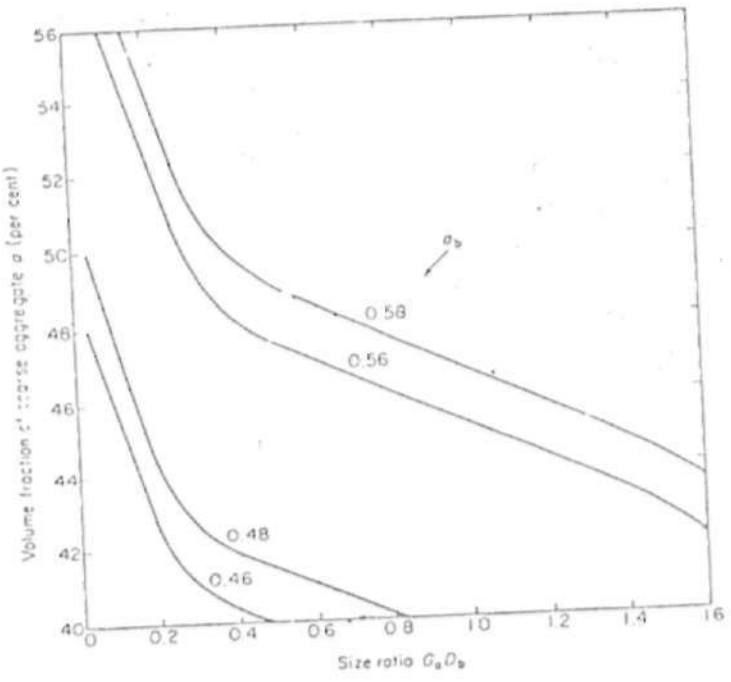


Fig 4.4: Recommended Volume Fractions of Coarse Aggregate, Based on Hughes (1971)[17]



4.5. PREPARATION OF TEST SPECIMEN

In preparing the test specimens, concrete mixing was carried out in a horizontal rotating pan type mixer (Liner Ltd) of 0.03m^3 capacity. The dry materials were thoroughly mixed in the pan for 2 minutes before water was added, and after the addition of water, mixing was carried out for a further 2 minutes. The freshly mixed concrete was then transferred into concrete moulds of 150mm^3. Compaction was achieved by means of a hand compaction machine. The test specimens were compacted in three layers, each layer being vibrated for 20 seconds. The test specimens were then left overnight and demoulded the following day. They were then labelled appropriately.

4.6 CURING CONDITIONS EMPLOYED

After demoulding, the test specimens were immediately transferred to a water bath where they were kept moist for 28 days during which time they attained the designed strength of 40N/mm^2. At the expiration of the 28 days, the test specimens were removed from the water bath and dried in air for one week. The test specimens were finally immersed completely in the sulphuric acid bath with an acidic concentration of 46.31%. Since the concentration of acid procured at the outset had a concentration of 98%, the reduction in concentration from 98% to 46.31% was achieved as follows.

REDUCTION IN H_2SO_4 CONCENTRATION

Density = 1.84 g/cm^3

Molar mass = 98 g

1 cm^3 contains 1.84 g by weight of H_2SO_4

1000 cm^3 contains 1.84 x 1000g = 1840g

For a 98% concentration, the content is

$\frac{98}{100} \times \frac{1840}{1} = 1803.2 g/dm^3$

Thus, a 1% concentration is equivalent to

$\frac{1803.2}{0.95} \times 0.01 = 18.4\ g/dm^3$

and a 46.31 concentration is equivalent to

$\frac{1803.2}{0.98} \times 0.4631 = 852.104\ g/dm^3$

i.e. final concentration = 852.104 g/d^3

Final motarity, Mf = $\frac{\text{final concentration}}{\text{motar mass}}$

$= \frac{852.104}{98}$

Suppose, a final volume of 50cm^3 is desired,

i.e Mi - not known (the initial acid volume)

Mi - initial acid motarity = 18.4 mo/s/dm^3

Vf - Final volume of acid + dilution water = 50cm^3

Mf - final acid motarity = 8.69 mo/s/dm^3

MiVi = MfVf

$Vi = \frac{MfVf}{Mi}$

$= \frac{8.69 \times 50}{18.4}$

$= 23.6 cm^3$

Thus, in every 50cm of the dilute acid used,

23.6 cm3 will be the acid with 98% concentration while the remaining 26.4 cm3 wi.l be the dilution water.

4.7 TEST TECHNIQUE

The test technique adopted was the total immersion test technique. In all, 32 test specimens were used.

Sixteen of these specimens were immersed directly in the acidic medium. At the end of every seven days for 28 days, four out of these were removed from the acidic medium, dried, weighed and then crushed using the universal compression machine. The weights and compressive strengths of the test specimens after immersion were recorded.

Of the 32 test specimens, another eight were first coated with bitumen (about 5mm thick) before immersion. Two of these were removed from the medium at the end of every 7 days for 28 days, dried, weighed and then crushed. The weights and compressive strengths after immersion were also recorded. This was done in order to facilitate the effect of acidic aggressive environments on structural concretes coated with bitumen as exists for base courses at the case study site to be simulated and monitored.

The remaining eight test specimens were used as control specimens to facilitate comparative analysis.

CHAPTER FIVE

5.0 PRESENTATION OF RESULTS

5.1 INTRODUCTION

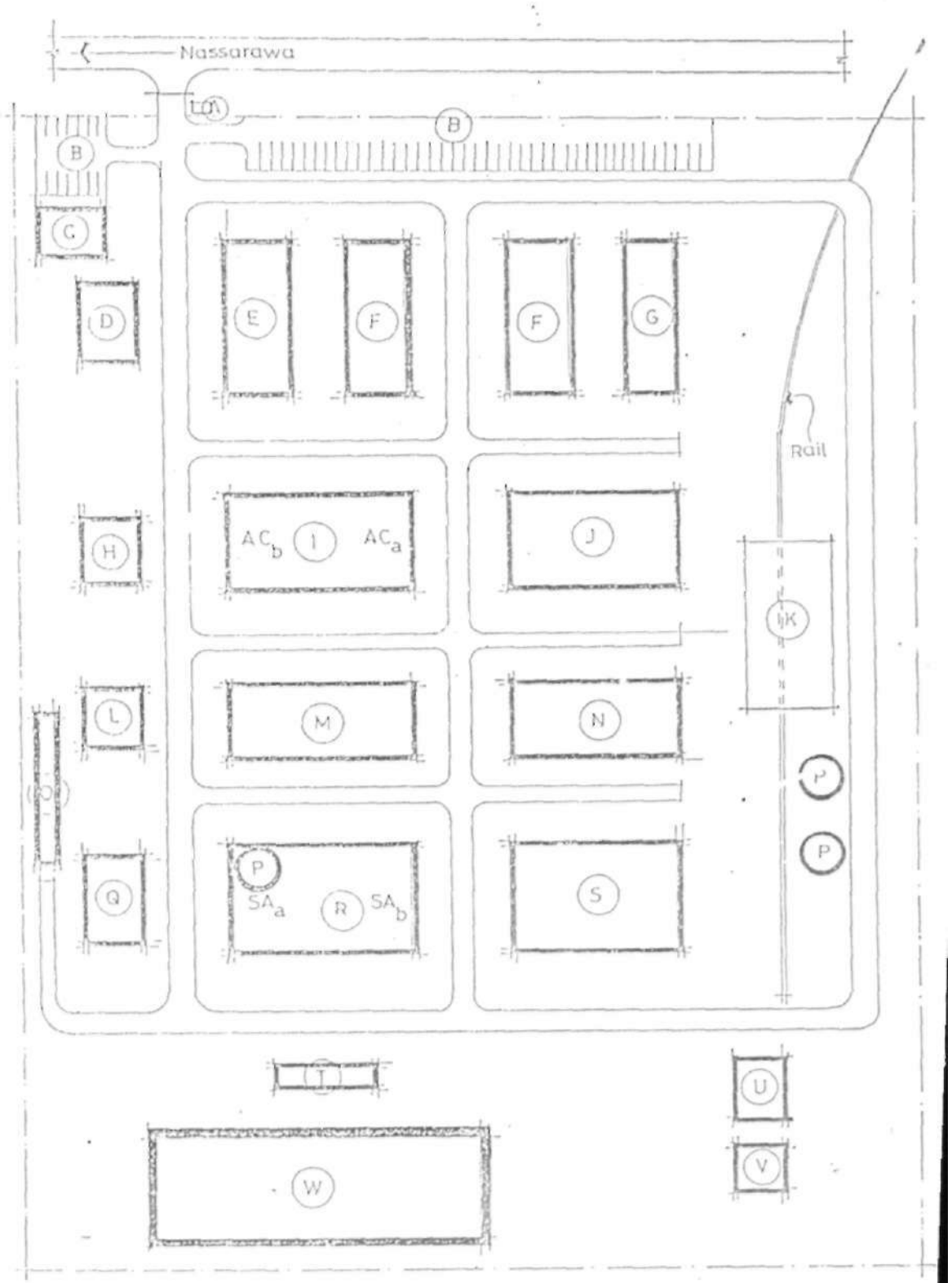
This chapter presents the results of the laboratory testings carried out during the course of this research, This is however, preceded by a summary of the in-situ testing results using the Punlit instrument at the case study site.

5.2 PUNDIT TEST RESULTS

For the purpose of clearity, the results presented hereafter will be coded SA_a, SA_b, AC_a and AC_b. The locations from which the readings were obtained are shown in fig 5.1

Fig 5.1

SITE PLAN SHOWING PUNDIT TEST LOCATIONS
(not to scale)



Pundit Test Result

Element: Foundation

Transmission Mode: Indirect

Correction Factors: Instrument Nil

Reinforcement 0.95

Table 5.1

S/No	Code No	Transmission Distance (mm)	Time (μs)	Velocity (km/s)	Mean Velocity (km/s)
1	SA_3	400	88.3	4.5300	
2		400	108.7	3.6799	
3		400	102.6	3.8986	
4		400	124.6	3.2103	
5		400	119.8	3.3389	
6		400	121.1	3.3031	
7		400	109.8	3.6430	
8		400	89.2	4.4843	
9		400	91.7	4.3621	
10		400	99.4	4.0241	
11		400	98.2	4.0733	3.85
12		400	86.3	4.6350	
13		400	88.8	4.5045	
14		400	90.5	4.4199	
15		400	90.3	4.4297	
16		400	125.0	3.2000	
17		400	111.1	3.6004	
18		400	110.0	3.6363	
19		400	108.4	3.6900	
20		400	120.7	3.3140	
21		400	132.2	3.0257	
22		400	128.1	3.1226	
23		400	99.4	4.0241	
24		400	97.2	4.1152	
25		400	98.8	4.0486	

Standard Deviation = 0.51

Pundit Test Result

Element: Foundation

Transmission Mode: Indirect

Correction Factors: Instrument Nil

Reinforcement 0.95

Table 5.2

		Transmission			
S/No	Code No	Distance (mm)	Time (μs)	Velocity (km/s)	Mean Velocity (km/s)
1	SA_b	400	116.7	3.4276	
2		400	117.6	3.4014	
3		400	114.5	3.4934	
4		400	120.4	3.3223	
5		400	115.5	3.4632	
6		400	119.5	3.3613	
7		400	115.4	3.4662	
8		400	117.6	3.4014	
9		400	116.2	3.4423	
10		400	120.1	3.3306	
11		400	121.8	3.2841	
12		400	122.8	3.2573	
13		400	114.7	3.4874	
14		400	119.9	3.3361	3.40
15		400	114.0	3.5088	
16		400	115.9	3.4513	
17		400	116.4	3.4364	
18		400	119.4	3.3501	
19		400	120.5	3.3195	
20		400	119.9	3.3361	
21		400	120.0	3.3333	
22		400	120.6	3.3167	
23		400	113.4	3.5273	
24		400	115.4	3.4662	
25		400	115.2	3.4722	

Standard Deviation = 0.10

Purdit Test Result

Element: Floor

Transmission Mode: Indirect

Correction Factors: Instrument Nil

Reinforcement 0.95

Table 5.3

S/No	Code No	Transmission Distance (mm)	Time (μs)	Velocity (km/s)	Mean Velocity (km/s)
1	AC_a	400	129.4	3.0912	
2		400	119.6	3.3445	
3		400	137.6	2.9070	
4		400	146.6	2.7285	
5		400	138.7	2.8840	
6		400	129.3	3.0036	
7		400	127.1	3.1171	
8		400	127.8	3.1299	
9		400	126.2	3.1696	
10		400	118.8	3.3670	
11		400	119.5	3.3473	
12		400	122.6	3.2626	
13		400	128.1	3.1226	3.17
14		400	128.1	3.1226	
15		400	128.0	3.1250	
16		400	134.4	2.9762	
17		400	121.9	3.2814	
18		400	125.5	3.1873	
19		400	123.2	3.2468	
20		400	124.7	3.2077	
21		400	119.6	3.3445	
22		400	122.3	3.2706	
23		400	114.8	3.4845	
24		400	119.1	3.3585	
25		400	126.7	4.1571	

Standard Deviation = 0.17

Pundit Test Result

Element: Floor

Transmission Mode: Indirect

Correction Factors: Instrument Nil

Reinforcement 0.95

Table 5.4

		Transmission			
S/No	Code No	Distance (mm)	Time (μs)	Velocity (km/s)	Mean Velocity (km/s)
1	AC_b	400	123.7	3.2336	
2		400	127.3	3.1299	
3		400	123.7	3.2336	
4		400	131.9	3.0326	
5		400	125.1	3.1974	
6		400	120.0	3.3333	
7		400	120.1	3.3306	
8		400	119.7	3.3417	
9		400	124.2	3.2206	
10		400	122.2	3.2733	
11		400	119.8	3.3389	
12		400	116.4	3.4364	
13		400	124.3	3.2180	3.28
14		400	123.9	3.2284	
15		400	130.5	3.0651	
16		400	120.6	3.3167	
17		400	119.0	3.3613	
18		400	114.8	3.4843	
19		400	114.8	3.4843	
20		400	124.8	3.2051	
21		400	117.3	3.4101	
22		400	117.0	3.4188	
23		400	117.8	3.3956	
24		400	119.5	3.3473	
25		400	121.7	4.2868	

Standard Deviation = 0.12

5.3 *RESULTS OF SOIL ANALYSIS*

The results of the soil sample analysis are presented in this section. Table 5.5 shows the chemical composition by weight of the soil samples while table 5.6 shows the PH value of the soil samples. For easy identification, these samples have been coded SA_1 - SA_4 and AC_1 - AC_4 representing sample collected from the sulphuric acid and acidulation plants respectively. The exact locations from which these samples were collected are shown in fig 5.2

Fig 5.2

SITE PLAN SHOWING SAMPLING LOCATIONS
(not to scale)

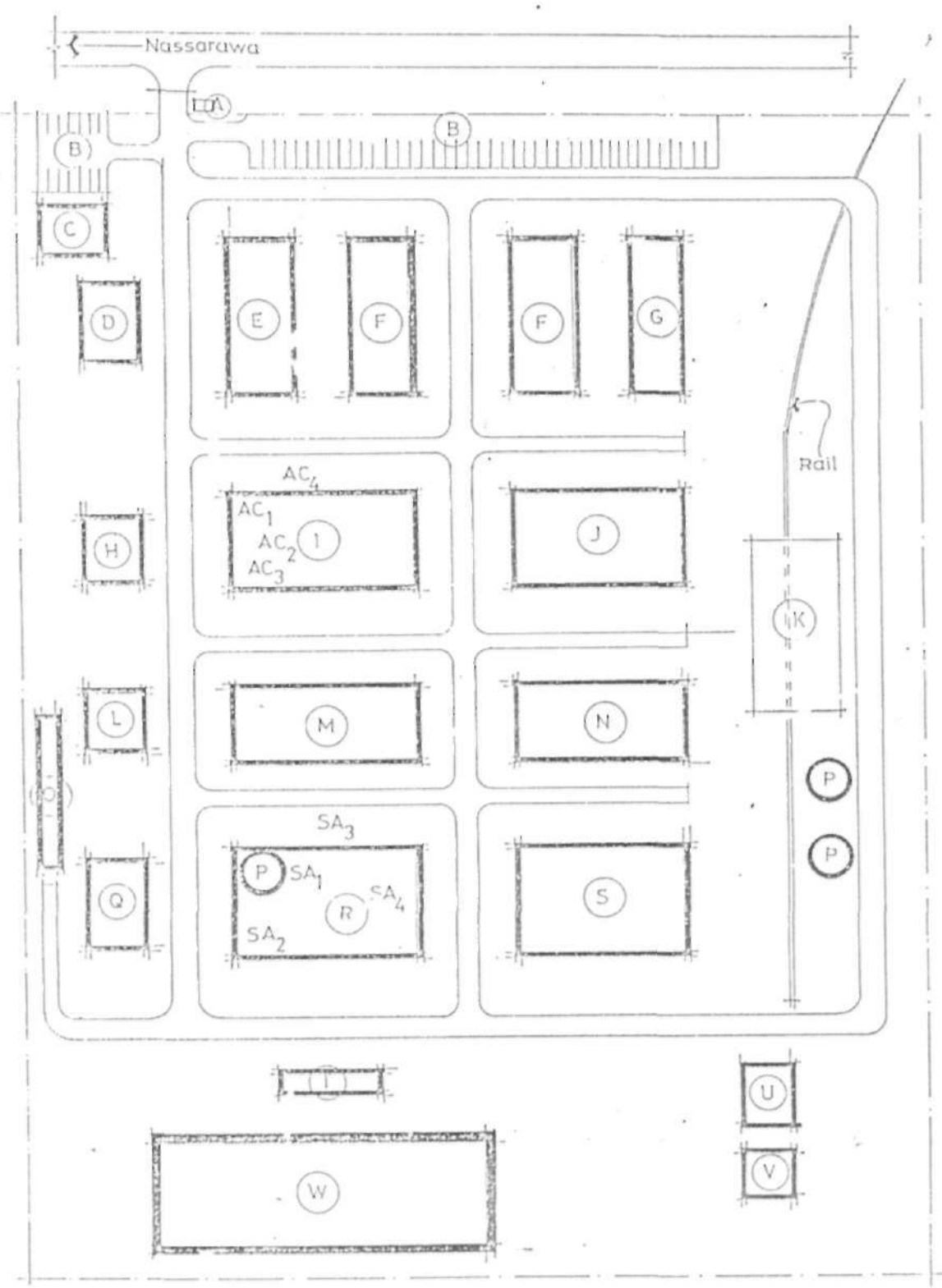


Table .5: Chemical Composition By Weight of Soil Samples

S/No	Samp Code	Sili. As (S_iO_2) %	Alum. As (Al_2O_3) %	Iron As (Fe_2O_3) %	Cal. As (C_a^{2+}) %	Sulp. As (SO_4) %	Phos. As (PO_4^{3-}) %	Others %	Tot.
1	SA_1	40.72	9.54	0.36	0.70	46.31	0.28	2.09	100
2	SA_2	43.88	10.93	2.56	0.42	39.98	0.32	1.91	100
3	SA_3	36.96	8.66	5.00	0.61	45.75	1.02	2.00	100
4	SA_4	36.14	16.02	1.96	0.82	42.96	0.26	1.84	100
5	AC_1	41.07	9.72	5.03	4.63	33.66	1.88	4.01	100
6	AC_2	41.13	9.72	2.12	2.20	41.24	0.94	2.65	100
7	AC_3	40.50	12.11	1.01	2.70	40.52	0.53	2.63	100
8	AC_4	45.45	10.39	1.00	2.31	38.13	0.69	2.03	100

5.3.2

Table 5.6: PH Results for Soil Samples

S/No	Sample Code	PH Value (-log H^+)
1.	SA_1	2.30
2.	SA_2	3.95
3.	SA_3	2.70
4.	SA_4	3.45
5.	AC_1	4.60
6.	AC_2	3.50
7.	AC_3	3.85
8.	AC_4	4.30

5.4 RESULTS OF IMMERSION TEST

The results of the immersion test are presented in this section. To facilitate easier identification of the specimens, the control specimens are coded CN_A - $_H$, the bitumen coated specimens BC_{A-B} while the rest of the test specimens are coded S_{A-D}. Thus, CN_A refers to the first control test specimen while CN_H refers to the eighth control specimen. BC_{2A} refers to the first of the two bitumen coated specimens removed after 14 days of immersion while BC_{3B} refers to the second of the two bitumen coated specimens removed after 21 days of immersion. S_{1A} refers to the first of the four uncoated specimens removed after 7 days of immersion while S_{4C} refers to the third of the four uncoated specimens removed after 28 days of immersion.

Table 5.7: Results of Control Specimens

S/No	Specimen Code	Weight (kg)	Density (kg/m^3)	Compressive Load (KN)	Compressive Strength (N/mm^2)
1.	CN_A	8.2	2429.63	960	42.67
2.	CN_B	8.2	2429.63	980	39.11
3.	CN_C	8.3	2459.26	920	40.89
4.	CN_D	8.4	2488.89	960	42.67
5.	CN_E	8.1	2400.00	970	43.11
6.	CN_F	8.1	2400.00	930	41.33
7.	CN_G	8.3	2459.26	880	39.11
8.	CN_H	8.4	2488.89	940	41.77
	Mean =	8.25	2444.45	930	41.33

Table 5.8: 7 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$S1_A$	8.4	2488.89	8.0	2370.37	650	28.89
2.	$S1_B$	8.1	2400.89	8.0	2370.37	620	27.56
3.	$S1_C$	8.3	2459.26	8.1	2400.00	630	28.00
4.	$S1_D$	8.2	2429.63	8.1	2400.00	690	30.67
Mean =		8.25	2444.45	8.05	2385.19	647.500	28.78

Table 5.9: 14 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$S2_A$	8.2	2429.63	8.0	2370.37	620	27.56
2.	$S2_B$	8.2	2429.63	8.0	2370.37	600	26.67
3.	$S2_C$	8.2	2429.63	8.0	2370.37	640	28.44
4.	$S2_D$	8.1	2400.00	8.0	2370.37	645	28.67
Mean =		8.18	2422.22	8.0	2370.37	626.25	27.84

Table 5.10: 21 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$S3_A$	8.2	2429.63	8.0	2370.37	440	19.56
2.	$S3_B$	8.4	2488.89	7.9	2340.74	650	28.89
3.	$S3_C$	8.3	2459.26	7.8	2311.11	590	26.22
4.	$S3_D$	8.4	2488.89	7.9	2340.74	540	24.00
Mean =		8.33	2466.67	7.9	2340.74	555.00	24.67

Table 5.11: 28 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$S4_A$	8.2	2429.63	7.8	2311.11	660	29.33
2.	$S4_B$	8.2	2429.63	7.8	2311.11	490	21.79
3.	S4	8.2	2429.63	7.8	2311.11	500	22.22
4.	$S4_D$	8.2	2429.63	7.9	2340.74	440	19.56
Mean =		8.20	2429.63	7.83	2318.52	522.5	23.22

Table 5.12: 7 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$BC1_A$	8.3	2459.26	8.1	2400.00	690	30.67
2.	$BC1_B$	8.4	2488.89	8.1	2400.00	740	32.89
Mean =		8.35	2474.08	8.1	2400.00	715	31.78

Table 5.13: 14 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$BC2_A$	8.2	2429.63	8.0	2370.37	690	29.78
2.	$BC2_B$	8.2	2429.63	8.1	2400.00	620	27.56
Mean =		8.2	2429.63	8.05	2385.19	645	28.67

Table 5.14: 21 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$BC3_A$	8.2	2429.63	7.9	2340.74	500	22.22
2.	$BC3_B$	8.2	2429.63	7.9	2340.74	360	16.00
Mean =		8.2	2429.63	7.9	2340.74	430	19.11

Table 5.15: 28 Days Immersion Test

S/No	Specimen Load	Before Immersion		After Immersion		Compres Load (KN)	Compres. Strength (N/mm^2)
		Weight (Kg)	Density (kg/m^3)	Weight (kg)	Density kg/m^3)		
1.	$BC4_A$	8.1	2400.00	7.8	2311.11	560	24.89
2.	$BC4_B$	8.4	2488.89	7.8	2311.11	560	24.89
Mean =		8.25	2444.45	7.8	2311.11	560	24.69

CHAPTER SIX

6.0 DISCUSSION OF RESULT

6.1. INTRODUCTION

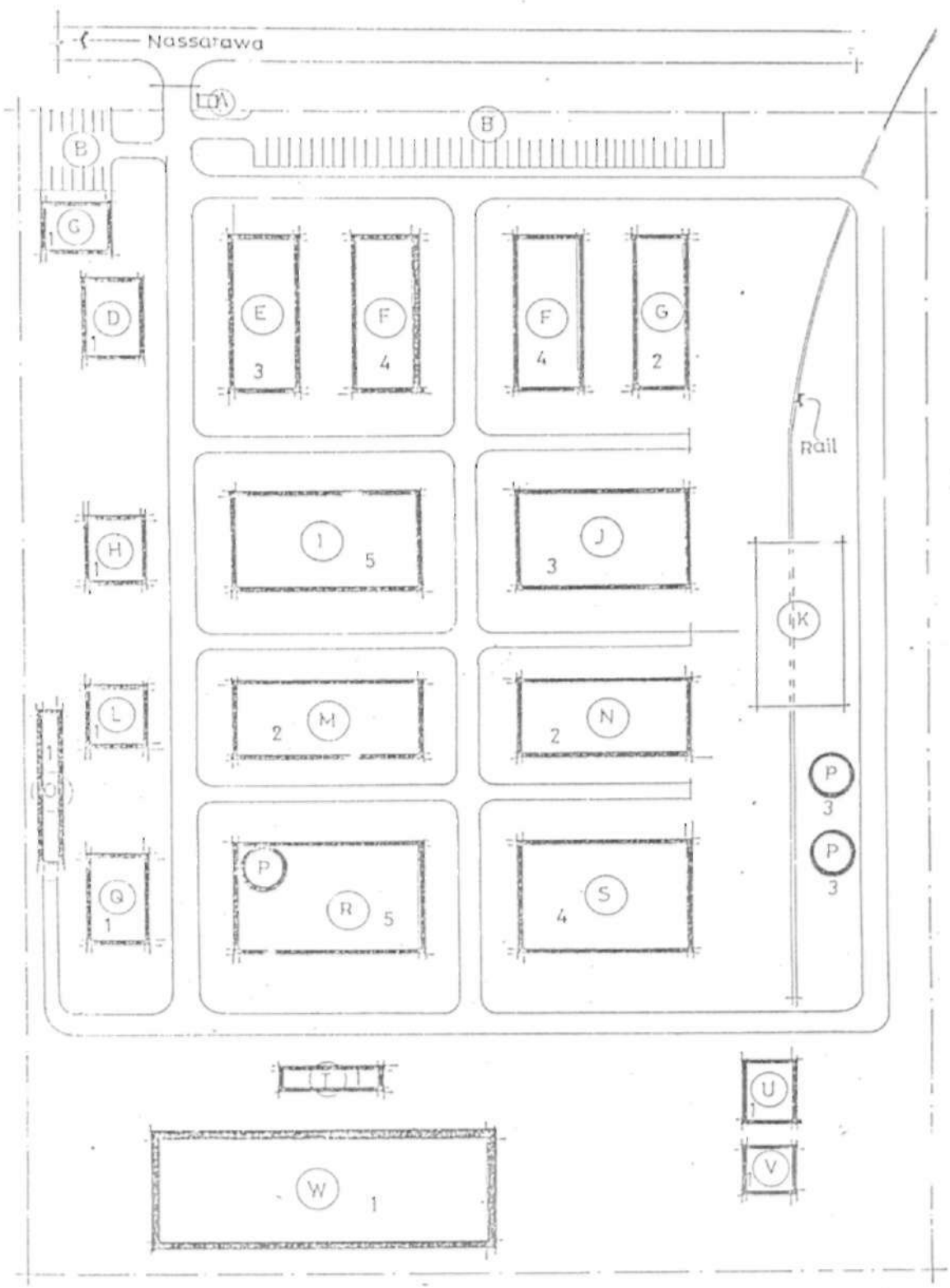
A concise discussion of the results of this research is presented in this chapter. To facilitate easy comprehension, the discussion will be presented in four parts. The first of these is on the visual observation, the second is on the in-situ test results while the third is on the laboratory test results. The last part of this chapter attempts to correlate the visual observations, in-situ test results and the laboratory simulation result with a view to predict the probable future of the structural concrete at the case study site.

6.2 VISUAL ASSESSMENT

From the visual assessment carried out at the case study site, it was observed that the sulphuric acid and acidulation plants were worst hit by the devastation. Judging from the manner in which the cementing component of the structural concrete in these areas had been dissolved and by the yellowish colouration of the resulting mass, the devastation must have been caused by sulphuric acid (H_2SO_4). This is not surprising when one considers the fact that large quantities of sulphuric acid are made use in these areas in the production process. The fact that most of the acid pipes in these areas were found to be leaking only helps in futher substantiating the above claim. Other areas within the factory were observed to have suffered devastation but to varied degrees (See fig. 6.1 and appendix 1).

Fig 6.1

SITE PLAN SHOWING A SUMMARY OF DAMAGE BASED ON VISUAL OBSERVATIONS (not to scale)



6.3 IN - SITU (PUNDIT) TEST

The ultrasonic pulse transmission readings for the acid tank foundation, stark machinery foundation, continuous den floor and the remaining floor portion of the acidulation plant are presented in tables 5.1,5.2,5.3 and 5.4. The mean ultrasonic pulse transmission velocities are 3.85 km/s, 3.40 km/s, 3.17km/s and 3.28km/s respectively. On the basis of the Whitehurst[35] classification (see appendix 2), a transmission velocity of 3.85 km/s suggests a concrete of good quality while the remaining transmission velocities suggest a doubtful state as regards the quality of the concrete. However, Jores[18] gives the lower limit of good quality concrete as one having an ultrasonic pulse transmission velocity of between 4.1 km/s and 4.7 km/s. On the basis of the Jones criterion therefore, the structural concrete in all the four tested areas are of poor quality.

The corresponding coefficients of variation are 13, 3,5, and 4 respectively. The last three values are relatively small and suggest that the structural concretes in these areas even though they might have suffered devastation, the devastation has been rather uniform. The rather large value of 13 is of practical significance. It signifies that the structural concrete here has undergone non-uniform devastation so that within the same structural concrete element, large variations in strength occur. This is a most unwanted feature in structural concrete and thus, the acid tank foundation must be of poor quality even though the Whitehurst[35] classification classifies it as belonging to the class of good quality concrete. The large variation in strength also suggests that the quality of the concrete must have

initially been good.

Table 5.1 shows velocity readings ranging from about 3km/s to about 4.6 km/s. A transmission velocity of 4.6 km/s is equivalent to a cube strength of about 37.5N/mm^2. This gives some credence to the suspected design strength of 40N/mm^2 used in the course of this research for laboratory simulations.

6.4 LABORATORY ASSESSMENT

Tables 5.5 and 5.6 show the results of the chemical analysis for the soil samples carried out. Table 5.5 gives the chemical composition by weight while table 5.6 gives the corresponding PH values. From Table 5.5 it can be discerned that the principal constituents by weight of the samples are the sulphate and silicate components. Table 5.6 reveals that the areas from which the samples were collected viz the sulphuric acid and acidulation plant are all acidic since all the pH values fall below the neutral value of 7. A scrutiny of both tables 5.5 and 5.6 reveal that generally, the higher the sulphate content of a sample, the greater the acidity. Thus, soil sample SA_1, which has the highest sulphate content by weight has the lowest pH value while soil sample AC_1, with the lowest sulphate content by weight has the highest pH value. There however, appears to be no discernible relationship between the silicate content and the pH value. The rather large sulphate contents by weight of the soil samples together with the low pH values of the samples are symptomatic features in the diagnosis of sulphuric acid attack. (see section 2.2.2.)

Table 5.7 gives the results of the control specimens. The

values 8.25kg, 2444.45kg/m^3 and 41.33 N/mm^2 for the mean weight, density and compressive strength respectively are all in conformity with the mix design (see section 4.3). Tables 5.8,5.9.5.10 and 5.11 on the one hand and tables 5.12,5.13,5.14 and 5.15 on the other show the results of the total immersion test for the uncoated and bitumen coated test specimens respectively.

The graphical representations of the variation in weight, density and compressive strength with age are shown in appendices 3,4 and 5 respectively for both the uncoated and bitumen coated specimens. From these appendices it can be seen that the weight, density and strength of both types of specimens decrease with age. This can only be because with increased age, more of the cement component of the concrete is dissolved by the acid. This thus results in a decrease in weight, consequently a decrease in density and ultimately, a decrease in compressive strength of the concrete. This is in agreement with an earlier work done by Lea[19] (see chapter two).

Another important feature is also made manifest by the graphical representations shown in the appendices. A survey of these appendices reveals that the first few days after immersion witness very rapid decreases in weight, density and strength. However, as the time of immersion increases, the decreases in weight, density and strength progressively diminishes. The reason for this it would seem, is because initially, the acid can attack the entire concrete face when the aggregates have not been exposed. However, as the aggregates begin to be exposed, the resultant surface area of the cement constituent gets

increasingly smaller. Thus, the amount of cement that can be dissolved reduces progressively resulting consequently in increasingly smaller weight, density and compressive strength reductions.

A further survey of the appendices show that initially, the bitumen coated specimens undergo smaller reductions in weight, density and strength relative to the uncoated specimens. However, at later ages, the trend reverses with the bitumen coated specimens undergoing greater reductions in weight, density and strength relative to the uncoated specimens. It was however, noticed that the period preceding this trend reversal was the period prior to which the bitumen coating had not dissolved and the period following the trend reversal was the period after which the bitumen coating had dissolved. It can only then mean that this reversal in trend must definitely be the consequence of a reaction of some sort between the dissolved bitumen and the attacking sulphuric acid yielding a mixture with a greater devastating influence on the now exposed concrete. This is given some credence when one considers the fact that bitumen is a waste product derived from the refining of crude oil. It is essentially a hydrocarbon but also constitutes of other chemicals which had been previously employed in the refining process. Sulphuric, nitric or hydrochloric acids are the principal chemicals employed to catalyse the refining process. Thus, when the bitumen coating becomes dissolved, any of these acids that had been previously used as the catalyst will separate out and in combination with the attacking sulphuric acid, produce a mixture of higher acidity and hence, a higher devastating

influence on the now exposed concrete as measured by the greater reductions in weight, density and strength relative to the uncoated specimen.

6.5 COMMENT ON THE PROBABLE FUTURE OF THE STRUCTURE

The results of the visual inspection and pundit test when combined, show that the structural concretes at both the sulphuric acid and acidulation plants have become structurally unsafe. The results of the immersion tests on their own, show that the loss in strength of structural concrete subjected to sulphuric acid attack occurs for as long as the cement component of the concrete has not been completely dissolved. This strength loss however, diminishes progressively in quantity with age. Thus, based on these results, it can safely be predicted that the structural concrete at the tested areas of the case study site will most probably collapse in the near future. This should be as a result of the small loses in strength which will continue to occur and which with time will assume appreciable dimension.

CHAPTER SEVEN

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 SUMMARY AND CONCLUSIONS

7.1.1 LITERATURE REVIEW

The main conclusions to emerge from the published literatures reviewed are listed below and their ordering is not necessarily in the order of decreasing importance.

1. Aggressive environments relative to concrete durability are more severe under hot weather conditions than under cold weather conditions.
2. There exists three types of aggressive environments relative to concrete durability. These are the chemically, physically and biologically aggressive environments with the degree of aggressivity gene ally decreasing in that order.
3. Dry concrete is generally immune to attack by dry chemicals. However, under moist conditions, a considerable number of chemicals will attack concrete.
4. No concrete is wholly acid resistant and therefore, any concrete with prolonged contact with acid will definitely suffer some deterioration.
5. When concrete is attacked by a chemical solution, the rate and extent of deterioration is generally dependent on the nature and concentration of substances in the solution in conctact with the concrete, the temperature and pressure of the solution, and importantly on the quality of the concrete as measured primarily but not solely by its premeability.

7.1 2 VISUAL OBSERVATION AND EXPERIMENTAL STUDIES

The following main conclusion were drawn from visual observations and experimental studies.

(1) The sulphuric acid and acidulation plants have both suffered damages with a severity classification index of 5 based purely on visual observations. These structures are thus structurally unsafe. Other areas within the factory have suffered lesser degrees of damages.

(2) The mean ultrasonic pulse transmission velocities of the tested area and structural elements gave residual strength readings that are all less than 12.5N/mm^2 which is just about a quarter of the initial suspected design strength. Thus, these structures are unserviceable. (see tables 5.1, 5.2, 5.3, 5.4 and appendix 6).

(3) The reductions in weight, density and strength of concrete as a result of sulphuric acid attack take place rapidly initially. However, at later ages, these reductions diminish in quantity progressively.

(4) The reductions in weight, density and strength of a bitumen coated concrete take place at a slower rate in comparison with an uncoated concrete initially. However, at later ages, this trend reverses with the reductions in weight, density and strength of the bitumen coated concrete being more. The severe devastation manifested by the tested areas which were once treated with bitumen as a base course must have been as a result of this.

(5. The visual observations in conjuction with the experimental studies have diagonised sulphuric acid attack as the main cause of the danage to structural concrete at the case study site.

7.3 RECOMMENDATIONS

Based on the findings of this research, the following recommendations are hereby made;

(1) The use of concrete structures at the sulphuric acid and acidulation plants should be discontinued immediately.

(2) New concrete structures should be put up to replace these old ones. However, for any meaningful result to be achieved by these new structures, the sulphuric acid rich soil within the immediate vicinity of these structures has to be thoroughly escavated and replaced by new soil.

(3) During the course of this research, it was discovered that plastics exhibit a highly degree of resistance to sulphuric acid attack. On this premise therefore, an exploration into the viability of encasing structural concrete in plastic at the case study site, particularly the structural concretes at the sulphuric acid and acidulation plants, and indeed any structural concrete prone to sulphuric acid attack, is suggested as an area of further research.

APPENDICES

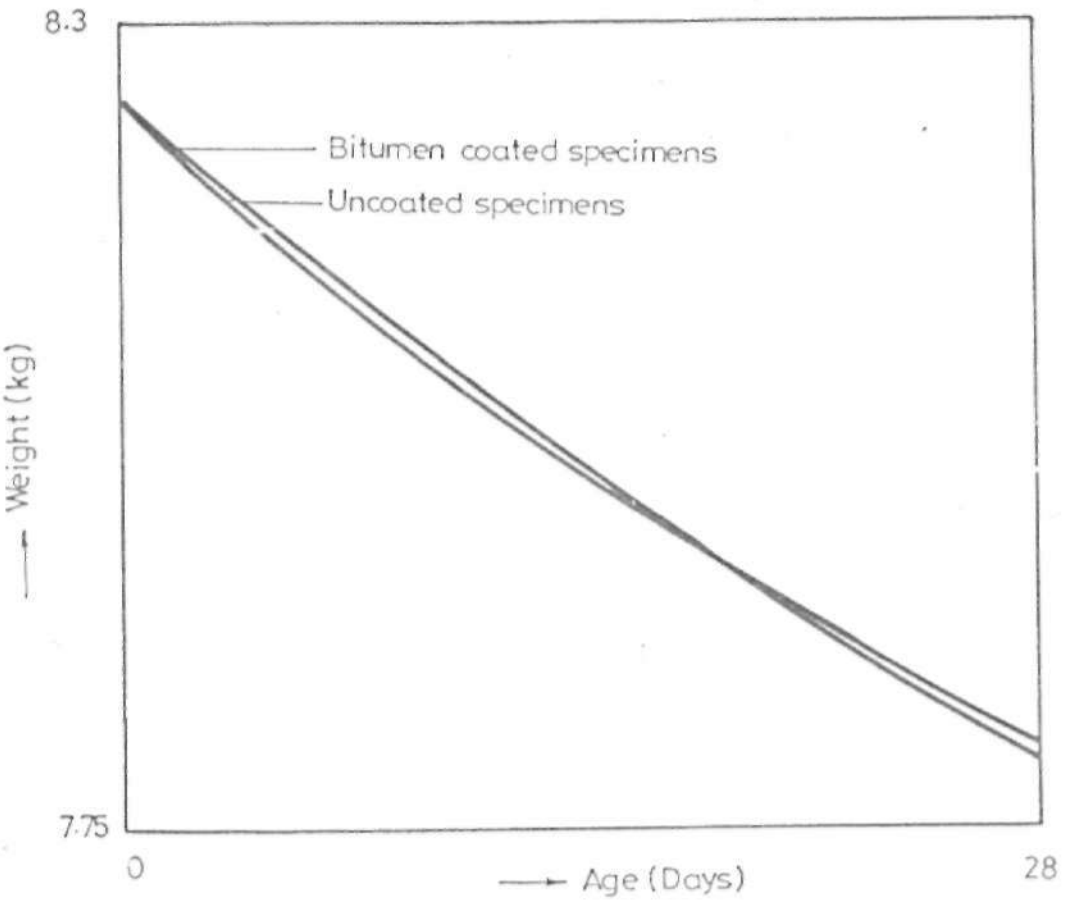
Appendix 1: Visual Features - Severity Indices[8]

Severity of Features	Index
Insignificant	1
Minor features of a non-urgent or purely comestic nature.	2
Unacceptable features requiring attention	3
Severe defects or problems requiriny immediate attention	4
Structurally unsafe	5

Appendix 2: Classification of the Quality of Concrete on the Basis of Pulse Velocity[35]

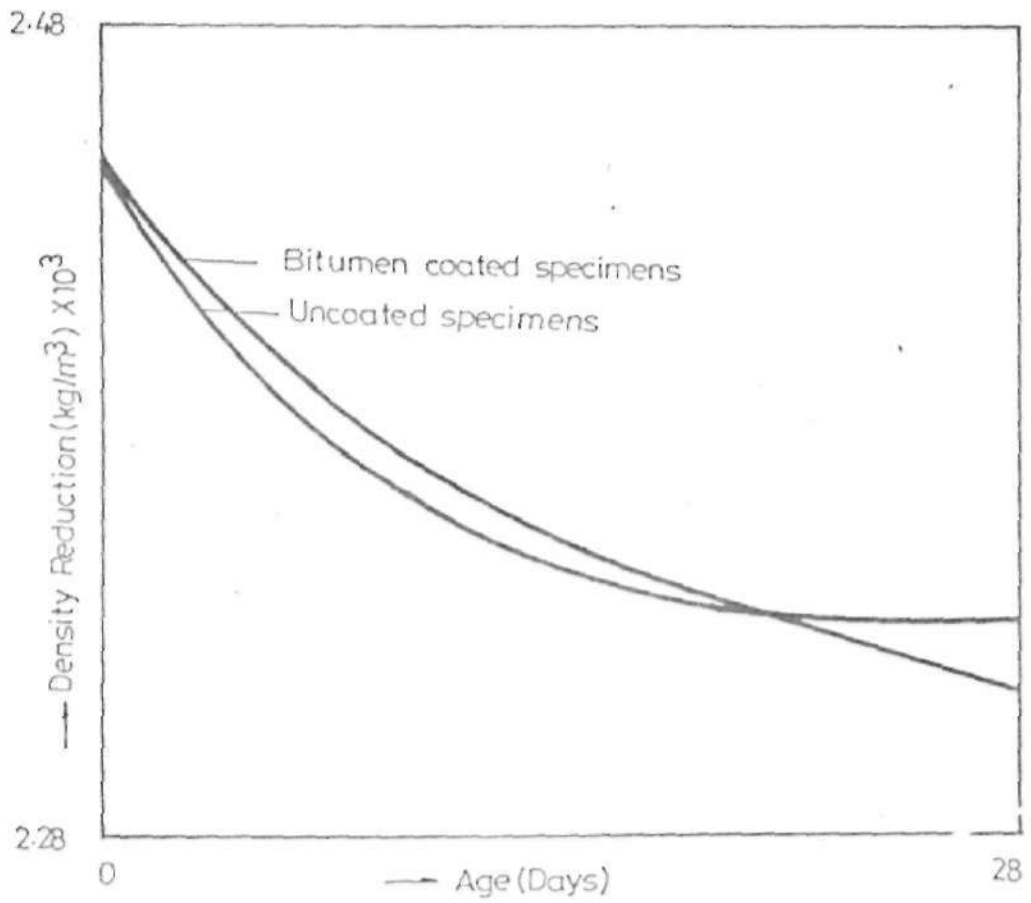
Iongitudinal Pulse Velocity Km/s	Quality of Concrete
> 4.5	excellent
3.5 - 4.5	good
3.0 - 3.5	doubtful
2.0 - 3.0	poor
< 2.0	very poor

Appendix 3:



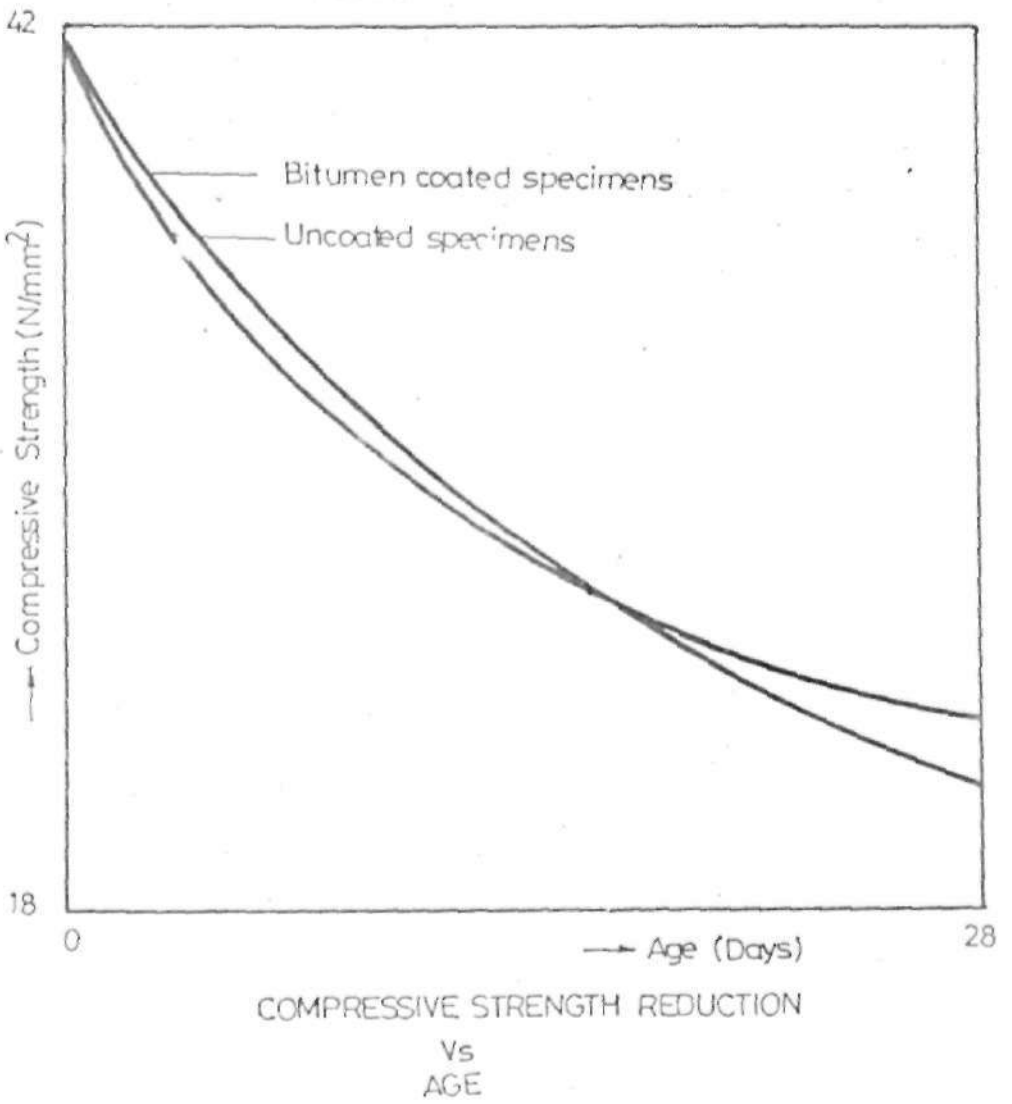
WEIGHT REDUCTION Vs AGE

Appendix 4:



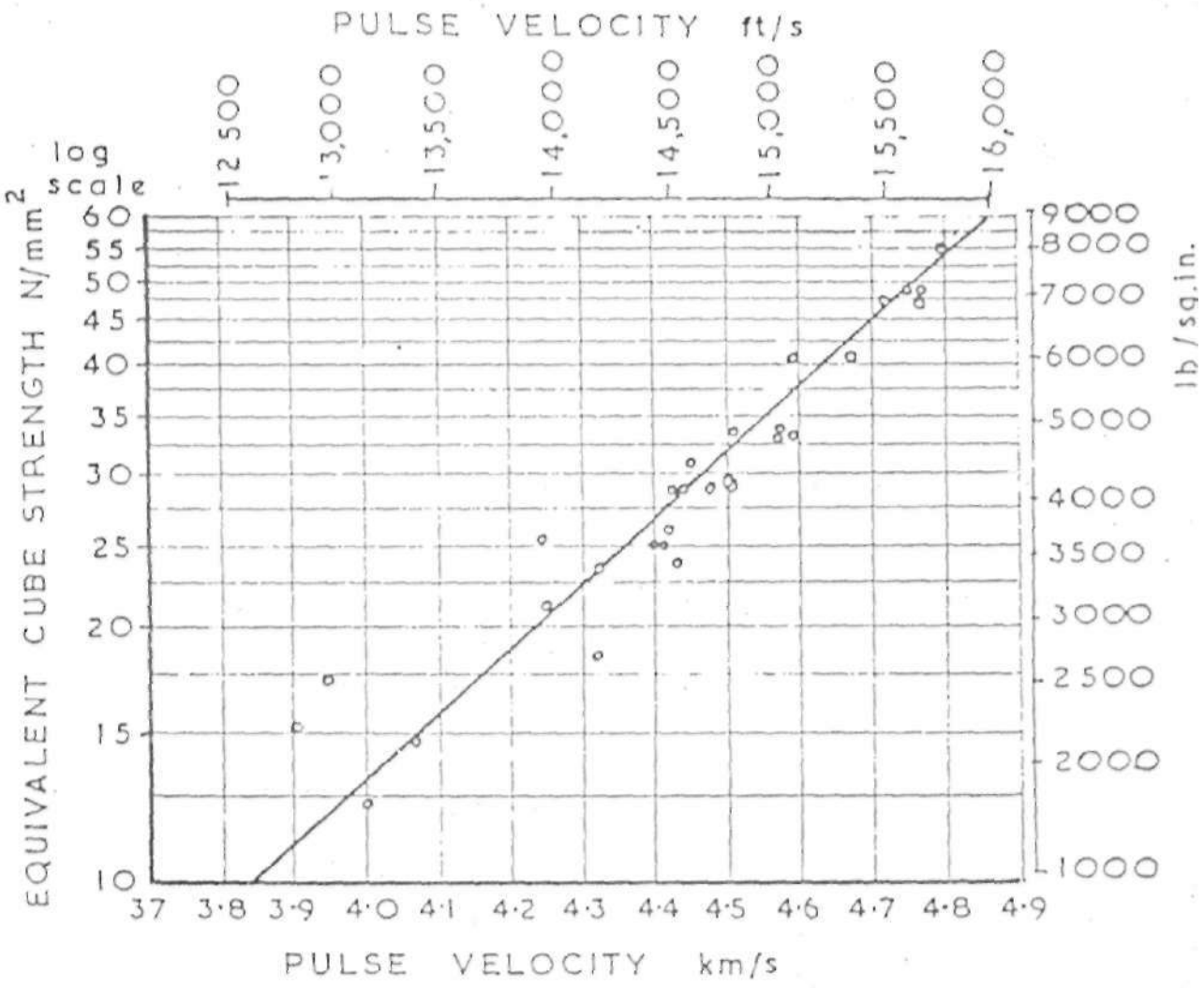
DENSITY REDUCTION Vs AGE

Appendix 5:



COMPRESSIVE STRENGTH REDUCTION
Vs
AGE

Appendix 6:



TYPICAL Strength-Velocity Correlation for Concrete

Appendix 7:

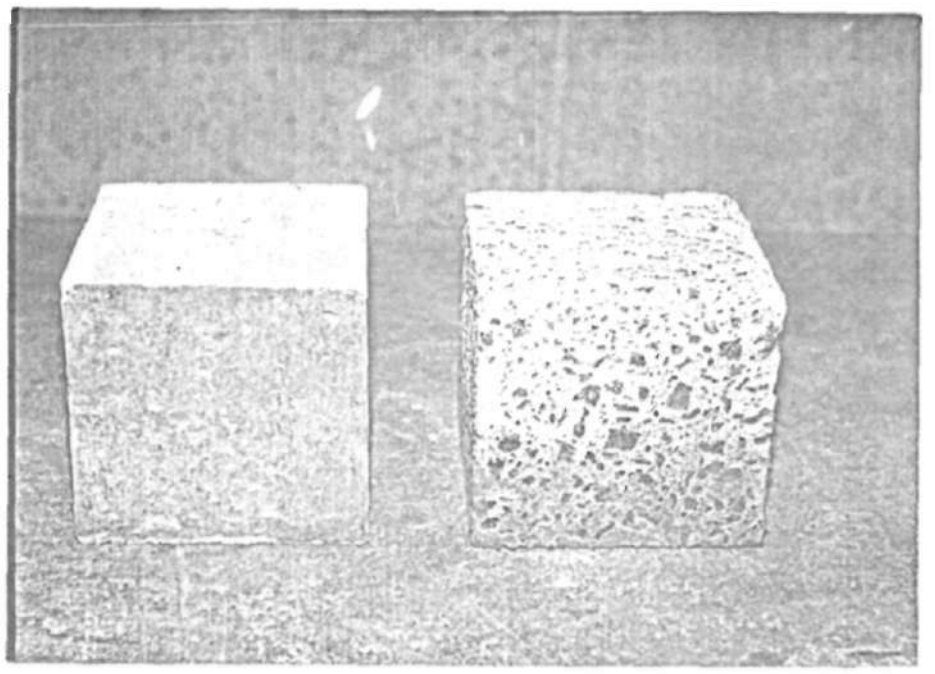


Plate 1: Cube Before Immersion (Left)

Cube After 28 Days of Immersion (Right)

Appendix 8:



Plate 2: Bitumen Coated Cube After 28 Days of Immersion

Appendix 9:



Plate 3: Devastation of Concrete Acid Tank Foundation at the Sulphuric Acid Plants Also Showing Corroded Steel Pipes.

Appendix 10:



Plate 4: Devastation of Concrete and Corrossion of Steel Pipes Near the Stark Equipment at the Sulphuric Acid Plant.

Appendix 11:



Plate 5. Devastation of Concrete Wall at the Acidulation Plant.

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