A PROJECT REPORT

ON

SAFETY ANALYSIS OF THE EFFECT OF POROSITY ON THE STRENGTH OF CONCRETE

BY

MUSTAFA WASIU AKOLADE
(93/3633)

A Project Submitted to the Department of Chemical Engineering,
School of Engineering and Engineering Technology,
Federal University of Technology, Minna.
In Partial Fulfilment of the Requirement
for the Award of Bachelor of
Engineering (B.Eng)

March, 2000

DECLARATION

I, Mustafa, Wasiu Akolade, declare that this project presented for the Award of Bachelor of Engineering in Chemical Engineering has not been presented either wholly or partial for any degree elsewhere.

-------------------------------------- --

Student Date

CERTIFICATION

This is to certify that this project 'Safety Analysis of the effect of porosity on a Concrete Structure' is the Original Work of Mustafa Wasiu Akolade, Carried out wholly by him under the supervision of Dr J.O. Odigure and submitted to the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna. Nigeria.

....	....
Supervisor	Date
....	....
Head of Department **Dr J.O.Odigure**	Date
....	....
External Examiner	Date

DEDICATION

I dedicate this project to the DEAD, LIVING and yet
UNBORN generation of freedom fighters around the
world, the Magma Charta of the poor and
oppressed, the human race is not in
a position to dispense with them.

ACKNOWLEDGMENT

My unalloyed thanks to HIM that existed before all things, within whom all things are held.

Also my unreserved gratitude to my loving parent Mr. & Mrs. Mustafa for their moral and financial support. Mr. P. O. Makinde for his unflinching support and encouragement.

My appreciation also goes to my Supervisor and honourable Head of Department, Dr. Odigure O.J. for his candid and constructive suggestions instrumental to the completion of this project work.

My appreciation also goes to the members of staff, especially Mr. Akpan U.G for his constructive suggestions.

To all my colleagues, friends and well wishers, I appreciate you all.

ABSTRACT

Safety analysis of the effect of porosity on concrete strength was carried out from the conceptual design stage of mixing water and cement at ratio within 1:2.5 and 1:1.2. A model equation of a hazard warning structure was developed on quick basic programme software to calculate porosity and the corresponding strength. Both historical and analytical risk quantification methods were used to modify the existing formula on strength calculation. From the simulation results of the developed programme, it was observed that the compressive strength of concrete increased with decrease in porosity with a corresponding decrease in the depth of carbonation using portland cement.

LIST OF TABLES

LIST OF ILLUSTRATIONS

TABLE OF CONTENT

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER ONE

1.0 INTRODUCTION

This project considered the issue of safety and loss prevention via application of risk management and analysis techniques of a concrete structure from the conceptual design stage to the commissioning and operation (Odigwre, 1995) Discussion of the behaviour of concrete is generally based on the assumption that the ambient medium is air which does not react with hydrated cement paste. However, in reality, air contain carbon (iv) oxide which in the presence of moisture, react with cement, the actual agent is carbonic acid because gaseous (Co_2) carbon dioxide is not reactive. The rate of carbonation of concrete increases with an increase in the concentration of Co_2 especially at high water/cement ratio. Calcium hydroxide $Ca(OH)_2$ readily react with Co_2 the product of the reaction being calcium trioxocarbonate (iv) $CaCo_3$ but other hydrates are also decomposed. This often result in increased permeability, diffusion coefficient and porosity with corresponding decrease in strength of hardened concrete structure. Thus in a simplified expression. carbonation could be seen as a function of the strength of concrete.

Need for Study

These compounds are known to react with cement mineral hydrate especially free Ca $(OH)_2$ in hardened concrete structure to produce soluble salts which when leached from the hardened concrete structure, leaves behind a loosely packed matrix. Thus exposes the reinforcement steel or inner layer as a result of the removal of the surface protective oxide thereby reducing the durability and safety of the concrete structure (Neville, 1996)

The extent to which the aforementioned compound enavate the concrete structure is dependent on the volume of total void, which include the entrained air, capillary pores and get pore spaces.

Others include porosity, diffusivity and the presence of microcracks. These are fundamental variables in determining the strength of the concrete. The relationship between the strength of concrete and the cement/water ratio range between 1.2 and 2.5 for minimum pore volume and maximum concrete strength. (NIELSEN, 1993)

Aim and Objective of Study

The main long term objective of this research work is to develop a safety evacuation procedure and techniques, estimate based on statistical data, the depth of carbonation and strength of the concrete of any given time. However, the effect on cement based concrete structure and existing mirocracks in the parent rock is not easily defined. In view of this, a model programme based on quick basic language will enhance the prediction of concrete structure conditions. This will enhance planning of maintenance programme and ensure the overall stability of the structure constructed using portland cement.

Scope/Limitation of Study

The scope of this work is to determine the strength of concrete as a function of the volume of void present measured from the conceptual design stage of mixing water/cement of a specified ratio to the hardened concrete within a safety margin. The fundamental factor controlling carbonation is the diffusivity of the hardened concrete paste which is a function of the concrete porosity. Thus the strength of hardened concrete understudied was determined from the period of curing through setting time and subsequently life time of the concrete structure.

However, the general applicable strength prediction equation for commercial cements is not possible for several reasons. This include the interaction between compounds, the influence of the alkali and of gypsum, the influence of particle size distribution of the cement, the presence of glass which does not contain all the compounds in the same proportions as well as the amount of free lime, are also factors varying between cement with nominally the same composition of the four main compounds. Therefore, no single method of hazard identification is suitable for all purpose. The choice of method depends upon the inherent hazard of the process being studied and the organisational framework within which the study will be done.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GENERAL

On a concrete building site, it is true that the quality of cement is guaranteed by the manufacturer in a manner similar to that of steel and, provided suitable cementation materials are chosen, it is hardly ever a cause of fault in concrete structure. But it is concrete, and not cement, that is the building material. The structural members are more often than not made in situ, and their quality is almost exclusively dependent on the workmanship of concrete making and placing. The primary requirements of a good concrete in its hardened stale are a satisfactory compressive strength and an adequate durability. Durability of concrete under various conditions of exposures, including carbonation and alkali-silica reaction. (LEA.F.M., 1960)

2.2 CEMENT

Cement can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole. For constructional purposes, the cements of interest in the making of concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore, called hydraulic cements consisting mainly of silicates and illuminates of lime, and can be classified broadly as natural cement, Portland Cement and high alumina cements. (Lerch et al 1948)

2.2.1 Portland cement

This is a name given a limestone quarried in Dorset in Rome in 1824 obtained by intimately mixing together calcareous and argillaceous, or other Silica, alumina, and iron oxide bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker. (Lerch et al 1948)

2.2.2 Chemical Composition of Portland Cement

Four compounds are usually regarded as the major constituents of cement: they are listed in table (1.0). Shortened notation used by cement chemists, describes each oxide by one letter.

$CaO = C$; $SiO_2 = S$; $Al_2O_3 = A$ and $Fe_2O_3 = F$

$H_2o = H$ and $SO_3 = S$.

Table 1.0

NAME OF COMPOUND	OXIDE COMPOSITION	ABBREVIATION
Tricalcium Silicate	$3Cao.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_2A
Dicalcium Aluminoferrite	$4CaO.Al_2O_3Fe_2O_3$	C_1AF

2.2.3 Setting

Setting refers to a change from a fluid to a rigid state. The setting time of cement decreases with a rise in temperature but above 30°C (85°F) a reverse effect may be observed. At low temperature setting is retarded.

2.2.4 Which Cement to Use

No one cement is the best one more than one type of class can be used. The choice depends on availability, on cost - that important element in engineering decision making - and or the particular circumstance of equipment, skilled labour force, speed of construction and the exigencies of the structure and its environment. (Lea, 1970)

2.3 CLASSIFICATION OF AGGREGATES

The size of aggregate used in concrete ranges from tens of millimeters done to particle sizes less than one-tenth of a millimeter in cross section (ozoi, 1979)

all-in or pit-run aggregate

Low grade concrete, aggregate from deposits containing a whole range of sizes, from the largest to the smallest.

In the manufacture of good quality concrete, aggregate in at least two size groups, the main division being between fine aggregate often called san (> 5mm) and the coarse aggregate which comprises of material at least 5mm.

Natural Sand: Generally considered to have a lower size limit of 70 to 60mm

Silt: 60Nm - 2mm

Loom: Sand + Silt + Clay in equal proportion.

[Xu et al 1993]

However, aggregate considered poor in more than one respect is unlikely to make satisfactory concrete, so that test on aggregate alone are of help in assessing its suitability for use in concrete.

2.3.1 Strength of Aggregate

Compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to state what is the strength of individual particles. The strength and elasticity of aggregate depend on its composition, texture and structure. Thus a low strength may be due to the weakness of constituent grains or the grains may be strong but not well knit or cemented together.

A good average valve of the crushing strength of aggregate is about 200MPa (86000 psi) but many excellent aggregate range in strength down to 80MPa. One of the highest values recorded is 530MPa for a certain quartzite. Aggregate of moderately low strength and modulus of elasticity can be valuable in preserving the integrity of concrete. It may be noted that no general relation exist between the strength and modulus of elasticity of different aggregate [Alford, 1982]

2.3.2 Porosity and Absorption of Aggregate

The porosity of aggregate, its permeability and absorption influences such properties of aggregate as the bond between it and the hydrated cement paste, the resistance of concrete to freezing and thawing, as well as the chemical stability and resistance of abrasion. The valve of porosity of some common rocks are given in table 1-2 below:

Table 1.2

Rock Group	Porosity, Per Cent
Gritstone	0.0 - 48.0
Quartzite	1.9 - 15.1
Limestone	0.0 - 37.6
Granite	0.4 - 3.8

The water absorption of aggregate is determined by measuring the increase in mass for an over-dried sample when immersed in water for 24 hours. (The surface water being removed). [Ayota, 1986]

2.3.3 Maturity of Concrete

As the strength of concrete depends on both age and temperature, we can say that strength is a function of {(time interval x temperature), and this summation is called maturity. The temperature is reckoned from a datum found experimentally to be below -12 and -10°C. This is because at temperatures below the freezing point of water and down to about -12°C concrete shows a small increase in strength with time. A waiting period of 24 hours is usually required. Below -12° concrete does not appear to gain strength with time. The maturity relationship is established from a plot of strength versus logarithm of maturity. The slope of this line, b, makes it possible to estimate the strength S_2 at maturity M_2, from the strength S_1 at maturity M_1, from the strength S_1 at maturity M_1 using the equation.

$$S_2 = S_1 + b(\log M_2 - \log m_1) \ldots\ldots\ldots\ldots (1)$$

[Pearson, 1987]

2.4 CARBONATION

Of the hydrates in the cement paste, the one which reacts with CO_2 most readily is $Ca(OH)_3$, the product of the reaction being $CaCO_3$, but other hydrates are also decomposed, hydrated silica, alumina, and ferric oxide being produced. Theoretically, such a complete decomposition of calcium compounds in hydrated cement is chemically possible even at the low concentration of (carbon (iv) oxide) Co_2. In concrete containing portland cement solely, it is only the carbonation of $Ca(OH)_2$ that is of interest. When however, $Ca(OH_2)$ becomes depleted, for instance by secondary reaction with pozzolanic silica, the carbonation of calcium silicate hydrate, C-S-H, is also possible. When this occurs move $CaCo_3$ is formed, silica gel with large pores, larger than 100nm is formed which facilitates further carbonation [Bier, 1987]

2.4.1 Effect of Carbonation

Carbonation per se does not cause deterioration of concrete but it has important effect.

1] Carbonation shrinkage, which occur during drying. The importance of carbonation lies in the fact that it reduces the PH of the pore water in hardened Portland Cement from between 12.6 to 13.5 to a valve of about 9. When all $Ca(OH)_2$ has become carbonated, the valve of PH in reduced to 8.3.

2.4.1.0 The significance of covering the PH.

Steel embedded in hydrating cement paste rapidly forms a thin passivity layer of oxide which strongly adhere to the underlying steel and gives it complete protection from reaction with oxygen and water. Thus, when the low PH front reaches the vicinity of the surface of the reinforcing steel, the protective oxide film is removed and corrosion can take place, provided oxygen and moisture necessary for the reactions of corrosion are present. For this reason, it is important to know the depth of carbonation front has reached the surface of the embedded steel.[Parrott, 1989]

2.4.2 Rate of Carbonation

Carbonation occurs progressively from the outside of concrete exposed to CO_2, but does so at a decreasing rate because CO_2 was to diffuse through the pore system, including already. Carbonated surface zone of concrete. The diffusion of CO_2 in water is 4 orders of magnitude slower than in air. If follows that the highest rate of carbonation occurs at a relative humidity of between 50 and 70 per cent. Under steady hygrometric conditions, the depth of carbonation increases in proportion to the square root of time. It is therefore possible to express the depth of carbonation, D, in millimeters as:

$$D = Kt_{0.5} \quad . . . \text{(ii)}$$

where K = Carbonation coefficient in mon/year$^{0.5}$; and

t = time of composure in year.

K often greater than 3 or 11 mon/year$^{0.5}$

In concrete with a water/cement ratio of 0.50, the depth of carbonation of 15mm would be reached after 15 years. However, the expression in equation (ii) is not applicable when the exposure conditions are not stable [Papada Kii,1991].

2.4.3 Factor Influencing Carbonation

- The fundamental factor affecting or controlling carbonation is the diffusivity of the hardened cement paste. The diffusivity is a function of the pore system. Thus in a simplified expression, carbonation could be seen as a function of the strength of concrete.

- Carbonation as a function of the water/cement ratio or of cement content, or of both of these.

- Curing or carbonation of concrete. [Matthews,1984]
- A general statement can be made to the effect in a situation conducive to continuing carbonation, concrete with a strength lower than 30MPa will have at least 15mm depth of carbonation in a period of several years.[Nischer, 1984]

2.4.4 Measurement of Carbonation

Laboratory techniques which can be used include chemical analysis, X-ray diffraction, infrared spectroscopy and thermographimetric spectroscopy. The common method applied is the treatment of a freshly broken surface of concrete with a solution of phenolphthalein in dilute alcohol. The free $Ca(OH)_2$ is coloured. The coloured pink about 9-5 pH indicate the presence of $Ca(OH)_2$.

To determine how rapidly a given concrete is likely to undergo carbonation:

Expose a concrete specimen to concentrated CO_2 of C_s(%) Determine the depth of carbonation at period of exposure t_t at time, t_s, on the basis that the time is inversely proportional to the concentration of CO_2:

$$t_t : t_s \quad = \quad C_s \ : \ 100 \ . \ . \ . \ (v)$$ [kabayashi, 1994]

2.5 SULPHATE ATTACK ON CONCRETE

Sulphate in ground water are usually of natural origin found in ground water but can also occur in fertilizer or from industrial effluents. These sometimes contain ammonium sulphate, which attacks hydrated cement paste by producing gypsum. Sulphides can be oxidized to sulphates under some conditions, e.g. under compressed air used in excavation. The reaction of the various sulphates with hardened cement paste is as follow:

$2Ca(OH)_2 + Na_2O_3.12H_2O) + 3(Na_2So_4.\ 10H_2O)\text{-->}$

$3CaO.Al_2O_3.3CaSo_4\ .\ 31H_2o + 2Al(OH)_3 + 6NaOH + 17H_2O.$

2.5.1 Magnesium Sulphate attack

$3CaO.2Sio_2.(aq) + MgSo_4.7H_2o \text{-->} CaSo_4.2H_2O + Mg(OH)_2O + SiO_2(aq)$

2.5.2 Ettringite: This is formed when calcium sulphate attacks only calcium acuminate forming calcium sulfo-acuminate ($3CaO.Al_2O_3.3CaSo_4.32H_2O$) [Serada 1975]

2.5.3 Mechanism of Attack

The attack occurs only when the concentration of the sulphate exceeds a certain threshold. Above that, the rate of sulphate attack increases with an increase in the strength of the solution, but beyond a concentration of about 0.5 per cent of $MgSO_4$ or 1% of Na_2SO_4 the rate of increase in the intensity of the attack becomes smaller [Odler, 1988]

Table 1.1

CLASSIFICATION OF SEVERITY OF SULPHATE ENVIRONMENT ACCORDING TO ACI 202. 2R - 92[10,42]

EXPOSURE	CONCENTRATION OF SOLUBLE SULPHATES EXPRESSED AS SO_4 IN SOIL PER CENT	IN WATER PPM
MILD	<0.1	<150
MODERATE	0.1-0.2	150-1500
SEVERE	0.2-2.0	1500-10000
VERY SEVERE	>2.0	>10000

2.5.4 Preventive Measures

1] Minimize the C_3A content in the cement, that is to use sulphate - resisting cement.

2] Reduce the quantity of $Ca(OH)_2$ in hydrated cement paste by the use of blended cement containing pozzuolana. or blast furnace slag.

3] Construct concrete as dense as possible with as low permeability as possible.

4] For severe cases of attack employ (1) and (2).

5] The relevant property of blast furnace slag is given in ASTM 989-93 and in ref. 10.135. [Hobbs, 1988]

2.6 CARBONATION SHRINKAGE

Carbonation shrinkage is probably caused by the dissolving of crystals of $Ca(OH)_2$ while under a compressive stress (imposed by the drying shrinkage) and depositing of $CaCo_3$ in spaces free from stress; the compressibility of the dehydrated cement paste in thus temporarily increased. If carbonation proceeds to the stage of dehydration of C-S-H, this also produces carbonation shrinkage. Carbonation increases the shrinkage at intermediate humidities, but not at 100 per cent or 25 per cent. In this case, there is sufficient water in the pores within the cement paste for CO_2 to form carbonic acid. On the other hand, when the pores are full of water, the diffusion of calcium ions from the paste lead to precipitation of $CaCo_3$ with consequent clogging of surface pores [Verbeck,1958]

2.6.1 Bond Between Concrete and Reinforcement

The strength of bond between the two material is of considerable importance with respect to structural behaviour. The critical properly is the tensile strength of concrete thus, bond strength is usually expressed as being proportional to the square root of compressive strength. A rise in temperature of 200-300°C reduces the bond strength.

2.6.2 Pitfall of Strength Prediction Equation

The general applicable strength prediction equation for commercial cement is not possible for several reasons. These are:

(a) The interaction between compounds.

(b) The influence of the alkali and of gypsum.

(c) The influence of particle size distribution of the cement.

(d) The presence of glass, which does not contain all the compounds in the same proportions as the rest of the clinker, but which effects reactivity, as well as the amount of free time, are also factors varying between cement with nominally the same composition of the four main compounds.

2.6.3 Nature of Strength of Concrete

The paramount influence of voids in concrete on its strength has been repeatedly mentioned, and it should be possible to relate this factor to the actual mechanism of failure. For this purpose, concrete is considered to be a brittle material, a strain of 0.001 to 0.005 at failure has been suggested as the limit of brittle than normal strength concrete but there is no quantitative method of expressing the brittleness whose behaviour in practice falls between the brittle and the ductile types (Griffith, 1920)

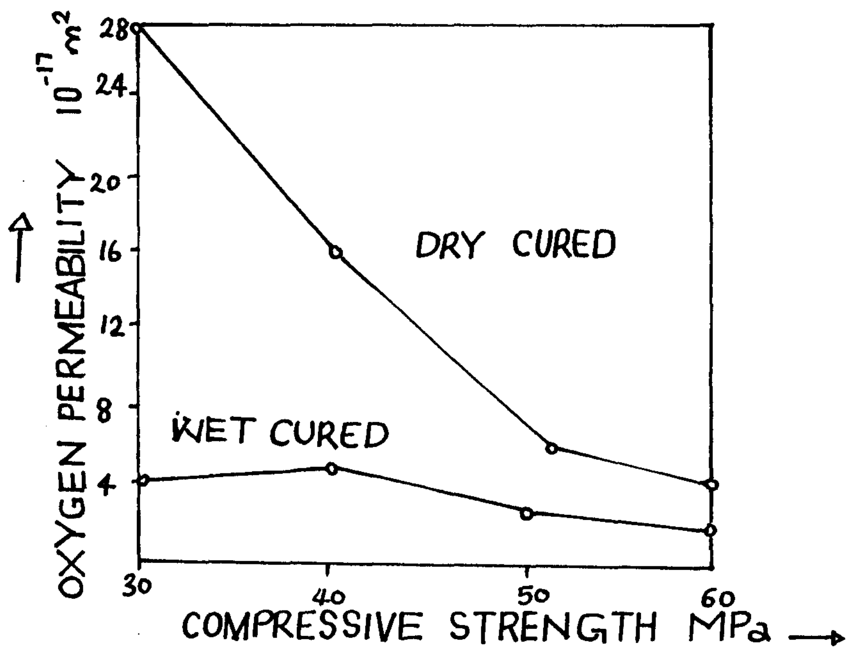
2.7 AIR AND VAPOUR PERMEABILITY

Since gases are compressible, the pressure, Po, at which the volume flow rate, q(inm^3/s) is measured, has to be taken into account, in addition to the inlet pressure, p, and outlet pressure, Pa; all pressure are absolute valves in N/M^2. Air permeability is greatly affected by curing, especially in concrete of low and moderate strengths. The intrinsic permeability coefficient, K, expressed in M^2 is:

$$K = \frac{2qR_oL\}}{A(P^2 - P^2_a)} \ldots\ldots\ldots\ldots \text{(iii)}$$

where A = cross section area of the specimen in m^2
L - its thickness in m, and
= dynamic viscosity in Ns/m_2

Fig.(2.7)



Relation between oxygen permeability and compressive strength of concretes cured for 28 days in water and in air at a relatively humidity of 65 per cent. [Ludirdja 1989]

2.7.1 Porosity

It is a measure of the proportion of the total volume of concrete occupied by pores, and is usually expressed in per cent. If the porosity is high and the pores are interconnected, the contribute to the transport of fluids through concrete so that its permeability is also high.

2.7.2 Diffusivity

Gases can diffuse through water filled space or through air filled space but, in porosity case, the process is 10^4 to 10^5 times slower than in the diffusivity. Gases concerned are primarily carbon (iv) oxide and oxygen.

2.7.2.1 Sorption

This is the result of capillary movement in the pores in concrete which are open to ambient medium.

2.7.3 Diffusion Coefficient

The diffusion coefficient of a gas is inversely proportional to the square root of its molar mass. Thus, theoretically, oxygen diffuses 1.17 times faster than carbon dioxide. This relationship makes it possible to calculate the diffusion coefficient of one gas from experimental data on another gas as shown below from sick's first law.

$J = Ddc/dL$

where dc/dL = concentration gradient m kg/m^4 or $mole/m^4$

D = mass transport rate in kg/m^2 or $mole/m^2s$

L = thickness of the sample in meters.

2.7.4 Water Permeability of Concrete

With the progress of hydration, the permeability decreases rapidly because the gross volume of gel is approximately 2.1 times the volume of the unhydrated cement, so that the gel gradually fills some of the original water-filled space. The reduction in the coefficient of permeability is faster the lower the water/cement ratio of the paste, so that there is little reduction after wet curing for a period stipulated. [Power,1959]

2.8 DURABILITY OF CONCRETE

It is essential that every concrete structure should continue to perform its intended functions, that is maintain its required strength and serviceability, during the specified or traditionally expected service life. It follows that concrete must be able to withstand the process of deterioration to which it can be expected to be exposed. Such concrete is said to be durable.

Figure 2.8.1

Flow Chart on the Calculation of Concrete Strength and Porosity for a Hazard Warning Structure.

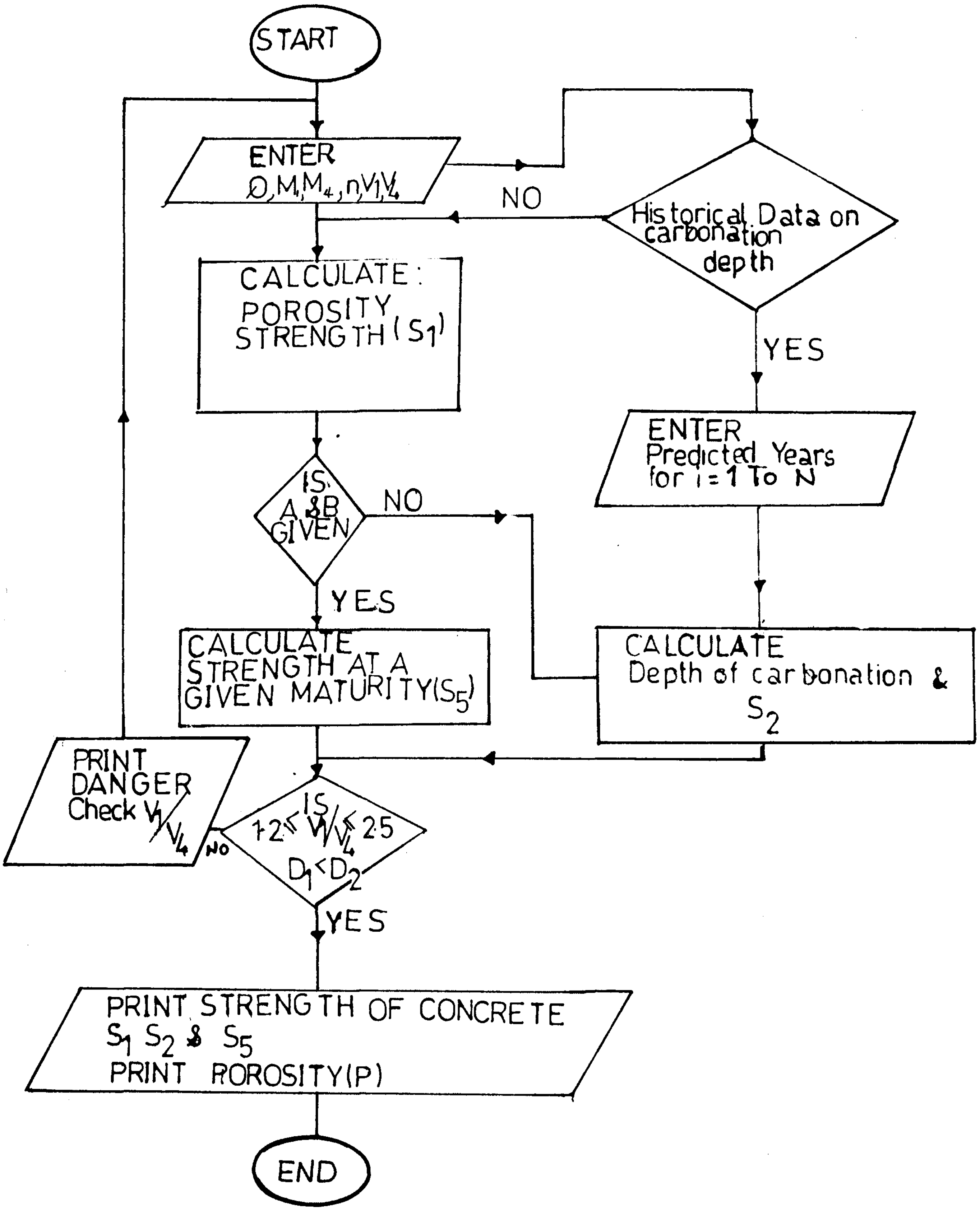
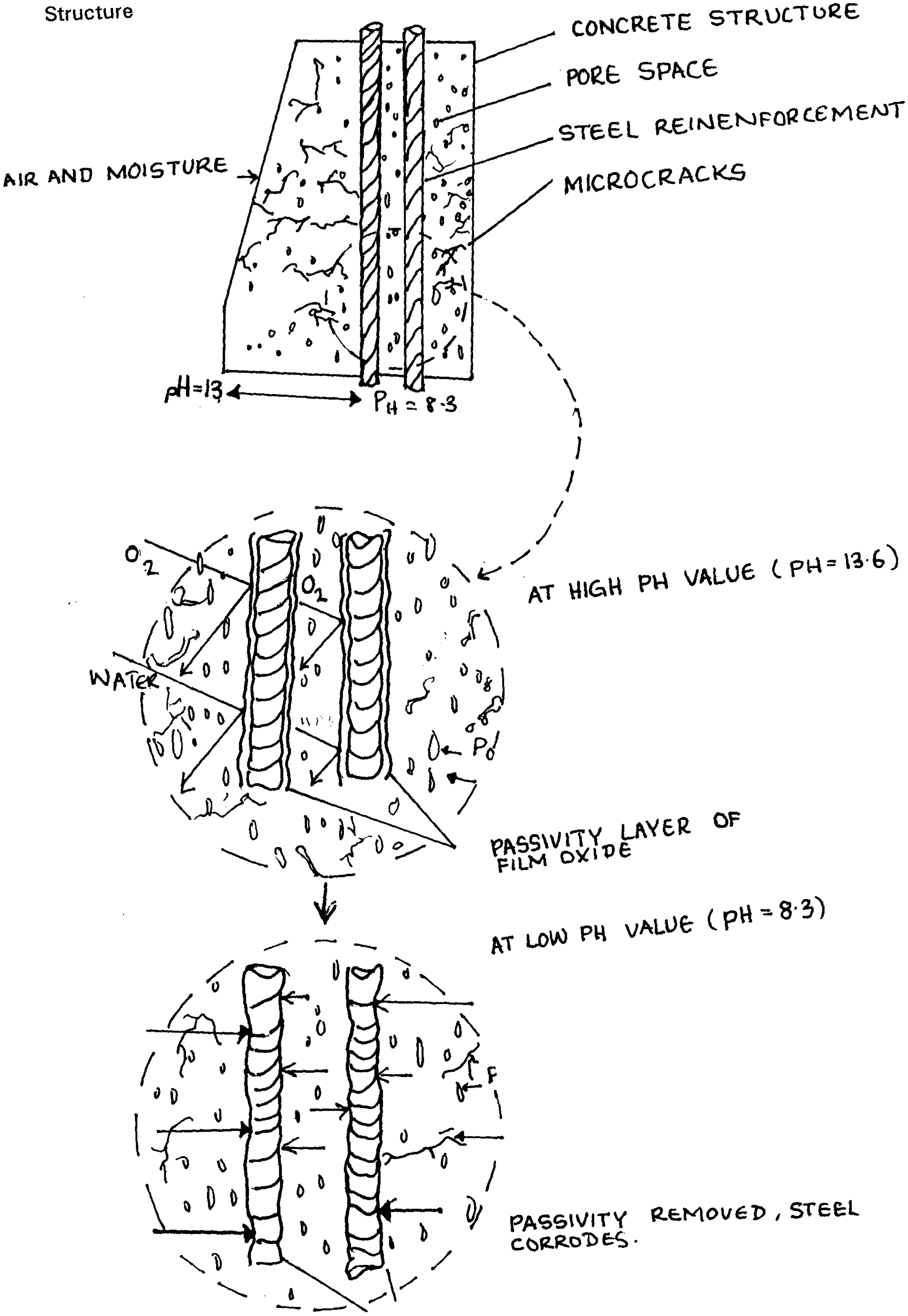


Figure 2.8.2

Diagrammatic Illustration of the Effect of Carbonation on Concrete Structure



2.8.1 Causes of Inadequate Durability

The various action can be physical, chemical, or mechanical.

Mechanical Damage:

This is caused by impact, abrasion, erosion or cavitation.

Chemical Damage:

External chemical attack occurs mainly through the action of aggressive ions, such as chlorides, sulphates, or of carbon dioxide, as well as many natural or industrial liquid and gases.

Physical Damage:

An important cause of damage is alternating freezing and thawing of concrete and the associated action of de-icing salt, and the difference in thermal expansion of aggregate and hardened cement [Carter,1989]

2.8.2 Influence of the Pore System

The interface between the cement paste and the aggregate occupies as much as one-third to one-half of the total volume of hardened cement paste in concrete which is known to harbour microcracks. The pore relevant to permeability are those with a diameter of at least 120 or 160nm. [Rioy et al 1992]

2.9 SAFETY PROVISIONS

2.9.1 Factor of Safety

The factor of safety is the ratio of the load that would cause collapse of the service or working load.

2.9.1.0 Factor Determining Safety

Factor of safety is necessary for a number of reasons that are individually important but have no real interrelation.

Some are matter beyond the control of the engineer, such as the possibility of unforeseen future load.

The quality of material used, which could be controlled by specification and inspection [Ferguson et al 1981].

Others relate to the importance of the member in maintaining the integrity of the structure.

Other factors vary with the degree of safety factor that is justified, such as the hazard to life from collapse of a school building as compared to that from collapse of a simple shed for storage of equipment.

2.9.2 Partial Factor of Safety

Safety has always been clearer when thought of in terms of partial safety factor. In design, these might well be in term of load construction practices, the quality of the material used and the importance of the member or structure. Probability theory can predict the reduced probability of each occurring separately where known.

2.9.3 Code Safety Philosophy

The ACI Code separates safety provisions into two parts. The two factors prescribed are load factor and Ø factor:

2.9.3.1 Load factor

Load factors greater than unity attempt to access the possibility that prescribed service load may be exceeded. A specified load is more apt to be exceeded than a dead load which is largely fixed by the weight construction.

2.9.4 The Ø factor

The Ø factor (less than unity) are provided to allow for variations in materials, construction dimensions, and calculation approximations, that is matters at least partially under the engineers control. The general building code prescribes live loads that are assumed to cover adequately the relative hazard resulting from failure [Ferguson et al, 1981]

2.10 NUMERICAL ANALYSIS OF HAZARDS AND FAILURES

2.10.1 Quantification of Risk

There are two basic methods used in the quantification of risk or accident probability estimation:

1] The use of historical data on failure of plant and analysis of possible event occurring; and

2] The analytical method. The approach is adopted where the historical data is inadequate or simply not available and where there is reason to expect the plant to have another failure probability from that indicated in the historic data. The analytical approach is consistent with the basic principle of breaking down the judgement of how likely the even is, into smaller units with more accurate judgement or proof, which are backed by practical experience.

2.10.2 Type of Data

There are many types of data that can be used in quantifying risk:

1] Information about accidents;

2] Information on system malfunction which produced less harmful consequence or "near misses" of a major accident;

3] Event data according of the particulars of all non-trivial event or occurrence;

4] Performance or reliability data of system;

5] Data on human error.

2.10.2.1 Data for assessment of the probably frequencies of the elementary event can be obtained from:

1] European Reliability Data Bank Association

2] Reliability analysis Centre, RAC, America Department of Defence.

3] United States Geological Survey.

4] United States Coast Guard.

Quantitative risk analysis can be obtained subjectively from:

1] Meeting people via interviews, meetings and discussions.

2] Observation - Inspection, listening and looking. This include:

i] Physical arrangement.

ii] Environmental conditions (heating, cooling, draughts, noise, sanitation, ventilation etc.)

iii] People at work (team work, alertness, observation of safety rules, maintenance, stress, fatigue, self discipline etc.)

2.10.3 Risk Analysis

An essential part of risk analysis is to identify the approach and method to be used. Factors such as concern for safety of life and properly, environmental protection, economy and operational reliability, etc. should be performed at an early stage during design to correctly assess the suitability and acceptability of the technology. [Odigore,1998]

2.10.4 Risk and Reliability Methodology

Risk analysis techniques are categorised using the project stages into conceptual design, detail design, construction, commissioning and operation. For each of these stages, a detailed description of the suitable risk analysis technique can be given early risk analysis of the conception design help in identification of possible malfunctions and enhance the viability of the process. The methodology of risk analysis include:

Identification of potential failure cases;
Quantification of consequences;
Probability estimation of event occurrence;
Careful examination of design to check its viability, especially for high probability event.

2.10.5 HAZOP (Hazard Operability) Technique

The possible malfunctions of the process and utility systems are examined individually and on synchronised pattern.

2.10.6 Fault Tree Technique

All possible scenarios of the top undesirable event are drawn up and the possible causes identified.

Irrespective of the technique applied, a qualitative engineering review of the conceptual design of a concrete structure should be performed to:

- Form the basis for comments and recommendation on identified possible accident prevention;
- Reduce their consequence to the barest minimum;
- Enhance safety evaluation; and
- Provide engineering information relevant to the reduction of the probabilities of failure causes.

Estimation of expected frequency of occurrence. These can be evaluated in two stages.

1) The primary event (minor) expected frequency, such as frequency of initial mechanical or mitigating features failures, number of observed failure/time.
2) The event tree traditional probabilities like the probabilities of the final possible outcome of the top or major events.

2.10.7 Consequence Evaluation

The consequence of any accidental event is its aftermath. The accuracy of consequence evaluation depends on the reliability of available input data, and the appropriateness of the assumption on which the calculations were based. This include wind, earthquake, collision, crash due to mobile object etc.on the concrete structure.

2.10.8 Assessment of Results

The results of risk analysis can be expressed as the total probabilities with which certain even exceed the design criteria. The total probability of "Residual accidental Event" must not exceed the target probability set be guidelines outlined for the given process.

Where total probabilities of the residual even exceed the target, measures outline below are considered.

1) Reducing the consequences of one or more residual events.
2) Eliminating one or more accidental event through alternative design; and
3) Identifying and reducing the probabilities of major risk contributors.

2.10.9 Risk and Survivability Assessment

The survivability assessment or general system performance can be evaluated from available quantified information about the total probabilities and extent of accidental events harmful consequences. The survivability evaluation can be by:

1] Predicting the impact on operation personnel or the community;
2] Quantified in terms of the economic implication. [Alain et al 1979]

2.11 IDENTIFICATION OF ACCIDENTAL EVENTS

Potential accidental events can be identified using techniques for synthesis of failure logic. For any technique adopted, the entire process must be broken down into its component parts or stages. Containment measures during failures for each item are then listed. For the checklist method, this process should be systematically followed for each zone or stage.

Overall methodology frame work for conceptual design risk analysis. [Odigore 1998]

2.12 LIMITATION OF RISK ANALYSIS

The limitations of the various risk analysis techniques are considered in detail as follows:

i] In many cases only very general data are available on concrete failure, for which statistical accuracy is often poor. In other case, there may be very little data available at all. This applies in particular to data on human failure.

ii] The quantification of the effect and consequences of incidents also have uncertainties associated with them, even where the physical process are understood.

iii] The analytical exercise associated with the qualification of risk might be considered to be objective. However, it must be realised that because of the large body of assumptions, estimates, judgement and opinions involved much of the input information is often subjective. Considerable skill is needed to interpret the results produced by a quantified risk analysis.

iv] It should also be appreciated that a full quantified risk analysis entails considerable work and therefore is costly. The scope should be tailored to the situation to be analyzed and the depth should be no greater than is needed for making a sound decision.

v] It is not possible, nor is it desirable, to set up absolute criteria for risk acceptability because:

  a) The risk estimates are uncertain and many assumptions are made, so that comparisons with criteria can be misleading.

  b) Safely performances ought to improve both as society's expectation change and as improved safety becomes technically achievable. The latter is already implicit in the legislation in many countries.

  c) Safety is only one important factor in the appraisal of the acceptability of an industrial activity. It should be considered together with the economic benefit of the community. [cox A.P et al 1982]

In conclusion, no single method identification is suitable for all purposes. The choice of method depends upon the inherent hazards of the process being studied and on the organisational framework within which the study will be done. Nevertheless, there are certain key points which apply to all method.

2.12.1 Future Developments

One area which may be explored in future is the automation of hazard identification based on computer modelling of the concrete. This will become an attractive possibility as Computer Aided Design System are used which call upon a data based which holds not only the drawing for the concrete structure but the process information. However, the complexity of logic involved and the degree of "experience" which would need to be built into the system suggest that we are still several years away from having a tool powerful enough to significantly help the hazard identification team.

CHAPTER THREE

3.0 METHODOLOGY

3.1 CONCRETE STRENGTH AS A FUNCTION OF WATER/CEMENT RATIO

The relationship between the strength and the cement/water ratio is approximately linear in the range of cement/water ratio between 1.2 and 1.5. The linearity of the relation between strength and cement/water ratio does not extend beyond the cement/water ratio of 2.6 as shown below in figure 1.0. [Kukizaki et al 1992]

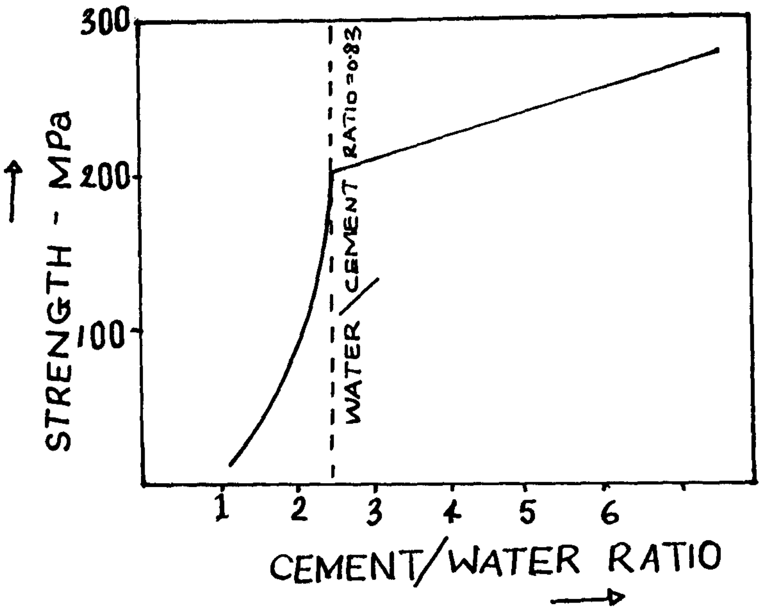


Figure 3.0: Relation between calculated strength of neat cement paste and cement/water ratio.

The figure 1.0 above represent calculated value for cement paste which have achieved maximum possible hydration for water/cement ratio smaller than 0.38 the maximum possible hydration is less than 100 per cent. Consequently the slope of the curve is different from that for higher values of water/cement ration. This observation is worth remembering as nowadays mixes with water/cement ratio both somewhat above and somewhat below 0.38 are often used.

3.1.2 **Porosity**

The influence of the volume of pore on strength can be expressed by a power function of this type.

$f_c = t_{10} (1 - P)^n$

where P = Porosity of the volume of void expressed as a fraction of the total volume of concrete.

f_c = Strength of concrete with porosity P

f_{10} = Strength of zero porosity

n = a coefficient which need not be constant

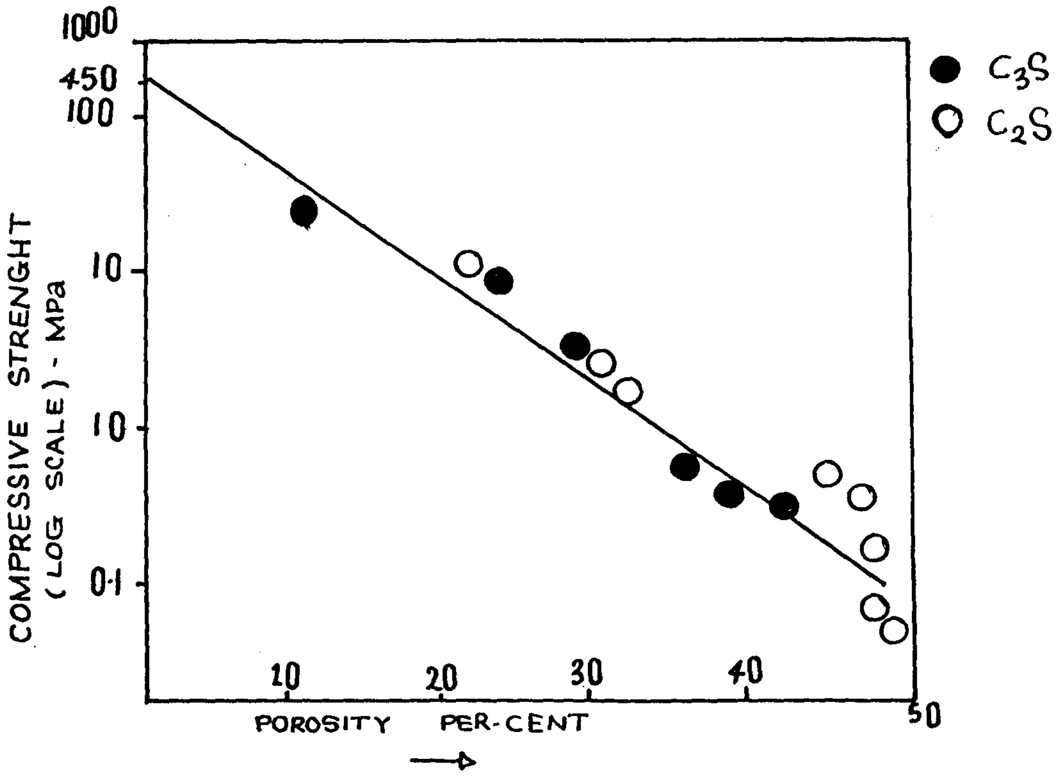


figure 3.1: Relation between compressive strength and porosity of pure cement compound.

At zero porosity t_{10} is taken as 450MPa. [Nielsen et al, 1972]

Assuming Porosity (P) = 0.375

$$f_c = 450 (1 - 0.375)^{2.56}$$

$$= 140.70\text{MPa}$$

It may be recalled that the water/cement ratio determine the porosity of the hardened cement paste at any stage of hydration. At very low value of the water/cement ratio and an extremely high cement content probably above 530kg/m^3 exhibit retrogression of strength when large size aggregate is used. Thus at later ages, in this type of mix, a lower water/cement ratio would not lead to a higher plotted against the logarithm of maturity gives a straight line. It is therefore possible to express strength of concrete at any maturity (S_2) as a percentage of strength of concrete at a known maturity often taken as 19800°ch (Degree F-hour) (35600 °Fh), being the maturity of concrete cured at 18°C (64°F) for 28 days.

3.2 CALCULATING TOTAL VOID CONTENT

Example of an experimental mixture of concrete in percentage by volume is as follows: Taking 100g as basis.

Cement (dry) = 7.8
Fine aggregate = 32.00
Coarse aggregate = 38.50
Water = 19.40
Total = **97.70**

Air content = 100 - 97.70 = 2.3%

The rate of hydration of cement is dependent on the type of cement which influences the degree of hydration achieved at a given age.

The gel pore occupy about 28 per cent of the total volume of gel. The material left after drying in a standard manner being considered as solid is as follows:

Voids are:
Capillary pores = 13.1
Gel pores = 3.3
Air Content = 2.3
TOTAL VOID CONTENT = **18.7** Per cent

for 100g f cement equivalent to 31.8ml
specific gravity dry cement = 3.15
absolute volume of unhydrated cement = $100/_{3.15}$
= 31,8ml
The non evaporable water is 23% = 31,8ml
Solid product of hydration = Volume of anhydrous
\+ (water less 0.254 of the volume of non-evaporable water)
that is:

$$31.8 + 0.23 \times 100\,(1-0.245) = 48.9\text{ml}$$

At this condition characteristic porosity = 28% [Rossler et al, 1985]

Therefore, volume of gel water = $\dfrac{wg}{28.9 + wg}$

when wg = 19.0ml

Volume of hydrated cement = 48.9 + 19.0 = 67.9ml

Porosity = $\frac{wg}{0498x + wg}$ = 0.28...(iii)

If we mix 100g of cement and 30g of water.

Total water = 0,23x + wg = 30 [Copeland et al, 1953]

Volume occupied by solid product of hydration is:

$$= \frac{x}{3.15} + 0.23x - 0.0585x = 0.489x$$

Hence, x = 71.5g = 22.7ml

Therefore wg = 13.5g

Volume of hydrated cement = 0.489 x 71.5 + 13.5

= 48.46ml

Volume of unhydrated cement = 31.8 - 22.7 = 9.1ml

Volume of empty capillary = (31.8 + 30) - (48.5 + 9.1)

= (31.8 + 30) - (48.5 + 9.1) = 4.2ml

$$= \frac{4.2 + (100 \times 0.105)}{48.4926}$$

Total Void: = 0.30

= 0.30 x 100 = 30%

Strength at zero porosity = 450MPa

Therefore, strength (S_3) at 30% porosity = $^{S1}/_{S2}$

S_3 = $450 \times (1 - P)^n$ ....(vii)

Where n = 6 (Coefficient, not necessarily constant) and P = 0.3

Substituting for n and P in equation .... (vii)

S_3 = 52.94 MPa

3.2.1 Plowman's coefficient for the maturity equation strength after 28 days at 18°c maturity of 19800°ch is as presented in Table 3.3

Table 3.3

Plowman's Coefficient for the Maturity Equation			
S/NO.	Strength (MPa)	COEFFICIENT (Units in °Ch B	 A
1.	<17	68	10
2.	17-52	61	21
3.	54	54	32
4.	46.5	46.5	43

[Plowman 1956]

The ratio of strength expressed as a percentage can then be written as:

$^{S1}/_{S2}$ = $A + B \log_{10}$ (Maturity x 10^{-3}) ....(viii)

The valves of A and B are Coefficients depending on water/cement ratio

Where strength at zero porosity = 450 MPa

3.2.1.0 Calculation

(1) $^{S1}/_{S2}$ = $10 + 68 \times \log (19800 \times 10^{-3})$
= $10 + 68 \times 1.3 \times 0.45$
= 49.78 MPa

(2) $^{S1}/_{S2}$ = $21 + 61 \times \log (19800 \times 10^{-3})$
= $21 + 61 \times 1.3 \times 0.45$
= 56.68 MPa

(3) $^{S1}/_{S2}$ = $32 + 54 \times 1.3 \times 0.45$
= 63.59 MPa

(4) $^{S1}/_{S2}$ = $42 + 46.5 \times 1.3 \times 0.45$
= 69.20 MPa

3.2.2 Data

Applying the formula for the calculation of porosity and strength, the following data were generated giving the mass of water to cement ratio ranging from 0.4 to 0.83.

Table 3.3.2

RELATIONSHIP BETWEEN STRENGTH, WATER/CEMENT RATIO AND POROSITY

S/NO	DRY MASS OF CEMENT m_1(g)	MASS OF WATER M_4(g)	$^{M4}/_{M1}$ Ratio	COMPRESSIVE STRENGTH (MPa)	POROSITY (%)
1.	40	16.0	0.40	65.63	24.53
2.	60	25.2	0.42	64.25	24.15
3.	80	34.4	0.43	62.92	23.79
4.	120	54.0	0.45	60.52	23.12
5.	180	84.6	0.47	58.33	22.51
6.	220	107.8	0.49	56.33	21.94
7.	260	132.8	0.51	54.82	21.17
8.	300	159.0	0.53	52.83	20.94
9.	300	220	0.55	51.32	20.50
10.	440	250.8	0.57	49.90	20.08
11.	480	283.3	0.59	48.59	19.70
12.	520	317.2	0.61	47.37	19.33
13.	560	352.8	0.63	46.59	18.80
14.	600	390	0.65	45.19	18.68
15.	640	428.8	0.67	44.20	18.38
16.	700	483.0	0.69	43.28	18.03
17.	740	525.4	0.71	42.41	17.84
18.	780	569	0.73	41.62	17.59
19.	820	615	0.75	41.62	17.35
20.	860	662.2	0.77	40.10	17.12
21.	900	711.0	0.79	39.42	16.91
22.	940	761.4	0.81	38.78	16.71
23.	980	813	0.83	38.59	16.52

CHAPTER FOUR

4.0 DISCUSSION OF RESULT

The graph obtained from the plot of cement/water ratio and porosity both against compressive strength of a concrete in (MPa) showed that permeability which is a function of porosity is governed by the water/cement ratio and the effectiveness of curing. Since porosity decreases with decrease in water/cement ratio, there is reduction in void content of the concrete formed and reduced permeability and consequent increase in compaction thus, in the compressive strength, carbonation of concrete made with type I Portland Cement results in slightly increase strength and a reduced permeability, possibly because water which is released by the decomposition of $Ca(OH)_2$ on carbonation, aid the process of hydration and $CaCo_3$ is deposited in the void within the cement space. The valves obtained from calculation of strength and porosity gave a good agreement when compared with the Plowman's coefficient for the maturity equation of 28 days, 18°c and maturity of 19800°ch. It could be concluded that the diffusivity of Co_2 is a function of the pore system of the hardened cement paste during the period when the diffusion of Co2 takes place which subsequently lead to the formation of $CaCO_3$, carbonation thus neutralizes the alkaline nature of the hydrated cement paste and thus the protection of steel from corrosion is vitiated.

Consequently, if the full depth of cover of reinforcement is carbonated and moisture, oxygen can ingress, the corrosion of the steel and possible cracking will result.

On the graph of porosity against strength of concrete, deviation from linearity of water/cement ratio 0.69 to water/cement ratio 0.83 was recorded. This was due largely to considerable decrease in porosity relative to the mass of water/cement ratio ranging from 0.4 to 0.83 as recorded from historical data over long period of research has been proven to be the safety margin. Strength lower than

30MPa and porosity equal or greater than 60% was observed to have undergone carbonation of 15mm in 5 years. This is hazardous for concrete formation and construction which is liable to crumble within a very short span of time.

FIG. 4.1: GRAPH OF COMPRESSIVE STRENGHT (MPa) AGAINST RATIO OF MASS OF WATER(m4) TO MASS OF DRY CEMENT(m1)

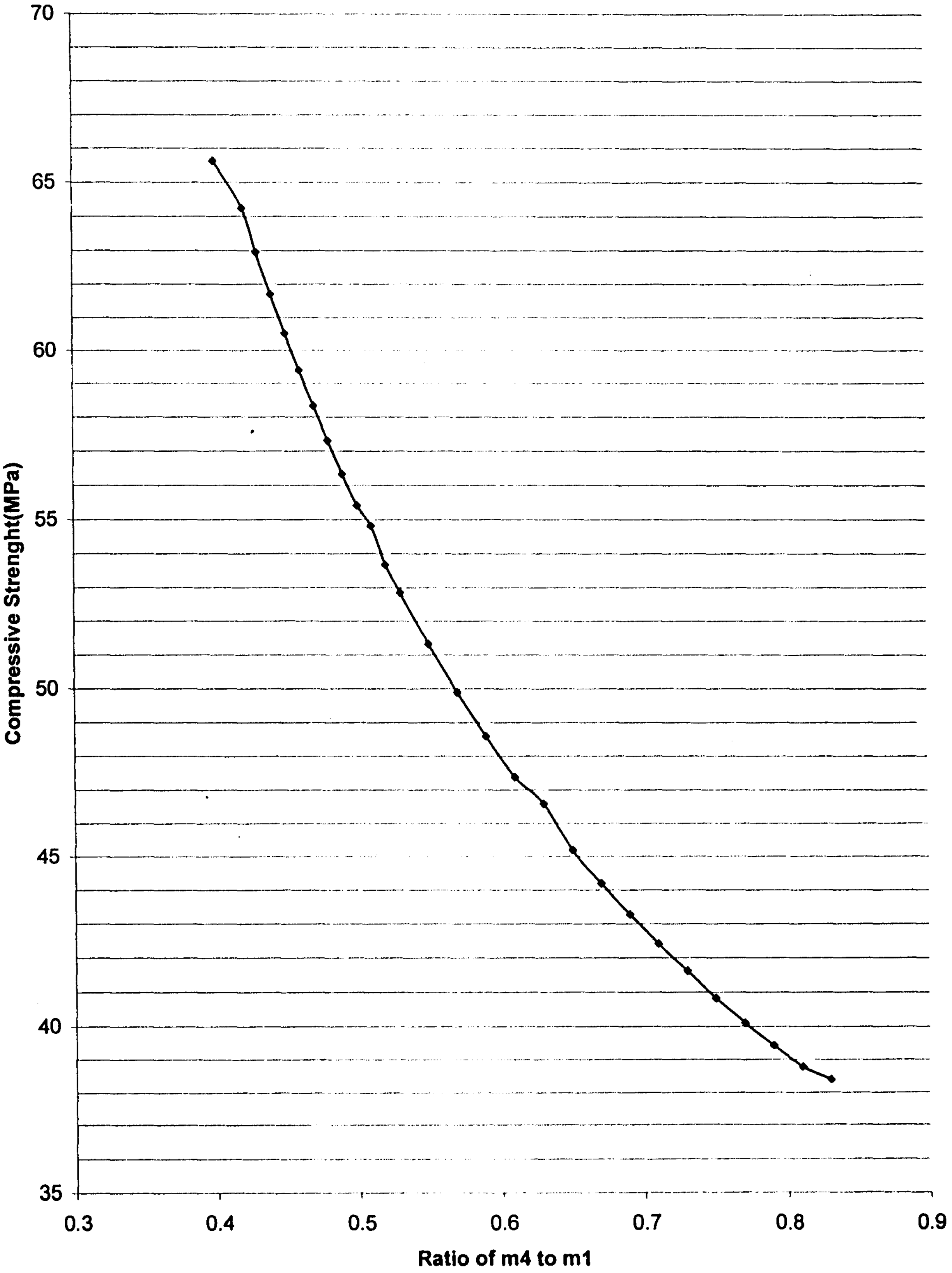
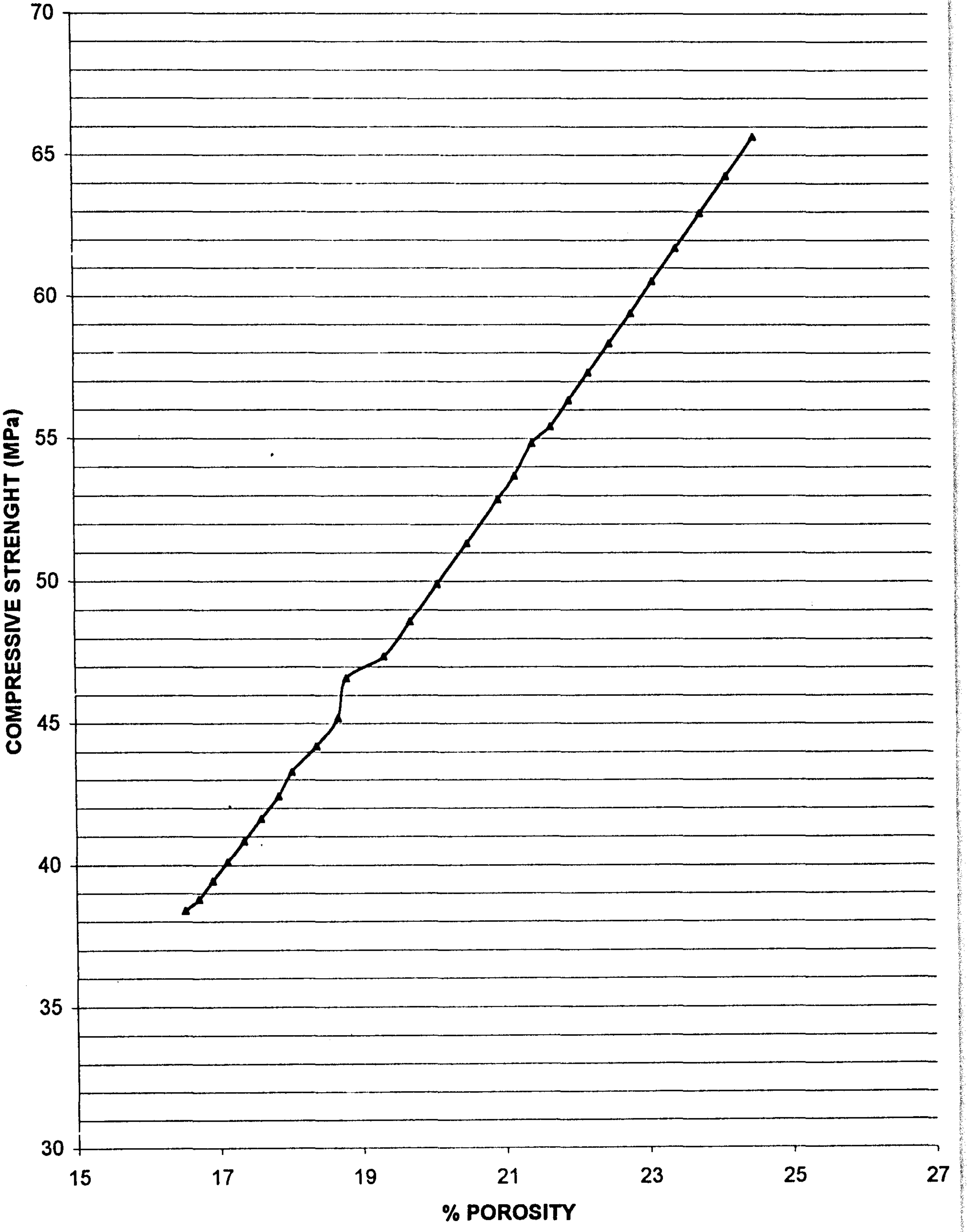


FIG. :GRAPH OF COMPRESSIVE STRENGHT AGAINST
4·2 % POROSITY



CHAPTER FOUR

5.0 CONCLUSION

Compressive strength of concrete was found to increase with decrease in porosity and a corresponding decrease in the depth of carbonation. The modified model equation of a hazard warning structure upon which the basic programme software was developed for the above named parameters gave a good agreement with the expected values obtained from both historic and analytical data for the risk quantification methods.

However, no single method of hazard identification is suitable for the analysis of an existing concrete structure, this is because:

(i) A full risk analysis of a concrete structure requires considerable time and is expensive.

(ii) The extent to which risk analysis techniques are used by a company will depend on its structural and management philosophy as well as upon the legislative requirement in the country concerned.

5.1 RECOMMENDATION

Successful hazard identifications depends upon having documentation to review which truly reflects the way the concrete will be built are operated. The quality of the hazard study is improved by having the designer present his design to the Hazard Identification (HAZID) study team. The report of the hazard identification study should not attempt to convey an impression of the thoroughness of the survey by listing how each hazard was identified but should adequately describe how each was controlled. For further studies on the safety analysis on concrete structure, detail experimental analysis should be carried out on other factors upon which the strength of concrete structures are dependent such as alkali silica reaction, sulphate attack, ettringite formation, acid attack wet and dry season changes, corrosion test and morphology of minerals. A programme software interrelating each of the aforementioned factors should be developed using, for example, advanced programming language (C^{++}) for better characterization and simulation of a concrete model from conceptual stage to the operational stage.

REFERENCES

1] Jeffery G.H. Bassel, Meddham J., Denney, R.C., Rogel's Textbook of Quantitative Chemical Analysis, Longman Scientific and Technical, 5th Edition (1989).

2] Odigore J. O., Safety, Loss and Pollution Prevention in Chemical Process Industries 1-5, 65 - 88 (1995).

3] Neville, A.M. Properties of Concrete, Fourth Edition, 1-40, 269-311, 412-448, 482-521 (1994)

4] Alain V. Reliability, Availability, Maintainability and Safety Assessment Volume 2, 461-498, 504-514, 605-620 (1992)

5] Neville A. M., Chatterton M. New Concrete Technology and Building Design 19-24, 129-130 (1979)

6] Airapto D. Architectural Material Science 187-192 (1983).

7] Neville A. M., Brooks J. J. Concrete Technology. 98-121, 368-369 (1994).

8] Cox A. P., Pasman H. J. Shell International.

9] Meyer A., Investigation on the Carbonation of concrete pg. 394-401 (1968)

10] Smolczyk H.G., Neutralization of concrete and corrosion of reinforcing steel pp. 134-170 (1968)

(i)

APPENDIX

```
  DIM k(40)
  PRINT "PROGRAMM WRITTEN BY MUSTAFA. W . A . REG.No: 93/3633  "

PRINT "ON;SAFETY  ANALYSIS OF THE EFFECT OF CARBONATION ON
CONCRETE STRUCTURE"
PRINT "ALL RIGTHS RESERVE,1999.@  "

10 PRINT "programm to predict the"

20 PRINT "depth of carbonation"

30 PRINT "strength of concrete(S)"

40 PRINT

50 INPUT "total no of years =?", n

60 INPUT "critical coefficient (mm/year) =?", Q1

70 FOR I = 1 TO n

80 PRINT "enter coefficient for year", I

90 INPUT k(I)

00  NEXT I

  REM calculate the mean & standard deviation

  LET A = 0

  FOR I = 1 TO n

  LET A = A + k(I)

  NEXT I

  LET y = A / n

  LET A = 0

  FOR I = 1 TO n

  LET L = k(I) - y

  LET w = A + (L ^ 2)
```

```
    NEXT I

    LET x = SQR(w / n)

    LET k2 = y + x

    PRINT "actual coefficient (mm/year) = ", k2

    t = n
     LET D1 = k2 * SQR(t)
     PRINT "D1 actual depth(mm) =", D1
     LET D2 = Q1 * SQR(t)
     PRINT "D2 critical depth(mm) =", D2
    IF D1 > D2 THEN

     PRINT "CAUTION!! DEPTH OF CARBONATION ABOVE CRITICAL "
   END IF
REM calculate porosity and strength
270 INPUT "dry mass of cement =?", M1

     INPUT "fine aggregate =", V2

    INPUT "coarse aggregate  =", V3

     INPUT "water mass =?", M4

     PRINT "non evaporable water=23%"
        V1 = M1 / 3.15
        M11 = M4 * 2.38
        V2 = M11 * .318
        V3 = M4 - (.23 * M11)
        V4 = (.489 * M11) + V3
        V5 = V1 - V2

       p = (((V1 + M4) - (V4 + V5)) + (M1 * .105)) / V4

     PRINT "p=", p

     PRINT "porosity=p", p
     p1 = p * 100
     PRINT "porosity in(%)=p1", p1

     PRINT "STRENGTH AT ZERO POROSITY =450(Mpa)"


     s1 = (450 * (p ^ 1.37))
```

```
    PRINT "STRENGTH IN (Mpa)=S1", s1

    LET z = M4 / M1

IF (z < .4) OR (z > .833) THEN
    PRINT "DANGER !! CHECK CEMENT /WATER (M1/M4) DUE FOR CHECK"
    GOTO 270
    END IF
    IF (z > .4) OR (z < .833) THEN
    PRINT "z ="; z
    GOTO 300
   END IF
300 IF (s1 < 16) THEN 305
    IF (s1 > 16) AND (s1 < 35) THEN 306
    IF (s1 > 35) AND (s1 < 52) THEN 307
    IF (s1 > 52) AND (s1 < 69) THEN 308
    IF (s1 > 69) THEN 310
    IF p = .6 AND s1 <= 30 THEN 309
305 A = 10: B = 68: GOTO 450
306 A = 21: B = 61: GOTO 450
307 A = 32: B = 54: GOTO 450
308 A = 42: B = 46.5: GOTO 450
309 PRINT "DEPTH OF CARBONATION  >=15mm"
310 PRINT "MATURITY AT 18(DEG) & 28 DAYS = 19.8"
400   INPUT "MATURITY AT STRENGTH S2=", A1
402   PRINT "STRENGTH IN (MPa) = S1", s1
            IF A1 < 0 THEN 400
                  M3 = 19.8
                  M4 = M3 + A1
                  S5 = M3 + 3 * (LOG(M4) + LOG(M3))
                  S6 = S5 * 4.5
                 PRINT "STRENGTH (WHEN S2 IS GIVEN)  IN MpA=", S6
                END

450  S3 = (A + (B * 1.3) * .45)
   PRINT "STRENGTH IN MPa=S3 ", S3
   GOTO 270
   END
```

Table II

Typical Valves of Depth of Carbonation for Various Concretes and Ages [Smolczky 1968]		
Depth of Carbonation,mm	Age (Years)	
	20 MPa Concrete	40 MPa Concrete
5	$^{1}/_{2}$	4
10	2	16
15	4	36
20	7	64

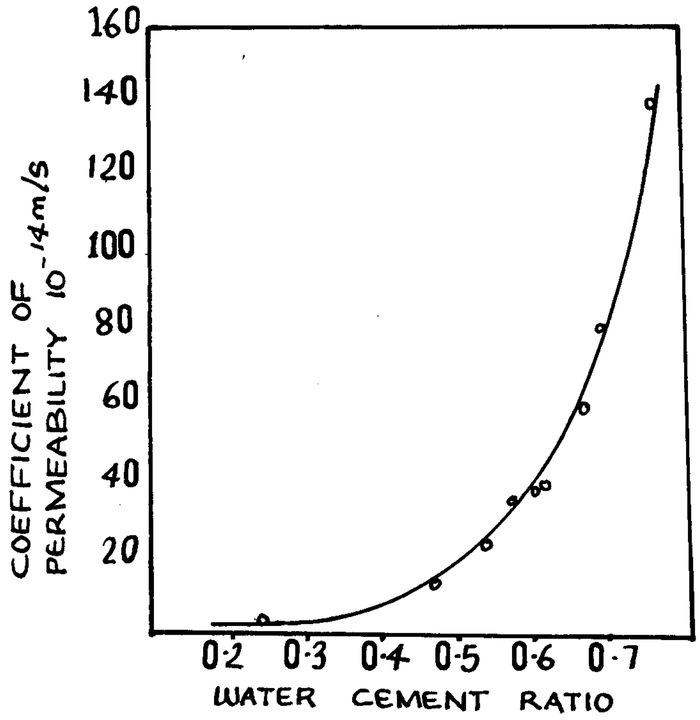
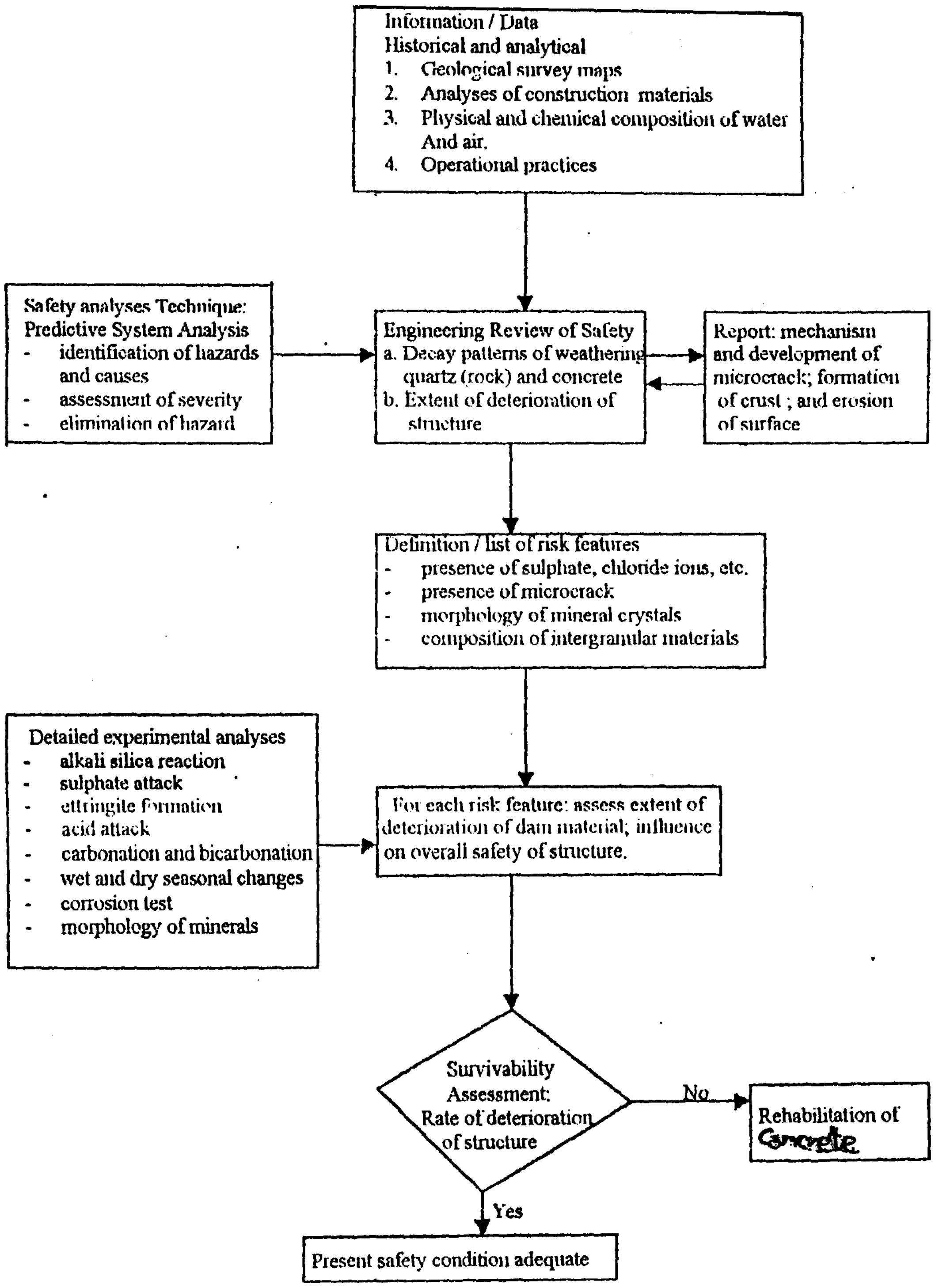


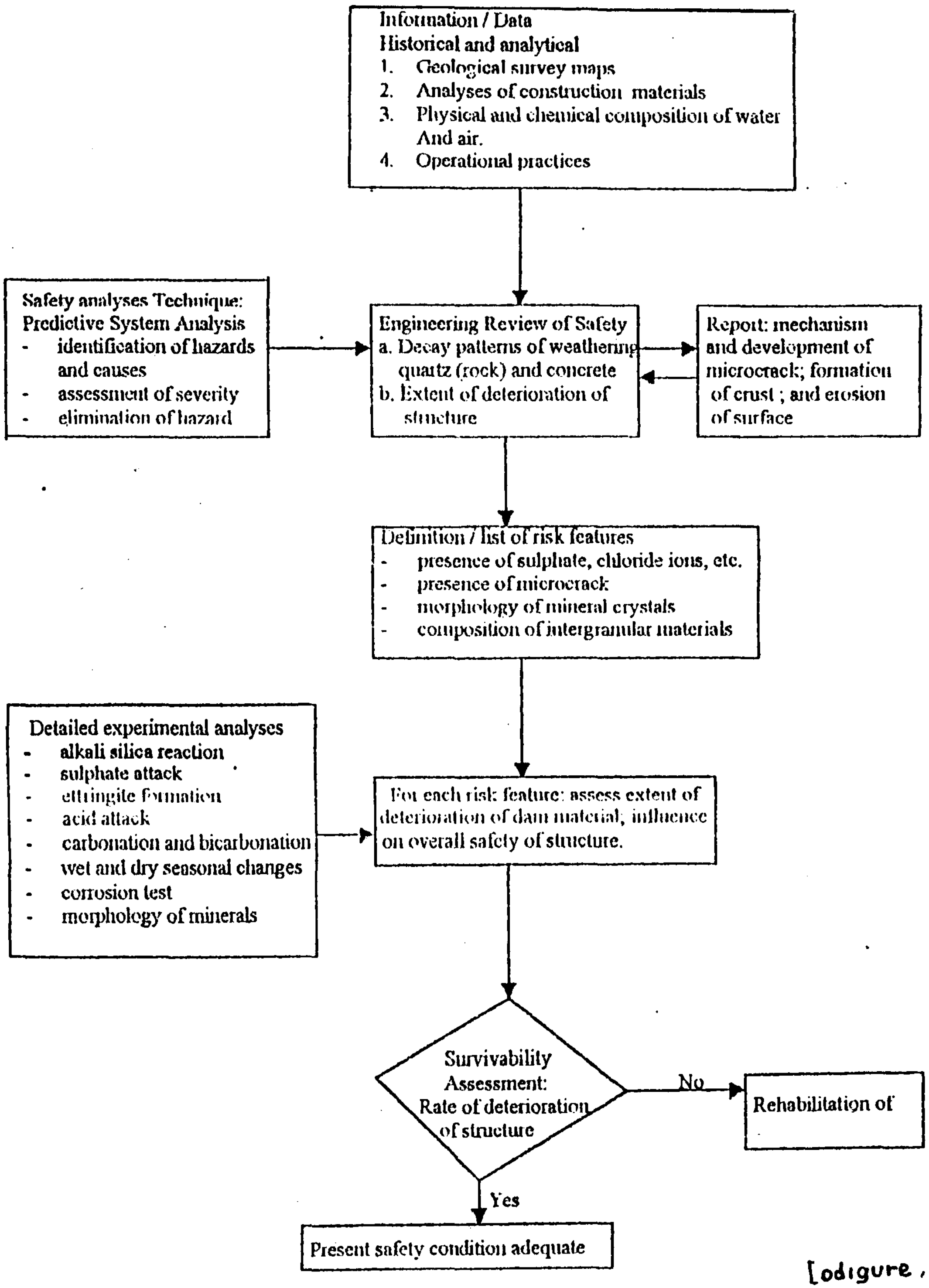
FIGURE II : RELATIONSHIP BETWEEN COEFFICIENT OF PERMEABILITY AND WATER/CEMENT RATIO.

Figure (iii)



Safety Analysis Procedure for Concrete Construction Material

Figure (iii)



[odigure, 1998]

Safety Analysis Procedure for Concrete Construction Material