EXPERIMENTAL INVESTIGATION AND PREDICTION OF FLY ASH EFFICIENCY FACTOR IN CONCRETE WITH COST ECONOMIC ANALYSIS

Submitted in partial fulfilment of the requirements

for the degree of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(With specialization in Construction Engineering and Management)

by

Afroz Naeem Khan

(Registration Number: Anjuman-24)

Under the guidance of

Dr. R. B. Magar

Department of Civil Engineering
School of Engineering and Technology
Anjuman-I-Islam's Kalsekar Technical Campus
New Panvel, Navi Mumbai-410206

2017

A Dissertation Report on

EXPERIMENTAL INVESTIGATION AND PREDICTION OF FLY ASH EFFICIENCY FACTOR IN CONCRETE WITH COST ECONOMIC ANALYSIS

Submitted in partial fulfilment of the requirements

for the degree of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(With specialization in Construction Engineering and Management)

by

Afroz Naeem Khan

(Registration Number: Anjuman-24)

Under the guidance of

Dr. R. B. Magar

Department of Civil Engineering

School of Engineering and Technology

Anjuman-I-Islam's Kalsekar Technical Campus

New Panvel, Navi Mumbai-410206

2017

CERTIFICATE

This is to certify that the project entitled **"Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis"** is a bonafide work **of Mr. Afroz Naeem Khan (15CEM07)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Master of Engineering" in "Civil Engineering (With Specialization in Construction Engineering and Management)"

Dr. R. B. Magar	**Dr. Abdul Razak Honnutagi**
(Guide and Head of Department)	(Director, AIKTC)

APPROVAL SHEET

This dissertation report entitled "Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis" by Afroz Naeem Khan is approved for the degree of "Civil Engineering with Specialization in Construction Engineering and Management"

Examiners

1. ……………………………

2. ……………………………

Supervisors:

1. ……………………………

2. ……………………………

Date:

Place: Panvel

DECLARATION

I declare that this written submission represents my ideas in our own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Afroz Naeem Khan
(15CEM07)

Date:

ABSTRACT

The use of supplementary cementitious materials (SCMs) is ever increasing due to technical, economical and environmental benefits. SCMs are most commonly used in producing ready-mixed concrete (RMC). Hence, a quantitative understanding of the efficiency of SCMs as a mineral admixture in concrete is essential for its efficient utilisation. The effective use of SCMs and its performance in concrete is decided by estimating efficiency factor. A practical and generally accepted approach to evaluate the contribution of SCMs to the strength of the hardened concrete is through the concept of the efficiency factor (i.e. k- value concept), which expresses the fraction of portland cement that can be replaced by a SCM at unchanged strength. This study explains an experimental work, based on the compressive strength results of fly ash (FA) at various replacement levels ranging from 20% to 35%, an efficiency factor has been calculated using Bolomey's Law. In this study, efficiency factor is experimentally calculated by using 217 trails from each mix of M40, M35, M30, M25 and M20. Further, in order to predict the efficiency factor, multi-linear regression (MLR) models has been developed for five mixes, based on wide range of mix proportions and a number of parameters such as, ordinary portland cement (OPC), FA, admixture and W/C. The models generated through MLR, provides a tool to predict efficiency factor (k) and capture the effects of different parameters in concrete behaviour. Further, comparison of MLR results has been made using Artificial neural network (ANN) which shows a good correlation between actual and predicted efficiency factor of fly ash concrete.

Keywords— Efficiency Factor, Fly Ash, Supplementary Cementitious Materials, Regression Analysis; Artificial Neural Network.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION NOTATION AND NOMENCLATURE

SCM	Supplementary cementitious material
OPC	Ordinary Portland cement
FA	Fly ash
HVFA	High volume fly ash
GGBS	Ground granulated blast furnace slag
W	Water
SP	Super plasticizer
CA	Coarse aggregate
FA	Fine aggregate
PR	Pozzolanic reaction
CHR	Cement hydration rate
ANN	Artificial neural network
MLR	Multi-linear regression
MATLAB	Matrix Laboratory
DOE	Department of environment
w/c	Water to cement ratio
c/w	Cement to water ratio
f/w	Fly ash to water ratio
k	Efficiency factor

Chapter 1

Introduction

1.1 General

Supplementary cementitious materials (SCMs) may be divided into natural materials and artificial ones. To the former belong true pozzolan and volcanic tuffs. To the second category belong siliceous by-products, such as fly ashes, condensed silica fume and metallurgical slags (blast furnace slag, steel slag and nonferrous slags). Fly ash is the combustion residue (coal mineral impurities) in coal-burning electric power plants, which flies out with the flue gas stream and is collected by mechanical separators, electrostatic precipitators or bag filters. Condensed silica fume, sometimes known simply as silica fume or micro silica, is produced by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. Slags are by-products of metallurgical furnaces producing pig iron, steel, copper, nickel and lead. According to ASTM C 595, a pozzolan is defined as ‘‘a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties (pozzolanic activity).’’ Thus, a pozzolanic material requires $Ca(OH)_2$ in order to form strength products, whereas a cementitious material itself contains quantities of CaO and can exhibit a self-cementitious (hydraulic) activity. Usually, the CaO content of the latter material is insufficient to react with all the pozzolanic compounds. Thus, it also exhibits pozzolanic activity (pozzolanic and cementitious materials). However, all these materials are often used in combination with Portland cement, which contains the essential for their activation, $Ca(OH)_2$ from its hydration.

A quantitative understanding of the efficiency of fly ash as a mineral admixture in concrete is essential for its effective utilisation. Research efforts in the past have not been successful in quantifying this efficiency because of the numerous variables involved, both in terms of the characteristics of fly ash and cement as well as the parameters influencing the concrete mix design itself. Initially, the use of fly ash started as direct replacement of cement in concrete, which is still advocated by a few. Later efforts towards an effective utilization led to rational methods of incorporating fly ash in concrete, considering the fact that the two concretes (with or without fly ash) can be made to reach the same strength at a given age by adjusting the water cementitious materials ratios. This was done either by adjusting the quantity of fly ash introduced for replacing the cement or through the “cementing efficiency factor” of fly ash.

In general, it was observed that fly ash exhibits very little cementing efficiency at the early ages and acts rather like fine aggregate (filler), but at later ages the pozzolanic property becomes effective leading to a considerable strength improvement. This obviously means that the cementing efficiency of fly ash improves with age due to the pozzolanic reaction. It is also observed that that cementing efficiency of fly ash depends on many of its characteristic-physical properties like particle shape, size and distribution, chemical properties like composition, glass content etc. other parameters related to cement and the ones effecting mix proportioning can also influence the resulting concrete behaviour significantly. Several investigators reported the effect of fly ash in concrete through a comparison of the compressive strength of fly ash concretes with the normal concretes. The variation of strength with age was also discussed by a few. In spite of all these investigations, it is felt that there is a lack of quantitative understanding of the behaviour of fly ash in concrete.

1.2 Fly ash in concrete

The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons per year and its percentage utilization is less than 10%. The use of fly ash in concrete has gained significant attention over the recent years due to environmental concerns regarding its disposal from one hand and significant benefits to concrete on the other, when it is used as a supplementary cementitious material. Fly ash is widely used as a pozzolanic supplementary cementitious material in different concrete applications. Also recent environmental policies and regulations concerning the disposal of by products have necessitated the use of fly ash in concrete. During the last few years, some cement companies have started using fly ash

in manufacturing cement, known as "Pozzolona Portland Cement", but the overall percentage utilization remains very low and most of the fly ash are dumped as landfills (Siddique 2003). Class C Fly ash is high lime ash originating from lignite coal. It may occasionally have a lime content of 24 percent. High lime ash has some cementitious properties of its own (Neville 1995).

1.3 High volume fly ash concrete

High volume fly ash (HVFA) concrete uses high volumes of fly ash to replace the portland cement content. Replacement levels as high as 60% has been reported to be successful (Hardjito and Rangan, 2005). HVFA concrete has been proven to be more durable and resource-efficient than the OPC concrete (Malhotra, 2002). The HVFA technology has been practised in the field, for example the construction of roads in India has implemented 50% OPC replacement by the fly ash (Desai, 2004). The use of fly ash can improve workability, easier flow-ability, pump-ability, compact-ability. Further the use of fly ash can reduce the heat of hydration and increase the resistance to sulphate attack, alkali-silica reactivity and other types of deterioration as compared to normal mixes (Solis *et al.* 2010). HVFA concrete has very high durability to the reinforcement corrosion, alkali-silica expansion, sulphate attack and have superior dimensional stability and resistance to cracking from thermal shrinkage, autogenous shrinkage and drying shrinkage (Mehta, 2004). High volume fly ash concrete has better surface finish and quicker finishing time when power finish is not required (Mehta, 2004). It has slower setting time and will have a corresponding effect on the joint cutting and lower power-finishing times for slabs. HVFA concrete has much higher electrical resistivity and resistance to chloride ion penetration after three to six months of curing according to ASTM Method C1202 (Mehta 2004). HVFA concrete has better cost economy due to lower material cost and highly favourable lifecycle cost (Solis *et al.* 2010; Mehta, 2004). These concrete have superior environmental friendliness due to ecological disposal of large quantities of fly ash, reduced carbon-dioxide emissions and enhancement of resource productivity of the concrete construction industry (Mehta, 2004).

1.4 Efficiency factor of SCMs in concrete

Supplementary cementitious materials (SCMs), such as fly ash, pozzolan or blast furnace slag, are widely used to produce blended portland cements, since they lead to a significant reduction in CO_2 emission in the production phase compared to portland cement. A practical and generally accepted approach to evaluate the contribution of SCMs to the strength of the hardened concrete is through the concept of the SCMs efficiency factor (i.e. $k -$ value concept), which expresses the fraction of portland cement that can be replaced by a SCM at unchanged strength.

The Bolomey's empirical expression frequently used to predict the strength of concrete is theoretically well founded when applied to hardened concrete. Efficiency factors found from this strength equation are used to describe the effect of the SCMs replacement. Efficiency factors are generally used to describe the impact of SCMs replacements on the compressive strength of Concrete mixes. The Bolomey's strength equation is:

$$S = A\left[\frac{c}{w}\right] + B \quad (1)$$

S is compressive strength in MPa,

c is cement content in kg /m^3, and

w is water content in kg/m^3.

This factor describes the mineral admixture's ability to act as cementing material recognizing that mineral admixture's contribution to concrete strength which comes mainly from its ability to react with free calcium hydroxide produced during cement hydration. The rate of this reaction, called as pozzolanic reaction (PR), when compared to cement hydration rate (CHR) determines the value of k.

When $k = 1$, both PR and CHR would be same and the water-binder ratios of concretes with and without mineral admixture could be almost same.

When $k < 1$, PR would be slower than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture need to be less than that of concrete without mineral admixture and also, at same water-binder ratio, the strength of concrete with mineral admixture would be less than that of concrete without mineral admixture. In this case, the mineral admixture is less efficient than Portland cement in imparting strength to concrete. The GGBS has generally $k < 1$ at early ages and k would reach a value of unity at later ages.

When $k > 1$, PR would be faster than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture would to be more than that of concrete without mineral admixture. However, at similar water-binder ratios, the strength of concrete with mineral admixture would be more than that of concrete without mineral admixture. In this case, the mineral admixture is more efficient than Portland cement in imparting strength to concrete.

1.5 Multi-linear regression (MLR)

MLR is the simplest and a well-developed representation of a casual, time invariant relationship between an input function of time and corresponding output function (Chau *et al.* 2005). Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. MLR attempts to model the relationship between two or more independent variables and dependent variables by fitting a linear regression equation to observed data. If it is assumed that the dependent variable Y is affected by m independent variables X_1, X_2,…., X_m and a linear equation is selected for the relation among them, the regression equation of Y (Eq. 2) can be written as:

$$y = a + b_1x_1 + b_2x_2 + \cdots + b_mx_m \tag{2}$$

"y" In this equation shows the expected value of the variable Y when the independent variables take the values; $X_1 = x_1$, $X_2 = x_2$,…., $X_m = x_m$.

The regression coefficients as shown in Eq. 3. Here, a, b_1, b_2,….,b_m are evaluated, similar to simple regression, by minimizing the sum of the e_{yi} distances of observation points from the plane expressed by the regression equation (Bayazit and Oguz, 1998).

$$\sum_{i=1}^{N} e_{yi}^2 = \sum_{i=1}^{N}(y_i - a - b_1x_{1i} - b_2x_{2i} - b_mx_{mi})^2 \tag{3}$$

In this study, the coefficients a, b_1, b_2,…., b_m are determined using least squares method.

1.6 Artificial neural network (ANN)

The study of neural networks started by the publication of McCulloch and Pitts (1943). The single layer networks, with threshold activation functions, were introduced by Rosenblatt (1962). These types of networks were called perceptron. In the 1960s it was experimentally shown that perceptron could solve many problems, but many problems which did not seem to be more difficult could not be solved. These limitations of one-layer perceptron were mathematically shown by Minsky and Papert in their book Perceptron. The result of this publication was that the neural networks lost their interestingness for almost two decades. In the mid-1980s, back-propagation algorithm was reported by Rumelhart, Hinton, and Williams (1986), which revived the study of neural networks. The significance of this new algorithm was that multilayer networks could be trained by using it. Neural network makes an attempt to simulate human brain. The simulating is based on the present knowledge of brain function, and this knowledge is even at its best primitive. So, it is not absolutely wrong to claim that artificial neural networks probably have no close relationship to operation of human brains. The operation of brain is believed to be based on simple basic elements called neurons which are connected to each other with transmission lines called axons and receptive lines called dendrites (see Fig. 1.1.). The learning may be based on two mechanisms: the creation of new connections, and the modification of connections. Each neuron has an activation level which, in contrast to Boolean logic, ranges between some minimum and maximum value.

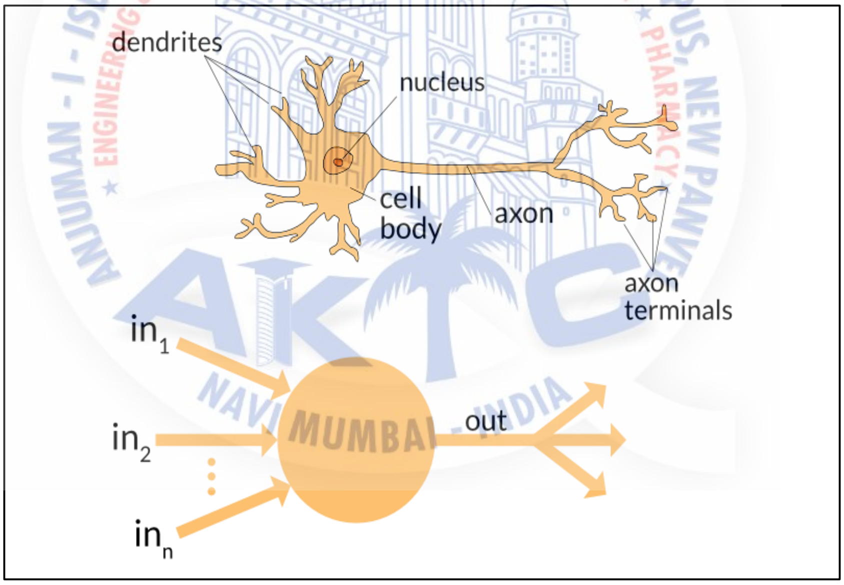

Figure 1.1 Simple illustration of biological and artificial neuron (Haykin, 1994)

In artificial neural networks the inputs of the neuron are combined in a linear way with different weights. The result of this combination is then fed into a non-linear activation unit (activation function), which can in its simplest form be a threshold unit. Neural networks are often used to enhance and optimize fuzzy logic based systems, e.g., by giving them a learning ability. This learning ability is achieved by presenting a training set of different examples to the network and using learning algorithm which changes the weights (or the parameters of activation functions) in such a way that the network will reproduce a correct output with the correct input values. The difficulty is how to guarantee generalization and to determine when the network is sufficiently trained. Neural networks offer nonlinearity, input-output mapping, adaptivity and fault tolerance. Nonlinearity is a desired property if the generator of input signal is inherently nonlinear (Haykin, 1994). The high connectivity of the network ensures that the influence of errors in a few terms will be minor, which ideally gives a high fault tolerance.

1.7 Motivation of the present study

Concrete is being widely used as a construction material, hence it is necessary to improve its properties. These days' supplementary cementitious materials are used for enhancement of concrete properties. Use of SCMs is gaining importance due to its vital characteristics, these materials help in developing high performance concrete (Babu and Rao, 1993). This study aims at determining efficiency factor 'k' for SCMs. The efficiency factor helps in economic mix design of supplementary cementitious materials.

1.8 Scope of the study

Today, supplementary cementitious materials (SCMs) are widely used in concrete either in blended cements or added separately in the concrete mixer. The significance of this investigation is to determine efficiency of SCMs (*k*-factor) which describes the efficiency of SCMs to act as a cementing material. When $k>1$, it indicates the SCM used is more efficient than cement, as hydration process is fast compared to OPC. In such a case saving of cement is possible resulting economic mix design of concrete. When $k<1$, it indicates the SCM used is less efficient than cement as hydration process is slow compared to OPC. In such a case more quantity of SCM should be used to achieve required target strength. Currently, there is no specific mixture proportioning method available to design SCM concrete for a desired strength and workability. In this study, the efficiency of SCMs with regard to compressive strength and workability in concrete was investigated using MLR and ANN approach.

1.9 Objective of the study

Today Supplementary cementitious materials or by products and mineral additives such as Fly Ash, GGBS, Micro Silica, Rice Husk Ash and natural pozzolans etc. are frequently used in the production of High performance concrete as well as high strength concrete. But to know the efficiency and optimum dosage of SCMs, it is desirable to know the efficiency factor which is a part of supplementary cementitious material in the SCM concrete which can be considered as equivalent to portland cement. The primary aim of this investigation is to find out efficiency factor of SCMs. More specifically, the research had the following objectives:

1. To save the resources used in concrete like cement and aggregates. Reduction in cement will help to reduce the pollution and make concrete environmental friendly.
2. To produce durable and economical concrete mix design.
3. To predict the Efficiency factor of SCMs at different levels of replacements using soft computing techniques.
4. To investigate the effects of various replacement levels of SCMs on compressive strength and workability of concrete.
5. To develop efficiency factor model which, could be helpful in the design of SCM concretes at different age, at different level of replacement, and different water-binder ratio with greater confidence.
6. Efficiency factor model can be used as a tool for a more efficient proportioning of blended concrete.

1.10 Organization of dissertation

This dissertation has been arranged in five chapters. A brief description of each chapter is given below.

Chapter 1 provides the importance of replacement of cement with fly ash. It provides brief introduction of high volume fly ash concrete. The importance of the present study is described. Objectives of this research work and the scopes of the present study have been explained in this chapter.

Chapter 2 provides a detailed review of literature in three phases about the efficiency factor of concrete which is based on mechanical properties of concrete, durability of concrete, statistical analyses, life and strength prediction studies using Artificial Neural Networks (ANNs).

Chapter 3 presents the overall methodology followed in this work, materials used with specifications. A flow chart explaining the various events such as experiments on fresh and hardened concrete, statistical analyses and life prediction analysis etc., are furnished in this chapter.

Chapter 4 presents the detailed discussions of the results of efficiency factor, based on replacement of fly ash concrete, statistical analyses of efficiency factor depends on various parameters, applications of ANN and validation of the models developed.

Chapter 5 describes the summary and conclusions of Bolomey's empirical equation, efficiency factor at different replacement levels, MLR and ANN comparisons. It also describes the cost economic analysis and future scope of the project.

Chapter 2

Literature Review

2.1 General

The work done by the various investigators is referred and summarized here in this chapter. The referred journal and conference papers and reports are presented in the following three phases;

- Phase-I Efficiency Factor
- Phase-II Efficiency factor of SCMs in concrete
- Phase-III Application of Soft Computing Techniques

At the end, the research gaps have been reviewed from each of the above three phases.

2.2 Phase-I Efficiency factor

The coefficient ‘χ’ thus represents a measurement of the relative performance of the mineral additives compared to portland cement. The evaluation of this factor can be carried out using various approaches. The mixture “cement + additive” is replaced by the equivalent binder, which introduces the activity index into the evaluation of the efficiency factor (Lawrence, 2000). An earlier study was carried out by Smith (1967) who was one of the first to define 'χ' for an additive with the aim of proposing a rational approach in the mixture proportioning of concrete containing fly ash. Smith (1967) determined 'χ' based on the relation between concrete compressive strength and the water cement ratio (w/c) and obtained the efficiency of fly ash using Eq. (4).

$$\frac{w}{c_o} = \left(\frac{w}{c+\chi F}\right) \tag{4}$$

where 'χ' is the efficiency factor, c_o is the cement content of normal concrete, C is the cement content of the equivalent binder, and F is the fly ash content in a concrete of equal strength.

In recent years' variety of blending materials are more widely used to improve the performance of cement concrete (Hongxia, 2012). The efficiency factor for Silica fume and Metakoline replaced concrete mixes shows increasing trend as the replacement level is increased up to 10%, whereas fly ash replaced mixes shows decreasing trend (Malathy and Subramanian, 2007). Sinha (2014), Using the k-value, an attempt for the design for the fly ash concrete with different percentages of fly ash replacement is made. Author has observed that by using the k value, there is no need to accept the loss of early strength at different replacement levels.

A remarkable contribution towards a sustainable development of the cement and concrete industries can be achieved by the utilization of cementitious and pozzolanic by-products, such as fly ash (FA) and ground granulated blast furnace slag (GGBS), produced by thermal power plants and metallurgical industries, or natural pozzolanic additions (PZ) as well as limestone, (Aïtcin 2011; Thomas 2013). The use of such supplementary cementitious materials (SCMs) leads to a significant reduction in CO_2 emissions per mass of concrete and, for some additions, it also allows to utilize by-products of industrial manufacturing processes.

Lollini *et al.* (2016) practical and generally accepted approach to evaluate the contribution of SCMs to the strength of the hardened concrete is through the concept of the SCMs efficiency factor (i.e. k-value concept), which expresses the fraction of portland cement that can be replaced by a SCM at unchanged strength. There are many methods for designing or predicting the behaviours of fly ash in mortar and concrete (Hwang and Hsieh, 2007; Chakraverty *et al.* 2008; Rukzon and Chindaprasirt, 2008). One specific method for strength predicting is known as the fly ash cementing efficiency factor concept proposed by Smith (1967). The efficiency factor (k) is defined as a number representing a part of the fly ash in concrete mixture which can be considered as equivalent to Portland cement. The equivalent fly ash produces concrete with the same properties as the concrete without fly ash (Ganesh Babu and Siva Nageswara Rao, 1996; Papadakis and Tsimas, 2002). Many researchers in this field have considered the efficiency factor of various type of fly ash and others pozzolan. The BS EN 206 (2000) recommends that fly ash can be introduced as a pozzolanic addition in designed concrete mixture with an equivalent k = 0.2 or 0.4 depending on the cement class. Papadakis and Tsimas, (2002) and Papakadis *et al.* (2002) studied the efficiency factor of supplementary cementitious materials (SCM) such as silica fume, fly ash, slag, and natural pozzolan and reported that these values were valid for a content of SCM in concrete and depended on the concerned properties such as strength and durability. Oner *et al.* (2005) investigated the efficiency and the maximum Class F fly ash content for maximum compressive strength using Bolomey and Feret strength equation and showed that the optimum fly ash was about 40% of cement and fly ash/ cement ratio was an important factor determining the efficiency of fly ash.

2.3 Phase-II Efficiency factor of SCMs in concrete

The concept of an efficiency factor may be applied for comparing the relative performance of various SCMs (silica fume, fly ash, slag, natural pozzolans, etc.) as regards to portland cement. The efficiency factor (k-value) is defined as the part of the SCM in an SCM concrete, which can be considered as equivalent to portland cement.

Papadakis and Tsimas (2002) calculated the efficiency factors for various SCMs and summarized in tabular form. These values are valid for a certain amount of SCM in concrete and they are different depending on the property that it concerns (compressive strength at various ages, chloride resistance and carbonation resistance).

Sata *et al.* (2011) used modified Bolomey's law with linear relationship, for the analysis of the result of compressive strength of concrete, cement to water ratio (c/w), and fly ash to water ratio (f/w), author also uses the multilinear regression to determine the k-factor and other constants in the equations. Quantification of the contribution of fly ash in concrete has been under study for many years and a brief review of some of the important works is presented below.

Ho and Lewis (1985) have observed that the 'k' value of fly ash with respect to 28-day compressive strength varies over a wide range depending on the amount of fly ash added, type of cement, incorporation of chemical admixture and the particular strength level chosen.

Gopalan and Haque (1989) have reported that the efficiency factor depends on the quantity of fly ash in the mix. Fraay *et al.* (1989) have reported that the reaction of fly ash in concrete is only initiated after one or more weeks and during this incubation period; the fly ash behaves more or less as an inert material. Hence, the efficiency values of fly ash can be very low or even negative at early ages.

Bijen and Selst (1993) have reported that the contribution of fly ash to concrete strength is strongly dependent on the water cement (w/c) ratio, type of cement and fly ash and age of concrete.

Babu and Rao (1996) have reported that the overall efficiency factor of fly ash (k) is the combination of general efficiency factor (ke) depending on age and an additional percentage efficiency factor (kp) depending on replacement percentage. It has been reported that the overall efficiency factor (k = ke + kp) varies from 1.25 to 0.35. The authors have inferred that the efficiency of fly ash increases with decrease in w/c, whereas it decreases with increase in replacement percentages.

Babu and Rao (1993) have reported that k value has been suggested as 0.25 for replacements up to 25 %, German standards recommend a value of 0.3 for replacements between 10 and 25 %, British code refers to a value of 0.4 for replacements up to 25 %, CEBFIP model code proposes a value of 0.4 for replacements between 10 and 25 %. It has also been reported that for concrete with different types of fly ash and cement (up to 28 % replacement and w/c between 0.5 and 0.65) a value of 0.5 is appropriate. It has been mentioned that cementing efficiency factor of fly ash depends on the physical and chemical characteristics of fly ash and cement, mix design parameters, strength range, age, w/cm ratio and replacement level.

Hanehara *et al.* (2001) have reported that hydration of cement is accelerated with increase in the water-cement ratio. It has been mentioned that the pozzolanic reaction of fly ash proceed from the age of 28-91 days and the reaction ratio of fly ash decreases with increase in the substitution rate.

Wong and Abdul Razak (2005) recently proposed a model for evaluating ‘χ’ values using an alternative approach. The method was developed following Abram’s strength-w/c ratio rule and calculates efficiency in terms of relative strength and cementitious materials content. It was found that ‘χ’ values ranged from 1.6 to 2.3 for metakaolin and 2.1 to 3.1 for silica fume mixtures at 28 days, whereas at 180 days, the ‘χ’ values varied from 1.8 to 4.0 for metakaolin and 2.4 to 3.3 for silica fume mixtures. This method can be rather complicated for practical application, however, because it requires an extensive set of data to establish beforehand, a relationship between strength, and a w/c for different amounts of a particular additive.

2.4 Phase-III Application of MLR and ANN

The standard 28-day compressive strength test is widely used for the characterisation of cement properties (Tsivilis and Parissakis, 1995). Compressive strength is the most important cement property, also it is the main parameter for quality control (Tango, 1998). It is a long time for the industry to wait for 28 days to get the experimental results for the compressive cement strength (CCS). Therefore, faster determination of compressive cement strength is a need for the cement industry and deserves research interest from the researchers. There are mainly two different ways for compressive cement strength determination: (a) accelerated strength test methods and (b) use of mathematical models. The focus in this report is on the second one. The most widely used mathematical approach in the past is to use simple regression models (Tsivilis and Parissakis, 1995; Tango, 1998). Compressive cement strength depends on many different factors, which are chemical and physical in nature. Analytical models including the statistical ones (e.g., regression analysis) used to describe the effects of these factors on strength can be very complex prediction of CCS (Akkurt, 2003).

Currently, there has been a growing interest in a class of computing programs which known as artificial neural networks (ANNs) that function in a manner analogous to biological nervous systems. The neural network modelling (NNM) approach is very accurate and more direct than other conventional statistical methods, especially when modelling nonlinear multivariate interrelationships (Sobhani *et al.* 2010; Hagan et al. 1996; Rumellhert et al. 1986). Based on the experimental results and analysis by using ANN, it can be concluded that the ANN model is an efficient way of predicting physical properties of concrete (Najigivi *et al.* 2013).

Recently, many researchers have used neural networks models for predicting various properties of concrete. The principal property of ANN in solving civil engineering problems are their learning ability directly from experiments. The other significant properties of ANN are their accurate or nearly accurate response to incomplete tasks, their withdrawal of information from noisy or poor data, and their creation of generalized results from the novel cases. The aforementioned potentials make ANN a very powerful tool for solving many civil engineering problems which deals with complex or an insufficient data (Ince, 2004; Topc¸u and Sarıdemir, 2008a; Topc¸u and Sarıdemir, 2007, 2008b; Pala and O¨ zbay, 2007; Adhikary and Mutsuyoshi, 2006).

2.5 Summary

From literature survey following summary is extracted from Phase-I, II and III are as follows:

Phase-I: It may be expected that the findings of the above literature review, may serve as a useful guideline for judiciously applying the concept of efficiency factors to optimize the effect of supplementary cementitious materials in concrete and lead to improvement in the method of mix design of SCMs in concretes. Hence there is a need to investigate the effect of different additives, there optimum content and efficiency of utilization.

Phase-II: It is observed from the above reporting that the efficiency of supplementary cementitious materials in concrete depends on a number of parameters such as type of cement and fly ash, replacement level, age, w/b, strength level etc. where 'b' is the cementitious binder content. Hence, efficiency of fly ash should not be considered as an intrinsic or fundamental property of the material as it depends on a host of parameters. Since, the efficiency value is not a constant one evaluation of the same requires a considerable amount of judgment and understanding on the part of the designer. Hence, there is a need to develop efficiency factors which would be very useful for effective utilization/quantification of supplementary cementitious materials in concrete.

Phase-III: The previous research has been utilized similar techniques of ANN model proved to be reasonable and feasible, showed a satisfactory performance, and demonstrated its ability to predict the efficiency of fly ash or ggbs. Further work is required to develop neural network models for predicting the efficiency factor of other SCMs, such as silica fume, micro silica, rice husk ash and natural pozzolans. These models will be necessary to establish the reliability of the proposed method, particularly with respect to its incorporation into the design of blended concrete. Hence there is a need to investigate the application of soft computing tools like artificial neural network and genetic algorithm to predict the efficiency factor for time saving and optimization of supplementary cementitious materials for cost saving.

Chapter 3

Materials and Methodology

3.1 General

This study demonstrates the feasibility of regression analysis and artificial neural networks for the prediction of the efficiency factor of SCMs in concrete. In which, An Experimental work will be carried out to find the compressive strength and workability of concrete at different replacement levels of fly ash. The results generated through experimental work will be used to find out the efficiency factor at various replacement levels. Soft computing techniques can be used to predict the efficiency factor (k) of fly ash. Models generated through software would be helpful for effective utilization of fly ash with respect to percentage of replacements of fly ash in concrete.

3.2 Materials

The materials used in this work are broadly classified as base material, filler material, binders and admixtures. Both inert and reactive materials are used for this study. The various materials used in this work are discussed with their properties and with the test results as follows.

3.2.1 Cement

Ordinary Portland Cement of 53 grade was used in this study which was provided by Ambuja Cements Ltd. The oxide composition limits of OPC are given in Table 3.2.

Table 3.1 Oxide composition limits of OPC (Neville 1995)

Chemical composition	Content in percent
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.5-4
Na_2O	2-3.5
SO_3	2-3.5

Specific gravity value of OPC 53 grade is 3.15 (IS: 12269- 1987). The initial and final setting times of cement were provided by suppllier, and the values are 92 minutes and 440 minutes respectively.

3.2.2 Fly ash

The Fly Ash is finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has pozzolanic properties, and is blended with cement for this reason. Fly ash is finely divided residue resulting from the combustion of pulverized coal and transported by the flue gases of boilers by pulverized coal. It was obtained from thermal power station, dried and used. Class F fly ash is designated in ASTM C 618 and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher loss of ignition (LOI) than

Class C fly ash. The class F fly ash was used in this study, the chemical composition of Class F fly ash (ASTM C618) is given in Table 3.2.

Table 3.2 Class F fly ash chemical composition (Neville 1995)

Property	ASTM C618 requiremets
$SiO_2+Al_2O_3+Fe_2O_3$	70% (min)
SO_3	5% (max)
Moisture content	3% (max)
Loss of ignition	6% (max)

3.2.3 Coarse aggregate

Crushed angular granite stones of maximum particle size 10 mm were used as coarse aggregate, sourced from a quarry in Turbe in Mumbai, India. The materials were collected and cleaned for impurities. The aggregates were tested as per IS: 383- 1970. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.69 and 6.8 respectively.

3.2.4 Fine aggregate

The fine aggregate (FAg) taken for this work is the locally available crushed sand sourced from a quarry in Turbe in Mumbai, India. Sand particles passing through IS sieve of 4.75 mm were used in this work. It was tested in the laboratory as per specifications recommended by IS: 383-1970. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.52 and 2.62 respectively.

3.2.5 Chemical admixture

Extreme workability can be produced with the help of superplastcizers. And thus, reduction in water content can be achieved. The increased workability is produced due to electrochemical activity. Superplasticizer molecules and cement particles are oppositely charged and hence they repel each other. This increases the mobility and hence makes concrete to flow. Also superplasticizers enable savings in cement for given strength (Santhakumar 2007). The various superplasticizer of brand names Sikament 5204 NS, Sikaplast 5201 NS and Sikaviscocrete 5210 NS was used in this work and conforming to IS: 9103-1999 and ASTM C- 494 requirements.

3.2.6 Mixing water

Free water encountered in freshly mixed concrete, reacts with the cement powder thus producing hydration, acts as a lubricant to contribute workability to fresh concrete and secures necessary space in the paste for the development of hydration products (Popovics 2002). Generally, water that is suitable for drinking is satisfactory for use in concrete. Boring water has been used for this project which conformed to IS 456-2000 requirements.

3.3 Mix design

Concrete mix design is a step by step procedure to work out the various proportions of ingredients which makes the concrete. Mix design can be defined as the process of selecting suitable ingredients of concrete a determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design depends on the type of structure being built, how the concrete will be mixed and delivered and how it will be placed to form this structure. Design of concrete mix requires complete knowledge of various properties of the materials, the changes in their quantity as per environmental conditions, the impact of properties of plastic concrete and hardened concrete and interrelationship between ingredients. All these make the task of mix design more complex. Table 3.3. shows a mix proportion which is obtained by DOE (Department of environment) method and further evaluated these replacement of fly ash for efficiency factor.

Table 3.3 Reference mix of fly ash at different level of replacement

Mix Code	OPC (kg)	FA (kg)	% FA	C/Sand (kg)	CA I (kg)	CA II (kg)	Total Agg (kg)	Admixture (%)	W/C
M40	400	130	25	650	440	640	1730	1.2	0.45
M35	360	110	25	870	321	644	1835	1.2	0.37
M30	295	125	30	820	468	595	1883	1.2	0.56
M25	280	110	28	925	380	600	1905	1.2	0.59
M20	250	90	26	950	450	570	1970	1.2	0.64

In this experimental work, mix design is done by DOE method. The DOE method was first published in 1975 and then revised in 1988. This method is applicable to concrete for most purposes; including road. The method can be used for concrete containing fly ash. DOE method presently is the standard British method of concrete mix design. The baseline of the grade up to M40 concrete was provided by Navdeep Construction Company, Mumbai, RMC plant and according to the materials and other factors, the final mix was to be designed. The baseline was obtained by DOE method of Mix design and the modifications were done on the basis of the workability and compressive strength tests results of the trials. The ultimate aim was to design various grades of fly ash concrete for finding efficiency factor.

3.4 Methodology

Initially, M40, M35, M30, M25 and M20 concrete is prepared as per the mix proportions. Types and properties of concrete components were gathered from documents, such as material test reports, mixture reports, and acceptance test reports of RMC, obtained from three construction sites, respectively. The data for this study were limited to concretes using only OPC (OPC concrete) and concrete using partly FA as a cement replacement material (FA concrete), having the specified compressive strength below 50 MPa. 217 specimens for each mix are cast and tested for 28 days as per the Indian Standard guidelines (IS 10262:2009). From the replacement level of fly ash, the strength efficiency factor ‘k’ is evaluated using modified Bolomey’s equation (refer Appendix-I, II, III, IV and V). The reliability and applicability of prediction model was evaluated by coefficient of determination (R^2).

3.4.1 Multi Linear Regression (MLR)

MLR is the simplest and a well-developed representation of a casual, time invariant relationship between an input function of time and corresponding output function, Chau et al. (2005). Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. MLR attempts to model the relationship between two or more independent variables and dependent variables by fitting a linear regression equation to observed data. If it is assumed that the dependent variable Y

is affected by m independent variables X_1, X_2,…., X_m and a linear equation is selected for the relation among them, the regression equation of Y (Eq. 3) can be written as:

$$y = a + b_1x_1 + b_2x_2 + \cdots + b_mx_m \tag{3}$$

"y" In this equation shows the expected value of the variable Y when the independent variables take the values; $X_1 = x_1$, $X_2 = x_2$,….,$X_m = x_m$.

The regression coefficients as shown in Eq. 4. Here,a,b_1,b_2,….,b_m are evaluated, similar to simple regression, by minimizing the sum of the e_{yi} distances of observation points from the axis plane, expressed by the regression equation, Bayazit and Oguz (1998).

$$\sum_{i=1}^{N} e_{yi}^2 = \sum_{i=1}^{N}(y_i - a - b_1x_{1i} - b_2x_{2i} - b_mx_{mi})^2 \tag{4}$$

In this study, the coefficients a, b_1, b_2,…., b_m are determined using least squares method.

3.4.2 Artificial neural network (ANN)

A neural network model's degree of success in predicting the efficiency factor largely depends on the availability of a large variety of pre-existing experimental data. The experimental data, however, showed the ability of learning the network in all aspects of the relationship between the concrete mixture variables.

Figure 3.1, shows the model of a neuron. As shown in this figure, the neuron receives multiple inputs (OPC, FA, Admixture and W/C ratio) through weighted connections in the previous layer, performs the appropriate computations, and transmits its output to other neurons as a network output (Efficiency Factor) using an assigned transfer function.

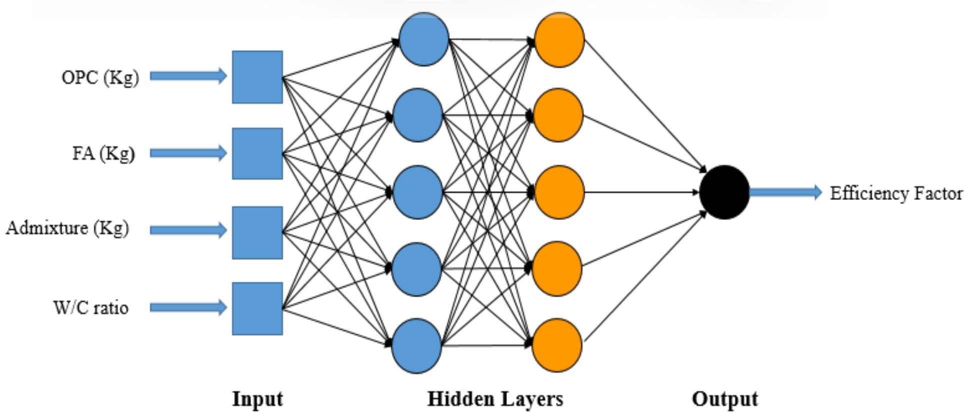

Figure 3.1 Architecture of neural network

The principal property of ANN in solving civil engineering problems are their learning ability directly from experiments where, Kaveh and Khaleghi (2000) compared and trained for one, two and three hidden layers by employing back propagation algorithm, and selected a most efficient network in order to predict the strength of concrete. In spite of back-propagation algorithm, other significant properties of ANN are accurate or nearly accurate response to incomplete tasks, their withdrawal of information from noisy or poor data, and their creation of generalized results from the novel cases.

This work is organized into following five stages and as shown in flowchart and Figure 3.1

Stage-I: Literature review

- Phase-I: Efficiency Factor of SCMs in Concrete
- Phase-II: Application of Soft Computing Techniques
- Phase-III: Concept of Efficiency Factor of SCMs
- Phase-IV: Review of Research Gaps or Summary

Stage-II: Concept formulation

- Statement of the Problem
- Research Objectives
- Expected Outcomes

Stage-III: Data collection

- Laboratory Experimental Data
- RMC Plant Data

Stage-IV: Soft computing techniques

- MATLAB
- Multi-Linear Regression
- Artificial neural network

Stage-V: Research outcomes/results

- K-factor of fly ash concrete
- Regression model
- ANN prediction model

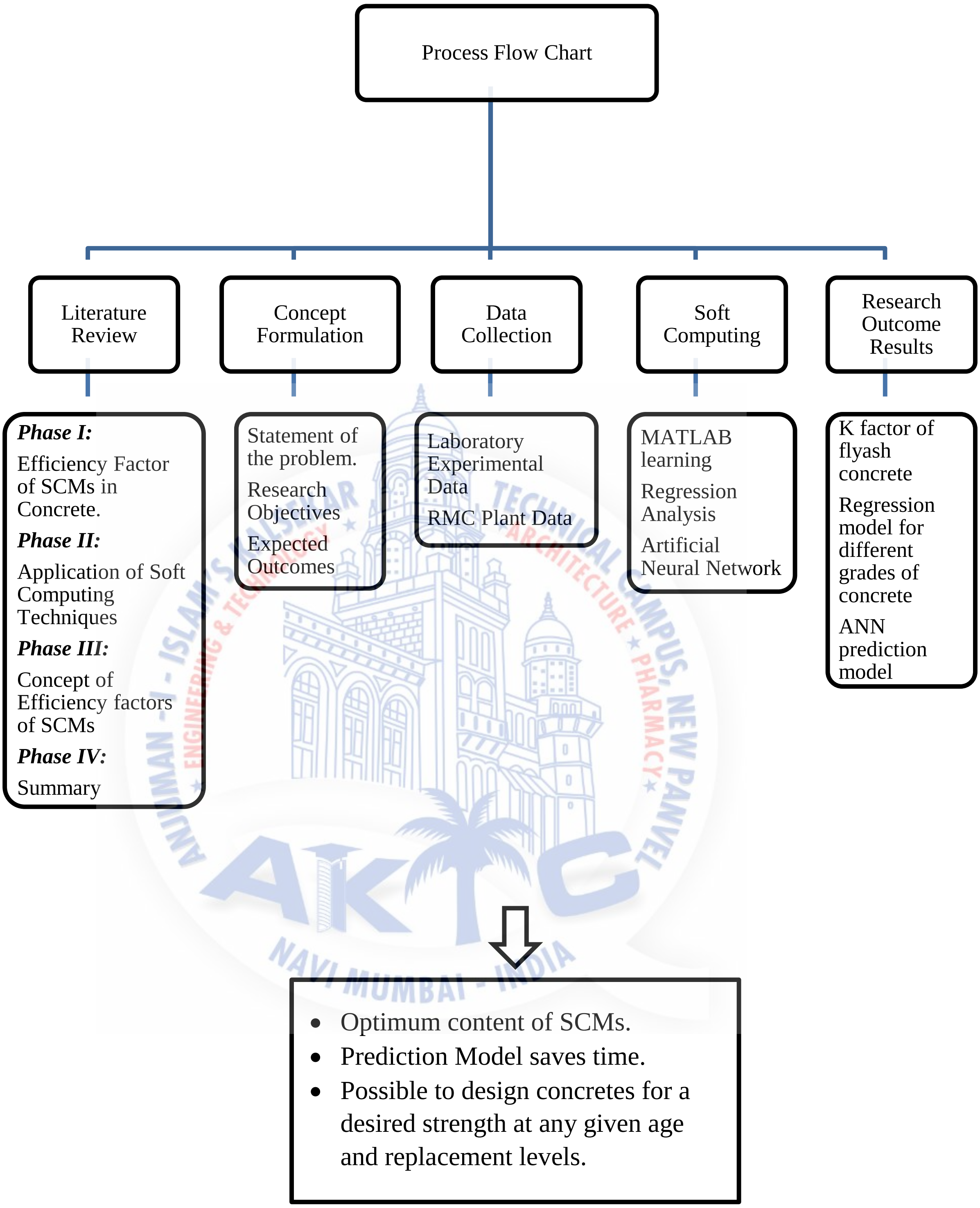

Figure 3.2 Methodology adopted in the present work

Chapter 4

Results and Discussions

4.1 General

The concrete mix was designed for M40, M35, M30, M25 and M20 grade and the mix design was done as per DOE (Department of environment) method. Mix design for concrete was made considering the properties of constituents of concrete. Different concrete mixes with varying fly ash content percentage were produced, replacing 20%, 25%, 30%, and 35% cement in terms of weight. Cubic specimens of 150 mm size were casted for compressive strength test and tamping was done as per Indian standard, as shown in below Figure 4.1 and 4.2. The cubes were casted in stainless steel moulds and wet cured at standard temperature until the time of test. The cubes were cured for a time period 28 days. Further Bolomey’s law have been applied to calculate efficiency factor and regression technique have been applied to predict the efficiency factor for different grades of concrete. In order to validate the results a comparison of results has been made between MLR and ANN.

Figure 4.1 Filling the cube moulds

Figure 4.2 Tamping of concrete

4.2 Efficiency factor by modified Bolomey's l aw

The k-value obtained in the range of ±1, which describes the mineral admixture's ability to act as cementing material, recognizing that mineral admixture's contribution to concrete strength which comes mainly from its ability to react with free calcium hydroxide produced during cement hydration. Table 4.1., shows a cementing efficiency factor (k-value) based on the replacement of fly ash at 20%, 25%, 30% and 35% with OPC for M40, M35, M30, M25 and M20 respectively. The efficiency factor for different grades of concrete corresponding to replacement of fly ash shown in Appendix-I, II, III, IV and V

Table 4.1 Compressive strength and $\boldsymbol{k}$-value at different replacement level of fly ash

Mix Code	OPC (kg)	FA (kg)	% FA	Admixture (kg)	W/C	Compressive Strength at 28 day's (MPa)	Efficiency Factor ($\boldsymbol{k}$-value)
M40	424	106	20	6.36	0.34	49.53	-0.23
	397.5	133	25	6.36	0.34	46.33	0.02
	371	159	30	6.36	0.34	42.49	0.18
	344.5	186	35	6.36	0.34	38.71	0.30
M35	376	94	20	5.64	0.37	41.02	1.06
	353	117	25	5.64	0.37	39.87	1.05
	329	141	30	5.64	0.37	36.51	1.04
	305	165	35	5.64	0.37	33.25	1.03
M30	336	84	20	5.04	0.39	37.63	-0.51
	315	105	25	5.04	0.39	36.15	-0.21

	294	126	30	5.04	0.39	35.84	-0.01
	273	147	35	5.04	0.39	32.68	0.14
M25	312	78	20	4.68	0.42	35.12	-0.44
	292.5	98	25	4.68	0.42	33.58	-0.15
	273	117	30	4.68	0.42	31.48	0.04
	253.5	137	35	4.68	0.42	28.58	0.18
M20	272	68	20	4.08	0.47	27.12	-0.32
	255	85	25	4.08	0.47	24.71	-0.06
	238	102	30	4.08	0.47	22.61	0.12
	221	119	35	4.08	0.47	19.87	0.24

From the Table 4.1., it has been observed that the rate of this reaction, called as pozzolanic reaction (PR), when compared to cement hydration rate (CHR) determines the value of k. When $k = 1$, both PR and CHR would be same and the water-binder ratios of concretes with and without mineral admixture could be almost same. When $k < 1$, PR would be slower than CHR and for equal strengths, the water-binder ratio of concrete with a mineral admixture need to be less than that of concrete without mineral admixture and also, at same water-binder ratio, the strength of concrete with mineral admixture would be less than that of concrete without mineral admixture. In this case, the mineral admixture is less efficient than Portland cement in imparting strength to concrete. The class F Fly Ash has generally $k < 1$ at early ages and k would reach a value of unity at later ages. When $k > 1$, PR would be faster than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture would to be more than that of concrete without mineral admixture. However, at similar water-binder ratios, the strength of concrete with mineral admixture would be more than that of concrete without mineral admixture. In this case, the mineral admixture is more efficient than Portland cement in imparting strength to concrete.

4.3 Variation in strength at different replacement level of fly ash

The strength properties of M40, M35, M30, M25 and M20 grades of concrete with various levels of replacement of cement by fly ash and to arrive at optimum percentage of fly ash content which gives higher strength in case of M35 grade of concrete. The experimental investigation includes determination of compressive strength and workability with various levels of replacement of cement by fly ash. The replacement levels selected for the study are

20%, 25%, 30%, and 35% of cement by weight. As shown in Fig. 4.3, variation in compressive strength at different replacement level of fly ash has been obtained.

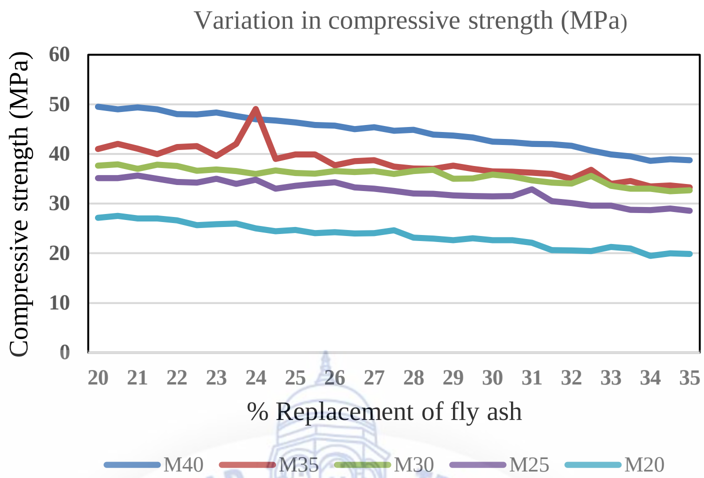

Figure 4.3 Variation in compressive strength

In the above figure, shows an increase in a unit percentage by weight of fly ash in replacement of OPC there is a constant decrease in the compressive strength of concrete, the maximum compressive strength is achieved in M35 mix of concrete by replacement of OPC to fly ash at an average replacement of 24%. This may be due to the effective combination of particle size distribution of materials used for concrete.

Figure 4.4 Mixing of concrete

Figure 4.5 Tested cubes and

The above Figure 4.4 shows the mixing of concrete carried out for experimental purpose wherein the other Figure 4.5, shows the fractured concrete cubes with marking after the testing in compression testing machine (CTM) is carried out.

4.4 Variation in efficiency factor at different replacement levels

In the present investigation cementing efficiency of fly ash was calculated for the range of 20% to 35%. The corresponding cementing efficiency factor can be found as +1 to -1. The calculations for the k-factor were presented in Appendix-I, II, III, IV and V for different grades of concrete. The cementing efficiency factor is a useful parameter in the mix design of fly ash concretes. The German standards (DIN 1045) value of k- factor was proposed as 0.3 for 10-25% replacement. The higher value of k-factor reported in this investigation may be because of higher reactivity of the fly ash. However some more confirmatory tests are needed to specify this value. Figure 4.6 to Figure 4.10, showing variation in efficiency factor for different grade of concrete are as follows:

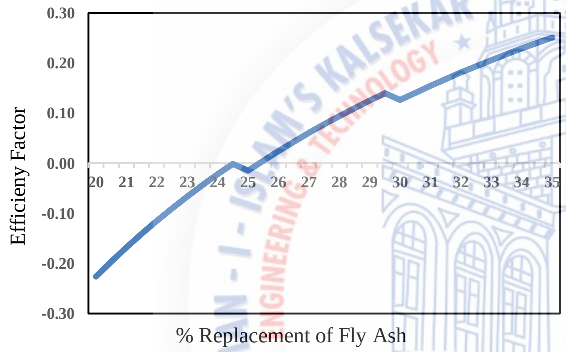

Figure 4.6 Efficiency factor for M40

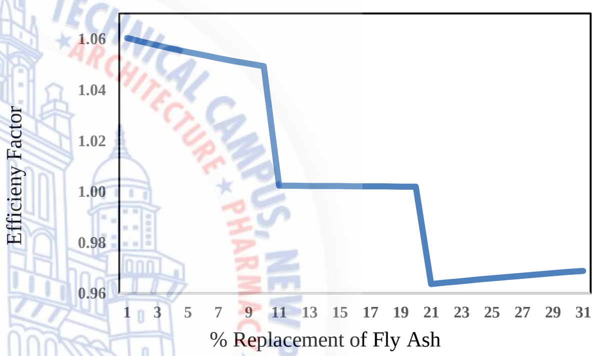

Figure 4.7 Efficiency factor for M35

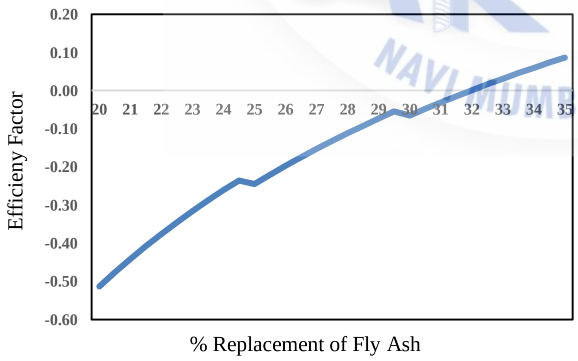

Figure 4.8 Efficiency factor for M30

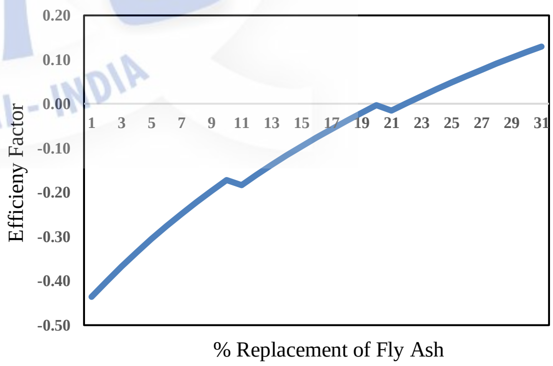

Figure 4.9 Efficiency factor for M25

Figure 4.10 Efficiency factor for M20

From the above Figures, it can be very well noted that for various grades of concrete viz. M40, M35, M30, M25 and M20, with the various combinations of replacement of OPC with Fly ash it is evident that, except M35 grade of concrete the others combinations are having negative value of efficiency factor apart from a positive value based on the experimental test results as carried out in the research, whereas M35 concrete is showing a constant positive value of efficiency factor this may be due to Pozzolanic reaction is faster than cement hydration rate.

4.5 Multi-linear regression

Multiple linear regression (MLR) is the most common form of linear regression analysis. As a predictive analysis, the multiple linear regression is used to explain the relationship between one continuous dependent variable and two or more independent variables. The independent variables can be continuous or categorical. The goal of multiple linear regressions technique (RT) is to model the relationship between the explanatory and response variables. In the other terms it is model the relation between the independents and dependent variables.

In this study, MLR model was developed as shown in Eq. 5 to Eq. 9 for M40, M35, M30, M25 and M20 respectively.

$$k_{m40} = -85.636 \times OPC + 3.824 \times FA + 116.560 \times ADM + 8.243 \times W/C + 62.560 \quad (5)$$

$$k_{m35} = 10.673 \times OPC - 0.214 \times FA - 11.656 \times ADM + 5.435 \times W/C - 9.512 \quad (6)$$

$$k_{m30} = -201.244 \times OPC + 8.730 \times FA + 284.110 \times ADM + 8.795 \times W/C + 145.314 \quad (7)$$

$$k_{m25} = -141.073 \times OPC + 6.901 \times FA + 205.173 \times ADM + 7.995 \times W/C + 99.259 \quad (8)$$

$$k_{m20} = -85.582 \times OPC + 5.009 \times FA + 129.053 \times ADM + 7.015 \times W/C + 55.776 \quad (9)$$

Where k represents efficiency factor and $m40$, $m35$, $m30$, $m25$, $m20$ are the grade of concrete at different replacement levels of fly ash respectively, OPC is ordinary portland cement in *kg/m³*, FA is fly ash in *kg/m³*, ADM is admixture in *kg/m³* and W/C is water by cement ration.

Based on the multi-regression analysis results as shown in Figure 4.11 to Figure 4.15, R square value comes out an average of 0.97, which shows a good correlation between various parameters and efficiency factor.

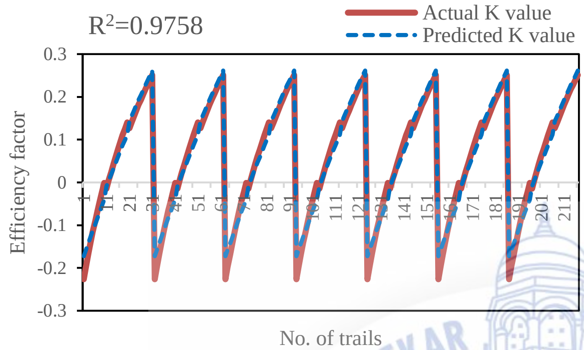

Figure 4.11 Actual versus predicted efficiency factor for M40

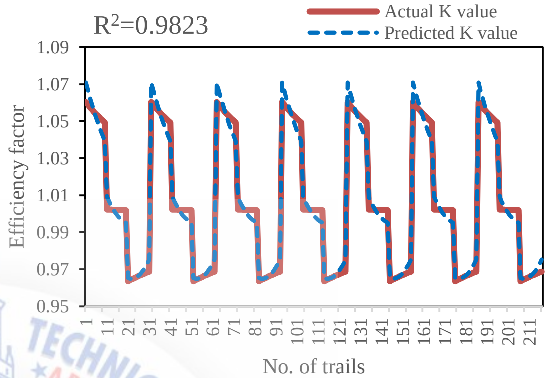

Figure 4.12 Actual versus predicted efficiency factor for M35

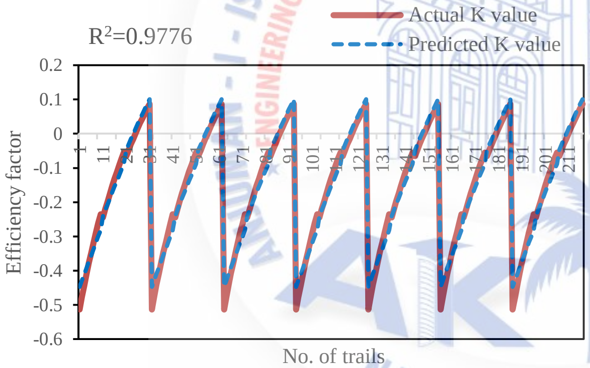

Figure 4.13 Actual versus predicted efficiency factor for M30

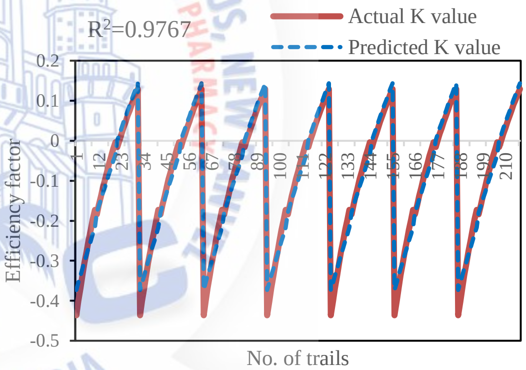

Figure 4.14 Actual versus predicted efficiency factor for M25

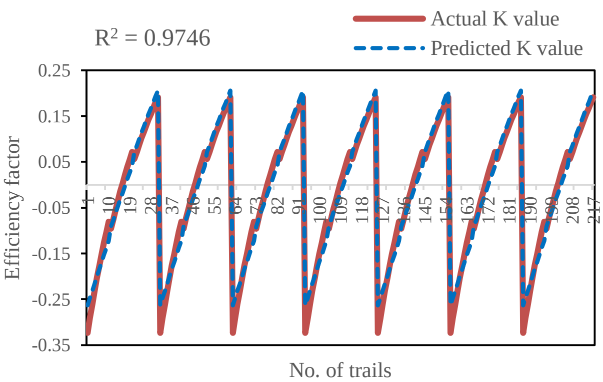

Figure 4.15 Actual versus predicted efficiency factor for M20

4.6 ANN prediction model for different grades of concrete

An artificial neuron network (ANN) is a computational model based on the structure and functions of biological neural networks. Information that flows through the network affects the structure of the ANN because a neural network changes - or learns, in a sense - based on that input and output. ANNs are considered nonlinear statistical data modelling tools where the complex relationships between inputs and outputs are modelled or patterns are found.

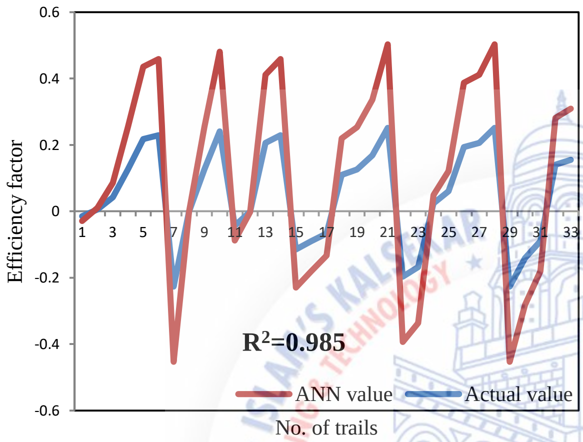

Figure 4.16 Actual and predicted efficiency factor for M40

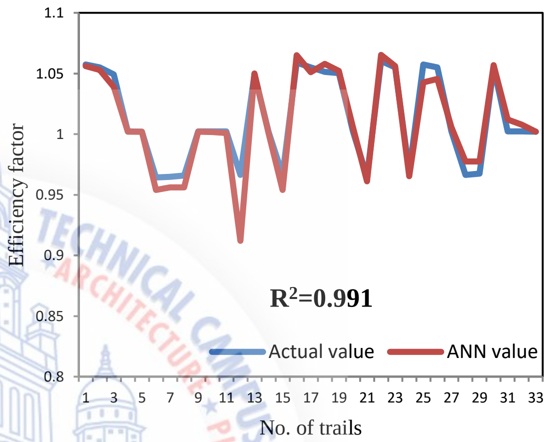

Figure 4.17 Actual and predicted efficiency factor for M35

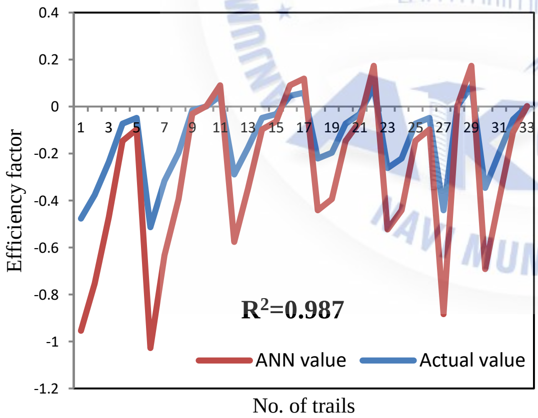

Figure 4.18 Actual and predicted efficiency factor for M30

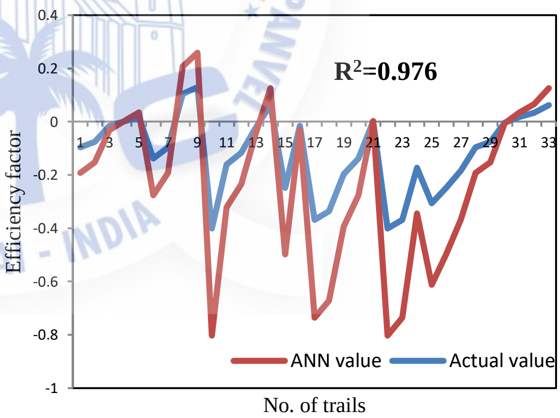

Figure 4.19 Actual and predicted efficiency factor for M25

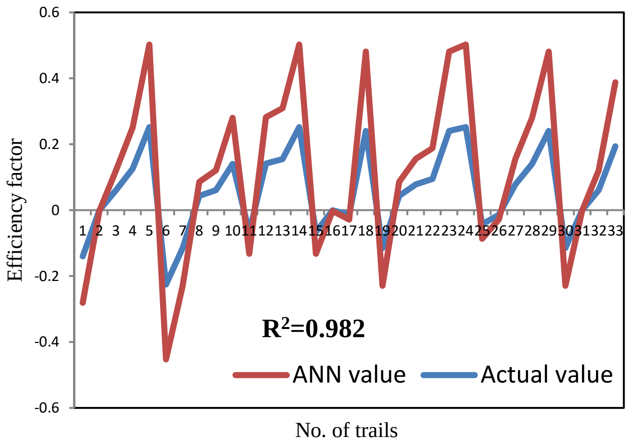

Figure 4.20 Actual and predicted efficiency factor for M20

ANN model developed in this research has four neurons in the input layer (independent variables) and 1 neuron in the output layer (dependent variable). Depending on previous researches along with trial and error method the adopted network has one hidden layer with 12 neurons as it provided the best performance: minimum % error and maximum correlation values for training, validation and testing sets. The parameter used for prediction efficiency factor were, ordinary Portland cement, fly ash, admixture and water by cement. These parameters used to predict the only independent variable which is the efficiency factor of fly ash.

As shown in above Figure 4.16 to 4.20, the actual and predicted efficiency factor of fly ash shows a fairly good correlation. This may be because of the variation in efficiency factor of different mixes are very less ranging from (−1 to +1). The R square value comes out an average of 0.98 which shows a good co relation between the input parameters and dependent output variable.

4.7 Comparison of MLR and ANN results with respect to k-value

The comparisons of MLR and ANN model has been made considering the R square value in both the cases. The ANN model performances are compared with Multiple Linear Regression Techniques. The models are evaluated by comparing the predicted results and measured k-values (statistical measures). As shown in below Figures 4.21 to 4.25, by comparing results of ANN and MLR model, it has been observed that ANN models provide better results than MLR models. The visual comparison illustrated in Figures it is quite obvious that ANN model had a better agreement and response to parameter variation rather than MLR model.

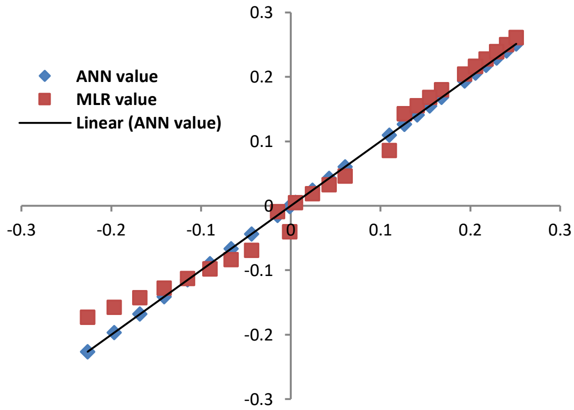

Figure 4.21 Comparison of MLR and ANN results M40

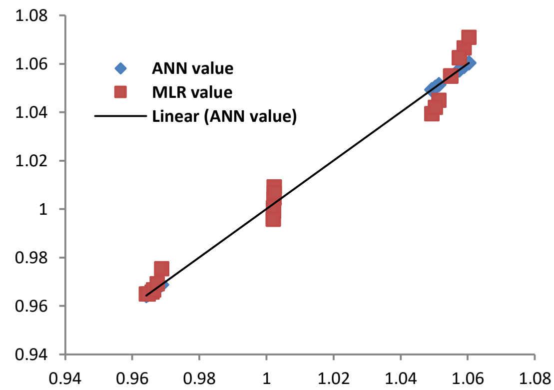

Figure 4.22 Comparison of MLR and ANN results M35

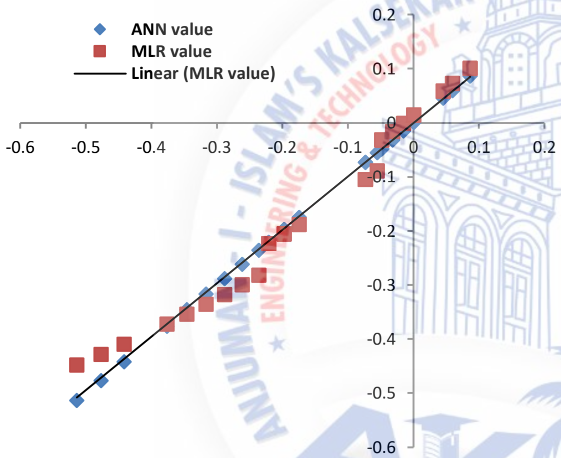

Figure 4.23 Comparison of MLR and ANN results M30

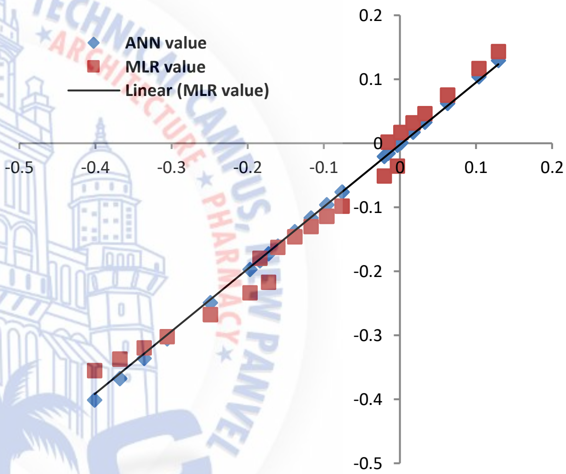

Figure 4.24 Comparison of MLR and ANN results M25

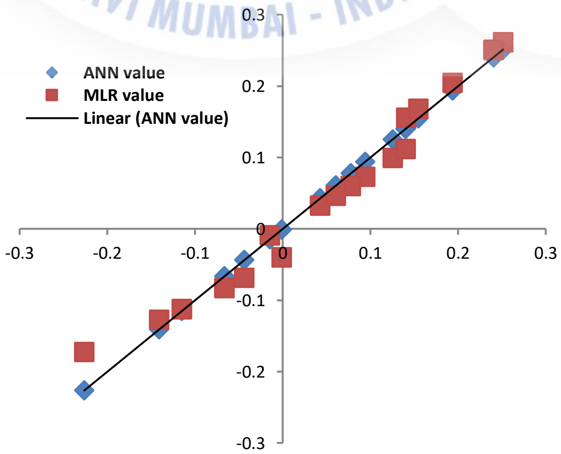

Figure 4.25 Comparison of MLR and ANN results M20

Also, Figure 4.22 shows the models performance, it can be seen that both ANN and MLR model results are closer to the observed results and the majority of result are being located on the line of equality (linear). This is quite true, because the model has an average R square of 0.98 for the prediction of efficiency factor in case of M35 grade of concrete.

4.8 Cost economic analysis

The cost economic analysis is carried out for understanding the proportionate relationship between the cost of construction materials required for the considered grade of concrete.
The cost analysis of various grade of concrete considered is compared with respect to the cost of ingredient of mix which is presented below, the lowest cost based on the maximum efficiency factor achieved as per the design mix and current exercise is taken for this study.

Table 4.2 shows a current unit rates of the ingredients of the concrete are as follows.

Table 4.2 Unit rate of materials

Materials	Rates (Rs)	Unit
OPC	6.5	Per Kg
Fly ash	2.53	Per Kg
Crushed sand	4,600	Per brass
10 mm	3,350	Per brass
20 mm	3,350	Per brass
Water	0.2	Per Kg
Sikaviscocrete 5210 NS	165.3	Per Kg

The above table shows a present unit rates of concrete ingredient, depending upon the rates provided by suppliers. Further cost analysis is made for 1 cubic meter (cum) of concrete. Considering the dry loose bulk density of crushed sand, 10mm aggregate and 20mm aggregate as 1.83, 1.58 and 1.53 respectively.

The detail cost analysis of the replacements ranging from 20% to 35% of fly ash for the grades of M40 to M20 has been made as shown in Appendix VI. Based on the efficiency factor, compressive strength and optimum replacement levels, the cost of different mixes has been achieved. Table 4.3 shows a cost analysis for different grades of concrete are as follows.

Table 4.3 Cost analysis for different grades of concrete

Mix Code	M40	M35	M30	M25	M20
OPC (Rs)	2,412	2,139	1,775	1,648	1,547
FA (Rs)	402	357	372	345	258
FA (%)	30	30	35	35	30
C/sand (Rs)	580	782	736	828	851
CAI (Rs)	302	238	348	281	335
CAII (Rs)	492	496	459	462	439
Admixture (Rs)	1,051	932	833	774	674
Water (Rs)	36	35.2	32.8	32.8	32
Total Cost (Rs)	5,275	4,978	4,556	4,371	4,136
Strength (MPa)	42.49	36.51	32.68	28.58	22.61
k-factor	0.18	1.04	0.14	0.18	0.12

From the above table, it has been observed that, the efficiency factor for all the mixes are positive and 30% replacement of class F fly ash with OPC is optimum, it may be because of Pozzolanic reaction would be faster than cement hydration rate, the water-binder ratio of concrete with mineral admixture would to be more than that of concrete without mineral admixture. Also, for M30 and M25 mixes the replacement level of fly ash was 35% and efficiency factor is 0.14 and 0.18 respectively. Which shows an economical mix as compared to other mixes.

Chapter 5

Summary and Conclusions

5.1 Summary

This work consists of assessment of strength and efficiency factor of fly ash concrete. The strength of concrete is assessed by parameters such as compression test, workability, percentage replacement of fly ash etc. The efficiency factor of fly ash concrete is studied by Bolomey's law based on modified water-cement ratio. Statistical analyses were also used in this work to study the influence of water-cement ratio on k-factor of fly ash concrete and developed a regression model depending on various parameters of concrete. The fly ash efficiency factor predictions using Artificial Neural Network was also attempted in this work. The efficiency factor model generated by statistical analysis and model developed through Artificial Neural Network, could be helpful in the design of fly ash concretes at different age, at different replacement percentage, and different water-cement ratio with greater confidence. However, the model that can predict the cementing efficiency of FA using concrete mixing factors such as OPC content, FA content, Admixture content and water-cement ratio are suggested by a partial correlation analysis and regression analyses. Based on the experimetal work, the following conclusions are arrived.

5.2 Conclusions

Based on the literature review, efficiency factor, compressive strength results, type of soft computing technique used (MLR, ANN) and based on the results presented in the foregoing chapters, following conclusions were derived.

5.2.1 Bolomey's empirical equations

- The Bolomey's empirical expression can be used to predict the strength efficiency factors of Fly ash in concrete mixes at different percentage of replacement levels.
- The k factor concept is suitable for Class F fly ash. It is useful for estimating the degree of the pozzolanic activity of high calcium Class fly ash and compressive strength of concrete.
- The k values obtained from the efficiency estimate equations range from -0.51 to 1.06 at FA replacement ratios of 20-35% and water-cement ratio of 0.34-0.47.
- The k value obtained from regression analysis can be further used as a means of mix design and quality control of FA concrete.
- For M35 concrete mix, Efficiency of Fly ash varies between 1.03 and 1.06 for percentage replacement levels varying from 20 to 35%.

5.2.2 Efficiency factor at different replacement levels

- For various grades of concrete viz. M40, M35, M30, M25 and M20, with the various combinations of replacement of OPC with Fly ash it is evident that, except M35 grade of concrete the others combinations are having negative value of efficiency factor apart from a positive value.
- Based on the experimental test results as carried out in the research, M35 concrete is showing a constant positive value of efficiency factor this may be due to pozzolanic reaction is faster than cement hydration rate.
- Higher k values for M35 mix at 20% replacement of fly ash were found, indicating that fly ash can be efficiently utilized for M35 mix as compared to other mixes.

5.2.3 MLR and ANN

- Based on the multi-regression analysis results, R square value comes out an average of 0.97
- Based on the ANN predicted results, R square value comes out an average of 0.98 which shows a good co relation between the input parameters and dependent output variable
- Comparing results of ANN and MLR model, it has been observed that ANN models provide better results than MLR models.
- The models performance, it can be seen that both ANN and MLR model results are closer to the observed results and the majority of result are being located on the line of equality (linear).

5.2.4 Cost economic analysis

- The efficiency factor for all the mixes are positive and on an average 30% replacement of class F fly ash with OPC is optimum, it may be because of Pozzolanic reaction would be faster than cement hydration rate, the water-binder ratio of concrete with mineral admixture would to be more than that of concrete without mineral admixture.
- For M30 and M25 mixes the replacement level of fly ash was 35% and efficiency factor is 0.14 and 0.18 respectively.
- The cost analysis shows and efficient use of fly ash and economical mixes in case of M30 and M25 concrete.
- Consequently, the replacement-based efficiency factor may be employed in conjunction with other factors, such as those related to cost for optimization and effective use of an additive in concrete at various replacement levels.

5.2.5 Scope for future work

- The above developed statistical model proved to be reasonable and feasible, showed a satisfactory performance, and demonstrated its ability to predict the efficiency of Fly ash.

- Further work is required to develop neural network models for predicting the efficiency factor of other SCMs, such as ground granulated blast furnace slag, silica fume, rice husk ash and natural pozzolans.
- These models will be necessary to establish the reliability of the proposed method, particularly with respect to its incorporation into the design of blended concrete.
- Further, method of soft computing such as Genetic Algorithm can be applied for optimization of SCMs and developed a reliable model which easily modify the content of mix proportions.

REFERENCES

[1] Adhikary, B. B., and Mutsuyoshi, H. (2006), “Prediction of shear strength of steel fiber RC beams using neural networks”, Construction and Building Materials, 20(9), pp. 801–811.

[2] Aïtcin, P.C. (2011), “Sustainability of Concrete, Modern Concrete Technology Series”, Spon press.

[3] Akkurt, S; Ozdemir, S; Tayfur, G; Akyol, B. (2003), “The use of GA-ANNs in the modelling of compressive strength of cement mortar”, Cem Concr Res, 33 (2003), pp. 973–979.

[4] Babu K.G. and Rao G. S. N. (1996), “Efficiency of fly ash in concrete with age”, Cem Concr Res, 26 (3), pp. 465–474.

[5] Babu K. G and Rao, G. S. N. (1993), “Efficiency of fly ash in concrete”, Cement Concr Compos, 15, pp. 223–228.

[6] Bayazit, M. and Oguz, B. (1998), “Probability and Statistics for Engineers,” Birsen Publishing House, Istanbul, Turkey, 159.

[7] Bijen J, Van; Selst, R. (1993), “Cement equivalence factors for fly ash”, Cem Concr Res, 23, pp. 1029–1039.

[8] BS EN 2061 (2000), Concrete Part 1: Specification, performance, production and conformity, British Standard Institute.

[9] Chakraverty, S., Himani, Saini and Panigrahi, S.K. (2008), “Prediction of product parameters of fly ash cement bricks using two dimensional polynomials in the regression analysis”, Comput. Concrete, 5(5), 449459.

[10] Chau, K. W., Wu, C.L. and Li, Y.S. (2005), “Comparison of several flood forecasting models in Yangtze River”, Journal of Hydrologic Engineering, 10(16), 485-491.

[11] DIN 1045. Belton und Stahlbeton, GMBH, Koln.

[12] Desai, J. P. (2004), “Construction and performance of high-volume fly ash concrete roads in India”, Eighth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Las Vegas, USA, American Concrete Institute, Vol.221, pp.589-604.

[13] Fraay, A. L. A; Bijen, J. M; De Haan, Y. M. (1989), “The reaction of fly ash in concrete. A critical examination”, Cem Concr Res, 19, pp. 235–246.

[14] Ganesh Babu, K. and Siva Nageswara Rao, G. (1996), "Efficiency of fly ash in concrete with age", Cement Concrete Res., 26(3), 465474.

[15] Gopalan, M. K, Haque, M. N. (1989), "Mix design for optimal strength development of fly ash concrete", Cem Concr Res, 19, pp. 634–641.

[16] Hagan, M., Demuth, H., & Beale, M. (1996), "Neural network design", Boston, MA: PWS Publishing.

[17] Hanehara S, Tomosawa F, Kobayakawa M, Hwang K. (2001), "Effects of water/powder ratio, mixing ratio of fly ash, and curing temperature on pozzolanic reaction of fly ash in cement paste", Cem Concr Res ,31, pp. 31–39

[18] Hardjito, D. and Rangan, B. V. (2005), "Development and properties of low calcium fly ash-based geopolymer concrete", Perth, Australia, Curtin University of Technology.

[19] Haykin, S. (1994), "Neural Networks - A Comprehensive Foundation", Macmillan College Publishing Company, New York.

[20] Ho, D. W. S and Lewis, R. K. (1985), "Effectiveness of fly ash for strength and durability of concrete", Cem Concr Res, 15, pp. 793–800.

[21] Hongxia, Y, (2012) "Strength and shrinkage properties of Nano Silica powder concrete", 2nd International Conference on Electronic, Mechanical Engg & Information technology, pp. 794-797.

[22] Hwang, C.L. and Hsieh, S.L. (2007), "The effect of fly ash/slag on the property of reactive powder mortar designed by using fuller's ideal curve and error function", Comput. Concrete, 4(6), 425436.

[23] Ince, R. (2004), "Prediction of fracture parameters of concrete by artificial neural networks", Engineering Fracture Mechanics, 71(15), pp. 2143–2159.

[24] IS: 3025-1983 "Quality of Water - procedures for collection and testing samples", Bureau of Indian Standards New Delhi, 1983.

[25] IS: 10262-2009. "Indian Standard Concrete Mix Proportioning-Guidelines (First revision)", Bureau of Indian standards, New Delhi,2009.

[26] IS: 10500-1991. "Drinking Water Specifications", Bureau of Indian Standards, New Delhi, 1991.

[27] IS: 1199-1959. "Indian Standard Methods of Sampling and Analysis of Concrete", Bureau of Indian Standards, New Delhi, 1959.

[28] IS: 12269-1987. "Specification for 53 grade Ordinary Portland Cement", Bureau of Indian Standards, New Delhi, 1987.

[29] IS: 383-1970. “Specification for Coarse and Fine Aggregates from Natural sources for Concrete”, Bureau of Indian Standards, New Delhi, 1970.

[30] IS: 456-2000. “Indian Standard Code of Practice for Plain Reinforced Concrete”, Bureau of Indian Standards, New Delhi, 2000.

[31] IS: 516-1959. “Specification for testing of hardened concrete properties”, Bureau of Indian Standards, New Delhi, 1959.

[32] IS: 9103-1999. “Specification for admixtures for concrete”, Bureau of Indian Standards, New Delhi, 1999.

[33] Kaveh, A and Khalegi, H. A, (2000), Prediction of strength for concrete specimens using artificial neural network, Asian Journal of Civil Engineering, No. 2, pp. 1-13.

[34] Lawrence, P., and Ringot, E. (2000), “Prise en Compte des Addition Minérales dans le Calcul des Résistances de Mortier,” Revue Française de Génie Civil, 4(4), pp. 525-542.

[35] Lollini, F; Redaelli, E; Bertolini, L. (2016), A study on the applicability of the efficiency factor of supplementary cementitious materials to durability properties, Construction and Building Materials, 120 (2016), pp. 284–292.

[36] Malathy, R & Subramanian K, (2007), “Efficiency factor for Silica fume and Matakaoline at various replacement levels”, 32nd conference on our world in concrete and structures at Singapore.

[37] Malhotra, V. M. (2002), “High-performance high-volume fly ash concrete”, ACI Concrete International, Vol. 24, pp.1-5.

[38] Metha, P.K. (2004), “ASTM C 1202, Electrical indication of concrete’s ability to resist chloride ion penetration,” Annual book of American Society for Testing Materials Standards, Vol.C04-02.

[39] Mc Culloch, W.S. and Pitts, W. (1943), “A Logical Calculus of the Ideas Immanent in Nervous Activity”, Bulletin of Mathematical Biophysics, 5, 115-133.

[40] Najigivi1, A; Khaloo, A; Iraji zad, A and Abdul Rashid, S. (2013), “An Artificial Neural Networks Model for Predicting Permeability Properties of Nano Silica–Rice Husk Ash Ternary Blended Concrete”, International Journal of Concrete Structures and Materials, 7(3), pp. 225–238.

[41] Neville, A.M. A textbook on “Properties of Concrete”, 4(ed), Dorling Kindersley Pvt Ltd, Noida, India, pp.84-85, 1995.

[42] Oner, A., Akyuz, S. and Yildiz, R. (2005), "An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete", Cement Concrete Res., 35, 11651171.

[43] Pala, M., Ozbay, E., O¨ ztas¸, A., & Yuce, M. I. (2007a), "Appraisal of long term effects of fly ash and silica fume on compressive strength of concrete by neural networks", Construction and Building Materials, 20(9), pp. 769–775.

[44] Pala, M., Ozbay, E., O¨ ztas¸, A., & Yuce, M. I. (2007b), "Appraisal of long-term effects of fly ash and silica fume on compressive strength of concrete by neural networks", Construction and Building Materials, 21(2), 384–394.

[45] Papadakis, V.G., Antiohos, S. and Tsimas, S. (2002), "Supplementary cementing materials in concrete, Part II: Fundamental estimation of efficiency factor", Cement Concrete Res., 32, 15331538.

[46] Papadakis, V.G. and Tsimas, S. (2002), "Supplementary cementing materials in concrete, Part I: Efficiency and design", Cement Concrete Res., 32, 15251532.

[47] Qing, Y. E and Zhang Zenan, (2006), "A comparative study on the pozzolanic activity between Nano Sio2 and Silica fume", Journal of Wuhan university of Technology, pp. 153-157.

[48] Rosenblatt, F. (1962). Principles of Neurodynamics. New York: Spartan.

[49] Rukzon, S. and Chindaprasirt, P. (2008), "Mathematical model of strength and porosity of ternary blend Portland rice husk ash and fly ash cement mortar", Comput. Concrete, 5(1), 16.

[50] Rumelhart, D. E.; Hinton, G. E.; Williams, R. J. (1986), "Learning internal representations by error propagation. In Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Foundations, Cambridge, MA: MIT Press, 1, pp. 1318-362.

[51] Sata, V; Khammathit, P and Chindaprasirt, P. (2011), "Efficiency factor of high calcium Class F fly ash in concrete", Computers and Concrete, 8(5), (2011), 583595.

[52] Siddique Rafat. (2003), "Effect of fine aggregate replacement with class F flyash on the mechanical properties of concrete", Cement and Concrete Research, Elsevier Science Ltd, Vol. 33, pp.539-547.

[53] Sinha, D. A. (2014) "Evaluation of Cementing Efficiency of Flyash in Concrete", International Journal of Emerging Technology and Advanced Engineering, 4(5), pp. 44-49.

[54] Smith, I. A. (1967), "The Design of Fly Ash Concretes," Proceedings of the Institute of Civil Engineers, London, UK, pp. 769-790.

[55] Sobhani, J., (2010), "Prediction of the compressive strength of no-slump concrete: A comparative study of regression, neural network and ANFIS models", Construction and Building Materials, 24(5), 709–718.

[56] Solis, A.V. Durham, S. A., Rens, K. L. and Ramaswami, A. (2010), "Sustainable concrete for the urban environment", A proposal to increase Fly ash use in concrete. In Weinstein, N. (Ed.) Green Streets and Highways 2010 Conference, Denver, Colorado, ASCE.

[57] Tango, C.E. de Siquera. (1998), "An extrapolation method for compressive strength prediction of hydraulic cement products", Cem Concr Res, 28, pp. 969– 983.

[58] Thomas, M., (2013), "Supplementary Cementing Materials in Concrete", CRC Press, 2013.

[59] Topc¸u, I. B., and Sarıdemir, M. (2007), "Prediction of properties of waste AAC aggregate concrete using artificial neural network", Computational Materials Science, 41(1), pp. 117–125.

[60] Topc¸u, I. B., and Sarıdemir, M. (2008a), "Prediction of rubberized concrete properties using artificial neural network and fuzzy logic", Construction and Building Materials, 22(4), pp. 532–540.

[61] Topc¸u, I. B., and Sarıdemir, M. (2008b), "Prediction of compressive strength of concrete containing fly ash using artificial neural network and fuzzy logic", Computational Materials Science, 41(3), pp. 305–311.

[62] Tsivilis, S, Parissakis, G, A. (1995), "Mathematical-model for the prediction of cement strength", Cem Concr Res, 25, pp. 9-14.

[63] Wong, H. S., and Abdul Razak, H., "Efficiency of Calcined Kaolin and Silica Fume as Cement Replacement Material for Strength Performance," Cement and Concrete Research, V. 35, No. 4, 2005, pp. 696-702.

APPENDIX I

Results of efficiency factor (K-value) for M40

Sr. no	OPC	FA	% FA	C/Sand	CA I	CA II	Total Agg	Admixture	W/C	Efficiency Factor (K value)
1	424	106	20	650	440	640	1730	5.088	0.42	-0.23
2	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
3	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
4	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
5	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
6	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
7	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
8	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
9	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
10	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
11	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
12	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
13	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
14	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
15	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
16	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
17	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
18	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
19	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
20	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
21	371	159	30	650	440	640	1730	4.452	0.47	0.13
22	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
23	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
24	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
25	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
26	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
27	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
28	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
29	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
30	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
31	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
32	424	106	20	650	440	640	1730	5.088	0.42	-0.23

33	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
34	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
35	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
36	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
37	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
38	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
39	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
40	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
41	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
42	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
43	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
44	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
45	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
46	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
47	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
48	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
49	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
50	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
51	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
52	371	159	30	650	440	640	1730	4.452	0.47	0.13
53	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
54	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
55	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
56	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
57	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
58	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
59	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
60	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
61	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
62	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
63	424	106	20	650	440	640	1730	5.088	0.42	-0.23
64	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
65	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
66	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
67	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
68	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
69	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
70	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
71	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02

72	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
73	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
74	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
75	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
76	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
77	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
78	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
79	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
80	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
81	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
82	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
83	371	159	30	650	440	640	1730	4.452	0.47	0.13
84	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
85	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
86	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
87	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
88	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
89	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
90	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
91	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
92	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
93	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
94	424	106	20	650	440	640	1730	5.088	0.42	-0.23
95	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
96	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
97	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
98	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
99	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
100	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
101	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
102	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
103	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
104	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
105	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
106	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
107	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
108	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
109	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
110	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09

111	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
112	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
113	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
114	371	159	30	650	440	640	1730	4.452	0.47	0.13
115	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
116	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
117	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
118	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
119	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
120	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
121	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
122	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
123	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
124	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
125	424	106	20	650	440	640	1730	5.088	0.42	-0.23
126	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
127	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
128	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
129	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
130	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
131	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
132	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
133	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
134	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
135	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
136	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
137	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
138	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
139	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
140	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
141	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
142	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
143	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
144	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
145	371	159	30	650	440	640	1730	4.452	0.47	0.13
146	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
147	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
148	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
149	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18

150	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
151	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
152	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
153	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
154	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
155	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
156	424	106	20	650	440	640	1730	5.088	0.42	-0.23
157	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20
158	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
159	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
160	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
161	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
162	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
163	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
164	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
165	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
166	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
167	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
168	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
169	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
170	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
171	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
172	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
173	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
174	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
175	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
176	371	159	30	650	440	640	1730	4.452	0.47	0.13
177	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
178	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
179	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
180	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
181	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
182	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
183	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
184	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
185	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
186	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25
187	424	106	20	650	440	640	1730	5.088	0.42	-0.23
188	421.35	108.65	20.5	650	440	640	1730	5.0562	0.43	-0.20

189	418.7	111.3	21	650	440	640	1730	5.0244	0.43	-0.17
190	416.05	113.95	21.5	650	440	640	1730	4.9926	0.43	-0.14
191	413.4	116.6	22	650	440	640	1730	4.9608	0.44	-0.11
192	410.75	119.25	22.5	650	440	640	1730	4.929	0.44	-0.09
193	408.1	121.9	23	650	440	640	1730	4.8972	0.44	-0.07
194	405.45	124.55	23.5	650	440	640	1730	4.8654	0.44	-0.04
195	402.8	127.2	24	650	440	640	1730	4.8336	0.45	-0.02
196	400.15	129.85	24.5	650	440	640	1730	4.8018	0.45	0.00
197	397.5	132.5	25	650	440	640	1730	4.77	0.45	-0.01
198	394.85	135.15	25.5	650	440	640	1730	4.7382	0.45	0.01
199	392.2	137.8	26	650	440	640	1730	4.7064	0.45	0.02
200	389.55	140.45	26.5	650	440	640	1730	4.6746	0.46	0.04
201	386.9	143.1	27	650	440	640	1730	4.6428	0.46	0.06
202	384.25	145.75	27.5	650	440	640	1730	4.611	0.46	0.08
203	381.6	148.4	28	650	440	640	1730	4.5792	0.47	0.09
204	378.95	151.05	28.5	650	440	640	1730	4.5474	0.47	0.11
205	376.3	153.7	29	650	440	640	1730	4.5156	0.47	0.13
206	373.65	156.35	29.5	650	440	640	1730	4.4838	0.48	0.14
207	371	159	30	650	440	640	1730	4.452	0.47	0.13
208	368.35	161.65	30.5	650	440	640	1730	4.4202	0.48	0.14
209	365.7	164.3	31	650	440	640	1730	4.3884	0.48	0.15
210	363.05	166.95	31.5	650	440	640	1730	4.3566	0.48	0.17
211	360.4	169.6	32	650	440	640	1730	4.3248	0.49	0.18
212	357.75	172.25	32.5	650	440	640	1730	4.293	0.49	0.19
213	355.1	174.9	33	650	440	640	1730	4.2612	0.50	0.21
214	352.45	177.55	33.5	650	440	640	1730	4.2294	0.50	0.22
215	349.8	180.2	34	650	440	640	1730	4.1976	0.50	0.23
216	347.15	182.85	34.5	650	440	640	1730	4.1658	0.51	0.24
217	344.5	185.5	35	650	440	640	1730	4.134	0.51	0.25

APPENDIX II

Results of efficiency factor (K-value) for M35

Sr. no	OPC	FA	% FA	C/Sand	CA I	CA II	Total Agg	Admixture	W/C	Efficiency Factor (K value)
1	376	94	20	870	321	644	1835	4.512	0.47	1.06
2	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
3	371	99	21	870	321	644	1835	4.4556	0.47	1.06
4	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
5	367	103	22	870	321	644	1835	4.3992	0.48	1.05
6	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
7	362	108	23	870	321	644	1835	4.3428	0.49	1.05
8	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
9	357	113	24	870	321	644	1835	4.2864	0.49	1.05
10	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
11	353	118	25	870	321	644	1835	4.23	0.49	1.00
12	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
13	348	122	26	870	321	644	1835	4.1736	0.50	1.00
14	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
15	343	127	27	870	321	644	1835	4.1172	0.51	1.00
16	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
17	338	132	28	870	321	644	1835	4.0608	0.51	1.00
18	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
19	334	136	29	870	321	644	1835	4.0044	0.52	1.00
20	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
21	329	141	30	870	321	644	1835	3.948	0.52	0.96
22	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
23	324	146	31	870	321	644	1835	3.8916	0.53	0.96
24	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
25	320	150	32	870	321	644	1835	3.8352	0.54	0.97
26	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
27	315	155	33	870	321	644	1835	3.7788	0.55	0.97
28	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
29	310	160	34	870	321	644	1835	3.7224	0.55	0.97
30	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
31	306	165	35	870	321	644	1835	3.666	0.56	0.97
32	376	94	20	870	321	644	1835	4.512	0.47	1.06
33	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06

34	371	99	21	870	321	644	1835	4.4556	0.47	1.06
35	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
36	367	103	22	870	321	644	1835	4.3992	0.48	1.05
37	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
38	362	108	23	870	321	644	1835	4.3428	0.49	1.05
39	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
40	357	113	24	870	321	644	1835	4.2864	0.49	1.05
41	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
42	353	118	25	870	321	644	1835	4.23	0.49	1.00
43	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
44	348	122	26	870	321	644	1835	4.1736	0.50	1.00
45	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
46	343	127	27	870	321	644	1835	4.1172	0.51	1.00
47	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
48	338	132	28	870	321	644	1835	4.0608	0.51	1.00
49	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
50	334	136	29	870	321	644	1835	4.0044	0.52	1.00
51	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
52	329	141	30	870	321	644	1835	3.948	0.52	0.96
53	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
54	324	146	31	870	321	644	1835	3.8916	0.53	0.96
55	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
56	320	150	32	870	321	644	1835	3.8352	0.54	0.97
57	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
58	315	155	33	870	321	644	1835	3.7788	0.55	0.97
59	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
60	310	160	34	870	321	644	1835	3.7224	0.55	0.97
61	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
62	306	165	35	870	321	644	1835	3.666	0.56	0.97
63	376	94	20	870	321	644	1835	4.512	0.47	1.06
64	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
65	371	99	21	870	321	644	1835	4.4556	0.47	1.06
66	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
67	367	103	22	870	321	644	1835	4.3992	0.48	1.05
68	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
69	362	108	23	870	321	644	1835	4.3428	0.49	1.05
70	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
71	357	113	24	870	321	644	1835	4.2864	0.49	1.05
72	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05

73	353	118	25	870	321	644	1835	4.23	0.49	1.00
74	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
75	348	122	26	870	321	644	1835	4.1736	0.50	1.00
76	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
77	343	127	27	870	321	644	1835	4.1172	0.51	1.00
78	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
79	338	132	28	870	321	644	1835	4.0608	0.51	1.00
80	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
81	334	136	29	870	321	644	1835	4.0044	0.52	1.00
82	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
83	329	141	30	870	321	644	1835	3.948	0.52	0.96
84	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
85	324	146	31	870	321	644	1835	3.8916	0.53	0.96
86	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
87	320	150	32	870	321	644	1835	3.8352	0.54	0.97
88	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
89	315	155	33	870	321	644	1835	3.7788	0.55	0.97
90	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
91	310	160	34	870	321	644	1835	3.7224	0.55	0.97
92	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
93	306	165	35	870	321	644	1835	3.666	0.56	0.97
94	376	94	20	870	321	644	1835	4.512	0.47	1.06
95	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
96	371	99	21	870	321	644	1835	4.4556	0.47	1.06
97	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
98	367	103	22	870	321	644	1835	4.3992	0.48	1.05
99	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
100	362	108	23	870	321	644	1835	4.3428	0.49	1.05
101	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
102	357	113	24	870	321	644	1835	4.2864	0.49	1.05
103	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
104	353	118	25	870	321	644	1835	4.23	0.49	1.00
105	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
106	348	122	26	870	321	644	1835	4.1736	0.50	1.00
107	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
108	343	127	27	870	321	644	1835	4.1172	0.51	1.00
109	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
110	338	132	28	870	321	644	1835	4.0608	0.51	1.00
111	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00

112	334	136	29	870	321	644	1835	4.0044	0.52	1.00
113	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
114	329	141	30	870	321	644	1835	3.948	0.52	0.96
115	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
116	324	146	31	870	321	644	1835	3.8916	0.53	0.96
117	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
118	320	150	32	870	321	644	1835	3.8352	0.54	0.97
119	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
120	315	155	33	870	321	644	1835	3.7788	0.55	0.97
121	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
122	310	160	34	870	321	644	1835	3.7224	0.55	0.97
123	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
124	306	165	35	870	321	644	1835	3.666	0.56	0.97
125	376	94	20	870	321	644	1835	4.512	0.47	1.06
126	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
127	371	99	21	870	321	644	1835	4.4556	0.47	1.06
128	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
129	367	103	22	870	321	644	1835	4.3992	0.48	1.05
130	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
131	362	108	23	870	321	644	1835	4.3428	0.49	1.05
132	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
133	357	113	24	870	321	644	1835	4.2864	0.49	1.05
134	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
135	353	118	25	870	321	644	1835	4.23	0.49	1.00
136	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
137	348	122	26	870	321	644	1835	4.1736	0.50	1.00
138	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
139	343	127	27	870	321	644	1835	4.1172	0.51	1.00
140	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
141	338	132	28	870	321	644	1835	4.0608	0.51	1.00
142	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
143	334	136	29	870	321	644	1835	4.0044	0.52	1.00
144	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
145	329	141	30	870	321	644	1835	3.948	0.52	0.96
146	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
147	324	146	31	870	321	644	1835	3.8916	0.53	0.96
148	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
149	320	150	32	870	321	644	1835	3.8352	0.54	0.97
150	317	153	32.5	870	321	644	1835	3.807	0.54	0.97

151	315	155	33	870	321	644	1835	3.7788	0.55	0.97
152	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
153	310	160	34	870	321	644	1835	3.7224	0.55	0.97
154	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
155	306	165	35	870	321	644	1835	3.666	0.56	0.97
156	376	94	20	870	321	644	1835	4.512	0.47	1.06
157	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
158	371	99	21	870	321	644	1835	4.4556	0.47	1.06
159	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
160	367	103	22	870	321	644	1835	4.3992	0.48	1.05
161	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
162	362	108	23	870	321	644	1835	4.3428	0.49	1.05
163	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
164	357	113	24	870	321	644	1835	4.2864	0.49	1.05
165	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
166	353	118	25	870	321	644	1835	4.23	0.49	1.00
167	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
168	348	122	26	870	321	644	1835	4.1736	0.50	1.00
169	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
170	343	127	27	870	321	644	1835	4.1172	0.51	1.00
171	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
172	338	132	28	870	321	644	1835	4.0608	0.51	1.00
173	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
174	334	136	29	870	321	644	1835	4.0044	0.52	1.00
175	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
176	329	141	30	870	321	644	1835	3.948	0.52	0.96
177	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
178	324	146	31	870	321	644	1835	3.8916	0.53	0.96
179	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
180	320	150	32	870	321	644	1835	3.8352	0.54	0.97
181	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
182	315	155	33	870	321	644	1835	3.7788	0.55	0.97
183	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
184	310	160	34	870	321	644	1835	3.7224	0.55	0.97
185	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
186	306	165	35	870	321	644	1835	3.666	0.56	0.97
187	376	94	20	870	321	644	1835	4.512	0.47	1.06
188	374	96	20.5	870	321	644	1835	4.4838	0.47	1.06
189	371	99	21	870	321	644	1835	4.4556	0.47	1.06

190	369	101	21.5	870	321	644	1835	4.4274	0.48	1.06
191	367	103	22	870	321	644	1835	4.3992	0.48	1.05
192	364	106	22.5	870	321	644	1835	4.371	0.48	1.05
193	362	108	23	870	321	644	1835	4.3428	0.49	1.05
194	360	110	23.5	870	321	644	1835	4.3146	0.49	1.05
195	357	113	24	870	321	644	1835	4.2864	0.49	1.05
196	355	115	24.5	870	321	644	1835	4.2582	0.50	1.05
197	353	118	25	870	321	644	1835	4.23	0.49	1.00
198	350	120	25.5	870	321	644	1835	4.2018	0.50	1.00
199	348	122	26	870	321	644	1835	4.1736	0.50	1.00
200	345	125	26.5	870	321	644	1835	4.1454	0.50	1.00
201	343	127	27	870	321	644	1835	4.1172	0.51	1.00
202	341	129	27.5	870	321	644	1835	4.089	0.51	1.00
203	338	132	28	870	321	644	1835	4.0608	0.51	1.00
204	336	134	28.5	870	321	644	1835	4.0326	0.52	1.00
205	334	136	29	870	321	644	1835	4.0044	0.52	1.00
206	331	139	29.5	870	321	644	1835	3.9762	0.53	1.00
207	329	141	30	870	321	644	1835	3.948	0.52	0.96
208	327	143	30.5	870	321	644	1835	3.9198	0.53	0.96
209	324	146	31	870	321	644	1835	3.8916	0.53	0.96
210	322	148	31.5	870	321	644	1835	3.8634	0.53	0.97
211	320	150	32	870	321	644	1835	3.8352	0.54	0.97
212	317	153	32.5	870	321	644	1835	3.807	0.54	0.97
213	315	155	33	870	321	644	1835	3.7788	0.55	0.97
214	313	157	33.5	870	321	644	1835	3.7506	0.55	0.97
215	310	160	34	870	321	644	1835	3.7224	0.55	0.97
216	308	162	34.5	870	321	644	1835	3.6942	0.56	0.97
217	306	165	35	870	321	644	1835	3.666	0.56	0.97

APPENDIX III

Results of efficiency factor (K-value) for M30

Sr. no	OPC	FA	% FA	C/Sand	CA I	CA II	Total Agg	Admixture	W/C	Efficiency Factor (K value)
1	336	84	20	820	468	595	1883	4.032	0.49	-0.51
2	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
3	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
4	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
5	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
6	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
7	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
8	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
9	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
10	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
11	315	105	25	820	468	595	1883	3.78	0.51	-0.24
12	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
13	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
14	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
15	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
16	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
17	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
18	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
19	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
20	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
21	294	126	30	820	468	595	1883	3.528	0.54	-0.07
22	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
23	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
24	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
25	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
26	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
27	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
28	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
29	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
30	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
31	273	147	35	820	468	595	1883	3.276	0.59	0.09
32	336	84	20	820	468	595	1883	4.032	0.49	-0.51
33	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48

34	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
35	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
36	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
37	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
38	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
39	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
40	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
41	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
42	315	105	25	820	468	595	1883	3.78	0.51	-0.24
43	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
44	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
45	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
46	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
47	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
48	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
49	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
50	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
51	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
52	294	126	30	820	468	595	1883	3.528	0.54	-0.07
53	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
54	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
55	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
56	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
57	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
58	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
59	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
60	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
61	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
62	273	147	35	820	468	595	1883	3.276	0.59	0.09
63	336	84	20	820	468	595	1883	4.032	0.49	-0.51
64	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
65	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
66	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
67	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
68	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
69	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
70	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
71	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
72	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24

73	315	105	25	820	468	595	1883	3.78	0.51	-0.24
74	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
75	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
76	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
77	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
78	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
79	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
80	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
81	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
82	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
83	294	126	30	820	468	595	1883	3.528	0.54	-0.07
84	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
85	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
86	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
87	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
88	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
89	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
90	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
91	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
92	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
93	273	147	35	820	468	595	1883	3.276	0.59	0.09
94	336	84	20	820	468	595	1883	4.032	0.49	-0.51
95	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
96	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
97	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
98	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
99	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
100	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
101	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
102	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
103	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
104	315	105	25	820	468	595	1883	3.78	0.51	-0.24
105	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
106	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
107	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
108	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
109	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
110	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
111	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09

112	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
113	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
114	294	126	30	820	468	595	1883	3.528	0.54	-0.07
115	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
116	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
117	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
118	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
119	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
120	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
121	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
122	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
123	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
124	273	147	35	820	468	595	1883	3.276	0.59	0.09
125	336	84	20	820	468	595	1883	4.032	0.49	-0.51
126	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
127	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
128	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
129	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
130	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
131	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
132	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
133	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
134	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
135	315	105	25	820	468	595	1883	3.78	0.51	-0.24
136	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
137	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
138	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
139	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
140	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
141	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
142	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
143	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
144	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
145	294	126	30	820	468	595	1883	3.528	0.54	-0.07
146	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
147	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
148	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
149	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
150	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02

151	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
152	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
153	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
154	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
155	273	147	35	820	468	595	1883	3.276	0.59	0.09
156	336	84	20	820	468	595	1883	4.032	0.49	-0.51
157	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
158	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44
159	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
160	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
161	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
162	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
163	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
164	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
165	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
166	315	105	25	820	468	595	1883	3.78	0.51	-0.24
167	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
168	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
169	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
170	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
171	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
172	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
173	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
174	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
175	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
176	294	126	30	820	468	595	1883	3.528	0.54	-0.07
177	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
178	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
179	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
180	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
181	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
182	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
183	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
184	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
185	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
186	273	147	35	820	468	595	1883	3.276	0.59	0.09
187	336	84	20	820	468	595	1883	4.032	0.49	-0.51
188	333.9	86.1	20.5	820	468	595	1883	4.0068	0.49	-0.48
189	331.8	88.2	21	820	468	595	1883	3.9816	0.49	-0.44

190	329.7	90.3	21.5	820	468	595	1883	3.9564	0.50	-0.41
191	327.6	92.4	22	820	468	595	1883	3.9312	0.50	-0.38
192	325.5	94.5	22.5	820	468	595	1883	3.906	0.50	-0.35
193	323.4	96.6	23	820	468	595	1883	3.8808	0.51	-0.32
194	321.3	98.7	23.5	820	468	595	1883	3.8556	0.51	-0.29
195	319.2	100.8	24	820	468	595	1883	3.8304	0.51	-0.26
196	317.1	102.9	24.5	820	468	595	1883	3.8052	0.52	-0.24
197	315	105	25	820	468	595	1883	3.78	0.51	-0.24
198	312.9	107.1	25.5	820	468	595	1883	3.7548	0.52	-0.22
199	310.8	109.2	26	820	468	595	1883	3.7296	0.52	-0.20
200	308.7	111.3	26.5	820	468	595	1883	3.7044	0.52	-0.17
201	306.6	113.4	27	820	468	595	1883	3.6792	0.53	-0.15
202	304.5	115.5	27.5	820	468	595	1883	3.654	0.53	-0.13
203	302.4	117.6	28	820	468	595	1883	3.6288	0.54	-0.11
204	300.3	119.7	28.5	820	468	595	1883	3.6036	0.54	-0.09
205	298.2	121.8	29	820	468	595	1883	3.5784	0.54	-0.07
206	296.1	123.9	29.5	820	468	595	1883	3.5532	0.55	-0.05
207	294	126	30	820	468	595	1883	3.528	0.54	-0.07
208	291.9	128.1	30.5	820	468	595	1883	3.5028	0.55	-0.05
209	289.8	130.2	31	820	468	595	1883	3.4776	0.55	-0.03
210	287.7	132.3	31.5	820	468	595	1883	3.4524	0.56	-0.02
211	285.6	134.4	32	820	468	595	1883	3.4272	0.56	0.00
212	283.5	136.5	32.5	820	468	595	1883	3.402	0.56	0.02
213	281.4	138.6	33	820	468	595	1883	3.3768	0.57	0.03
214	279.3	140.7	33.5	820	468	595	1883	3.3516	0.57	0.05
215	277.2	142.8	34	820	468	595	1883	3.3264	0.58	0.06
216	275.1	144.9	34.5	820	468	595	1883	3.3012	0.58	0.07
217	273	147	35	820	468	595	1883	3.276	0.59	0.09

APPENDIX IV

Results of efficiency factor (K-value) for M25

Sr. no	OPC	FA	% FA	C/Sand	CA I	CA II	Total Agg	Admixture	W/C	Efficiency Factor (K value)
1	312	78	20	925	380	600	1905	3.744	0.53	-0.44
2	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
3	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
4	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
5	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
6	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
7	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
8	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
9	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
10	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
11	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
12	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
13	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
14	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
15	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
16	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
17	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
18	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
19	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
20	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
21	273	117	30	925	380	600	1905	3.276	0.59	-0.02
22	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
23	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
24	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
25	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
26	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
27	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
28	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
29	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
30	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
31	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
32	312	78	20	925	380	600	1905	3.744	0.53	-0.44
33	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40

34	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
35	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
36	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
37	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
38	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
39	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
40	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
41	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
42	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
43	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
44	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
45	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
46	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
47	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
48	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
49	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
50	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
51	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
52	273	117	30	925	380	600	1905	3.276	0.59	-0.02
53	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
54	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
55	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
56	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
57	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
58	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
59	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
60	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
61	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
62	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
63	312	78	20	925	380	600	1905	3.744	0.53	-0.44
64	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
65	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
66	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
67	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
68	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
69	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
70	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
71	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
72	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17

73	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
74	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
75	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
76	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
77	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
78	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
79	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
80	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
81	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
82	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
83	273	117	30	925	380	600	1905	3.276	0.59	-0.02
84	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
85	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
86	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
87	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
88	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
89	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
90	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
91	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
92	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
93	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
94	312	78	20	925	380	600	1905	3.744	0.53	-0.44
95	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
96	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
97	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
98	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
99	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
100	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
101	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
102	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
103	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
104	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
105	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
106	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
107	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
108	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
109	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
110	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
111	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04

112	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
113	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
114	273	117	30	925	380	600	1905	3.276	0.59	-0.02
115	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
116	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
117	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
118	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
119	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
120	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
121	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
122	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
123	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
124	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
125	312	78	20	925	380	600	1905	3.744	0.53	-0.44
126	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
127	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
128	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
129	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
130	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
131	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
132	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
133	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
134	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
135	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
136	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
137	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
138	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
139	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
140	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
141	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
142	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
143	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
144	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
145	273	117	30	925	380	600	1905	3.276	0.59	-0.02
146	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
147	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
148	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
149	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
150	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06

151	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
152	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
153	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
154	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
155	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
156	312	78	20	925	380	600	1905	3.744	0.53	-0.44
157	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
158	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37
159	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
160	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
161	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
162	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
163	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
164	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
165	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
166	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
167	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
168	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
169	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
170	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
171	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
172	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
173	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
174	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
175	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
176	273	117	30	925	380	600	1905	3.276	0.59	-0.02
177	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
178	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
179	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
180	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
181	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
182	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
183	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
184	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
185	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
186	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13
187	312	78	20	925	380	600	1905	3.744	0.53	-0.44
188	310.05	79.95	20.5	925	380	600	1905	3.7206	0.53	-0.40
189	308.1	81.9	21	925	380	600	1905	3.6972	0.53	-0.37

190	306.15	83.85	21.5	925	380	600	1905	3.6738	0.54	-0.34
191	304.2	85.8	22	925	380	600	1905	3.6504	0.54	-0.31
192	302.25	87.75	22.5	925	380	600	1905	3.627	0.54	-0.28
193	300.3	89.7	23	925	380	600	1905	3.6036	0.55	-0.25
194	298.35	91.65	23.5	925	380	600	1905	3.5802	0.55	-0.22
195	296.4	93.6	24	925	380	600	1905	3.5568	0.55	-0.20
196	294.45	95.55	24.5	925	380	600	1905	3.5334	0.56	-0.17
197	292.5	97.5	25	925	380	600	1905	3.51	0.55	-0.18
198	290.55	99.45	25.5	925	380	600	1905	3.4866	0.56	-0.16
199	288.6	101.4	26	925	380	600	1905	3.4632	0.56	-0.14
200	286.65	103.35	26.5	925	380	600	1905	3.4398	0.57	-0.12
201	284.7	105.3	27	925	380	600	1905	3.4164	0.57	-0.10
202	282.75	107.25	27.5	925	380	600	1905	3.393	0.57	-0.08
203	280.8	109.2	28	925	380	600	1905	3.3696	0.58	-0.06
204	278.85	111.15	28.5	925	380	600	1905	3.3462	0.58	-0.04
205	276.9	113.1	29	925	380	600	1905	3.3228	0.59	-0.02
206	274.95	115.05	29.5	925	380	600	1905	3.2994	0.59	0.00
207	273	117	30	925	380	600	1905	3.276	0.59	-0.02
208	271.05	118.95	30.5	925	380	600	1905	3.2526	0.59	0.00
209	269.1	120.9	31	925	380	600	1905	3.2292	0.59	0.02
210	267.15	122.85	31.5	925	380	600	1905	3.2058	0.60	0.03
211	265.2	124.8	32	925	380	600	1905	3.1824	0.60	0.05
212	263.25	126.75	32.5	925	380	600	1905	3.159	0.61	0.06
213	261.3	128.7	33	925	380	600	1905	3.1356	0.61	0.08
214	259.35	130.65	33.5	925	380	600	1905	3.1122	0.62	0.09
215	257.4	132.6	34	925	380	600	1905	3.0888	0.62	0.10
216	255.45	134.55	34.5	925	380	600	1905	3.0654	0.63	0.12
217	253.5	136.5	35	925	380	600	1905	3.042	0.63	0.13

APPENDIX V

Results of efficiency factor (K-value) for M20

Sr. no	OPC	FA	% FA	C/Sand	CA I	CA II	Total Agg	Admixture	W/C	Efficiency Factor (K value)
1	272	68	20	950	450	570	1970	3.264	0.59	-0.32
2	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
3	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
4	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
5	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
6	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
7	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
8	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
9	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
10	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
11	255	85	25	950	450	570	1970	3.06	0.62	-0.10
12	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
13	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
14	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
15	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
16	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
17	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
18	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
19	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
20	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
21	238	102	30	950	450	570	1970	2.856	0.66	0.06
22	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
23	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
24	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
25	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
26	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
27	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
28	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
29	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
30	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
31	221	119	35	950	450	570	1970	2.652	0.71	0.19
32	272	68	20	950	450	570	1970	3.264	0.59	-0.32
33	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29

34	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
35	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
36	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
37	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
38	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
39	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
40	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
41	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
42	255	85	25	950	450	570	1970	3.06	0.62	-0.10
43	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
44	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
45	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
46	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
47	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
48	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
49	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
50	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
51	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
52	238	102	30	950	450	570	1970	2.856	0.66	0.06
53	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
54	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
55	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
56	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
57	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
58	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
59	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
60	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
61	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
62	221	119	35	950	450	570	1970	2.652	0.71	0.19
63	272	68	20	950	450	570	1970	3.264	0.59	-0.32
64	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
65	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
66	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
67	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
68	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
69	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
70	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
71	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
72	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08

73	255	85	25	950	450	570	1970	3.06	0.62	-0.10
74	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
75	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
76	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
77	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
78	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
79	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
80	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
81	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
82	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
83	238	102	30	950	450	570	1970	2.856	0.66	0.06
84	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
85	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
86	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
87	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
88	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
89	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
90	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
91	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
92	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
93	221	119	35	950	450	570	1970	2.652	0.71	0.19
94	272	68	20	950	450	570	1970	3.264	0.59	-0.32
95	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
96	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
97	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
98	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
99	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
100	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
101	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
102	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
103	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
104	255	85	25	950	450	570	1970	3.06	0.62	-0.10
105	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
106	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
107	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
108	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
109	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
110	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
111	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04

112	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
113	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
114	238	102	30	950	450	570	1970	2.856	0.66	0.06
115	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
116	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
117	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
118	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
119	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
120	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
121	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
122	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
123	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
124	221	119	35	950	450	570	1970	2.652	0.71	0.19
125	272	68	20	950	450	570	1970	3.264	0.59	-0.32
126	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
127	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
128	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
129	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
130	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
131	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
132	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
133	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
134	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
135	255	85	25	950	450	570	1970	3.06	0.62	-0.10
136	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
137	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
138	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
139	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
140	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
141	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
142	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
143	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
144	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
145	238	102	30	950	450	570	1970	2.856	0.66	0.06
146	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
147	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
148	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
149	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
150	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13

151	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
152	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
153	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
154	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
155	221	119	35	950	450	570	1970	2.652	0.71	0.19
156	272	68	20	950	450	570	1970	3.264	0.59	-0.32
157	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
158	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26
159	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
160	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
161	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
162	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
163	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
164	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
165	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
166	255	85	25	950	450	570	1970	3.06	0.62	-0.10
167	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
168	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
169	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
170	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
171	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
172	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
173	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
174	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
175	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
176	238	102	30	950	450	570	1970	2.856	0.66	0.06
177	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
178	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
179	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
180	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
181	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
182	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
183	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
184	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
185	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
186	221	119	35	950	450	570	1970	2.652	0.71	0.19
187	272	68	20	950	450	570	1970	3.264	0.59	-0.32
188	270.3	69.7	20.5	950	450	570	1970	3.2436	0.59	-0.29
189	268.6	71.4	21	950	450	570	1970	3.2232	0.60	-0.26

190	266.9	73.1	21.5	950	450	570	1970	3.2028	0.60	-0.23
191	265.2	74.8	22	950	450	570	1970	3.1824	0.60	-0.20
192	263.5	76.5	22.5	950	450	570	1970	3.162	0.61	-0.18
193	261.8	78.2	23	950	450	570	1970	3.1416	0.61	-0.15
194	260.1	79.9	23.5	950	450	570	1970	3.1212	0.62	-0.13
195	258.4	81.6	24	950	450	570	1970	3.1008	0.62	-0.10
196	256.7	83.3	24.5	950	450	570	1970	3.0804	0.62	-0.08
197	255	85	25	950	450	570	1970	3.06	0.62	-0.10
198	253.3	86.7	25.5	950	450	570	1970	3.0396	0.62	-0.07
199	251.6	88.4	26	950	450	570	1970	3.0192	0.63	-0.05
200	249.9	90.1	26.5	950	450	570	1970	2.9988	0.63	-0.03
201	248.2	91.8	27	950	450	570	1970	2.9784	0.64	-0.01
202	246.5	93.5	27.5	950	450	570	1970	2.958	0.64	0.00
203	244.8	95.2	28	950	450	570	1970	2.9376	0.65	0.02
204	243.1	96.9	28.5	950	450	570	1970	2.9172	0.65	0.04
205	241.4	98.6	29	950	450	570	1970	2.8968	0.65	0.06
206	239.7	100.3	29.5	950	450	570	1970	2.8764	0.66	0.07
207	238	102	30	950	450	570	1970	2.856	0.66	0.06
208	236.3	103.7	30.5	950	450	570	1970	2.8356	0.66	0.07
209	234.6	105.4	31	950	450	570	1970	2.8152	0.66	0.09
210	232.9	107.1	31.5	950	450	570	1970	2.7948	0.67	0.10
211	231.2	108.8	32	950	450	570	1970	2.7744	0.67	0.12
212	229.5	110.5	32.5	950	450	570	1970	2.754	0.68	0.13
213	227.8	112.2	33	950	450	570	1970	2.7336	0.68	0.14
214	226.1	113.9	33.5	950	450	570	1970	2.7132	0.69	0.15
215	224.4	115.6	34	950	450	570	1970	2.6928	0.70	0.17
216	222.7	117.3	34.5	950	450	570	1970	2.6724	0.70	0.18
217	221	119	35	950	450	570	1970	2.652	0.71	0.19

APPENDIX VI

Cost analysis for different grades of concrete

Mix Code	M40			
	20%	25%	30%	35%
OPC (Rs)	2,756	2,584	2,412	2,239
FA (Rs)	268	335	402	469
C/sand (Rs)	580	580	580	580
CAI (Rs)	302	302	302	302
CAII (Rs)	492	492	492	492
Admixture (Rs)	1,051	1,051	1,051	1,051
Water (Rs)	36	36	36	36
Total Cost (Rs)	5,485	5,380	5,275	5,169
Strength (MPa)	49.53	46.33	42.49	38.71
k-factor	-0.23	0.02	0.18	0.3

Mix Code	M35			
	20%	25%	30%	35%
OPC (Rs)	2,444	2,295	2,139	1,983
FA (Rs)	238	296	357	417
FA (%)	20	25	30	35
C/sand (Rs)	782	782	782	5782
CAI (Rs)	238	238	238	238
CAII (Rs)	496	496	496	496
Admixture (Rs)	932	932	932	932
Water (Rs)	35.2	35.2	35.2	35.2
Total Cost (Rs)	5,165	5,074	4,978	4,883
Strength (MPa)	41.02	39.87	36.51	33.25
k-factor	1.06	1.05	1.04	1.03

Mix Code	M25			
	20%	25%	30%	35%
OPC (Rs)	2,028	1,901	1,775	1,648
FA (Rs)	197	247	296	345
FA (%)	20	25	30	35
C/sand (Rs)	828	828	828	828
CAI (Rs)	281	281	281	281
CAII (Rs)	462	462	462	462
Admixture (Rs)	774	774	774	774
Water (Rs)	32.8	32.8	32.8	32.8
Total Cost (Rs)	4,603	4,526	4,449	4,371
Strength (MPa)	35.12	33.58	31.48	28.58
k-factor	-0.44	-0.15	0.04	0.18

Mix Code	M30			
	20%	25%	30%	35%
OPC (Rs)	2,184	2,048	1,911	1,775
FA (Rs)	213	266	319	372
FA (%)	20	25	30	35
C/sand (Rs)	736	736	736	736
CAI (Rs)	348	348	348	348
CAII (Rs)	459	459	459	459
Admixture (Rs)	833	833	833	833
Water (Rs)	32.8	32.8	32.8	32.8
Total Cost (Rs)	4,806	4,722	4,639	4,556
Strength (MPa)	37.63	36.15	35.84	32.68
k-factor	-0.51	-0.21	-0.01	0.14

Mix Code	M20			
	20%	25%	30%	35%
OPC (Rs)	1,768	1,658	1,547	1,437
FA (Rs)	172	215	258	301
FA (%)	20	25	30	35
C/sand (Rs)	851	851	851	851
CAI (Rs)	335	335	335	335
CAII (Rs)	439	439	439	439
Admixture (Rs)	674	674	674	674
Water (Rs)	32	32	32	32
Total Cost (Rs)	4,271	4,204	4,136	4,069
Strength (MPa)	27.12	24.71	22.61	19.87
k-factor	-0.32	-0.06	0.12	0.24

LIST OF PUBLICATIONS

International Journal

1. "Efficiency Factor of Supplementary Cementitious Materials: A State of Art", *International Journal of Optimization in Civil Engineering* (Under Review, Communicated on 27th March 2017)
2. Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis", *Canadian Journal of Civil Engineering* (Under Review, Communicated on 30th June 2017)

ACKNOWLEDGEMENT

First and foremost, I am thankful to my guide Dr. R. B. Magar for his aspiring guidance, invaluable constructive criticism and advice during the project work. I am sincerely grateful to him for sharing his truthful and illuminating views on a number of issues related to the project.

I am thankful to Dr. Abdul Razak Honnutagi, Director, AIKTC, for providing me the required infrastructure, timely guidance and administrative support.

I am highly thankful to all faculties of M.E. (CEM) for their timely support and encouragement throughout this work. Also, I'm grateful to library staff for their assistance, useful views and tips.

I am thankful to Mr. Sanjeev Raje and Mr. Mehdi Abbas, Navdeep Construction Company Q.C Staffs for their valuable help, advice and encouragement throughout the completion of my work.

I would like to take this opportunity to thank all my classmates for their timely help during the course of completion of this report.

Last but not the least, I would like to thank my parents for supporting me spiritually throughout writing this dissertation and almighty god for his showers of blessings.