Chapter 1 Introduction

1.1 Introduction: Concrete is most widely used man-made construction material and will continue to be use in various forms of structure. Such a versatility of concrete to mould in any shape and size is due to the fact that the proportioning of basic ingredients of concrete likes cement, aggregates, water and sometimes admixtures; it is possible to tailor the properties of concrete so as to meet the desired properties of concrete at any particular situation.

Many different factors are taken into account, during the concrete mix design process. These factors can be heuristic or arising from previous experience in the form of empirical tables and graphs. There is no perfect relation established between these factors, as the codal guidelines have a non-numerical structure which is very difficult to quantify and hence they can be better expressed by linguistic values with fuzzy inference system which provides a prudent way to present uncertainty involved at various stages of concrete mix design.

The problem is how to incorporate these linguistic values into numerical analysis. While taking the decision when using such kind of information domain is having two possibilities. To put the linguistic numbers as numbers and arrive at outcome or to skip this knowledge during the numerical analysis and after getting the final result, modify it so as to meet to the desired properties taken into account the designer expertise.

The problem is that both approaches are not appropriate, in the first, while transferring the linguistic knowledge into numerical values much information is lost during the process; in the second approach, final result is required to be modified to meet the expected outcome e.g. increase in strength of concrete is achieved by minimum water cement ratio and aggregate cement ratio. However, it has not been possible to develop a precise mathematical model that can predict exact numerical crisp values of strength which correspond to crisp values of water cement ratio and aggregate cement ratio. It may due to uncertainties involved in various parameters and their uncertain behavior of constitute materials and tolerances. The conventional methods are based on the linear relationship among the variables holding the crisp numerical values. The output using these crisp values end up with some vague crisp values which requires adjustments through trial and errors to achieve the target values.

1.2 Basics of concrete: The concrete comprises of aggregate, fine and coarse with binding material such as cementitious material with sufficient workability by adding water which imparts strength.

Cement: Cement is the most important constituent of concrete. It acts a binding material and imparts strength, durability and permeability to the concrete. The tests
carried out on cement are; fineness, setting time, soundness, compressive strength and chemical composition.

**Single phase system**

![Single phase system diagram]

**Two phase system**

![Two phase system diagram]

**Three phase system**

![Three phase system diagram]

**Four phase system**

![Four phase system diagram]

**Five phase system**

![Five phase system diagram]

**Figure 1.1 Concrete as a five phase system**

**Aggregates:** Aggregates which occupy nearly 70 to 75 % of concrete are inert ingredients. Proper selection of the shape and particle size gradation of the aggregates sizes affects the workability and the hardened concrete properties. Aggregates are generally economical than cement and providing greater volume stability and durability to concrete.

**Water:** Water used for making and curing of concrete shall be clean and free from oils, acids, salts, alkalis, sugar and organic materials or other substances which may be deleterious to concrete. Potable water is generally suitable for mixing concrete.

**Admixtures:** A material which is used to modify or improve the properties of concrete in the plastic or hardened state is termed as admixtures. These are other than the basic ingredients of concrete like pozzolana or slag and fiber reinforcement.

**Concrete:** Concrete is an extremely versatile building composite material because, as it can be designed for low strength to high strength ranging from M10 to M100 and
workability ranging from 0 mm to 150 mm slump. In all these cases the basic ingredients of concrete are same, but it is their relative proportion that makes the different quality and properties of concretes which satisfy properties both in the fresh and hardened states. Properties desired from concrete in plastic stage are workability, cohesiveness, and initial setting of cement and in hardened stage is strength, imperviousness, durability

1.3 **Concrete as a five phase system:** A Concrete mass is considered as a five phase system as shown in Figure 1.1. Single phase system is considered to start with the cement powder as a basic ingredient of concrete. Water plays important role to activate the chemical reaction between cement and hydration process start in two phase system. To maintain the sufficient workability, fine aggregate particles plays important role and develops cement mortar in three phase system. Coarse aggregate provides strength to the concrete and acts as a five phase system which imparts durability to the concrete. Special concrete can be obtained by improving properties of concrete by addition of admixtures in the five phase system.

1.4 **Concrete mix design:** Design of concrete mix involves determination of the proportions of the given constituents, which satisfy the mix requirement with available materials specification. Concrete mix design is a standardized well established procedure adopted in various developed countries based on codal guidelines of each country.

The three well known methods of concrete mix design which are most widely used based on codal guidelines are:

- Indian Standard Institute Concrete Mix Design (ISI) Method [1]
- American Concrete Institute Mix Design (ACI) Method [2]
- Department of Environmental Engineering Mix Design (DOE) Method [3]

Existing methods of concrete mix design require large number of trial mixes to achieve the required plastic and harden stage properties of concrete with available materials. However, a good concrete mix design method is one which requires minimum number of trials and achieves an economical and satisfactory mix with desired properties. The general philosophies of different concrete mix proportioning methods are as follows;

1] Select the water cement ratio for the required strength.

2] Estimate the water content sufficient for required workability and aggregate surface area paste characteristics.

3] Obtain cement content based on estimated water content and water cement ratio selected as per durability criteria.

4] Estimate the coarse aggregate content based on fineness modulus of fine aggregate or aggregate grading.
5] Finally, fine aggregate content are obtained.

The objective of proportioning concrete mix is to design the most economical concrete that will satisfy the performance requirements under specific conditions of use.

1.5 Time line of concrete mix design: The time line historical developments in the field of concrete are discussed in this section.

2,000,000 BC : Discovered in Israel, natural deposits of cement compounds formed due to reactions initiated between limestone and oil shale with spontaneous combustion.

6500 BC : A form of concrete was discovered by archaeologists in Syria.

3000 BC : Chinese used cementitious materials to hold the bamboo together in their boats and in the Great Wall.

2500 BC : Egyptians used mud mixed with straw to bind dried bricks. For building the Pyramids they discovered lime and gypsum mortar as a binding agent.

800 BC : The Babylonians and Assyrians were used bitumen to bind large and small stone objects together and bricks.

600 BC : The Greeks peoples were discovered a natural pozzolana on Santorini Island, which was used to develop a hydraulic properties of concrete when mixed with the lime. It is possible to produce concrete which would harden under water, as well as in the air.

300 BC : Romans used slaked lime, a volcanic ash called pozzolana. They used lime as a cementitious material.

75 BC : Romans used a pozzolanic, obtained from a ground mix of lime and volcanic ash containing silica and alumina. The name pozzolanic cement was obtained as the volcanic material was discovered near the city Pozzouli of Italy.

44 BC : The Palatine hill is one of the most ancient parts of the city Rome, Italy. It is 70 meters high and looks down on one side upon the Forum Romanum and on the other side upon the Circus Maximus.

82 AD : The Colosseum is completed using large amounts of Roman concrete.

1812 – 1813 : Louis Vicat of France prepared an artificial hydraulic lime by calcining synthetic mix of limestone and clay.

1818 : Maurice St. Leger was granted a patent for manufacturing process of hydraulic cement.
1822: James Frost of England was prepared an artificial hydraulic lime and called it British Cement.

1824: Joseph Aspdin, a bricklayer and mason patented portland cement, since it resembled the stone quarried from the Isle of Portland British coast.

1905: The National Association of Cement Users is formed, which later was renamed the American Concrete Institute.

1936: The Hoover Dam and Grand Coulee Dam were built with concrete. The horizontal arch design ensures that the great compressive strength of concrete is employed.

1961: Le Corbusier builds the government complex at Chandigarh, India.

1970: Fiber reinforcement in concrete was introduced.

1985: Silica fume also known as micro silica which 100 times fine than the cement was introduced in the building, Union Plaza constructed in Seattle, Washington.

1997: Portland Cement Association reported that at least 104 million tons of concrete was recycled in the United States.

2009: The China's Three Gorges Dam project were used 27.2 million cubic meters of concrete mainly for the dam wall of 181 meters high.

1.6 Concept of fuzzy logic: Fuzzy logic is not a logic that is fuzzy but a logic that is used to describe vagueness involved in various parameters of complex engineering problems. Fuzzy logic is based on the idea that all things admit of degrees. A fuzzy set is characterized by a membership curves which assigns to each object a grade of membership ranging between zero and one. The inclusion, union, intersections, complement, relation, convexity, etc., are applicable to such sets, and various properties are established to fuzzy sets [5].

The theory of fuzzy logic was introduced by Zadeh [6]. In traditional Boolean logic, an outcome either belongs to a set or it does not i.e. the expression $x \in A$ is either completely true or false. However, in a fuzzy set, truth value of the said expression can fall between true and false. The extent to which an object belongs to the fuzzy set is represented by a degree of membership, which is a real number in the unit interval (0,1).

Fuzzy logic is a multi valued logic which also take into account the intermediate values between conventional evaluations like completely true or false, yes or no, high or low, etc. The linguistic language can be formulated mathematically using membership function and processed by computers, in order to apply a more human-brain like way of thinking in the computers [7].
**Linguistic Variables:** Fuzzy set theory deals with information linguistically, which performs numerical computation by using linguistic statement presented in the form of different types of membership functions.

**Membership Function:** Membership function is essentially a curve that defines every point in the input space is mapped to a degree of membership function value between 0 and 1. The X-axis represents the range of all possible values of chosen variable the universe of discourse. The Y-axis represents the membership value of the fuzzy set.

The concept of fuzzy set was preliminarily introduced by Zadeh [5], by replacing the Aristotelian logic which has two possibilities only. Although fuzzy logic was brought forward by Zadeh [5] in 1965, the concept of fuzzy systems attracted a more attention when a real control application was conducted by Mamdani and Assilian [8].

Fuzzy logic implements human experiences and preferences through membership functions and fuzzy rules. The fuzzy rules, which establish desirable relationships at a high level in a linguistic form are typically written as antecedent, the input parameters and consequent, the IF-Then statements.

Since the procedures used by human mind to manipulate the data are fuzzy in nature, a fuzzy frame based five layer fuzzy inference system has been proposed to design a concrete mix by using standard codal guidelines methods like Indian Standard Institute (ISI) method, American Concrete Institute (ACI) method and Department of Environmental Engineering (DOE) method.

1.7 **Concept of artificial neural network:** Artificial neural networks (ANN) system provides the output parameters based on learning environments provided through training history similar to human brain working capability. [9] ANN has some distinguished characteristics in knowledge and information processing and analysis due to its similarity with the human brain. Therefore, an ANN can be used as a powerful tool for engineering applications. [10] The first study on ANN is supposed to have started in 1943. McCulloch and Warrens [11] defined artificial neurons for the first time and developed a neuron model as in Figure 1.2.

![Artificial neuron model](image)

**Figure 1.2** Artificial neuron model
As it can be seen from Figure 1.2, an artificial neuron is mainly consisting of five main components. The inputs, weights, sum function, activation function and outputs. Input neurons hold the information from input variables values. The weights \( W_{ij} \) are assigned to perform the network with minimum errors. Sum function calculates the effect of net inputs and weights on this process element that comes to a neuron. [12, 13] The sums of the weighted input components \((\text{net})_j\) are calculated using Equation (1.1).

\[
(\text{net})_j = \sum_{i=1}^{n} W_{ij} X_i + b
\]  

where \((\text{net})_j\) is the input received from the previous layer neurons \(j^{\text{th}}\) neuron, \(W_{ij}\) is the weight between the \(j^{\text{th}}\) neuron \([14,15,16]\). Activation function calculates the net input obtained from previous layer sum function and determines the neuron output, as represented by Equation (1.2) gives outputs in \((0,1)\). where \(\alpha\) is a constant which controls the slope of the semi-linear region.

\[
\text{(out)}_j = f(\text{(net)})_j = 1 / 1 + e^{-\alpha (\text{net})_j}
\]

General block architecture of ANN has been constructed to outline the vagueness and approximations in various steps of mix design as per codal guidelines mentioned in the different methods of concrete mix design. The weights assigned to the input and outputs have been modified at various steps within the system itself by the use of back-propagation neural network architecture.

The present work investigates the potential of soft computing tools i.e. artificial neural network to solve the problem of mix design for required design stipulations based on available materials specification for estimating the proportions of ingredients of concrete mix of required strength, workability, durability and quality control parameters.

An Artificial Neural Network based five and six layer systems has been proposed to design a concrete mix, based on Indian Standard Institute (ISI) method, American Concrete Institute (ACI) method and Department of Environmental Engineering (DOE) method.

1.8 **Particle packing of aggregates:** The degree of packing is estimated in terms of the amount of aggregate particles per unit volume. It is defined as the ratio of solid volume of the aggregate particles to bulk volume occupied by the aggregates.

Good grading indicates that a sample of aggregates contains all standard sizes of particle fractions with minimum voids. A sample of well graded aggregate indicates minimum voids which will require minimum paste to fill up the voids. Hence less quantity of cement and water is required and hence increases the economy, higher strength, lower shrinkage and greater durability.

Concrete is particulate material and particle packing theory has significance while designing a concrete mix. The packing density is useful to cost reduction and
also to improve the concrete performance. The packing density is one of the key parameters governing the behaviour of concrete. The quantity of binder is estimated based on the amount voids in the aggregate keeping the freshly mixed concrete workable. The aim of optimizing concrete mix is to prepare concrete as densely packed as possible.