Chapter 3

METHODOLOGY ADOPTED

3.1 INTRODUCTION

Concrete mix design is a well established practice around the world. Adapting from developed countries, many developing countries have standardized their concrete mix design methods. These methods are mostly based on empirical relations, charts, graphs, and tables developed through extensive experiments and investigations using locally available materials (Nataraja, 2010). Some of the prevalent concrete mix design methods used for normal strength concrete (NSC) are: (a) ACI (American Concrete Institute) Mix Design Method, (b) USBR (United States Bureau of Reclamation) Mix design practice, (c) British Mix Design Method, and d) BIS (Bureau of Indian Standards) Recommended guidelines. These methods are not directly applicable to HPC mixes (Gopalkrishnan et al., 2001).

Mix proportioning of HPC is more critical process than that of NSC in view of the high powder content and the requirement of the low water cementitious (binder) ratio (Mavin Kurve et al., 2003). Mix proportioning methods of NSC are based on data for characteristic strength and the necessary consistency of the concrete. With data for characteristic strength, consistency and known available cement and aggregates, the mix proportioning for a normal concrete can be done using any one of the standard concrete mix design method. If an attempt is made to apply this procedure to HPC mixes, some of the problems will be encountered taking into account the specific characteristics found in HPC (Rama Rao and Sheshagiri Rao, 2005).

High Performance Concrete has become quite popular in recent years. However, the various required performance attributes of HPC, including strength, workability, dimensional stability and durability, often impose contradictory requirements on the mix parameters to be adopted, thereby rendering the concrete mix design a very difficult task. The conventional mix design methods are not capable of coping with such complexities and therefore a new mix design method is necessary for making HPC.
3.2 METHODOLOGY

The various Phases adopted for achieving the main objectives of the research work are summarized below:

3.2.1 Phase I: Determination of the properties of different ingredients for designing the mixes using existing mix design methods of NSC to assess their suitability for proportioning HPC mixes.

3.2.2 Phase II: Development of programs (softwares) in ‘Visual Basic’ for the procedures of mix design methods namely, IS Code, DOE method and ACI Code (proposed by Aitcin) for arriving at mix proportions for given design stipulations and test data of materials; and to check the validity of these programs.

3.2.3 Phase III: Preliminary trials for arriving at optimum or desirable contents of various ingredients for getting desired workability and strength properties of various grades of HPC mixes. This phase involves incorporation of different percentages of mineral admixture independently as well in combinations along with different dosages of suitable superplasticizers for achieving the target compressive strengths of various grades (M50 to M90) of HPC mixes.

3.2.4 Phase IV: Erection of a chamber or a room that controls or maintains the specific relative humidity and temperature conditions in it so that HPC mixes of different grades are exposed to several possible exposure conditions to study the effects of such exposure conditions on workability and strength properties of HPC mixes.

3.2.5 Phase V: Testing of cube specimens (M50- M90) for compressive strength test and durability tests, namely permeability, chloride attack, sulfate attack, acid attack etc. in the laboratories.
3.2.6 **Phase VI:** Development of software in ‘Visual Basics’ for sorting out or retrieval of the data gathered through the experimentation for the analysis.

3.2.7 **Phase VII:** Analysis and comparison of results obtained by different conventional mix design methods in order to select a suitable method for mix proportioning of HPC mixes.

3.2.8 **Phase VIII:** Development of a mathematical model using Artificial Neural Network (ANN) from the results of the experimentation for getting the mixture proportions of given variables.

3.2.9 **Phase IX:** Validation of the mathematical model through experimentation. To carry out the research work in a systematic manner for the development of a new mix proportioning method for HPC mixes, the methodology adopted is given in the form of a flowchart and is shown in the figure 3.1.
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Figure 3.1: Flowchart indicating Methodology Adopted

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3.3 CHARACTERIZATION OF CONSTITUENT MATERIALS

3.3.1 Determination of various properties of different materials

The ingredients such as cement, fine aggregate and coarse aggregate are used for the experimentation along with mineral admixtures namely, fly ash, micro silica and chemical admixtures (superplasticizers). The cement, fine and coarse aggregates procured from local sources are used to prepare concrete mixes. The fly ash obtained from Nashik Thermal Power Station is used whereas micro silica obtained from Elkem India Ltd., Mumbai has been used for the experimentation. The properties of these materials are determined in the laboratory as well as taken from the manufacturers before designing the HPC mixes using conventional methods of NSC.

3.3.1.1 Tests on cement, fly ash, micro silica

The various properties of cement such as standard consistency, initial setting and final setting time, fineness, specific gravity and compressive strength are determined in the laboratory following the standard procedures. The properties of fly ash and micro silica are used as given by the manufacturers and also cross-examined in the laboratory.

3.3.1.2 Tests on Fine Aggregates

The fine aggregates procured from local spots of “Krishna River” are used in the experimental work and tested for the properties such as fineness modulus, specific gravity, water absorption and moisture content using the standard procedures.

3.3.1.3 Tests on Coarse Aggregates

The coarse aggregates procured from local quarries are tested for the various properties such as fineness modulus, flakiness and elongation index, crushing strength, water absorption and moisture content using the standard procedures.

3.4 DEVELOPMENT OF SOFTWARE PROGRAMS

3.4.1 IS CODE Method (IS10262-1982)-M50 & M60 Grade Design

A software program using ‘Visual Basic 6’ language (Holzner, S., 2003) is developed for the procedure of IS Code method (IS: 10262-1982) for proportioning the concrete mixes. The software program is used for obtaining mix proportions for
the concrete grades upto M60. The program is developed considering such data established by this method, which is necessary for carrying out the proposed research work. The data used for the development of the program includes established relationships, charts etc. by the method.

3.4.2  **IS CODE Method (IS10262-2009) - M70, M80 & M90 Grade Design**

A software program is also developed for the procedure of revised IS Code method (IS: 10262-2009) using the same language (Visual Basic 6) for proportioning the concrete mixes. The program is used for proportioning of concrete mixes of M70, M80 and M90 grades. The program is prepared considering such data established by this method, which is necessary for carrying out the proposed research work. The data used for the development of the program includes established relationships, charts etc. by the method. The charts or curves indicating the relationships between compressive strength of the concrete and w/c ratio are extrapolated for getting the values not specified in the curves.

3.4.3  **Department of Environment (DOE) Method**

A software program using ‘Visual Basic 6’ language is also prepared for the procedure of DOE method for proportioning of concrete mixes considering such data established by method, which is necessary for the proposed research work. As this ‘British method of mix design’ can be used for concrete mixes containing fly ash or GGBS, the software program is developed for the procedure of this method for obtaining the mix proportions with or without the use of mineral admixtures such as fly ash, GGBFS, micro silica etc. The program is used for proportioning concrete mixes of grades upto M90. The data used for the development of the program includes established relationships, charts etc. by the method. The charts or curves indicating the relationships between compressive strength of the concrete and w/c ratio are extrapolated for getting the values not specified in the curves.

3.4.4  **ACI Method (Modified by P.C.Aitcin)**

A software program for the procedure of modified ACI method (modified by Aitcin, 1998) is also prepared to obtain the mix proportions using the same language of ‘Visual Basic 6’. The program is developed taking into account such data, established by this method, which is necessary for carrying out the proposed research
work. The software program is used for designing the HPC mixes of the grades M50 to M100. The program shows the validity for its application in designing the HPC mixes.

3.5 EXPERIMENTATION–CONSIDERATION OF PARAMETERS

The experimentation is proposed to be carried out by conducting preliminary trials on M50 HPC mixes by making variations in different parameters or ingredient contents of cement, mineral and chemical admixtures.

3.5.1 Trials for desired workability and strength properties of HPC mixes

The trial mixes are conducted for achieving the desired workability and compressive strength properties for HPC mixes.

3.5.1.1 Variations in cement, mineral and chemical admixtures- IS Code, DOE& ACI modified method guidelines

The preliminary experimentation work is carried out to decide the required contents of cement, fly ash, micro silica and superplasticizer to obtain desired workability and strength properties of M50 grade HPC mixes. The M50 grade mixes are designed by using the guidelines of IS Code, DOE and modified ACI method. Several HPC mixes are prepared making variations in cement content, mineral and chemical admixture contents. The trial mixes are prepared by incorporating different percentages of mineral admixtures such as fly ash (10% to 25%) and micro silica (5% to 15%) independently as well as in combinations. The mixes are prepared under the ambient humidity and temperature conditions.

3.5.2 Trials to study effect of zoning of sand on properties of HPC

Trial experimentation is carried out on M50 grade HPC mixes using the sand conforming to different zones namely, Zone I, Zone II, Zone III and Zone IV. The sand conforming to different zones is prepared in the laboratory and used for making HPC mixes to study the workability and strength properties.

3.5.3 Assessment of suitability of existing mix design methods

The mix proportions are obtained using the guidelines of existing methods namely IS Code, DOE and modified ACI method. The mix proportions obtained
using the guidelines of these methods are used for preparing M50 HPC mixes. The mineral admixtures namely, fly ash, micro silica are used in preparing HPC mixes separately as well as in several combinations along with different dosages of superplasticizers to achieve desired workability and strength properties. The properties of M50 grade HPC mixes are studied incorporating changes needed in the composition to obtain desired properties. From the observations and study of workability and compressive strength properties, the suitability of these existing mix design methods (IS Code, DOE and modified ACI) is assessed for their applicability in proportioning HPC mixes.

3.6 EXPERIMENTATION IN HUMIDITY AND TEMPERATURE CONTROLLING CHAMBER

3.6.1 Monitoring of Humidity Chamber

In order to investigate the effect of humidity and temperature on various properties of HPC mixes, a room controlled for specific humidity and temperature conditions is erected using airtight partitions. This room called ‘Humidity Chamber’ is provided with all the facilities necessary to prepare HPC mixes under varying humidity and temperature conditions. The instruments such as foggers, room heater, mercury lamps, humidity and temperature indicator (Hygro-Thermometer) and the machines / equipments such as pan type mixer, flow table and vibrator machine are installed in the chamber. The working of all these machineries is checked and trials are conducted to monitor the temperature and humidity variations using hygrothermometer, before starting experimentation in it.

3.6.2 Trial experimentation for making Reference Mixes

The experimental work to study workability and compressive strength properties for M50, M60, M70, M80 and M90 grades of HPC mixes is carried out by preparing reference mixes of each grade of HPC mix. The HPC mixes of different grades are designed using existing old and revised IS Code methods (IS 10262-1982 and IS 10262-2009) and mix proportions of these mixes are finalized to obtain desired workability and target compressive strength properties. Reference mixes of each grade are prepared in the humidity chamber under ambient humidity and temperature conditions by incorporating predetermined contents of micro silica and
superplasticizer. The superplasticizer dosages are adjusted so as to achieve the desired workability for each grade of HPC mixes in the humidity chamber under prevailing conditions of humidity and temperature.

HPC mixes of all the five grades (M50, M60, M70, M80, and M90) are then prepared by exposing them to different humidity and temperature conditions in the humidity chamber. A wide range of relative humidity ranging from 30% to 90% with an increment of 10%, with a constant temperature of 30°C, 35°C and 40°C for each humidity is considered for the experimentation. The mixes are exposed to such combined varying humidity and temperatures to study effects on various properties of HPC mixes such as w/b ratio, workability, compressive strength and durability. All the HPC mixes are prepared using the same mix proportions and same contents of mineral and chemical admixtures as that of reference mixes of each grade of HPC.

3.6.3. Trials for M70, M80 & M90 HPC Mixes with Revised mix Proportions (IS: 10262-2009)

The trials are conducted for higher grades of HPC mixes namely, M70, M80 and M90 by using higher contents of cement and mineral admixtures with appropriate dosage of superplasticizer to obtain the mixes of desired workability and target compressive strength properties. The mix proportions are obtained using the revised IS Code method (IS: 10262-2009) of mix design.

3.6.4. Tests on Reference HPC mixes of all Grades

The reference mixes of different grades of HPC (M50, M60, M70, M80 and M90) are prepared to study their compressive strength and durability properties. The mixes are tested for the study of various durability properties such as resistance to sulfate, chloride, acid and rapid chloride penetration (permeability test).

3.7. DEVELOPMENT OF ANALYTICAL / MATHEMATICAL MODEL

It is proposed to develop an analytical / mathematical model using Artificial Neural Network (ANN) approach for arriving at mix proportions of different grades of HPC mixes for any given exposure conditions and mix design variables.
3.7.1. Considerations of different variables (input and output)

The experimental work is carried out to determine governing properties of HPC mixes considering the variability of constituents and exposure conditions. From the experimental data base generation, a mathematical/analytical model is proposed to get the mix proportions for any given exposure condition and mix design variable.

The proposed mathematical model is expected to give the mix proportions for many inputs and output variables. The input variables for the proposed model are considered as given below:

1. Grade of the HPC mix, expected to be achieved,
2. Relative humidity,
3. Temperature and,
4. Slump (workability)

From the above mentioned input variables, the proposed ANN based model (software) should give the following outputs variables:

1. Flow (workability)
2. Ingredients for the given grade of HPC mix
   i. Cement content,
   ii. Fine aggregate content,
   iii. Coarse aggregate content,
   iv. Water content,
   v. Micro silica content
   vi. Superplasticizer and
3. Mix Proportion

From the predicted mix proportion and ingredient contents of the HPC mix under consideration, it is expected that similar mix results for the mix would be obtained when the mix is produced using the data obtained from the software.

3.7.2. Organization of experimental data required for development of ANN

The data obtained as a result of experimentation needs to be organized in a specific form to be used in the development of ANN model.
3.7.3. Development of a software in MATLAB and implementation of ANN tool

The analytical / mathematical model (ANN) proposed to be developed by writing the software program in MATLAB.

3.8. CONCLUDING REMARKS

In this chapter the focus is given on various phases adopted to carry out the research work. Also, to carry out this work in a systematic manner a flowchart indicating the methodology adopted is given in this chapter. The chapter discusses various ingredients used in developing HPC mixes and the tests performed on them. The software programs developed for the procedures of different mix design methods is also discussed in this chapter. The emphasis has been given on the experimentation process carried out in the humidity and temperature controlling chamber for various HPC mixes to study the various properties and to propose a modified method of mix proportioning of HPC by incorporating these effects at the stage of mix design process. The development of a mathematical model which covers many input and output variables is also covered in this chapter.