A FEASIBILITY STUDY ON THE USE OF HIGH PERFORMANCE CONCRETE IN HIGH RISE BUILDINGS

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AUTHOR'S DECLARATION

We the undersigned declare that we are the authors of this thesis. This is the original copy of the thesis. It is further declared, that we have fulfilled all the requirements in line with the quality assurance guidelines of the Higher Education Commission.

We understand that our thesis may be made electronically available to the public.

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ABSTRACT

High-performance concrete is rapidly getting acceptability for a wide range of applications in the construction of concrete structures. It is made for specific applications and having advantageous properties like high strength, high durability and high constructability as compared to the conventional normal strength concrete. To produce such a High Performance Concrete, mineral admixtures such as silica fume, fly ash and superplasticizer along with normal ingredients of concrete are used. The use of mineral admixtures in concrete enhances its properties regarding strength, durability, workability, and economy. It acts as pozzolanic materials as well as micro fillers; thereby the microstructure of hardened concrete becomes denser and stronger. superplasticizers help to disperse the cement particles in the mix and thus enhance the fluidity of the mixes at low water to cement ratio (W/C).

The scope of the this study is to prepare High Performance Concrete with strength higher than normal concrete using mineral and chemical admixtures in addition to normal constituents of concrete like cement, coarse and fine aggregates and also to find optimum water to cement ratio (W/C) in the presence of superplasticizers which will increase the strength without compromising the workability of the mix. This will lead us to our main objective of comparing the cost of using normal concrete and High Performance Concrete in multi-story buildings.

The compressive strength of concrete was investigated at different W/C ratio, superplasticizers, and silica fume dosage rates at different ages (3 days, 7 days, and 28 days) to find the optimum W/C ratio and dosage rate of superplasticizers for maximum strength. The coarse aggregates used were having a size less than 3/8”; the gradation curve for coarse aggregates was satisfying the requirement of ASTM. The fineness modulus of fine aggregate used was 2.68. The dosage rate of superplasticizers used was 1%, and the triggering W/C for superplasticizers used was 0.35. The maximum strength achieved was 8000 psi for 28 days.

After getting results from laboratory tests, the comparison was made between normal concrete having strength 4500 psi and high performance concrete of strength 8000 psi in ETABS. Column size reduced from 30”x30” to 24”x24” for HPC, the reinforcement requirement for normal concrete was 43 tons which reduced to 37 tons for HPC for first 2 stories of fifteen stories building. The overall cost reduction for these 2 stories in rupees was 3.6 lac.

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LIST OF ABBREVIATIONS

HPC	High Performance Concrete
NC	Normal Concrete
FA	Fine Aggregates
CA	Coarse Aggregates
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
psi	Pound per square inch
ksi	Kips per square inch
in	Inches
W/C	Water to Cement Ratio
lb	Pound
OPC	Ordinary Portland Cement

CHAPTER 01

INTRODUCTION

1.1 Project background

High Performance Concrete (HPC) has got importance in the construction industry because of its better performance and durability. It has become one of the potential research topics of civil engineering due to its improved characteristics. According to ACI High Performance Concrete can be defined as "Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices." HPC not only has the properties of traditional high strength concrete but also it has some other improved properties like high workability, high flowability, durability and high resistance to the segregation. High Performance Concrete makes it possible to not use vibrators during the placement and pouring of concrete because of its high workability. HPC saves a substantial amount of labor required in the field. In the construction of high rise buildings, the ordinary concrete with the lower strength and durability results in the very large column size and heavy reinforcement in this regard the strength of the concrete can be one of the property that can limit the two of the above-mentioned problems, using High Performance Concrete will result in a lower column size and will also lower reinforcement required in the column which can economize the project substantially. High Performance Concrete mixtures are nearly composed of the same materials as traditional materials but the proportions are designed such that it will result in a better performance such as high strength and durability which is needed for the construction projects.

High-performance concretes are made with carefully selected high-quality ingredients and optimized mixture designs; these are batched, mixed, placed, compacted and cured to the highest industry standards. Typically, such concretes will have a low water-cementing materials ratio of 0.20 to 0.45. Superplasticizers are usually used to make these concrete fluid and workable. American Concrete Institute, ACI-211.1 has been followed for decades in the construction industry for designing/proportioning of concrete. After a number of concrete mixes are designed by it, it will be recognized that in most cases the mixes designed may not fulfill the economical design checklists. So this study has been dedicated to such an economical aspect of the concrete mixes. There is a spectrum of parameters which result in the most economical concrete mix but may somehow be limited to normal strength and normal workability mixes. This study opens up such a spectrum of the economic feasibility of high strength and high workable concrete mixes in high rise buildings or any other complicated structures in Civil Engineering. At present one cubic yard of high performance concrete generally costs more than the conventional concrete.

1.2 Problem statement

Normal concrete does not have the properties which we need like high workability and high strength. If we make normal concrete of high workability, then it will affect strength due to high W/C ratio and if we decrease the W/C ratio than workability will decrease.

Normal concrete due to its lower strength results in large dimensions of member like column which increase the area, self-weight, and cost. Also in high rise buildings concrete is pumped to the top floor which requires high workability and generally bleeding and segregation phenomena occur in normal concrete due to pumping.

Normal concrete is vulnerable to chemical attacks and causes corrosion of reinforcement. The comparison between normal concrete and high performance concrete is given in Figure 1.

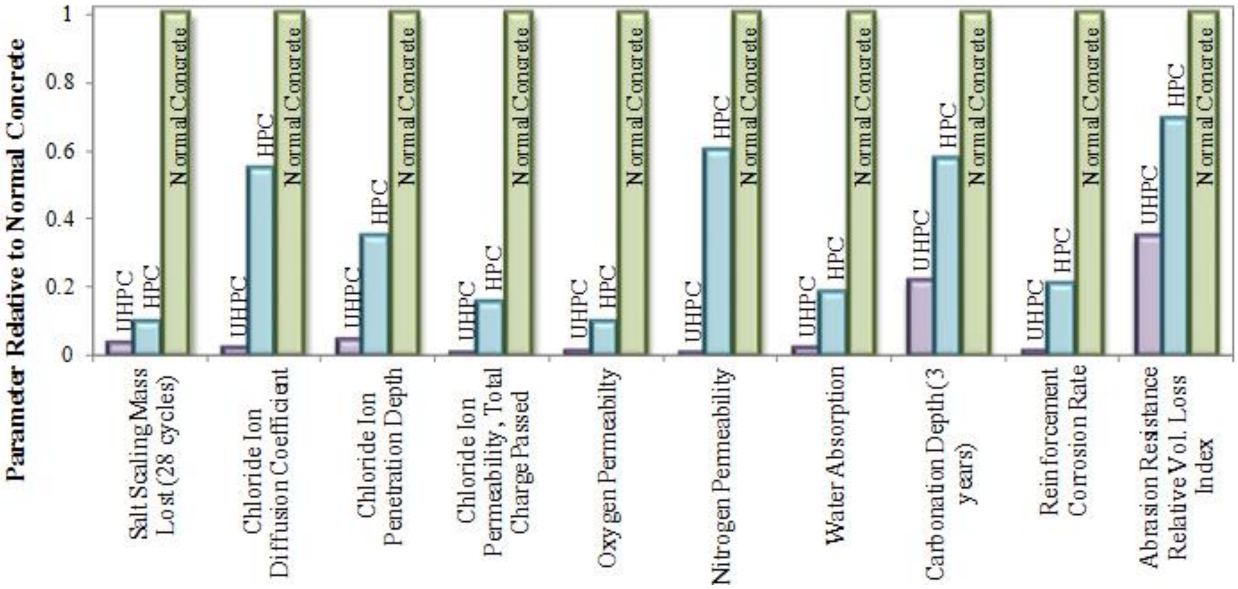


Figure 1 Comparison of a vulnerability of HPC and NC to chemicals attack [1]

References

1) https://www.fhwa.dot.gov/hfl/partnerships/uhpc/hif13032/chap01.cfm

1.3 Objectives

The objective of the project is to design and proportion such a mixture of Concrete that will result in High Performance Concrete i.e. having high strength, high workability, high flowability along with resistance to segregation and durability.

The project also describes the feasibility of the High Performance Concrete in high rise building by generating models in the software (ETABS) and seeing the variation of the concrete column size and reinforcement with the variation of the strength of the concrete.

The cost of the traditional normal concrete and High Performance Concrete used in the high rise building is compared and the effect of using High Performance Concrete in place of normal Concrete is figured out by looking for the reduction in the column size and reinforcement in the column.

1.4 Project scopes

The scope of the project lies in the fact that concrete with high compressive strength, high workability and durability will result in the good quality construction of high rise building. Large column sizes will be reduced which will lower the volume of concrete used in the building and thus the self-weight of the various building elements will also be reduced. The reinforcement requirement of the column will be lowered as compared to the column constructed with traditional concrete which will somehow economize the overall cost of the project.

1.5 Summary

- This chapter introduces the high performance concrete
- Describes the problems with normal concrete and the importance of high performance concrete
- Describes the objective and scope of the project

CHAPTER 02

LITERATURE REVIEW

This chapter includes the definitions of High Performance Concrete (HPC) and also the study about various topics that are related to the High Performance Concrete. The research work done on the High Performance Concrete until now is also included in the chapter. The goal of this chapter is to understand the properties of the materials that are to be used in the development of High Performance Concrete and to understand the various specifications and requirements for the design of High Performance Concrete mixes.

2.1 Definition of High Performance Concrete

Many different definitions have been proposed for the High Performance Concrete like The American Concrete Institute (ACI), The Strategic Highway Research Program (SHRP) and The Federal Highway Administration (FHWA) each and every one has proposed its own different definition of High Performance Concrete which is discussed below:

2.1.1 ACI general definition of HPC

The American Concrete Institute defined HPC as “Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices.” (1)

The requirements may involve enhancement of placement and compaction without segregation, long-term mechanical properties, early-age strength, volume stability, or service life in severe environments. Concretes possessing many of these characteristics often achieve higher strength. Therefore HPC is often a high strength, but high strength concrete may not necessarily be High Performance Concrete.

2.1.2 SHRP definition of HPC

SHRP defined HPC as “any concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes may be called High-Performance Concrete.” (2) Their design proportions criteria include a maximum water/cementitious material ratio of 0.35, and their performance criteria include a minimum relative dynamic modulus of elasticity (durability factor) of 80%, and a minimum strength meeting one of the criteria given in Table 2.1.

Table 2- 1 SHRP High Performance Concrete Strength Criteria

HPC Strength Rating	**Strength, Age**
Very Early Strength (VES)	3000 psi, 4 hours
High Early Strength (VES)	5000 psi, 24 hours
Very High Strength (VES)	10000 psi, 28 days

2.1.3 Federal Highway Administration Definition of HPC

Goodspeed et al. (3) have broken down HPC into different grades. Table 2.2 shows each grade along with their characteristics.

Table 2- 2 FHWA Performance Grades in US Units

Performance Characteristic	FHWA HPC Performance Grades			
	1	2	3	4
Freeze-thaw durability[1] (x = relative dynamic modulus of elasticity after 300 cycles)	60% ≤ x < 80%	80% ≤ x		
Scaling Resistance[2] (x = visual rating of the surface after 50 cycles)	x = 4, 5	x = 2, 3	x = 0, 1	
Abrasion resistance[3] (x = avg. depth of wear in inches)	2/25 > x ≥ 1/25	1/25 > x ≥ 1/50	1/50 > x	
Chloride Penetration[4] (x = coulombs)	3000 ≥ x > 2000	2000 ≥ x > 800	800 ≥ x	

Strength[5] (ksi) (x = compressive strength)	$6 \le x < 8$	$8 \le x < 10$	$10 \le x < 14$	$x \ge 14$
Elasticity[6] (psi) (x = modulus of elasticity)	$4 \le x < 6 \text{ x}10^6$	$6 \le x < 7.5 \text{ x}10^6$	$x \ge 7.5 \text{ x}10^6$	
Free Shrinkage[7] (x = micro-strain)	$4 \le x < 6 \text{ x}10^6$	$600 > x \ge 400$	$400 > x$	
Creep[8] (per psi) (x = micro-strain/pressure unit)	$0.52 \ge x > 0.41$	$0.41 \ge x > 0.31$	$0.31 \ge x > 0.21$	$0.21 \ge x$

1) Test in accordance with AASHTO T 161 (ASTM C 666 Procedure A)
2) Test in accordance with ASTM C 672
3) Test in accordance with ASTM C 944
4) Test in accordance with AASHTO T 277 (ASTM C 1202)
5) Test in accordance with AASHTO T2 (ASTM C 39)
6) Test in accordance with ASTM C 469
7) Test in accordance with ASTM C 157
8) Test in accordance with ASTM C 512

2.1.4 Other Definitions of HPC

Forster (4) defined HPC as “a concrete made with appropriate materials combined according to a selected mix design and properly mixed, transported, placed, consolidated, and cured so that the resulting concrete will give excellent performance in the structure in which it will be exposed, and with the loads to which it will be subjected for its design life.”

2.2 Materials

Concrete can be defined as a stone-like material that has a cementitious medium within which aggregates are embedded. In hydraulic cement concrete, the binder is composed of a mixture of hydraulic cement and water (ACI Committee 116). Concrete has an oven-dry density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3 (BS EN 206-1:2000).

The materials used for concrete will be briefly reviewed in the following sections.

2.2.1 Portland Cement

There are two different requirements that any cement must meet. It must develop the appropriate strength and secondly, it must exhibit the suitable rheological behavior. High performance concretes have been produced successfully using cement complying with BS EN 197-1 (2000) CEM 1 42.5N. The cement which meets this standard can vary quite widely in their fineness and chemical composition. As a result, the cement of nominally the same type will have quite different rheological and strength properties, especially when used in combination with chemical admixtures and supplementary cementing materials. Therefore, when choosing Portland cement for use in high performance concrete, it is compulsory to look vigilantly at the cement fineness and chemistry.

2.2.2 Fly ash

Fly ash (class F), also known as pulverized-fuel ash, is the by-product obtained by electrostatic and mechanical means from flue gases of power station furnaces fired with pulverized coal. The similarity of fly ash to natural pozzolans of volcanic origin has encouraged the use of fly ash in conjunction with Portland cement in making the concrete.

Fly ash is complicated in its chemical and phase compositions. It consists of heterogeneous combinations of glassy and crystalline phases. However, wide ranges exist in the amounts of the three principal constituents-SiO_2 (25 to 60%), Al_2O_3 (10 to 30%), and Fe_2O_3 (5 to 25%). Fly ash can be categorized into two classes, i.e. Class F and Class C, according to ASTM C 618-99 (1999). If the sum of these three ingredients is 70% or greater, the fly ash is categorized as Class F. However, as Class C, fly ash generally contains significant percentages of calcium compounds reported as CaO, the sum of the three constituents just mentioned is required only to be greater than 50%.

It is generally accepted that, in the pozzolanic reaction of fly ash, the $Ca(OH)_2$ produced during cement hydration reacts with the silicate and aluminate phases of fly ash to produce calcium silicate and aluminate hydrates (Lea, 1970). Its pozzolanic activity is attributed to the presence of SiO_2 and Al_2O_3 in amorphous form (Wesche, 1991). Due to its pozzolanic reaction, fly ash can beneficially affect various properties of concrete. The details of which are discussed in later sections.

2.2.3 Silica Fume

Silica fume (SF) is an extremely reactive pozzolanic material. It is a by-product obtained from the manufacturing of silicon or Ferro-silicon. It is extracted from the flue gases from electric arc furnaces. SF particles are very fine with particle sizes about a hundred times smaller than those of average size of OPC particles. It is a dandified powder or is in the form of water slurry. The standard specifications of silica fume are defined in ASTM 1240. It is commonly used as a replacement level of 5% to 12% by mass of total cementitious materials. It can be used successfully for the structures where high strength is needed or significantly reduced permeability to water is a major concern. Extraordinary procedures are required to be adopted for handling, placing and curing concrete with these very fine SF particles.

2.3 Aggregates

2.3.1 Introduction

Mixes consisting only of hydraulic cement and water will harden in the shape of any mold in which they are placed but they are of no practical use because they are too expensive and they shrink unacceptably during hydration. To overcome these problems, it is a common practice to introduce into the mix insoluble non-cementitious particles, known as aggregate, which is defined in BS EN 206-1:2000 as “granular mineral material suitable for use in concrete”. Aggregates may be natural or man-made. Recycled from material previously used in construction can be used as aggregates. As at least three-quarters of the volume of concrete are occupied by aggregates, they impart considerable influence on strength, dimensional stability, and durability of concrete. They also play a major role in determining the cost and workability of concrete mixtures. Table 2.3 summarizes the common effects of aggregates on properties of concrete.

2.3.2 Classification of Aggregates

According to particle size and source, aggregates can be divided into the following different categories:

I. In accordance with size:

- **Coarse aggregate**: Aggregate mainly retained on a 5.0 mm BS test sieve and containing no more finer material than is permitted in BS 882: 1992 (BS 882: 1992).
- **Fine aggregate (sand):** Aggregates mainly passing 5.0 mm BS test sieve and containing no coarser material than is permitted for the various grading in BS 882: 1992 (BS 882: 1992).

II. In accordance with sources:

- **Natural aggregate**: The material is not changed artificially during aggregate production, although the aggregate itself may be submitted to manufacturing processes, such as crushing, washing, sieving, and so on. Some examples are sand, gravel, and crushed limestone.
- **Artificial aggregate:** The material of the aggregate particles is produced, often as a by-product or waste, by certain manufacturing processes (heating, etc.) from naturally occurring materials. A typical example of this type is crushed blast-furnace slag and artificial lightweight aggregate. The most commonly used artificial lightweight aggregate is Lytag, which is produced by pyro-processing fly ash. The Lytag particles are spherical in shape and are of brown color with an internal black core (Swamy and Lambert, 1984)

Table 2- 3 Properties of concrete influenced by aggregate properties (Mindess et al., 2003)

Concrete Property	**Relevant Aggregate Property**
Strength Modulus of elasticity Unit weight	Strength, surface texture, cleanliness, particle shape, maximum size
Shrinkage and creep	Modulus of elasticity, Poisson’s ratio
Durability Resistance to freezing and thawing	Specific gravity, particle shape, grading, max. size Modulus of elasticity, particle shape, grading, cleanliness, maximum size, clay minerals
Resistance to wetting and drying Abrasion	Soundness, porosity, pore structure, permeability, degree of saturation, tensile strength, texture and structure, clay minerals
Resistance Alkali-aggregate reaction	Pore structure, modulus of elasticity Hardness Presence of certain reactive siliceous constituents

2.3.3 Properties of Aggregates

Properties of the aggregates which influence the properties of both the fresh and the hardened concretes are mainly the particle size distribution, the maximum size of the particles, shape and surface texture of the particles. Furthermore, the density and the porosity together with water absorption and moisture content have to be considered when the concrete is proportioned. Properties of the aggregates which are relevant to this investigation are described in the following sections.

- **Particle shape**

The shape of aggregate can be divided as rounded, flaky, irregular, angular, elongated and flaky-elongated.

- **Surface texture**

The surface texture of aggregates is classified as glassy, smooth, granular, rough, crystalline and honeycombed. Smooth aggregates need less water to achieve the same workability as rough aggregates. Nevertheless, the rough surface of aggregates is responsible for a better mechanical bond in the hardened concrete, so strength is comparatively higher (if concrete with the same w/c is compared).

- **Moisture content**

The moisture condition of aggregates consists of an accumulation of water in the pores and on the surface of aggregates. Four different moisture conditions are described below:

i) **Saturated and surface-dry (SSD)**: It is the condition in which the pores of the aggregate are fully filled with water but the surface is dry. This is the condition which is usually used for the concrete mix design (Teychenné et al., 1997). Since it is considered that the water contained in all pores of the aggregates does not take part in the chemical reactions of cement and can; therefore, be considered as a part of aggregate.

ii) **Air dry (AS):** If aggregate in SSD condition is allowed to stand free in the dry air, some of the water contained in the pores will evaporate and the pores inside the aggregate are partly filled with water.

iii) **Bone dry:** Prolonged drying of the aggregate in the oven would reduce the moisture content of the aggregate further, until when no moisture is left.

iv) **Moist**: The pores of the aggregate are entirely filled with water and also the surface of the aggregate is covered with a film of water.

- **Specific gravity**

The specific gravity of aggregates is determined for the saturated and surface-dry condition. This is defined as the ratio of the mass of the saturated and surface-dry aggregate to the mass of an equal volume of water.

- **Grading of Aggregate**

The grading of an aggregate defines the proportion of particles of different sizes. It is determined from the sieve analysis using the ASTM C136 standard procedure.

2.3.5 Water

Water plays two roles in the production of concrete, which are as mixing water and curing water (Popovics, 1992). The mixing water is the free water present in freshly mixed concrete. It has three main functions: it reacts with the cement powder, thus producing hydration; it acts as a lubricant, contributing to the workability of the fresh mixture; and it secures the necessary space in the paste for the development of hydration products. The amount of water needed for adequate workability is practically always greater than that needed for complete hydration of the cement. Usually, if water is potable, then it is also suitable in making the concrete.

2.4 Structure of Concrete

2.4.1 Introduction

Concrete has a highly heterogeneous and complex structure, which makes it very difficult to constitute exact models of the concrete structure. At the microstructure level, concrete can be regarded consisting of two phases, i.e. aggregate phase and binding medium phase (usually hydrated cement paste- HCP) (Neville, 1995a; Powers, 1958). However, at microstructure level, a third phase, the Transition Zone (or Interfacial Transition Zone – ITZ) is recognized, which represents the interfacial region between the particles of coarse aggregate and the HCP (Mehta and Monteiro, 1993). As the structure of concrete has a direct influence on the strength and durability properties of concrete, the following sections briefly review the structure of each phase and their significance to the properties of concrete.

2.4.2 Structure of aggregate phase

The aggregate in concrete is usually regarded as inert and generally is stronger than the other two phases of concrete. Therefore, it is frequently looked upon as an inert filler, except when they contain reactive silica. However as indicated by the section 2.3.3, highly porous and weak aggregate may influence properties of both fresh and hardened concrete.

2.4.3 Structure of hydrated cement phase (HCP)

The HCP generally consists of solid phases, viz. calcium silicate hydrate, calcium hydroxide, calcium sulfoaluminates, and unhydrated clinker grain, and various voids, i.e. interlayer space in C-S-H, capillary voids, and air voids. The typical sizes of both the solid phases and the voids in HCP are given below

- **Interlayer space in C-S-H:** The width of the interlayer space within the C-S-H is generally regarded varying from 0.5 to 2.5 nm (Feldman and Sereda, 1968), which is too small to have an adverse effect on the strength and permeability of the HCP.

- **Capillary voids:** Capillary voids represent the space not filled by the solid components of the HCP. Thus, the volume and size of the capillary voids are determined by the original distance between the anhydrous cement particles in the freshly mixed cement paste (i.e., water-cement ratio) and the degree of cement hydration (Parrott and Killoh, 1984; Parrott, 1985). In well-hydrated, low W/C ratio pastes, the capillary voids may range from 10 to 50 nm; in high W/C ratio pastes, at early ages of hydration, the capillary voids may be as large as 300 to 500 nm (Mehta and Manmohan, 1980).

- **Air voids:** Air voids in concrete are due to either entrapped air during casing or intentionally entrained by using an air-entraining agent. The entrapped air may be as large as 3 mm and the entrained air may range from 50 µm to 200 µm. They are much bigger than the capillary voids and are capable of adversely affecting the strength and permeation properties of concrete.

2.4.4 Structure of the transition zone

The transition zone is formed due to the existence of water films around the large aggregate particles in freshly compacted concrete. As a result, concrete becomes more porous close to the aggregates, with larger size capillary voids closer to them. Moreover, owing to the high W/C ratio in this region, the ettringite and calcium hydroxide tend to form larger crystals in oriented layers. All these features would detrimentally affect both the strength and permeation properties of concrete (Mehta and Monteiro, 1993).

2.5 Properties of Concrete

2.5.1 Definition and Significance of workability

The workability of concrete is defined in ACI 116R-90 as the "property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished". The workability of fresh concrete is usually measured by slump test, compacting factor test, Vebe test, and flow test.

2.5.2 Factors affecting workability of Concrete

The factors which can affect the workability of concrete are water content, cement content, aggregate grading, aggregate characteristics, and amount of entrained air, chemical admixtures and cementitious materials

- **Water Content**

It is assumed that for a given maximum size of coarse aggregate, the workability of concrete is a direct function of the water content (Falade, 1994; Hobbs, 1993; Popovics, 1962)

- **Cement Content**

Lowering the cement content of concrete, with given water content, will lower the workability. A high proportion of cement will result in excellent cohesiveness but may be too sticky to be finished conveniently (Mehta and Monteiro, 1993).

- **Aggregate characteristics**

As sufficient paste is required to coat the aggregate to provide lubrication, the shape of aggregate would affect the concrete workability. Since the surface-volume ratio of spherical aggregates is the smallest; the near-spherical aggregates thus need less water for mixing. As a general rule, the more spherical-round ratio of the particles, the more workable the resulting concrete will be. Another reason for the improved workability is due to the fact that the spherical particles can act as "ball bearings" while angular particles have a more mechanical interlock and therefore need more work to overcome the resulting internal friction. Moreover, the spherical particles have a better filling effect which can reduce the void contents in concrete. As a result, less cement paste is required to fill the voids, thus, ensuring more cement paste to lubricate the particles resulting improved workability of fresh concrete.

2.6 Supplementary Cementitious materials

2.6.1 Silica Fume (SF)

The effect of SF on the rheology of fresh concrete is known as a stabilizing effect. Incorporation of fine SF particles to a concrete mix results in reducing the segregation and bleeding tendencies. The finest particles in OPC concrete are those of the cement particles, which are normally in the 1-80µm size range. Since the fine and coarse aggregate particles are much bigger than the cement particles, the later act as stabilizers by reducing the size of the channels through which the bleed water rises to the surface of the concrete. When SF is added to concrete, the size of flow channels is greatly reduced because fine particles of SF tend to find their way into the empty spaces between two cement grains, causing strong segmentation of the bleed-water flow channels. Also, due to the increase in the number of solid-to-solid contact points, the cohesiveness of the concrete mix is greatly improved. This makes the material highly attractive for use in shotcreting, pumping, and tremie concreting operations. In fact, the replacement of SF in concrete at the high level (>20% by mass of cement) tends to make the concrete sticky. The addition of very small amounts of SF (up-to 15% by mass of cement) to normal structural concrete does not require the use of extra water or water-reducing admixtures to maintain the desired slump (Swamy, 1986). However, with higher levels of replacement, it is usually necessary to increase the water content of the concrete mix to maintain a certain slump.

2.7 High Performance Concrete

2.7.1 Introduction

The concept of HPC has definitely evolved over time. Initially, it was equated to high strength concrete (HSC), which certainly has some merit, but it does not show a complete and true picture. Other properties of the concrete must also be considered, and may even take priority over the strength criterion.

Use of supplementary cementitious materials (SCMs) is necessary for producing HPC. Concretes with these cementitious materials are used extensively throughout the world. In HPC, materials and admixtures are precisely selected and optimized to form higher strengths (early as well as ultimate) and higher durability as compared to normal concrete. HPC is also called "durable" concrete because its strength and impermeability to chloride penetration improves the service life as compared with that of conventional PCC. Some of the major users of HPCs are power, gas, oil and nuclear industries. The applications of such concretes are increasing with the passage of time due to their enhanced structural performance, environment friendliness and low bearing on energy utilization (Mehta, 1999).

Experience shows that there is variation in concrete performance as the source changes and proportions of SCMs added. In addition, SCM concrete often leads to a slower hydration, which can be successfully used in hot areas but acts as a challenge in the colder environment. The lack in knowledge about the dissimilarity in the performance of concrete incorporating SCMs from various sources is a big hurdle in its use by the construction sector. Therefore, the application of HPC was generally made in the architectural design, the private sector, and high rise buildings. Public agencies are more reluctant than the private sector in using these materials due to change in specifications, but the public sector now is dedicated to using this technology in the field.

HPC also provides enhanced mechanical properties (in terms of tensile and compressive strength) in the precast industry in addition to strong stiffness. The advantages of HPC cannot be denied in cold areas, where durability performance of concrete can resist penetration of chloride present in snow and water. This results in longer life for the embedded reinforcing steel and a reduction in the deterioration processes (Kuennen, 2004). The method of proportioning of fundamental components and the admixtures offer the main difference between HPC and conventional concrete. A high dosage of water reducing admixture may lead to a required low W/C ratio, leading positive effects on concrete properties.

In essence, the proportioning of HPC consists of three interrelated steps:

1. Selection of suitable ingredients: OPC, SCMs, aggregates, water, and chemical admixtures.

2. Determination of the relative quantities of these materials in order to produce, as economically as possible, a concrete that has the desired rheological properties, strength and durability.

3. Careful quality control of every phase of the concrete making process.

2.7.2 Material combination used for HPC

It is compulsory to get the maximum output of all of the materials involved in producing HPC. In many cases; however, concrete is classified as having ‘high performance’ exclusively because its strength is much greater than that of typically specified concrete. HPC is usually achieved by using very low W/C ratio. Indeed, in a recent publication (Aitcin, 1998) the author defined HPC as essentially all concrete having a W/C ratio not more than 0.40. Only in more recent times, recognition has been given to the fact that ‘high-strength’ concrete commonly offers other improvements in performance, such as higher flowability, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance and better durability (Aitcin, 1998). In spite of this, the term HPC continues to be used primarily for concrete suitable for high-strength application when one is looking for performance in terms of strength only.

Various materials used for making HPC are discussed separately below. However, it must be remembered that prediction with any certainty regarding the behavior of each ingredient, when combined in a concrete mixture, is not realistic. Any material incompatibilities will be highly detrimental to the finished product. Thus, the result of any mix design process must be the extensive testing of trial mixes. HPC will normally contain not only OPC, aggregate, and water but also superplasticizers and SCMs. It is possible to achieve compressive strengths up to 98 MPa using FA or GGBS as the SCMs. However, to achieve strengths in excess of 100 MPa, the use of SF has been found to be essential, and it is frequently used for concretes in the strength range of 63-98 MP as well (Mindess, 1994).

2.7.3 Supplementary cementitious materials

HPCs are produced often with large quantities of these SCMs. Such applications not only will help to improve the strength and durability characteristics of HPC but will also help to dispose of more of the industrial by-products which are major environmental threats.

The effects of SCMs on the pore structure and chloride permeability of concrete was examined by both Geiker et al. (1991) and Torii and Kawamura (1991). Using the AASHTO T 277 method, they found that the concrete with SCMs was much less permeable to chloride ions than the concrete without these materials regardless of curing and environmental conditions. Torii and Kawamura also found that at the surface of concretes with an SCM, the hydration of OPC was considerably low and coarse pores were developed when concrete with an SCM was stored in a dry condition for a long time. However, at the depth of 5cm from the surface of the concrete specimen, there was little change both in the degree of hydration and the pore structure. Numerous similar studies (Malhotra 1990; Ellis et al. 1991; Dunstan et al. 1993; Dhir and Byars 1993; Dhir et at. 1993; Ozyildirim 1992, 1994; Ozyildirim and Halstead 1994 and Bilodeau et al. 1994) have also been published in the past several years. These studies generally project specific with respect to constituent materials, curing methods, environmental exposures, and testing techniques. The results usually indicate the beneficial effects of FA, SF, and GGBS; the three commonly used mineral admixtures.

2.7.4 Superplasticizers

In recent times, it is essentially impossible to make HPC (inclusive of HSC) at adequate workability in the field without the use of superplasticizer. Unfortunately, different superplasticizer will behave quite differently with different types of cement (even cement of nominally the same type). This is because of the variability in the minor components of the cement (which are not generally specified), and in part to the fact that the acceptance standards for superplasticizers themselves are not very tightly written. Thus, some cement will simply be found to be incompatible with certain superplasticizers.

Currently, six different types of superplasticizer are used (Bradly and Howarth, 1986; Rixom and Mailvaganam, 1999 and Ramachandran and Malhotra, 1998).

- Lignosulfonates
- Poly melamine
- Poly naphthalene
- Carboxylates
- Polyacrylates
- Based on polyphosphonates and different copolymers

Until recently, Poly melamine and poly naphthalene were the principal sources of commercial superplasticizers, but recently carboxylates are used extensively in spite of their high price (Aïtcin, 2008).

2.7.5 Superplasticizer dosage

There is no specific way of determining the required superplasticizer dosage. It must be determined after carrying out some sort of trial and error procedure. For the development of high strength, one should work with the lowest W/C possible, and thus the highest superplasticizer dosage rate. For high strength concrete, the dosage of the superplasticizer is kept normally 5 to 15 liters per cubic meter of concrete, depending on the solids content in the superplasticizer and its nature. Such a dosage allows a reduction in water content of about 45 to 75 kg/m^3 of concrete (Aitcin and Neville, 1993). This is because HPC mix must be sufficiently workable for the solids to be dispersed in such a manner that dense packing is achieved, which requires deflocculation of cement particles. This is achieved by the use of a superplasticizer at a large dosage.

However, if the rheological properties of the HPC (in terms of strength) are very important, then the highest W/C consistent with the required strength should be used. Then the desired workability is achieved by adjusting the dosage of the superplasticizer. In general, some intermediate position must be found, so that the combination of strength and rheological properties can be optimized.

Table 2- 4 Mix proportions of Interfirst plaza, Dallas (adapted from Cook, 1989)

Materials	**1 cm max size of aggregate**	**25 cm max size aggregate**
Water (kg/cm^3)	166	148
Cement, Type 1(kg/cm^3)	360	357
Fly ash Class C (kg/cm^3)	150	149
Coarse aggregate(kg/cm^3)	1052	1183
Fine aggregate(kg/cm^3)	683	604
Water reduced L/m^3	1.01	1.01
Superplasticizer L/m^3	2.54	2.52
W/C	0.33	.29
fc' 28 days (MPa)-moist cured	79.5	85.8
fc' 91 days (MPa)-moist cured	89.0	92.4

Table 2- 5 Five examples of commercially produced high strength concrete mix designs (after Aitcin, Shirlaw, and Fines, 1992)

Mix #	**1**	**2**	**3**	**4**	**5**
Water (kg/cm^3)	195	165	135	145	130
Cement, Type 1(kg/cm^3)	505	451	500	315	513
Fly ash Class C (kg/cm^3)	60	-	-	-	-
Slag(kg/cm^3)	-	-	-	137	-
Silica Fume(kg/cm^3)	-	-	30	36	43
Coarse aggregate(kg/cm^3)	1030	1030	1110	1130	1080
Fine aggregate(kg/cm^3)	630	745	700	745	685
Water reduced L/m^3	0.975	-	-	0.9	-
Retarder L/m^3	-	-	4.5	1.8	-
Superplasticizer L/m^3	-	11.25	14	5.9	15.7
W/C	0.35	0.37	0.27	0.31	0.25
fc' 028 days (MPa)-moist cured	64.8	79.8	42.5	83.4	119
fc' 91 days (MPa)-moist cured	78.6	87.0	106	93.4	145

2.8 Aggregates

The aggregate properties, the most important with regard to HPC, are particle shape, particle size distribution, mechanical properties of the aggregate particles, and (in some cases) chemical reactions between the aggregate and the paste which may affect the bond. Unlike their use in ordinary concrete, where we rarely consider the strength of the aggregates, in HPC the aggregates may well become the strength limiting factor. Also, since it is necessary to maintain a low W/C to achieve high strength, the aggregate grading must be very tightly controlled.

2.8.1 Coarse Aggregate

It is worth noting that for HPC (inclusive of HSC); the coarse aggregate particles themselves must be strong. A number of different rock types have been used for this purpose. These types include limestone, dolomite, granite, andesite, diabase, and so on. It has been suggested that in most cases the aggregate strength itself is not usually the limiting factor for high strength but sometimes, it is the strength of the cement aggregate bond which controls (SHRP-C/FR-91-103, 1991). Like ordinary concretes, aggregates that may be vulnerable to the alkali-aggregate reaction, or to D-cracking, should be avoided. This should be done even though the low W/C used will tend to reduce the severity of these types of reaction.

From both strength and rheological point of views, the coarse aggregate particles should be roughly equidimensional; either crushed rock or natural gravels, particularly if they are of glacial origin. Flat or elongated particles must be avoided at all costs. They are inherently weak and lead to harsh mixes (Mindess, 1994). In addition, it is important to ensure that the aggregate is clean since a layer of silt or clay will reduce the cement aggregate bond strength, in addition to increasing the water demand. Finally, the aggregates should not be highly polished (as is sometimes the case with river-run gravels), because this too will reduce the cement aggregate bond.

Not enough work has been carried out on the effects of aggregate mineralogy on the properties of HPC. However, a detailed study by Aitcin and Mehta (1990) involving four apparently hard strong aggregates (diabase, limestone, granite, natural siliceous gravel) revealed that the granite and the gravel yielded much lower strengths than the other two aggregates. These effects appeared to be related both to aggregate strength and to the strength of the cement aggregate transition zone. Cook (1989) has also pointed out the effect of the modulus of elasticity of the aggregate on that of the concrete. However, much work has to be investigated to relate the mechanical and mineralogical properties of the aggregate to those of the resulting high performance concrete.

It is commonly assumed that a smaller maximum size of coarse aggregate will lead to higher strengths (SHRP-C/FR-91-103, 1991; FIP/CEB, 1990; Perenchio, 1973; Mehta and Aitcin, 1990 and ACI Committee 363, 1984), largely because smaller sizes will improve the workability of the concrete. However, this is not necessarily the case. While Mehta and Aitcin (1990) recommended a maximum size of 10-12 mm, they advised that 20-25 mm maximum size may be used for high strength concrete. On the other hand, using South African materials, Addis (1992) found that the strength of HPC increased as the maximum size of aggregate increased from 13.2 to 26.5 mm (Mindess, 1994). This is the area which needs to be further investigated. The durability of coarse aggregate particles is vital when the concrete containing the given aggregate is likely to be exposed to freezing and thawing.

2.8.2 Mix proportion

The proportioning (or mix design) of normal concrete is based primarily on the W/C 'law' first proposed by Abrams in 1918. At least for concretes with strengths up to 6000 psi (42MPa), it is assumed that almost any normal weight aggregates will be stronger than the hardened cement paste. There is, thus, no consideration of aggregate strength in the commonly used mix design procedures, such as those proposed by the American Concrete Institute ACI Standard 211.1 (1989). Similarly, the interfacial regions (or the cement-aggregate bond) are also not explicitly addressed. Rather, it is assumed that the strength of the hardened cement paste will be the limiting factor controlling the concrete strength.

For HPC, however, all of the components of the concrete mixture are pushed to their critical limits. HPC may be modeled as three-phase composite materials i.e. the hardened cement paste (HCP), the aggregate and the interfacial zone (between the hardened cement paste and the aggregate). These three phases must all be independently considered in the design process.

2.8.3 Water to cement ratio

For normal concretes, mix proportioning is based to a large extent on the W/C 'law'. For these, concretes, in which the aggregate strength is generally much greater than the paste strength, the W/C determines the strength of the concrete for any given set of raw materials. For HPC, however, in which the aggregate strength, or the strength of the cement-aggregate bond, is often the strength controlling factors, the role of the W/C is less clear. Hence, it is necessary to use very low W/C to manufacture HPC. However, the relationship between W/C and concrete strength is not as straightforward as it is for normal strength concretes.

2.8.4 Superplasticizer

The careful mix design and aggregate grading can make it possible to achieve strengths of about 98 MPa without superplasticizers. However, as they are readily available they are now almost universally used since they make it much easier to achieve adequate workability at very low W/C ratio.

2.8.5 Coarse to Fine aggregate ratio

For normal concretes, the ratio of coarse to fine aggregate (for a 0.55 in 14 mm max size of aggregate) is in the range of 0.9 to 1.4 (Canadian Portland Cement Association,1991). However, for HPC (inclusive of HSC), the coarse/fine is much higher. For instance, Peterman and Carrasquillo (1986) recommend a coarse/fine of 2.

2.8.6 Quality control

It is necessary to pay careful attention to all aspects of HPC production (i.e. selection of materials, mix design, handling and placing). It can be emphasized too strongly that quality control is an essential part of the production of HPC and requires full cooperation among all the stakeholders. Conventional NSC is a relatively forgiving material. It can absorb small changes in the constituent materials, mix proportions or cure conditions without any big change in its properties. However, HPC is not at all a forgiving material. Therefore, to ensure the quality of HPC, every aspect of the concrete production must be controlled, from the uniformity of the raw materials to proper batching and mixing procedures. Proper transportation, placement, vibration, curing and proper testing of the hardened concrete must be monitored. The quality control procedures, such as the types of test on both the fresh and hardened concrete, the frequency of testing, and interpretation of test results are essentially the same as those for ordinary concrete. However, Cook (1989) has presented data which indicate that for his HSC, the compressive strength results were not normally distributed, and the standard deviation for a given mix was not independent of test age and strength level. This led him to conclude that the 'quality control techniques used for low to moderate strength concretes may not necessarily be appropriate for very HSC.

2.9 Performance of HPC

2.9.1 Aspects of HPC in the Fresh state

The particular proportions of the ingredients of HPC, mainly, the high OPC content, the low water content and the high dosage of superplasticizer, influence the properties of the fresh concrete in some respects in a manner different from the usual mixes.

First of all, batching and mixing require great care. Because of the importance of thorough mixing, using the mixer at less than its rated capacity may be beneficial; a reduction of one-third, or even one-half, may be desirable (SHRP-C-364, 1993). A longer mixing time than usual is required to ensure homogeneity rather than a sticky mix. 90 seconds has been recommended (Larrard and Mailer, 1992) but even longer periods may be desirable.

The sequence of feeding the ingredients into the mixer is best established by trial-and-error, and it can be complicated. In one case, some water and one-half of a superplasticizer were fed first; then, aggregate and cement; finally, the remainder of the water and the superplasticizer. Often, a part of the superplasticizer is added only immediately prior to the placing of concrete. An example of the effect of the mixing sequence upon slump loss of concrete with a W/C of 0.25, mixed during 225 seconds is shown in Fig. 3.3 (Kakizaki, 1992). Three sequences were used: (A) feeding all the ingredients simultaneously; (B) mixing cement and water prior to the feeding of the remaining ingredients; and (C) mixing cement and fine aggregate prior to the feeding of the remaining ingredients. Method A resulted in the lowest slump loss, but this observation may not be generally valid.

2.9.2 Durability of HPC

One of the typical main features of HPC is its very low penetrability, resulting from a usually dense structure of the hydrated cement paste. HPC has been shown to provide high levels of resistance to durability phenomena such as chloride attack, alkali-silica reaction, freezing and thawing, and abrasion (Neville, 1995a). Therefore, HPC possesses a high resistance to external attack.

This is particularly true with respect to the ingress of chlorides into the concrete. For instance, tests similar to those of ASTM C 1202-94 on 3-month-old cores from columns made with 120 MPa concrete have shown negligible chloride ion permeability (Miao et. al; 1993). Even concrete with a w/b of 0.22, subjected to drying at 105°C was found, on subsequent exposure to chloride ions. It removes the evaporable water from the hardened cement paste. It has an extremely low permeability to chloride ions (Pigeon et al., 1993).

With respect to the risk of alkali-silica reaction, HPC containing SF can be expected to be particularly resistant because it has a very low permeability, which limits the mobility of ions in addition to low water content (Criaud and Cadoret, 1992). It should be remembered that the presence of water is essential for the alkali-silica reaction to take place. Figure 3.4 shows the very low relative humidity in the interior of concretes with 28-day strengths above 80 MPa (or 12000 psi) (Larrard and Larive, 1994). This stops the alkali-silica reaction. Indeed, no cases of alkali-silica reaction in HPC have been reported in the literature up to 1994, but the harmful effects of such a reaction take a very long time to visible themselves.

As far as the resistance to freezing and thawing is concerned, several aspects of HPC should be considered. Firstly, the structure of HCP is such that very little freezable water is present. Also, entrained air reduces the strength of HPC because the improvement in workability due to the air bubbles cannot be fully compensated by a reduction in the water content in the presence of a superplasticizer. Besides, air entrainment at very low w/b is difficult. It is, therefore, desirable to establish the maximum value of the w/b below which alternating cycles of freezing and thawing do not cause damage to the concrete.

2.10 Mix proportion of High Performance Concrete

There exist no standard or even typical mix proportions of mix HPC. It is useful to present information on several mixes.

Table 2- 6 Mix proportions of some high performance concretes (Neville, 1995a)

Ingredient (kg/m^3)	Mix								
	A	B	C	D	E	F	G	H	I
Portland cement	534	500	315	513	163	228	425	450	460
Silica Fume	40	30	36	43	54	46	40	45	-
Fly ash	59	-	-	-	-	-	-	-	-
Ggbs	-	-	137	-	325	182	-	-	-
Fine aggregate	623	700	745	685	730	800	755	736	780
Coarse aggregate	1069	1100	1130	1080	1100	1110	1045	1118	1080
Total water	139	143	150	139	136	138	1751	143	138
W/C	0.22	0.27	0.31	0.25	0.25	0.3	0.38	0.29	0.3
Slump mm	255	-	-	-	200	220	230	230	110
Cylinder strength (MPa) at age (days)									
1	-	-	-	-	13	19	-	35	36
2	-	-	-	65	-	-	-	-	-
7	-	-	67	91	72	62	-	68	-
28	-	93	83	119	114	105	95	111	83
56	124	-	-	-	-	-	-	-	-
91	-	107	93	145	126	121	105	-	89
365	-	-	-	-	136	126	-	-	-

2.11 Summary

From the review of the high performance concrete in this chapter, the following points have been identified:

1. If silica fume is used in combination with other supplementary cementitious materials, then it is advisable to develop HPC in terms of strength.

2. Much care is needed at each step of batching, mixing, curing, conditioning and testing high performance concrete.

3. A thorough research is required to investigate the influence of SCMs on the properties of high performance concrete.

CHAPTER 03

METHODOLOGY

In order to achieve our objective the whole work was divided into two phases i.e. Experimental work and Computer work. In the first phase, experiments were carried out in the lab using different constituents of concrete along with the use of chemical and mineral admixtures. While in the second phase we carried out a case study for cost analysis of using normal concrete and high performance concrete in the multi-story building.

The methodology was split into the following work breakdown structure (WBS):

i) - Experimental Work

- Materials procurement (cement coarse and fine aggregates etc.)
- Acquiring Chemical and Mineral admixtures
- Carrying tests on procured materials
- Mix design
- Preparation of mix

ii) - Computer Work

- Preparation of graphs and sheets
- Conducting a case study in ETABS

While conducting all these chunks of work a meeting was arranged with the supervisor on weekly basis throughout the two-semester span of the project. The following sections categorically explain how each phase of work was conducted and it also contains the findings and results of the work done in each phase. The result reached provides support to the conclusion and recommendation chapter of this document. The details of overall work are presented in Appendix A, along with the details of different superplasticizers used in this project.

3.1 Experimental work

Since we were aiming to produce HPC of high strength as well as good workability. For this, it was necessary to select a proper mix design along with a proper selection of coarse and fine aggregates as well as the selection of appropriate Chemical and Mineral Admixtures. The following sections will show how these constituents were selected and how they were procured and which types of tests were performed on them before their final use in the mix.

3.2 Materials procurement

The properties which the Cement, Coarse and fine aggregates should possess in order to be used in the preparation of High Performance Concrete are mentioned against each of them in the table 3-1 along with the W/C ratio range for High Performance Concrete.

Table 3- 1 Properties of materials

Materials	**Requirements**	**ASTM documents**
Cement	Ordinary Portland cement (Type I) Fineness (400 m^2/kg) Compatible with admixture (Low C_3A content) Cement content (400-550 kg/m^3)	ATSM C 150. ASTM C 595. ASTM C 1157
Fine Aggregates	Uniformly graded Not necessarily completely finer Fineness modulus (2.8-3.2)	ASTM C 33
Coarse Aggregates	Uniformly graded (Particles of all size and approximately rounded) Maximum size (10-15mm) No adhering dust High CA/FA than normal strength concrete	ASTM C 33
Water	Portable quality water W/C of 0.22-0.4	ASTM C 1602

The cement (Ordinary Portland Cement), Coarse Aggregates were obtained from local dealers in Peshawar and for the procurement of fine aggregates concrete plant of BRT (Bus Rapid Transit, Peshawar) Reach III Peshawar Hayatabad, was approached.

3.3 Acquiring Chemical and Mineral Admixture

As the aim was to achieve High Performance Concrete which has to satisfy not only the high strength requirement but also has good workability, for this reason, it was required to use Chemical and Mineral admixture. In our project, we used superplasticizers as chemical admixture and Silica Fumes as a mineral admixture. In order to be used, the chemical admixture (Superplasticizers) and mineral admixture (Silica Fume) should adhere to the properties mentioned against their names in the table 3-2 given below.

Table 3- 2 Properties of Chemical & Mineral admixtures to be used

Materials	**Requirements**	**ASTM documents**
Chemical admixtures (Superplasticizers)	Compatible with cement Optimum dosage (1L for 1bag) As a replacement for water Increase In slump 3.5”	ASTM C 494, ASTM C 260, ASTM C 1582
Mineral admixtures (Silica fume)	In accordance with ASTM C 1240-05 SiO_2 (min 85%) Moisture content (max 3%) Loss on ignition (max 6%) Resistance to sulphate Not reactive with alkalis	ASTM C 618, ASTM C 989, ASTM C 1240

The Superplasticizers used in this project is Superplast-470 and Ultra 520 BA-S. For Superplasticizer and Silica fume, the following chemical companies and their dealer were approached

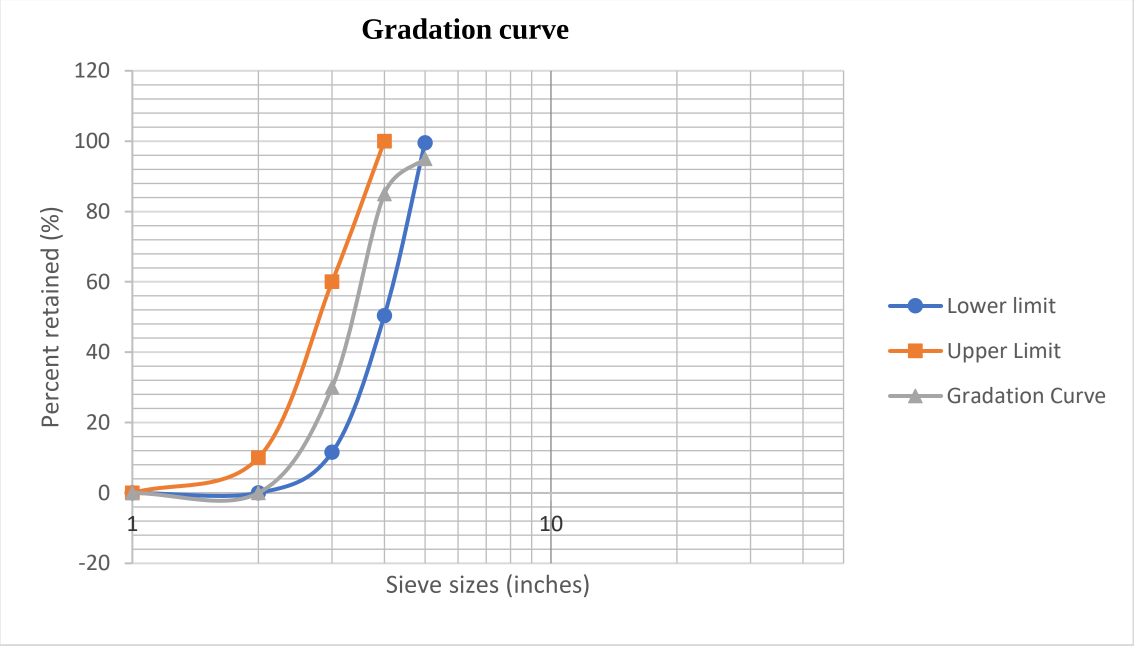
- Imporient Chemicals (Dealer name: Tasaduq Hussain)
- Ultra Chemicals (Dealer name: Khalid Ayaz)

3.4 Testing the procured materials

Once the materials were procured on the observational basis the next step was to check whether the procured materials were adhering to the necessary properties like FM (Fineness Modulus) for fine aggregates and uniform gradation and maximum particle size for coarse aggregates as were mentioned in table 3-1. In order to check cement and aggregates for their properties, several tests were carried out in the lab on them. These tests include the strength check of cement, Sieve analysis of coarse and fine aggregates and the results obtained are shown in figure 2 & table 3-3 for sieve analysis of coarse aggregates.

3.4.1 Sieve Analysis for Coarse Aggregates

Figure 2 Sieve Analysis for Coarse Aggregates



Sample weight = 5 Kg

Table 3- 3 Sieve Analysis table showing test results along with upper and lower limits

IS sieve size	Weight Retained (g)	Cumulative weight retained (g)	Cumulative %age wt. retained	Cumulative %age wt. passing	Upper limit	Lower limit
1”	-	-	-	-	-	-
¾”	0	0	0	100	0	0
½”	577	577	9.32	88.46	10	0
3/8”	1944	2551	50.42	49.58	60	30
#4	2456	4977	99.54	0.46	100	85
#8	18	4995	99.9	0.1	100	95

3.4.2 Sieve analysis for Fineness Modulus of sand

- Sieve analysis for fine aggregates was performed according to ASTM C136 and the result obtained is shown in table 3-4.
- Sample weight 500g

Table 3- 4 Sieve analysis for Fine aggregates

Sieve size	**Retained (g)**	**Retained (%)**	**Cumulative Retained (%)**
#8	10	2.1	3.2
#16	97	20.3	23.5
#30	167	35.0	58.5
#50	113	23.7	82.2
#100	90	18.9	100
#200	16	-	-
Pan	7	-	-
Total	500	100	268

Result: Fine Modulus = 2.68

As the fine modulus obtained from sieve analysis is not in the range of (2.8-3.2) as mentioned in the tables. It was accepted as a constraint in the production of High Performance Concrete at the local level in Peshawar due to unavailability of coarse sand with local dealers of Peshawar. In the laboratory tests carried out in the endeavor of High Performance Concrete the sand having a fine modulus of 2.68 was used.

3.5 Mix design

Mix design plays a key role in obtaining a concrete mix of a certain strength. During literature study, we founded that HPC (High Performance Concrete) can be prepared using a variety of mix proportion of cement, coarse and fine aggregates with W/C ratio in the range of 0.22-0.45. We selected the mix proportion of 1:1:2 on the advice of our supervisor.

3.6 Mix preparation and the Results

As we have already selected a mix proportion of 1:1:2. In the laboratory we prepared various trial mixes keeping the same mix proportion for each trial but using different W/C ratio and superplasticizers with and without the addition of Silica fumes. During the trial phase it was observed that some constant W/C ratio is required for the activation of plasticizing action of a particular superplasticizer and it was called as triggering W/C ratio for that plasticizer and if the W/C ratio is kept low below this value the superplasticizer will not be able to fulfill its function.

3.6.1 Trial 01

For first trail a mix with mix proportion of 1:1:2 was prepared using W/C ratio of 0.47, with maximum aggregates size less than ½'', without the addition of Silica fumes using both Superplast-470 and Ultra 520 BA-S as superplasticizer and the dosage of superplasticizer was kept 1% of cement. The slump was checked and 28 days strength was checked using UTM (Universal Testing Machine). Table 3-5 summarize the test and also shows the results.

Table 3- 5 Results of Trial 01

Material	**Mix 1**	**Mix 2**
Coarse aggregate (lb)	14.14	14.14
Fine aggregate (lb)	7.07	7.07
Cement (lb)	7.07	7.07
Water (lb)	3.32	3.32
Super-plasticizer (%)	1% Superplast-470	1% 520 BA-S
Silica fume (%)	-	-
W/C	0.47	0.47
Slump (inch)	7	7
Max aggregate size (inch)	½	½
28 days strength (psi)	5500	5500

3.6.2 Trial 02

A 2nd trial mix was prepared with the same mix proportion, same aggregate size, without the addition of silica fumes in case of superplast-470 and with the addition of silica fumes in case of Ultra 520 BA-S and using W/C ratio of 0.42, the slump was checked and 28 days strength was found with UTM. The table 3-6 summarizes the whole trial along with results of slumps and 28 days strength of concrete.

Table 3- 6 Results of Trial 02

Material	**Mix 1**	**Mix 2**
Coarse aggregate (lb)	14.14	14.14
Fine aggregate (lb)	7.07	7.07
Cement (lb)	7.07	6.57
Water (lb)	2.97	2.97
Super-plasticizer (%)	1% Superplast 470	1% 520 BA-S
Silica fume (%)	-	7
W/C	0.42	0.42
Slump (inch)	6	4
Max aggregate size (inch)	½	½
28 days strength (psi)	7800	6200

Further trials

Further, a series of trials were conducted using Ultra 520 BA-S as a superplasticizer and using a range of W/C ratios. The information of trials conducted is given below.

W/C ratios used are 0.35, 0.39 and 0.40. The Slump results, use of mineral admixtures (silica fumes) dosage, the strength of the concrete along with other information are given in the tables.

3.6.3 Trial 03

Table 3-7 shows the details of the trial.7% silica fume was used as a replacement of cement with W/C ratio of 0.35 and 3 days strength of the concrete was found through compressive strength test with UTM.

Table 3- 7 Results of Trial 03

Material	**Mix 3**
Coarse aggregate (lb)	14.14
Fine aggregate (lb)	7.07
Cement (lb)	7.07
Water (lb)	2.47
Super-plasticizer (%)	1% 520 BA-S
Silica fume (%)	7
W/C	0.35
Slump (inch)	7
Max aggregate size (inch)	½
3 days strength (psi)	2200

3.6.4 Trial 04

In this trial, 7% Silica fume was used as a replacement for Cement. W/C was kept 0.39 and 7 days strength of the concrete was found by UTM by conducting Compressive Strength of the Cylinder

Table 3-8 shows the trial test detail.

Table 3- 8 Results of Trial 04

Material	Mix 4
Coarse aggregate (lb)	14.14
Fine aggregate (lb)	7.07
Cement (lb)	7.07
Water (lb)	2.76
Super-plasticizer (%)	1% 520 BA-S
Silica fume (%)	7
W/C	0.39
Slump (inch)	8.5
Max aggregate size (inch)	½
7 days strength (psi)	3200

3.6.5 Trial 05

Table 3-9 shows the mixing details of concrete constituents and the trial results.

Table 3- 9 Results of Trial 05

Material	Mix 5
Coarse aggregate (lb)	14.14
Fine aggregate (lb)	7.07
Cement (lb)	7.07
Water (lb)	2.47
Super-plasticizer (%)	1% 520 BA-S
Silica fume (%)	7
W/C	0.35
Slump (inch)	5
Max aggregate size (inch)	½
7 days strength (psi)	3000

3.6.3 Trial 06

The summary and the result of the trial 06 is shown in table 3-10.

Table 3- 10 Results of Trial 06

Material	**Mix 6**
Coarse aggregate (lb)	14.14
Fine aggregate (lb)	7.07
Cement (lb)	7.07
Water (lb)	2.83
Super-plasticizer (%)	1% 520 BA-S
Silica fume (%)	-
W/C	0.40
Slump (inch)	4.5
Max aggregate size (inch)	3/8
28 days strength (psi)	6500

3.7 Computer work

ETABS software for the modeling, analysis, and designing of 15 story building was used. In this case study of 15 stories building, two different materials were assigned i.e. Normal concrete and High Performance Concrete. Normal concrete strength was taken to be 4500psi and High Performance Concrete strength was taken to be 8000psi. Both of these concrete mixes were assigned to the model and properties like structural member dimensions, reinforcement requirement in the column and cost of the materials was compared.

3.7.1 Model information

The building model was generated in ETABS software. The total number of stories was 15 and the height of each story was taken to be 12’. The thickness of the slab in each story was taken to be 6 inches and the size of the beam was 18” by 12”. The size of the outer columns was 24” by 24” and all the columns in the middle were 30” by 30” when normal concrete was assigned to the model. The rest of the details of the model are mentioned in the table 3-11.

Figure 2 Fifteen story building

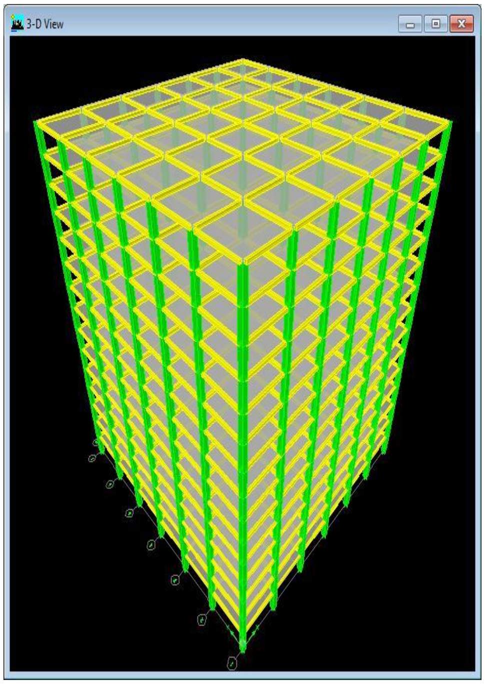


Table 3- 11 Building Story details

Story	Height	Elevation
STORY15	12	180
STORY14	12	168
STORY13	12	156
STORY12	12	144
STORY11	12	132
STORY10	12	120
STORY9	12	108
STORY8	12	96
STORY7	12	84
STORY6	12	72
STORY5	12	60
STORY4	12	48
STORY3	12	36
STORY2	12	24
STORY1	12	12
BASE	0	0

3.7.2 Loads details

The loads taken on the building were dead load, live load and earthquake load for zone 2B. The magnitude of the dead load taken was 60psf and live load 50 psf. The loading information is given in table 3-12.

Table 3- 12 Loads Detail

Dead load	50 psf
Live load	60 psf
Earthquake loading	zone 2B

3.7.3 Grid details

The grid of the building has six bays in each direction and the size of the grid was 25’ by 25’.The plan view is shown in figure 4.

Figure 3 Plan View of fifteen stories building

3.7.4 Column details

The table 3-13 shows the details of the columns of the building when normal concrete was assigned to the building columns

Table 3- 13 Building Detail for 4500 psi concrete strength

Columns	**Size**	**Strength (psi)**	**Unit volume (kip/ft^3)**	**Modulus of Elasticity (ksi)**	**Poisson's ratio**	**Number of columns in the first story**
On the edge	24" by 24"	4500	0.15	3600	0.2	24
Middle	30" by 30"	4500	0.15	3600	0.2	25

The table 3-14 shows the details of the columns of the building when High performance concrete was assigned to the building columns

Table 3- 14 Building Detail for 4500 psi concrete strength

Columns	**Size**	**Strength (psi)**	**Unit volume (kip/ft^3)**	**Modulus of Elasticity (ksi)**	**Poisson's ratio**	**Number of columns in the first story**
On the edge	18" by 18"	8000	0.15	5000	0.2	24
Middle	24" by 24"	8000	0.15	5000	0.2	25

3.7.5 Design results

The design results for Normal concrete and High Performance Concrete was obtained and the cost was compared between the material used for the production of normal concrete and High Performance Concrete.

Design reinforcement for 4500 psi. The reinforcement details for 4500 psi concrete is shown in the table 3-15 and that for 8000psi is shown in table 3-16.

Table 3- 15 Reinforcement Detail for 4500 psi concrete strength

Story	**ColLine**	**AsMin**	**As**	**Story**	**ColLine**	**AsMin**	**As**
STORY1	C1	5.76	13.066	STORY2	C1	5.76	11.408
STORY1	C2	5.76	5.76	STORY2	C2	5.76	5.76
STORY1	C3	5.76	16.793	STORY2	C3	5.76	12.184
STORY1	C4	5.76	5.76	STORY2	C4	5.76	5.76
STORY1	C5	5.76	16.071	STORY2	C5	5.76	11.408
STORY1	C6	5.76	16.793	STORY2	C6	5.76	12.184
STORY1	C7	5.76	16.805	STORY2	C7	5.76	12.201
STORY1	C8	5.76	5.76	STORY2	C8	5.76	5.76
STORY1	C9	5.76	21.286	STORY2	C9	5.76	15.876
STORY1	C10	9	37.831	STORY2	C10	9	29.114
STORY1	C11	9	38.14	STORY2	C11	9	29.545
STORY1	C12	9	38.151	STORY2	C12	9	29.564
STORY1	C13	9	38.14	STORY2	C13	9	29.545
STORY1	C14	9	37.831	STORY2	C14	9	29.114
STORY1	C15	5.76	21.286	STORY2	C15	5.76	15.876
STORY1	C16	5.76	22.255	STORY2	C16	5.76	16.912
STORY1	C17	9	38.575	STORY2	C17	9	30.147
STORY1	C18	9	38.723	STORY2	C18	9	30.355
STORY1	C19	9	38.726	STORY2	C19	9	30.363
STORY1	C20	9	38.723	STORY2	C20	9	30.355
STORY1	C21	9	38.575	STORY2	C21	9	30.147
STORY1	C22	5.76	22.255	STORY2	C22	5.76	16.912
STORY1	C23	5.76	22.289	STORY2	C23	5.76	16.956
STORY1	C24	9	38.6	STORY2	C24	9	30.193
STORY1	C25	9	38.741	STORY2	C25	9	30.389
STORY1	C26	9	38.743	STORY2	C26	9	30.396
STORY1	C27	9	38.741	STORY2	C27	9	30.389
STORY1	C28	9	38.6	STORY2	C28	9	30.193
STORY1	C29	5.76	22.289	STORY2	C29	5.76	16.956
STORY1	C30	5.76	22.266	STORY2	C30	5.76	16.93
STORY1	C31	9	38.57	STORY2	C31	9	30.147
STORY1	C32	9	38.717	STORY2	C32	9	30.353
STORY1	C33	9	38.72	STORY2	C33	9	30.364
STORY1	C34	9	38.717	STORY2	C34	9	30.353

STORY1	C35	9	38.57	STORY2	C35	9	30.147
STORY1	C36	5.76	22.266	STORY2	C36	5.76	16.93
STORY1	C37	5.76	21.288	STORY2	C37	5.76	15.89
STORY1	C38	9	37.8	STORY2	C38	9	29.088
STORY1	C39	9	38.106	STORY2	C39	9	29.514
STORY1	C40	9	38.119	STORY2	C40	9	29.535
STORY1	C41	9	38.106	STORY2	C41	9	29.514
STORY1	C42	9	37.8	STORY2	C42	9	29.088
STORY1	C43	5.76	21.288	STORY2	C43	5.76	15.89
STORY1	C44	5.76	5.76	STORY2	C44	5.76	5.76
STORY1	C45	5.76	15.852	STORY2	C45	5.76	11.153
STORY1	C46	5.76	16.564	STORY2	C46	5.76	11.918
STORY1	C47	5.76	16.592	STORY2	C47	5.76	11.953
STORY1	C48	5.76	16.564	STORY2	C48	5.76	11.918
STORY1	C49	5.76	15.852	STORY2	C49	5.76	11.153

Design reinforcement for 8000 psi

Table 3- 16 Reinforcement Detail for 8000 psi concrete strength

STORY	**column**	**Asmin**	**As**	**STORY**	**Column**	**Asmin**	**As**
STORY1	C1	4	6.366	STORY2	C1	4	5.65
STORY1	C2	4	4	STORY2	C2	4	4
STORY1	C3	4	7.607	STORY2	C3	4	6.32
STORY1	C4	4	4	STORY2	C4	4	4
STORY1	C5	4	6.366	STORY2	C5	4	5.12
STORY1	C6	4	7.607	STORY2	C6	4	6.23
STORY1	C7	4	7.64	STORY2	C7	4	6.24
STORY1	C8	4	4	STORY2	C8	4	4
STORY1	C9	4	11.743	STORY2	C9	4	5.826
STORY1	C10	5.76	26.425	STORY2	C10	5.76	17.195
STORY1	C11	5.76	27.296	STORY2	C11	5.76	18.258
STORY1	C12	5.76	27.332	STORY2	C12	5.76	18.307
STORY1	C13	5.76	27.296	STORY2	C13	5.76	18.258
STORY1	C14	5.76	26.425	STORY2	C14	5.76	17.195
STORY1	C15	4	11.743	STORY2	C15	4	5.826
STORY1	C16	4	13.274	STORY2	C16	4	7.25
STORY1	C17	5.76	28.509	STORY2	C17	5.76	18.934
STORY1	C18	5.76	28.528	STORY2	C18	5.76	19.745
STORY1	C19	5.76	28.553	STORY2	C19	5.76	19.781
STORY1	C20	5.76	28.528	STORY2	C20	5.76	19.745

STORY1	C21	5.76	28.509	STORY2	C21	5.76	18.934
STORY1	C22	4	13.274	STORY2	C22	4	7.25
STORY1	C23	4	13.325	STORY2	C23	4	7.3
STORY1	C24	5.76	27.927	STORY2	C24	5.76	19.013
STORY1	C25	5.76	28.575	STORY2	C25	5.76	19.811
STORY1	C26	5.76	28.598	STORY2	C26	5.76	19.846
STORY1	C27	5.76	28.575	STORY2	C27	5.76	19.811
STORY1	C28	5.76	27.927	STORY2	C28	5.76	19.013
STORY1	C29	4	13.325	STORY2	C29	4	7.3
STORY1	C30	4	13.282	STORY2	C30	4	7.259
STORY1	C31	5.76	27.862	STORY2	C31	5.76	18.935
STORY1	C32	5.76	28.517	STORY2	C32	5.76	19.743
STORY1	C33	5.76	28.542	STORY2	C33	5.76	19.779
STORY1	C34	5.76	28.517	STORY2	C34	5.76	19.743
STORY1	C35	5.76	27.862	STORY2	C35	5.76	18.935
STORY1	C36	4	13.282	STORY2	C36	4	7.259
STORY1	C37	4	11.733	STORY2	C37	4	5.823
STORY1	C38	5.76	26.377	STORY2	C38	5.76	17.168
STORY1	C39	5.76	27.244	STORY2	C39	5.76	18.22
STORY1	C40	5.76	27.281	STORY2	C40	5.76	18.271
STORY1	C41	5.76	27.244	STORY2	C41	5.76	18.22
STORY1	C42	5.76	26.377	STORY2	C42	5.76	17.168
STORY1	C43	4	11.733	STORY2	C43	4	5.823
STORY1	C44	4	4	STORY2	C44	4	4
STORY1	C45	4	6.13	STORY2	C45	4	4
STORY1	C46	4	7.311	STORY2	C46	4	4
STORY1	C47	4	7.355	STORY2	C47	4	4
STORY1	C48	4	7.311	STORY2	C48	4	4
STORY1	C49	4	6.13	STORY2	C49	4	4

3.8 Summary

The summary of computer work and their results such as a reduction in column size reduction in reinforcement and cost is given in table 3-17.

Table 3- 17 Comparison between HPC and Normal Concrete

Parameters	**Normal strength concrete**	**High Performance Concrete**
Strength (psi)	4500	8000
Column sizes	30”x30”	24”x24”
	24”x24”	18”x18”
Reinforcement required (tons)	43.24	37
Super-plasticizers (liters)	-	800
Silica Fume cost	-	1.4 lac
Cost of Reinforcement (Rs)	39 lac	33.5 lac
Cost of super-plasticizers (Rs)	-	50,000

CHAPTER 04

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- The success of High Performance Concrete requires more attention to proper mix design, production, placing and curing of concrete.
- Using 3/8 inch down aggregates in the range of ASTM standards and fine aggregates of fineness modulus (2.8-3.2) gives us strength up to 8000 psi in the presence of super plasticizers.
- Washed out coarse aggregates i.e. free from dust particles required less water as compared to coarse aggregates having dust particles.
- Strength also decreases due to bleeding and segregation if the W/C ratio, mix design ratio and super plasticizers are kept same for two different samples.
- Mixing and curing process also affect the strength of concrete.
- The triggering W/C ratio for super plasticizers (superplast470, 520 BA-S) is found out from the laboratory test which is 0.35.
- While comparing Normal Concrete having strength 4500 psi with High Performance Concrete having strength 8000 psi the column size is reduced from 30”x30” to 24”x24”.
- The reinforcement is reduced to 37 tons from 43.24 tons for the first 2 stories of 15 stories building due to the use of concrete having 8000 psi strength.
- The overall cost reduction is 3.6 lac due to the use of High Performance Concrete for the first 2 stories of 15 stories building. The details of the comparison between normal concrete of strength 4500 psi and High Performance Concrete of strength 8000 psi is given in table 4-1.

Table 4- 1 Conclusions

Parameters	**Normal strength concrete**	**High Performance Concrete**
Strength (psi)	4500	8000
Column sizes	30”x30”	24”x24”
	24”x24”	18”x18”
Reinforcement required (tons)	43.24	37
Super-plasticizers (liters)	-	800
Silica Fume cost	-	1.4 lac
Cost of Reinforcement (Rs)	39 lac	33.5 lac
Cost of super-plasticizers (Rs)	-	50,000

4.2 Recommendations

- Reducing W/C ratio affects the workability of concrete so to achieve good workability we have to use proper super plasticizers. W/C ratio should be selected such that the slump is not less 4 inch.
- Proper selection of super plasticizer is necessary, which should be compatible with the cement used. It is not always necessary that the dose recommended by the manufacturer may always hold proper with the materials and their proportions used in a particular work. Therefore, verification tests with the given material are needed
- Tricalcium aluminate (C_3A) is mostly related to the heat of hydration. It releases a large amount of heat during the first few days of hardening which generally results in early age cracking. Cement with a high content of C_3A is not suitable for mass concreting and are better to be mixed with fly ash.
- The success of High Performance Concrete requires more attention to proper mix design, production, placing and curing of concrete.
- Super plasticizers do not activate at every W/C ratio so knowledge regarding the triggering point of super plasticizers is necessary.
- Adding higher amounts of silica fume reduces bleeding and may eliminate it.
- A comparison should be made using different types of software like ETABs and SAP2000 for the final result.
- For high rise building, high performance concrete is recommended.

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APPENDIX

Ultra Superplast-470

Ultra superplast-470, superplasticizer is the latest generation of advanced organic polymer dispersed in used to modify Portland cement grout or concrete. Ultra superplast-470 lowers water demand and increases slump without having slump loss associated with other superplasticizers. It is ideal to be used in any concrete where it is desired to keep the water-cement ratio to a minimum and still achieve the degree of workability necessary to provide placement and consolidation.

The normal dosage range is from 0.80 to 1.80 liters per 100 kg of cementitious material. For higher workability concrete dosage range should be from 0.5 to 2 liters per 100 kg of cementitious material.

Appearance: Brown liquid

Specific Gravity: Typically 1.155 at 20^{o}C

Chloride content: Nil to BS 5075

Air Entrainment: Typically less than 3%

Alkali Content: Typically less than 72g

Chemrite 520 BA-S

It is used as a highly effective water reducing agent and superplasticizers for the production of high-quality free flowing concrete. It promotes set retardation followed by high earlier and ultimate strength.

It is used whenever high-quality concrete is demanded under different placing and climatic condition. The dosage rate is generally 0.6-3 % by weight of cement. It is advisable to carry out trial mixes to establish exact dosage rate required.

Density at 25^{o}C: Approximately 1.18 kg/l

PH Value: Approximately 7

Chloride content: Nil

Silica Fume

Silica fume is a new generation admixture with extremely powerful concrete additives in powder form, whose addition results in a strong and more durable concrete. Silica fume is used in structural concrete, pre-cast concrete and other fields of concrete construction where high performance, high strength concrete is required. The dosage rate is 6-10 % by weight of cement for an optimum result in concrete, field trials are recommended. Always use high range water reducing admixtures in conjunction with silica fume.