DEVELOPMENT OF STRENGTH VS WATER-CEMENT RATIO GRAPHS FOR NORMAL CONCRETES MADE WITH VARIOUS TYPES OF LOCAL CEMENTS AND PROPOSING A MIX DESIGN METHOD FOR PAKISTAN

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the requirement for the award of degree of

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This is to certify that

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ABSTRACT

The w/c ratio-strength relation plays a key role in selection of an adequate recipe against a particular target strength of concrete with and without admixtures. The relation proposed by American Concrete Institute (ACI) for normal concrete using ordinary Portland cement (OPC) is frequently used in Pakistan as a definite rule to decide the mix contents. However it is observed that in some cases, the desired strength is not achieved while using ACI method of mix proportion with locally available materials and the mix needs to be adjusted several times later on. This research has investigated the applicability of previous internationally established or proposed w/c-strength relations of concrete systems in Pakistan. Various charts and graphs are designed using relevant computer software packages for convenient and handy use of results.

Detailed strength testing on various types of concrete specimens (with different local cement types and other ingredients) is carried out according to International standards in order to develop a consistent relation between w/c and compressive strength for locally available aggregate and cement types and to address the absence of data regarding adjustments to trial batches while selecting a suitable proportion against strength, workability and resistance to segregation and bleeding. Empirical equations for w/c ratio – Strength relations are proposed for all available cement types and have been checked subsequently in order to comment on accuracy of their prediction against target strength. A wide range of other variables including maximum aggregate size, fineness modulus and percentage of fine aggregates, super plasticizer dosage, splitting tensile strength and elastic modulus are also considered in the study for assessing the validity of various International code provisions regarding these parameters. Based on these relations, a method of mix proportion is proposed and a computer software is developed in MATLAB GUI Environment in order to ensure the practicality and convenience in using the method in Pakistan for the benefit of end users including Postgraduate students, Professional Engineers, Consultants and concrete plant managers.

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List of Notations

ASTM	American Society for Testing and Materials
ACI	American Concrete Institute
PSQCA	Pakistan Standards and Quality Control Authority
BS	British Standards
HRWR	High Range Water Reducer
XRF	X-ray Fluorescence
DOE	Department of Environment
IS	Indian Standards
OPC	Ordinary Portland Cement
fc’	Compressive Strength of Concrete specified at certain age
E	Modulus of Elasticity of Concrete
w_c	Unit weight of concrete
SP	Super Plasticizer
w/c ratio	Water Cement Ratio
w/p ratio	Water Powder Ratio
σ	Standard Deviation
V	Absolute volume of fresh concrete
W	Water demand of Mix
C	Cement content of Mix
FA	Quantity of fine aggregate in Kg per m^3
CA	Quantity of coarse aggregate in Kg per m^3
S_C	Specific Gravity of Cement
S_{FA}	Specific gravity of fine aggregates
S_{CA}	Specific Gravity of Coarse aggregates
SR	Sulfate Resistant
SSD	Saturated Surface Dry

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CHAPTER 1

CONCRETE MIX DESIGN – AN INTRODUCTION

1.1 General

Concrete like other engineering materials needs to be designed for properties like strength, durability, workability and cohesion. Concrete mix design is the science of deciding relative proportions of ingredients of concrete, to achieve the desired properties in the most economical way [1]. With the advent of high-rise buildings and pre-stressed concrete, use of higher grades of concrete is becoming more common. Mix design of concrete is becoming more relevant in this scenario. Present study is an attempt to address the absence of local data regarding effect of different properties of indigenous aggregates and cement types on mixture proportioning as well as on desired properties of mix. Concrete is an extremely versatile building material as it can be designed for strength ranging from 10 Mpa to 200 Mpa and workability ranging from 0 mm slump to 250 mm slump. It's all characteristics and properties including strength, workability and durability are in our hands. One can make it flow like a liquid, make it light like foam and dense like a stone. One can predict its behavior under any possible circumstances. In all these cases the basic ingredients of concrete are the same, but it is their relative proportioning that makes the difference.

Water-Cement ratio (w/c) is the single most important factor governing the strength and durability of concrete. All time dependent phenomenon like creep, shrinkage and elastic modulus are somehow or the other, related to water-cement ratio. As a thumb rule, every 1% increase in quantity of water, reduces the strength of concrete by 5% and every extra liter of water per m^3 will approximately reduce the strength of concrete by 2 to 3 Mpa (290 Psi to 435 Psi) and increase the workability by 25 mm [2]. Hence, the knowledge of water demand of concrete system is the key to a mix designer. There is a small confusion regarding minimum w/c ratio required for complete hydration of cement. A designer must entirely be clear about the difference between the *"water used up in the hydration of cement"* and *"the water necessary for the hydration to proceed"*. The volume of products of hydration of cement is larger than the sum of the volumes of the cement and water participating in the reaction. Hydrated cement paste contains about 30% of very fine pores, known as gel pores. The gel pores must remain filled with water. It follows that a mix with a w/c of 0.22 (minimum w/c required for chemical reaction) cannot hydrate fully. It requires a volume of 1.2 mL to accommodate the products of hydration of 1mL of cement. In other words, the minimum w/c by volume for complete hydration is 1.2 (to fill gel pores and to complete hydration process) which is equivalent to a w/c of about 0.42 by mass. ***Resultantly, the minimum mass of water necessary for full hydration is almost twice the mass required stoichiometrically for the formation of calcium silicate hydrates*** [3].

The study involves an in-detail investigation of a combined effect of cement type and ingredient quantities on mix performance and their relation with the desired properties of final product.

1.2 Early Approaches and Practices

When concrete was formally adopted as a construction material during the 19th century, compressive strength probably was the only criterion in the proportioning of a mix. The strength of concrete was supposed to increase with the quantity of cement and better compaction. The role of mixing water was not clearly understood except it helped concrete to become plastic for easy compaction. It was also realized that use of aggregates for having less voids resulted in stronger concrete. Some of the methods used earlier were based on the principles of minimum voids and maximum density. Even in past age of mud mortars, we can safely say that there must be some definite rules according to which, the amount of mud, clay and water was decided. Even in villages today the amount of water in the mix is established on the basis of “plasticity” or “wetness”, or more precisely the “consistency” of the mix.

The amount of cement was always associated with required strength and this association is quantized and standardized in this study by accepting the rule that cement content must be selected by dividing the mean target strength by the *“average strength increase per 1 Kg/m^3 increase in cement content”*. This *“average strength increase”* is established after testing of a large number of specimens having a wide range of Mix proportions, Compressive strengths and Slump values.

Perhaps, the earliest approach towards proposing a definite set of rules to decide a mix proportion was “Minimum voids approach”. It can also be called as “Maximum Density Approach”. The idea is to give main consideration to the density and minimum voids. ***In early***

methods proposed based on this approach, all other factors including aggregate grading, resistance to segregation and durability etc. are completely ignored.

In this approach, the voids of coarse aggregate and fine aggregate are determined separately. The quantity of sand used should be such that it completely fills the voids of the coarse aggregate. Similarly, the quantity of cement used should be such that it fills the voids of sand, so that a dense mix having minimum voids is obtained. To the mix of cement, sand and coarse aggregate so obtained, sufficient water is added to make the mix workable. However, this method does not give satisfactory characteristics of the mix because the presence of cement, sand and water separates the coarse aggregates, thereby increasing its voids which were determined previously in absence of these two fillers. Therefore, we do not always get a dense concrete and problems like bleeding, segregation and lack of workability persisted.

1.3 Objectives of Designing a Mix

The overall objective of proportioning concrete mixtures can be summarized as *"selecting the suitable ingredients among the available materials and determining the most economical combination that will produce concrete with certain minimum performance characteristics"*. The requirements which form the basis of selection and proportioning of mix ingredients are [4]:

a. The minimum compressive strength required from structural consideration (usually termed as f_c')
b. The adequate workability necessary for full compaction (usually in terms of slump)
c. Maximum water-cement ratio to give adequate durability for the particular site conditions
d. Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete
e. Economy

An obvious constraint is that within a fixed volume, one cannot alter a component independent of others. For example, in a cubic meter of concrete, if the aggregate component is increased, the cement paste component decreases. With concrete making materials of given characteristics and with given job conditions, generally the variables are as follows:

a. Cement paste-aggregate ratio in the mixture
b. Water-cement ratio in the cement paste
c. Sand-coarse aggregate ratio in the aggregates
d. Use of admixtures

The task of mixture proportioning is complicated by the fact that certain desired properties of concrete may be oppositely affected by changing a specific variable. For example, the addition of water to a stiff concrete mixture with a given cement content will improve the flowability of fresh concrete but at the same time will reduce the strength. In fact, workability itself is composed of different components [i.e., consistency (ease of flow), yield stress, cohesiveness (resistance to segregation) and viscosity], and these tend to be affected in an opposite manner when water is added to a given concrete mixture. The process of mixture proportioning, therefore boils down to the "*art of balancing various conflicting requirements*".

1.4 The Process – Knowns and Unknowns

The following information is generally given to the designer as requirements.

a. Grade of concrete (the characteristic strength specified at a certain age)
b. Workability requirement in terms of Slump, Vebe Time or Compacting factor
c. Other requirements may include,
    i. Retardation of initial set
    ii. Slump retention
    iii. Pumpability
    iv. Acceleration of strength
    v. Flexural strength (normally required for concrete pavements)
d. Exposure conditions.
e. Degree of quality control at site.

After reviewing all the requirements and going through the complete process of mixture proportioning, the designer is supposed to submit the following results.

a. Ingredient quantities in Kg/m^3 or lb/yd^3 of concrete
b. Volumetric and by weight ratio of quantities
c. Results of all tests performed on ingredients including gradation and moisture condition of aggregates
d. Fresh density of Concrete
e. Dosage of admixture
f. Mixing and curing regime adopted in laboratory for trial batches

1.5 Design Office Practice in Pakistan

The method proposed by ACI 211 [5] Committee for mix design of normal concrete is widely used by practicing engineers, contracting firms as well as academicians in Pakistan. However it is found in many cases that quantities recommended by this method as a first trial batch were quite far from quantities which gave desirable characteristics at the end of all trials in Laboratory. The solution for this cumbersome process of making trials and waiting for 28 or so days was found in development of some thumb rule proportions by contractors for each strength level of concrete. Common proportions (by weight) of Cement, Sand and Crush used in small and medium level projects in Pakistan are listed below.

Table 1.1: Common ingredient ratios (by weight) used in local projects in Pakistan

Design Strength (Psi)	Ratio (by weight) of Cement, Sand and Crush
Less than 2500	1 : 3 : 6
3000	1 : 2 : 4
4000	1 : 1.5 : 3
5000	1 : 1 : 2
Greater than 5000	1 : 0.8 : 1.7

A general practice is to make a small change in these proportions according to site conditions in the name of so called "Past Experience". Some firms have developed their own fixed "*Confidential Recipes (ready-to-use mix designs)*" and they don't bother to test trial batches in laboratories for validation and examining the applicability of a particular "*Job Mix*" before the start of project. Hence, keeping in view all these practices, there is a need of a unified approach towards developing a *"Pakistani Mix Design Method"*.

1.6 Research Objectives and Methodology

The study aims to address the absence of data regarding applicability of previous internationally established mix design methods on local crushed stone aggregates and sand types as well as cements of Pakistan. Detailed strength testing on various types of concrete specimens (with varying local cement types and other ingredients) was carried out according to ASTM and BS standards in order to develop a consistent relation between w/c and compressive strength for locally available aggregate and cement types.

Based on these relations, a method of mix proportion is proposed and computer software is developed in order to ensure the practicality and convenience in using the method for the benefit of end users including postgraduate students, professional Engineers and consultants.

Graphical relations are developed between Compressive Strength (at various ages) and almost all variables including w/c ratio, Cement type, Splitting Tensile Strength, Fineness modulus, maximum aggregate size, type and dosage of Super plasticizer as well as volumetric percentage of fine aggregates in the mix. More than 400 Cylinder Specimens were casted and cured according to ASTM C 192 and tested according to C 39 at subsequent ages. Following is the list all variables investigated in this study.

a) Water-Cement Ratio (w/c): Mixes with five w/c ratios were prepared (0.3, 0.4, 0.5, 0.6 and 0.7).
b) Cement Type: Mixes with three cement types were prepared (OPC Grade 43, OPC Grade 53 and Sulfate Resistant Cement).
c) Concrete Age: Specimens were tested at 1,7,28 and 56 days in compression and at 3 and 7 days for splitting tensile strength.
d) Maximum Aggregate Size: Mixes with three maximum aggregate sizes were prepared (3/8”, 1/2” and 3/4”).
e) Fineness Modulus of Sand: Mixes with five sand blends of different fineness moduli were prepared (2.058, 2.233, 2.408, 2.582 and 2.758).
f) Percentage of Fine Aggregates in Mix: Mixes with six different volumetric percentages (of total aggregate volume) of sand were prepared (0%, 30%, 35%, 40%, 45%, and 50%).

g) Superplasticizer Type: Mixes with two High range water reducers (HRWRs) were prepared (Rheobuild 858 and Gelenium 51).
h) Superplasticizer Dosage: Mixes with four Superplasticizer dosages were prepared (0%, 1%, 1.5% and 2%).
i) Elastic Modulus: Secant and Chord Moduli were determined for mixes with five different w/c ratios at 28 day age.

The same experimental scheme is presented in following flow chart.

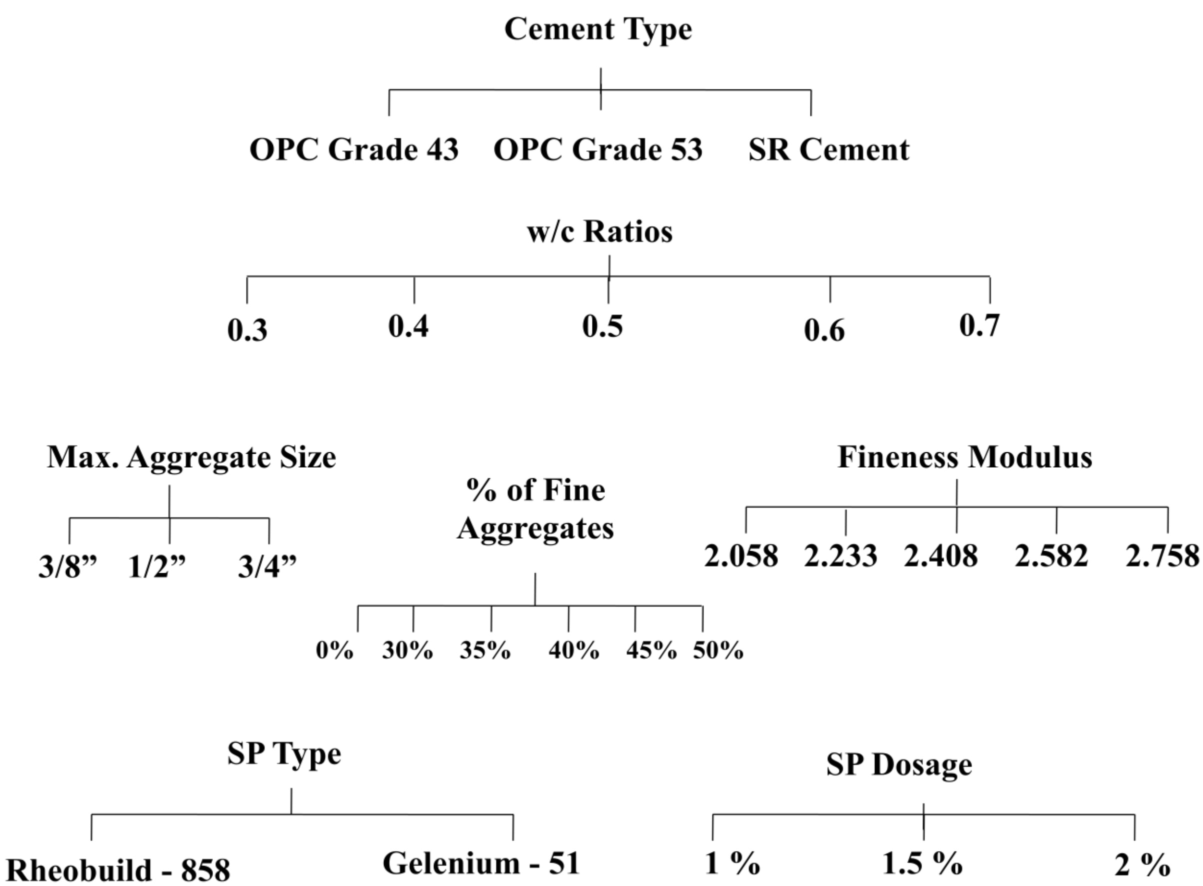


Figure 1.1: Factors considered in experimental program

CHAPTER 2

LITERATURE REVIEW – DIFFERENT METHODS OF MIX PROPORTIONING

2.1 General

This chapter is reviews different methods of mix proportioning. After a brief introduction and comparison of these methods, an example will be solved at the end of this chapter to compare recommended quantities as first trial batches and to comment on their applicability on local aggregates and cement types in Pakistan.

2.2 Critical View of Various Methods of Mix Proportioning

Three methods ACI [5], BS [1] and IS [4] methods will be discussed in some detail. The basic assumption made in all these methods is that the compressive strength of workable concretes, by and large, governed by the water/cement ratio. Also it is assumed that for a given type, shape, size and grading of aggregates, the amount of water determines workability. However, there are various other factors which affect the properties of concrete, for example the quality & quantity of cement, water and aggregates, batching, transportation, placing, compaction and curing etc. Therefore, the specific relationships that are used in proportioning concrete mixes should be considered only as the basis for trial, subject to modifications in the light of experience as well as for the particular materials used at the site in each case. No mix design method directly gives the exact proportions that will most economically achieve end results. ***These methods only serve as a "base to start" and achieve the end results in the fewest possible trials.***

2.2.1 ACI method

This method is recommended by ACI Committee 211 [5] and is based on determining the coarse aggregate content (in terms of percentage of concrete volume) from dry rodded bulk density and fineness modulus of sand, thus taking in to account the actual voids in compacted coarse aggregates that are to be filled by sand cement and water. The Committee report provides two methods for calculating aggregate quantities i.e. Weight method and Absolute Volume method. The *weight method* is considered less exact but does not require the information on the specific gravity of the concrete-making materials. The *absolute volume method* is considered more exact as well as easy to use in site conditions. Using volumetric ratios of ingredients, batching becomes quite convenient at site with containers and buckets. Complete steps of this method will be explained in an example solved at the end of this chapter.

This method has the following limitations.

i. It gives coarse aggregate contents for sand with FM range of 2.4 to 3.0 (Table 2, Appendix B). It is found that sands available in many parts of Pakistan including Lawrencepur and Ghazi are generally very fine and have fineness moduli less than 2.4.

ii. In this method the density of fresh concrete is not given as function of specific gravity of its ingredients. In British Method (also referred to as Department of Environment, DOE method) and IS methods, the plastic density or yield of concrete is linked to specific gravity of ingredients.

iii. The ACI method also does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content, neither does it distinguish between crushed stone aggregates and natural aggregates.

iv. The ACI method does not have a specific method of combining two different aggregates sizes.

v. The fine aggregate content cannot be adjusted for different cement contents. Hence the richer mixes and leaner mixes may have same sand proportion, for a given set of materials.

2.2.2 DOE Method

The British method of concrete mix design, popularly referred to as the "DOE method", is used in the United Kingdom and other parts of the world and has a long established record. In 1975 "Design of Normal Concrete Mixes" was published by the British Department of the Environment (DOE). The DOE method utilizes British test data obtained at the Building

Research Establishment, the Transport and Road Research Establishment, and the British Cement Association. The aggregates used in the tests conformed to BS 882[8] and the cements to BS 12[9] or BS 4027[10].

In this method, the fine aggregate content is taken as a function of 600 micron (0.6 mm) passing fraction of sand and not the gradation zone of sand. The 600-micron passing fraction emerges as the most critical parameter governing the water demand, cohesion and workability of concrete mix. Thus sand content in DOE method is more sensitive to changes in fineness of sand when compared to the ACI method. The sand content is also adjusted as per workability of mix**. *It is well accepted that higher the workability greater is the fine aggregate required to maintain cohesion in the mix.*** The water content per m^3 is recommended based on workability requirement given in terms of slump and Ve Be time. It recommends different water contents for crushed aggregates and for natural aggregates. The quantities of fine and coarse aggregates are calculated based on a plastic density graph (Figure 3, Appendix B).
The DOE method also suffers from some limitations.

i. The fine aggregates content calculated from DOE method often is on the higher side resulting in over sandy mixes (it can also be observed in the solved example in Section 2.3).
ii. Like ACI method, In BS method the fine aggregate content cannot be adjusted for different cement contents. Hence a rich mix with cement of 400 Kg/m^3 will have the same fine aggregate proportion, as a lean mix with 300 Kg/m^3 cement for given sand. Thus richer mixes may not be as workable because of higher fines, when compared to mixes obtained from the IS method.
iii. Like ACI, the DOE method also does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content although it distinguishes between crushed stone aggregates and natural aggregates.

2.2.3 Indian Standards (IS) Method

There are several reasons of selecting this method for comparison in this study. Firstly, the aggregate mineralogy of India and Pakistan is almost identical. Both countries also share identical weather exposure and construction practices. Indian standards also classify various Cement types in terms of “Grade 43” and “Grade 53” just like Pakistan standard PS 232-2008(R)[6] developed by Pakistan Standards and Quality Control Authority (PSQCA).

IS 456-2000 [7] has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day 6” cube strength of mix in N/mm^2. The IS method treats normal mixes (up to M35) and high strength mixes (M40 and above) differently. The method also gives correction factors for different w/c ratios, workability and for rounded coarse aggregate. In IS method, the quantities of fine and coarse aggregate are calculated with help of yield equation, which is based on specific gravities of ingredients. Thus plastic density of concrete calculated from yield equation can be close to actual plastic density obtained in laboratory, if specific gravities are calculated accurately. Thus actual cement consumption will be close to that targeted in the first trial mix itself. The water cement ratio is calculated from cement curves based on 28 days strength of cement.

The IS method has following limitations: -

i. The IS method considers compacting factor as measure for workability, to calculate the water demand. Compacting factor may not correctly represent workability therefore the revised IS 456 2000 has excluded compaction factor as a measure of workability. Now, it recommends use of slump as a measure for workability.

ii. The IS method does not recommend any corrections when crushed fine aggregate is used against natural fine aggregate as in case of DOE method.

iii. The IS method gives water demand and fine aggregate content for 10 mm 20 mm and 40 mm down aggregate. In practice the maximum size of coarse aggregate is often between 20mm and 40mm, the estimation of water and sand content is difficult.

iv. The quantities of fine aggregate and coarse aggregates are calculated from the Yield equation. The yield equation is based on concept, that volume of concrete is summation of absolute volumes of its ingredients. Absolute volume of ingredients is function of specific gravities of ingredients .The plastic density of concrete if theoretically calculated on the basis of specific gravities, may not match with that actually measured from concrete.

2.3 Solved Example

In order to perform a fair comparison of recommended quantities of ingredients for first trial batch, an example is solved with following constituent properties and desired mix characteristics using ACI, BS and IS methods.

Given Data:

28 Day Concrete Strength = 30 Mpa = 4350 Psi (M30 grade in IS Designation)
Slump range = 50mm to 75mm (2 to 3 in)
Cement Type = OPC 53 grade
FM. of Fine Aggregates = 2.785
Percentage of fine aggregate Passing 600 micron = 30 %
Specific gravity of fine aggregates= 2.75
Maximum Size of coarse aggregate = 20 mm
Specific gravity of coarse aggregate = 2.65
Dry Rodded bulk density of coarse aggregates= 1600 Kg/m^3

Step 1: Find the target mean strength:

Concrete is designed for strength higher than characteristic strength by a margin due to statistical variation in results and variation in degree of control exercised at site. This higher strength is defined as the target mean strength and is calculated as follows:
Target mean strength = Characteristic strength + K * σ

K= Himsworth Coefficient is taken as 1.65 for 5 % probability of failure [8].
σ = Standard deviation

Better the degree of control, lesser is the value of σ and lower is the target mean strength. In other words, the 'margin' kept over characteristic strength is more for fair degree of control to that of good degree of control. For 30 Mpa concrete, K=1.65 (for 5% failure) and assuming an average Standard Deviation of 5 Mpa, Target Mean Strength = 30 + 1.65 x 5 = 38.25 Mpa.

Step 2: Determine water/cement ratio:

a) ACI Method: For mean target strength of 38.25 Mpa (5546 Psi) a w/c ratio of 0.44 is determined using interpolation from ACI 211 relation (given in Table 4.1).
b) DOE Method: From Table 3 in Appendix B, the 28 day compressive strength of mix with w/c ratio of 0.5 is 42 Mpa. Using this 42 Mpa in Figure 1 of Appendix B, a w/c ratio of 0.54 is determined for target mean strength (38.25 Mpa) of this example.
c) IS Method: In IS the cement is classified into various curves based on the strength of cement. (Figure 4 in Appendix B)

Table 2.1: Curves for various Strength Levels

Curve	Strength of Cement (Mpa)
A	31.9 to 36.8
B	36.8 to 41.7
C	41.7 to 46.6
D	46.6 to 51.5
E	51.5 to 56.4
F	56.4 to 61.3

After selecting the appropriate curve based on the strength of cement (Curve E in our case as we are using Grade 53 cement), water/cement ratio is interpolated for given target mean strength. For F curve and target mean strength of 38.25, the water cement ratio is 0.44.

Step 3: Finding cement content

Most of the mix design methods suggest the following simple relation for cement content.

$$\text{Water/Cement Ratio} = \frac{\text{Weight of Water per m}^3}{\text{Weight of Cement per m}^3}$$

$$\text{Weight of Cement per m}^3 = \frac{\text{Weight of Water per m}^3}{\text{Water/Cement Ratio}}$$

a) ACI Method:

From Table 1 in Appendix B, Water demand for 30 to 50 mm Slump and maximum aggregate size of 20 mm = 185 Liters

Water demand for 80 to 100 mm Slump = 200 Liters

Water demand for 50 to 80 mm can be interpolated as average of the above =192.5 Liters

Hence, Cement Content = 192.5 /0.44 = 437.5 Kg/m^3

b) DOE Method:

From Table 4 in Appendix B, water demand for 30 to 60 mm range and maximum aggregate size of 20 mm = 180 Liters

Cement Content =180/0.54 = 333.33 Kg/m^3.

c) IS Method:

From Table 6 in Appendix B, Water Demand for Concrete grade up to M 35 and maximum aggregate size of 20 mm =186 Liters

Cement Content =186/0.44

= 422.73 Kg/m^3

Step 4: Determination of fine and coarse aggregate content:

The fine aggregate to coarse aggregate ratio is determined in different methods as follows:

a) ACI Method:

Using Table 2 in Appendix B, For F.M = 2.758, Volume of dry rodded coarse aggregates per m^3 can be interpolated as = 0.635. Dry rodded density of coarse aggregate is 1600 Kg/m^3, So Total coarse aggregate content = 1600 x 0.635 = 1044 Kg/m^3.

Total sand content per m^3 = 2350 – 437.5 - 192.5 -1044 = 676 Kg/m^3

b) DOE Method:

From Figure 2 in Appendix B, Sand Content for slump range of 30 to 60 mm and 30% 600 micron passing fraction in sand is calculated as 42%. Hence, Average specific gravity of combined aggregates (both coarse and fine) is calculated as [(0.42 x 2.75) + (0.58 x 2.65)] = 2.692.

Using water demand of 180 Liters and combined specific gravity of aggregates, Plastic Density of concrete is interpolated from Figure 3 in Appendix B as 2440 Kg/m^3. Total aggregate content per m^3 is calculated as (2440 – 333.33 – 180) = 1926.67 Kg/m^3.

Sand content = 1926.67 x 0.42 = 809.20 Kg/m^3.

Total coarse aggregate content = 1926.67 x 0.58 = 1117.47 kg/m^3

c) IS Method:

From Table 7 in Appendix B, for 20 mm down coarse aggregate and Concrete Grade of M 35, Sand Requirement = 35%

Weights of fine and coarse aggregates are calculated using the expressions,

$$V = \frac{\left[W + \frac{C}{SC} + \left(\frac{1}{P}\right)\left(\frac{FA}{SFA}\right)\right]}{1000}$$

$$V = \frac{\left[W + \frac{C}{SC} + \left(\frac{1}{1-P}\right)\left(\frac{CA}{SCA}\right)\right]}{1000}$$

Where,

V = Absolute volume of fresh concrete i.e. (gross volume –volume of entrapped Air) = 1 - 0.02 = 0.98

W = Water demand = 186 Liters

C = Cement content = 422.73 Kg/m^3

P = Ratio of fine aggregate to total aggregate = 0.35

FA = total quantity of fine aggregate in Kg/m^3

CA = total quantity of coarse aggregate in Kg/m^3

SC = Specific Gravity of Cement =3.15

SFA = Specific gravity of fine aggregate =2.75

SCA = Specific Gravity of Coarse aggregates = 2.65

Substituting values, we get the following results.

FA = 635 Kg/m^3

CA = 1137 Kg/m^3

Summary of Results:

The results from all three methods are summarized in the table below. However, the actual laboratory results during the study showed that a Concrete with Cement content of 437 Kg/m^3 and w/c ratio of 0.44 couldn't yield 28 Day Average Compressive strength of 5546 Psi. Mostly it was in the range of 4000 Psi – 4500 Psi.

Table 2.2: Comparison of results obtained from ACI, BS and IS methods

Mix Design Method	Cement (Kg/m^3)	Water (Kg/m^3)	Sand (Kg/m^3)	Crush (Kg/m^3)	w/c Ratio
ACI	437.50	192.2	676	1044	0.44
BS	413.04	190.0	809	1117	0.54
IS	422.73	186.0	635	1137	0.44

2.5 Need of a New Method for Pakistan

The specific relationships constituting figures and tables given in American and British methods are based on their natural aggregates and materials. Applying these relationships to local materials and expecting the same result will be an erroneous approach. The relationship between compressive strength of concrete and water/cement ratio for local constituents is compared with those given by ACI, BS and IS methods in chapter 4. A reasonable difference is found and hence the amount of cement recommended by these methods often needs revision during preparation of a final job mix. Also the aggregate properties (Specific gravities, absorption values, bulk densities etc.) are different from those used by ACI and BS for developing different relations. Keeping in view all these factors, there is a great need of exploring and evaluating the performance of local materials and the extent up to which they affect the desired characteristics of concrete in both fresh and hardened states.

CHAPTER 3 – EXPERIMENTAL PROGRAM

3.1 General

As discussed in the preceding chapter, there are a lot of variables involved in the process of reaching at an adequate compromise between strength, durability, workability and economy of a concrete mix. To examine the effects of these variables on desired properties of a mix, the method of factorial experimental design [9] was adopted which enables the researcher to evaluate the combined effect of various factors and their interactions. The effect of simultaneous variation of more than one factor is of reasonable interest in case of concrete mixes as each variable has its own extent of contribution towards the desired properties. This chapter will explain in detail, the complete methodology adopted in order to carry out this parametric study.

3.2 Materials

Three cements were used in the experimental program conforming to ASTM C150 and C 595 as shown below.

Table 3.1: Cements used in the study

Concrete	Cement
C43-30,…C43-70	OPC Grade 43
C53-30,…C53-70	OPC Grade 53
CSR-30,…CSR-70	Sulfate Resistant Cement

The nomenclature selected for control mixes indicates both type of cement as well as w/c ratio by weight as percentage of weight of cement i.e. C43-30 stands for a mix prepared with OPC Grade 43 with a w/c ratio of 0.3. Tests were carried out to ascertain the properties of cement are presented in Appendix A. Coarse aggregate was procured from Margalla quarry site. The maximum aggregate size used was 0.75 inch. Sand from two different sources were used, Lawrencepur (FM = 2.057) and Qibla Bandi (FM = 2.758). Both fine and coarse aggregates were used in "as obtained" condition with adjusting the mix according to their water demands. A blend of 80% ½" down and 20% ¾" uniform sized coarse aggregates was used in order to meet the grading requirements of ASTM 136.

The results of tests conducted to determine the properties of aggregates are presented in Appendix A. No admixture was used in control mixes however to examine the effect superplasticizers on fresh and hardened properties of concrete separate mixes were prepared with two different HRWRAs (Rheobuild – 858 and Gelenium – 51) in similar formulations conforming to ASTM C 494M – 04. Ordinary tap water from Structures Lab (NICE) was used during the entire experimental work. Cylindrical specimens of two sizes 100 mm x 200 mm [10] and 150 mm x 300 mm, were casted as per ASTM C 192M – 02. All points on strength graphs presented in this study are an average value of three cylinder specimens.

3.3 Selection of Control Mixes

Five "Control Mixes" were adopted to evaluate the effects of age, w/c ratio and cement type on both compressive and Splitting Tensile strengths of concrete. Five w/c ratio levels were considered i.e. 0.3, 0.4, 0.5, 0.6 and 0.7 [11]. Mixes were prepared with three cement types namely OPC (Grade 43) Bestway Cement, OPC (Grade 53) Fauji Cement and Sulfate Resistant Cement (Maple Leaf Brand). Recipes of these five Control mixes were designed so as to yield a wide slump range of 0-5 in, thus incorporating almost all levels of workability required in normal concrete construction. The w/c ratio was increased by reducing cement content and keeping water content constant at 200 Kg/m^3 which is 22 Kg/m^3 (10.5%) less than the average water demand of whole system given in Table 3.3. Absolute volume of aggregates was calculated by subtracting fractional volumes of water, cement and air (assumed 1.5% - an average value for slump between 0-5 inches) from 1 m^3. 40% of that absolute volume is converted to mass and set as fine aggregate content and remaining 60% is coarse aggregates [12]. To summarize this all, following are the steps of this preliminary mix design method [13] used to establish control mixes.

Step 1: Set W = 200 Kg/m^3 [14]

Step 2: Calculate C = W/(w/c), 5 w/c ratios were selected as discussed above.

Step 3: Absolute Volume of Total Aggregate Content = $1 - \frac{C}{Sp.Gr\ X\ 1000} - \frac{W}{1\ X\ 1000} - 0.015$

Step 4: Absolute Volume of Fine Aggregates = 0.4 x (Absolute Volume of Total Aggregates)

Fine Aggregate Content = (Absolute Volume of Fine Aggregates) x Specific Gravity x 1000

Step 5: Absolute Volume of Coarse Aggregates = 0.6 x (Absolute Volume of Total Aggregates)

Coarse Aggregate Content = (Absolute Volume of Coarse Aggregates) x Specific Gravity x 1000

Results are listed in Table 3.2.

Table 3.2: Calculations for Control Mixes

Concrete Nomenclature	w/c	Water	Cement	Absolute Vol. of Cement	Absolute Vol. of Water	Absolute Vol. of Air	Absolute Vol. of Crush	Absolute Vol. of Sand
		Kg/m^3	Kg/m^3	Per m^3	Per m^3	Per m^3	Per m^3	Per m^3
C43-30, C53-30, CSR-30	0.30	200	666.67	0.21	0.20	0.015	0.34	0.23
C43-40, C53-40, CSR-40	0.40	200	500.00	0.16	0.20	0.015	0.38	0.25
C43-50, C53-50, CSR-50	0.50	200	400.00	0.13	0.20	0.015	0.39	0.26
C43-60, C53-60, CSR-60	0.60	200	333.33	0.11	0.20	0.015	0.41	0.27
C43-70, C53-70, CSR-70	0.70	200	285.71	0.09	0.20	0.015	0.42	0.28

Table 3.3: Batch weights and Ratios for Control Mixes

w/c ratio	Water (Kg/m^3)	Cement (Kg/m^3)	Sand (Kg/m^3)	Crush (Kg/m^3)	Ratios by weight	Ratios by Volume	Agg. to Cement ratio	Water Demand of the system (Kg/m^3)
0.30	200.00	666.67	619.23	911.64	1 : 0.93 : 1.37	1 : 0.95 : 1.62	2.30	220.88
0.40	200.00	500.00	676.37	995.77	1 : 1.35 : 1.99	1 : 1.56 : 2.38	3.34	222.80
0.50	200.00	400.00	710.66	1046.25	1 : 1.78 : 2.62	1 : 2.00 : 3.00	4.39	223.96
0.60	200.00	333.33	733.51	1079.90	1 : 2.20 : 3.24	1 : 2.45 : 3.73	5.44	224.73
0.70	200.00	285.71	749.84	1103.93	1 : 2.62 : 3.86	1 : 3.11 : 4.67	6.49	225.28

Note that these quantities are without moisture adjustments of aggregates. Moisture conditions of both coarse and fine aggregates are taken into account at the time of actual batching. Moisture absorption values of both coarse and fine aggregates are listed in Appendix A. To calculate water contribution or absorption by aggregates, the percentage difference between their "as obtained" and "Saturated Surface Dry (SSD)" conditions is applied to their dry quantities [5]. As an example a 55 Kg adjusted batch is shown in Table 3.4.

Table 3.4: Water Adjustment in Control Mixes

Cement (Kg)	Sand (Kg)	Crush (Kg)			Water Without Correction (g)	Water absorbed by Fine Aggregates (g)	Water contributed by Coarse Aggregates (g)	Water to be Mixed (g)
		Total	3/4"	1/2"				
16.69	15.50	22.82	4.56	18.25	5005.60	201.47	82.14	4886.27
12.66	17.13	25.21	5.04	20.17	5064.13	222.64	90.77	4932.26
10.20	18.12	26.68	5.34	21.34	5099.91	235.58	96.04	4960.37
8.54	18.79	27.67	5.53	22.13	5124.04	244.31	99.60	4979.34
7.34	19.28	28.38	5.68	22.70	5141.42	250.59	102.16	4992.99

A graphical representation of mix proportions of these Control mixes is shown in Figure 3.1.

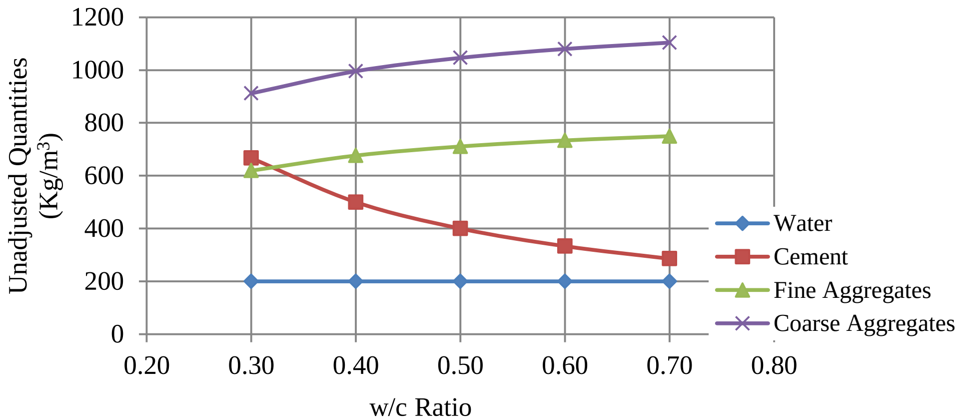


Figure 3.1: Constituent quantities in Control Mixes

Figure 3.2 is showing the actual slump values of all control mixes.

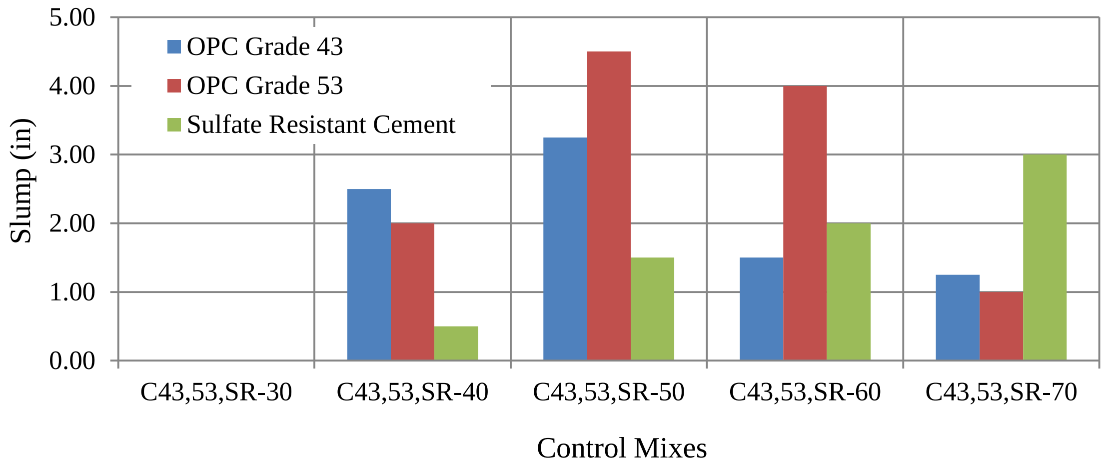


Figure 3.2: Actual Slump values of Control Mixes

3.4 Factors/Parameters considered in Experimental Work

Following are the details of some important factors that were considered in experimental program. It must be remembered that many of the ingredient properties which have a reasonable influence on strength cannot be assessed truly quantitatively e.g. aggregate grading, shape and their texture. However, the influence of factors like water content of the mix, w/c ratio and maximum size of coarse aggregates can be examined easily for a given cement type and concrete age.

3.4.1 w/c Ratio and Age

Fifteen mixes with five different w/c ratios and three different cement types were prepared and subsequently tested for compressive and splitting tensile strengths at the ages of 1,7,28 and 56 days. Graphs are prepared showing relations between these three important parameters. Each reading or point on a graph is an average value of three 100 mm x 200 mm (4" x 8") cylinders as required in ACI 318 Article 5.6.2.4 [15].

Detwiler and Terry [16] reported that compressive strength tests of 100 mm x 200 mm cylinders are of comparable precision to those of 150 mm x 300 mm cylinders. ASTM C 31 also treats the two specimen sizes as equivalent.

The compressive and splitting tensile strength results of these 15 mixtures at different ages will be reported graphically in succeeding chapter and sufficient discussion will be made the effect of local cement types and w/c ratio on the rate of strength growth.

3.4.2 Relationship between Compressive and Splitting Tensile Strength

Although the actual design methods and calculations do not consider tensile strength directly, however an understanding of plain concrete behavior under tensile and flexural loading helps in evaluating structures where bond and shear cracking is of reasonable concern as well as unreinforced pavements and highways. Cracks in tension develop and propagate more rapidly as the tensile stress has no tendency to arrest them. It is assumed by most of the researchers that the compressive strength is an adequate indicator for all tensile modes of strengths including flexure and direct tension strength.

Various investigators have proposed different equations relating compressive and tensile strengths of ordinary concrete up to 6000 Psi, mostly of the form, $ft = K(f'c)^x$ in megapascals, where "K" ranges between 0.15 and 0.9 and "x" ranges between 0.5 and 0.8 [17]. Splitting tensile test is most widely used test for assessing the tensile strength of cylindrical specimens. The maximum vertical compressive load "P" acting diametrically on sample causing splitting failure can be converted into horizontal splitting stress using the relation.

$$fct = \frac{2P}{\pi LD}$$

Where, P = Maximum Compressive Load on Cylinder

L = Length of Cylinder

D = Diameter of Cylinder

Neville [18] reported that the power exponent "x" used in the ACI Building code 318-89 is too low so that the splitting strength is overestimated at low compressive strengths and underestimated at high compressive strengths. It is found in the study that same seems to be the problem with ACI 318-08 expression as well.

3.4.3 Fineness Modulus of Fine Aggregates

Fineness modulus is an empirical factor used as an index of the fineness of aggregate. Higher is the fineness modulus, coarser is the particle size. It is computed from Sieve analysis data and is obtained by dividing the sum of cumulative percentages retained (up to sieve # 100) by 100.

ACI mix design method prescribed by ACI Committee 211 [5] incorporates the effect of fineness modulus along with maximum size of aggregate while selecting the proportion of fine aggregates in total aggregate content. To examine the effect of FM on strength while keeping all other parameters constant, five mixes were prepared with five different blends of sands as shown in the Table 3.5.

Table 3.5: Parameters for batches with varying Fineness Moduli of Sands

Sand	Mix Proportions	Fineness Modulus
100% Lawrencepur	C53-40	2.058
25% Qibla Bandi + 75% Lawrencepur		2.234
50% Qibla Bandi + 50% Lawrencepur		2.408
75% Qibla Bandi + 25% Lawrencepur		2.583
100% Qibla Bandi		2.758

Compressive strengths were recorded at 28 days and are presented graphically in Section 4.9 in chapter 4.

3.4.4 Maximum Size of Coarse Aggregates

The usual practice in our country (for normal construction) is to use a 50-50 blend of ½" down and ½" uniform sized crushed stone coarse aggregates which in most of the cases, falls in between the grading limits prescribed by ASTM C 33. It was observed that for Margalla coarse aggregates, a blend of 80% ½” down and 20% ¾” down crush comes inside the grading limits of ASTM and hence this formula was used in all Control mixes. However to investigate the effect of maximum aggregate size on compressive strength, three mixes with maximum sizes of 3/8", ½” and ¾” were casted. Control mix C53-40 (w/c = 0.4) was used with OPC 53 grade Cement. Samples were cured in water at 25ºC and were tested in compression at 28 days.

3.4.5 Ratio of Fine Aggregate to Total Aggregate Content

It was discussed earlier in section 3.3 that fine to total aggregate ratio of 0.4 was selected to be used in all Control mixes. It was selected on the basis of maximum bulk density and minimum percentage voids in loose state [12]. However mixes with other ratios were also casted with w/c ratio of 0.4. Water and Cement contents are kept same as C53-40. Details of mixes prepared are as under.

Table 3.6: Parameters for batches with varying ratios of Fine aggregates

Fine to Total aggregate ratio of Absolute Volumes	w/c ratio	Water (Kg/m3)	Cement (Kg/m3)	Coarse Aggregates (Kg/m3)	Fine Aggregates (Kg/m3)
0.3	0.4	200	500	1161.73	507.28
0.35	0.4	200	500	1078.75	591.83
0.4	0.4	200	500	995.77	676.37
0.45	0.4	200	500	912.788	760.92
0.5	0.4	200	500	829.808	845.46

3.4.6 Super plasticizer Type and Dose

Two super plasticizers were used in this study namely Rheobuild 858 and Gelenium 51. Both are manufactured by BASF. A comparison of important properties of these two HRWRs is given in Table 3.8 [20].

Table 3.7: Properties of High Range Water Reducers (HRWR) Used

High Range Water Reducer	Rheobuild - 858	Gelenium - 51
Chemical Family	Beta-Naphthalenesulphonate - Polycondensate – BNS	Polycarboxylic ether polymer (PCE) with long lateral chains.
Physical appearance	Dark brown ready-to-use viscous liquid	Light brown ready-to-use viscous liquid

Compatibility	all cements	not compatible with admixtures containing melamine or naphthalene sulphonates
Specific Gravity	1.245 at 25°C	1.1 at 20°C
Chloride Content	Chloride Free	Chloride Free
Recommended Dosage for Normal Concrete	0.8 to 2.0 litres per 100kg	between 0.2-0.8 liters per 100kg of cement

Sixteen mixes were prepared with these two SP types, four different SP contents (0%, 1%, 1.5% and 2% by weight of cement) and two different w/c ratios (0.3 and 0.4). Mix Proportions from control mix C53-30 and C53-40 were selected.

Relations between type and dosage of super plasticizer, age and w/c ratio will be discussed in Sections 4.12 and 4.13 of chapter 4.

3.5 Tests and Experiments Performed

3.5.1 Water demand and setting time of cements: AASTM C 187 specifies the measurement of consistency of hydraulic cement paste using penetration resistance. Hobart mixer (5 Liter) was used in order to prepare neat cement pastes as per DIN EN 196 [21].

Setting is another important phenomenon related to cements pastes. It is a gradual and progressive change from a fluid material to a rigid solid, due to hydration. Hydration is a dissolution-precipitation process resulted due to chemical reaction between cement particles and water. ASTM C 191 recommends the use of Vicat needle for determining time of setting. Results are listed in Appendix A.

3.5.2 XRF Analysis: XRF (X – Ray Fluorescence) Analysis (ASTM C 114) of all powders as well as aggregates were carried out at Institute of Environmental Sciences and Engineering (IESE), NUST, Islamabad. The results are discussed in the Tables 4.1 and 4.2 in chapter 4.

3.5.3 Compressive Strength Test: Compressive strengths of all cylindrical specimens were determined as per ASTM C 39/C39 M -03. Details are given below.

Rate of Loading = 0.2 MPa/s (1740 Psi/min)

ASTM C39 Limit = 0.15 – 0.35 MPa/s (20 – 50 Psi/s)

Type of Machine = Load Controlled, Flexible (However displacement control machines are considered ideal for testing of cement based materials)

Figure 3.3: A Servo-hydraulic Computer Controlled Compression Testing Machine

3.5.4 Splitting Tensile Strength: At ages of 3 and 7 days, splitting tensile strength of specimens from all 5 Control mixes were determined as per ASTM C 496/C 496M – 04. An aligning jig was used with wooden bearing strips. Loading rate is given below.

Rate of Loading = 0.02 MPa/s (2.9 Psi/s)

ASTM C 496 Limit = 0.7 to 1.4 MPa/min (1.67 – 3.33 Psi/s)

3.5.5 Tests for properties of aggregates: Water absorption capacities, density, specific gravity in as-stored condition of both coarse and fine aggregates were determined according to ASTM C 127 and ASTM C 128. Crushing value of coarse aggregate was also determined. Sieve analysis was also carried out according to ASTM C 136.

CHAPTER 4 RESULTS AND DISCUSSION

This chapter presents the analysis of results obtained in the study.

4.1 Chemical Compositions (XRF Results) of Cements and Aggregates:

An x-ray fluorescence (XRF) spectrometer is an x-ray instrument used for routine, relatively non-destructive chemical analyses of material samples. This technique provides the bulk chemical composition of samples. Samples are brought in to the form of powders and pressed into pellets. Quick quantitative determinations can be made for elements with a wide range of atomic numbers. The technique works in both "Elemental" as well as in "Oxide" modes. Chemical analysis of all materials including cements and aggregates is carried out at Institute of Environmental Sciences and Engineering (IESE), NUST, Islamabad. The results are listed in the tables below.

Table 4.1: Chemical Composition of Cements Used.

Compounds	**Mass %**		
	Fouji Cement (OPC Grade 53)	Bestway Cement (OPC Grade 43)	Maple Leaf Cement (Sulfate Resistant)
MgO	1.1922	1.8451	1.4609
Al_2O_3	3.8747	3.1734	2.7664
SiO_2	15.8674	14.6920	16.6938
SO3	4.9317	5.3143	3.5032
K_2O	1.2328	0.0000	0.0000
CaO	67.6617	69.7641	68.2008
TiO_2	0.4130	0.3249	0.2673
V_2O_5	0.0395	0.0630	0.0465
Cr_2O_3	0.1323	0.1392	0.1410
Fe_2O_3	4.2753	4.3446	6.5575
CuO	0.0000	0.0000	0.0275
SrO	0.3794	0.2964	0.3352
ZrO_2	0.0000	0.0429	0.0000

Graphical results of XRF Analysis are presented in figures 1(a), 1(b), 1(c), 1(d) and 1(e) of Appendix C.

Table 4.2: XRF Results of Margalla Crush and Lawrencepur Sand.

Element	Mass %	
	Margalla Crush	Lawrencepur Sand
MgO	1.8723	3.5110
Al_2O_3	1.5149	15.0125
SiO_2	6.7206	50.8630
SO_3	0.2415	0.0000
CaO	87.8446	12.7428
TiO_2	0.0626	1.1928
V_2O_5	0.0882	0.0395
Fe_2O_3	0.9918	12.4409
SrO	0.6142	0.0961
RuO_2	0.0491	0.0000
Na_2O	0.0000	1.9286
K_2O	0.0000	2.0463
Cr_2O_3	0.0000	0.0608
MnO	0.0000	0.0091
CoO	0.0000	0.0050
ZrO_2	0.0000	0.0517

4.2 Laser Particle Analysis Results of Cements

Particle size distribution measurements are now routinely employed to characterize cement powders. Laser diffraction particle size analyzers are used to measure the sizes of particles in a material. Particle size is calculated by measuring the angle of light scattered by the particles as they pass through a laser beam. The light source used by a laser particle size analyzer affects particle size measuring limits. Shorter wavelength violet and Ultra Violet lasers are better suited to measure submicron-sized particles than red lasers [22].

Laser Particle analysis of cements was carried out using Horiba LA-920 laser Granulometer at School of Chemicals and Materials Engineering (SCME), NUST, Islamabad. Particle characterization parameters of all three cements are shown in Table 4.3.

Table 4.3: Comparison of Laser Particle Analysis Results of Fauji, Bestway and SR Cements

Parameter	Fauji Cement (OPC Grade 53)	Bestway Cement (OPC Grade 43)	Maple Leaf Cement (Sulfate Resistant)
Specific Area (cm^2/cm^3)	8955.9	12904	10486
Median (μm)	9.4588	8.8349	8.4289
Mean (μm)	9.3462	10.4532	8.5823
Variance (μm^2)	13.772	52.909	9.5747
S.D. (μm)	3.7111	7.2739	3.0943

Graphical results of Laser Particle Analysis are presented in Figures 2(a), 2(b) and 2(c) of Appendix C.

4.3 Effect of w/c ratio, Cement Type and Age on Compressive Strength

ACI and BS Specified relations between w/c ratio and 28 day compressive strength of non air entrained concrete are given below.

Table 4.4: Relation between w/c ratio and 28 Day Compressive strength proposed by ACI 211 [5]

Source	Compressive Strength at 28 Days, Psi	w/c ratio by weight			
ACI 211.1 Committee Report	2000	0.82			
	3000	0.68			
	4000	0.57			
	5000	0.48			
	6000	0.41			
ACI 211.4 Committee Report (High Strength Concrete)		Maximum Size of Aggregates			
		3/8”	1/2”	3/4”	1”
	7000	0.42	0.41	0.40	0.39
	8000	0.35	0.34	0.33	0.33
	9000	0.30	0.29	0.29	0.28
	10000	0.26	0.26	0.25	0.25

Table 4.5: Relation between w/c ratio and 28 Day Compressive strength proposed by BS [1]

w/c ratio	150 mm Cube Compressive Strength (MPa)	150 mm Cube Compressive Strength (Psi)	Equivalent 100 mm x 200 mm Cylinder Strength (Psi)
0.3	47	6815	8382.45
0.4	32	4640	5707.2
0.5	20	2900	3567
0.6	15	2175	2675.25
0.7	10	1450	1783.5
0.8	8	1160	1426.8
0.9	6	870	1070.1

A graphical comparison of experimental w/c-strength relation with ACI and BS relations are given in Figure 4.1. It is obvious that the strength achieved in laboratory following the same procedures and standards given in ASTM, is less than proposed by ACI. However, BS values are more close to experimental results than IS as well as ACI. A conversion factor of 1.23 is used to convert Cube strengths in to Cylinder Strengths [23].

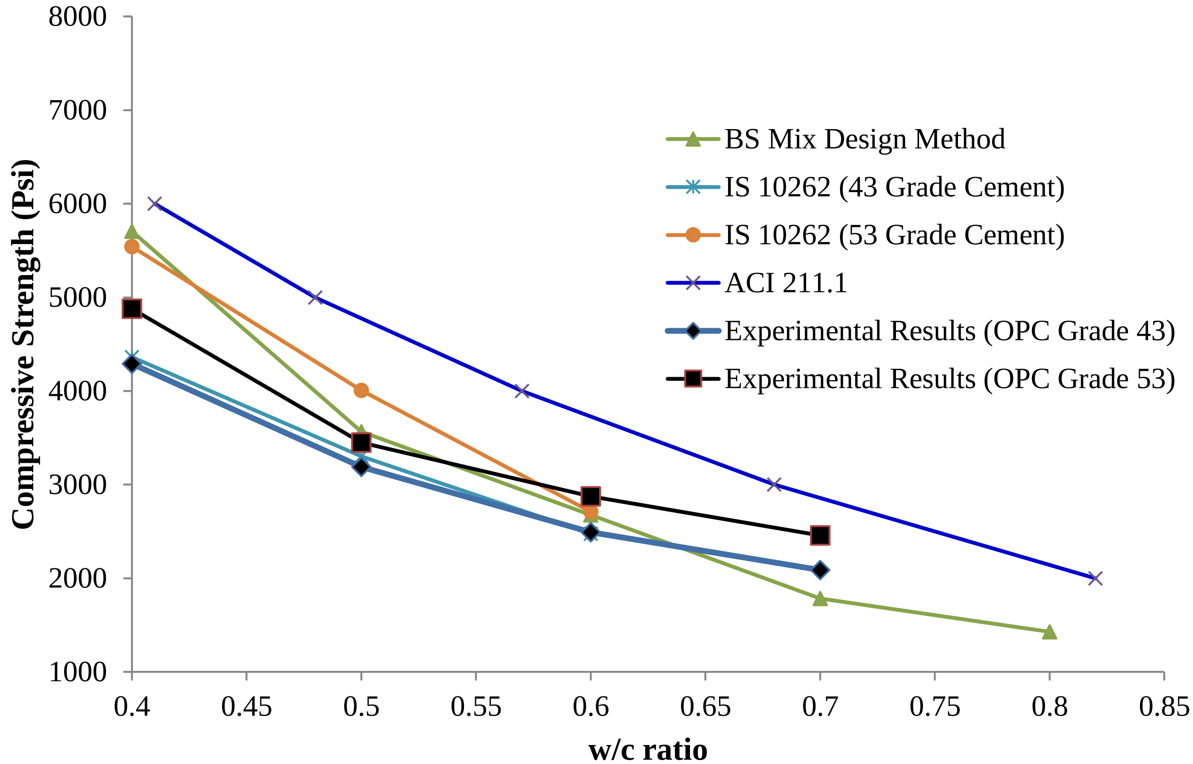


Figure 4.1: Comparison of Experimental relation between Strength and w/c ratio with relation Proposed by ACI Committee 211, BS (DOE) mix Design Methods and IS 10262 [24].

To examine strength growth rates of mixes with different w/c ratios, a bar chart comparison is given in Figure 4.2 for three cement types. It is also obvious from the graphs that the strength difference between 56-day strengths of mixes with w/c ratios varying from 0.3 to 0.7 is less than their difference at 28 days for both 43 and 53 Grade Cements. This is due to the fact that most of cement is hydrated in first 28 days rendering the system in a relatively inert state of strength growth [25]. Also the strength difference between 28 day strengths of mixes with w/c ratio 0.3 and 0.4 is reasonably greater than difference between mixes with greater w/c ratios strengthening the idea that strength as well as other mechanical properties is sensitive to water contents closer to water demand of the mix.

It is also observed that at later ages (28 and 56 days), strength difference between OPC 53 Grade and OPC 43 Grade decreases significantly than difference at 1 or 7 days. The reason lies in the fact that finer grains of OPC Grade 53 cement first hydrated, giving greater strengths (at early ages) than relatively coarser OPC Grade 43 cement. However at later ages, after complete hydration of relatively finer particles the reaction slows down exhibiting slow rate of strength gain.

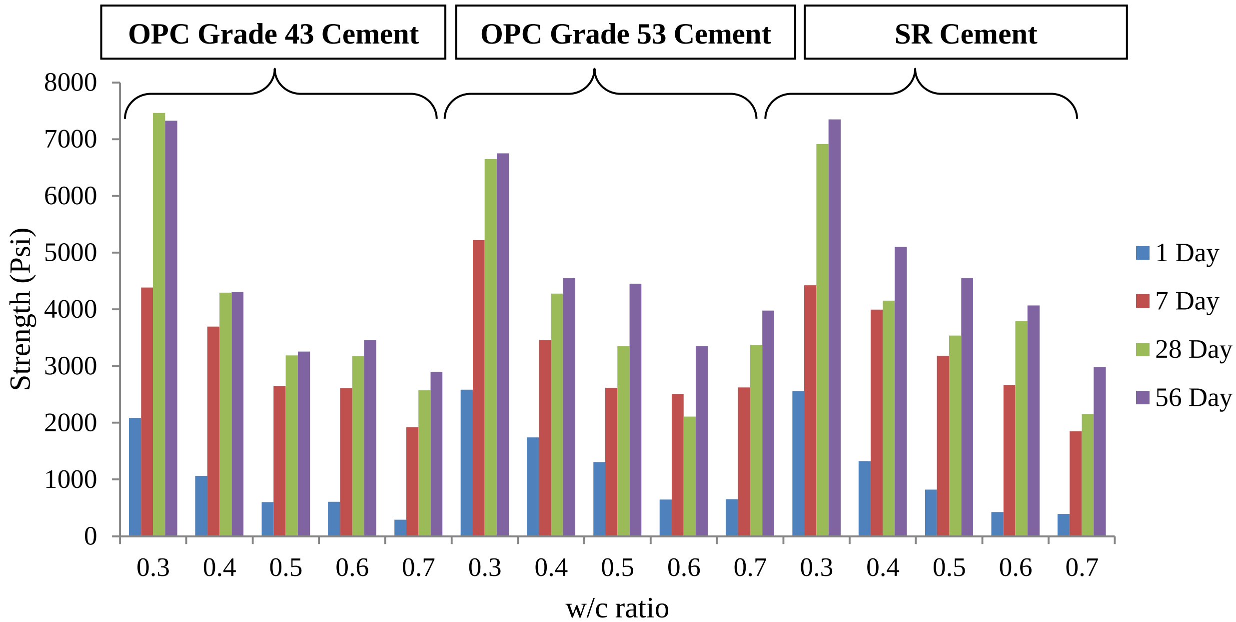


Figure 4.2: Comparison of Compressive Strengths of concretes with various Cement types, w/c ratios with age

Figures 4.3, 4.4 and 4.5 show w/c ratio – strength relation of all three cements with respect to various ages. 1 Day and 7 Day curves are almost parallel with an average difference of about 2000 Psi. This indicates a similar trend in growth rates at early age however, 28 Day and 56 Day curves are almost overlapping indicating no significant increase in strength. The reason can be explained in context of lesser availability of fine cement grains at later ages.

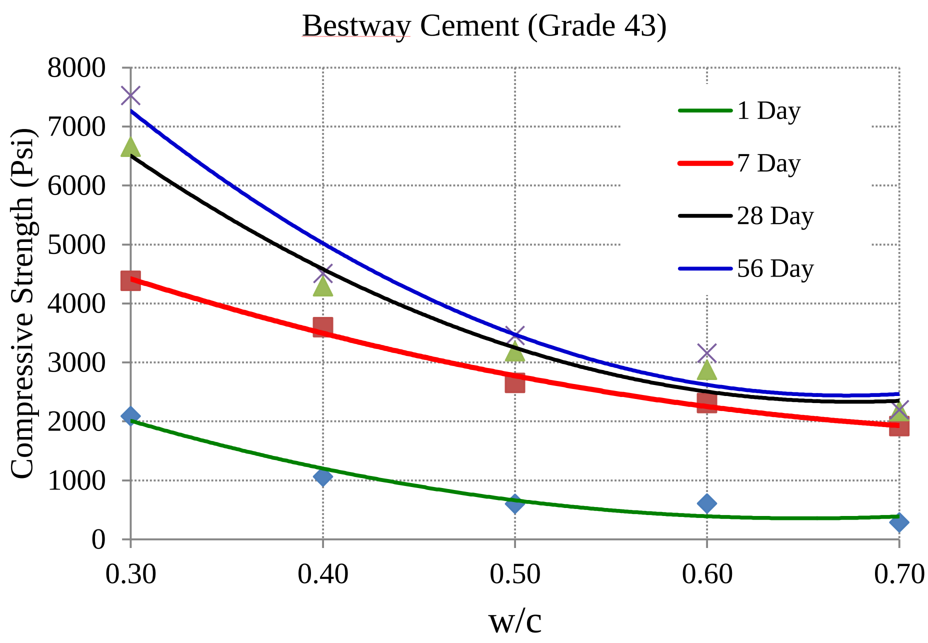


Figure 4.3: Experimental Relation between w/c ratio and Compressive Strength for Grade 43 Cement at various ages

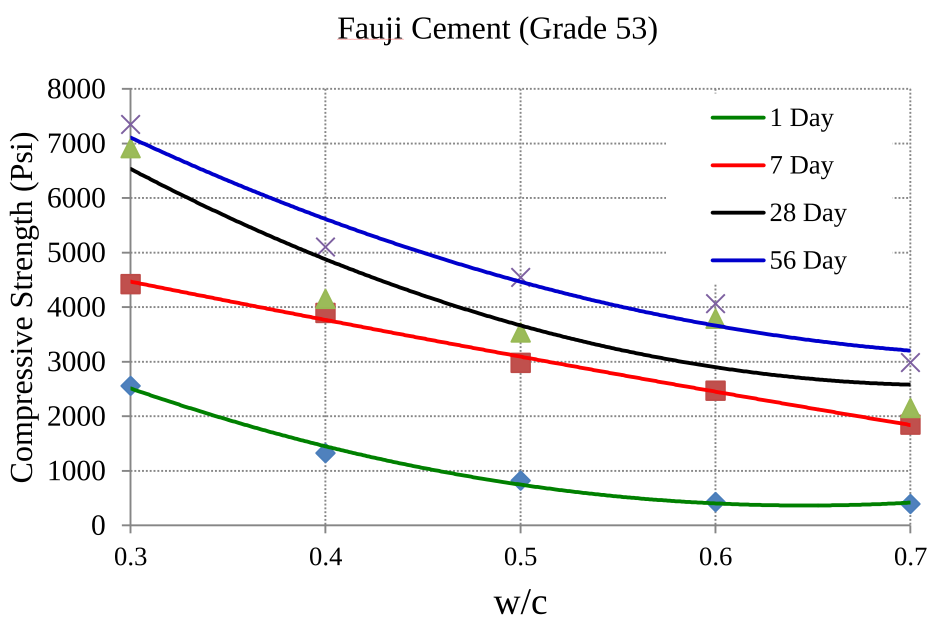


Figure 4.4: Experimental Relation between w/c ratio and Compressive Strength for Grade 53 Cement at various ages

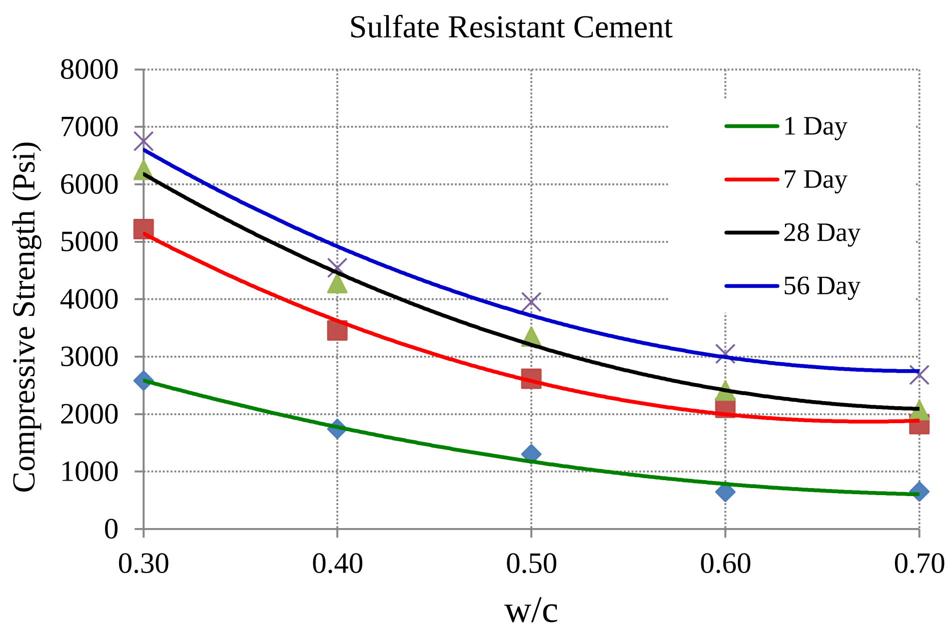


Figure 4.5: Experimental Relation between w/c ratio and Compressive Strength for SR Cement at various ages

4.4 Effect of w/c ratio on rate of Compressive Strength gain

Figure 4.6 is showing the effect of w/c ratio on rate of gain of strength. The strength versus time relation becomes very important in cases where structure is required to be put in use early. It can be observed from the graph that mixes with low w/c ratios gain strength more rapidly relative to high w/c ratios. This is due to the fact that in mixes with lesser water content, the cement grains are closer to one another and a continuous system of gel is established more rapidly [26].

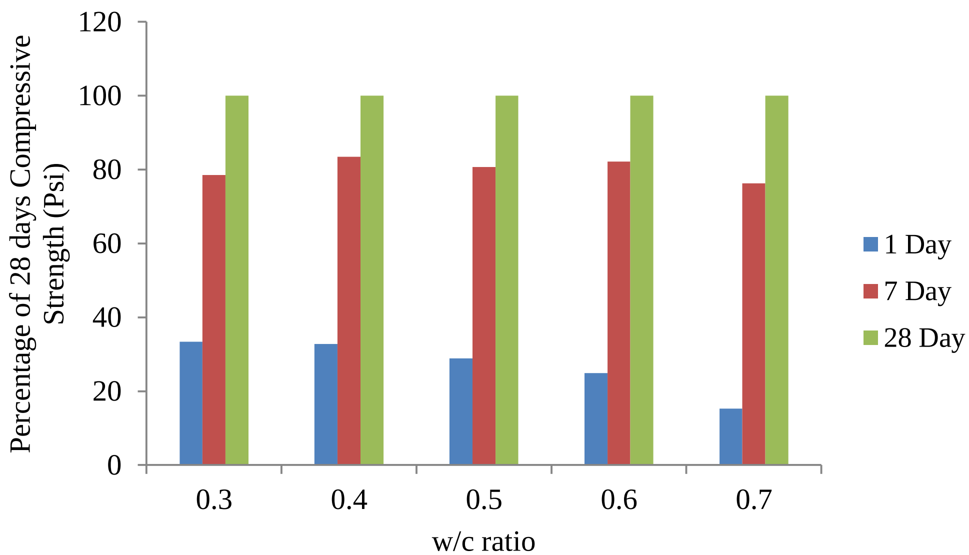


Figure 4.6: Relative rate of strength gain Vs w/c ratio

Strength development relations suggested by two different code provisions are compared with experimental results. It is found that CEB-FIP MC 90 expression [27] gave better prediction than ACI 209 expression [28] as shown in Figure 4.7.

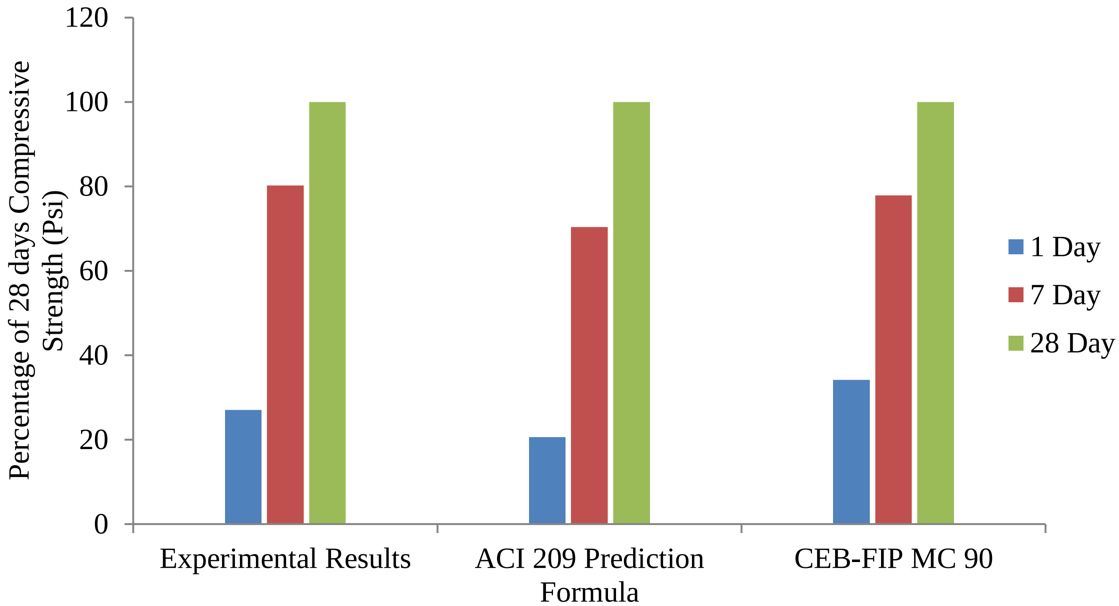


Figure 4.7: Comparison of various Strength Vs Age Relations with Experimental Results

4.5 Development of a new w/c ratio – compressive strength Model:

Duff Abrams [29] presented his famous w/c ratio – strength model in 1919, commonly known as "Abrams rule". Experimental results are compared with those predicted by Abram's rule and are presented in both tabular and graphical forms below.

Table 4.6: Comparison of Experimental values with Abram's rule

w/c ratio by volume	Experimental Average Value (Psi)	Values Predicted by Duff Abram's rule (Psi)
0.452	7054.25	5811.85
0.602	4284.75	4335.51
0.753	3269.75	3234.21
0.904	2642.62	2412.62
1.054	2573.75	1799.75

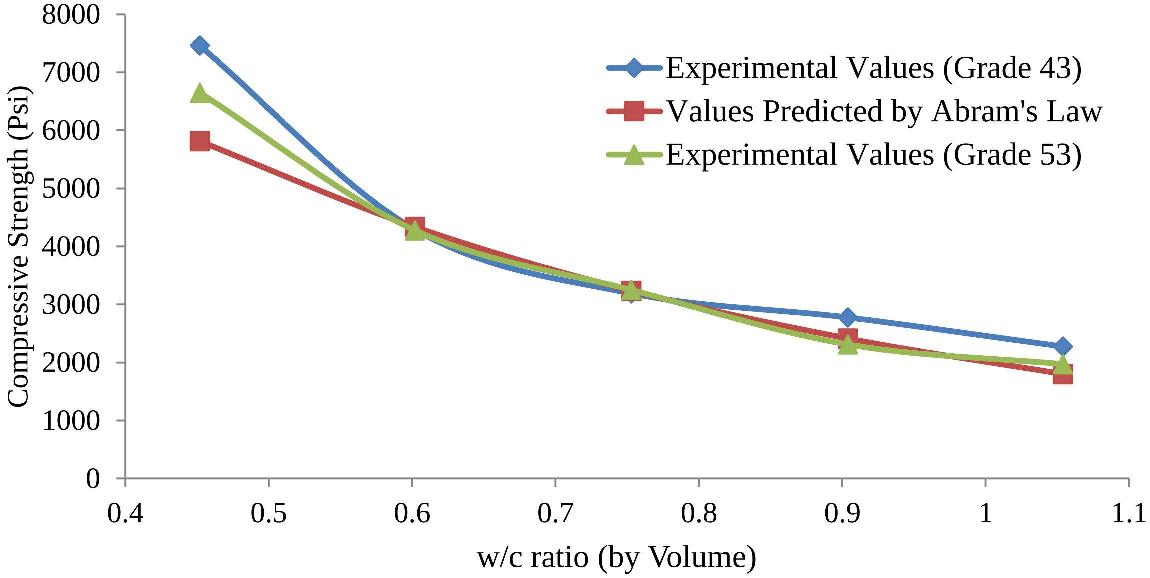


Figure 4.8: Comparison of Experimental average values with values predicted by Abram's Law

The expression developed by Duff Abram is given below.

$$S = \frac{14000}{7^x}$$

Similar exponential expressions are developed from experimental data obtained in this study (using statistical analysis). These expressions can be considered as suggested alterations of Abrams rule valid for normal strength concrete made with locally available aggregate and cement types.

For OPC Grade 43, $$S = \frac{14874}{2.718^{1.86x}}$$ (R^2 = 0.925)

For OPC Grade 53, $$S = \frac{15367}{2.718^{2.02x}}$$ (R^2 = 0.977)

Expressions for all three cements have also been developed of the form given below.

$$S = \frac{A}{(w/c)^B}$$

The values of "A" and "B" for each cement type determined from regression analysis of experimental data are listed in Table 4.7.

Table 4.7: Values of "A" and "B"

Cement Type	A	B	R^2
OPC Grade 43	1598	1.19	0.928
OPC Grade 53	1711	1.04	0.695
Sulfate Resistant Cement	1644	1.15	0.854

For Average Experimental data of both OPCs, we get the following equation.

$$S = \frac{1701}{(w/c)^{1.1}} \qquad (R^2 = 0.949)$$

Polynomial regression of experimental data is also performed and empirical equations have been developed of the form, $S = a (x)^2 + b (x) + c$, where S is the average 28 day compressive strength and “x” is w/c ratio by weight. Values for constants “a”, “b” and “c” are listed in Table 4.8.

Table 4.8: Values of “a”, “b” and “c”

Cement Type	a	b	c	R^2
OPC Grade 43	49662	-58384	19735	0.964
OPC Grade 53	44432	-55322	19802	0.953
Sulfate Resistant Cement	22268	-32157	14177	0.863
Average Data	38788	-48621	17905	0.970

4.6 Effect of w/c ratio, Cement Type and Age on Tensile Strength

Tensile strength of concrete is of prime importance in case of water retaining structures, runway slabs, pre-stressed concrete members, bond and shear failure of reinforced concrete members and cracking of mass concrete works. So far much of the work is done upon the evaluation of tensile strength of concrete by indirect methods and comparatively fewer efforts have been made for its determination by direct methods. Splitting Tensile test is also an indirect method. Samples with 5 different w/c ratios are tested at 3 and 7 days and the results for all three cement types are presented in the form of Bar Chart in Figure 4.9. It is found that on average, 3 day Splitting Tensile strength is 80% of 7 day Splitting Tensile strength.

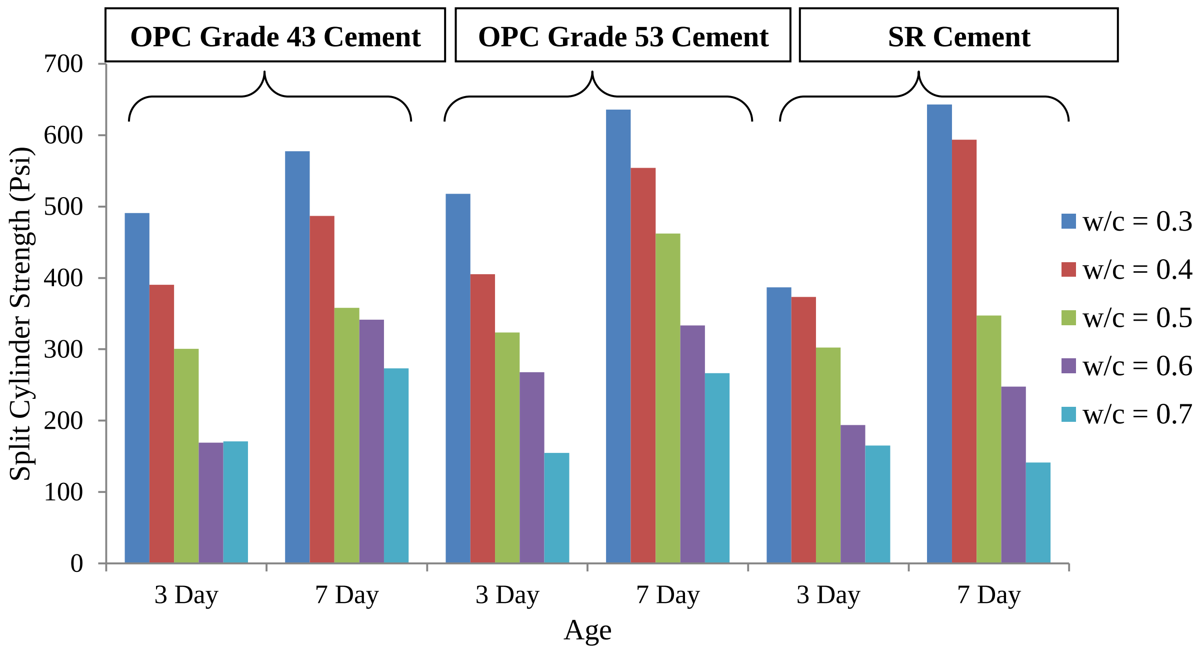


Figure 4.9: Comparison of Splitting Tensile Strengths for different w/c ratios at 3 and 7 Days

4.7 Relation between Compressive and Split Cylinder Strengths

The relationship between the compressive and the tensile strength seems to be determined by the combined effect of various factors on properties of both the matrix and the interfacial transition zone in concrete. It is observed that not only the age but also the characteristics of the concrete mixture, such as water-cement ratio and type of aggregate affect the tensile to compressive strength ratio to varying degrees. It is also found that tensile strength cannot be always expressed as a percentage of compressive strength as shown in Figure 4.10 in which a wide degree of scatter rules out the possibility of a general percentage law.

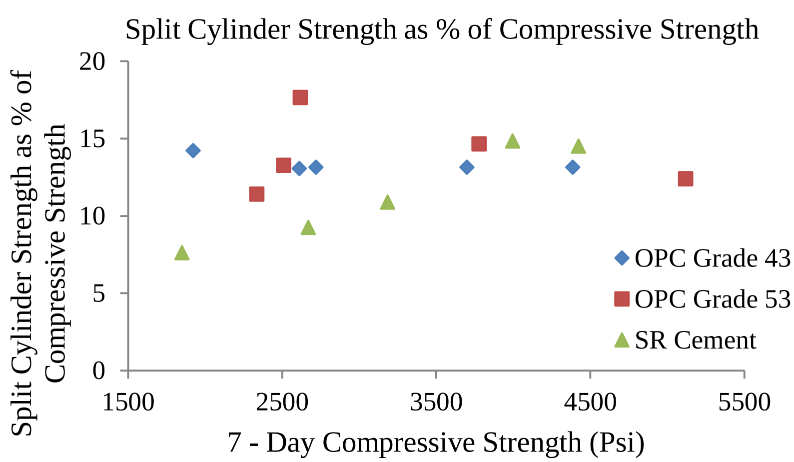


Figure 4.10: 7 Day Splitting Tensile Strength shown as a percentage of 7 Day Compressive Strength

Figures 4.11, 4.12 and 4.13 show a comparison of experimental results with ACI 318-08 [15] expression for splitting tensile strength (6.7√fc'). It is found that for lower values of fc', ACI expression overestimates the tensile strength and for higher values of fc', it underestimates the actual tensile strength. The same is depicted in next graphs.

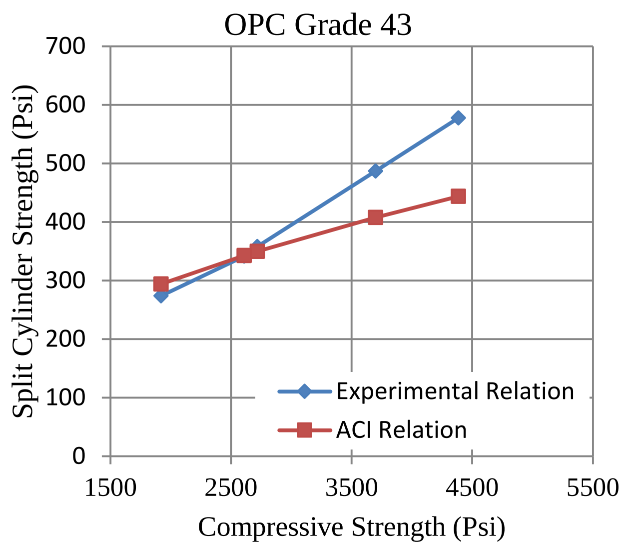


Figure 4.11: Comparison of Experimental and ACI 318-08 recommended Relations between Compressive and Splitting Tensile Strengths for OPC Grade 43

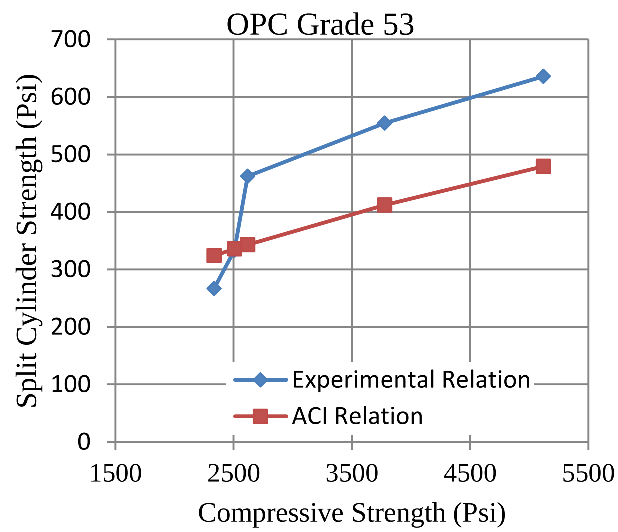


Figure 4.12: Comparison of Experimental and ACI 318-08 recommended Relations between Compressive and Splitting Tensile Strengths for OPC Grade 53

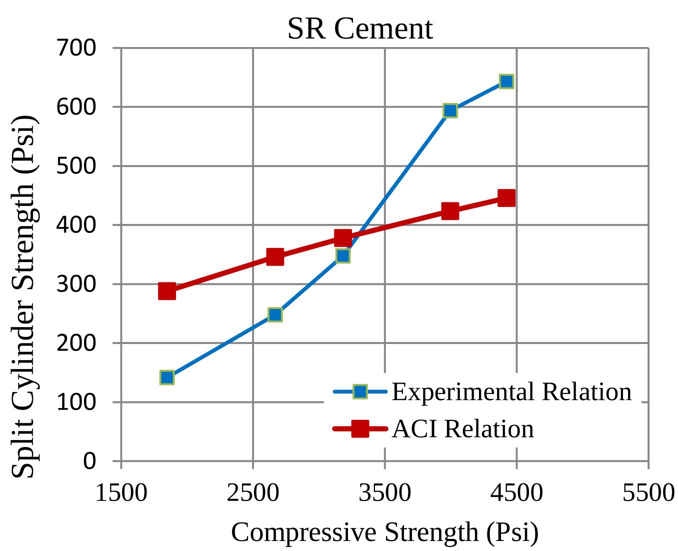


Figure 4.13: Comparison of Experimental and ACI 318-08 recommended Relations between Compressive and Splitting Tensile Strengths for SR Cement

4.8 Effect of Maximum Coarse Aggregate Size on Compressive Strength

The relation between 28 day average compressive strength of 100 mm x 200 mm cylinders and maximum size of coarse aggregates is shown below. Mix proportions and other details have been mentioned in article 3.4.4. As Turan [30] reported, there is an increase in strength with increasing maximum aggregate size. Since all relations which are established in this study are developed by using a maximum aggregate size of ¾", its effect is incorporated in the proposed method of mix design using a factor applied to specified strength. This factor is calculated by dividing the strength obtained using regression equation of this relation by strength achieved at a maximum aggregate size of ¾".

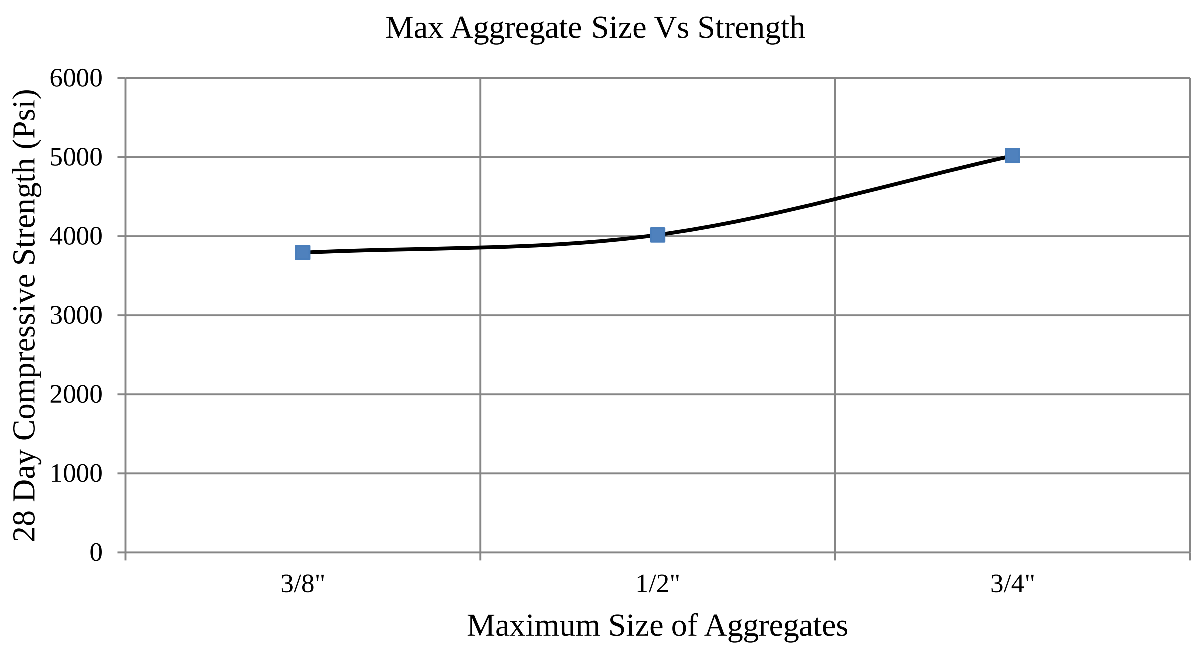


Figure 4.14: Experimental Relation between maximum aggregate size (in) and 28 Day Compressive Strength (Psi)

4.9 Effect of Fineness Modulus of Fine Aggregates Size on Compressive Strength

Experimental relation between Fineness Modulus of sand and 28 day average compressive strength suggests that FM of 2.4 corresponding to a blend of 50% Qibla Bandi sand and 50% Lawrencepur sand is giving optimum strength while keeping all other parameters constant when used with ¾" down grading of margalla coarse aggregates. Since all relations which are established in this study are developed by using Lawrencepur sand with FM of 2.058, its effect is incorporated in the proposed method of mix design in the same manner as Maximum aggregate size, i.e. using a factor applied to specified strength. This factor is calculated by dividing the strength obtained using regression equation of relation given below by strength achieved at FM of 2.058. The relation between 28 day average compressive strength of 100 mm x 200 mm cylinders and FM of sand aggregates is shown below.

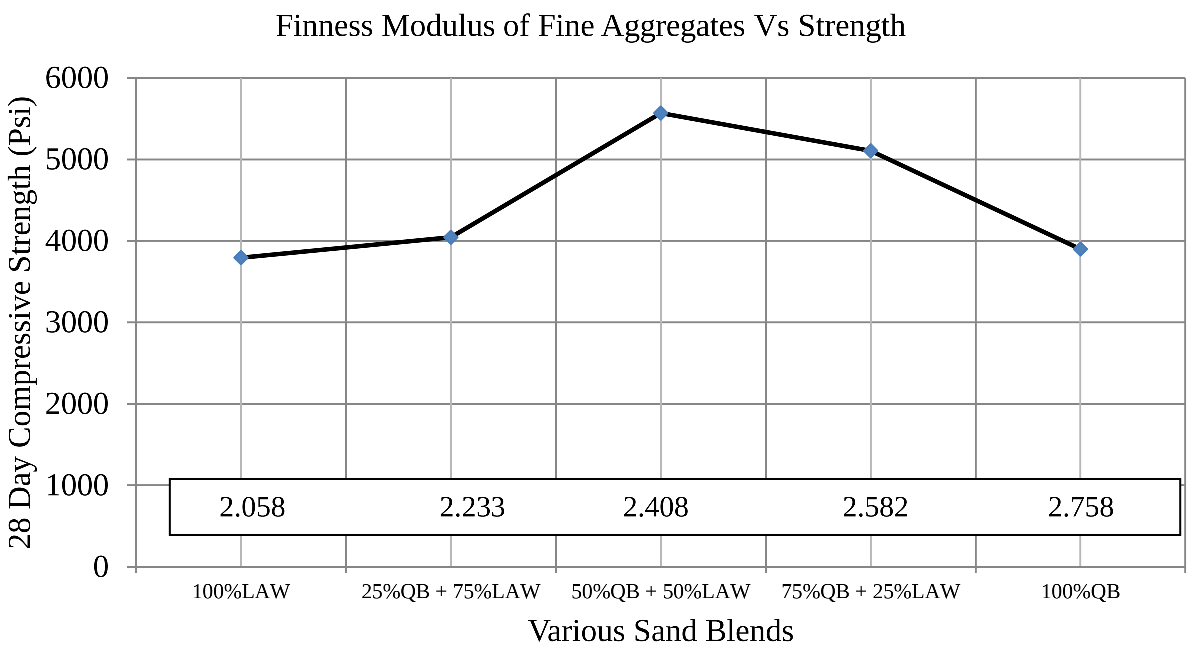


Figure 4.15: Various Sand Blends and 28 day Average Compressive Strength (Psi)

4.10 Effect of Fine Aggregate to Total Aggregate ratio on Compressive Strength

The fine aggregate content in a mix is an important parameter affecting workability, homogeneity as well as compressive strength. A relation is developed by varying volumetric ratios of fine aggregates to total aggregate volume. Results of 28 Day Compressive Strengths of mixes with 0%, 30%, 35%, 40%, 45% and 50% sands (of total aggregate content) are shown graphically in Figure 4.24. Maximum strengths were found at 35% and 45%. However, the mixes corresponding to 45% and 50% sand were too dry and were not workable enough to be used as a routine job mix. A reasonable effort was employed in terms of vibration and mixing to maintain cohesion and avoid segregation in these two mixes. Phil Bamforth [31] reported that for aggregate/cement ratio of greater than 3, voids start increasing at exponential rate when the sand content is increased above 40 %, thus rendering the mix susceptible to segregation. A slight decrease in strength at 40% sand content can be explained in the context of having less packing density than others. Hence ignoring the second peak corresponding to 45% sand content, a volumetric FA/TA ratio of 0.35 is fixed in proposed method of mix design.

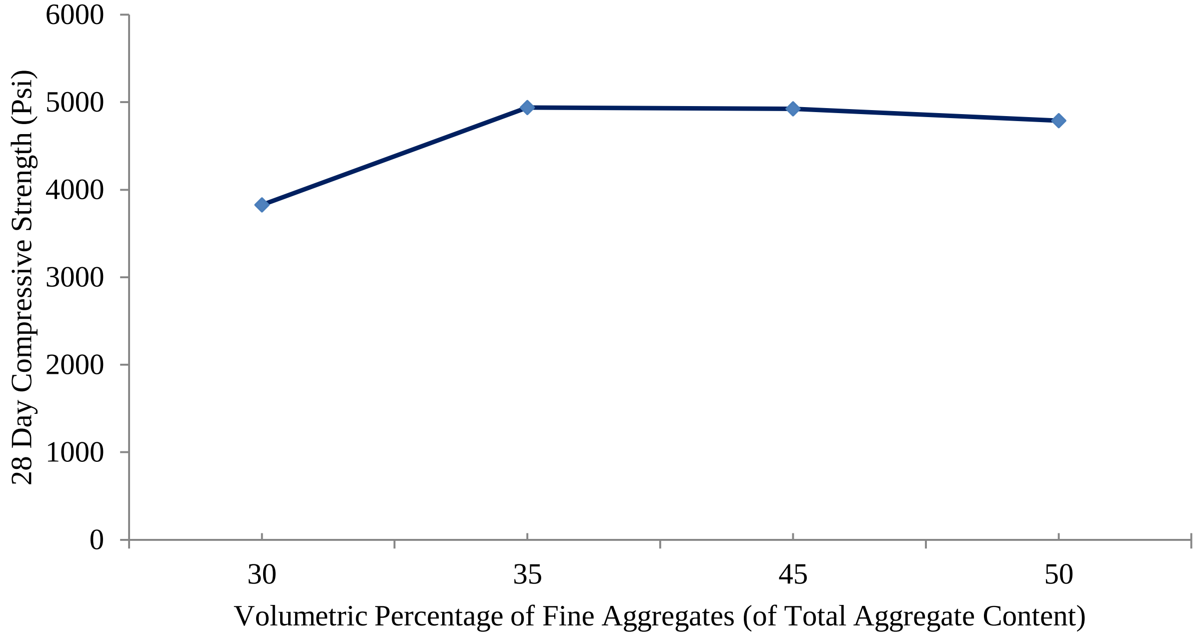


Figure 4.16: Experimental Relation between Fine Aggregate Content and 28 day Average Compressive Strength (Psi)

4.11 Effect of Super Plasticizer Type and Content on Slump

Polycarboxylic ether polymer (PCE) based superplasticizer (Gelenium - 51) gave more slump values at dosages greater than 1% by weight of cement than Beta-Naphthalene sulphonate Polycondensate based superplastcizer (Rheobuild - 858). This is attributed to the fact that PCE based SPs work on the principle of electrostatic repulsion; however BNS based SPs work on both electrostatic repulsion as well as chain grafting [32]. Increase in slump seems to increase at a high rate with w/c ratio in the mixes with SP. This behavior can be attributed to an ease in availability of medium to reveal SP action.

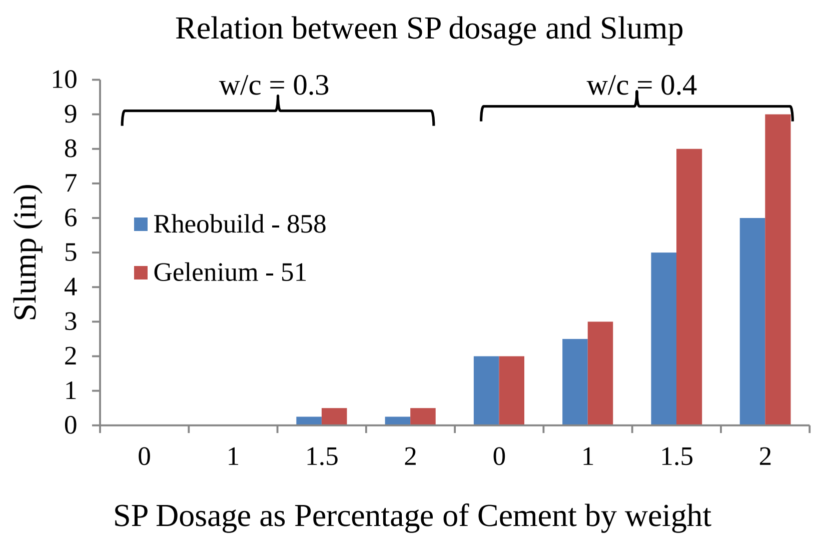


Figure 4.17: Experimental Relation between Super plasticizer Dosage and Slump of Concrete mix

CHAPTER 5 PROPOSED METHOD OF MIX DESIGN

5.1 General

A critical review of various mix design methods was presented in chapter 2. Various limitations were highlighted with regards to their use with local aggregate and cement types. This chapter presents the details of various steps involved in a new proposed method of mix design for normal concrete. The method is based upon w/c – strength relations developed for various cement types as well as some other relationships established in this study between various parameters including Slump, age, type and dosage of super plasticizers (Figures 4.1, 4.2 and 4.27). To automate this method, a Graphical User Interface (GUI) is developed in MATLAB R2009a environment and will be presented in succeeding topics.

5.2 Various Steps of Proposed Mix Design Method

The complete process is explained below by dividing it in various steps.

Step 1: Determination of Mean Target Strength: Mean target strength is proposed to be calculated using the following relationship.

$$fcr' = \left(\frac{4-f1-f2}{2}\right) fc' + SD \quad \text{------------------- (eq. 5.1)}$$

Where,

f_c' = Compressive Strength of Concrete specified at 28 days

f_{cr}' = Mean Target Strength

f_1 = A factor incorporating the effect of Maximum Size of Coarse Aggregates (f_1 = 1, at Maximum aggregate size of ¾")

f_2 = A factor incorporating the effect of Fineness Modulus of sand (f_2 = 1, at fineness modulus of 2.057)

SD = Standard Deviation in target compressive strength is recommended by ACI 318-08 committee report [15].

Since w/c - strength relations are established using maximum aggregate size of 0.75 inch and fineness modulus of 2.057, the idea is to apply two factors, accounting the effect of these two parameters, to specified strength. Therefore,

$$f1 = \frac{\text{28 day compressive strength at given max. aggregate size (from exp. graph)}}{\text{28 − day compressive strength at maximum aggregate size of 0.75 inch}}$$

$$f1 = \frac{(387.5(msa)^2 - 937(msa) + 4340)}{3855.219}$$ ------------------- (eq. 5.2)

$$f2 = \frac{\text{28 day compressive strength at given Fineness Modulus (from exp. graph)}}{\text{28 − day compressive strength at Fineness Modulus of 2.057}}$$

$$f2 = \frac{(-9080(fm)^2 + 43889(fm) - 47890)}{3969.932}$$ ------------------- (eq. 5.3)

Where "msa" is the maximum aggregate size in inches and "fm" is the fineness modulus. These expressions for f_1 and f_2 are obtained from regression analysis of their graphical relations presented in chapter 4.

In fact the equation 5.1 is a simplification of,

$$fcr' = \alpha fc' + SD$$ ------------------- (eq. 5.4)

Where "α" is a factor incorporating the combined effect of maximum coarse aggregate size as well as fineness modulus of fine aggregate.

$$\alpha = 2 - (\frac{f1+f2}{2})$$ ------------------- (eq. 5.5)

Putting the value of "α" in equation 5.2, we get,

$$fcr' = 2fc' - (\frac{f1+f2}{2})fc' + SD$$ ------------------- (eq. 5.6)

Values of "α" for typical maximum aggregates sizes and fineness moduli are listed in Table 5.1 below.

Table 5.1: Typical Values of "α"

Maximum Aggregate Sizes	3/8"	1/2"	3/4"
Fineness Modulus			
2	1.026	1.036	1.051
2.1	0.942	0.952	0.967
2.2	0.881	0.891	0.906
2.3	0.843	0.853	0.868
2.4	0.828	0.838	0.852
2.5	0.836	0.845	0.860
2.6	0.866	0.876	0.890
2.7	0.919	0.929	0.944
2.8	0.996	1.005	1.020

Standard deviation in target compressive strength recommended by ACI 318-08 is shown below.

Table 5.2: Standard Deviations specified by ACI 318-08

Specified compressive strength, psi	Required average compressive strength, psi
$fc' < 3000$	$fcr' = fc' + 1000$
$3000 \leq fc' \leq 5000$	$fcr' = fc' + 1200$
$fc' > 5000$	$fcr' = 1.10fc' + 700$

Step 2: Determination of $(w/c)_{st}$: Using *fcr′*, w/c ratio can be obtained from w/c – strength curves for given Cement type. It is denoted as $(w/c)_{st}$.

Step 3: Determination of $(w/c)_{wo}$: Using required slump value, w/c ratio is obtained from w/c – slump curves for given Cement type. It is denoted as $(w/c)_{wo}$. If Super plasticizer is to be used, an adjusted slump value is calculated by subtracting "average slump increase" provided by SP from original slump requirement. This "Average Slump increase" provided by SP is determined from graphical relation between SP dosage and average slump increase at a given w/c ratio. In case SP is used, calculate $(w/c)_{wo}$ using adjusted slump requirement instead of original slump requirement.

Step 4: Determination of final w/c ratio: Final w/c ratio is established by averaging $(w/c)_{st}$ and $(w/c)_{wo}$.

$$Final\ w/c = \frac{(w/c)st+(w/c)wo}{2} \text{ ------------------- (eq. 5.7)}$$

Step 5: Determination of Cement content: Cement content is obtained using the following relationship [35].

$$C = \frac{fcr'}{C_1} \text{ ------------------- (eq. 5.8)}$$

Where,

fcr′ = Mean Target Strength (Psi)

C_1 = Average increase in Strength per 1 Kg/m^3 increase in Cement Content (Psi)

It is observed that value of C_1 is not constant over a wide range of Cement Content as well as Strength rather it increases linearly with *fcr′*, the following expression is obtained by linear regression of above tabular data.

$$C_1 = 0.0014\,(fcr') + 4.1025 \text{ ------------------- (eq. 5.9)}$$

Therefore,

$$C = \frac{fcr'}{0.0014\, fcr' + 4.1025} \text{ ------------------- (eq. 5.10)}$$

Step 6: Determination of Water content: Water content is calculated by multiplying final w/c ratio with Cement content calculated in Step 5.

$$W = (^{W}/_{C}) \times C$$ ------------------- (eq. 5.11)

Step 7: Determination of Total absolute volume of aggregates: Find total absolute volume of aggregates by subtracting absolute volumes of Cement, Water and Air (average value assumed as 1.5% for normal slump ranges) from 1 using the following relation.

$$\text{Absolute Aggregate Volume} = 1 - \frac{C}{3.15 \times 1000} - \frac{W}{1000} - 0.015$$ ------------------- (eq. 5.12)

Step 8: Determination of Fine aggregate Content: Since it is confirmed from the study that optimum compressive strength is achieved when 35% volume of total aggregate volume was comprised of fine aggregates, the sand content is fixed at 35% of total aggregate content by volume.

$$\text{Fine Aggregate Volume} = 0.35 \text{ x Total Aggregate Volume}$$

$$\text{Fine Aggregate Content} = \text{Fine Aggregate Volume x Sp. Gr of Fine Aggregates x } 1000$$

Step 9: Determination of Coarse aggregate Content: Remaining 65% volume is comprised of Coarse Aggregates.

$$\text{Coarse Aggregate Volume} = 0.65 \text{ x Total Aggregate Volume}$$

$$\text{Coarse Aggregate Content} = \text{Coarse Aggregate Volume x Sp. Gr of Coarse Aggregates x } 1000$$

Step 10: Moisture Adjustment:

The final mix is then adjusted by taking into account the absorption values of aggregates in "as stored" and saturated surface dry conditions.

In this regard, the author wants to highlight a small oversight made in moisture adjustment in a Solved example in ACI 211.1 Committee report. In article 7.2 a solved example is solved with following aggregate moisture conditions.

Table 5.4: Absorption Values of solved example in ACI 211 Committee report

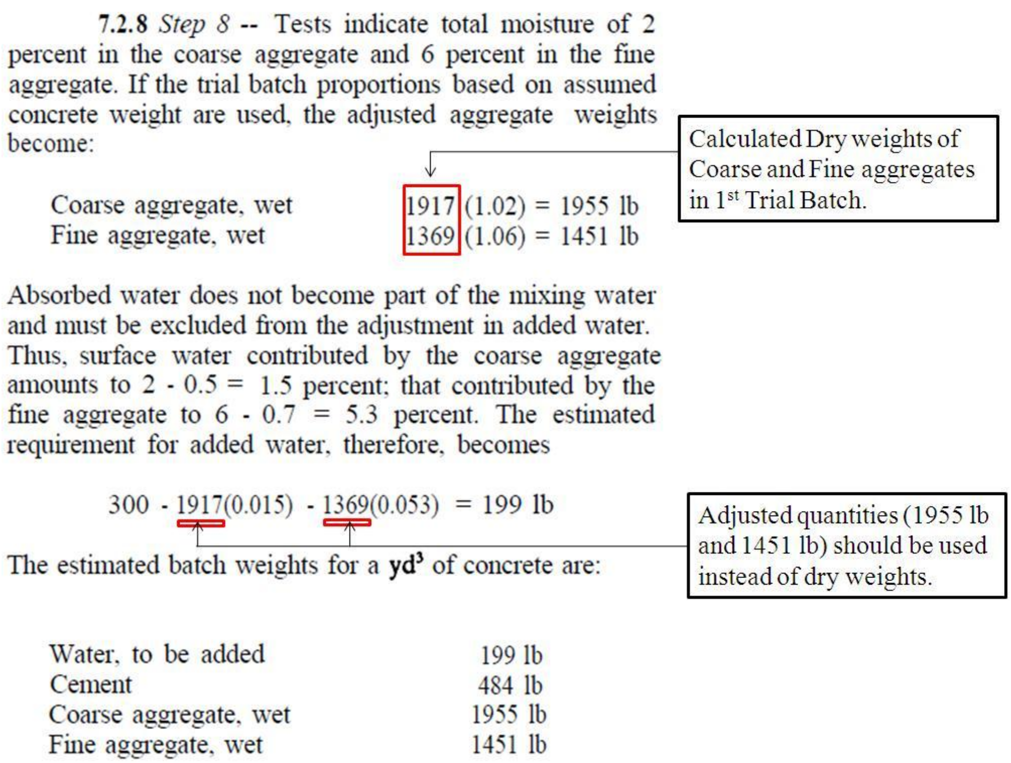
Material	% Moisture in Aggregates (As available)	% Absorption in SSD state (Water Demand in SSD state)
Sand	6 %	0.7 %
Crushed Stone Aggregates	2 %	0.5 %

Batch weights calculated per yd^3 of concrete are,

Table 5.5: Batch Quantities of solved example in ACI 211 Committee report

Material	Weight (lb)
Water	300
Cement	484
Coarse Aggregates, dry	1917
Fine Aggregate, dry	1369

Aggregate contents are adjusted by adding 2% and 6% masses in Coarse and fine aggregates respectively. However in water adjustment, dry weights are used instead of wet. Following diagram elaborates the situation.


7.2.8 *Step 8* -- Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed concrete weight are used, the adjusted aggregate weights become:

Coarse aggregate, wet	1917 (1.02) = 1955 lb
Fine aggregate, wet	1369 (1.06) = 1451 lb

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 - 0.5 = 1.5 percent; that contributed by the fine aggregate to 6 - 0.7 = 5.3 percent. The estimated requirement for added water, therefore, becomes

300 - 1917(0.015) - 1369(0.053) = 199 lb

The estimated batch weights for a **yd³** of concrete are:

Water, to be added	199 lb
Cement	484 lb
Coarse aggregate, wet	1955 lb
Fine aggregate, wet	1451 lb

Figure 5.1: A cutting from ACI 211.1 Committee Report indicating a small mistake.

If wet weights were used the adjusted water content would become [300 – 1955(0.015) – 1451(0.053) = 193.772 lb], which is 5.228 lb less than as calculated by ACI 211.1. Also the water/cement ratio is changed from 0.663 to 0.645 and the difference may increase in case of use of aggregates with higher absorption values. Hence it is reccomended to use wet weights of aggregates in water content adjustment instead of dry weights.

5.3 Computer Software for Proposed Method

MATLAB R2009a is chosen to develop a computer application for convenient use of proposed method. MATLAB is both a computer programming language and a software environment for using that language effectively (The name MATLAB stands for “Matrix Laboratory”). It is maintained and sold by “The Math Works Inc.” of Natick, Massachusetts and is available for MS

Windows and other operating systems. Its interactive environment allows the user to manage variables, import and export data, perform calculations, generate plots and develop files [36].

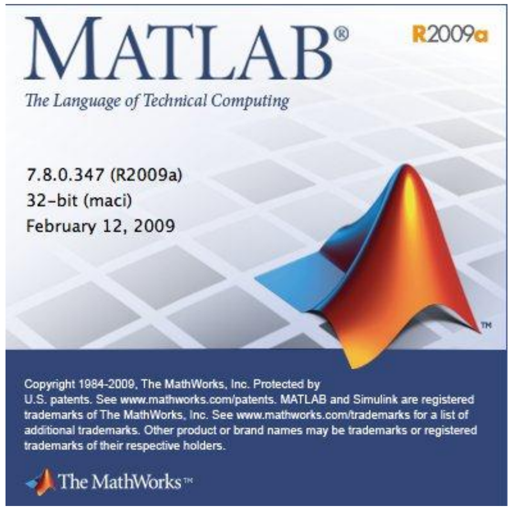


Figure 5.2: MATLAB R2009a – A registered Trade Mark of Math Works Inc.

5.3.1 Computer Aided Mix Design

A very few commercial software are available covering various aspects of concrete mix proportioning. Till recent times, the field of concrete materials is not as affected by computer programs and software as other fields of Civil Engineering. There is a great need of solid collaboration between advanced computing and Concrete Engineering.

5.3.2 Graphical User Interface (GUI) and Its Elements

A GUI provides a pictorial interface between the user and the computer program. It provides a convenient environment with the help of its components, Figures and Callbacks. Keyboard inputs or mouse clicks are referred to as events. The code executed in response to an event is known as callback. The components used in this GUI include push-buttons, edit boxes, pop-up menus, frames, and text fields. These can be seen in Figures 5.3 and onwards.

The software responds to each event and implements the functions of each graphical object on the figure window. The code sets in the callbacks include the equations developed in this study, input and output commands, and other formulas used in the calculations. The program consists of following two types of files.

a) A FIG-file, with extension .fig, that contains a complete description of the GUI layout and the GUI components, such as push buttons, axes, panels, menus, and so on. The FIG-file is a binary file and user cannot modify it except by changing the layout in a GUI development module of MATLAB known as GUIDE.
b) An M-file, with extension .m, that initially contains initialization code and templates for some callbacks that are needed to control GUI behavior.

Explanatory notes are also provided as help files to guide the user on decision-making. The program is capable of giving the material constituent of concrete for the first trial batch from given performance criteria. Below are some figures elaborating some of the features of this software.

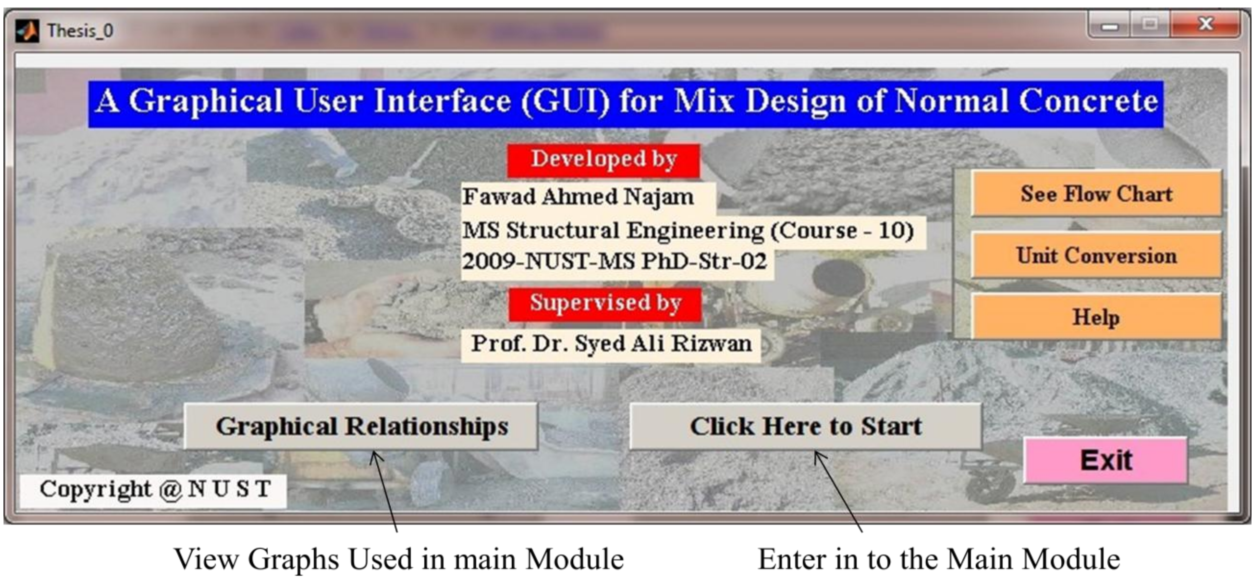


Figure 5.3: Start Page

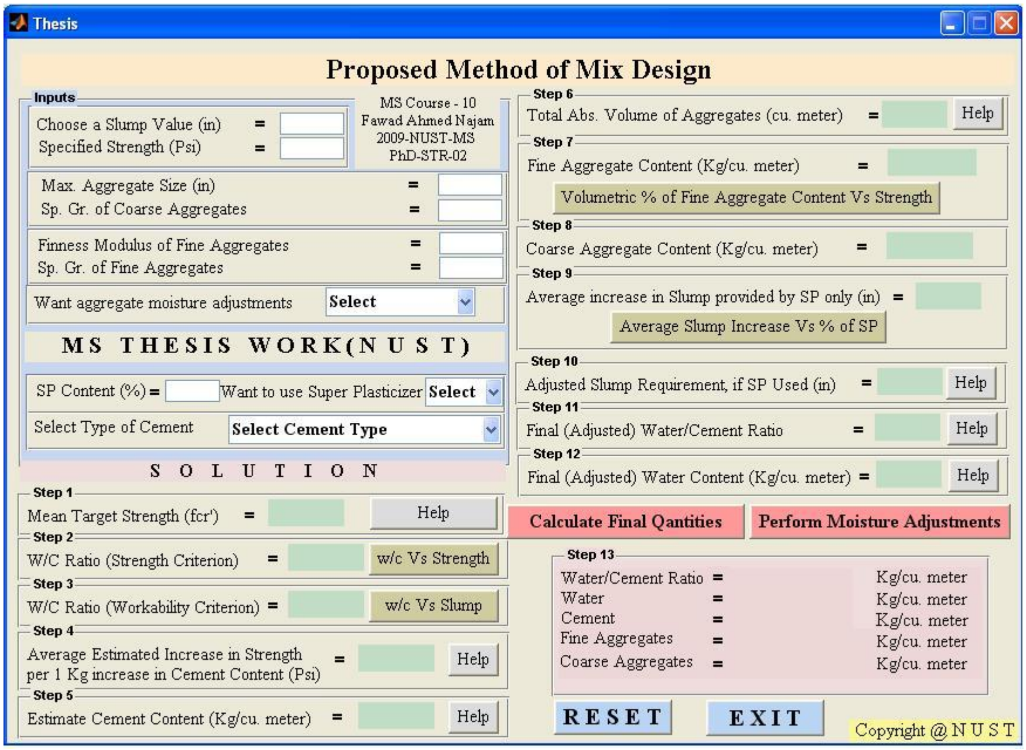


Figure 5.4: The Main Module

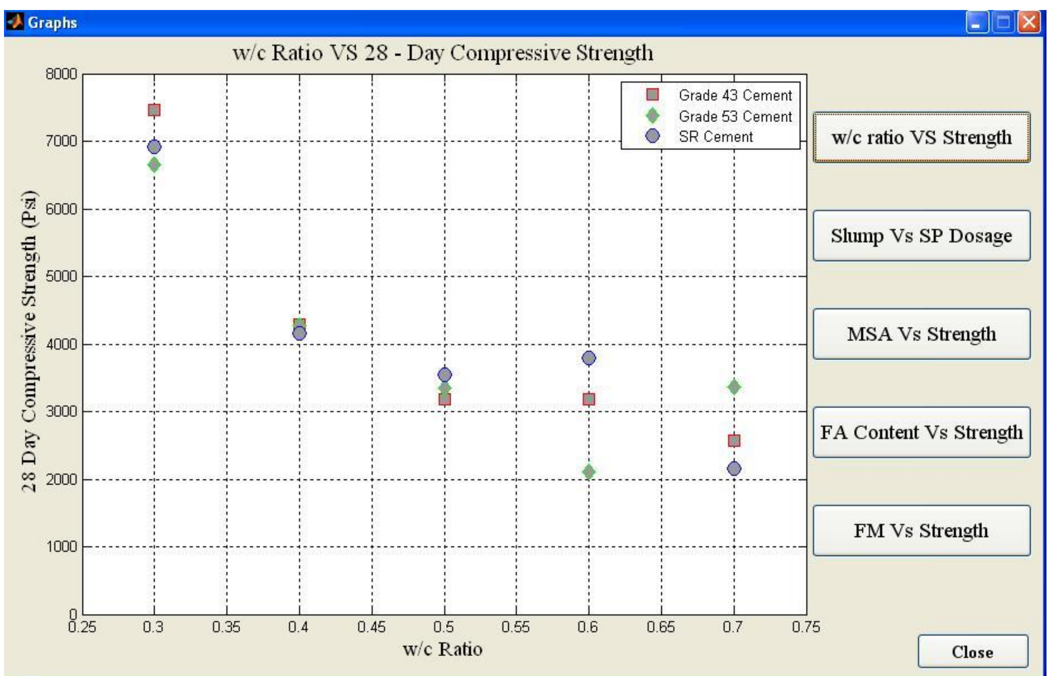


Figure 5.5: Graphical Relationships Module

Regression equations for all graphical relationships were determined and used in the code of this software.

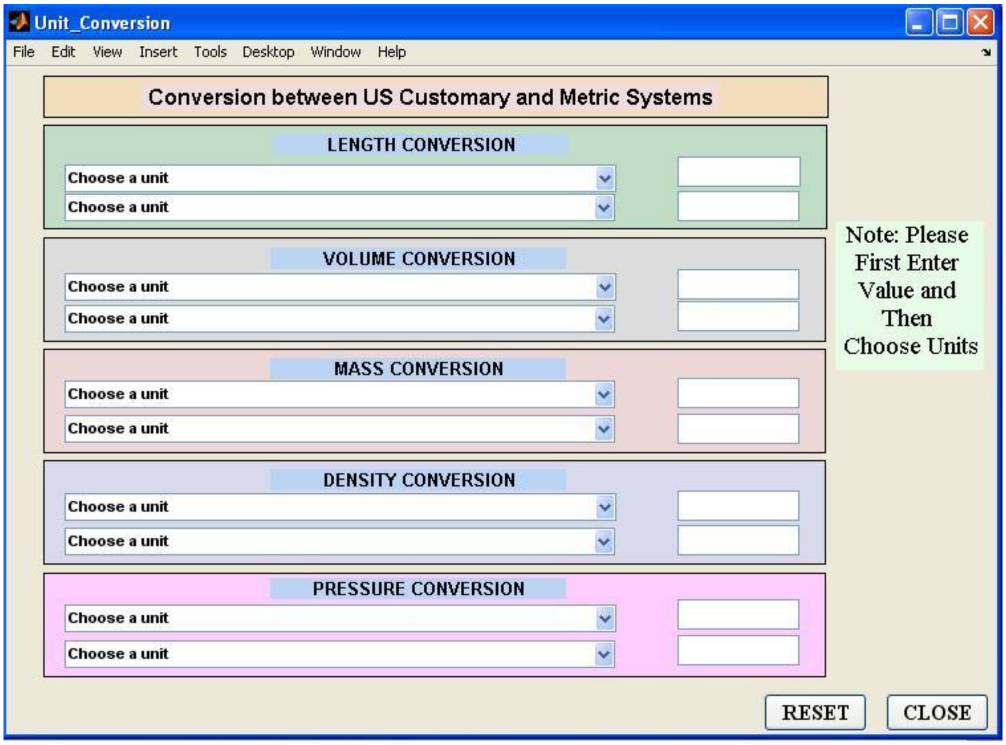


Figure 5.6: Unit Conversion Module

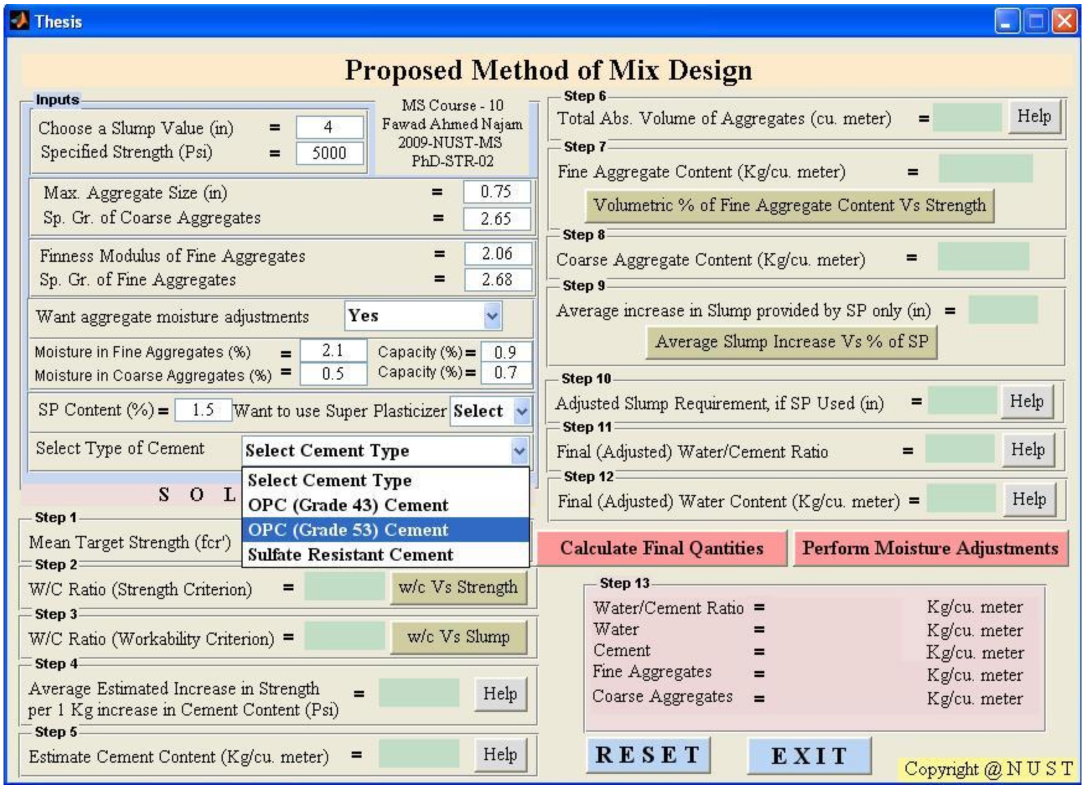


Figure 5.7: Entering Input Data

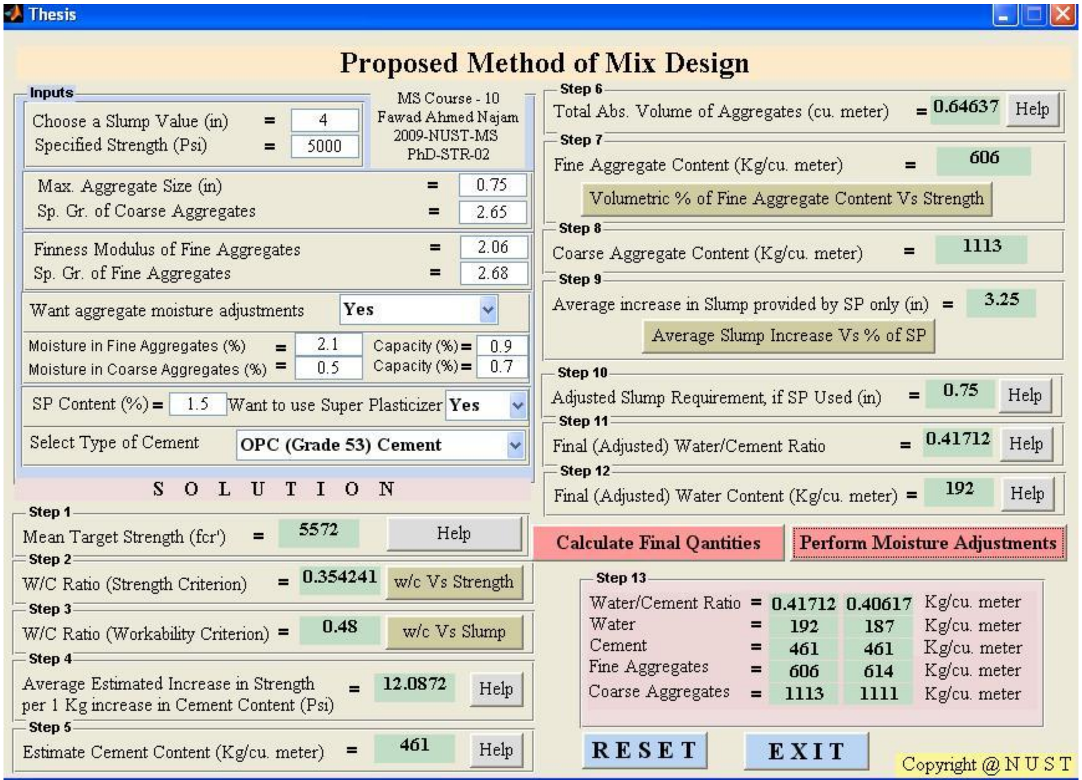


Figure 5.8: A complete Example Solved

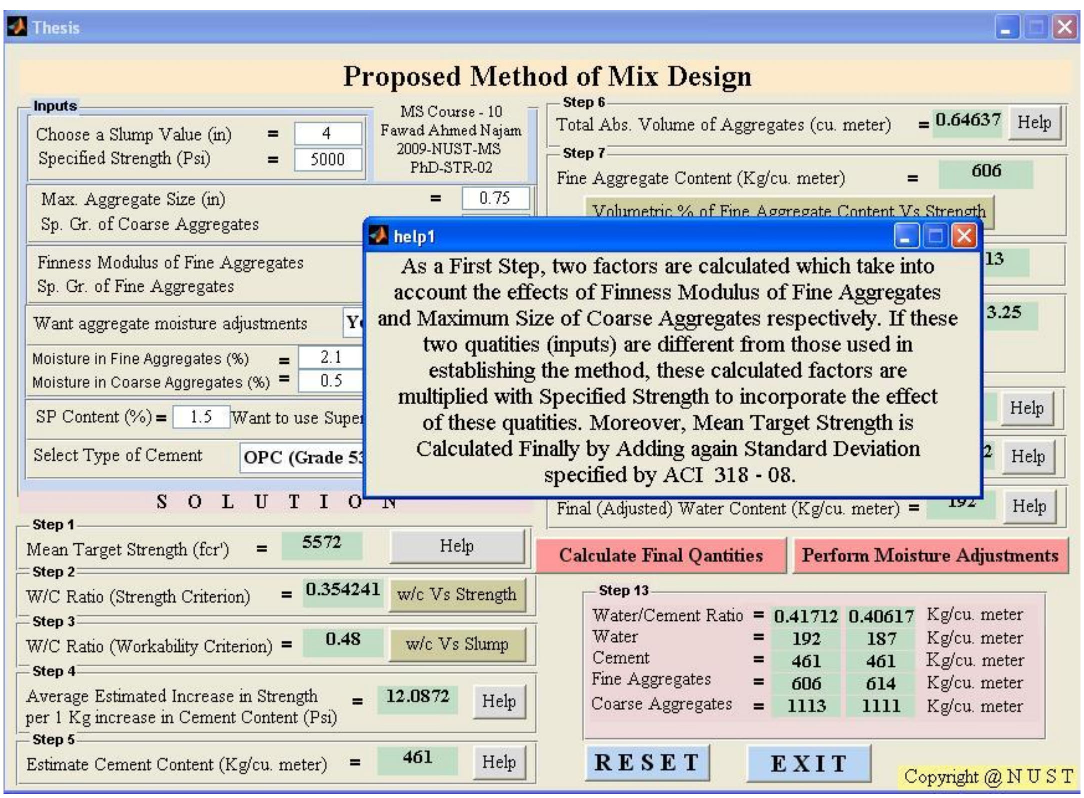


Figure 5.9: Using “Help” Buttons

5.3.3 Flow Chart for Developed Software

Below is a flow chart for the proposed method. Above presented GUI works according to this flowchart.

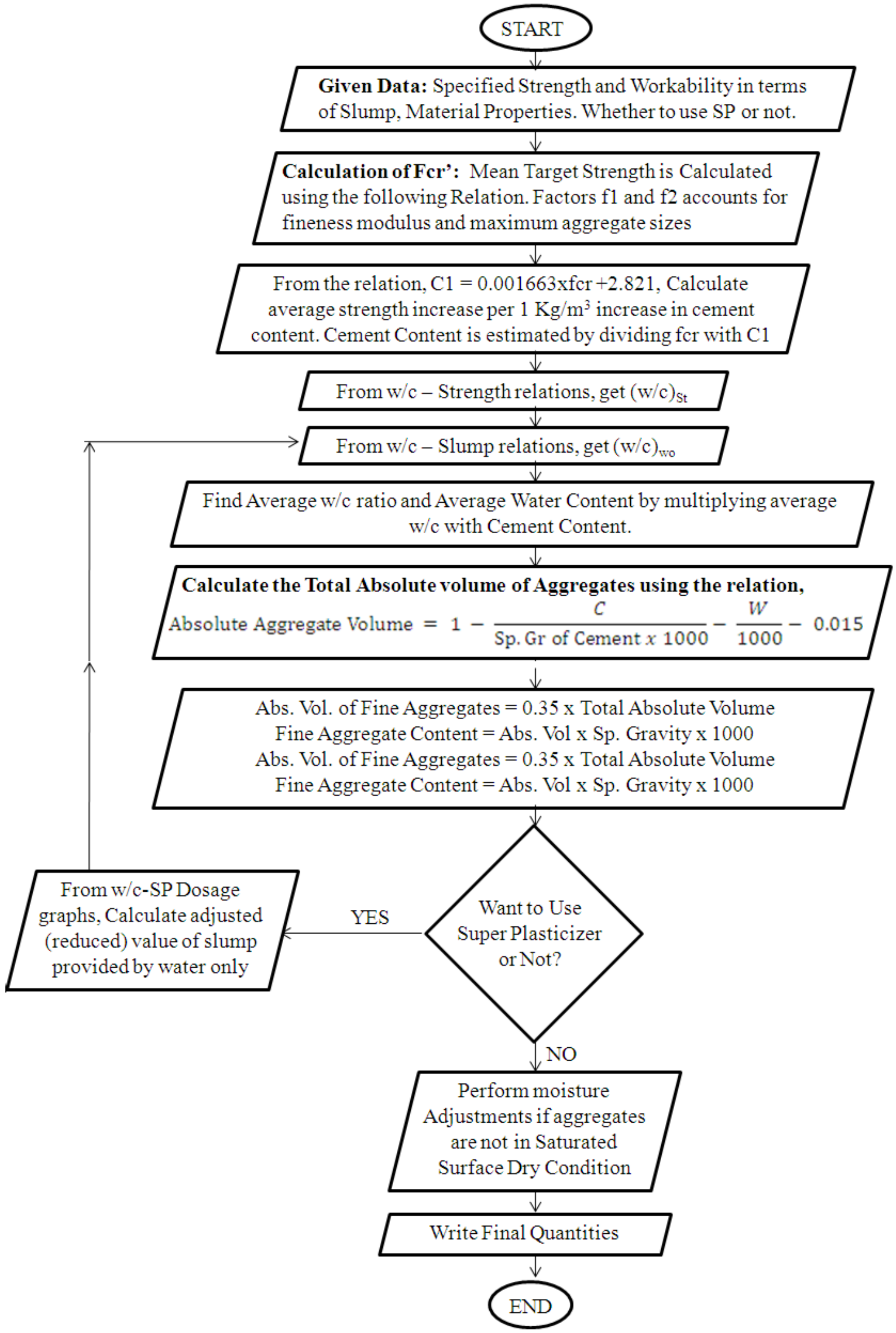


Figure 5.10: Flow Chart for the proposed Method

The main calculating functions and formulae are embedded in two Popup Menus i.e. "Selection of Super plasticizer" and "Selection of Cement Type". "Calculate Final Quantities" and "Perform Moisture Adjustments" buttons are used to unhide/show the calculated results. Selected parts of .m file code of this GUI are given below. Commands working behind all important buttons and Popup Menus are given.

5.3.4 Matlab .m File code for developed GUI

This part of Commands executes on selection change in popup menu for Selection of Cement Types.

```
function cement_Callback(hObject, eventdata, handles)
sslump = get(handles.slump,'String');
sl = str2num(sslump);
sstrength = get(handles.strength,'String');
smsa = get(handles.msa,'String');
sfm = get(handles.fm,'String');
st = str2num(sstrength);
max = str2num(smsa);
fmo = str2num(sfm);
sslump = get(handles.slump,'String');
sstrength = get(handles.strength,'String');
smsa = get(handles.msa,'String');
sspgrcoarse = get(handles.spgrcoarse,'String');
sfm = get(handles.fm,'String');
sspgrfine = get(handles.spgrfine,'String');
smfine = get(handles.mfine,'String');
smcoarse = get(handles.mcoarse,'String');
scapfine = get(handles.capfine,'String');
scapcoarse = get(handles.capcoarse,'String');
sl = str2num(sslump);
st = str2num(sstrength);
max = str2num(smsa);
sc = str2num(sspgrcoarse);
fmo = str2num(sfm);
sf = str2num(sspgrfine);
mf = str2num(smfine);
mc = str2num(smcoarse);
cf = str2num(scapfine);
cc = str2num(scapcoarse);
f1 = (387.5*(max^2)-(937*max)+4340)/3855.219;
f2 = (-9080*(fmo^2)+43889*(fmo)-47890)/3969.932;
f11=2-f1;
f22=2-f2;
if st<3000
    fcr=(((f11+f22)/2)*st)+1000;
    if st>=3000&&st<=5000
        fcr=(((f11+f22)/2)*st)+1200;
    end
else
    fcr=(((1.1+f11+f22)/3)*st)+700;
end
b1 = get(hObject,'Value');
if (b1 ==2)
   wc = -0.00007*(fcr)+0.793;
   wcw = 0.056*(sl)+0.292;
```

```
elseif (b1 ==1)
    wc = -0.00008*(fcr)+0.8;
    wcw = 0.044*(sl)+0.304;
elseif (b1 ==3)
    wc = -0.00008*(fcr)+0.8;
    wcw = 0.044*(sl)+0.304;
elseif (b1 ==4)
    wc = -0.00008*(fcr)+0.835;
    wcw = 0.131*(sl)+0.315;
end
c1 = 0.0014*(fcr)+4.1025;
c = fcr/c1;
avwc = (wc+wcw)/2;
w=avwc*c;
vc=c/3150;
vw=w/1000;
air=0.015;
vtagg = 1-vc-vw-air;
vcoarse = 0.65* vtagg;
vfine = 0.35 * vtagg;
crush = vcoarse*sc*1000;
sand = vfine*sf*1000;
rw=round(w);
rfcr=round(fcr);
rc=round(c);
rcrush = round(crush);
rsand = round(sand);
newcrush =(1+(mc-cc)/100)*crush;
newsand =(1+(mf-cf)/100)*sand;
neww=w-((mc-cc)/100)*crush-((mf-cf)/100)*sand;
newwc=neww/c;
rneww=round(neww);
rnewsand=round(newsand);
rnewcrush=round(newcrush);
srw=num2str(rw);
savwc=num2str(avwc);
src=num2str(rc);
sfcr=num2str(rfcr);
sc1=num2str(c1);
scrush=num2str(rcrush);
ssand = num2str (rsand);
svtagg = num2str(vtagg);
ssnewwc=num2str(newwc);
ssneww=num2str(rneww);
ssnewsand=num2str(rnewsand);
ssnewcrush=num2str(rnewcrush);
set(handles.w,'String',srw);
set(handles.fwc,'String',savwc);
set(handles.tagg,'String',svtagg);
set(handles.crush,'String',scrush);
set(handles.sand,'String',ssand);
set(handles.text168,'String',ssnewwc);
set(handles.text167,'String',ssneww);
set(handles.text166,'String',src);
set(handles.text165,'String',ssnewsand);
set(handles.text164,'String',ssnewcrush);
set(handles.mts,'String',sfcr);
set(handles.c1,'String',sc1);
set(handles.c,'String',src);
set(handles.wc,'String',wc);
set(handles.wcw,'String',wcw);
guidata (hObject, handles);
function cement_CreateFcn(hObject, eventdata, handles)
```

```
% hObject    handle to cement (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

This part of Commands executes on selection change in popup menu for Selection of Super Plasticizer.

```
function spask_Callback(hObject, eventdata, handles)
sslump = get(handles.slump,'String');
sstrength = get(handles.strength,'String');
smsa = get(handles.msa,'String');
sspgrcoarse = get(handles.spgrcoarse,'String');
sfm = get(handles.fm,'String');
sspgrfine = get(handles.spgrfine,'String');
smfine = get(handles.mfine,'String');
smcoarse = get(handles.mcoarse,'String');
scapfine = get(handles.capfine,'String');
scapcoarse = get(handles.capcoarse,'String');
sl = str2num(sslump);
st = str2num(sstrength);
max = str2num(smsa);
sc = str2num(sspgrcoarse);
fmo = str2num(sfm);
sf = str2num(sspgrfine);
mf = str2num(smfine);
mc = str2num(smcoarse);
cf = str2num(scapfine);
cc = str2num(scapcoarse);
sslump = get(handles.slump,'String');
sl = str2num(sslump);
sp = get(handles.sp,'String');
nsp = str2num(sp);
q1 = get(hObject,'Value');
f1 = (387.5*(max^2)-(937*max)+4340)/3855.219;
f2 = (-9080*(fmo^2)+43889*(fmo)-47890)/3969.932;
f11=2-f1;
f22=2-f2;
if st<3000
    fcr=(((f11+f22)/2)*st)+1000;
    if st>=3000&&st<=5000
        fcr=(((f11+f22)/2)*st)+1200;
    end
else
    fcr=(((1.1+f11+f22)/3)*st)+700;
end

if (q1 ==2)
   wc = -0.00007*(fcr)+0.793;
   avsi = -4.5*(nsp^2)+16.75*(nsp)-11.75;
   adsr=sl-avsi;
   wcw = 0.056*(adsr)+0.292;
   fwc=(wc+wcw)/2;
   sfwc=num2str(fwc);
   c1 = 0.0014*(fcr)+4.1025;
   c = fcr/c1;
   w=fwc*c;
```

```
    rw=round(w);
    swcw=num2str(wcw);
    srw=num2str(rw);
    set(handles.w,'String',srw);
    sadsr=num2str(adsr);
    set(handles.adsr,'String',sadsr);
    set(handles.fwc,'String',sfwc);
    set(handles.wcw,'String',swcw);
elseif (q1 ==3)
     avsi = 0;
elseif (q1 ==1)
     avsi = 0;
end
savsi=num2str(avsi);
set(handles.avsi,'String',savsi);
guidata (hObject, handles);
% --- Executes during object creation, after setting all properties.
function spask_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

This part of Commands executes on while entering dosage of Super plasticizer. A message box appears stating that Super plasticizer Dosage must be in the range of 1% to 2%.

```
function sp_Callback(hObject, eventdata, handles)
%        str2double(get(hObject,'String')) returns contents of sp as a double
%store the contents of input1_editText as a string. if the string
%is not a number then input will be empty
input = str2num(get(hObject,'String'));
%checks to see if input is empty. if so, default input1_editText to zero
if (isempty(input))
     set(hObject,'String','0')
end
msgbox('Superplasticizer Dosage must be in the range of 1% to 2%','Warning Window
Name','warn');
guidata(hObject, handles);
% --- Executes during object creation, after setting all properties.
function sp_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

This part of Commands executes on pressing the “Calculate Final Quantities” button.

```
function calculate_Callback(hObject, eventdata, handles)
sslump = get(handles.slump,'String');
sstrength = get(handles.strength,'String');
smsa = get(handles.msa,'String');
sspgrcoarse = get(handles.spgrcoarse,'String');
sfm = get(handles.fm,'String');
sspgrfine = get(handles.spgrfine,'String');
smfine = get(handles.mfine,'String');
smcoarse = get(handles.mcoarse,'String');
scapfine = get(handles.capfine,'String');
scapcoarse = get(handles.capcoarse,'String');
sl = str2num(sslump);
st = str2num(sstrength);
max = str2num(smsa);
sc = str2num(sspgrcoarse);
```

```
fmo = str2num(sfm);
sf = str2num(sspgrfine);
mf = str2num(smfine);
mc = str2num(smcoarse);
cf = str2num(scapfine);
cc = str2num(scapcoarse);
set(handles.fwc,'Visible','on');
set(handles.w,'Visible','on');
set(handles.c,'Visible','on');
set(handles.sand,'Visible','on');
set(handles.crush,'Visible','on');
guidata(hObject, handles);
```

This part of Commands executes on pressing the “Reset” button.

```
function reset_Callback(hObject, eventdata, handles)
set (handles.slump, 'String','');
set (handles.strength, 'String','');
set (handles.msa, 'String','');
set (handles.fm, 'String','');
set (handles.spgrcoarse, 'String','');
set (handles.spgrfine, 'String','');
set (handles.sp, 'String','');
set (handles.mcoarse, 'String','');
set (handles.mfine, 'String','');
set (handles.capcoarse, 'String','');
set (handles.capfine, 'String','');
set (handles.mts, 'String','');
set (handles.wc, 'String','');
set (handles.wcw, 'String','');
set (handles.c1, 'String','');
set (handles.c, 'String','');
set (handles.tagg, 'String','');
set (handles.sand, 'String','');
set (handles.crush, 'String','');
set (handles.avsi, 'String','');
set (handles.adsr, 'String','');
set (handles.fwc, 'String','');
set (handles.w, 'String','');
set (handles.text164, 'String','');
set (handles.text165, 'String','');
set (handles.text166, 'String','');
set (handles.text167, 'String','');
set (handles.text168, 'String','');
set(handles.moistureframe,'Visible','off');
set(handles.text174,'Visible','on');
```

This part of Commands executes on selection change in popup menu for Moisture adjustment.

```
function popupmenu6_Callback(hObject, eventdata, handles)
s1 = get(hObject,'Value');
if (s1 ==2)
   set(handles.moistureframe,'Visible','on');
   set(handles.text174,'Visible','off');
elseif (s1 ==3)
    set(handles.moistureframe,'Visible','off');
    set(handles.text174,'Visible','on');
elseif (s1 ==1)
    set(handles.moistureframe,'Visible','off');
    set(handles.text174,'Visible','on');
end
% --- Executes during object creation, after setting all properties.
```

```
function popupmenu6_CreateFcn(hObject, eventdata, handles)
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

This part of Commands executes on pressing the “Perform Moisture Adjustments” button.

```
function madj_Callback(hObject, eventdata, handles)
set(handles.text168,'Visible','on');
set(handles.text167,'Visible','on');
set(handles.text166,'Visible','on');
set(handles.text165,'Visible','on');
set(handles.text164,'Visible','on');
guidata(hObject, handles);
```

5.4 Comparison of Proposed Methods with Other Methods

In order to compare the proposed method with other methods, an example is solved with ACI, BS, IS and proposed method. The given data is,

Inputs:

28 Day Concrete Strength = 5075 Psi = 35 MPa

Slump range = 50mm (2 in)

Compacting Factor = 0.8

Cement Type = Ordinary Portland cement

FM. of Fine Aggregates = 2.60

Percentage of Fine aggregate Passing 600 micron = 60 %

Specific gravity of Fine Aggregates= 2.64

Coarse Aggregate = 20 mm (Sp. gr. = 2.64, Dry Rodded bulk density = 1600 Kg/m^3).

The Above data is entered in the software and results are obtained for all three cement types as shown in figures.

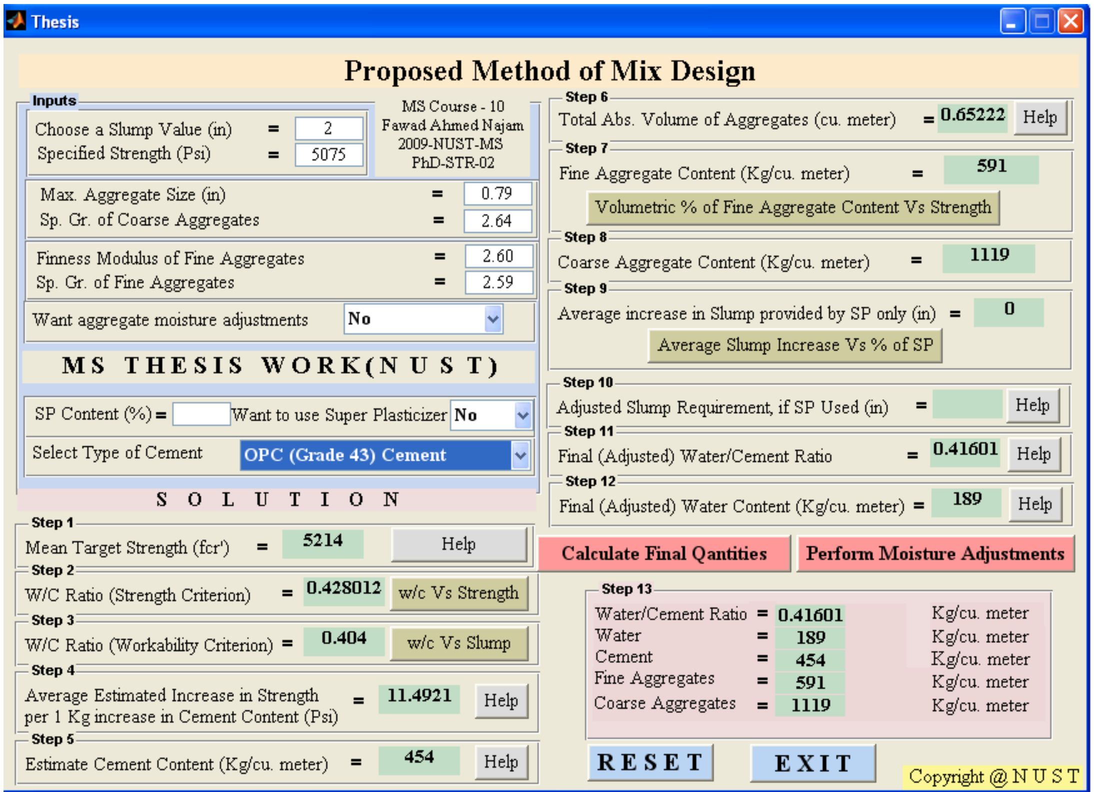


Figure 5.11: Solved Example for Bestway Cement

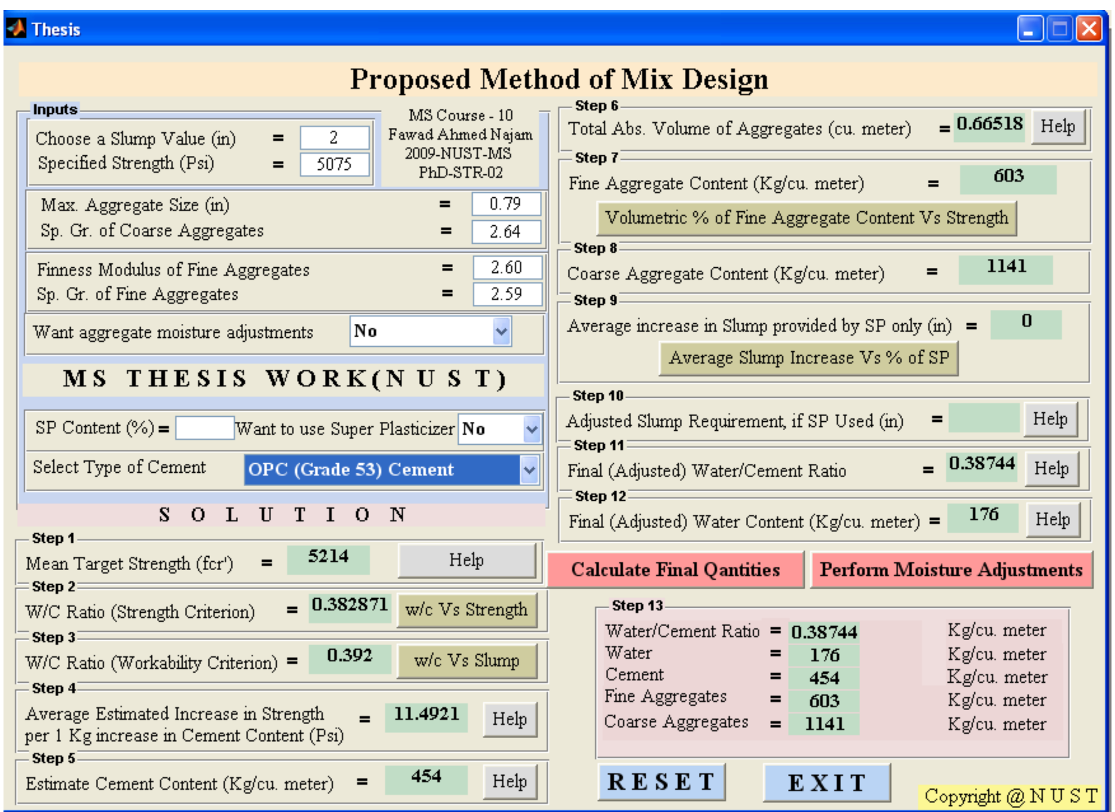


Figure 5.12: Solved Example for Fauji Cement

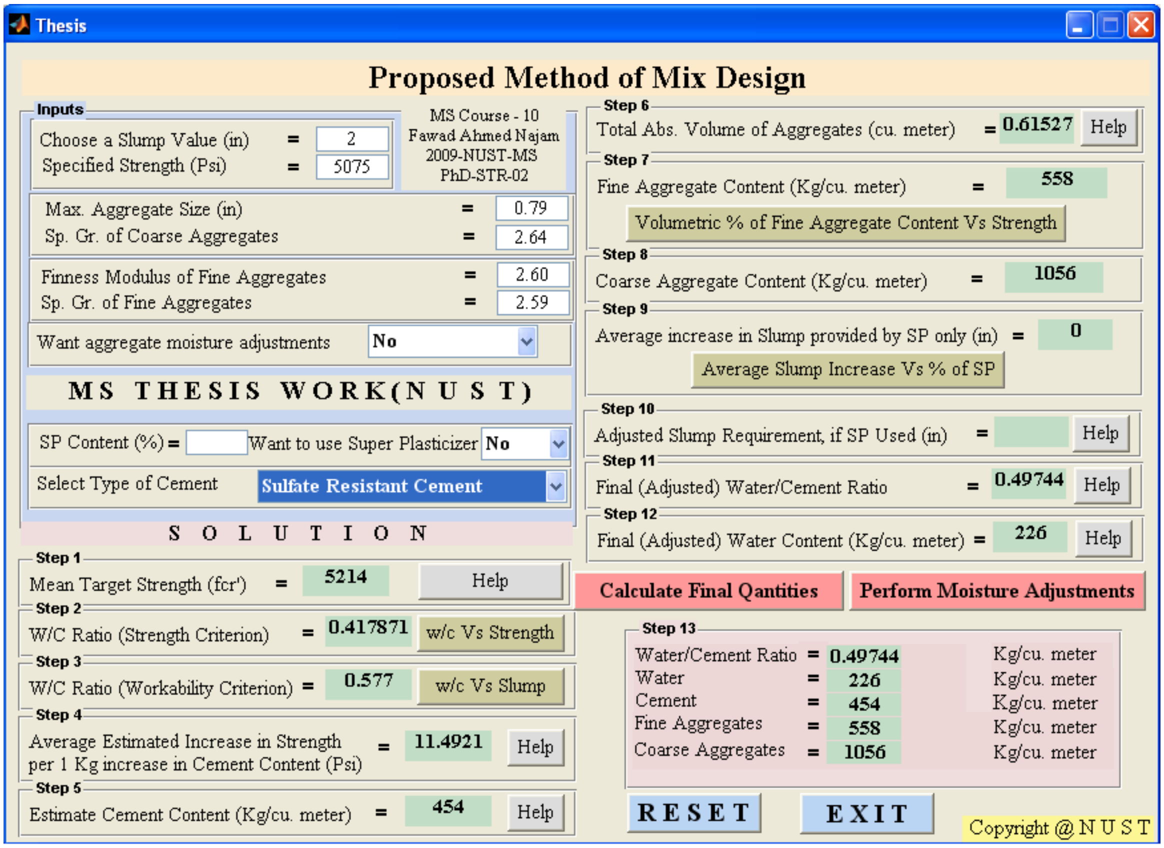


Figure 5.13: Solved Example for SR Cement

The results are compared as follows.

Table 5.6: Comparison of Mix Design Methods

Mix Design Method	ACI Method [37]	BS Method [37]	IS Method [38]	Proposed Method		
				Bestway Cement	Fouji Cement	SR (Maple Leaf) Cement
Cement	395	375	552	454	454	454
Water	190	180	186	189	176	226
Sand	690	590	486	591	603	558
Crushed Stone Aggregate	1020	1255	1147	1119	1141	1056
w/c Ratio	0.48	0.48	0.34	0.42	0.39	0.49

ACI and BS methods are giving quite less cement content and a high w/c ratio of 0.48, however the IS method is recommending a very high cement content with low w/c ratio of 0.34. Both these “Extremes” are not validated by the laboratory results during the study. Now, it is obvious that the proposed method is a reasonable compromise between these quantities with Cement content of 454 Kg/m^3 and w/c of 0.39-0.49 depending upon cement brand.

CHAPTER 6 CONCLUSIONS

Following are some conclusions that can be drawn from the results obtained from the study.

i. ACI, BS and IS methods of mix design do not reccomend quantities with desired characteristics and hence the mixes containing local aggregate and cement types needs to be adjusted several times.

ii. Proposed method of mix design incorporates the effects of maximum aggregate size as well as fineness modulus of fine aggregates in mean target strength.

iii. Proposed method is automated by creating a standalone application in MATLAB GUI Environment.

iv. Strength Vs w/c ratio relations proposed by ACI, BS and IS methods of mix designs will overestimate the strength at a given w/c ratio when apply them on concretes made with local sand and crush.

v. Proposed Method of mix design incorporates the effects of maximum aggregate size, fineness modulus and cement type.

vi. For lower values of *fc'*, ACI expression overestimates the Splitting tensile strength and for higher values of *fc'*, it underestimates the actual splitting tensile strength.

vii. Sands with Fineness Modulus (FM) in the range of 2.35 – 2.5 give optimum strength while keeping all other parameters constant when used with ¾" down grading of margalla crush.

viii. A volumetric ratio of fine aggregates to total aggregates of 0.35 gives the optimum strength at 28 days while keeping all other parameters constant.

ix. Polycarboxylic ether polymer (PCE) based superplasticizer (Gelenium - 51) is more efficient in reducing water content for same workability than Beta-Naphthalenesulphonate Polycondensate based superplastcizer (Rheobuild - 858).

x. Strength vs. w/c ratio relation predicted by Abram's law is reasonably comparable with experimental results between w/c ratios of 0.4 to 0.6.

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Appendix A **MATERIAL PROPERTIES**

1. **Properties of Cement:**

Table 1: Properties of Cements

Tests	Test results			Specifications
	OPC Grade 43	OPC Grade 53	Sulfate Resistant	
Water Demand	29%	28.5%	27.5%	ASTM C 187
Initial setting time (at 17 ^{0}C)	175 minutes	112 minutes	150 minutes	ASTM C 191
Final setting time (at 17 ^{0}C)	280 minutes	226 minutes	245 minutes	ASTM C 191

2. **Gradation Curves:**

Coarse Aggregate (3/4"):

Mass of sample taken = 4000 g

Table 2: Sieve Analysis of ¾" Coarse Aggregates

Sieve Number	Mass Retained	Cumulative Mass Retained	% Retained	% Passing
	(gram)	(gram)		
1"	0	0	0	100
3/4"	2053	2053	51.325	48.675
1/2"	1947	4000	100	0
3/8"	0	4000	100	0
#4	0	4000	100	0

Coarse Aggregate (1/2"):

Mass of sample taken = 3000 g

Table 3: Sieve Analysis of ½" Coarse Aggregates

Sieve Number	Mass Retained	Total Mass Retained	% Retained	% Passing
	(gram)	(gram)		
1"	0	0	0	100
3/4"	0	0	0	100
1/2"	1824	1824	60.8	39.2
3/8"	933	2757	91.9	8.1
#4	234	2991	99.7	0.3
#8	9	3000	100	0

Blend of 80% 1/2” and 20% 3/4”:

Table 4: Sieve Analysis of blended Coarse Aggregates

Sieve Number	Coarse Aggregate 3/4"	Coarse Aggregate 1/2"	combined mass retained	Cumulative mass retained	% passing
	% Retained	% Retained	% Retained		
1"	0	0	0.00	0.00	100.00
3/4"	51.325	0	10.27	10.27	89.74
1/2"	48.675	60.8	58.38	68.64	31.36
3/8"	0	31.1	24.88	93.52	6.48
#4	0	7.8	6.24	99.76	0.24
#8		0.3	0.24	100.00	0.00

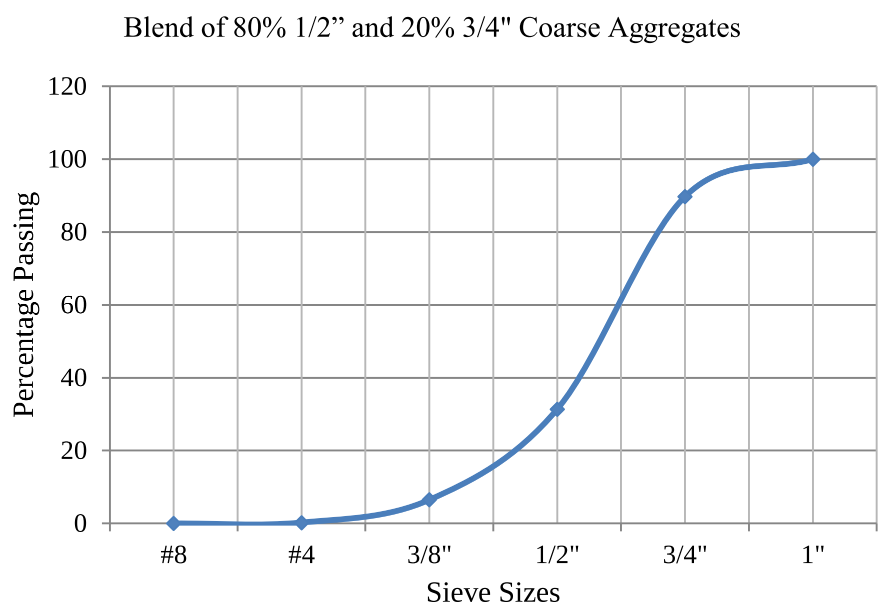


Figure 1: Gradation Curve of Coarse Aggregates

Fine Aggregates:

Mass of sample taken = 1500 g

Table 5: Sieve Analysis of fine Aggregates

Sieve Number	Mass Retained	Total Mass Retained	% Retained	% Passing
	(gram)	(gram)		
#4	2	2	0.13	99.87
#8	5	7	0.47	99.53
#16	62	69	4.60	95.40
#30	370	439	29.27	70.73

#50	696	1135	75.67	24.33
#100	301	1436	95.73	4.27
#120	19	1455	97.00	3.00
#200	29	1484	98.93	1.07
Pan	16	1500	100.00	0.00

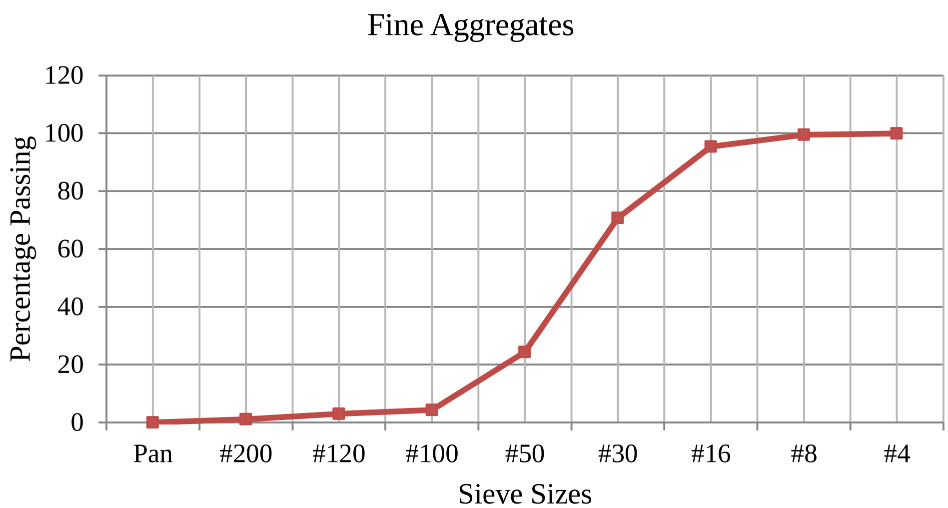


Figure 2: Gradation Curve of Fine Aggregates

3. Aggregates Moisture Conditions:

% Moisture (As Obtained) coarse aggregates	=	3.20 %
% Moisture (SSD) coarse aggregates	=	1.00 %
% Moisture (As Obtained) fine aggregates	=	0.64 %
% Moisture (SSD) fine aggregates	=	1.90 %

Appendix B TABLES AND GRAPHS FOR ACI, DOE (BS) AND IS METHODS

1) ACI Method

Table 1: Approximate mixing water requirements for different slumps and maximum size of aggregate

Slump mm	Water per kg/m^3 of concrete, for the maximum sizes of coarse aggregates							
	10 mm	12.5 mm	20 mm	25 mm	40 mm	50 mm	70 mm	150 mm
	NON-AIR ENTRAINED CONCRETE							
30 to 50	205	200	185	180	160	155	145	125
80 to 100	225	215	200	195	175	170	160	140
150 to 180	240	230	210	205	185	180	170	-
Approximate Entrapped air content, percent	3	2.5	2	1.5	1	0.5	0.3	0.2

Table 2: Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness moduli of sand			
	Fineness Modulus of Sand			
	2.40	2.60	2.80	3.00
10 mm	0.50	0.48	0.46	0.44
12.5 mm	0.59	0.57	0.55	0.53
20 mm	0.66	0.64	0.62	0.60
25 mm	0.71	0.69	0.67	0.65
40 mm	0.76	0.74	0.72	0.70
50 mm	0.78	0.76	0.74	0.72
70 mm	0.81	0.79	0.77	0.75
150 mm	0.87	0.85	0.83	0.81

2) DOE (BS) Method

Table 3: Approximate Compressive Strengths of Concretes made with a free w/c ratio of 0.5 according to British Method

Type of Cement	Type of Coarse Aggregates	Compressive Strength at the age of Days (Mpa)			
		3	7	28	91
OPC Sulfate Resistant	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid Hardening	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Figure 1: Relation between free w/c ratio and Compressive Strength

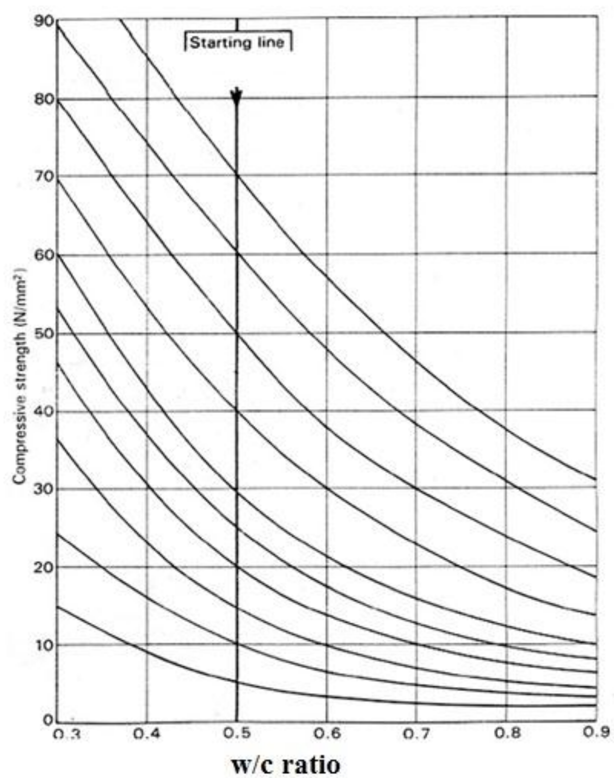
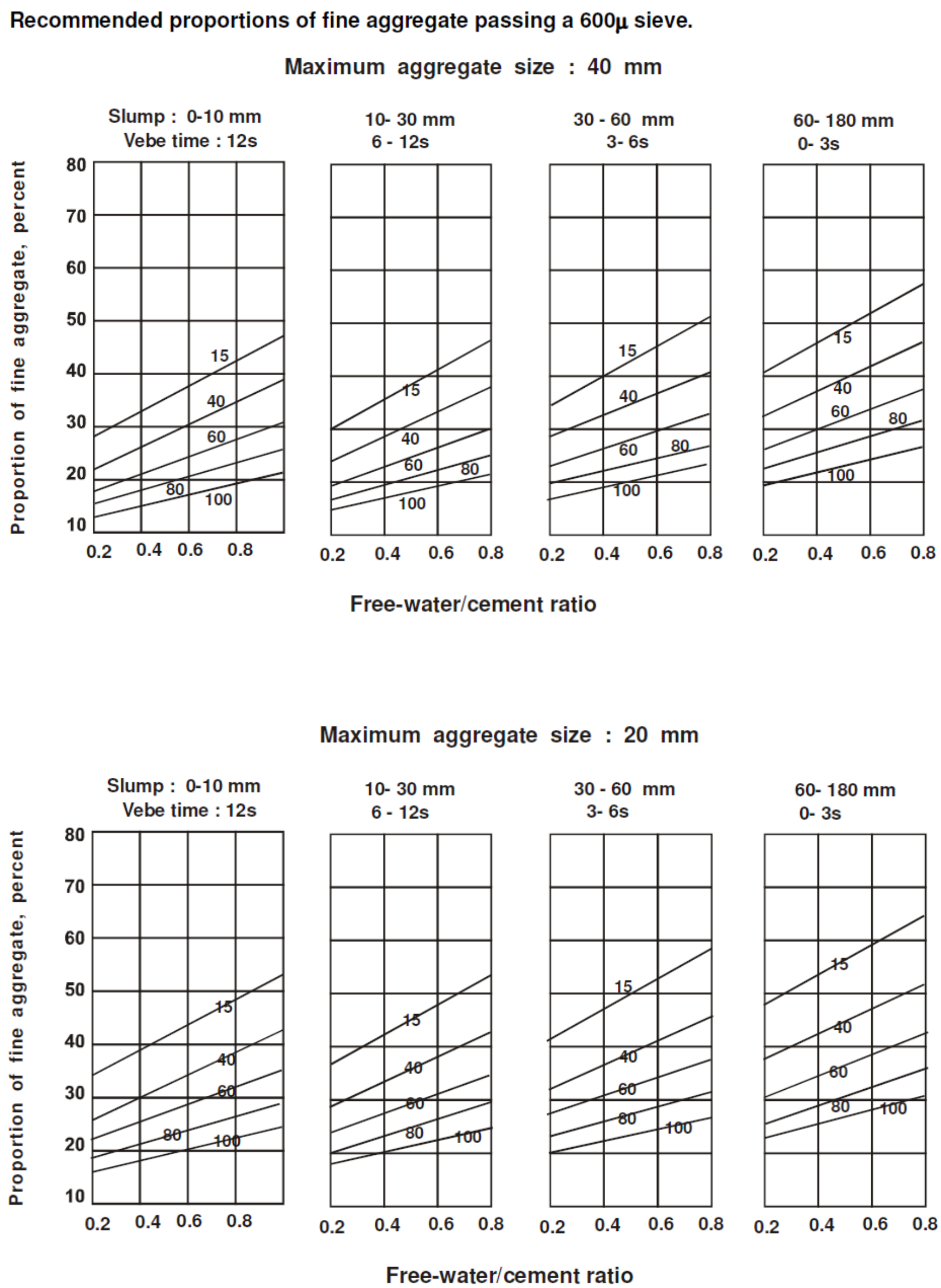


Table 4: Approximate water demand for different workability

Slump, mm		0-10	10-30	30-60	60-180
V-B time, sec		> 12	6-12	3-6	0-3
Maximum size of aggregate	Type of aggregate				
10 mm	Uncrushed Crushed	150 180	180 205	205 230	225 250
20 mm	Uncrushed Crushed	135 170	160 190	180 210	195 225

25 mm	Uncrushed Crushed	130 166	155 186	175 206	190 221
40 mm	Uncrushed Crushed	115 155	140 175	160 190	175 205

Figure 2: Recommended proportions of fine aggregate passing a 600 μm (0.6 mm) sieve



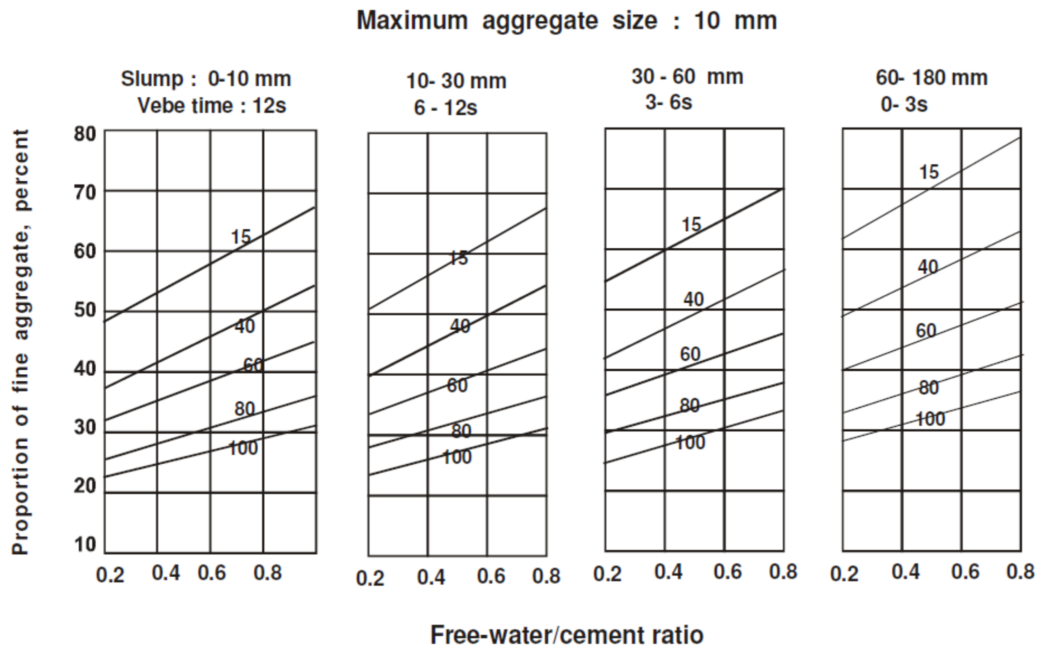
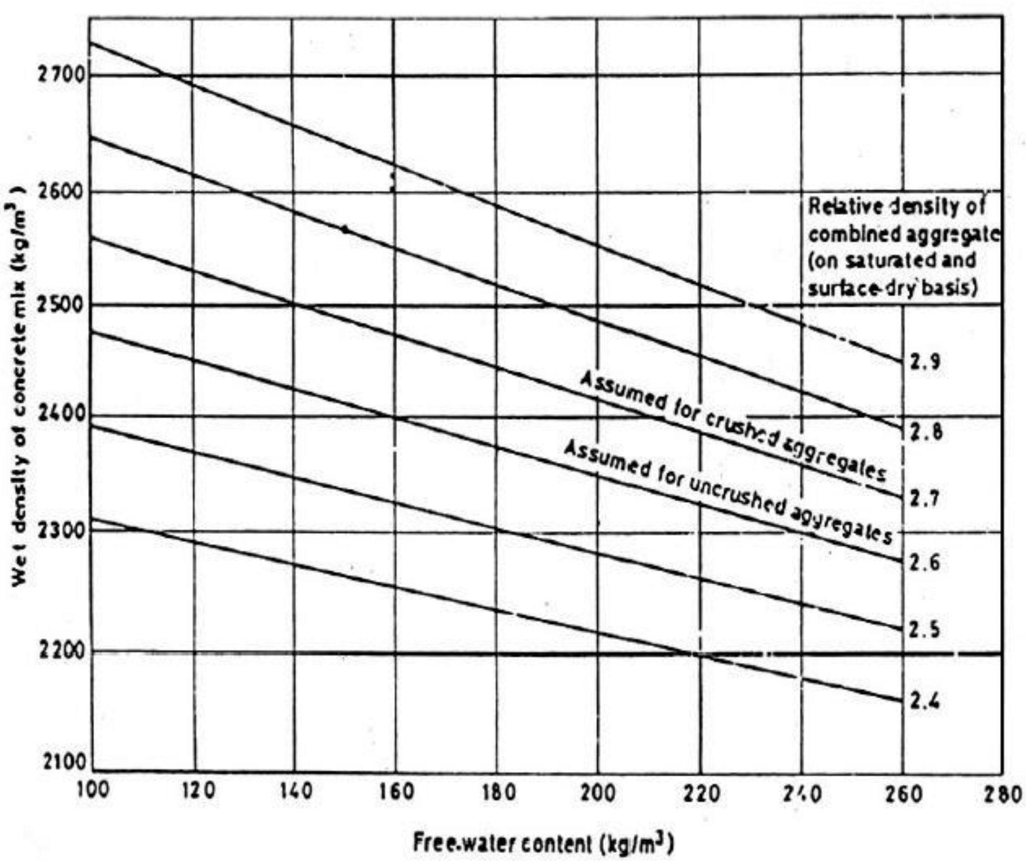


Figure 3: Wet density of fully compacted concrete for varying relative densities of aggregate



3) IS Method

Figure 4: Relation between free water/cement ratio and concrete strength at 28 days for different cement curves

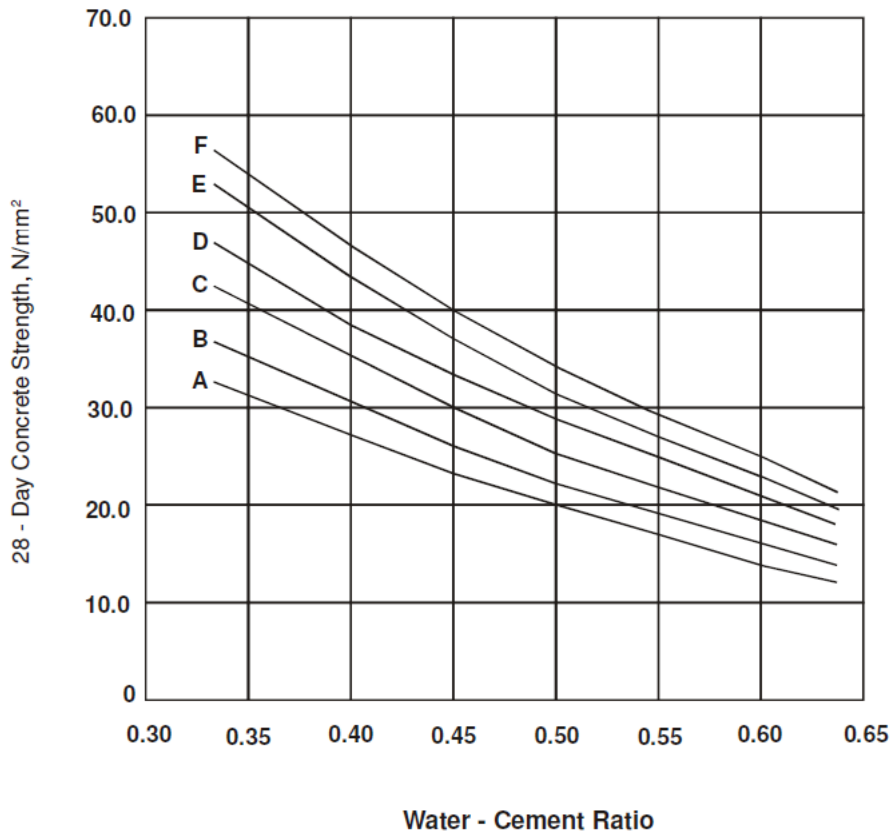


Table 5: Suggested values of standard deviation

Grade of Concrete	Standard Deviation for different Degree of Control (MPa)		
	Very Good	Good	Fair
M 10	2.0	2.3	3.3
M 15	2.5	3.5	4.5
M 20	3.6	4.6	5.6
M 25	4.3	5.3	6.3
M 30	5.0	6.0	7.0
M 35	5.3	6.3	7.3
M 40	5.6	6.6	7.6
M 45	6.0	7.0	8.0
M 50	6.4	7.4	8.4
M 55	6.7	7.7	8.7
M 60	6.8	7.8	8.8

Table 6: Approximate water content per m^3 of concrete

Nominal maximum size of aggregate, mm	Water content per m^3 of concrete Kg
	For Grades up to M 35
10	208
20	186
40	165
	For Grades above M 35
10	200
20	180

Table 7: Approximate sand per m^3 of concrete

Nominal maximum size of aggregate,mm	Sand as percentage of total aggregate by absolute volume
	For Grades up to M 35
10	40
20	35
40	30
	For Grades above M 35
10	28
20	25

Table 8: Approximate air content

Nominal maximum size of aggregate, mm	Entrapped air, percentage of volume of concrete
10	3.0
20	2.0
40	1.0

Appendix C GRAPHICAL RESULTS OF XRF AND LASER PARTICLE ANALYSIS

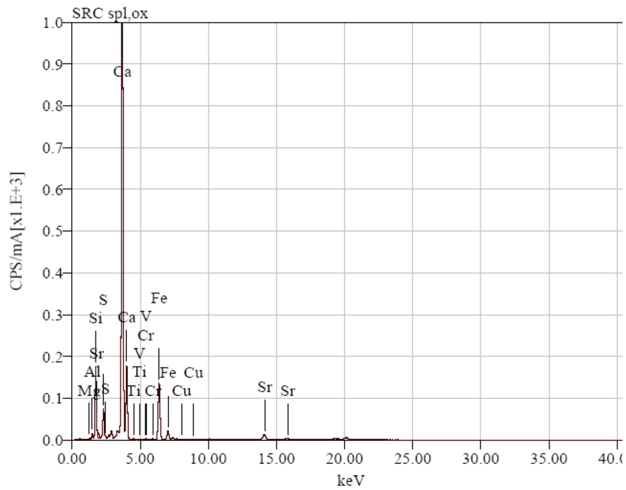


Figure 1(a): XRF Result of SR (Maple Leaf) Cement

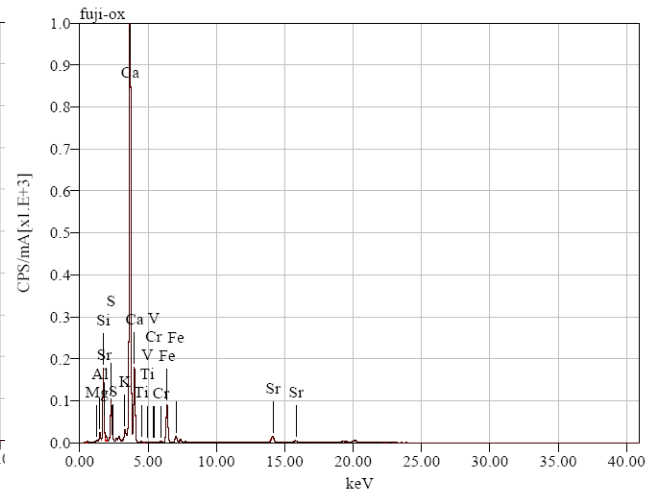


Figure 1(b): XRF Result of Fauji Cement

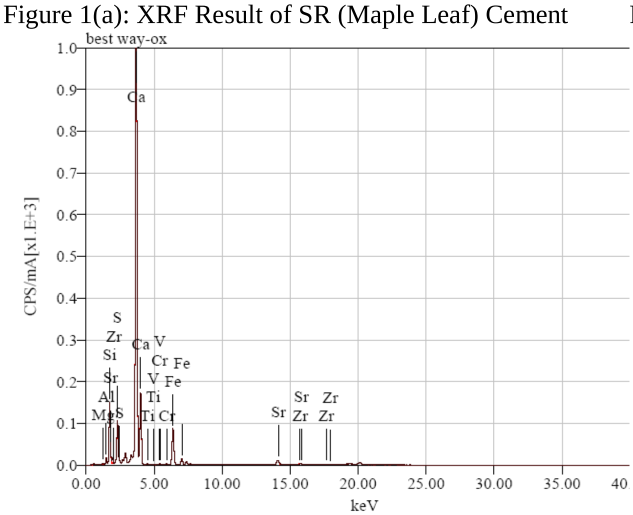


Figure 1(c): XRF Result of Best Way Cement

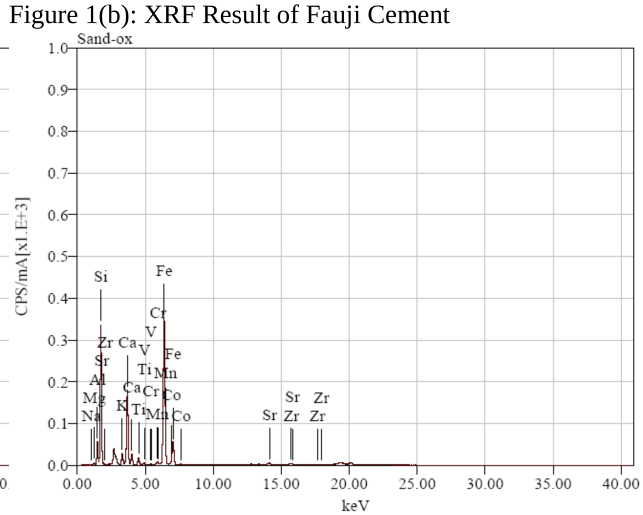


Figure 1(d): XRF Result of Lawrencepur Sand

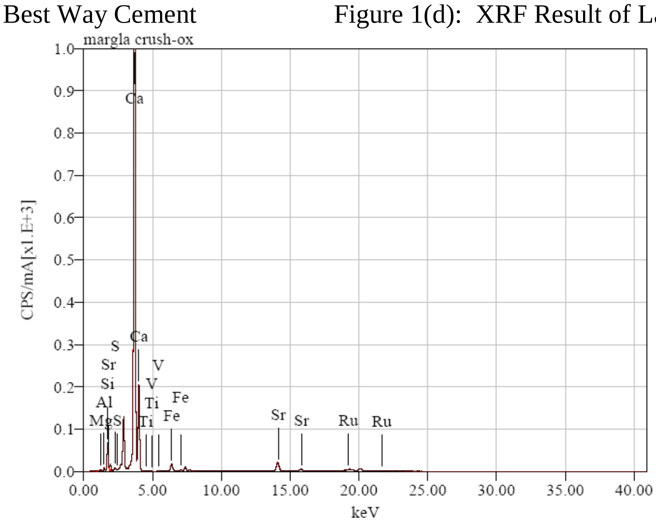


Figure 1(e): XRF Result of Margalla Crush

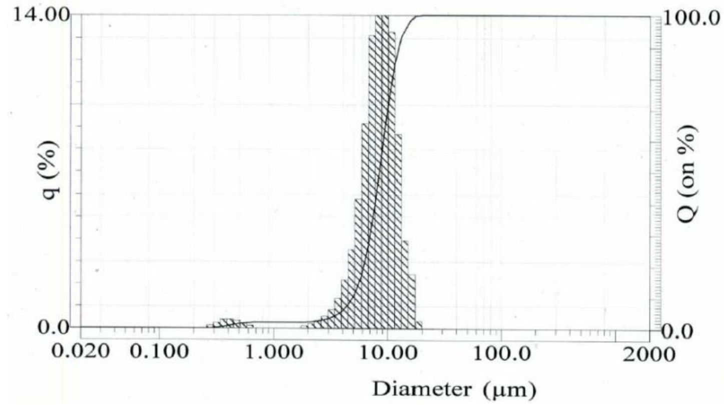


Figure 2(a): Laser Particle Analysis Results of SR (Maple Leaf) Cement

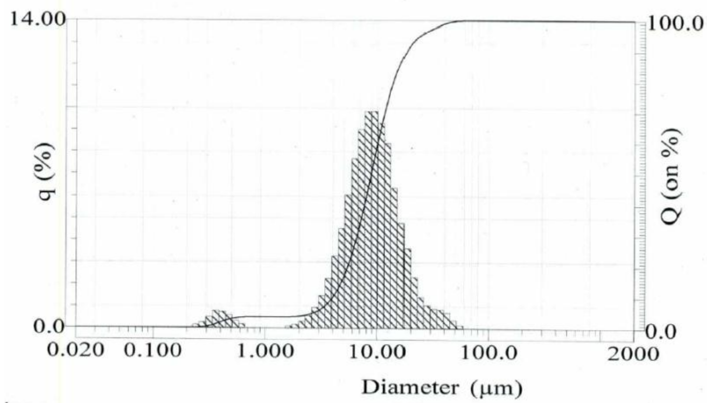


Figure 2(b): Laser Particle Analysis Results of Bestway Cement

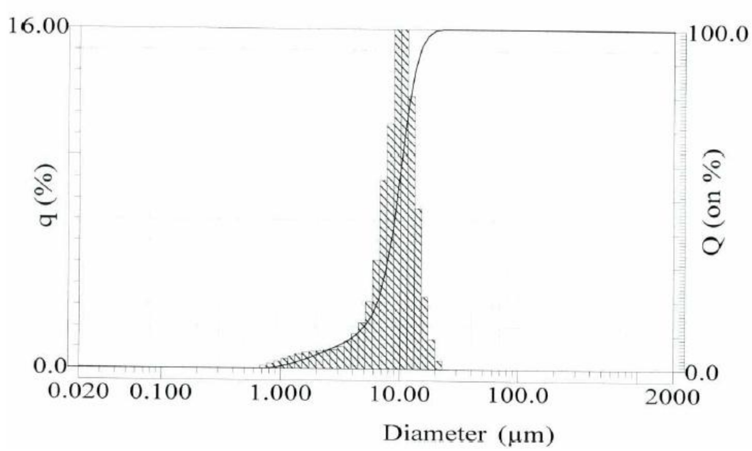


Figure 2(c): Laser Particle Analysis Results of Fauji Cement