TO DEVELOP AN ANDROID APPLICATION USING DIFFERENT CONCRETE MIX DESIGN METHODS

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This is to certify that the

Final Year Project Titled

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has been accepted towards the requirements for
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Finally we would like to thank our parents for their prayers, understanding and psychological support.

Abstract

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.

This project has two main objectives:

1) Mobile application capable of calculating concrete mix proportions based on different methods of Concrete Mix Design
2) Use our application to study, compare and analyse different Mix Design Standards and recommend a best suitable method for the material used in Pakistan

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CHAPTER 1

CONCRETE MIX DESIGN – AN INTRODUCTION

1.1 General

Concrete like other building materials should be designed for properties like quality, solidness, workability and union. Concrete mix design is the study of choosing relative extents of elements of concrete, to accomplish the coveted properties in the most conservative way. With the coming of tall structures and pre-focused on concrete, utilization of higher evaluations of concrete is ending up noticeably more typical. Mix design of concrete is winding up plainly more applicable in this situation. Present study is an attempt to automate this process of mix design by developing an android application and use that application to test the applicability of various mix design methods to locally available materials in Pakistan. Concrete is a really multipurpose building material as it can be designed for any strength ranging from 10 MPa to 200 MPa and workability in the range 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 constituents of concrete are the same, but the relative proportioning is the key factor that makes the difference.

The factors like strength and durability are governed by the Water-Cement ratio (w/c) 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, the strength of the concrete is reduced by 5% for every 1% increase in quantity of water and every extra liter of water per m^3 will approximately decrease the strength of concrete by 2 to 3 MPa (290 psi to 435 psi) and increase the workability by 25 mm. 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 totality 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. A volume of 1.2 mL is required to accommodate the hydration products of 1 mL 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**.

The study involves an investigation about the relationships that different mix design methods use to select a water cement ratio for a mix. It also discovers the differences in amounts of cement, water and aggregates selected by different methods and differences in procedures used to select these quantities.

1.2 Early Approaches and Practices

Mix design of concrete is winding up plainly more applicable in this situation. 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 general point of proportioning solid blends can be condensed as "choosing the reasonable fixings among the accessible materials and deciding the most conservative mix that will create concrete with certain base execution qualities". The necessities which shape the premise of choice and proportioning of blend fixings are:

a. The least compressive quality required from auxiliary thought (generally named as fc')

b. The satisfactory workability important for full compaction (typically as far as droop)

c. Maximum water-concrete proportion to give satisfactory sturdiness for the specific site conditions

d. Maximum bond substance to maintain a strategic distance from shrinkage breaking because of temperature cycle in mass cement

e. Economy

A prominent basic is that inside a settled volume, one can't change a section free of others. For example, in a cubic meter of cement, if the aggregate fragment is extended, the bond stick part decreases. With solid making materials of given attributes and with given employment conditions, by and large the factors are as per the following:

a. Cement glue total proportion in the blend

b. Water-bond proportion in the concrete glue

c. Sand-coarse total proportion in the totals

d. Use of admixtures

The task of blend proportioning is perplexed by the way that particular wanted properties of cement may be oppositely impacted by changing a specific variable. For example, the extension of water to a solidified solid blend with a given bond substance will upgrade the stream limit of new concrete yet meanwhile will lessen the quality. Frankly, workability itself is made out of different parts [i.e., consistency (effortlessness of stream), yield push, cohesiveness (impenetrability to separation) and viscosity], and these tend to be affected in a backwards way when water is added to a given solid blend. The system of blend proportioning, appropriately comes down to the "forte of modifying distinctive conflicting necessities".

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. Retention of Slump
    ii. Quickening of strength
    iii. Initial setting retardation
    iv. Ability of pumping
    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 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 suggested by this method as a first trial batch were quite far from quantities which gave required characteristics at the end of all trials in Laboratory. The solution for this clumsy process of making trials and waiting for 28 or so days was found in progress 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 aim of the study is to address the absence of data regarding the applicability of previous internationally established mix design methods on local crushed stone aggregates and sand types as well as cements of Pakistan. Strength tests were carried out on various mix designs obtained from the different approaches discussed in this study for a required characteristic 28 day compressive strength of 4000 psi and a slump range of 2 to 4 inches. The results obtained gave a clearer picture of the difference between the strength required and the actual strength obtained from the tests. Four methods of concrete mix designs were compared for this study:

- ACI-211 method
- IS 10262-2009 method
- A method developed in NICE (NUST) in 2011 (referred to as NICE (NUST) method in this text)
- A method developed in Iowa State University in 2015

Furthermore, an android app was developed which is capable of calculating the mix designs when the required inputs are given. The application can implement the ACI, IS and NICE (NUST) methods of mix designs.

The application has the potential of being commercialized as it greatly reduces the time required in calculating the mix designs by any of the methods mentioned above. It was also successfully used during the study to calculate mix proportions for comparisons of the methods and during the laboratory tests.

Mix designs were calculated from all of the above stated methods for required strengths of 3000, 4000 and 5000 psi. The results obtained were compared according to the following criteria:

- Water to Cement ratio

- Cement quantity
- Aggregate to Cement ratio
- Fine aggregate to coarse aggregate ratio

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

Two techniques (ACI, IS) will be talked about in some detail. The essential supposition made in every one of these techniques is that the compressive quality of workable concretes, all around, coordinated by the water/bond proportion. Additionally it is expected that for a given sort, shape, size and reviewing of totals, the measure of water decides workability. Nonetheless, there are different variables which influence the properties of concrete, for instance the quality and amount of bond, water and totals, clumping, transportation, putting, compaction and curing and so forth. Subsequently, the particular connections that are utilized as a part of proportioning concrete mixes ought to be viewed as just as the reason for trial, subject to alterations in the light of involvement and in addition for the specific materials utilized at the site for each situation. No mix design technique specifically gives the correct extents that will most monetarily accomplish final products. These strategies just guide as a "base to begin" and achieve the final products at all conceivable trials.

2.2.1 ACI method

This method is recommended by ACI Committee 211 and is based on defining the coarse aggregate content (in terms of percentage of concrete volume) from dry rodded bulk density and FM of sand, thus taking in to justification the actual voids in compacted coarse aggregates that are to be occupied by sand cement and water. The Committee report provides two methods for calculating aggregate quantities i.e. The Weight method and The Absolute Volume method. The weight method is considered less precise but does not need the information on the specific gravity of the concrete-making materials. The absolute volume method is considered more precise 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 content of coarse coarse aggregate 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 IS method, the plastic density or yield of concrete is linked to specific gravity of ingredients.

iii. The ACI method also does not take into justification the outcome of the surface texture and flakiness of aggregate on sand and water content, neither does it differentiate between crushed stone aggregates and normal aggregates.

iv. The ACI method does not have an exact method of combining two different aggregates sizes.

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

2.2.2 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) developed by Pakistan Standards and Quality Control Authority (PSQCA).

IS 456-2000 has designated the concrete mixes into various evaluations as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M alludes to the mix and the number to the predetermined 28 day 6" block quality of mix in MPa. IS proposes that the w/c bend be created in light of the kind of materials to be utilized as a part of the venture. Then again, the w/c esteems given in IS 456:2000 in light of toughness conditions can likewise be utilized to begin with the mix design. Already, the water concrete proportion was computed from bond bends in view of 28 days quality of bond. A table for most extreme water content per cubic meter of concrete for ostensible greatest size of total is given. The strategy gives rectification components for various w/c proportions, workability and for adjusted coarse total. For coarse and fine total substance, IS technique is same as that of ACI strategy, wherein the volume of coarse total per unit volume of aggregate total for various zones of fine total is figured in light of most extreme size of total. The air substance is ignored in this strategy. 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.

iii. The IS method does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content.

iv. The IS method does not have an adjustment in fine aggregate content for different levels of workability. Higher workability mixes require more fine aggregate content to maintain cohesion of mix.

v. 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.

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 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.

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) IS method: From Table 5 of IS 456:2000, maximum water cement ratio = 0.55 (Mild exposure).

Based on experience adopt water cement ratio as 0.44

0.44 < 0.55, hence ok.

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) IS Method:

From Table 6 in Appendix B, maximum water content for 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) IS Method:

From Table 3, Volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60

In the present case water-cement ratio is 0.44. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.06, the proportion of volume of coarse aggregate is increased by 0.032 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio). Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.44 = 0.612.

So Total aggregate content = 1-0.1342-0.186= 0.6798 m3.

Coarse aggregate content per m3 = 0.6798 x 0.612 x 2.65 x 1000 = 1138.53 Kg/m3

Total sand content per m3 = 0.6798 x (1-0.612) x 2.75 x 1000 = 688 Kg/m3

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.

Table 2.1: Comparison of results obtained from ACI 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
IS	422.73	186.0	725.35	1102.5	0.44 (from experience)

2.4 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

METHODOLOGY

3.1 General

This chapter is reviews the steps followed to build up a handy tool. The procedure was divided into two phases which are discussed in this chapter. This chapter provides a brief overview of the steps followed to build an application and the steps followed for its experimental validation.

3.2 Phase 1: App Development

Phase 1 consisted of four steps:

- In depth study of mix design methods
- Establishing logics and then algorithms
- Android SDK (software development kit) implementation
- Bug testing and revision

Step 1:

Three methods are added in our android application. All three of the methods were studied in depth so that better android application could be built. The methods are discussed in detail in previous chapter.

Step 2:

Step 2 is the most difficult step. It involves creation of logics and algorithms based on the available methods. The relationships were built between the steps and loops were also required in order to generate a result which have all the factors catered. The simplified algorithms of the three methods are shown in the charts. These algorithms show the relationships built in each step to get the mix design in each method used in our application.

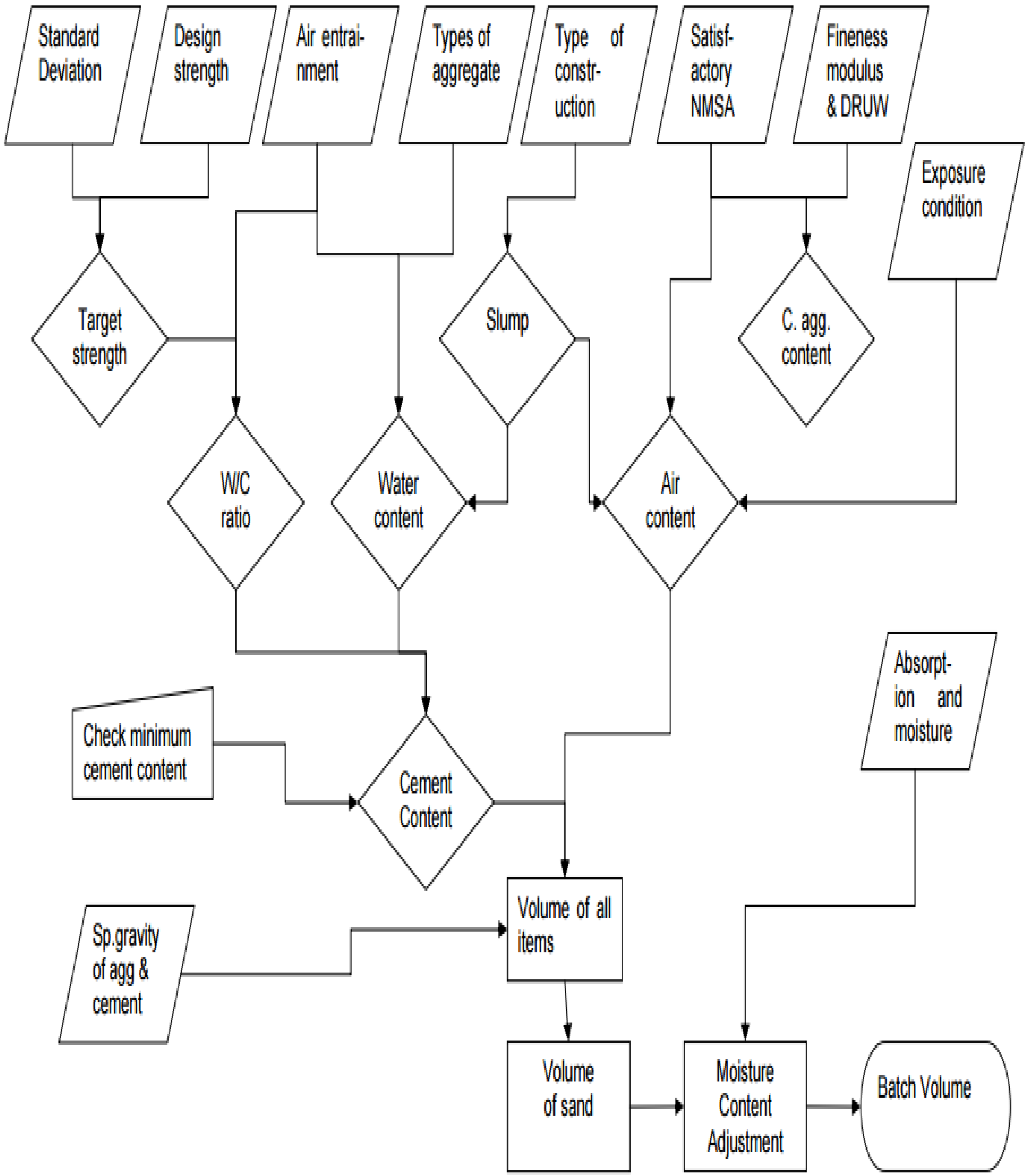


Fig 3.1: Flowchart representation of ACI method's logic

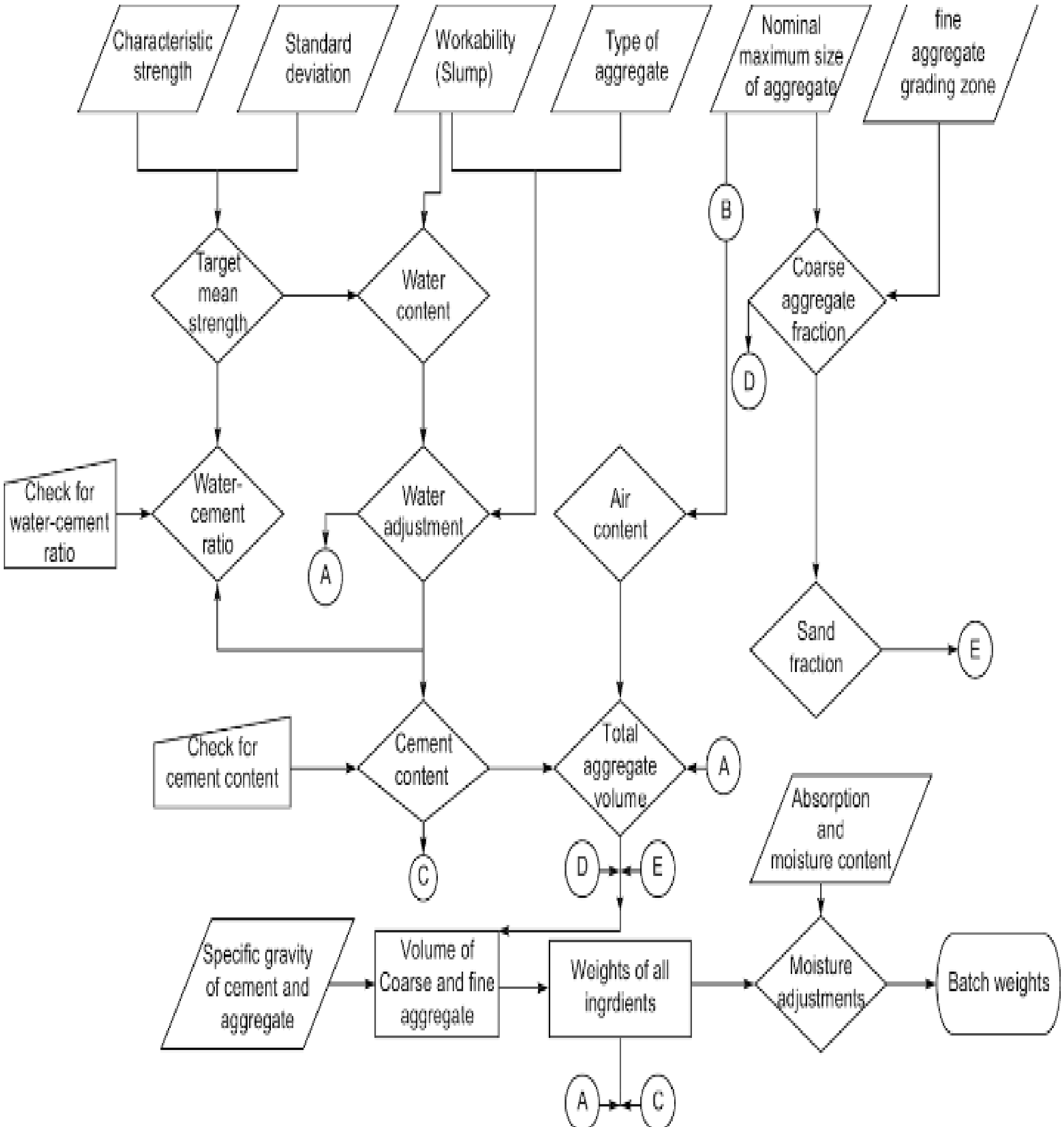


Fig 3.2: Flowchart representation of IS method's logic

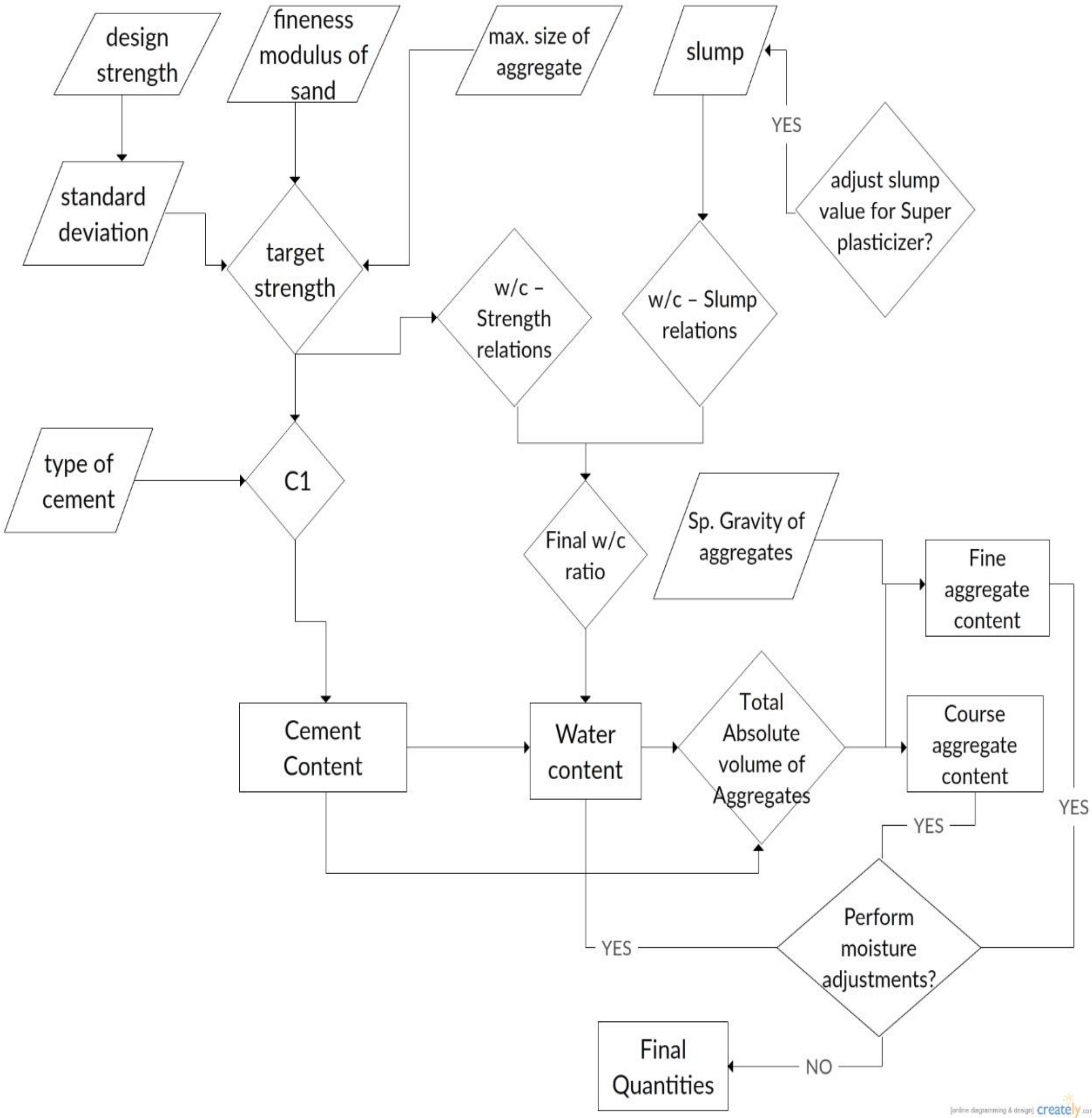


Fig 3.3: Flowchart representation of NICE method's logic

Step 3:

The application is built on “Java”. Java is an OOP (object oriented programming) language. In this language the objects are defined in classes (set of functions) and then relationships are built in these classes. The graphical interface of the application was created in an SDK (software development kit) named “Eclipse”. This kit has drag and drop option of the buttons to create the GUI of the application and the programming can be done on any language at the back end.

Step 4:

To make our application more reliable we had to perform bug testing and revision. We went through each and every step and counter checked our results for different inputs and compared them with hand calculations.

3.3 Phase 2: Experimental Validation

The mix design results obtained was further tested in the laboratory for 4000 psi. Results are shown in appendix.

CHAPTER 4

INTRODUCTION TO TWO NEW MIX DESIGN METHODS

4.1 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 will discuss two new methods of mix design. The first method was developed in NICE (NUST) as master thesis research project in 2011. The other method is developed in Iowa State University as a research project of National Concrete Pavement Technology Center and was published in March 2015. Both these methods will be discussed in detail and their procedures will be explained in this chapter which will provide a good basis for their comparison with the older mix design methods discussed in chapter 2.

4.2 Method Developed in NICE (NUST)

The method is based upon w/c – strength relations developed for various cement types as well as some other relationships established between various parameters including Slump, age, type and dosage of super plasticizers.

4.2.1 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.

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,

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

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

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

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

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,

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

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

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

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

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

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

Table 4.1: Typical Values of "α"

Maximum Aggregate Sizes	3/8"	½"	¾"
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 4.2: Standard Deviations specified by ACI 318-08

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

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 $(w/c)_{wo}$.

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

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

$C = \frac{fcr\prime}{C_1}$ ------------------- (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.

$C_1 = 0.0014 (fcr') + 4.1025$ ------------------- (eq. 5.9)

Therefore,

$C = \frac{fcr'}{0.0014\ fcr' + 4.1025}$ ------------------- (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.

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

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

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

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

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

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 4.3: 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 %

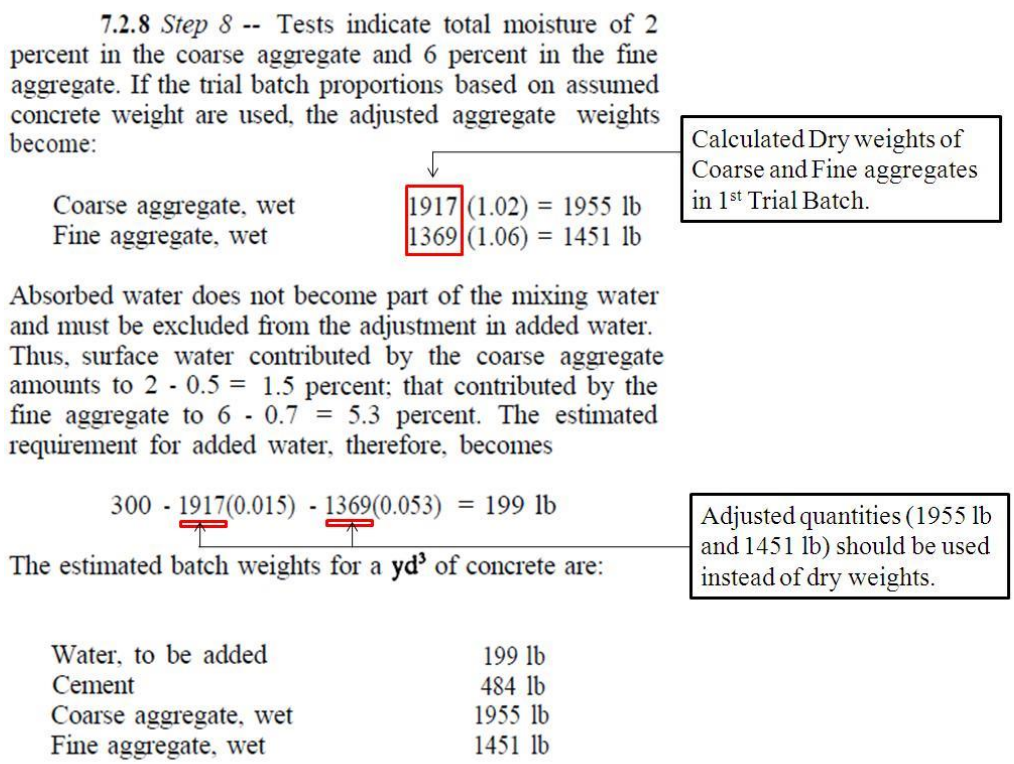
Batch weights calculated per yd^3 of concrete are,

Table 4.4: 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 4.1: 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.

CHAPTER 5

EXPERIMENTAL PROGRAM

5.1 General

As explained earlier, the objective of the research is to compare the results of concrete mix designs developed using ACI, IS and a method developed in NICE (NUST) and check their applicability using locally available materials in Pakistan. Mix designs were developed using all three methods discussed above for a strength of 4000 psi and a slump of 4 inches. All the parameters were kept constant for each method. The mix designs obtained from each method were tested in the laboratory for their slump and compressive strength. Results were later compared to see which of the three methods achieved their required compressive strength and slump using the local materials available in Pakistan.

5.2 Materials

The cement was used in the experimental program conforming to ASTM C150. OPC Grade 53 (Bestway) cement was for all experiments. Coarse aggregate was procured from Margalla quarry site. The maximum aggregate size used was 1 inch. Sand from Lawrencepur (FM = 2.11) was used. Both fine and coarse aggregates were used in "as obtained" condition.

The results of tests conducted to determine the properties of aggregates are presented in Appendix A. No admixture was used in mixes however to examine the effect superplasticizers on fresh and hardened properties of concrete separate mixes were prepared with HRWRA (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 100 mm x 200 mm ^{size}, 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.

5.3 Tests and Experiments Performed

5.3.1 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 5.1: A Servo-hydraulic Computer Controlled Compression Testing Machine

5.3.2 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.

5.4 Concrete Mix Design Parameters

The properties of concrete making ingredients were tested in the laboratory. Accordingly, the parameters used for design of concrete mixes were as per Table 5.1, below:

S. No.	Parameters		Data
1	Characteristic compressive strength		4000 psi
2	Type of cement :		OPC Grade 53
3	Specific gravity of cement		3.15
4	Nominal maximum size of Coarse Aggregate		1.0 inch
5	Type of Coarse aggregate		Crushed angular stone
6	Type of fine aggregate		Lawrencepur sand
7	Specific gravity of :	Coarse aggregate	2.65
		Fine aggregate	2.67
8	Unit weight of :	Coarse aggregate	97 lb/ft3
9	Fineness modulus of sand		2.11
10	Water absorption capacity (SSD):	Coarse aggregate	0.6
		Fine aggregate	1
11	Free surface moisture :	Coarse aggregate	2.5
		Fine aggregate	2
12	Workability desired		Slump 2 to 4 inch
13	Chemical/ mineral admixtures		Gelenium 51 (HRWRA)
	Specific Gravity of admixture		1.1 at 20°C

Table 5.1: Concrete mix design parameters

5.5 Concrete Mix Design Developed using all three methods

The proportions of ingredients of concrete mixes designed by IS, ACI and method developed in NICE (NUST) were as below. With these relative proportions of ingredients trial mixes were prepared and the cylinders were cast.

S. No.	Method	Strength of concrete (psi)	Water to Cement Ratio	Water Content (litre/m^3)	Cement Content (kg/m^3)	Coarse aggregate Content (kg/m^3)	Fine aggregate Content (kg/m^3)
1	ACI method	4000	0.47	201.62	432.66	1023.47	677.96
2	IS method	4000	0.39	191.58	494.42	1139.0	591.0
3	NICE (NUST) method	4000	0.43	189.95	442.01	1127.77	611.84

Table 5.2: Proportions of concrete ingredients by IS, BS and ACI methods

CHAPTER 6

RESULTS

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

6.1 Experimental results of Compressive Strength Tests

The workability of the concrete mixes was measured in terms of Slump. After water curing of cylinders, compressive strengths of 3 days, 7 days and 28 days were tested. The experimental test results were obtained as below:

S. No.	Method	Required Strength (psi)	Slump required (inch)	Target Mean Compressive Strength (psi)	Avg. 3 days Cylinder Compressive Strength (psi)	Avg. 7 days Cylinder Compressive Strength (psi)	Avg. 28 days Cylinder Compressive Strength (si)
1	ACI Method	4000	2 to 4	5196	1914		
2	IS Method	4000	2 to 4	5196	2160.5		
3	NICE (NUST) method	4000	2 to 4	5196	2445.67		

Table 6.1: Experimental test results

Appendix

For ACI Method

Non-Air-Entrained Concrete

Slump(in)	Maximum aggregate size (in.) 0.375	0.5	0.75	1	1.5	2	3	6
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	-
Air Content	3.0%	2.5%	2.0%	1.5%	1.0%	0.5%	0.3%	0.2%

Air-Entrained Concrete

Slump(in)	Maximum aggregate size (in.) 0.375	0.5	0.75	1	1.5	2	3	6
1 to 2	305	295	280	270	250	240	225	180
3 to 4	340	325	305	295	275	265	250	200
6 to 7	365	345	325	310	290	280	270	-
Air Content								
Mild	4.5%	4.0%	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%
Moderate	6.0%	5.5%	5.0%	4.5%	4.5%	4.0%	3.5%	3.0%
Extreme	7.5%	7.0%	6.0%	6.0%	5.5%	5.0%	4.5%	4.0%

Relationship between water/cement ratio and compressive strength of concrete

28-day Compressive Strength (psi)	Non-AE	AE
2,000	0.82	0.74
3,000	0.68	0.59
4,000	0.57	0.48
5,000	0.48	0.40
6,000	0.41	0.32
7,000	0.33	---

Max Aggregate (in.)	Fineness Modulus 2.4	2.5	2.6	2.7	2.8	2.9	3
0.375	0.50	0.49	0.48	0.47	0.46	0.45	0.44
0.500	0.59	0.58	0.57	0.56	0.55	0.54	0.53
0.750	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1.000	0.71	0.70	0.69	0.68	0.67	0.66	0.65
1.500	0.75	0.74	0.73	0.72	0.71	0.70	0.69
2.000	0.78	0.77	0.76	0.75	0.74	0.73	0.72
3.000	0.82	0.81	0.80	0.79	0.78	0.77	0.76
6.000	0.87	0.86	0.85	0.84	0.83	0.82	0.81

For IS Method

TABLE 1 SUGGESTED VALUES OF STANDARD DEVIATION

GRADE OF CONCRETE	STANDARD DEVIATION FOR DIFFERENT DEGREE OF CONTROL IN N/mm 2		
	Very Good	Good	Fair
(1)	(2)	(3)	(4)
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

NOTE — Appendix A provides guidance regarding the different degrees of quality control to be expected, depending upon the infrastructure and practices adopted at the construction site.

Durability Criteria as per IS 456- 2000

Exposure	Plain Concrete			Reinforced Concrete		
	Min. Cement	Max w/c	Min grade	Min. Cement	Max w/c	Min grade
Mild	220 kg/m^3	0.60	--	300 kg/m^3	0.55	M 20
Moderate	240 kg/m^3	0.60	M 15	300 kg/m^3	0.50	M 25
Severe	250 kg/m^3	0.50	M 20	320 kg/m^3	0.45	M 30
V. Severe	260 kg/m^3	0.45	M 20	340 kg/m^3	0.45	M 35
Extreme	280 kg/m^3	0.40	M 25	360 kg/m^3	0.40	M 40

Nominal Maximum Size of Aggregates	Entrapped Air, as percentage of volume of concrete
10	3 %
20	2 %
40	1 %

Approximate Sand and water Content per Cubic Meter of Concrete for Grades up to M 35 W/C = 0.6 Workability= 0.8 C.F

Nominal Maximum size of aggregate (mm)	Water Content per cubic metre of concrete (kg)	Sand as percentage of total aggregate by absolute volume
10	208	40
20	186	35
40	165	30

Approximate Sand and Water Content per cubic meter of concrete for grades above M 35 W/C = 0.35 Workability= 0.8 C.F.

Nominal Maximum size of Aggregates	Water Content per cubic metre of concrete (kg)	Sand as percentage total aggregate by absolute volume of (%)
10	200	28
20	180	25

Adjustment of values in water content and sand percentage for other conditions

Change in Condition	Adjustment Required	
	Water Content	Percentage sand in total aggregate
For sand confirming to grading Zones I , III and IV	0	+ 1.5 percent for zone I -1.5 percent for zone III -3.0 for zone IV
Increase or decrease in values of compacting factor by 0.1	± 3 %	0
Each 0.05 increase or decrease in free water cement ratio	0	± 1 %
For rounded aggregates	$-15\ kg/m^3$	-7 %

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