ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

EVALUATION OF UNIFORMITY OF CONCRETE PROPERTIES ON SELECTED BUILDING CONSTRUCTION SITES IN ADDIS ABABA

A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Construction Technology and Management)

By

Sity Mensur Mudesir

(B. Sc. in Construction Technology and Management)

Advisor: Dr. Ephraim Senbetta (PhD. P.E., LEED AP)

May, 2016

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

EVALUATION OF UNIFORMITY OF CONCRETE PROPERTIES ON SELECTED BUILDING CONSTRUCTIONSITES IN ADDIS ABABA

By

Sity Mensur Mudesir

Approved By Board of Examiners

Dr. Ephraim Senbetta ____________________ ____________________

Advisor

Prof. Abebe Dinku ____________________ ____________________

Internal Examiner

Eng. Yibeltal Zewdu ____________________ ____________________

External Examiner

Dr. Agizew Nigussie ____________________ ____________________

Chairman

Declaration

I, Sity Mensur researcher declare that this research is my original work. The findings presented in this paper are not found in any other previous research works.

Sity Mensur

____

May, 2016

Acknowledgments

First of all, I would like to thank my creator Allah, the Beneficent, the Merciful. Next I would like to extend my heartiest gratitude to my advisor, Dr. Ephraim Senbetta for his invaluable suggestions and constructive comments throughout the research work.

I would also like to thank my beloved family (my mother Muntaha Mussa, my elder brothers Tariku M., Nurhassen M., Semir M. and my beloved husband Kalid Ali) without whose support and motivation; this thesis would not have been completed. I also wish to extend my sincere thanks to my friends Gizman A, Amin Muktar, Samson Walelign and Ato Yohannes Beyene (Project Manager of Rama Construction Plc) for supporting me materially, physically and with ideas as well.

Lastly but not least, I would like to thank those people who were willing to fill the questionnaire and also for those who allowed me to use their site to take samples, and those who helped me directly or indirectly to finalize the thesis thank you a lot.

Sity Mensur

May, 2016

Abstract

In any mixer, it is essential that sufficient interchange of materials between different parts of mixer chamber takes place, so that the uniform concrete is produced. The efficiency of the mixer can be measured by the variability of the mix discharged into a number of cubes without interrupting the flow of concrete.

The objective of this research is to evaluating the uniformity of site produced concrete by taking slump tests and compressive strength test on selected sites in Addis Ababa.

To meet the above mentioned objective questioner survey and experimental works were conducted. Two hundred (200) questionnaires were distributed; out of these only one hundred thirty four (134) were collected. Field tests were conducted on three selected on-going building projects. On those sites five (5) slump tests and four (4) compressive strength test samples were conducted from each site. For compressive strength test four samples were taken for 7 days and 28 days. A total of fifteen (15) slump tests and seventy two 150mm cube tests were conducted by taking sample concrete produced in/at the ongoing selected project sites.

From the questionnaire survey, most of the respondents agreed the produced concrete properties are sometimes uniform or sometimes not uniform. However, the test results showed that most of the samples are not uniform. Coefficient of variation was used to evaluate the uniformity of concrete produced on selected sites. And results showed that the same grade of concrete produced at different time (day) is significantly inconsistent. There is a significant variation in compressive strength among the same concrete produced at different times.

Key Words: Compressive Strength, Slump, Test, Uniformity, Workability

Table of Contents

List of Tables

List of Figures

Abbreviations

ACI	American Concrete Institute
ASTM	American Standard for Testing of Materials
BS	British Standard
CV	Coefficient of Variation
EBCS	Ethiopian Building Code Standard
SD	Standard Deviation

Chapter One ---Introduction

1.1. Background

Concrete is a product obtained artificially by hardening of the mixture of: binding material (cement), fine aggregate (sand), coarse aggregate (gravel), admixtures in some cases, and water, in predetermined proportions. Since concrete is made from different materials which form different parts, it is known as a composite material. The cement and water form a paste that hardens and bonds the aggregates together.

Control of quality of concrete on site is very essential. To make a good concrete there are two criteria. The concrete has to be satisfactory in its hardened state which means the concrete should have satisfactory compressive strength and an adequate durability. The second one is the concrete should be satisfactory in its fresh state while being transported from the mixer and placed in the formwork which means the mix should be consistent to be compacted easily and also the mix should be cohesive enough for the method of transporting and placing used so as not to produce segregation with a consequent lack of homogeneity of the finished product **[1]**.

Properties of concrete are classified in to two: fresh concrete properties and hardened concrete properties. Among the fresh concrete properties workability is one of them and compressive strength is one of the hardened properties of concrete. It is known that concrete is an important structural element, so to know the properties of concrete a number of different tests can be performed both on a job site and in a laboratory.

For performing field tests ASTM standards define precise procedures to determine the quality of freshly mixed concrete. By always performing tests the same way, it's possible to detect changes in fresh concrete that could affect concrete performance. Most of the construction sites in Ethiopia, the frequency of taking fresh and hardened concrete tests for quality control is not as per the standards.

Taking this into account, this research evaluates the uniformity of concrete properties by focusing only on workability and compressive strength of concrete.

1.2. Research Problem

Construction in Ethiopia is increasing rapidly. In relation with this, use of concrete as a construction material is also increasing. It is known that maintaining the uniformity of fresh concrete properties have a significant effect on the service life of the structure. Different experienced engineers said that uniformity of concrete properties is not maintained. This indicates that the uniformity of concrete properties are not given due attention in the Ethiopian construction industry. Therefore, this research has been initiated to evaluate the uniformity of concrete properties on selected sites in Addis Ababa.

1.3. Objective of the Research

The objective of this research is:

Evaluating the uniformity of site produced concrete by taking slump tests and compressive strength test on selected building construction sites in Addis Ababa.

1.4. Deliverables

The deliverables of the research are:

- To assess the uniformity on the production of concrete on site by conducting fresh and hardened concrete properties tests.
- To identify possible causes for variation of concrete properties for the same grade of concrete and slump value.
- Showing the degree of uniformity of workability and compressive strength of concrete produced on site.
- At the end providing recommendation for improving the uniformity of concrete properties.

1.5. Scope of the Research

Due to time and budget constraints the researcher was not able to take samples from each sub-city as well as from each grade of building contractors. Therefore, the research with the objective of evaluating the uniformity of fresh concrete properties was conducted by taking samples only from three on-going projects comprising of three different grades of building contractors, namely Grade 1, Grade 3 and Grade 5 Building contractors.

1.6. Methodology

For the objective of the research the following methodologies are followed.

1) Preparation of questionnaire

Questionnaire was developed in order to understand the overall concrete production processes and precautions taken in Addis Ababa.

2) Questionnaire distribution

From the total population representative numbers of samples were determined using sampling sheet, by determining level of confidence and margin of error. The questionnaire was distributed to Engineers in the construction industry.

3) Site selection

Many contractors were requested in order to take sample from there construction sites for the case study. However, only the following three of the contractors were willing and make their site open for this study. Due to this the case study was limited on the following three projects.

- The first construction site found at Kirkos Sub-City (around Wolo Sefer) was selected. It is G+5 and constructed by BC3 grade of contractor.
- The second construction site found at Yeka Sub-City (around kotebe) was selected. It is G+16 and constructed by BC1 grade of contractor.
- The third construction site found at Akaki-Kality Sub-City (around kilento) was selected. It is G+4 and constructed by BC5 grade of contractor.

4) Sampling of test specimen

Concrete sample was taken from the concrete prepared for building structures of the building at different time in a day. From the concrete mix four samples for compressive strength test at different time in a day were taken. Three samples were taken for each 7 and 28 days compressive strength test to get average test result.

Five slump tests and four concrete cube samples for compressive strength test were taken from each site. A total of fifteen slump tests and seventy two cube test samples were taken.

5) Curing of the specimen

Concrete samples were cured in water in the Addis Ababa Institute of Technology Laboratory for 7 and 28 days duration. Rate of loading is 0.28MPa/sec and loading direction is 90^0 from compacted direction.

6) Testing of concrete sample

After completing curing the samples were tested for 7 days and 28 days compressive strength.

7) Analysis of the results

The test data were then analyzed. Standard deviation and coefficient of variation were determined for compressive strength results. Differences from the specified slump value were determined for slump test results.

8) Conclusion and recommendation

Finally conclusion and recommendation were drawn based on the findings resulted from questionnaire and case study.

Chapter Two---Literature Review

2.1 Definition of Consistency/ Uniformity of Concrete

In any mixer, it is essential that sufficient interchange of materials between different parts of the chamber of the mixer takes place, so that the uniform concrete is produced. The efficiency of the mixer can be measured by the variability of the mix discharged into a number of cube molds without interrupting the flow of concrete **[1]**.

2.2 Properties of Concrete

Properties of concrete are classified in to two: fresh concrete properties and hardened concrete properties. Those are workability, durability, compressive strength, tensile strength and etc. The focus point of this research is to assess the uniformity of concrete properties specific to uniformity of workability and compressive strength. Therefore, the literature review discusses only workability and compressive strength of concrete.

2.2.1 Workability

2.2.1.1 Definition

Different scholars in the field of concrete define workability in different ways. In this part some of the definitions of workability defined by different people and organizations will be discussed.

- Workability can be defined as the amount of useful internal work necessary to produce full compaction **[2]**.
- The ***ASTM C125*** defines workability as property determining the effort required to manipulate a freshly mixed quality of concrete with minimum loss of homogeneity.
- The ***ACI 116R-90*** is that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished.
- The ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is called ***workability***. Concrete should be

workable but the ingredients should not separate during transport and handling. The degree of workability required for proper placement of concrete is controlled by the placement method, type of consolidation, and type of concrete. Different types of placements require different levels of workability **[3]**.

- The strength of concrete of given mix proportions is very seriously affected by the degree of its compaction; it is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed and finished sufficiently easily and without segregation. A concrete satisfying those conditions is said to be workable **[1]**.
- Workability means how easy it is to:
    - Place
    - Handle
    - Compact and
    - Finish a concrete mix **[4]**.

In the definitions of workability discussed above they all said, directly or indirectly, that workability is one of the properties of concrete which makes the concrete to be easily placed, handled, compacted and finished.

In general there are two basic properties of concrete which clearly describe the meaning of workability. Those two points are consistency and cohesiveness of concrete, will be discussed as follow.

a. Consistency (slump): how easy to flow

Consistency is considered a close indication of workability. Slump is used as a measure of the consistency or wetness of concrete. A low-slump concrete has a stiff consistency. If the consistency is too dry and harsh, the concrete will be difficult to place and compact and larger aggregate particles may separate from the mix. However, it should not be assumed that a wetter, more fluid mix is necessarily more workable. If the mix is too wet, segregation and honeycombing can occur. The consistency should be the driest practicable for placement using the available consolidation equipment **[3]**.

b. Cohesiveness: tendency to bleed and segregate

Bleeding is the development of a layer of water at the top or surface of freshly placed concrete. It is caused by sedimentation (settlement) of solid particles (cement and aggregate) and the simultaneous upward migration of water. Bleeding is normal and it should not diminish the quality of properly placed, finished, and cured concrete. Some bleeding is helpful to control plastic shrinkage cracking.

Excessive bleeding increases the water-cement ratio near the top surface; a weak top layer with poor durability may result, particularly if finishing operations take place while bleed water is present. A water pocket or void can develop under a prematurely finished surface **[3]**.

Segregation can be defined as separation of the constituents of heterogeneous mixture so that there distribution is no longer uniform. There are two forms of segregation. In the first, coarser particles tend to separate out since they tend to travel further along a slope to settle more than the finer particles. The second form of segregation, occurring particularly in wet mixes, is manifested by the separation of grout (cement plus water) from the mix. With some grading when a lean mix is used, the first type of segregation may occur if the mix is too dry; addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second type of segregation would take place **[1].**

2.2.1.2 Factor affecting workability of concrete

Factors that influence the workability of concrete are:

a. Water content

Water that is acceptable for drinking (except in respect of bacteriological requirements) is suitable for making concrete. Curing water should be free of materials that significantly affect the hydration reaction of the cement or promote possible alkali – silica reaction or produce unsightly stain or deposit on the surface **[15].**

The function of the water, other than enabling the chemical reactions which cause setting and hardening to proceed, is to lubricate the mixture of aggregates and cement in order to facilitate placing.

The amount of water mixed with the concrete determines the strength of the hardened paste. The use of too much mixing water will thin or dilute the fresh cement paste and weaken its cementing properties when hard. Consequently, it will be readily seen that the strength and quality of concrete depend primarily upon the quality and quantity of water mixed with the cement. The relation between the amounts of water and cement used in a mixture is called the water-cement ratio.

The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. The main factor is water content of the mix, expressed in kilograms of water per cubic meter of concrete **[1].**

This indicates that the amount of water added to the concrete mix will affect the workability and the final output of the concrete compressive strength. This is therefore; care should be taken during preparation of a concrete mix.

b. Grading, shape, size and surface texture of aggregates

The particle shape and surface texture of an aggregate influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, elongated particle's require more water to produce workable concrete than do smooth, rounded, compact aggregates. Hence, aggregate particles that are angular require more cement to maintain the same water cement ratio. However, with satisfactory gradation, both crushed and non-crushed aggregates (of the same rock types) generally give essentially the same strength for the same cement factor. Angular or poorly graded aggregates can be more difficult to pump **[3].**

This implies that the shape and surface texture of the aggregate will affect the workability of concrete properties.

Particle size distribution of aggregates is important to get the maximum possible close packing of aggregates, which reduces voids and consequently the required paste, and attain economical mix. Close packing also results in stronger mix, as aggregates tend to carry more loads **[17].**

The effects of aggregate characteristics on concrete properties, such as ability to be vibrated, strength, and resistivity, were investigated using mixtures in which the paste content and the w/cm were held constant. By using intermediate sizes in a concrete mixture, the compressive strength increases. A distinct increase in the slump was observed with the majority of river rock compared to crushed limestone. The crushed limestone’s slump ranged from 0.5 in. (1.27cm) to 1.5 in. (3.81cm), while the river rock’s slump ranged from 1 in. (2.54cm) to 2.5 in. (6.35cm).

The different aggregate proportions, the maximum nominal aggregate sizes, and combinations of different aggregates all had an impact on the performance in the strength, and slump **[5].**

c. Entrained air

Entrained air improves the workability of concrete. It is particularly effective in lean (low cement content) mixes that otherwise might be harsh and difficult to work.

Workability of mixes with angular and poorly graded aggregates is similarly improved. Because of improved workability with entrained air, water and sand content can be reduced significantly. A volume of air-entrained concrete requires less water than an equal volume of non-air-entrained concrete of the same consistency and maximum size aggregate.

Freshly mixed concrete containing entrained air is cohesive, looks and feels fatty or workable, and can usually be handled with ease; on the other hand, high air contents can make a mixture sticky and more difficult to finish. Entrained air also reduces segregation and bleeding in freshly mixed and placed concrete **[3].**

d. Ambient air temperatures

Freshly mixed concrete stiffens with time. This should not be confused with setting of cement. As temperature increases, the workability decreases. Also, workability decreases with time. These effects are related to the progression of chemical reaction.

The water content of the mix can be lost by evaporation, by absorption of aggregate, and also by initial chemical reactions. Due to this the amount of water in the mix will reduce significantly and affect the workability of the fresh concrete.

e. Admixtures

Admixtures are those ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. Concrete should be workable, finishable, strong, durable, watertight, and wear resistant.

For example: the use of air entraining and super plasticizers admixture can improve the workability of fresh concrete significantly, and segregation and bleeding are reduced or eliminated. Entrained air greatly improves concrete’s resistance to surface scaling caused by chemical deicers. However, surface scaling is not the major problem in Ethiopian condition.

2.2.2 Strength of concrete

2.2.2.1 Definition

Strength is defined as the ability of a material to resist stress without failure. The strength of concrete is commonly considered to be its most valuable property. It usually gives an overall picture of the quality of a concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element in structural design and is specified for compliance purposes **[1].**

Of the various strength properties of concrete, it is generally the compressive strength which attracts the greatest interest since it is this property which is made use of in designing building units of structural or of simple load bearing quality. In addition, it has a great practical and economic significance because the sections and sizes of the concrete structures are determined by it **[6].**

In general, compressive strength is considered to be the most important mechanical property of concrete. In most structural applications, concrete is employed primarily to resist compressive stresses. Compressive strength is generally used as a measure of the overall quality of a concrete **[19].**

In the definitions of compressive strength discussed above they all said, directly or indirectly, that compressive strength is a very important parameter to measure the quality of the mixed concrete.

2.2.2.2 Factors Affecting Concrete Strength

The strength of concrete at a given age and cured at a prescribed temperature is assumed to depend primarily on two factors: the water to cement ratio (W/C) and the degree of compaction **[1]**.

For a given cement and acceptable aggregates, the strength that may be developed by a workable, properly placed mixture of cement, aggregate, and water (under the same mixing, curing, and testing conditions) is influenced by: (a) ratio of cement to mixing water, (b) ratio of cement to aggregate, (c) grading, surface texture, shape, strength, and stiffness of aggregate particles, (d) maximum size of the aggregate **[7].** Among many factors which affect the compressive strength of concrete are some of it is discussed below.

a. Quality of Water

Water is an important ingredient of concrete. Part of mixing water is utilized in the hydration of cement and the balance of water is required for imparting workability to concrete. Thus the quantity and quality of water is required to be looked into very carefully. The strength and durability of concrete is reduced due to the presence of chemical impurities in water. Most of the specifications recommended the use of potable water for making concrete.

Neville A. M. specified that, drinking water may be unsuitable as mixing water when the water contains a high concentration of sodium or potassium which leads to danger of alkali-aggregate reaction. While the use of potable water is generally safe, water not fit for drinking may also be satisfactorily used in making concrete. As a rule, any water with pH of 6.0 to 8.0 which does not taste saline or brackish is suitable for use. Color and odor do not necessarily mean that, deleterious substances are present in water. Natural waters that are slightly acidic are harmless, but water containing organic acids may adversely affect the strength of concrete **[1]**.

Kucche K. J. and et.al concluded that degree and rate of attack of corrosion of steel is increases as pH value of water decreases. The rate of corrosion is more below 3.0 pH value of water. Chlorine ions present in water form hydrochloric acid (HCl), can act as a catalyst for oxidation of steel in concrete. This will results in formation of $Fe(OH)_2$ which allows to easier penetration of chloride ions and hence formation of corrosion **[14].**

Therefore, the quality of water used for concrete making should be given due attention to maintain service life of the structural member of building and concrete pavement.

b. Effects of aggregate type, size, and content on concrete strength

Aggregates contribute the significant proportion of strength possessed by concrete due to its higher modulus of elasticity as compared to the cement paste **[16].**

Fine and coarse aggregates make about 70% by volume of concrete production. The quality of concrete is strongly influenced by aggregate's physical and mechanical properties as well as chemical composition of the parent aggregate making material **[17].**

The research done in Nigeria shows the compressive strength of concrete containing basalt have slightly greater than concrete containing limestone. The concrete containing basalt and concrete containing basalt or limestone yield higher compressive strengths with higher coarse aggregate contents than with lower coarse aggregate contents **[8]**.

From the above research finding, type of parent rock and also the amount of aggregate added to the mix will affect the compressive strength of concrete significantly. Therefore, during selection of construction material especially coarse aggregate due care should be taken.

Aggregate type has effect on the compressive strength of normal concrete. Highest compressive strength was achieved from concrete containing crushed quartzite, followed by concrete containing river gravel. Concrete containing crushed granite shows the least strength development at all ages **[9].**

In general the weathered granite by nature has weaker strength than the fresh granite. This may be the main reason for the concrete made with crushed granite aggregate achieving least compressive strength. From this can be understood that the type of aggregate and also the status of the aggregate directly affect the final output of the quality of concrete.

On the research done by Biruk Negash, he found out that the compressive strength of concrete reduced by 48% by keeping constant other things and changing aggregate quality **[18].**

This indicates that quality of aggregate have significant impact on the quality of concrete and also will affect the compressive strength of concrete.

The effects of aggregate characteristics on concrete properties, such as ability to be vibrated, strength, and resistivity, were investigated using mixtures in which the paste content and the w/cm were held constant. By using intermediate sizes in a concrete mixture, the compressive strength increases **[5].**

c. Water/Cement Ratio

Water is mandatory for hydration reaction to proceed. But if the amount of water added is exceedingly much, the excess water remains free in the concrete forming capillary pores. These pores remain the concrete to be permeable and weak in strength.

When concrete is fully compacted, its strength is taken to be inversely proportional to its water/cement ratio. This relationship was established by Duff Abrams in 1919 and described by the equation:

$$\left\{ fc = \frac{K1}{K2^{\frac{w}{c}}} \right\}$$ ………………………………………………. [Eq. 2.1]

Where: fc is the compressive strength of the concrete,

w/c is the water to cement ratio of the mixture (originally taken by volume), and

K1 and K2 are empirical constants.

Abrahams' "law", although established independently, is similar to a general rule formulated by Feret in 1896 in that they both relate strength of concrete to the volumes of water and cement. Feret's rule was in the form

$$\left\{ fc = K\left(\frac{c}{c+w+a}\right)^2 \right\}$$……………………………………… [Eq. 2.2]

Where: fc is the strength of concrete,

c is the absolute volume of cement,

w is the absolute volume of water,

a is the absolute volume of air, and

K is a constant.

The water/ cement ratio determines the porosity of the hardened cement paste at any stage of hydration. Thus the water/ cement ratio and the degree of compaction both affect the volume of voids in concrete. Figure 2.1 shows water cement ratio inversely proportional to compressive strength of concrete. The general form of the strength versus water/cement ratio curve is shown in Figure 2.1.

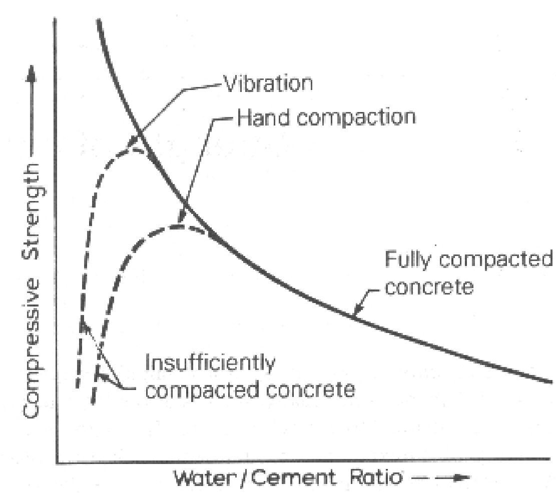

Figure 2.1: The relationship between strength and water/cement ratio of concrete (Neville 1996)

d. Degree of Compaction

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. Immediate upon placement of concrete in the forms, it should be compacted to assure close contact of the constituent materials with themselves, as well as with other forms. This consolidation may be accomplished with the use of hand tools, but vibrators are much preferred. This consolidation eliminates entrapped air and achieved maximum density which gives the concrete higher strength and durability.

For a concrete to have better strength, the aggregate should be well compacted and grading, shape and surface texture are also among the main factors in determining the degree of compaction with a reasonable effort and without causing segregation **[20].**

From this it is understandable that compaction of fresh concrete after placing of concrete is very important for getting the required compressive strength of concrete.

e. Air Content

Air content is that portion of the pores in the fresh cement paste portion of concrete that is filled with air. The quantity of liquid-filled pores can be characterized by the water cement ratio of fresh cement paste **[19].**

Air entrainment in fresh concrete can improve the workability and cohesiveness of fresh concrete. The fine air bubbles in fresh concrete act as many fine aggregates with low friction and elastic which form a lubricating layer around solid particles so as to improve the workability such as flowability, resistance to segregation, resistance to bleeding, improved finishing quality, etc. So entraining more fine air bubbles with stability can reduce the amount of fine particles such as cement and water required on the same slump condition in concrete. This is sustainable for hardened properties of concrete, such as reduced shrinkage, creeps and permeability due to reduced content of cement paste. Moreover, by reducing the water in concrete, this partially offset the reduction of strength in hardened concrete caused by air entrainment.

f. Temperature and Aging

The rate of hydration reaction is temperature dependent. If the temperature increases the reaction also increases. This means that the concrete kept at higher temperature will gain strength more quickly than a similar concrete kept at a lower temperature. However, the final strength of the concrete kept at the higher temperature will be lower. This is because the physical form of the hardened cement paste is less well structured and more porous when hydration proceeds at faster rate.

If the concrete is properly cured, the strength increases with time due to the increased degree of hydration. As a rule of thumb, the 7 days strength can range from 60 – 80% of the 28 days strength, with a higher percentage for a lower w/c ratio. After 28 days, the strength can continue to go up **[19].**

g. Moisture Content

Most concrete specifications, such as ASTM C39 require that the concrete be maintained in a saturated state. However, changes in moisture content caused by wetting or drying have been shown to have a considerable effect on the mechanical properties of concrete and in a variety of ways. Concrete that has been dried has a higher compressive strength and lower static modulus than concrete with a high moisture content taken from the same mix and subjected to an identical curing process.

Moisture content in concrete does have a significant effect on the mechanical properties of concrete. Moisture content in the concrete will decrease the compressive strength and pressure tensile strength, but have a much lesser effect on the splitting tensile strength **[19].**

h. Curing of Concrete

Curing is the last step and exceedingly important one in the manufacturing of concrete. As hydration of cement takes place only in the presence of moisture and at favorable temperatures, these conditions must be maintained for a suitable time interval called curing time.

The degree of completeness of hydration which is an important factor in cement paste characteristic depends on the ability to maintain the moisture in concrete which is called curing of concrete.

At the time concrete is mixed, sufficient water is added to give workability. The amount of mixing water actually used is ordinarily in excess. Therefore, if the original water can be retained, there is more than sufficient for curing purposes.

Concrete gains strength most rapidly at early ages so that the greatest benefit from curing is secured during this period and each additional day is lesser importance than the preceding one.

Specification usually require that the surface of concrete be protected to prevent loss of moisture for at least 7 days where normal cement is used, and some specification require curing for 14days. Where high early strength cements are used, the curing may be reduced by half, while for slow hardening cements the time should be longer than for normal cements **[6].**

i. Rate of Loading

Since the response of concrete to the applied load depends on the type of load, the compressive strengths measured under laboratory and field-testing conditions will differ (Mehta and Monteiro 1993). ASTM C 39-01 requires that the loading rate for cylindrical specimens be maintained between 20 (2900MPa/sec) and 50 psi/sec (7300MPa/sec). Generally, the higher the rate of loading on the specimen the higher the apparent compressive strength will be recorded.

As per the research done on Factors Affecting the Relationship between Rate of Loading and Measured Compressive Strength of Concrete was found that the moisture content at the time of testing was one of the most important factors influencing the relationship of rate of loading and compressive strength and also age and curing have an influence too **[21].**

The data obtained under the different loading methods indicated that, when a specimen made from cement paste is loaded at slower rates up to approximately one-third of its ultimate strength value, the resulting ultimate strength is increased. However, if a slower rate of loading is continued throughout the test, the ultimate strength is decreased significantly **[21].**

j. Sampling and Testing Technician

A Concrete Strength Testing Technician is an individual who has demonstrated the knowledge and ability to properly perform, record, and report the results of basic laboratory procedures related to the determination of concrete compressive and flexural strength**.**

As per ACI Certification of Concrete Strength Testing Technician have two certification requirements those are one the applicants who meet a passing grade on the ACI written examination, and two who successfully complete the ACI performance examination. This certification program shows how much the technician performance is important for the test result of the concrete. Therefore, if the sampling and testing technician is not well trained it will have a negative impact on the test result of concrete compressive strength **[24].**

In general, ACI 214R-1, in the following table reviews the principal sources of strength variation.

Table 2.1:- Principal Sources of Strength Variation

Variations due to the properties of concrete	Variations due to testing methods
• Changes in w/cm caused by: ▪ Poor control of water ▪ Excessive variation of moisture in aggregate or variable aggregate moisture measurements. ▪ Retempering	• Improper sampling procedures
• Variations in water requirement caused by: ▪ Changes in aggregate grading, absorption, particle shape ▪ Changes in cementitious and admixture properties ▪ Changes in air content ▪ Delivery time and temperature changes	• Variations due to fabrication techniques: ▪ Handling, storing, and curing of newly made cylinders ▪ Poor quality, damaged, or distorted molds
• Variations in characteristics and proportions of ingredients: ▪ Aggregates ▪ Cementitious materials, including pozzolans ▪ Admixtures	Changes in curing: ▪ Temperature variation ▪ Variable moisture control ▪ Delays in bringing cylinders to the laboratory ▪ Delays
• Variations in mixing, transporting, placing, and consolidation	• Poor testing procedures: ▪ Specimen preparation ▪ Test procedure ▪ Uncelebrated testing equipment
• Variations in concrete temperature and curing	

2.3 Factors that affect both workability and compressive strength of concrete at site

a. Adding water on site

Adding water at the jobsite will increase slump, but will also reduce strength. The added water dilutes the paste and increases the water to cementitious materials ratio (w/cm). Too much water can increase drying shrinkage, and lead to other service-related problems.

Water content in a given volume of concrete, will have significant influences on the workability and strength of concrete. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete and the higher water/ cement ratio, which is one of the important factors affecting workability and strength. At the work site, supervisors who are not well versed with the practice of making good concrete resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at the site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

A great deal of care is taken to develop the proportions of the concrete mixtures to achieve desired performance characteristics such as compressive strength and resistance to damage from freezing and thawing, exposure to sulfates, and corrosion. It is critical to understand that these performance characteristics may become vulnerable with additions of water above the design limitations **[10].**

With the addition of water to a load of concrete in excess of the design w/cm, the following performance characteristics will likely be negatively affected: **[15]**

- Compressive Strength
- Resistance to cycles of freezing and thawing
- Resistance to damage from sulfates in soil and water
- Permeability – and its associated impact to strength and various durability characteristics
- Minimizing potential for corrosion of reinforcing steel

Almost all of the above mentioned effect will happen in Ethiopia except the second one which is resistance to cycle of freezing and thawing. Because the climate condition of Ethiopia did not expose the concrete to freezing and thawing cycle.

b. Batching methods

Volume batching is not a good method for batching the material because of the difficulty it offers to measure granular materials in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The weight of solid granular material in a cubic meter is an indefinite quantity. However, use of weight system in batching, facilitates accuracy, flexibility and simplicity.

As per the study done in Nigeria, on the Effect of Batching Methods on The Fresh and Hardened properties of Concrete, the results indicated higher workability for concrete batched by mass than concrete batched by volume at all w/c ratios and mix proportions investigated. The workability increased with increase in w/c ratios in both methods. The compressive strength results showed that for rich structural mixes (1:1:2 and 1:1.5:3), concrete batched by mass had 20% and 6% strength increases respectively over the concrete batched by volume. Ordinary structural mix (1:2:4) had 14% increase while non-structural mixes (1:3:6 and 1:4:8) had 8% and 6% increases respectively. In all cases, concrete batched by mass had better fresh and hardened properties of concrete **[11]**.

c. Constituent material handling

As per the study done, by Nwabueze M.A., in Nigeria, the field survey inspection and observations conducted at selected and sampled project sites also revealed that, methods of storing, stockpiling and selecting concrete materials are irregular and follows no standard format. At the same time, the procedure adopted in batching, mixing, compaction, placing and curing concrete are sub-standard implying that the necessary skills, training and technology inputs are lacking resulting in the present unsatisfactory and unsafe concrete product that will likely fail as soon as possible **[12]**.

2.4 Compliance and Quality Control

Quality control applies to each action used to measure the properties of the concrete, or its components, and to control them within the established specifications.

Quality Assurance refers collectively to all of the steps taken to ensure adequate confidence that the concrete will perform satisfactorily in service.

Concrete, in common with other engineering materials, is inherently a variable material. That is, tests on nominally identical samples of concrete will show some variation in mechanical properties between samples **[23].**

In general the factors that contribute to this variability may be grouped as follows:

a. *Materials*: this include variability in cement itself; in the grading, moisture content, mineral composition, physical, and particle shape of the aggregate; and in the admixtures used.

b. *Production:* this involves the type of batching plant and equipment, the method of transporting the concrete to the site, and the procedures and workmanship used to produce and place concrete.

c. *Testing:* this includes sampling procedures, the making and curing of test specimens, and the test procedure used.

Uniform concrete can be obtained only through proper quality control of all operations from selection and production of materials through batching, mixing, transporting, conveying, placing, consolidation, finishing, and curing. The uniformity of concrete production and delivery should always be evaluated, because the better the uniformity during production, transportation, and placing, the greater the opportunity to obtain desired hardened concrete properties **[26].**

Sampling Fresh Concrete

As per ACI 318M-08, samples for strength tests are to be taken on a strictly random basis if they are to measure properly the acceptability of the concrete. To be representative, the choices of times of sampling, or the batches of concrete to be sampled, are to be made on the basis of chance alone, within the period of placement. Batches should not be sampled on the basis of appearance, convenience, or other possibly biased criteria, because the statistical analyses will lose their validity.

Samples for strength tests of each class of concrete placed each day shall be taken not less than

- Once a day, nor less than,
- Once for each 110 m^3 of concrete,
- Once for each 460 m^2 of surface area for slabs or wall surface area placed each day.

According to EBCS 2, stated that the minimum rate of sampling shall be decided by the engineer taking into account the nature of the work. Higher rates would be appropriate at the start of the work, to establish quickly the level of quality, or during periods of production when quality is in doubt, or for highly-stressed structural elements. In general, the following may be adopted as the minimum requirement on size of lot and frequency of sampling, except for the special cases given hereunder:

- No individual sampling can, represent, on the average, more than 100 mixes or 100 m3, whichever is the smaller volume of Concrete.
- For each grade of concrete, at least one sample shall be taken every week
- For each grade of concrete, at least two lots shall be made.

A typical specification for sampling fresh concrete is the one described in ASTM C172. This covers sampling from stationary and track mixers and from equipment used to transport central mixed concrete. The specification requires that test done on composite samples, that is, samples taken at several points during the discharge of the concrete, and then combined. It is important to carry out the sampling as quickly as possible (within 15min), as workability, in particular, quickly changes with time. A minimum sample size of $0.03m^3$ ($1ft^3$) is required for strength test but smaller samples are permitted for air content and slump tests.

2.4.1 Test for Workability

The different measures of workability that have been developed over the years will be described under the following categories:

a. Subjective Assessment,
b. Slump Test
c. Compaction Tests,
d. Flow Tests,
e. Remolding Tests, and
f. Miscellaneous Tests.

Among the aforementioned categories of workability measures only slump test will be reviewed and used as workability measuring test on this research.

2.4.1.1 Slump Test

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to rapidly determine whether a concrete batch should be accepted or rejected. The test method is widely standardized throughout the world, including in ASTM C143/C143M in the United States and EN12350-2 in Europe (European Committee for Standardization 2000a).

Four types of slumps are commonly encountered, as shown in Fig. 2.2 **[22].** The only type of slump permissible under ASTM C143/C143M is frequently referred to as the true slump, where the concrete remains intact and retains asymmetric shape. A zero slump and a collapsed slump are both outside the range of workability that can be measured with the slump test. Specifically, ASTM C143/C143M advises caution in interpreting test results less than 15 mm (1/2 in.) and greater than 230 mm (9 in). If part of the concrete shears from the mass, the test should be repeated with a different sample of concrete. A concrete that exhibits a shear slump in a second test is not sufficiently cohesive, and should be rejected.

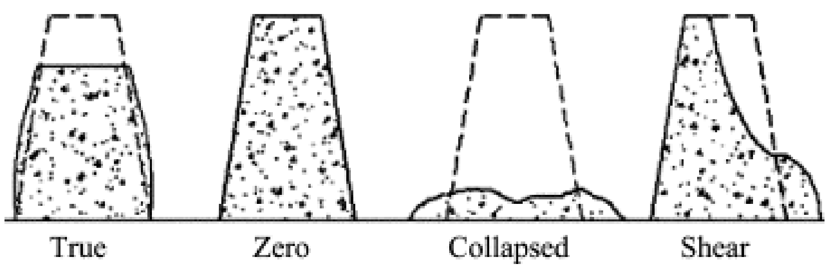

Fig.2.2 Four types of slump

2.4.2 Test for Compressive Strength

The most common test carried out on concrete is the compressive strength test. There are several reasons for this:

a. It is commonly assumed that most of the important properties of concrete are directly related to the compressive strength;

b. Since concrete has very little tensile strength, it is used primarily in a compressive mode, and therefore it is the compressive strength that is important in engineering practice;
c. The structural design codes are based mainly on the compressive strength of concrete; and
d. The test is easy and relatively inexpensive to carry out.

On this research to identify the compressive strength test of the concrete 150mm cube is used.

Chapter Three---Questionnaire Analysis

To achieve the objective of this research a questionnaire was developed and distributed to be filled by professionals in building construction industry in Addis Ababa. Their responses were analyzed and presented as follows.

3.1. Response Rate of Questionnaire

The following table 3.1 shows questionnaire response rate of the distributed questionnaires.

Table 3.1:- Questionnaire response rate

	Questionnaire Distributed	Collected Questionnaire	Response Rate
Number	200	134	66.5%
Level of Confidence:	90%	85%	
Margin of Error:	5%	5.6%	

The targeted populations, to whom the questionnaires were distributed, were engineers working in various building construction companies in Addis Ababa. According to the Ministry of Urban Development, Housing and Construction the number of building contractors in Addis Ababa are estimated to be around 775.The number of questionnaires to be distributed was determined by using sampling excel (annex 2) based on the required level of confidence and margin of error needed to be achieved. Then using this level of confidence (90%) and margin of error (5%) were determined. After the questionnaires were collected with the response rate of 66.5% the level of confidence and margin of error was re-determined from the number of questionnaires actually collected (i.e. 134). Consequently, the level of confidence and margin of error reduced to 85% and 5.68% respectively.

3.2. Method of Data Analysis

Mean Score (MS) value was calculated using the equation shown below.

$$MS = \sum \{(f * S) \div N\}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \{Eq. 3.1\}$$

Where:

- F = frequency of responses to each rating
- S = Score given to each factor
- N = the total number of responses concerning the factor

For analyzing the response from the questionnaire the mean score value of respondents' responses were determined. The mean score tells us where the center of the data set is. Once the mean score is calculated the center of the data can be selected based on the scale shown in table 3.2 below. **[13]**

Table 3.2:- Rating Scale

Rating Scale(the score given to each possible choice)	Mean Score Scale
$0.00 \leq MS < 1.50$	1
$1.50 \leq MS < 2.50$	2
$2.50 \leq MS < 3.50$	3
$3.50 \leq MS < 4.50$	4
$4.50 < MS < 5.50$	5

3.3. Results and Analysis of Questionnaire Response

Level of experience of respondents:

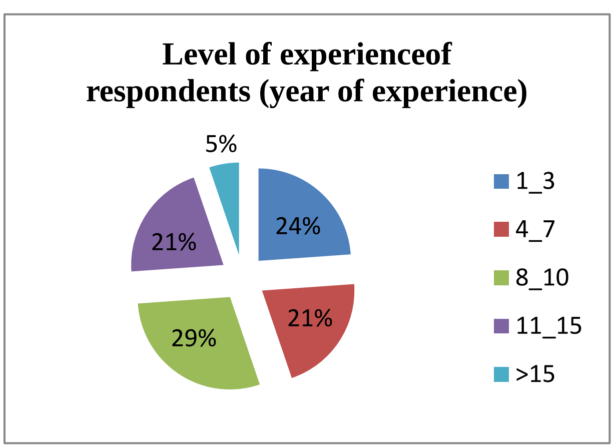

Figure 3.1: Level of experience of Respondents (Year of Experience)

Grade of concrete mostly produced in Addis Ababa

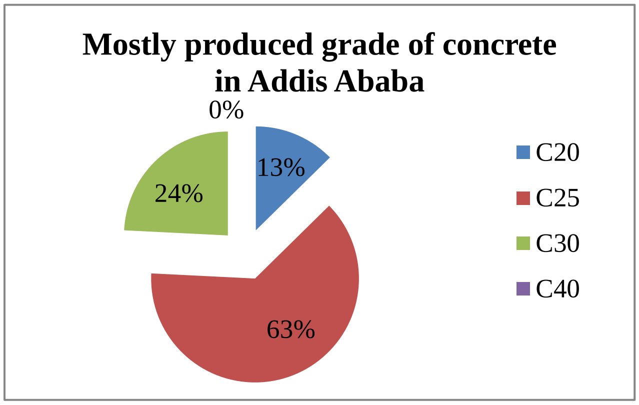

Figure 3.2: Mostly produced grade of concrete in Addis Ababa

Analysis: Majority of the respondents agreed that mostly produced grade of concrete is C25.

MS = 2.12, *(Score given: C20 = 1,* ***C= 25 = 2****, C30 = 3, C40 = 4)*

Type of cement mostly used to produce the specified type of concrete

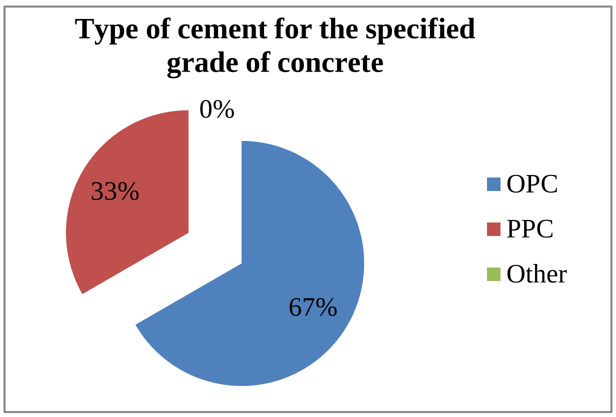

Figure 3.3: Type of cement used to produce the specified type of concrete

Analysis: Majority of the respondent agreed that mostly used type of cement for the specified grade of concrete is OPC.

MS = 1.33, *(Score given:* ***OPC= 1****, PPC = 2, Other = 3)*

Majority of the respondents agreed that OPC is the mostly used type of cement for the specified grade of concrete. The main reason is that OPC gets its strength early than PPC and also sometimes in the contract document the consultants force the contractors to use OPC for structural works.

Mix design method mostly used for concrete production

Respondents mentioned the following as the most frequently used methods of mix design.

- ACI
- EBCS
- From past experience
- By conducting trial mix

The majority (75%) of the respondents replied that they adopt EBCS as a mixing design method. On the other hand some (13%) of the respondents mentioned that they adopt conducting trial mix as a mix design method. The remaining (7% and 5%) respondents replied that they implement ACI and from their past experience to design the mix respectively.

This result indicates EBCS is mostly used standard in Ethiopia.

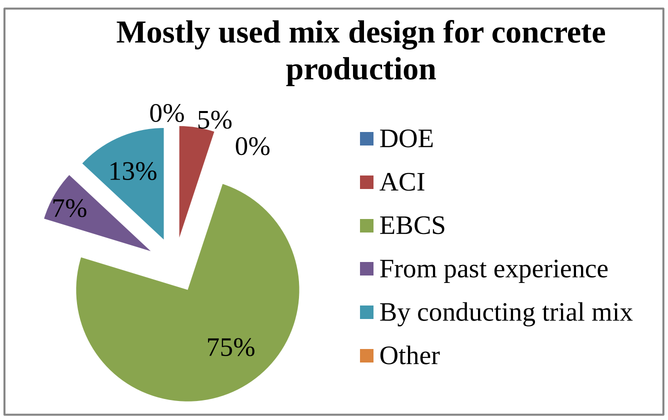

Figure 3.4: Mix design method used to produce concrete

Analysis: Majority of the respondents agreed mostly used mix design method is EBCS.

MS = 3.28, *(Score given: DOE=* ***1****, ACI = 2,* ***EBCS = 3****, From past experience=4, By conducting trial mix=5, Other=6)*

Variation of mix design when there is variation on constituent materials of concrete.

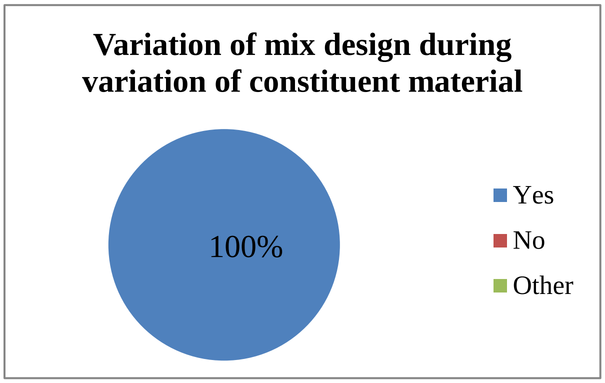

Figure 3.5: Variation of mix design during variation of constituent material

Analysis: All the respondents agreed that as the constituent materials change the mix design varies.

All of the respondents agreed that the mix design of the concrete varies when the source of constituent materials vary. As per the respondents said to vary the mix design first the new material samples send to the laboratory for characterizing its properties then as per the test result redesigning of mix will be done.

Type of tests conducted for aggregate quality control

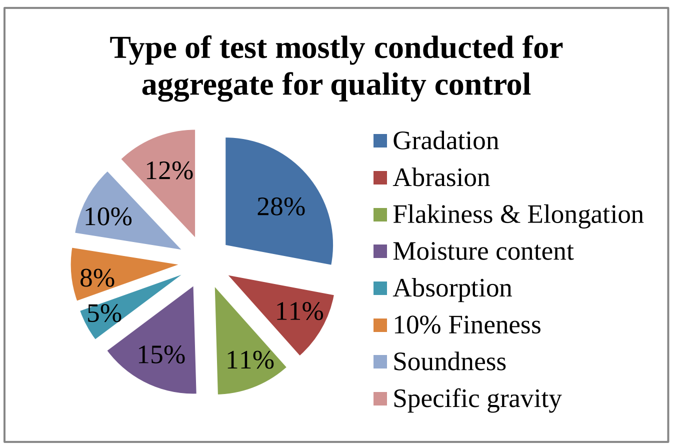

Figure 3.6: Type of test mostly conducted for aggregate quality control

Analysis: Most of the respondents agreed mostly conducted test for quality control of aggregate is gradation.

Type of tests conducted for Sand quality control

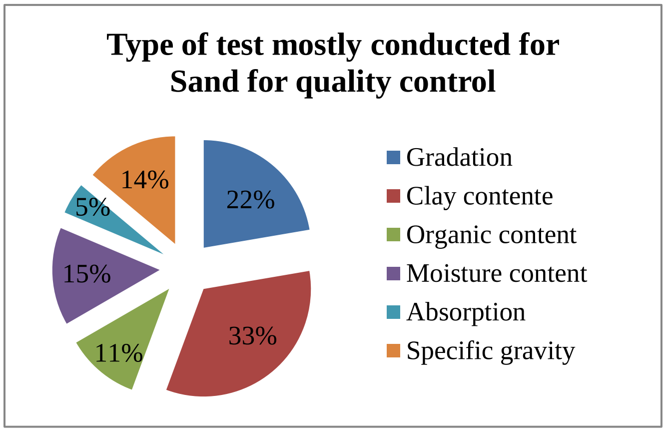

Figure 3.7: Type of test mostly conducted for sand quality control

Analysis: Most of the respondents agreed mostly conducted test for quality control of sand is clay content.

Type of tests conducted for Cement quality control

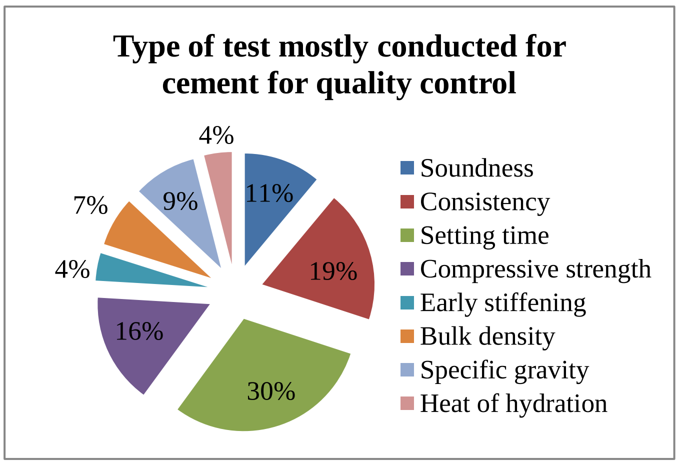

Figure 3.8: Type of test mostly conducted for cement for quality control

Analysis: Most of the respondents agreed that mostly conducted test for quality control is setting time.

The respondents said that those tests are done when request comes from the consultants and also when the cement comes from different factory. Those tests are done by outsourcing to the consultants in there laboratory.

Type of tests conducted on the Concrete quality control

Respondents mentioned the following as the type of test mostly conducted for concrete quality control.

- Compressive strength
- Slump
- Temperature measure

Most of the respondents agreed that compressive strength and slump are the two mostly conducted tests for quality control. A few of respondents agreed that temperature measure is the other test done for quality control of concrete.

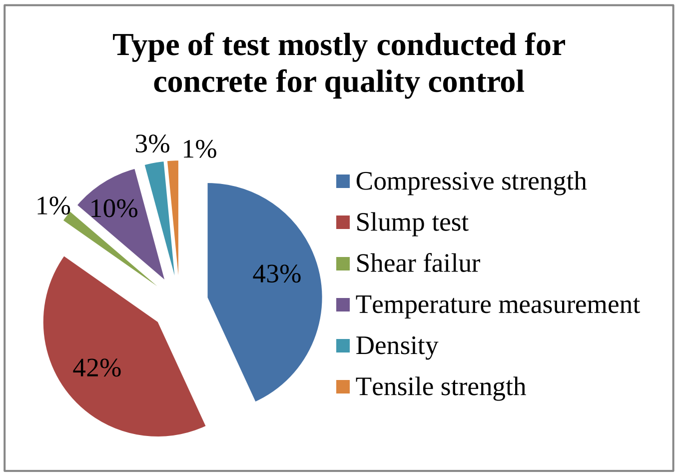

Figure 3.9: Type of test mostly conducted for concrete for quality control

Analysis: Most of the respondents agreed that mostly conducted test for quality control of concrete is compressive strength and slump.

MS = 1.88, *(Score given: **Compressive strength = 1, Slump test = 2**, Shear failure = **3**, Temperature measurement=4, Density=5, Tensile strength =6)*

Frequency of concrete sampling per story mostly taken for quality control

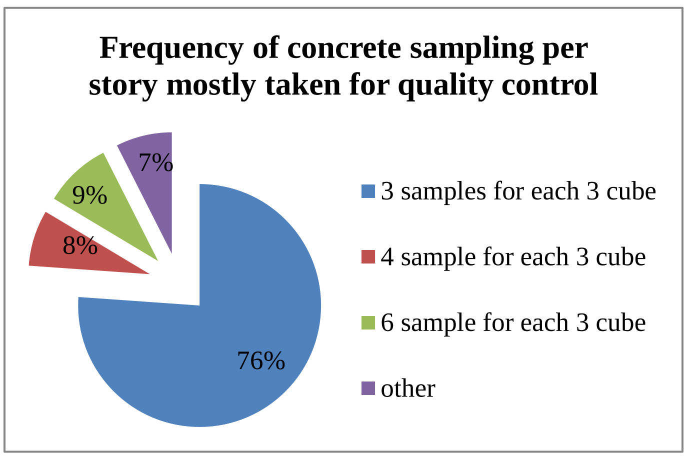

Figure 3.10: Frequency of concrete sampling per story mostly taken for quality control

Analysis: Most of the respondents agreed that mostly concrete samples taken for quality control is 3 samples per story from mixed concrete.

MS = 1.48, *(Score given: **3 sample = 1**, 4sample = 2, 6 sample = **3**, Other=4)*

Those respondents who use ready mixed concrete, they take samples for every 50m3 of concrete produced and also for each structural element.

Uniformity of test result for the tests made on the produced concrete

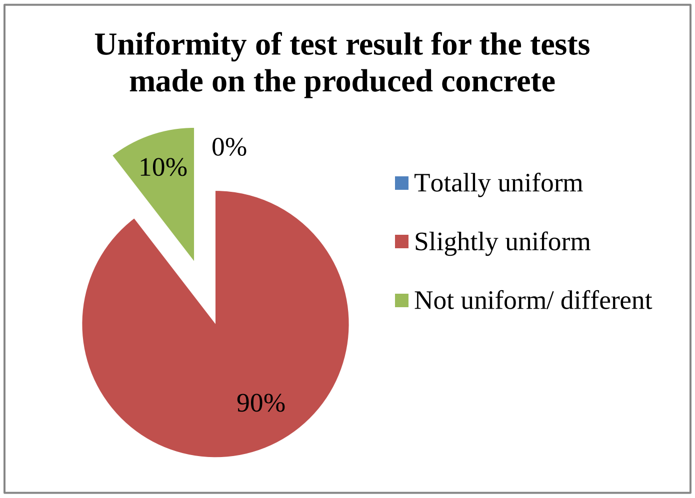

Figure 3.11: Uniformity of test result for the tests made on the produced concrete

Analysis: Majority of the respondent agreed that the result of tests made from concrete produced is sometimes uniform (sometimes uniform sometimes not uniform).

MS = 2.10, *(Score given: Totally uniform = 1,* ***Sometimes uniform = 2****, Not uniform = 3, Other=4)*

Properties of concrete that are mostly affected by variation or inconsistency of raw materials

Almost all of the respondents agreed that compressive strength and workability is affected by variation of construction raw materials. This response indicates the importance of making this research.

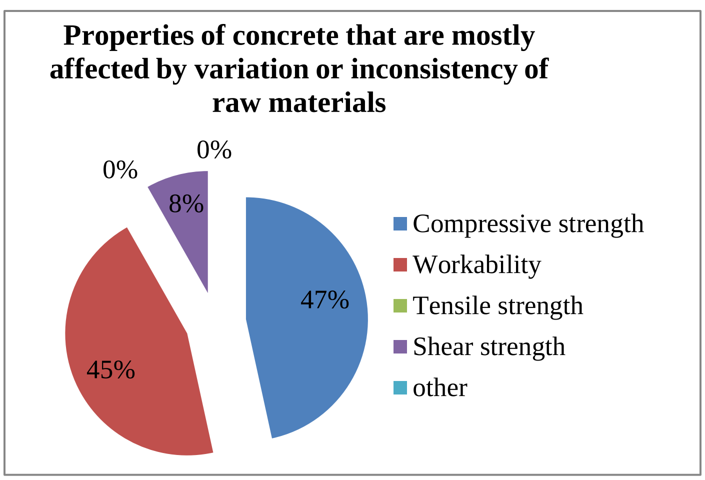

Figure 3.12: Properties of concrete that are mostly affected by variation or inconsistency of raw materials

Analysis: Majority of the respondents agreed that among properties of concrete mostly affected by variation or inconsistency of concrete are compressive strength and workability (slump).

MS = 1.61, *(Score given:* ***Compressive strength = 1, Workability = 2****, Tensile strength = 3, Shear strength=4, Other = 5)*

The objective of this research was to evaluate the uniformity of concrete properties. So as to understand the overall concrete production processes and precautions taken questionnaire were developed. Most of the respondents respond for question number 13 of the questionnaires are the uniformity of concrete properties are sometimes uniform and for question 14 of the questionnaires are the following list of causes for variation of concrete properties.

a) Improper mix of concrete, segregation and also improper vibration of concrete.
b) Variation of water to cement ratio.
c) Error in conducting tests
d) Sampling and testing machine problem
e) Constituent material variation
f) The quality of material varies among different production sources.
g) Workmanship problem
h) Curing time difference

The above mentioned causes for non-uniformity of concrete properties have impact on the properties of concrete and also on the service life of the concrete structure.

Chapter Four---Case Study on Three Ongoing Building Construction Projects

The field test conducted on selected on-going project sites were slump test. The numbers of tests done at different times in a day were five (5). A total of fifteen (15) slump tests were done on different site from the produced concrete.

The technique adopted was to conduct laboratory tests which entailed collection of concrete samples from selected on-going project sites into available 150mm square metal cube molds. The numbers of selected on-going projects were three (3) and from each project a total of four (4) samples were taken at different time, on each sampling six (6) cubes were taken for seven (7) days and twenty eight (28) days test. These were cured and tested in the laboratory to determine their compressive strength. A total of seventy two (72) cubes 150mm x 150mm x 150mm concrete molds were casted, cured and tested at different time in a day.

4.1.Tolerances in Slump

According to ASTM C 94 / C 94M, the tolerance in slump, unless other tolerances are included in the project specifications, the following shall apply.

- When the project specifications for slump are written as a “maximum” or “not to exceed” requirement. Table 4.1 shows tolerance in slump.

Table 4.1:- *Tolerance in slump (case 1)*

Tolerance	Specified slump:	
	If 3 in. [75 mm] or less	**If more than 3 in. [75 mm]**
Plus tolerance	0	0
Minus tolerance	11⁄2 in. [40 mm]	21⁄2 in. [65 mm]

- When the project specifications for slump are not written as a “maximum” or “not to exceed” requirement. Table 4.2 shows tolerance in slump.

Table 4.2:- *Tolerance in slump (case 2)*

Tolerances for Nominal Slumps	
For Specified Slump of	**Tolerance**
2 in. [50 mm] and less	±½ in. [15 mm]
More than 2 through 4 in. [50 to 100 mm]	±1 in. [25 mm]
More than 4 in. [100 mm]	±1½ in. [40 mm]

4.1.1. Results obtained from slump test done on site

I. Site one

The following table 4.3 shows the slump test result of site one (Grade 3 contractors). The second column shows the specified slump value for that specified contract document, the third column shows the result obtained from field test results and the last column shows the percentage given to each test results.

Table 4.3:- *Slump result of site one*

No.	Specified Slump (A) in mm	Result (B) in mm	Difference (B-A) in mm
1.	50	80	30
2.		70	20
3.		60	10
4.		80	30
5.		80	30

The above table shows the slump result obtained from the site work. As per ASTM C 94 / C94M, the tolerable slump variation is ± 15mm for ≤50mm specified slump. However, as shown in table 4.3 the results obtained are more than the tolerable limit. The difference of the result and specified slump value shows the concrete mix done on site one is not uniform.

Out of the five test result four of them are beyond the tolerance in slump, out of the four results three of them are excessively beyond the tolerance in slump. This indicates the amount of water added to the mix is in excess. This leads the compressive strength of concrete will be reduced. Reduction of compressive strength will have considerable impact on the service time of building elements.

On site addition of water done simply by observation of the mix workability this shows the personnel who work on site are layman. The practical situation shows proper site supervision not done in accordance with the standards.

II. Site two

The following table 4.4 shows the slump test result of site two (Grade 5 contractors). The second column shows the specified slump value for that specified contract document, the third column shows the result obtained from field test results and the last column shows the percentage given to each test results.

Table 4.4:- *Slump result of site two*

No.	Specified Slump (A) in mm	Result (B) in mm	Difference (B-A) in mm
1.	50	80	30
2.		70	20
3.		80	30
4.		80	30
5.		70	20

The above table shows the slump result obtained from the site work. As per ASTM C 94 / C94M, the tolerable slump variation is ± 15mm for ≤50mm specified slump. However, as shown in table 4.4 the results obtained are more than the tolerable limit. This indicates the concrete produced on site two are not uniform.

All of the results are beyond the tolerance in slump; out of it three of them are excessively beyond the tolerance in slump. This indicates the amount of water added to the mix is excess this leads the compressive strength of concrete will reduce. Reduction of compressive strength will have considerable impact on the service time of building elements.

On site the mismatch of water proportion with other concrete ingredients are observed. This was due to the fact that the laborers add water simply by observation of the mix. This is as a result of lack of awareness and wrong approach to simplify the workability of the concrete. In short, there was very limited site supervision done by the consultant to monitor the site.

III. Site three

The following table 4.5 shows the slump test result of site one (Grade 1 contractors). The second column shows the specified slump value for that specified contract document, the third column shows the result obtained from field test results and the last column shows the percentage given to each test results.

Table 4.5:- *Slump result of site three*

No.	Specified Slump (A) in mm	Result (B) in mm	Difference (B-A) in mm
1.	80	160	80
2.		100	20
3.		160	80
4.		150	70
5.		150	70

The above table shows the slump result obtained from the site work. As per ASTM C 94 / C94M, the tolerable slump variation is ± 25mm for specified slump between 50mm and 100mm. However, as shown in table 4.5 the results obtained are more than the tolerable limit even it is doubled from the required slump value. This indicates the concrete produced on site three is also not uniform.

All of the results are beyond the tolerance in slump; out of it four of them are excessively beyond the tolerance in slump. This indicates the amount of water added to the mix is excess this leads the compressive strength of concrete will reduce. Reduction of compressive strength will have considerable impact on the service time of building elements.

In a similar fashion as the other two sites, the observation I made in this site during my visit was also misconfiguration of the amount of water mix with the other concrete ingredients. This again is attributed to the addition of water to the mix is simply by observation of the mix. These show that the laborers are layman and there is strong limitation on site supervision.

4.2.Acceptable Range for Coefficient of Variation of Compressive Strength

The laboratory finding of compressive strength result is going to be discussed according to ASTM C39 / C39M-9a and ACI 214R-02 of acceptable range of coefficient of variation for compressive strength.

4.2.1. According to ASTM C39 / C39M-9a

As per ASTM C39 / C39M - 9a, it says the within-test coefficient of variation represents the expected variation of measured strength of companion cylinders prepared from the same sample of concrete and tested by one laboratory at the same age.

The following table4.6 provides the within-test precision of tests of 150 by 300 mm [6 by 12in.] and 100 by 200 mm [4 by 8 in.] cylinders made from a well-mixed sample of concrete under laboratory conditions and under field conditions.

The values given for the within-test coefficient of variation of 150 by 300mm cylinders are applicable for compressive strengths between 15-55MPa and those for 100-200mm cylinder are applicable for compressive strength between 17-32MPa.

Table 4.6:- Acceptable Range of Individual Cylinder Strengths

	Coefficient of Variation	Acceptable Range of Individual Cylinder Strengths	
		2 cylinders	3 cylinders
150 by 300 mm [6 by 12 in.]			
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	***2.9 %***	8.0 %	***9.5 %***
100 by 200 mm [4 by 8 in.]			
Laboratory conditions	3.2 %	9.0 %	10.6 %

The following steps are used to analyze the result of compressive strength test executed in the laboratory.

Step 1:-Equivalent value of strength for cylinder test is calculated as: value of compressive strength for cube test divided by 1.25.

Step 2:- Standard deviation of the samples is calculated using the formula

$$\sigma = \sqrt{\frac{\sum(Y-\bar{y})^2}{n-1}}, \text{-- [Eq. 4.1]}$$

Where: Y – Compressive strength value of each sample;
$\bar{y}$ – Average value of the samples;
n – Number of samples

Step 3:-Coefficient of variation is calculated by dividing the standard deviation by the average value of the samples.

Step 4:- Then comparing calculated coefficient of variation with the acceptable range and concluding whether the concrete produced is consistent or inconsistent.

4.2.2. According to ACI 214R-02

Inevitably, strength test results vary. Variations in measured strength may originate from any of the following sources:

- *Batch-to-batch variations* of the proportions and characteristics of the constituent materials in the concrete, the production, delivery, and handling process, and climatic conditions; and
- *Within-test variation* is variations in the sampling, specimen preparation, curing, and testing procedures.
- *Overall variation* σ (for a population) or s (for a sample), has two component variations, the within-test, σ_1 (population) or s_1 (sample), and batch-to-batch, σ_2 (population) or s_2 (sample) variations. The overall variation can be computed as:

$$s^2 = s_1^2 + s_2^2 \text{--- [Eq.4.2]}$$

The following table 4.7 provides the overall variation of tests made from a well-mixed sample of concrete under laboratory conditions and under field conditions. The values given for the overall variation of standard deviations are applicable for compressive strengths $f_c' \leq 34.5$ MPa.

Table 4.7: Standard deviation for different control standards, MPa

Overall variation					
Class of operation	Standard deviation for different control standards, MPa				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 2.8	2.8 to 3.4	3.4 to 4.1	4.1 to 4.8	Above 4.8
Laboratory trial batches	Below 1.4	1.4 to 1.7	1.7 to 2.1	2.1 to 2.4	Above 2.4

The following table 4.8 provides the within-test variation of tests made from a well-mixed sample of concrete under laboratory conditions and under field conditions. The values given for the within-test variation of coefficient of variations are applicable for compressive strengths $f_c' \leq 34.5$ MPa.

Table 4.8: Coefficient of variation for different control standards, %

Within-test variation					
Class of operation	Coefficient of variation for different control standards, %				
	Excellent	Very good	Good	Fair	Poor
Field control testing	Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Laboratory trial batches	Below 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	Above 5.0

According to the above two standards the compressive strength test result will be evaluated and discussed.

4.3. Results obtained from the compressive strength test conducted on the samples taken from the selected building construction sites

4.3.1. Seven days compressive strength cube tests

On the three selected sites the grade of concrete used was C25. Accordingly, the following test results show the compressive strength test for C25 grade of concrete. The tables below show the test results obtained from 7 days compressive strength cube test of each site. The 7-day test result is used to monitor early strength gain and is often estimated to be about 75% of the 28-day strength **[3].** Concrete, by Mindness and Young, gives a general rule: The ratio of 28-day to seven-day strength lies between 1.3 and 1.7 and generally is less than 1.5, or the seven-day strength is normally between 60% to 75% of the 28-day strength and usually above 65%. From the above literature the 7days compressive strength test estimated to be 65% up to 70%of the specified value of compressive strength. Therefore, the test result of each sample estimated to range from 16.25 to 17.50MPa (which is equivalent to the cylinder compressive strength test value of 13-14MPa).

I. Site One

Site one is a grade three building contractor. The following tables (i.e. from 4.9a up to 4.9d) show the compressive strength test results and their analysis for the concrete samples taken from site one at different times.

a. Sample One

***Table 4.9a**:- 7days compressive strength test results of sample one taken from site one*

<table>
<tr><th rowspan="2">No.</th><th colspan="2">Date</th><th rowspan="2">Age in days</th><th>Unit weight</th><th>Weight</th><th>Compressive strength for cube test</th><th>Equivalent value of strength for cylinder test</th><th>Standard deviation (MPa)</th><th>Coefficient of variation (%)</th></tr>
<tr><th>Sampled</th><th>Tested</th><th>Kg/m3</th><th>kg</th><th>MPa</th><th>MPa</th><th>SD</th><th>CV</th></tr>
<tr><td>1</td><td>3/1/2015</td><td>10/1/2015</td><td>7</td><td>2329.26</td><td>7.86</td><td>12.3</td><td>9.84</td><td rowspan="2">0.97</td><td rowspan="2">10.35</td></tr>
<tr><td>2</td><td>3/1/2015</td><td>10/1/2015</td><td>7</td><td>2361.88</td><td>7.97</td><td>10.3</td><td>8.24</td></tr>
<tr><td>3</td><td>3/1/2015</td><td>10/1/2015</td><td>7</td><td>2355.76</td><td>7.95</td><td>12.48</td><td>9.98</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Average</td><td>11.69</td><td>9.35</td><td></td><td></td></tr>
</table>

As can be seen in the above table, the average 7days compressive strength test result is 11.69MPa.This indicates that the average value of the 7days compressive strength test result of sample one (taken from site one) is below the expected compressive strength. This variation from the expected value will have a significant adverse impact on the service life of the structure.

b. Sample Two

***Table 4.9b**:- 7days compressive strength test results of sample two taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	3/1/2015	10/1/2015	7	2470.95	8.34	25.17	20.14	***1.33***	***7.11***
2	3/1/2015	10/1/2015	7	2461.77	8.31	21.84	17.47		
3	3/1/2015	10/1/2015	7	2421.00	8.17	23.33	18.66		
				Average		***23.45***	***18.76***		

As depicted in the above table, the average value of compressive strength test result for sample two of site one is 23.45MPa. This value is above the expected 7days compressive strength test result. However, this does not mean that the compressive strength of concrete is uniform.

c. Sample Three

***Table 4.9c**:- 7days compressive strength test results of sample three taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	17/01/15	24/01/15	7	2396.53	8.09	16.89	13.51	***0.71***	***5.04***
2	17/01/15	24/01/15	7	2444.44	8.25	17.22	13.78		
3	17/01/15	24/01/15	7	2456.68	8.29	18.56	14.85		
				Average		***17.56***	***14.05***		

As depicted in the above table, the average value of compressive strength test result for sample three of site one is 17.56MPa. This value is above the expected 7days compressive strength test result. However, this does not mean that the compressive strength of concrete is uniform.

d. Sample Four

***Table 4.9d**: -7days compressive strength test results of sample four taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	17/01/15	24/01/15	7	2370.03	8	13.2	10.56	***1.27***	***11.83***
2	17/01/15	24/01/15	7	2299.69	7.76	15.05	12.04		
3	17/01/15	24/01/15	7	2355.76	7.95	11.9	9.52		
				Average		***13.38***	***10.71***		

As can be seen in the above table, the average value of compressive strength test result for sample four of site one is 13.38MPa. This value is below the expected 7days compressive strength test result.

II. Site Two

Site two is contracted by grade five building contractor. The following tables (i.e. from 4.10a up to 4.10d) show the compressive strength test results and the analysis for the concrete samples taken from site two at different time.

a. Sample One

***Table 4.10a:**- 7days compressive strength test results of sample one taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	29/01/15	5/2/2015	7	2506.63	8.46	16.82	13.46	***0.93***	***6.45***
2	29/01/15	5/2/2015	7	2483.18	8.38	18.04	14.43		
3	29/01/15	5/2/2015	7	2497.45	8.43	19.14	15.31		
				Average		***18***	***14.40***		

As can be seen in the above table, the average 7days compressive strength test result is 18MPa. This indicates that the average value of the 7days compressive strength test result of sample one (taken from site two) is above the expected compressive strength.

b. Sample Two

Table 4.10b:*-7days compressive strength test results of sample two taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	29/01/15	5/2/2015	7	2494.39	8.42	18.56	14.85	***0.93***	***6.32***
2	29/01/15	5/2/2015	7	2512.74	8.48	17.07	13.66		
3	29/01/15	5/2/2015	7	2515.80	8.49	19.35	15.48		
				Average		***18.33***	***14.66***		

As depicted in the above table the average value of compressive strength test result for sample two of site two is 18.33MPa. This value is above the expected 7days compressive strength test result. However, this does not mean that the compressive strength of concrete is uniform.

c. Sample Three

Table 4.10c:*- 7days compressive strength test results of sample three taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	29/01/15	5/2/2015	7	2545.36	8.59	12.05	9.64	***0.32***	***3.20***
2	29/01/15	5/2/2015	7	2435.27	8.22	12.8	10.24		
3	29/01/15	5/2/2015	7	2477.06	8.36	12.67	10.14		
				Average		***12.51***	***10.01***		

As can be seen in the above table, the average 7days compressive strength test result is 12.51MPa. This indicates that the average value of the 7days compressive strength test result of sample three (taken from site two) is below the expected compressive strength. This variation from the expected value will have a significant adverse impact on the service life of the structure.

d. Sample Four

Table 4.10d: *-7days compressive strength test results of sample four taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	29/01/15	5/2/2015	7	2343.53	7.91	10.59	8.47	***0.99***	***10.87***
2	29/01/15	5/2/2015	7	2337.41	7.89	10.68	8.54		
3	29/01/15	5/2/2015	7	2396.53	8.09	12.77	10.22		
				Average		***11.35***	***9.08***		

As depicted in the above table, the average 7days compressive strength test result is 11.35MPa. This indicates that the average value of the 7days compressive strength test result of sample four (taken from site two) is below the expected compressive strength.

III. Site Three

Site three is contracted by grade one building contractor. The following tables (i.e. from 4.11a up to 4.11d) show the compressive strength test results and there analysis for the sample of concrete taken at different time.

a. Sample One

Table 4.11a: *- 7days compressive strength test results of sample one taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	30/01/15	6/2/2015	7	2361.88	7.97	8.95	7.16	***0.06***	***0.90***
2	30/01/15	6/2/2015	7	2379.20	8.03	9.09	7.27		
3	30/01/15	6/2/2015	7	2391.44	8.07	8.95	7.16		
				Average		***9***	***7.20***		

From the above table the average of the compressive strength of 7dayscompressive strength test result is 9MPa, this value indicate that the concrete compressive strength of sample one (taken from site three) is below expected 7days test result.

b. Sample Two

***Table 4.11b: -** 7days compressive strength test results of sample two taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	30/01/15	6/2/2015	7	2382.26	8.04	10.77	8.62	***0.70***	***8.95***
2	30/01/15	6/2/2015	7	2373.09	8.01	9.36	7.49		
3	30/01/15	6/2/2015	7	2320.08	7.83	9.17	7.34		
				Average		***9.77***	***7.81***		

As seen in the above table the average value of 7days compressive strength test result of sample two (taken from site three) is 9.77MPa. This value is less than the expected 7days concrete compressive strength.

c. Sample Three

***Table 4.11c:** 7days compressive strength test results of sample three taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	30/01/15	6/2/2015	7	2388.38	8.06	9.74	7.79	***0.41***	***5.16***
2	30/01/15	6/2/2015	7	2370.03	8	10.59	8.47		
3	30/01/15	6/2/2015	7	2382.26	8.04	9.66	7.73		
				Average		***10***	***8.00***		

As shown the above table the average concrete compressive strength of 7days test result of sample three of site three is 10MPa.This indicates that the average value of the 7days compressive strength test result of sample three (taken from site three) is below the expected compressive strength.

d. Sample Four

Table4.11d: - *7days compressive strength test results of sample four taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m 3	kg	MPa	MPa	SD	CV
1	30/01/15	6/2/2015	7	2379.20	8.03	10.08	8.06	***0.31***	***3.94***
2	30/01/15	6/2/2015	7	2385.32	8.05	9.39	7.51		
3	30/01/15	6/2/2015	7	2362.90	7.975	10.04	8.03		
				Average		***9.96***	***7.87***		

As depicted in the above table the average value of 7days concrete compressive strength test result is 9.96MPa. This value indicates that the concrete 7days compressive strength test result is below the expected compressive strength in 7days.

4.3.2. Twenty eight days compressive strength cube tests

The following tables show the test results obtained for compressive strength cube test after 28 days for each site. From the cube test result the expected outcome is 25MPa (equivalent cylinder test value of 20MPa).

I. Site One

a. Sample One

Table4.12a: - *28dayscompressive strength test results of sample one taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	3/1/2015	31/01/15	28	2398.57	8.1	16.99	13.59	***1.34***	***8.85***
2	3/1/2015	31/01/15	28	2297.66	7.76	19.94	15.95		
3	3/1/2015	31/01/15	28	2329.26	7.86	19.84	15.87		
				Average		***18.92***	***15.14***		

As can be seen from the above table the average value of 28days concrete compressive strength test result is 18.92MPa. This value indicates that the 28days concrete compressive strength below the value of the specified grade of concrete.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.12a the coefficient of variation (i.e. 8.85%) obtained from sample one of Site one is beyond the coefficient of variation. This value indicates that the concrete mix is not uniform.

As shown in the above table 4.12a the coefficient of variation is 8.85% which is, according to ACI214R-02, above 6% classified as poor concrete control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

b. Sample Two

***Table 4.12b:** -28dayscompressive strength test results of sample two taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	3/1/2015	31/01/15	28	2370.03	8	21.8	17.44	***1.77***	***10.13***
2	3/1/2015	31/01/15	28	2334.35	7.88	24.05	19.24		
3	3/1/2015	31/01/15	28	2364.93	7.98	19.63	15.70		
				Average		***21.83***	***17.46***		

As can be seen in the above table, the average value of concrete28days compressive strength test result is 21.83MPa.This value indicates that the 28days concrete compressive strength below the value of the specified grade of concrete.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.12b the coefficient of variation (i.e. 10.13%) obtained from sample two (taken from site one) is more than the specified coefficient of variation. This indicates that the concrete mix is not uniform.

As shown in the above table 4.12b the coefficient of variation is 10.13% which is, according to ACI 214R-02, above 6% classified as poor concrete control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

c. Sample Three

Table 4.12c:*28dayscompressive strength test results of sample three taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	17/01/15	14/02/15	28	2414.88	8.15	35.49	28.39	***2.89***	***11.09***
2	17/01/15	14/02/15	28	2492.35	8.41	28.55	22.84		
3	17/01/15	14/02/15	28	2415.90	8.16	33.77	27.02		
				Average		***32.6***	***26.08***		

As depicted in the above table the average value of 28days compressive strength test result is 32.60MPa. This value indicates that the 28days concrete compressive strength is above the value of the specified grade of concrete.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.12c the coefficient of variation (i.e. 11.09%) obtained from sample three of site one is more than the specified coefficient of variation. However, the concrete performance is more than expected which means the concrete is stronger than the expected. However, the coefficient of variation indicates that the concrete mix is not uniform.

As shown in the above table 4.12c the coefficient of variation is 11.09% which is, according to ACI 214R-02, above 6%it means the concrete mix is in a poor concrete control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

d. Sample Four

Table 4.12d: *28days**c**ompressive strength test results of sample four taken from site one*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	17/01/15	14/02/15	28	2435.27	8.22	18.44	14.75	***0.46***	***3.08***
2	17/01/15	14/02/15	28	2483.18	8.38	19.52	15.62		
3	17/01/15	14/02/15	28	2454.64	8.29	18.61	14.89		
				Average		***18.86***	***15.09***		

As can be seen in the above table the average value of 28days concrete compressive strength test result is 18.86MPa. This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as seen in the table 4.12d the coefficient of variation (i.e. 3.08%) obtained from sample four (taken from site one) is greater than the coefficient of variation by only 0.18%. This concrete is somehow near to uniformity but the concrete is not uniform.

As shown in the above table 4.12b the coefficient of variation is 3.08% which is, according to ACI 214R-02, in between 3 to 4% it means the concrete mix is in a very good control. This value indicates that concrete mix is uniform.

II. Site Two

a. Sample One

***Table4.13a:** - 28dayscompressive strength test results of sample one taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	29/01/15	26/02/15	28	2382.26	8.04	18.76	15.01	***1.38***	***8.67***
2	29/01/15	26/02/15	28	2346.59	7.92	21.8	17.44		
3	29/01/15	26/02/15	28	2394.50	8.08	18.89	15.11		
				Average		***19.82***	***15.85***		

As depicted in the above table the average value of 28 days concrete compressive strength test result is 19.82MPa. This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as can be seen in table 4.13a the coefficient of variation (i.e. 8.67%) obtained from sample one of site two is beyond the specified coefficient of variation. Which means the concrete mix is not uniform.

As shown in the above table 4.13a the coefficient of variation is 8.67% which is, according to ACI 214R-02, above 6% it means the concrete mix is in a poor control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

b. Sample Two

***Table4.13b:** - 28dayscompressive strength test results of sample two taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m^3}$	kg	MPa	MPa	SD	CV
1	29/01/15	26/02/15	28	2506.63	8.46	25.23	20.18	***2.32***	***10.19***
2	29/01/15	26/02/15	28	2459.73	8.3	29.37	23.50		
3	29/01/15	26/02/15	28	2447.50	8.26	30.82	24.66		
				Average		***28.47***	***22.78***		

As shown in the above table the average value 28days concrete compressive strength test result is 28.47MPa. This value indicates that the 28days concrete compressive strength is above the specified value of compressive strength. This shows the strength is above the design value.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.13b the coefficient of variation (i.e. 10.19%) obtained from sample two (taken from site two) is more than specified coefficient of variation. However, the concrete performance is more than the design value. But the coefficient of variation indicates that the concrete mix is not uniform.

As shown in the above table 4.13b the coefficient of variation is 10.19% which is, according to ACI 214R-02, above 6% it means the concrete mix is in a poor control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

c. Sample Three

***Table 4.13c:** 28dayscompressive strength test results of sample three taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	29/01/15	26/02/15	28	2509.68	8.47	28.57	22.86	***1.27***	***5.92***
2	29/01/15	26/02/15	28	2477.06	8.36	26.31	21.05		
3	29/01/15	26/02/15	28	2486.24	8.39	25.51	20.41		
				Average		***26.8***	***21.44***		

As can be seen in the above table the average value of 28days concrete compressive strength test result is 26.8MPa. This value indicates that 28days concrete compressive strength is above the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.13c the coefficient of variation (i.e. 5.92%) obtained from sample three (taken from site two) is more than specified coefficient of variation. Even though, the concrete performance is more than expected design value of the concrete, the coefficient of variation indicates that the concrete mix is not uniform.

As shown in the above table 4.13c the coefficient of variation is 5.92% which is, according to ACI 214R-02, 5 to 6% it means the concrete mix is in a fair control.

d. Sample four

***Table 4.13d:** 28dayscompressive strength test results of sample four taken from site two*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	29/01/15	26/02/15	28	2424.06	8.18	20.46	16.37	***0.45***	***2.78***
2	29/01/15	26/02/15	28	2391.44	8.07	20.46	16.37		
3	29/01/15	26/02/15	28	2417.94	8.16	19.49	15.59		
				Average		***20.14***	***16.11***		

As depicted in the above table the average value of 28days concrete compressive strength test result is 20.14MPa. This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. As shown in table 4.13d the coefficient of variation (i.e. 2.78%) obtained from sample four (taken from site two) is less than the specified coefficient of variation. This value indicates that the concrete mix is uniform. Among the four samples taken from site two only sample for shows uniformity of concrete mix.

As shown in the above table 4.13d the coefficient of variation is 2.78% which is, according to ACI 214R-02, below 3% it means the concrete mix is in excellent control of concrete.

III. Site Three

a. Sample One

***Table4.14a:** -28dayscompressive strength test results of sample one taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m3	kg	MPa	MPa	SD	CV
1	30/01/15	27/02/15	28	2382.26	8.04	16.86	13.49	***0.54***	***3.90***
2	30/01/15	27/02/15	28	2402.65	8.11	18.06	14.45		
3	30/01/15	27/02/15	28	2385.32	8.05	16.93	13.54		
				Average		***17.28***	***13.83***		

As shown in the above table the average value of 28days concrete compressive strength test result is 17.28MPa. This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength (design value).

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.14a the coefficient of variation (i.e. 3.9%) obtained from sample one of site three is greater than the specified coefficient of variation. This value indicates that the concrete mix is not uniform.

As shown in the above table 4.14a the coefficient of variation is 3.90% which is, according to ACI 214R-02, in between 3 to 4% it means the concrete mix is in a very good control.

b. Sample Two

***Table4.14b:** -28dayscompressive strength test results of sample two taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m3	kg	MPa	MPa	SD	CV
1	30/01/15	27/02/15	28	2358.82	7.96	19.97	15.98	***1.04***	***6.96***
2	30/01/15	27/02/15	28	2379.20	8.03	17.4	13.92		
3	30/01/15	27/02/15	28	2238.53	8.06	18.42	14.74		
				Average		***18.6***	***14.88***		

As seen in the above table the average value of 28days concrete compressive strength of test result is 18.6MPa.This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength (design value).

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.14b the coefficient of variation (i.e. 6.96%) obtained from sample two of site three is greater than the specified coefficient of variation. This value indicates that the concrete mix is not uniform.

As shown in the above table 4.14b the coefficient of variation is 6.96% which is, according to ACI 214R-02, above 6% it means the concrete mix is in a poor control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

c. Sample Three

***Table 4.14c:** 28dayscompressive strength test results of sample three taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		$^{Kg}/_{m}{}^{3}$	kg	MPa	MPa	SD	CV
1	30/01/15	27/02/15	28	2366.97	7.99	16.69	13.35	***1.71***	***11.24***
2	30/01/15	27/02/15	28	2370.03	8	20.88	16.70		
3	30/01/15	27/02/15	28	2373.09	8.01	19.54	15.63		
				Average		***19.04***	***15.23***		

As depicted in the above table the average value of 28days concrete compressive strength test result is 19.04MPa. This value implies that the 28days concrete compressive strength is below the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as seen in the table 4.14c the coefficient of variation (i.e. 11.24%) obtained from sample three (taken from site three) is beyond the specified coefficient of variation. This value indicates that the concrete mix is not uniform.

As shown in the above table 4.14c the coefficient of variation is 11.24% which is, according to ACI 214R-02, above 6% it means the concrete mix is in a poor control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

d. Sample Four

Table 4.14d: *28dayscompressive strength test results of sample four taken from site three*

No.	Date		Age in days	Unit weight	weight	Compressive strength	Equivalent value of strength for cylinder test	Standard deviation (MPa)	Coefficient of variation (%)
	Sampled	Tested		Kg/m^3	kg	MPa	MPa	SD	CV
1	30/01/15	27/02/15	28	2329.26	7.86	22.43	17.94	***1.86***	***11.70***
2	30/01/15	27/02/15	28	2427.12	8.19	17.95	14.36		
3	30/01/15	27/02/15	28	2421.00	8.17	19.14	15.31		
				Average		***19.84***	***15.87***		

As can be seen in the above table the average value of 28days concrete compressive strength test result is 19.84MPa. This value indicates that the 28days concrete compressive strength is below the specified value of compressive strength.

As per ASTM C39/ C39M – 9a, the coefficient of variation for field condition is 2.9%. If the coefficient of variation less than or equal to 2.9% the sampled concrete is uniform. However, as shown in table 4.14d the coefficient of variation (i.e. 11.7%) obtained from sample four (taken from site three) is beyond the specified coefficient of variation. This value indicates that the concrete is not uniform.

As shown in the above table 4.14d the coefficient of variation is 11.70% which is, according to ACI 214R-02, above 6% it means the concrete mix is in a poor control. This value indicates that the concrete mix varies due to variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens.

4.3.3. The Overall Variation of the Concrete Mix Sampled at Different Days

The following tables show the average value of 28 days compressive strength test results of each site and its overall variation of the concrete mix. According to ACI 214R-02, the overall variation contents both variation within the test result and batch to batch variation. The overall variation of concrete (s) is calculated by using eq. 4.2 for each batch to batch variation and variation within the test.

Table 4.15a:- *Overall variation of concrete compressive strength test result of Site One*

Samples	Averages	Equivalent value of strength for cylinder test	Standard deviation of within test (MPa)	Standard deviation of batch to batch (MPa)	Standard deviation of overall variation (MPa)	Coefficient of variation (%)
	MPa	MPa	SD (s_1)	SD (s_2)	SD (s)	CV
1	18.92	15.14	***1.34***	***5.21***	***5.38***	***28.26***
2	21.83	17.46	***1.77***		***5.50***	
3	32.6	26.08	***2.89***		***5.96***	
4	18.86	15.09	***0.46***		***5.23***	
	23.05	***18.44***				

As depicted in the above table the average value of 28days concrete compressive strength result among the samples are 23.05MPa. This value is below the design value of 28days concrete compressive strength of site one of samples taken at different times and days.

As shown in the above table 4.15a the overall standard deviations of the concrete mix produced in Site one is above 4.8MPa. This value indicates that the control of the concrete mix is poor.

In addition as shown in the above table 4.15a the coefficient of variation of the concrete mix among different samples for the same grade of concrete is very high (i.e. 28.26%). This value shows the concrete mix is not uniform even among the samples.

Table 4.15b:- *Overall variation of concrete compressive strength test result of Site Two*

Samples	Averages	Equivalent value of strength for cylinder test	Standard deviation of within test (MPa)	Standard deviation of batch to batch (MPa)	Standard deviation of overall variation (MPa)	Coefficient of variation (%)
	MPa	MPa	SD (s_1)	SD (s_2)	SD (s)	CV
1	19.82	15.86	***1.38***	***3.58***	***3.84***	***18.79***
2	28.47	22.78	***2.32***		***4.27***	
3	26.8	21.44	***1.27***		***3.80***	
4	20.14	16.11	***0.45***		***3.60***	
	23.81	***19.05***				

As can be seen in the above table the average value of 28days concrete compressive strength result among the samples are 23.81MPa. This value is below the design value of 28days concrete compressive strength of site two of samples taken at different times and days.

As shown in the above table 4.15b the overall standard deviations of the concrete mix produced in Site two is three of the sample are in between 3.4 to 4.1 MPa and one of the sample is in between 4.1 to 4.8MPa. This value indicates that the control of concrete mix of the three samples is good and the rest is control of the mix is fair.

However, the coefficient of variation (i.e. 18.79%) as shown in the above table 4.15b varies significantly among the samples for the same grade of concrete. This value shows the concrete mix is not uniform even among the samples.

Table 4.15c:- *Overall variation of concrete compressive strength test result of Site Three*

Samples	Averages	Equivalent value of strength for cylinder test	Standard deviation of within test (MPa)	Standard deviation of batch to batch (MPa)	Standard deviation of overall variation (MPa)	Coefficient of variation (%)
	MPa	MPa	SD (s_1)	SD (s_2)	SD (s)	CV
1	17.28	13.82	***0.54***	***0.86***	***1.02***	***5.73***
2	18.6	14.88	***1.04***		***1.35***	
3	19.04	15.23	***1.17***		***1.90***	
4	19.84	15.87	***1.86***		***2.05***	
	18.69	***14.95***				

As can be seen in the above table the average value of 28days concrete compressive strength result among the samples are 18.69MPa. This value is below the design value of 28days concrete compressive strength of site three of samples taken at different times and days.

As shown in the above table 4.15c the overall standard deviations of the concrete mix produced in Site three are below 2.8MPa. This value indicates that the control of concrete mix excellent.

The coefficient of variation (i.e. 5.73%), as shown in the above table 4.15c, is compared with the above two sites are much better however, still the value indicates the concrete mix is not uniform.

4.4.Summary of the Findings

The total numbers of samples taken from the three selected construction sites were twenty four. Among the twenty four samples twelve samples were tested for 7days and twelve samples were tested for 28days compressive strength test. Each sample has three representative concrete specimens to get the average of the three. Among the specimens only three of the samples are above the design value and the rest of the nine samples are below the required design value of concrete compressive strength.

The following table 4.16 provides the summary of the laboratory test results according to ACI 214R-02, which shows the finding of the test results in accordance with different control standards.

Table 4.16:- *Summary of the overall variation of concrete control of the three sites*

Site Name	Sample Name	The Value of Overall standard deviation of different sites (MPa)	Standard deviation for different control standards, MPa				
			Excellent	Very good	Good	Fair	Poor
			Below 2.8	2.8 to 3.4	3.4 to 4.1	4.1 to 4.8	Above 4.8
Site One	Sample One	5.38					χ
	Sample Two	5.50					χ
	Sample Three	5.96					χ
	Sample Four	5.23					χ
Site Two	Sample One	3.84			χ		
	Sample Two	4.27				χ	
	Sample Three	3.80			χ		
	Sample Four	3.60			χ		
Site Three	Sample One	1.02	χ				
	Sample Two	1.35	χ				`
	Sample Three	1.90	χ				
	Sample Four	2.05	χ				

As can be seen in the above table 4.16, the concrete control is poor on Site One. However, the concrete control is excellent on Site Three and good concrete control on site two only the second sample of site two illustrate fair concrete control.

The following table 4.17 provides the summary of the laboratory test results according to ACI 214R-02, which shows the finding of the test results in accordance with different control standards.

Table 4.17:- *Summary of the within test variation of concrete control of the three sites*

Site Name	Sample Name	The Value of within test coefficient of variation (%)	Coefficient of variation for different control standards, %				
			Excellent	Very good	Good	Fair	Poor
			Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Site One	Sample One	8.85					χ
	Sample Two	10.13					χ
	Sample Three	11.09					χ
	Sample Four	3.08		χ			
Site Two	Sample One	8.67					χ
	Sample Two	10.19					χ
	Sample Three	5.92				χ	
	Sample Four	2.78	χ				
Site Three	Sample One	3.90		χ			
	Sample Two	6.96					χ
	Sample Three	11.24					χ
	Sample Four	11.70					χ

As can be seen in the above table 4.17, 66.67% of the samples taken from different sites are shows poor control of concrete. This indicates that the attention given for concrete control is very poor.

The following table 4.18 summarizes the laboratory finding.

Table 4.18: *Summary of the laboratory finding*

No.	***Site Name***	***Sample Name***	***28days compressive Strength***	***As per ACI 318-02 is compressive strength below by ≥ 3.45MPa the design value(25MPa)***	***Acceptable range individual cylinder strength 9.5% (2.375)***	***The concrete mix Accepted or rejected as per ACI* 318-02**	***Coefficient of Variation as per ASTM C39 is 2.9% (CV)***	***Is the concrete mix is uniform***
1.	***Site One***	Sample One	18.92	6.08MPa	As per ASTM C39 most of the concrete compressive strength is below the acceptable range this means most of the concrete mix are rejected.	Sample 2 and 3 are accepted Sample 1 and 4 are rejected	***28.26***	All of coefficients of variation found from the three sites are above the acceptable value (i.e. 2.9%).
		Sample Two	21.83	3.17MPa				
		Sample Three	32.6	Above by 7.6MPa				
		Sample Four	18.86	6.14 MPa				
2.	***Site Two***	Sample One	19.82	5.18MPa		Sample 2 and 3 are accepted Sample 1 and 4 are rejected	***18.79***	
		Sample Two	28.47	Above by 3.47 MPa				
		Sample Three	26.8	Above by 1.8 MPa				
		Sample Four	20.14	4.86 MPa				
3.	***Site Three***	Sample One	17.28	7.72MPa		All samples are Rejected	***5.73***	
		Sample Two	18.6	6.4 MPa				
		Sample Three	19.04	5.96 MPa				
		Sample Four	19.84	5.16 MPa				

According to the above two standards the compressive strength test result will be evaluated and discussed.

According to ACI 318-02, the strength level of an individual class of concrete is considered to be satisfactory if every arithmetic average of any three consecutive strength tests equals or exceeds the specified compressive strength and no individual strength test (average of two cylinders) falls below the specified compressive strength by more than 500 psi (3.45 MPa) when the specified compressive strength is 5000 psi (34.5 MPa) or less.

As depicted in the above table 4.18 the 28 days average value of each sample are below the design value which is 25MPa. As per ACI 318-02, all of the sample in site three falls below the design value by more than 3.45MPa, sample two and three of the respective site one and two are below the design value by less than 3.45MPa. Out of the total sample only 25% of the samples are accepted as per the above standard. In addition, as can be seen in the above table the value of coefficient of variation is very high. This indicates that the concrete mixes prepared in all of the three sites are not uniform.

In general, the control of concrete mix has significant impact on the overall quality of concrete production. The finding indicates that the impact of making non uniform concrete mix will have directly or indirectly a negative impact on compressive strength and workability of the concrete. Therefore, due care should be taken for the uniformity of concrete during production and concrete should be controlled during production.

Chapter Five ---Conclusion and Recommendation

5.1. Conclusion

Based on the results and analysis from questionnaire survey and laboratory test results the following conclusions are drawn.

- Three samples are taken from each batch for quality control. But results showed that there is a significant variation with-in the samples. According to ACI 214R-02, acceptance criteria, the results are not acceptable from the point of view of uniformity. There is inconsistency among the samples.
- The inconsistency is not only observed among the samples. The overall variation (Batch to Batch) variation is not also consistent from site to site. There is a huge gap between sites in terms of their concrete properties even if each site is aimed to produce the same concrete grade.
- Addition of water during mixing by labors, un-standardized materials, use of traditional and using the same concrete mix design in all concrete works are among the different factors which causes the inconsistency among the samples and batch to batch.

5.2. Recommendation

- Scientific way of concrete mix design should be used for each specific project. Tests should be done on constitute materials and the concrete proportion has to be done accordingly.
- There should be standardization of constituent material, especially for aggregate, since there are different aggregate sources.
- The amount of water should be pre-determined from the trial tests and site adjustment should not be allowed unless it is proofed by tests.
- I recommend for further research on this area by taking representative number of sites and by doing constituent materials and fresh concrete tests to assess the main causes of concrete inconsistency in Addis Ababa concrete production.

Reference

[1] Neville, A. M., 1996, ***"Properties of Concrete"***, Fourth Edition, John Wiley and Sons, New York, NY (page 228, 223, 268, 269, etc.)

[2] Glanville W.H., Collins A.R. and Matthew D.D. ***"The grading of aggregates and workability of concrete"***, Road Research Tech. paper No.5 (HMSO, London, 1947)

[3] Kosmatka S. et al, 2002, "***Design and Control of Concrete Mixtures***", 14th Edition, PCA Engineering Bulletin EB 001, Portland Cement Association, Skokie, IL

[4] Cement Concrete & Aggregates Australia, ***"Concrete Basics a Guide to Concrete Practice"***, Sixth Edition August 2004, published in July 1991

[5] ***"Effect of Aggregate Systems on Concrete Mixture Properties",*** Technical Report, National Concrete Pavement Technology Center, Iowa State University, 2711 South Loop Drive, Suite 4700, Ames, IA 50010-8664, July 2012

[6] George Earl Troxell et al, ***"Composition and Properties of Concrete"***, McGraw-Hill, Technology & Engineering, 1956.

[7] Gilkey, H. J. (1961). Water/Cement Ratio versus Strength – Another Look. Journal of the American Concrete Institute, Part 2, 1851-1878.

[8] Rozalija Kozul and David Darwin, ***"Effects of Aggregate Type, Size, and Content on Concrete Strength and Fracture Energy"*** Structural Engineering and Engineering Materials, SM Report No. 43, University of Kansas Center for Research, Inc. Lawrence, Kansas, June 1997.

[9] Abdullahi. M, ***"Effect of Aggregate Type on Compressive Strength of Concrete"***, Civil Engineering Department, Federal University of Technology P.M.B 65, Minna Niger State, Nigeria International Journal of Civil and Structural Engineering, Volume 2 Issue 3 2012.

[10] CEMEX USA - Technical Bulletin on ***"The Effects of Water Additions to Concrete: "What's a little water going to hurt?"*** www.cemexusa.com, 2013.

[11] Kolapo O. Olusolaet.al. *"**Effect of batching methods on the fresh and hardened properties of concrete",*** International Journal of Research and Reviews in Applied Science, Vol. 13, Issue 3, December, 2012.

[12] Nwabueze M.A., ***"Parameters for Good Site Concrete Production Management Practice in Nigeria",*** Covenant University, School of Environmental Sciences, College of Science & Technology, PhD Thesis, July, 2011.

[13] Ellen Taylor- Powell, ***"Analyzing Quantitative Data",*** Program Development and Evaluation Specialist for cooperative Extension, University of Wisconsin-Extension, published in 1989.

[14] Kucche K. J. and et.al **"*Quality of Water for Making Concrete: A Review of Literature",*** International Journal of Scientific and Research Publications, Volume 5, Issue 1, ISSN 2250-3153, January 2015.

[15] Tayler W. H., ***"Concrete Technology and Practice*"**, 4th Edition, Published in 1997.

[16] Orchard, D.F, ***"Concrete Technology Properties of Materials"***(Volume1) Science publishers Ltd. London (3rd edition)(1973).

[17] Abebe Dinku, ***"The Need for Standardization of Aggregates for Concrete Production in Ethiopian Construction Industry"*** Civil Engineering Department Addis Ababa University, Article May, 2005.

[18] Biruk Negash, ***"The Importance of Standardization of Aggregate in Ethiopian Construction Industry",*** Addis Ababa University, Institute of Technology School of Civil and Environmental Engineering, Master's Thesis, February, 2014.

[19] Guang Li, ***"The Effect of Moisture Content on the Tensile Strength Properties of Concrete",*** University of Florida, Master of Engineering, 2004.

[20] Nigus G/Egziabher, ***"Comparison of Concrete Properties Produced Using Mugher, Messebo and Diredawa Cements",*** Addis Ababa University, Master's Thesis, November, 2005.

[21] Seyit Ali Kaplan (PhD),***"Factors affecting the relationship between rate of loading and measured compressive strength of concrete"*** Magazine of Concrete Research, ISSN 0024-9831/ E-ISSN 1751-763X, Volume 32 Issue 111, June 1980, pp. 79-88.

[22] Eric P. Koehler and David W. Fowler, "***Summary of Concrete Workability Test Methods***" International Center for Aggregates Research, ICAR 105-1, August 2003, pp. 11.

[23] Sidney Mindess, J. Francis Young and David Darwin, (2003); "**Concrete**", prentice hall, 2nd edition, USA.

[24] ***"American Concrete Institute Certification of Concrete Strength Testing Technician"*** https://www.concrete.org/certification/certificationprograms.

[25] ASTM International, West Conshohocken, PA., ***"Significance of Tests and Properties of Concrete and Concrete-Making Materials (STP 169C)",*** published in 1994.

[27] ASTM C39, ***Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,*** ASTM Standard.

[28] ASTM C94, ***Standard Specification for Ready-Mixed Concrete***, ASTM Standard.

[29] ASTM C125, ***"Standard Terminology Relating to Concrete and Concrete Aggregates",*** ASTM standard.

[30] ASTM C143, ***Standard Test Method for Slump of Hydraulic-Cement Concrete,*** ASTM Standard.

[31] ASTM C172, ***Standard Practice for Sampling Freshly Mixed Concrete,*** ASTM Standard.

[32] ACI 116R-90, ***Cement and Concrete Terminology***, ACI Standard.

[33] ACI 318-02, ***Building Code Requirements for Structural Concrete***, ACI Standard. ACI

[34] EBCS 2, ***"Structural Use of Concrete",*** EBCS Standard.

Appendix:

Annex 1: Questionnaire for Engineers

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil& Environmental Engineering

Questionnaire for Engineers

Dear Sir/Madam

I am currently working on a research study on Assessing the Consistency of Concrete Properties in Addis Ababa, as a partial fulfillment for my MSc study in Civil Engineering under Construction Technology and Management at Addis Ababa Institute of technology. This research is aimed to Assessing the consistency of properties of concrete produced in Addis Ababa, specifically uniformity (consistency) of concrete workability and compressive strength.

Your genuine, honest and prompt response to the questionnaire will have contribution to the success of the research. Your response will be kept confidential, and anonymity will be maintained. Moreover, the information you provide will be used strictly for academic purpose and be reported in aggregate form.

Filling the questionnaire will not take more than 30 minutes. I thank you in advance for the time you devote, effort you make, and consideration you give in filling this questionnaire.
If you have any question concerning the items of the questionnaire, please call on mobile: 0911-78-02-45, or e-mail sitykal@yahoo.com

With Great Respect

Sity Mensur

Questionnaire

Title: Assessing the Consistency of Concrete Properties in Addis Ababa

Please indicate your response by ticking (X or √) the appropriate box (es), and also filling the blank spaces provided as appropriate. Since this survey is required for academic research, your prompt response is highly appreciated.

1. Respondent's Name:

   ____

2. If you are agreed to be contacted if there is follow up question please leave your phone number:

   ____

3. Name of the Organization you are working in:

   ____

4. What is your current position:

   ____

5. How many year/s of work experience do you have in building construction:

   ☐ 1-3 ☐ 4-7 ☐ 8-10 ☐ 11-15 ☐ >15

6. Based on your experience which grade(s) of concrete is (are) **mostly** produced / used in the construction industries, especially in Addis Ababa, for structural use?

   ☐ C 20 ☐ C 25 ☐ C 30 ☐ C 40 ☐ Other

   If you tick "Other", Specify: ______________________________

7. What type of cement is mostly used to produce the specified concrete grade?

   ☐ OPC ☐ PPC ☐ Other

   If you tick "Other", what is the type of cement?

   ____

8. What mix design method do you follow in the concrete production?

☐ DOE ☐ ACI ☐ EBCS

☐ From past experience ☐ By conducting trial mix ☐ Other

If you tick "Other" please write the mix design method you follow____

____

____

9. Is there any variation in mix-design when there is a variation in aggregate, sand and type of cement to be used?

☐ Yes

☐ No

If your answer is No, what will happen the test result during quality control of the concrete____

____

____

10. What type of tests do you conduct on the aggregate, sand and cement for quality control?

Aggregate	***Sand***	***Cement***
☐ Gradation	☐ Gradation	☐ Soundness
☐ Abrasion	☐ Clay content	☐ Consistency
☐ Flakiness & Elongation	☐ Organic content	☐ Setting time
☐ Moisture Content	☐ Moisture Content	☐ Compressive Strength
☐ Absorption	☐ Absorption	☐ Early Stiffening
☐ 10%Fineness	☐ Specific gravity	☐ Bulk density
☐ Soundness		☐ Specific gravity
☐ Specific gravity		☐ Heat of hydration

11. What type of tests do you conduct on concrete for quality control?

- [ ] Compressive strength
- [ ] Slump test
- [ ] Shear failure
- [ ] Temperature measurement
- [ ] Density
- [ ] Tensile Strength

12. How frequently do you take samples per story from the produced concrete for quality control?

- [ ] 3 Samples for beams, slab, column, staircase & shear wall each 3 cube
- [ ] 4 Samples for beams, slab, column, staircase & shear wall each 3 cube
- [ ] 6 Samples for beams, slab, column, staircase & shear wall each 3 cube
- [ ] 9 Samples for beams, slab, column, staircase & shear wall each 3 cube
- [ ] 12 Samples for beams, slab, column, staircase & shear wall each 3 cube
- [ ] Other, Please specify if you found different from the above

____

____

13. Are the test result uniform for all story for the same type of concrete produced?

- [ ] Totally Uniform
- [ ] Sometimes Uniform
- [ ] Not Uniform/ Different
- [ ] Other, Please specify for other cases

14. For question no. 13, if you found different results for the same concrete class, what do you think the cause for this variation?

____

____

____

____

15. Which concrete properties are mostly affected by variation or inconsistency of raw materials?

☐ Compressive Strength

☐ Workability

☐ Tensile Strength

☐ Shear Strength

☐ Other, Please specify ____-
____

Time is the precious gift of mankind, and I would like to thank you for your kind gift!!

Annex 2: Sampling Size Excel

Required Sample Size†
from: The Research Advisors

Population Size	Confidence = 85.0% Degree of Accuracy/Margin of Error 0.056	0.035	0.025	0.01	Confidence = 99.0% Degree of Accuracy/Margin of Error 0.056	0.035	0.025	0.01
10	9	10	10	10	10	10	10	10
20	18	19	20	20	19	20	20	20
30	26	28	29	30	28	29	30	30
50	39	45	47	50	46	48	49	50
75	52	64	69	74	66	71	73	75
100	63	81	89	98	84	93	96	99
150	79	111	127	146	117	135	142	149
200	91	136	161	193	145	174	186	198
250	100	157	192	239	170	211	229	246
300	107	176	220	284	192	246	270	295
400	117	206	270	371	228	309	348	391
500	124	229	312	456	257	365	421	485
600	130	248	348	538	281	416	490	579
700	134	264	380	617	302	462	554	672
800	137	277	407	693	319	503	615	763
900	140	288	432	767	333	541	672	854
1,000	142	297	453	838	346	575	727	943
1,200	145	313	490	974	367	636	827	1119
1,500	149	330	534	1163	391	712	959	1376
2,000	153	349	586	1443	418	808	1141	1785
2,500	155	362	623	1686	437	879	1288	2173
3,500	158	377	670	2089	460	977	1510	2890
5,000	160	390	711	2545	478	1066	1734	3842
7,500	162	400	746	3064	494	1147	1960	5165
10,000	163	406	766	3413	502	1193	2098	6239
25,000	164	416	802	4291	518	1285	2399	9972
50,000	165	419	815	4694	523	1318	2520	12455
75,000	165	421	820	4846	525	1330	2563	13583
100,000	165	421	822	4926	526	1336	2585	14227
250,000	165	422	826	5075	528	1347	2626	15555
500,000	165	423	828	5128	528	1350	2640	16055
1,000,000	165	423	828	5154	529	1352	2647	16317
2,500,000	165	423	829	5170	529	1353	2651	16478
10,000,000	165	423	829	5178	529	1354	2653	16560
100,000,000	165	423	829	5180	529	1354	2654	16584
264,000,000	165	423	829	5181	529	1354	2654	16586

The recommended sample size for a given population size, level of confidence, and margin of error appears in the body of the table.

For example, the recommended sample size for a population of 1,000, a confidence level of 99%, and a margin of error (degree of accuracy) of 3.5% would be 575.

(light blue box)	Change these values to select different levels of confidence.
(yellow box)	Change these values to select different maximum margins of error.
(purple box)	Change these values to select different (e.g., more precise) population sizes.