ASSESSMENT OF QUALITY CONTROL PRACTICES FOR IN-SITU CONCRETE: CASE STUDY OF NAIROBI CITY COUNTY

BY:

MAITHULIA CHARLES KANYITHIA

REG NO: B53/82716/2015

A RESEARCH PROJECT SUBMITTED AS PART FULFILMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN CONSTRUCTION MANAGEMENT AT THE DEPARTMENT OF CONSTRUCTION MANAGEMENT AND QUANTITY SURVEYING, UNIVERSITY OF NAIROBI

JULY 2020

Declaration

I Maithulia Charles Kanyithia do hereby declare that this research project is my original work and has not been presented for an award of degree in any other University.

____

Date: _____________________________

<u>Supervisor's Declaration</u>

This Research has been submitted for examination with our approval as the Supervisors

Isabella Njeri Wachira-Towey (PhD) ____________________________

Date: _____________________________

Eng. (Dr.) John Mwero _____________________________

Date: _____________________________

Acknowledgement

I would like to sincerely thank the almighty God for his Grace and Strength, My family for the unwavering support and understanding, my supervisors QS (Dr.) Njeri Wachira-Towey and Eng. (Dr.) John Mwero for their firm, tireless and diligent support accorded to me in the process of carrying out this research.. They both found and took time with me throughout this exercise. Much gratitude also goes to the contractors who gave me access to their sites and offered valuable information. My staff at Buffalo Construction and services for their hard work and support that made it possible for me to spare some time for undertaking this research.

To all of you I say THANK YOU.

Abstract

Site production of in-situ concrete by small contractors (registration category NCA5 to NCA8), face numerous challenges ranging from site safety and organisation, poor conditions of equipment, understanding of design information, lack of experienced supervisory staff and other field obstacles. These challenges compromise the quality of concrete manufactured and the constructed facility. This study therefore investigated key site practices under which in-situ concrete is being produced by this category of contractors. This was done with a view to establishing if these practices have effect on the quality of concrete so manufactured. The study objectives were to compare achieved strengths with target mean strengths (measured in compressive strength units) with additional exploration of the effect of some of these key practices on the strength of concrete produced. One hundred and Thirteen (113) building contractors registered under NCA5 to NCA8 categories were sampled through multilevel sampling and stratified random sampling for concrete cubes for testing.

Performance ratings were carried out based on the selected key site practices. When rated as good, fair or poor, the findings showed that only 11% of contractors attained good rating on site safety; only 15.5% attained good rating on site organisation; and 18% recorded good rating with regards to condition of equipment. On key site quality control practices; 97% of contractors did not record water-cement ratio; 99% did not carry out slump tests; and 100% did not have weighing instruments on site for accurate batching. Although singularly these poor site practices had only small impacts on concrete quality as indicated by the achieved compressive strength, together they led to significant variations in the concrete strength (as per hypothesis testing results) – minimum 12.5 N/mm2 and maximum 36.5 N/mm2 - as further exemplified by the average mean strength achieved from the samples was 24.22 N/mm2 as compared to the targeted standard strength of 25 N/mm2. Improvement of quality of in-situ concrete production must therefore focus on enhancement of appropriate site practices.

To improve in-situ concrete production, the study recommends more proactive supervision by consultants, capacity building amongst contractors via training and availing of appropriate equipment and technology; and strict quality control of the in-situ concrete production process. These recommendations have the potential to improve the country's construction industry through enhanced quality management, safety standards, and the achieved value for clients' finances.

Table of Contents

List of Plates

List of Tables

List of Figures

List of Equations

Acronyms

AASHTO:	American Association of State Highway and Transportation Officials
ACI:	American Concrete Institute
ACV:	Aggregate Crushing Value.
ASTM:	American Society for testing of Materials
BS:	British Standards
CIOB:	Chartered Institute of Builders
ISO:	International Standards Organisation
NCA:	National Construction Authority
OSHA:	Occupational Safety and Health Act
PMBOK:	Project Management Book of Knowledge
PPE:	Personal Protective Equipment
RICS:	Royal Institution of Chartered Surveyors
UNCRD:	United Nations Centre for Research and Development

CHAPTER 1: INTRODUCTION

1.1 Introduction

The Kenyan Construction industry and the region's as a whole has seen huge growth in regard to infrastructural development spearheaded by both the government and the private sector. Some of the large scale projects includes the Thika road superhighway built at a cost of USD 360million, the Standard Gauge Railway (SGR) built at a cost of USD 3.6 billion, Lamu port-South Sudan- Ethiopia Transport (LAPSET) estimated to cost USD 23 billion and the ongoing Tatu city development, Buffalo Hills and Northlands City developments which are spearheaded by the private sector. According to Kenya Economic Survey (2017) Construction industry grew by 9.2% making it the second highest after tourism. This accelerated growth requires modern construction project management practices, key of which is Quality Management. Project Quality Management (which constitutes quality control, quality assurance, and quality planning) will ascertain that a project satisfies the particular needs it as intended for (PMBOK, 2000).

Cases of collapsing buildings which have been witnessed in the country and the region may be a strong pointer to deficiencies and/or lack of proper quality management in our project undertakings. Recent examples of collapsed buildings (with fatalities) in Kenya includes; a 5-story residential building in Ruaka –Kiambu county (29/03/2018), a 5-story housing complex in Kisii (11/10/2017), mixed use building in Kenol- Murang'a county (26/06/2019) and the collapse of a residential flat in Huruma, Nairobi in April 2016 where 52 people lost their lives..

As a building material, Concrete; in its various forms and specifications is one of the major components comprising most building fabrics and civil engineering structures. Concrete, (both mass and reinforced) has played a leading role in this rapid growth of the construction industry due to its availability, ease of use and increased knowledge of its properties. One of its most significant features is the ability to cast shells, arches, columns, beams, and slabs (McCormack, 2001). Concrete has high compressive strengths and also possesses other desirable properties including durability, resistance to abrasion, impermeability and resistance to sulphate attack. Sinha (2007) reports on concrete's feature to take any shape as desired. The process of production of concrete is elaborate and commences from the point when the design engineer prescribes a particular concrete class for a job, based on a design mix exercise.

The accuracy of the batching process especially where it is done manually is controlled by human factors, the working environment and the accuracy of the equipment and/ or tools being used. Quality control at the fresh concrete production stage and the environment under which it is done are very important elements of construction quality control practices which further feeds into quality planning and finally the whole process of project management.

1.1.1 Quality Management

Project quality management involves the enhancement of quality project delivery strategies and frameworks in a bid to ensure the end product meets the desired purpose(s). On the other hand, quality planning entails the identification of quality standards that suits the features of a project as well as the determination of their satisfaction. Quality control is also defined as the process of monitoring particular aspects of a project to assess if they adhere to applicable regulations as well as the identification of methods and strategies to improve performance (PMBOK, 2000). Concrete, being a key structural component for most building and civil works has specific quality control requirements to ensure safe and durable structures.

1.1.1.1 Design Mix

Achievement of desired quality of concrete is dictated by the mix design data and information. Concrete design mixes are elaborate laboratory trials that take into account various factors including type and quality of material and the way they should be proportioned (batched) to achieve target design strengths.

1.1.1.2 Batching

The use of volume and mass measurements on concrete ingredients and their introduction to a mixer for production is called batching. The production of quality concrete relies on the ability to accurately measure each of the ingredients. Standard calibration, maintenance, and inspection of batching equipment must be done so as to give a reliable between-mixes-batch of aggregates (Murdock & Brook, 1979). Depending on construction site size, varying equipment is used. For instance, manual mixing and loading hopper are common in small scale production while larger scale production involves an entire mechanized process. Nevertheless, mass batching is highly recommended than volume batching by most specifications (ASTM C 94 or AASHTO M 157). However, the specifications allow the freedom to use either mass or volume measurements for liquid state ingredients. In continuous mixers, concrete is mixed through volumetric batching as illustrated in ASTM C685 or AASHTO M 241.

According to Batterchajee (2012), Concrete batching process may be volumetric and weight based, The Batching processes may be mechanized or manual depending on the state of the technology available. Code of practice for concrete works including; BS 1881 (methods of testing concrete), BS 8110 (structural use of concrete and other materials), and *American Concrete Institute* (ACI 304R) stipulates concrete mixes by weight batching.

The main quality criteria for fresh concrete are workability, consistency, water-cement ratio and ultimately target compressive strength. These control parameters are directly related or controlled by the ratios of the main ingredients of the mixture and also the water- Cement ratio. Faulty or reckless batching process will lead to concrete that lacks in some quality aspects and ultimately result in compromised end product (Batterchajee, 2012). For this reason, therefore, it becomes critical that batching is accurately done and that the correct method of mixing, placing, compacting and curing of concrete is followed. Furthermore, concrete design mixes are a critical requirement before commencement of any concrete works. The mix design when properly carried out will take cognizance of all properties of the various ingredients resulting in the achievement of target compressive strengths.

As stared by Neville (1981), concrete strength stands as the most significant property followed by other features such as permeability and durability (Neville, 1981). This is because concrete strength portrays the overall quality level as it has a direct association with the quality structure obtained from its hardening.

In order to realize safe or required load bearing capacities for concrete, its production process requires correct control and care. Concrete production process includes;

- Batching
- Mixing
- Transporting
- Placing
- Compacting.
- Curing

Once the above processes are correctly followed, the strength of concrete will then mainly depend on the degree of compaction and the water cement- ratio (Neville, 1981).

Inadequate mixing of the ingredients results to reduced concrete quality since the consistency and homogeneity of the materials is compromised. Uniform distribution of the constituent ingredients is imperative through each step of the production process and key determinant of the quality of the achieved product. Failure to adhere to these two conductions leads to reduced durability and strength of the hardened concrete (Jackson and Dhir, 1988). AASHTO and ACI specification usually gives the following percentages of accuracy for the ingredients of Concrete manufacture:

Table 1.1: BS Percentages of accuracy

Cementitious material	± 1%
Aggregates	± 2%,
Water	± 1%,
Admixtures	± 3%

(Source: BS 8110, Structural use of concrete)

The process of batching should ensure that the above tolerances are not exceeded. This is achievable if the batching process is well controlled, equipment well calibrated and the workers experienced in the batching process. Shortcomings in this area will result in concrete not meeting strength and other critical requirements. The equipment used to conduct batching should be tolerant and flexible to contain these tolerances in cases of either large or small batchers. Additionally, they should be frequently inspected to ascertain their accuracy and make adjustments as necessary.

1.2 Problem Statement

Building Contractors falling under NCA category NCA5 to NCA8 constitute 82.4% of all registered Contractors (NCA register at 31.01.2017). These contractors have been noted to operate under certain limitations resulting from their financial incapacity or inexperience. These include lack of experienced technical staff, poor conditions of equipment and low investments in site safety and site organisation. Under these circumstances site practices that are likely to compromise on the quality of concrete so produced emerges. Moreover, nonadherences to quality control requirements by workers operating under conditions that are not favourable also tend to arise.

By virtue of their numbers, these categories of contractors are responsible for production of a significant volume of in-situ concrete in Kenya. Assessment of site practices such as level of compliance to safe working conditions for workers, site organisation, conditions of equipment, supervisory capacity, adherence to design quality control standards and the compressive strengths realised under these circumstances becomes necessary as a way of enhancing construction quality management.

Human factors play a very important role in the production process and quality control. According to Rukwaro (2016), ergonomical considerations are important in the science of workplace designing with considerations of worker limitations and the human mind abilities. This is because poorly designed worksite design results in hurting, fatigued, and frustrated workers. It is, important therefore, that concrete is produced within a safe environment that protects the workers, surrounding neighbourhood and the environment. Good construction management practices should result in safe structures in our built environment, safe working conditions for workers and a well preserved environment. Cases of collapsing buildings suggests that good construction management may be lacking in in-situ concrete manufacturing site practices in Nairobi City County, but no documentation is currently available hence this research. Additionally, cases of collapsing building and workers exposure to unsafe and unhealthy working conditions may be minimised by ensuring good and healthy site practices leading to a healthy construction industry and overall national growth.

This research sought to interrogate site practices and their effect on the resulting concrete quality. Choice of in-situ concrete production is informed by the high prevalence of this method of concrete production amongst middle to lower cadre contractors; of significance was the strength of concrete achieved under these conditions. The target group are the contractors in and around Nairobi City registered under National Construction Authority (NCA) category NCA 5 up to NCA 8

1.3 Research Objectives

The overall aim of this research was to investigate site practices with a view to assessing their effects on quality of in-situ concrete produced in construction sites in Nairobi City County and its environs.

The specific objectives of the study are:

1. To identify the key site practices that may have effects on quality of in-situ concrete

2. To establish the compressive strength achieved and compare them with target mean strength.

3. To determine the relationship between the compressive strength achieved and key site practices.

1.4 Research Questions

The research addressed the following question.

- What are the current in-situ concrete production practices on sites?
- Is the achieved compressive strength equal to the target mean strength?
- What is the relationship between the achieved compressive strength and the site practices?

1.5 Research Hypothesis

(i) **Null Hypothesis**: In-situ concrete production site practices do not have a significant effect on the quality of concrete produced.

(ii) **Alternate Hypothesis:** In-situ concrete production site practices have a significant effect on the quality of concrete produced.

1.6 Scope of Investigation

The study was limited to the investigation of in-situ mixed concrete by contractors falling under category NCA5 to NCA8 operating in Nairobi City County and adjoining metropolitan areas of Kiambu and Machakos. Nairobi appears to be the epicentre of the construction activities in the country. It enjoys better supervision controls due to its city status and more access to a large pool of construction related professionals at all levels. It was presumed that if any significant shortcomings in concrete quality control are noticeable in Nairobi, the same could be far more pronounced in other counties which do not enjoy the same level of limelight.

1.7 Significance of the Research

Project Quality Management entails Project Quality Control, Quality Assurance, and Project Planning (PMBOK, 2000). The production of fresh Concrete under suitable conditions for workers and continuous achievement of specified (design) parameters is a key aspect of quality control where works of Building and/or civil engineering nature are concerned. This study assessed the site conditions under which in-situ concrete is being produced as well as compliance to quality control standards for fresh concrete production. Monitoring the

Conditions under which Concrete is being produced is necessary in order to ensure quality control, a dignified workforce that is productive and vibrant, and adherence to design strengths. These aspects contribute to safe built environment and positive human development. Continuous attainment of desired structural strengths of Concrete is beneficial to our built environment in regard to service life of buildings, additional to capital investments, human safety, comfort and added utility.

Field observations indicate that majority of the contractors falling in category NCA 5 to NCA8 are mainly producing their concrete manually on site as opposed to using ready mixed concrete (Lamka, 2015). Cognizance is made of the fact this category of contractors contributes to approximately 82.4% of all building contractors according to the National construction Authority (NCA) – (contractors' registration status as at 31.01.2017) of all registered contractors in Kenya. This class of constructors, therefore, provides significant contribution in the construction industry in the provision of quality work. For this reason therefore, it is important to ascertain if there exists significant variation between qualities of concrete being achieved and the corresponding design strengths.

If significant variation in strength exists, it is an important call to our construction industry to pay a closer attention to this matter in light of its prevalence and its implications to the quality standards in our built environment. As part of the reforms in the construction industry, the National Construction Authority, Local Authorities, Contractors and other Government regulatory bodies will endeavour to adopt measures that ensure quality of concrete in all our project undertakings is ensured.

With the noted increase in the number of collapsing buildings in our country, every care or contribution that can help to eliminate the problem or trend is important so as to ensure safe and durable buildings. Building owners and users and humanity at large will stand to benefit from safe structures.

1.8 Definition of Terms

Batching: The Quantities of cement aggregates and water required for making concrete. These should be determined by mass. Syal and Goel (2009). For practical purposes, if cement is supplied in bulk the batch quantities are chosen such that their sum is equal to the capacity of the mixer Neville (1981).

Concrete Mix Design**:** The determination of the optimum proportions of ingredients (water, Cement, fine and course aggregates to achieve concrete of specified properties; Sinha (2014).

Workability: The simplicity or easiness in mixing, placing, compacting, and finishing fresh concrete (Kong and Evans, 1987).

Characteristic Mean Strength**:** The standard mean strength that a particular concrete should possess measured as compressive strength (BS 8110: Part 1). For a particular concrete sample, the achieved strength is allowed to variations within 5% below the standard strength (Kong and Evans, 1987).

Target (design) Mean Strength**:** The average strength of concrete achieved after a stipulated period say 28 days. It is statistically related to the Characteristic Strength as follows;

Target mean strength = Characteristic strength -1.64σ.

Where; σ is the standard deviation of the strength tests (Kong and Evans, 1987).

Project Quality Management**:** A set of strategies and frameworks required for a project to achieve the desired features for accomplishment of anticipated needs. These elements entail the management of projects through quality improvement, control, assurance, and planning (Kerzner, 2017).

1.9 Structure

Chapter 1: Introduction

In this chapter, the Research topic is introduced; the research problem and Question are stated. The Research Hypothesis, the aim and the research benefits are formulated. The methodology of the research and scope is then presented.

Chapter 2: Literature Review

Review of literature was undertaken on relevant books, codes and standards of practice including the British standards (BS), Various American standards, Indian Standards, Kenya Bureau of standards, Ministry of Public works (materials branch) and published journals. The main areas of Literature review included the following: Construction Management in relation to Concrete production; History of the use of Concrete; Properties of Concrete; Concrete Mix Design Process and the Batching process in Concrete Production

Chapter 3: Research Methodology

In this chapter, the methodology, design applied in the study is outlined and the population, sampling, data collection method and analysis spelt out.

Chapter 4: Data Analysis and Presentation.

Field observation of concreting operations were carried out to identify important site practices including Site Safety, Site organisation, Condition of Equipment, Design information available on site and Qualification of supervisor. Other information was obtained via Questionnaires and interviews administered to the site supervisors responsible for these concreting operations. Laboratory concrete strengths from these in-situ concreting activities were obtained and analysed for distribution, test of normality and comparison with target mean strength. Co-relation exercise was done to establish how the above field practices relate to the average strengths achieved by the contractors sampled.

Chapter 5: Conclusion and Recommendations.

This contains conclusions informed by the results of this study, which relate to the aims, objectives and in line with the research question earlier that guided the study. Recommendations were drawn and areas of further investigation recommended.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Chapter one provided a detailed introduction to the current study. Precisely, the chapter provide an illustration of the background to the research, the aims and objectives to be achieved, a statement of the problems identified that prompted the conduction of this research with concise justification on their existence and the significance in researching about them. This chapter seeks to undertake analytical review of studies and past literature relevant to the study as guided by the objectives and problem. To achieve this, relevant literature on the site practices, quality management and factors influencing concrete quality will be reviewed. Additionally, the chapter critically reviews the concrete mix design process which guides achievement of desired concrete quality.

2.2 Construction Management

A project is an undertaking that is carried out to achieve established objectives within quality, time, and cost provisions (UNCRD publication, 2000).

2.3 Statistical Quality Control (SQS)

The process of and /or all activities associated with the achievement of an appropriate level of results is referred to as Quality assurance. When techniques are used which are based upon sampling methods, the term Statistical Quality Control is employed (Lockyer, 1983). Testing of concrete strength is one such activity that employs statistical quality Control method where sample cubes are taken to represent every concrete pour.

Quality assurance is defined as "an objective" demonstration of a builders ability to apply strategies that promote presentation of quality products to customers cost effectively (CIOB, 1989). On the other hand, RICS (1989) argues that it is the application of effective management practices that lead to consistent achievement of set objectives and thus building customer confidence. BS 5750:1987 defines quality management as the events, resources, activities, responsibilities, and organisation structure of an organisation that promote its ability to achieve quality requirements through the application of organised implementation methods and procedures.

According to Seely (1996), quality assurance calls for suitable documentation, procedures, systems, and clear communication and that is easily understood and accurate with illustration of standards to be achieved. In respect to a building project, the established goals or objectives will normally be to deliver works of acceptable or specified quality and with the ultimate results being the attainment of; added utility to users, structural integrity, durability, aesthetics, and environmental compliance.

The process of delivery of a project is as important as the final project itself. It is in this regard, that good Construction Management practices should seek to ensure that the delivery process is in line with expected standards to both the personnel handling the construction activities and the environment.

2.3.1 Site Layout

Lockyer (1974) states that it is necessary to ensure that the organisation of the site, method and workflow are made before the plant is laid out rather than to lay the plant out first and then try to fit organisation, method and workflow to it. He further stresses out that attention should be paid to supply points which should be ample and of easy access. This fact is very essential when it comes to the production of fresh concrete on site.

The Occupation Safety and health Act (OSHA) 2007 provides a platform and structure where procedures, workplace standards, code of practice, and regulations stipulate the general duty of care (OSHA 4, 2007), under which all involved parties with a project, have responsibilities for work health and safety (OSHA 6-31, 2007)

When mixing concrete on site, the layout of the aggregate material heaps; sand and ballast, and water in relation to the mixing plant and final placement location are crucial to an efficient, safe and effective flow of the production process.

2.3.2 Working Space

A confined working space is not only psychologically distressing; it may increase physical fatigue by causing muscles to be tensed in an effort to avoid the constriction **(**Keith, 1983). Field Concreting operations are characterised by intense physical activities involving large numbers of workers who are more often than not driven by a desire to complete the works and earn an agreed day’s wage. They are normally less interested in matters of quality, safety or environmental issues. As stated by Thomas (2004), having a working environment that is less satisfying adversely affect how workers are motivated to work and thus lead to reduced performance.

Provisions of the public health Act 242 require the provision of proper lighting and ventilation and prevention of overcrowding. Our construction sites tend to crate overcrowding and poorly ventilated environments that is further complicated by presence of fumes from concrete mixers some of which are poorly serviced leading to excess noise and emission of dangerous gasses. Lamka (2014) concludes that improved labour productivity is one of the key determinants of projects prediction and therefore an important ingredient of construction delivery.

2.3.3 Communication and Instruction

According to Kranker Larsen et al. (2015) human generated factors often lead to complications in project management where the managing team is responsible for the identification and implementation of efficient strategies for processes and organisation's stability. Such problems and factors include newly of inexperienced consultants, construction supervisors, change of business partners, slow user decision making, disputes, miscommunication, and conflicts between partners. This view though related to managerial levels, applies to lower level work crews. Concrete production sites are characterised by large number of construction personnel some of who have low levels of education.

The people doing the work need to have clear instructions about what is expected of them, but the supervisor has to ensure that they are viewing the work plans in the same way as he/she is (Trevor, 1994). Field crews need to be well instructed in the way the batching, loading, mixing, tipping and subsequent handling of the fresh concrete. Batching involves ratios of the various ingredients. The crews responsible for feeding the fine and the coarse aggregate, water and (admixtures where applicable) have to be well instructed and monitored to ensure continued consistency and uniformity. Marzouk, Tarek and El Rasas (2014) in their study on causes of delays in Egyptian construction projects identified design delays and poor supervision as causes of delays to construction projects

2.3.4 Site Safety

The working conditions of workers are of paramount importance to the aspect of productivity. Productivity in this case being seen not only from the sense of quantity of output but the attainment of the same within a safe and conducive atmosphere. Production of Concrete is one of those construction activities where the chances of breeching required working conditions are highly likely.

The Occupational Safety and Health (OSHA) Act (2007) clearly stipulates the expected standards in regards to; site cleanliness section 47(1), Overcrowding 48(1), Lighting 50(1), Sanitation 52(1), Protective Clothing 101(1), and Protection of eyes 102(1) among other regulations.

According to Rukwaro (2016), work design in ergonomics explores Human- machine systems design and development for the purpose of enhancing human performance by studying the aspects of the work, the machinery required and the human interface. Construction sites should be set out in a manner that portrays humane procedures and practices characterised by;

Well Organised: Constituent materials for Concrete production should be located in a manner that ensures; Ease of picking, Ease of movement using wheelbarrows, frames etc. Ease of manual lifting and devoid of congestion.

Safe working environment: The working area should be well ventilated, safe distance from moving plant, and Workers well equipped with acceptable Personal Protective Equipment (PPEs').

Work designed: The tasks comprising site work should be designed such that the workers are matched with the tasks, postures, lifting capacity and ability, body postures and other ergonomical considerations Rukwaro (2016). The informal workforce engaged in the construction industry lucks any significance degree of social protection including their health and safety Kinyanjui and Mitulla (1999). High levels of joblessness are often causing workers to accept duty under poor conditions and terms.

2.4 Definition of Concrete

Concrete is a composite material which consists essentially of a binding medium of cement, and water called the cement-water paste and particles of relatively inert filler called aggregates; Kong and Evans (1968). According to Sinha (1998), it is an artificial stone obtained by mixing Aggregates, Cement and water and allowing the product to cure for hardening. The water and cement react with each other chemically to form a paste that binds the aggregates together.

In its plastic (fresh) state, concrete can be moulded into various shapes for architectural or decorative purposes while hardened concrete is a hard rock like material which exhibits a high compressive strength but low tensile strength. Concrete is primarily a construction material of the modern age with over 13 billion metric tons being used globally every year. Its properties largely depend on the raw material used, the skills of the concrete mix designer, and how the concrete is proportioned, placed and finished (Koteng, 2013).

2.4.1 Brief History of Concrete Use

In the past, most structures were made either of masonry, steel or wood, depending on the availability of the material and the nature of the structure in question. Concrete has however gained so much importance that today 65% of the structures coming up in the world are constructed with Concrete (Syal and Goel, 2009). The history and development of Concrete is directly or closely associated with the progressive development of knowledge of cement which is the main binding component of concrete mix. The romans made Cement- called Pozzolana - before the birth of Christ by mixing slaked lime with a volcanic ash from Mount Vesuvius and used it to make concrete for building. The art was lost during the Dark Ages and was not revived until the eighteenth and nineteenth century (McCormack, 2001).

The ancient Egyptians used calcined impure gypsum while the Greeks and ancient Romans used Calcined limestone and later learned to add lime and water, sand and crushed stones or brick and broken tiles to produce concrete (Neville, 1981). The real breakthrough for concrete occurred in 1824 when Joseph Aspin (an English Bricklayer) developed and obtained a patent for Portland cement from Portland limestone found in Dorset. The material used for the manufacture of Portland cement are calcium carbonate found in calcareous rock such as limestone or chalk, and Silica, Alumina and Iron oxide found in argillaceous rock such as clay or shale.

2.4.2 Composition of Concrete

Concrete is a composite material consisting essentially of; a binding medium of water and cement called the cement paste and particles of a relatively inert filler material called aggregates.

2.4.3 Cement

Cement is the ingredient in Cement that plays the binding role to the other components, Cement is a finely ground powder which undergoes hydration when mixed with water which with time produces a very hard and strong binding medium for the aggregate particles. Ordinary Portland cement is the most widely used; while other types of cement are used where concrete with special properties are required. British Standards (BS) 4550 specifies various methods of testing cement for various properties. The following is a summary of the various types of cement and their relevant British Standards which specify their specific physical and chemical requirements.

Table 2.1: Classification of Cements

Main Cement Class	***Types***
Ordinary Portland Cement	Ordinary, BS 12 1978 Rapid Hardening BS 12 1978 Sulphate Resisting BS 4027 1980
	Others
	Air Entraining Hydrophobic (waterproof & water repellent Ultra-Rapid hardening White Coloured BS 12 1978 Low heat BSB 1370 1979 Extra Rapid Hardening
Slag Cement	Low heat Portland blast furnace BS 4246 1974 Portland Blast furnace, BS 146 1973
	Super sulphated BS 4248 1974
	Trief
Pozzolanic Cement	Portland pulverized fuel Ash, BS 6588 1985 Pozzolana with pfa, BS 6610 1985
High Alumina Cement	High Alumina BS 915 1972

(Source: A.M Neville: Properties of concrete 1978)

2.4.4 Aggregates

Aggregates constitute the bulky and inert part of concrete which contributes to the concrete's durability and stability by volume. Aggregate is much cheaper than cement and hence maximum economy is obtained by using as much aggregates as possible in concrete. Though aggregate is held to be inert, is not exactly true because it's physical qualities and at times its synthetic arrangement influencing to a fluctuating degree the properties of concrete. The basic requirement for aggregates is that it should provide the required properties both when fresh and requisite strength when hardened.

The most important properties of aggregates that affect the resulting concrete properties includes; strength, shape and surface texture, deformation characteristics, toughness, volume changes, porosity and its volume changes. Aggregate can be broadly classified as heavy weight, Normal Aggregates and Lightweight aggregates. Procedures for sampling and testing Concrete are stipulated in British Standards (BS 812 part 102).

2.4.5 Water

Water plays a vital role in concrete production by reacting with the cement to cause it to set and then harden. Water also facilitates the compaction, placing, and mixing of the concrete when fresh. It also serves to wash and cure the concrete to facilitate completion of the hydration process. Water for concrete works is required to be free of impurities, and other substances including clay, acid, alkalis, salts and organic matter. BS 3148 prescribes the method of testing water for suitability for concrete works.

2.4.6 Admixtures

Admixtures are the additives introduced into concrete in order to alter the properties of the fresh concrete. Admixtures are normally introduced during mixing or immediately before. Admixtures when introduced play the role of influencing properties of the concrete by development of the gel structure, formation of pores, liberation of heat affecting hydration. The main types of admixtures include super plasticizers, water reducers or plasticizers, accelerating agents, air- entraining agents, bonding agents, water repelling agents, and pozzolanas.

2.5 Properties of Fresh Concrete

Concrete properties are dependent upon several factors such as amount of cement, fine and coarse aggregates, water/cement ratio (wc/ratio), and temperature. After mixing, various actions (operations) may affect the properties of the fresh concrete which also finally affects hardened concrete. These operations include transporting, placing, compacting and finishing. Fresh concrete features which have an impact on optimal compaction include compatibility, mobility, and consistency. These are collectively referred to as workability.

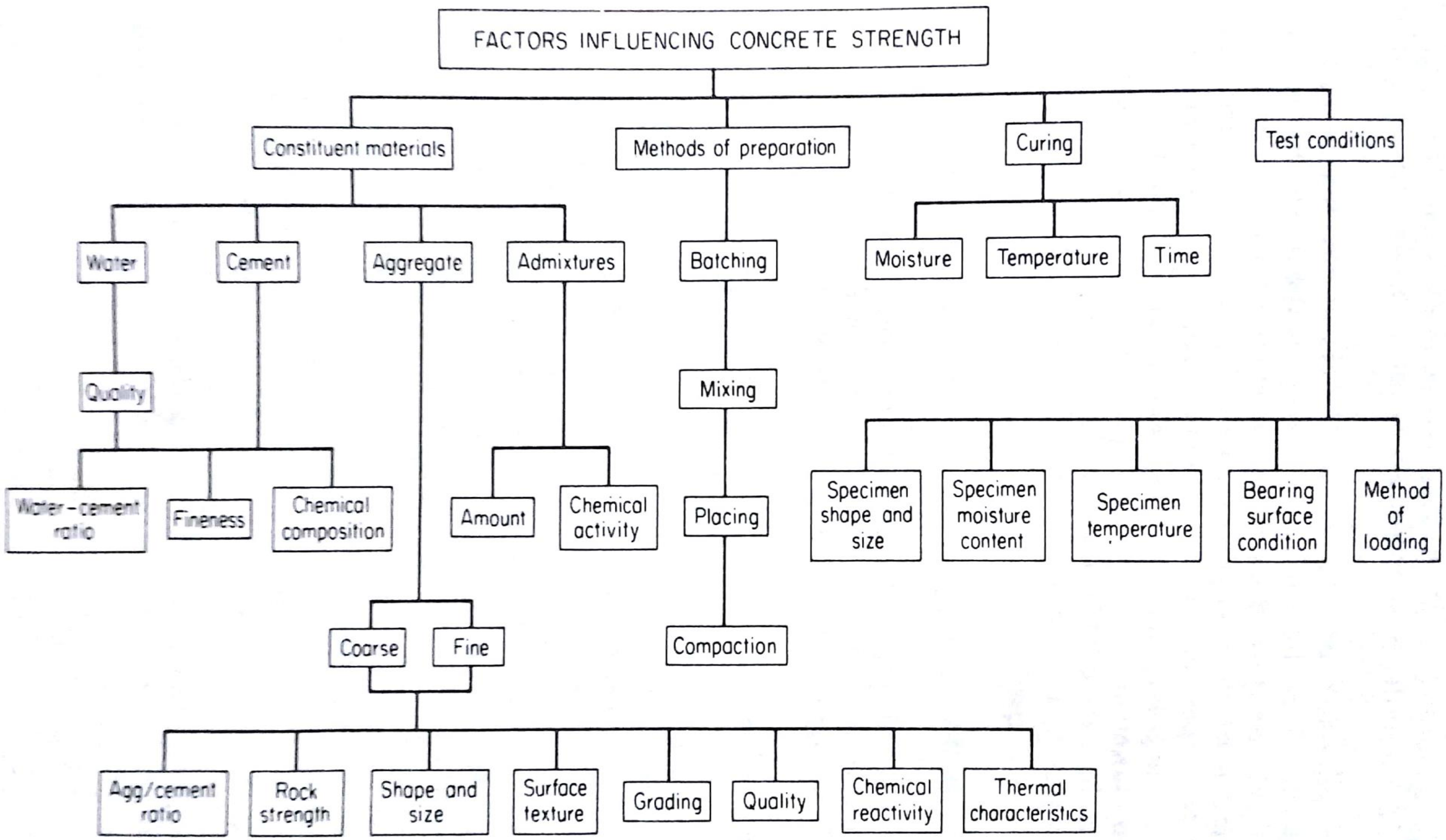

Figure 2.1: Factors influencing concrete strength (source: N. Jackson and Dhir: Civil Engineering Materials,1988)

2.5.1 Production of Fresh Concrete

Fresh concrete may be produced manually in the field by use of simple production equipment or may be produced by way of automated and sophisticated stationary batching plant. The former method which is the focus of this research is prone to various quality control shortcomings as compared to the latter which enjoys more accuracy due to computer-controlled batching and mixing operations.

Batching (the proportioning of various ingredients to achieve a required class of concrete) may be done by volume or by weight. However, volume batching of concrete materials is a bad practice (Neville and Brooks, 1987). On the other hand, variations in aggregate quantity in a particular volume can be affected through the occurrence of possible sources of error in batching of error (Olusola et al., 2012). Such errors often lead to properties variations in the fresh and hardened properties of concrete as against specified characteristics properties (Kolapo, et al., 2012).

According to Olusola et al (2012), batching by weight produce varying results from batching by volume which also affects the overall compressive strength mix proportion of 1:1:2, batched by weight are always higher than concrete batched by volume at all water-cement (w/c) ratios and for curing ages 7 to 28 days. Hedidor and Bondinuba (2017) concludes that volume batching is the most regularly used batching approach for medium to small scale building firms in Nigeria, Ghana and other neighbouring West African countries. Neville and Brooks (2010) in their study on concrete conclude that the use of volumetric batching method in concrete production be averted.

According to Olusola et. al.,(2012), batching by volume as opposed to grouping by weight as endorsed in the norms, results to try and lower solid toughness as far as quality by over 14%, quality variety and lower nature of new solid property , and subsequently, the creation of less sturdy basic cement in structures.

2.5.2 Workability

Workability of concrete is the ease with which it is transported, placed and sufficiently finished without segregation. According to Jackson and Dhir (1988), Workability is the straightforwardness with which a solid blend can be dealt with from the blender to its at last compacted shape. Sinha (2002) defines workability as the amount of useful internal work required in overcoming the inner rubbing between singular particles of the blend to produce full compaction.

Kong and Evans (1987) define workability as the ease with which the concrete can be mixed, placed, compacted and finished. Concrete should be sufficiently workable so that it can be compacted to the maximum density. On the off chance that Concrete doesn't have the necessary usefulness in its plastic stage it won't be conceivable to create Concrete with the necessary qualities in its solidified state, i.e. strength, durability and desired surface finish

Workability involves three main components;

Consistency: This is a measure of wetness or fluidity

Mobility: This defines ease with which the fresh concrete can flow into and completely fill the formwork or mould.

Compatibility: This is the ease with which a given mix can be fully compacted, all the trapped air being removed.

Workability is estimated by utilization of some sort of consistency estimations as a file to usefulness: the droop test, the compacting factor test and the VB consistometer test among others. The necessary usefulness of a solid blend depends not just on the attributes of the general extents of the fixings yet in addition on technique for transportation and compaction, size shape and unpleasantness of the formwork and the size shape and situation of support. Workability is fundamentally influenced by the water content and the particular surface of concrete and totals.

Table 2.2: Workability requirements for various works

Degree of workability	Slump (mm)	Compacting factor	Type of Work
Very low	0	0.75	Roads and other large sections
Low	0 – 5	0.85	Simple to normal reinforced work
Medium	5 – 25	0.90	Normal to heavy reinforced work
High	25 – 100	0.95	Sections with heavy congested reinforcement not suitable for vibration

Source: Kong and Evans: Reinforced and Pre-stressed Concrete, (1968)

2.5.3 Cement and Water

It very well may be said that quality is basically reliant on the water/concrete proportion, for example the proportion of weight of blending water to that of the concrete in the blend - the blending water being comprehended to incorporate the surface water of the totals yet not the ingested water (Kong and Evans, 1968). The connection between the Water – Cement proportion (by volume) and the part of concrete for various workabilities is a direct one (Hughes, 1971).

According to Jackson and Dhir (1988), contrasts in solid quality can happen attributable to the nature of concrete however the rule factor influencing the quality is the amount of water, or all the more explicitly the water-concrete proportion in the solid. During site blending activities, human mistake will likewise regularly bring about varieties in Water-Cement proportion prompting qualities falling on either side of the ideal quality worth.

Any varieties in blend extents or noteworthy changes in the total evaluating will influence the amount of water expected to keep up the necessary usefulness and this also will bring about varieties in the water – concrete proportion and thus in solid quality. For a given blend, the usefulness of the solid declines as the fineness of the concrete increments because of the expanded explicit surface, this impact being increasingly articulated in rich blends. The connection among workability and Water substance can be communicated as;

Equation 2.1: Relationship between workability and water content

$$Y = CW^n$$

Where ***Y*** = specified workability value

C = a coefficient which depends on the composition of concrete and method of measuring workability

W = water content

n = a coefficient which depends on the maximum size of the aggregates.

According to Kong and Evans (1987);

1. The water /Cement ratio is the single most important factor that influences the strength and the durability of concrete

2. The water content is the single most important factor that influences the workability of the fresh concrete mix.

In regard to the water/cement ratio, only the free water is used (i.e. excluding the absorbed water), and the water content is the weight of the free water per unit volume of concrete. It is therefore important that batching process takes into account this factor in order to achieve required concrete strengths. (See figure 2.2)

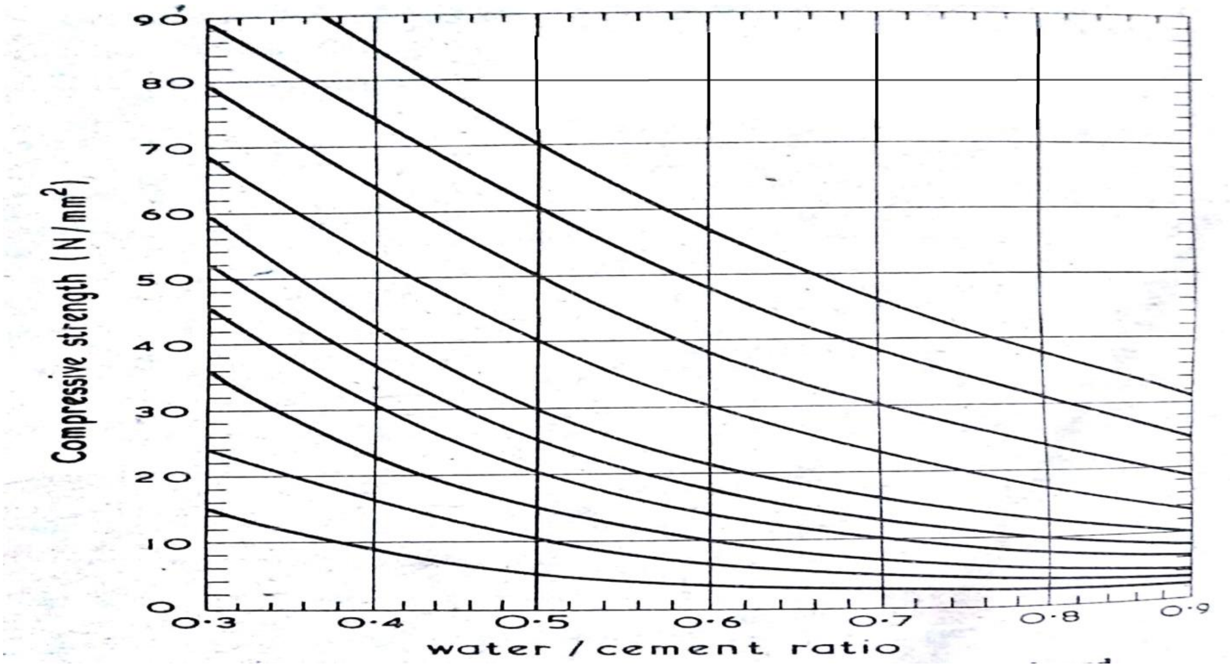

Figure 2.2: Relationship between Cube compressive strength and free Water - Cement Ratio. (Source: Doe mix design method (1975)

2.5.4 Admixtures

Admixtures (agents) that affect the workability of concrete are those that that are associated with water-reducing and those that are Air-entraining. Their effect on workability will mainly depend on their type and amount used. Other factors that will affect workability includes; Aggregates content and characteristics ambient conditions and Time (between mixing and final placement)

2.5.5 Stability

Besides from being functional, new concrete ought to have a synthesis with the end goal that its constituent materials remain consistently conveyed in the solid during its creation up to the time it solidifies. However due to the differences in the constituent materials' particle size and specific gravity, there is a natural tendency to segregate. This is more pronounced in high workability mixes. Stability is the ability of the concrete to maintain the required uniformity. A good guide is concrete designed to have a maximum of 450Kg/m3 combined fines (cement plus sand fractions less than 0.3mm**)** (Jackson and Dhir, 1988).

2.5.6 Segregation

This is the tendency of the large and fine aggregates in the mix to separate. Less cohesive mixes have more tendencies to segregate and vice versa. Segregation will normally depend on the complete explicit surface of the strong particles including the concrete and the amount of the mortar in blend.

2.5.7 Bleeding

During the process of compaction of concrete, solid particles will tend to move downwards within the mix. This downward movement depends on the size and specific gravity of the aggregate particles. This downward movement of the bigger particles tends to displace the water which moves upwards or is squeezed and leaks through the joints of the formwork. This process of water displacement or separation is called bleeding. Bleeding affects the properties of concrete especially workability and ultimately its strength.

2.6 Methods of Production of fresh Concrete

Production of fresh concrete will normally be done at or in stationary batching plants located off site. The latter will normally be afforded by large construction companies who will have the financial wherewithal to afford the initial costs of the plant. This method will result in higher quality control of concrete due to advanced technology at play. Smaller construction firms on the other hand will normally produce concrete using basic mixing equipment and at times manually. The basic equipment will comprise of a tilting drum mixer being manually fed though self-loading mixers are also in use.

Plate 2.1: Modern Concrete production plant (by large contractors and suppliers)
Source: Kajima Construction company site, Debre markos road project Ethiopia 1999.

Plate 2.2: Basic concrete mixing equipment

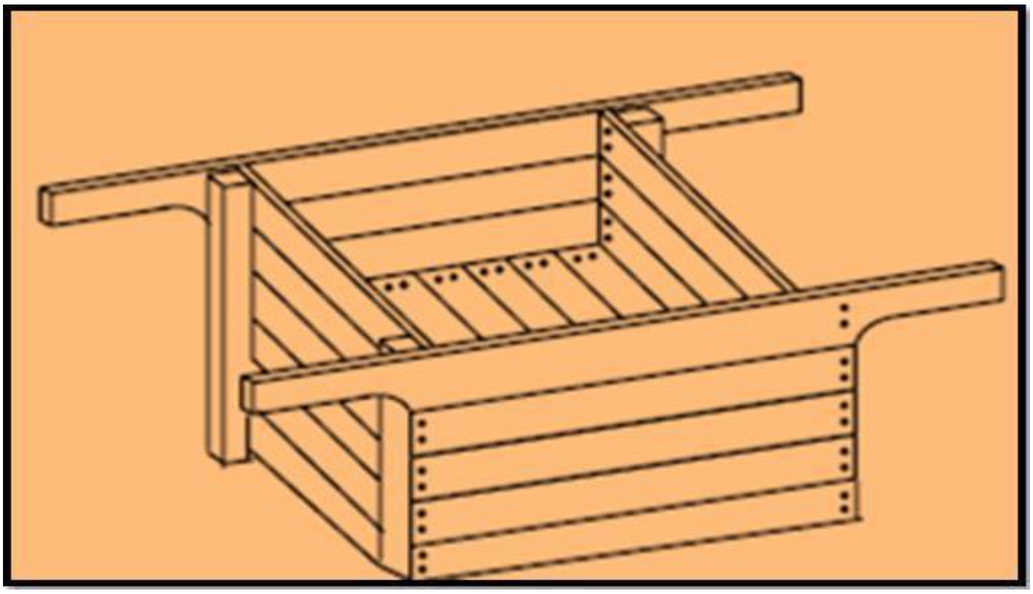

Figure 2.3: Wooden batch box.

2.6.1 Compressive strength

The compressive strength of concrete is taken as the most extreme compressive burden it can convey per unit territory. High Concrete qualities can be accomplished by particular utilization of Type of concrete, blend extents, technique for compaction and restoring conditions. Solid structures aside from streets, are typically planned on the premise that solid is fit for opposing just pressure, the strain being conveyed by the steel fortification.

2.6.2 Testing the strength of concrete

A sample of a concrete framed in a 150mm cube is regularly utilized for deciding of compressive quality. BS 1881 Part 116 specifies that the test example be restored in water at 20 ± 2º and squashed after a predetermined term by stacking it at a consistent pace of pressure increment of somewhere in the range of 12 and 24 N mm^{-2} min^{-1} following it has been expelled from the relieving tank.

Testing of concrete is by way representative samples scooped from each concrete pour or session. The concrete is placed in a standard Mould (usually 150mmx150mm x150mm). The specimen is compacted by use of a standard Metal rod for specified number of blows. The resulting cube is removed from the mould after 12 hours and then cured by soaking in water for the a specified period for 7 days, 21 days or 28 days as the specification may dictate. More than one sample is recommended so as help in making better judgement on the testing results.

Plate 2.3: A standard Mould (150mm x 150mm x150mm)

Plate 2.4: Placing fresh samples in cube moulds.
Source : Construction site in Nairobi

Hardened concrete is tested in a laboratory by means of a compressive machine that applies a steady load to the concrete cube until failure. The maximum load at failure is recorded and is the strength of the concrete. This is normally recorded in N/MM2.

Plate 2.5: Compression machine for testing concrete cubes.
Source: Matest Equipment catalogue from internet.

2.7 Properties of Hardened Concrete

2.7.1 Strength

Compressive strength is the most important property of hardened concrete. This strength relies on the nature of fixings, and the way where they are blended, compacted and relieved. Strength of concrete increases with age, attaining a maximum strength after 28 days. The ultimate strength is achieved if the concrete is kept cured under water. The strength of any concrete will be influenced by the method and adequacy of curing. The strength of Concrete of a given mix proportions will also be seriously affected by the degree of its compaction. Neville (1993) argues that the consistency of the mix should be to such an extent that the solid can be moved, set and completed adequately effectively and without isolation. This implies that workability of fresh concrete is a critical factor for attainment of required of concrete.

Concrete is exceptionally strong in Compression, however amazingly feeble in tensile strength. The compressive quality of concrete is taken as the most extreme compressive load it can carry per unit area. Reinforced concrete structures, are designed on the premise that Concrete will bear the compressive force while tensile forces are borne by steel reinforcement.

According to BS 1881 part 116, a 150 mm cube is used to determine the compressive strength. The specification requires that the test specimen (cube) be cured in water at 20 degrees centigrade and crushed by loading it at a constant rate of stress increase of between 12 and 24 N/mm2 per minute, immediately after it has been removed from the curing tank. Concrete compressive strength is therefore a scientifically tested parameter that has been carried out for as long as the use of structural concrete has been in use. With advancements in the structural use of concrete, much has been understood and standardized in form of codes and standards.

2.7.2 Durability of Concrete

Besides ability to sustain loads, concrete is also required to be durable. Durability can be defined as the ability to resist deterioration resulting from external and internal causes. The external causes include the effect of environmental and service conditions to which it is exposed; (wear, chemical action, and weathering). The internal causes are the effects of salts, (especially chlorides and sulphates) in the constituent materials, interaction between the constituent material, such as permeability, absorption, volume changes, and alkali- aggregate reaction.

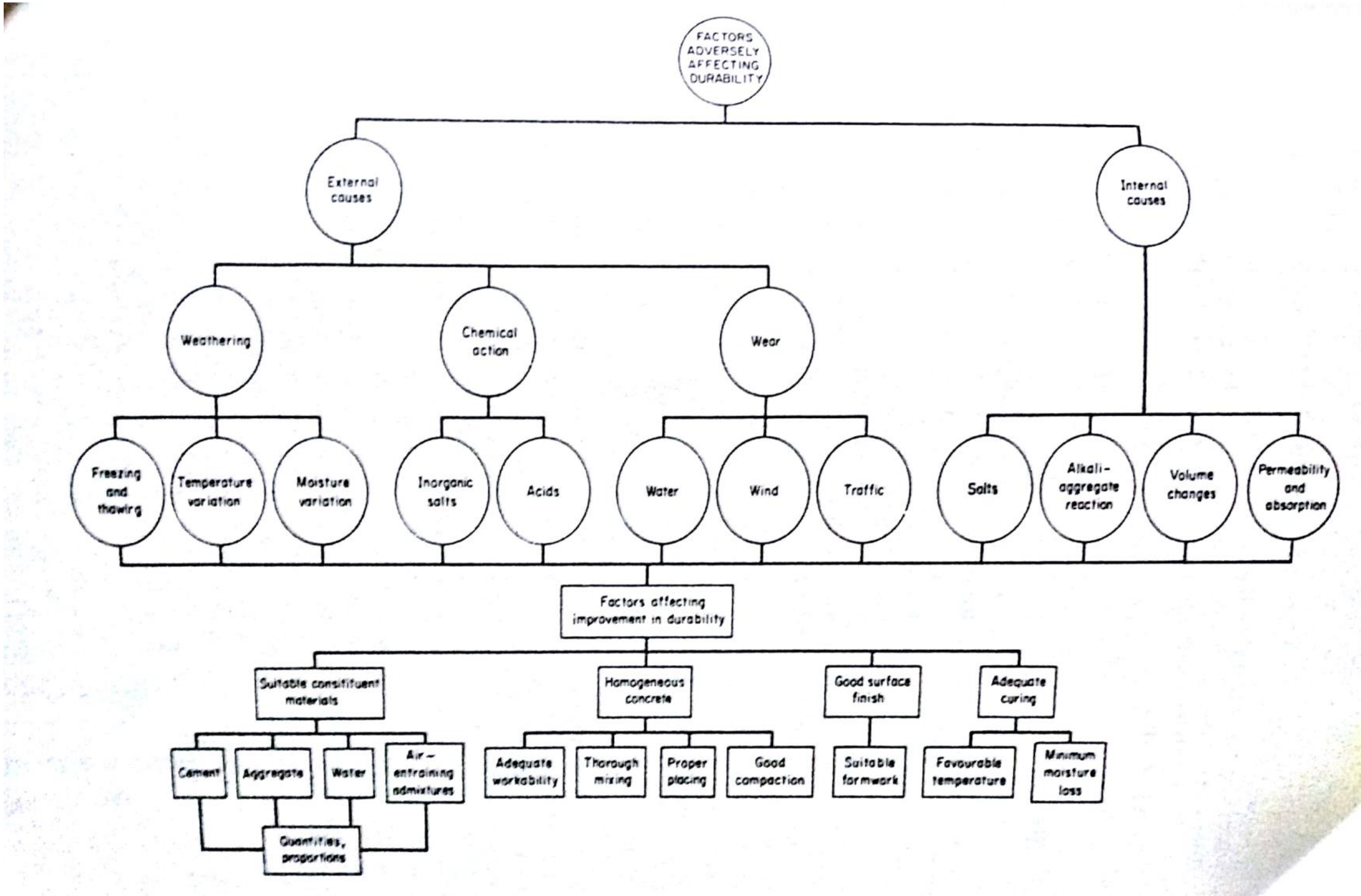

Figure 2.4: Factors affecting the Durability of Concrete. (source Jackson and Dhir:Civil Engineering Materials, (1988)

2.7.3 Impermeability

This is the resistance of concrete to the flow of water into it. It is affected by the amount of voids in the concrete. The voids are created by the evaporation of superfluous water that does not combine with the cement or the presence of air voids. Impermeability therefore increases with reduction of such pore spaces. Impermeability increases durability of concrete by increasing its resistance of weathering, chemical attack and corrosion. Other important behaviour characteristics include behaviour under stress (uniaxial, biaxial and triaxial stress), Creep and Shrinkage.

2.8 Concrete Mix Design and Quality Control

Every concrete operation is aimed at achieving concrete of desired characteristics to meet its intended purpose. One of the main requirements is that the concrete should meet certain strength targets**.** Solid Mix configuration can be characterized as the technique by which, for some random arrangement of conditions, the extents of the constituent materials are picked in order to deliver a solid with all the necessary properties at the base cost (Jackson and Dhir, 1988). In this setting the expense of any solid remembers for expansion to that of the materials themselves, the expense of the blend configuration, clumping, blending and putting the solid.

Kong and Evans (1968) describe design mix as the selection of relative proportions of Cement, Water and Aggregates. Sinha (1998) describes concrete mix designs as the determination of proportions of water, Cement, course and fine aggregates so that concrete of specified properties can be obtained most economically. Concrete mix design is thence meant to provide a reasonably accurate guide to arrive at an optimum combination of ingredients. Quality control concerns in the mix design process refers to the care taken to guarantee that the materials utilized in the creation of the solid are of the necessary quality and that the expressed blend extents are clung to.

2.8.1 Importance of Mix Design to this Research

From the foregoing, the purpose of design mix is simply to achieve the correct quantities of the ingredients and at economical costs. The mix design process is a very key reference as it gives the step by step process of determining the various proportions that result to a desired target mean strength. Concrete mix design process can hence be looked at as an advance procedure that requires to be followed to achieve the required concrete class (target mean strength) for an immediate future concrete works operation.

In their study on the appropriate ratios for use in blended cement in Kenya, Okumu Shitote and Oyawa (2017) concluded that no distinction is made in concrete qualities bringing about the utilization of same blend extents regardless of the concrete kind and quality. This assertion requires the understanding of what blended cement is as the current blended cement in Kenya meets the standard KS EAS 18-1:2001. It is imperative that from a mix design point of view, the proportions required to achieve a desired target mean strength is arrived at procedurally.

In view of the above therefore, the practices and accuracy to which field crews produce in-situ concrete requires critical evaluation against the stringent procedures of mix designs that results in a desired concrete class or strength.

2.8.2 Factors Governing Concrete Mix Designs

The proportioning of ingredients of concrete is governed by the following factors; size and grading of the aggregates, concrete grade required (Grade refers to the characteristic strength), the concrete mix is designed for a target mean strength, water-cement ratio (water content), and type of cement,

2.8.3 Statistics and Target Mean Strengths in Mix design

2.8.3.1 Characteristic Mean Strength

The strength requirements of concrete are generally specified in terms of a characteristic strength as per BS 8110- Part 1, coupled with requirements that the strength falling below this shall not exceed a certain value. Qualities of cement from various development undertakings will typically be differed and will by and large follow some example of the ordinary recurrence appropriation which is balanced about the normal with the greater part of the test outcomes falling near the normal. It is thusly conceivable to relate the necessary trademark solidarity to be utilized in the blend structure. The trademark quality is the shape quality beneath which not over 5% of the test outcome may fall. Characteristic strength is regarded as the 28-day strength of a concrete cube. This concept is illustrated in the following figure.

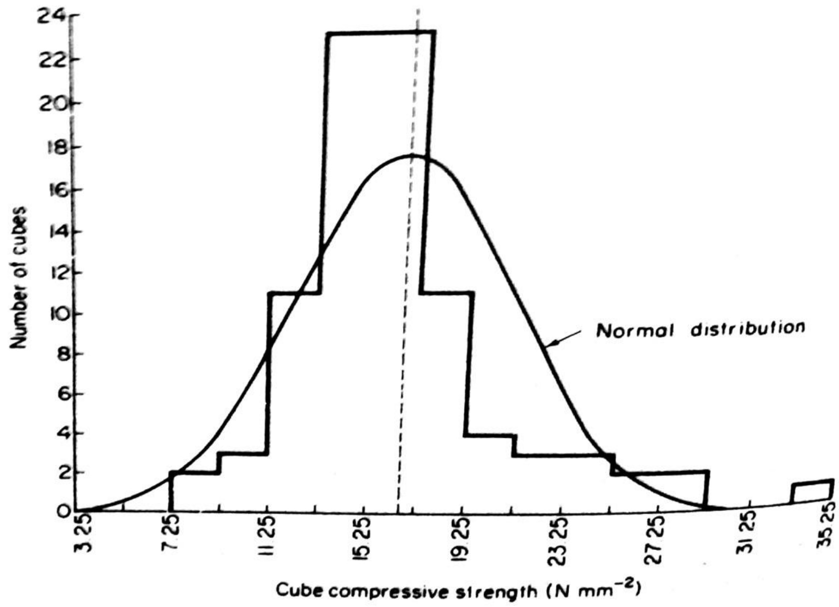

Figure 2.5: Illustration of distribution of Cube characteristic strengths for a project

(Source: Jackson and Dhir (1988)

Good control of concrete production will result in steep and symmetrical curve along the target mean strength**.**

2.8.3.2 Design Mean Strength

The basis of concrete mix designs to satisfy strength requirements and statistical quality control procedures is the assumption of a normal distribution. The probability of strength of a concrete cube falling outside a specified limit on either sides of a mean strength can be determined for a normal distribution. These limits are usually expressed in terms of the standard deviation **s,** defined by;

Equation 2.2: Standard deviation

$$S = \left[\frac{\sum(\int c - \int cm)^2}{n-1}\right]^{\frac{1}{2}} = \left[\frac{\sum(\int c)^2 \; - (\sum \int c)\, {}^{2}/_{n}}{n-1}\right]^{\frac{1}{2}} Nmm^{-2}$$

Where $\mathbf{f_c}$ is an observed strength, $\mathbf{f_{c\,m}}$ is the best estimate of the mean strength, equal to

$(\sum \mathbf{f_c})/^{\mathbf{n}}$ and **n** is the number of observations. The probabilities of a strength falling outside the range $(\mathbf{f_{cm}} \pm \boldsymbol{\beta s})$ for different values of β are given in the following in which the probability of strengths falling below the lowest limit $(\mathbf{fcm} \text{-} \boldsymbol{\beta s})$

Table 2.3: Probability Values

	Probability values	
Probability of an observed strength lying outside the range ($f_{cm} \pm \boldsymbol{\beta s}$)	$\boldsymbol{\beta}$	Probability of an observed strength (lying) being less **($\mathbf{f_{cm}} - \boldsymbol{\beta s}$)**
1:50	2.33	1 in 100
1:20	1.96	1 in 40
1:10	1.64	1 in 20

Source *Jackson and Dhir; Civil Engineering Materials, (1988)*

If the specified characteristic strength $\mathbf{f_{cu}}$ is the strength below which not more than 1: 20 of the population of strength shall fall, it follows that

$$\mathbf{f_{cu} = f_{cm} - 1.64s}$$

Hence $\mathbf{f_{cm} = f_{cu} + 1.64s}$

This relationship is illustrated in the following figure 2.6

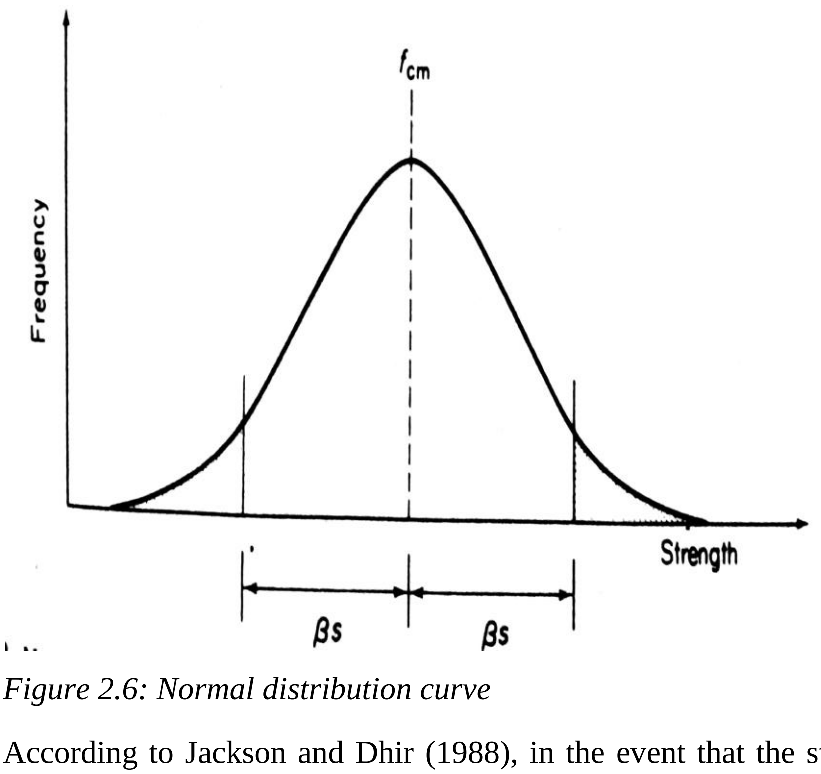

Figure 2.6: Normal distribution curve

According to Jackson and Dhir (1988), in the event that the standard deviation prone to be acquired can be surveyed, the mean quality for which a solid must be structured can be resolved. The free–water – Cement proportion required to invigorate this mean cement would then be able to be assessed utilizing suitable curves.

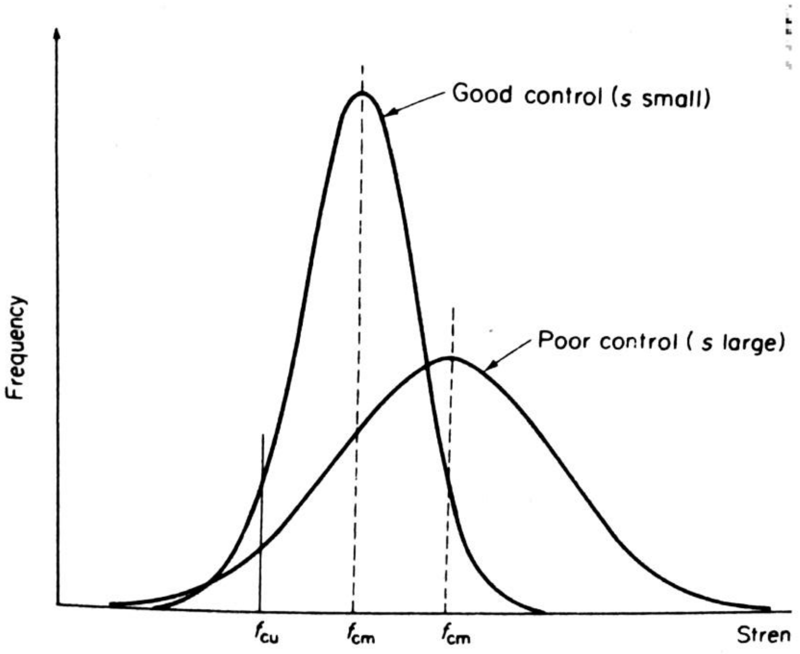

Figure 2.7: Effect of control on required mean strength

(Source Jackson and Dhir (1988)

Good quality Control will result in strengths for most samples being very close to the Characteristic or target mean strength i.e. smaller standard deviation (**s**) and vice vice versa.

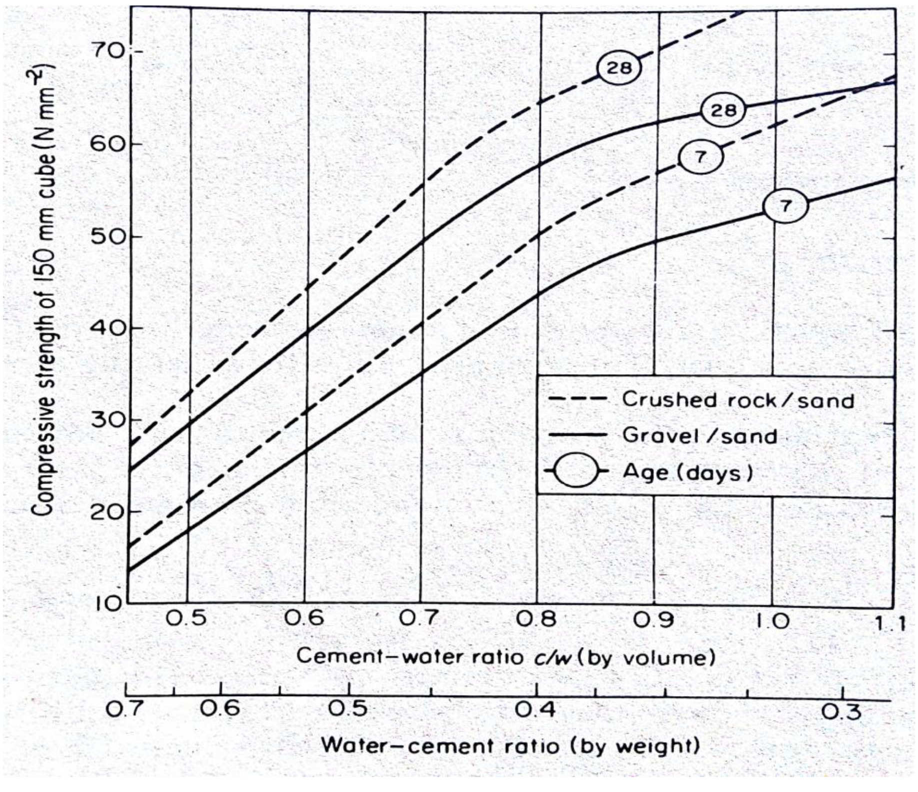

Figure 2.8: Cement – water ratio (by Volume) and Water –Cement ratio (by weight)
Source: A.M. Neville Properties of Concrete (1981)

2.8.4 Mix Design (Hughes Approach)

Site quality control practices should ensure that the concrete being produced meets the requisite standards in terms of procedures and ultimately the compressive strength. They should be guided by the mix design performed prior to the commencement of the project.

One of the more general approaches to Mix design was proposed by Hughes (1971). It considers the ideal coarse material content, this being the volume portion of coarse material that will result in a desired strength and workability with minimum cement content. Hughes approach which shapes the premise of the simplified method.is viewed as a valuable prologue to the DoE (1975) method,

2.8.5 Traditional mix design Method

Concrete mixing designs in the UK have been relying on concrete and constructional engineering paper developed by Dr A R Collins in 1939. From that time, the paper was endorsed as Road Note No 49. The paper indicated that the choice of water-cement ratio should be done in a way that would effectively facilitate achievement of desired workability. Additionally, the ratio, together with the aggregate-cement ratio which are comparable although the quantity of water used in each of the three variables is independent (Kong and Evans, 1987).

Assume it is required to produce concrete with a certain average strength at 28 days. This required average strength referred to as the target mean strength and is statistically related with the characteristic strength. It is noteworthy that the target means strength will be some value that surpasses the characteristic strength by a reasonable margin, called the present Margin. For well compacted concrete, the quality depends principally upon the proportion of water to cement. In the traditional mix design method, a target strength is chosen and then the water/ cement ratio is chosen from appropriate charts. The durability requirements constraints to water/Cement ratio are then imposed so as to adjust the water /Cement ratio earlier chosen.

2.8.6 The Importance of Mix design information to the study

The mix design process is a precise procedure meant to arrive at accurate quantities of the various ingredients to achieve the desired strength of concrete for a particular use. Adewole et al. (2015) in their research on appropriate concrete mixes for Portland-limestone grades 32.5 and 42.5 in Nigeria found that the use of Portland-limestone cement grade 42.5 is an efficient strategy towards achieving the minimum concrete strength using the 1:2:4 especially for the load-bearing building structural members. This finding implies that in the absence of a proper design mix, many assumptions are made as to the achievable strengths for many construction projects.

According to Okumu et al. (2016), the direct substitution of the ordinary Portland cements with the locally available, lower strength, and cheaper cements could be responsible for the failure of several concrete buildings in the country. From the general knowledge of available concrete in our Kenyan market, it is however noted that this study does not delve into the difference between blended cement of ordinary Portland cement. The findings however reinforce the need for mix design being a strict requirement for all structural works. Supervision of concrete production is also very essential to ensure adherence to specifications. In view of this, analysis of laboratory results coupled with field observations of concrete production practices were used in this study to reveal how strengths being achieved compare with target mean strengths.

In summary, quality control in the process of production of in-situ concrete is key to achieving concrete that satisfies intended structural and other user requirements. Workers safety and work design will contribute to a more productive work force and will ensure consistency when batching. In-situ concrete production should always be guided by the results of trial mix design and good quality control results in concrete strengths that are close to the target mean strength hence a steep symmetrical curve along the target mean strength**.** This can only be achieved through good site practices enabled by qualified site staff and proper professional supervision to ensure compliance to design requirements.

2.9 Conceptual Framework

In the conceptual; framework depicted in fig 2.9 below, site practices are hypothesized to influence the quality of concrete produced. Site practices zeroed include safety, organisation, condition of equipment, qualification of supervisors and other fresh concrete quality control practices at production. Concrete quality on the other hand refers to the ability of the hardened Concrete to withstand applied compressive forces, long service time (durability), impermeability and resistance to abrasion.

The framework postulates that site practices of safety, organisation, condition of equipment, qualification of site supervisors and other fresh concrete quality control practices directly affect the quality of concrete so produced. Quality of concrete may however be affected by other factors including material quality, curing time and method of mixing, placing and placing. Prevailing weather condition and Staff motivation may also play a role in the quality of concrete produced.

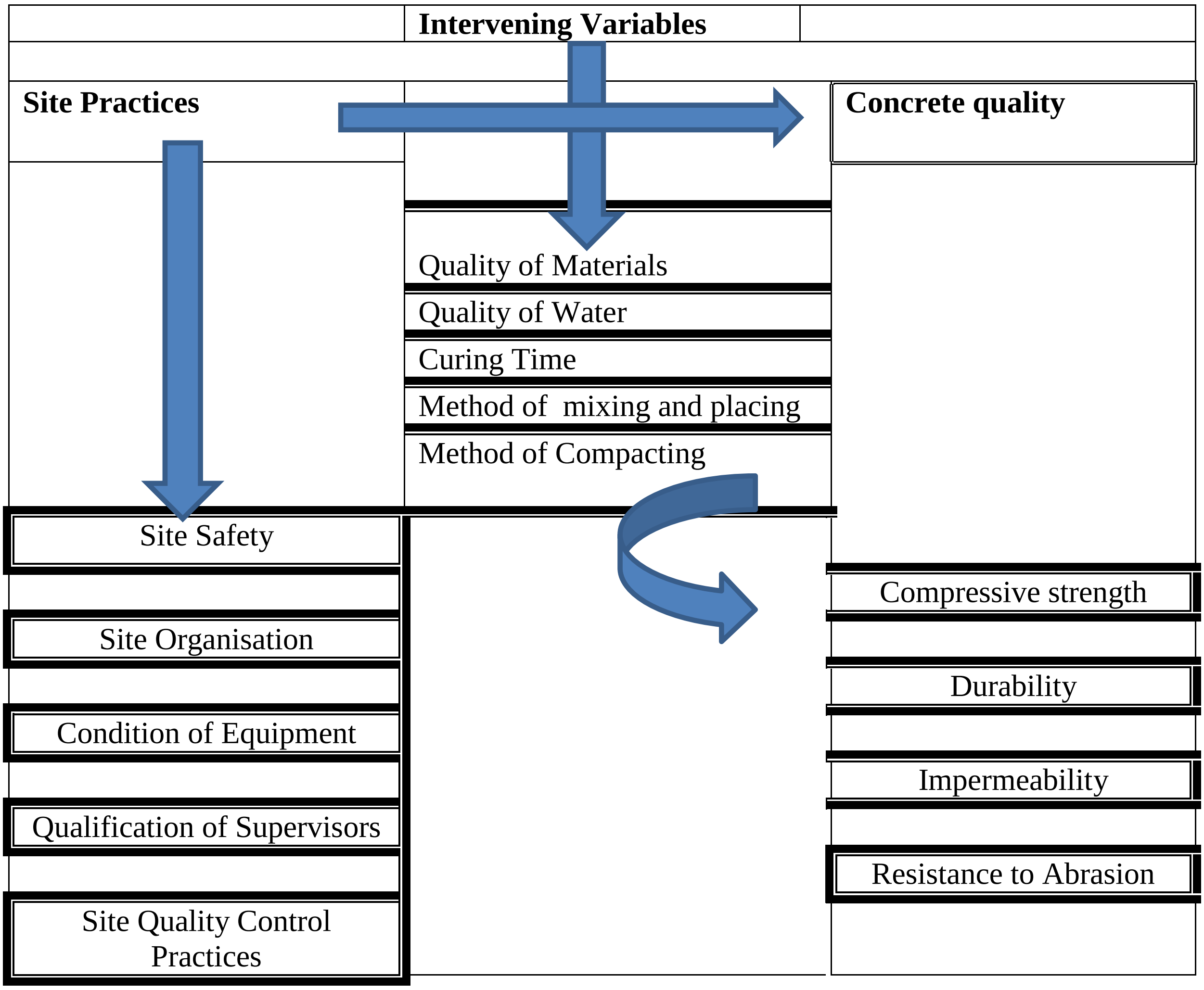

Figure 2.9: *Conceptual framework for the relationship between site practices and Concrete quality.*

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

The methodology applied in this research was tailored to ensure the capture and documentation of actual field in-situ concrete production exercises for the sampled contractors. The practices and information of interest were site safety, site organisation, availability of design information on site, condition of equipment and education level of the works supervisors. Test parameters of interest were Slump measurement, Water cement ratio and Laboratory Cube strengths results for concrete so produced.

3.1 Research Design

This study was conducted through field observations of the practices and conditions of in-situ Concrete production, site procedures/processes and analysis of 28 day compressive strengths of concrete so produced which were then compared to the design target mean strength; in this case 25N/mm2. The study utilized case study to improve the concentration of study population location and thus improving the relevance of the research findings. Additionally, such an approach allows for research flexibility allowing the researcher to explore and provide an in-depth analysis into a phenomenon in its real-life context (Quinlan et al, 2019). The researcher's target were contractors falling under category NCA5 up to NCA8. This class of contractors is mostly found to be producing concrete on site with basic concreting equipment. It is recognised that Concrete Quality is influenced by many factors including material quality, method of mixing, method of compaction and other factors like workability.

The study sought to document site practices and evaluate quality control measures being undertaken by the contractors under the following considerations;

Site Conditions focusing on; Site Safety, Site Organisation, and Condition of equipment. Technical information focussing on; Supervision capacity, Quality controls measures in regard to Materials, accuracy of batching, available site equipment and adherence to key mix design parameters such as water- cement ratio, slump measurement and Design information available on site.

A check list (See Appendix 01) of quality control practices was prepared to enable the researcher document adherence or otherwise to these important quality control measures and then evaluates the compressive strengths being achieved against the design target mean strengths.

3.2 Study Population

The sample Population will consist of selected contractors who are producing concrete through manual batching. According to the current NCA register of Building contractors (NCA, 2017) the numbers in each category are as in table 5. The study focused on category NCA5 to NCA8 contractors observed to be applying mostly stationery and basic concreting equipment and volumetric batching – this is the target population (see table 3.1).

Table 3.1: NCA 1 to NCA 8 Contractors

Category	Roads	Water	Building	Electrical	Machine	Total
NCA 1	118	70	182	90	52	513
NCA 2	83	47	143	21	22	318
NCA 3	189	110	231	47	21	22
NCA 4	699	119	723	195	74	2115
NCA 5	652	344	797	261	55	2049
NCA 6	1438	488	1806	378	86	4198
NCA 7	2681	566	2537	320	84	6238
NCA 8	1054	266	1094	65	45	2524
TOTAL	6914	2310	7570	1317	456	18551

Table 3.2: NCA 5 to NCA 8 Contractors under building category

Category	Building
NCA 5	797
NCA 6	1806
NCA 7	2537
NCA 8	1094
TOTAL	6234

Source: NCA records, (2017)

3.3 Sample Size and Sampling Procedure

A sample in this research is a portion of the target population. The purpose of sampling is to secure a representation from the population which enables a researcher to gain information about a population. The sample size suitable for this study was calculated by using Taro Yamane formula with 95% confidence level, AlKalbani et al, (2016). The target population in this research is the 6234 contractors (see appendix 4), from the data of NCA 5 to NCA 8 under building category NCA (2017). The calculation formula of Taro Yamane is presented as follows.

Equation 3.1: Sample size

Where: n = sample size required

N = number in the population

e = allowable error (%)

$$n = \frac{N}{1 + N(e)^2}$$

$$n = \frac{6234}{1+6234(0.05)^2} = 375 \text{ Contractors}$$

The last stage of sampling, the study utilized 30% through purposive sampling. 30% of 375 is 112.5 rounded off to 113 contractors. The research further targets two cubes per contractor on a random sampling basis, the cubes being taken during a concrete pouring exercise where the researcher is present. This results to a minimum sample population of 226 cubes. Additionally, the researcher added 10% to the sample size to cater for outliers in the observed values. This raised the sample size to approximately 124 contractors hence 248 cubes. Participating contractor identification was determined using an approximation of their respective category proportion to the entire population of contractors in Nairobi and its environment categorises as NCA 5-8. This ensured that all the required categories were evenly covered while maintaining the normality of the obtained sample population.

The study utilized multi-level sampling at the various research population sampling stages and data collection procedure. As argued by Sedgwick (2015), multistage sampling is suitable in studies that draw their sample population from more than one level of selection. The study drew the sampled contractors from categories 5 to 8 according to NCA ranking making multistage sampling suitable for application. Multi-level sampling was also preferred based on the nature of the research population and the need to obtain a sample that fairly presents the entire population with the desired features. In the first stage, typical case sampling was utilized to filter contractors to NCA category 5 to 8 from the entire contractors' population in the country. Typical case sampling is a purposive sampling method which is significant when one wants to study a specific trend or phenomenon from the average members of a particular population (Taherdoost, 2016).

Random sampling was used in the selection of two cubes from the contractors. Two cubes were randomly taken during the concreting operation on site. Random sampling was used to improve the independence of both the sample population as well as the collected data (Setia, 2016). Additionally, it enhances a fair representation of the entire population while in the present case, lowering possible errors that could have been experienced from the application of purposive sampling in determining the best probable percentage of the calculate sample population (Alvi, 2016).

Stratified random sampling technique was also used in the selection of contractor to ensure that each NCA category from 5 to 8 was well represented in the final sample. This method was selected to add up to purposive sampling as the tier in multi-level sampling step one. This was necessary for proper representation bearing in mind that NCA categorization look into years of experience, volume of works done, technical staff capacity, and financial capability among others. For this reason, stratified random sampling ensured that each category was adequately represented (Taherdoost, 2016).

3.4.1 Assessment Rating

i) Site Safety

Various features were considered under site safety. The site safety score in each of the considered area indicated how safe the site was to all its stakeholders. The development of a list of the most significant site safety variables was founded by literature review theories as well as from the study by Hardison, et al (2014). In the study, the following features were considered and evaluated to rate the safety of a construction site in order of their significance: These factors were; presence of safety officer on site, full PPEs', adequate site sanitation, adequate safety signage, presence of equipped first aid kit, safe working distance from moving equipment such as rotating concrete mixer, and availability of clean drinking water. Site score rating ranged between 0 and 20 with the following grading system being applied.

Score Grading	15- 20	=	Good
	10- 15	=	Fair
	Below 10	=	Poor

ii) Site Organisation

Site organisation has great bearing on the achievement of good quality concrete. It affects workers comfort, sense of safety and efficiency of the production process. How a construction site was organised was identified as a significant contributor to the overall quality of the project implementation process and which herein includes concrete strength versus standard strength (Boyle, 2017). The following features were considered under site organisation; Arrangement of the ingredient materials stockpiles, adequacy of space for free movement, smooth flow of materials inputs and outputs and site hoarding. The maximum score under site organisation a construction site could manage was 10 and the following grading system was used.

Score Grading	6 – 10	=	Good
	4-5	=	Fair
	Below 4	=	Poor

iii) Materials Testing

Methods used to test materials used in a construction determine the quality of the final product (Larsen et al, 2015). In this study, the researcher made a checklist of the most critical quality control practices in regard to materials testing that have an impact on concrete quality.

The quality rating scale was formulated which scored from 0 to a maximum of 15 points. The following is an illustration of the areas tested under material testing variable with an inclusion of important test conducted where possible and the grading system used.

Items	**Important tests**
Sand	Constant source, Grading, Fineness and silt content
Ballast	Constant source, Grading, ACV,
Water	Salt content and turbidity
Cubes are taken	
Slump being measured	
Water Cement ratio Recorded	

Materials testing score card: 10 – 15 = Good
6-9 = Fair
Below 5 = poor

iv) Level of Site Supervision

Professional site supervision has a significant contribution to the success and quality of a project (Marzouk & El-Rasas, 2014). In the present study, supervisor’s level of education:

graduate, diploma, certificate, and mason were used to determine the quality of supervision offered rated as very good, good, fair, and poor respectively.

v) Availability of Design Information on Site

Presence of design information in a construction site influences the ability of site workers to adhere to the set plans as proposed by the designer. Rosengaus, Levy & Bhaskar (2015) argue that site information has a significant impact on the quality of structures constructed. The current study used the following factors to evaluate presence of design information on site and the grading system used.

Information: Mix Design, Sources of Materials, Grading (Aggregates), and Water Cement ratio.

Grading	4-5	Good
	2-3	Fair
	0-1	Poor

vi) Availability and Condition of Tools & Equipment

The condition of tools and equipment used in a construction project have an imperative impact on the quality of the work done and consequently the quality of structure constructed (Walker, 2015). The present study evaluated the following site tools and equipment characteristics for the current factor: weighing machine on site, calibrated batching containers, mixer in good condition, cube soak tank available, and wheelbarrows in good condition. With a maximum score of 10, the following grading system was used;

Grading	6 – 10	=	Good
	4 - 5	=	Fair
	Below 4	=	Poor

vii) Fresh Concrete Quality Control Measures

The production of fresh concrete was identified a significant factor contributing to achieving the desired concrete strength in the previous chapter. Additionally, Kumar & Morawska (2014) found in their study that use of fresh concrete results in more quality structures compare to recycled concrete. The following features were evaluated under the ability of a site to apply fresh concrete quality control measures: cubes being taken, slump being, measured, and water cement ratio adhered to.

3.4.2 Questionnaire

The study used structured questionnaires and interviews to collect information. These data collection instruments were administered to site supervisors and/or foremen. The choice of structured questionnaires was enhanced by their simplicity in large population data collection as well as data coding and interpretation (McIntosh & Morse, 2015). On the other hand, interviews were carried out on site supervisors found on the sampled sites which helped get detailed information as well as providing avenue for seeking clarification in addition to the questionnaires they were asked to file. According to Creswell & Creswell (2017), the application of multiple data collection techniques helps in providing additional support to findings as well as neutralizing the limitations of individual methods. The questionnaire was geared to collection of factual information e.g. finding out the education level of the supervisor, prevalent method of batching and the existence of other factors that do affect the strength of concrete.

3.4.3 Questionnaire and Field Observations

Quality Management for concrete works starts at the design stage (mix design), then moves to specification and finally field quality control. Field quality control in this regard does not only focus on the materials and concrete quality achieved but also considers the working condition of workers; their safety concerns, the level of supervision and the protection of the environment. For this reason, it was necessary to verify all these aspects of quality management through actual observation of site concrete production operations. For this research therefore, field observations also sought to identify how well each of these aspects of quality management is addressed.

3.4.4 Field Observations.

Appendix 01 details the complete check list of the field observations made for all the sampled contractors. The checklist covered materials, supervision and key technical quality control aspects. The other factors documented included; Level of Site safety, Site layout and working conditions, and Design information available at the site

3.5 Data Analysis and Presentation

Available Data from the selected category of contractors was statistically analysed to determine the variance between the strength achieved and the target mean strengths for this class of concrete after 28 days of curing. The variance was tested for 95% the level of significance.

3.5.1 Research Instruments

The Instruments for this research are basically field data capturing tools including, Field Note books, Camera for onsite photography of concreting operations and Laboratory data recording materials. According to Parsons, Teare, & Sitch, (2018), unit of analysis refers to the subject or phenomenon being studies and analysed in a research study while the unit of observation refers to the elements or subjects being used to study the unit of analysis and it is usually its subset. In the current research, the strength of site-mixed concrete was measured using the laboratory compressive strengths for cubes from the sampled sites. Therefore, cube compressive strength was used as the unit of analysis/measurement while ratings on site practices were used as the units of observation.

3.5.2 Data Management

Laboratory results of compressive strength of cubes from the selected contractors will be carefully recorded ensuring that they belong to the contractors under investigation. The same will be tabulated to enable statistical analysis.

3.5.3 Limitations of the Research

Contractors will generally want to protect their activities from intrusion by “outsiders”. This creates some barriers in terms of information disclosures by supervisors. The nature of repercussions spelt out by job specifications may make Contractors not to disclose accurate results of their works. It is therefore possible that some results may not be accurately reported by the Laboratories. It is also possible that concrete samples tested may not represent the whole concrete pour. Time is also always a major limitation. Time to visit the contractors especially when they are concreting made the researcher’s sample size lower than would have been ideal.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

The objectives of this research were to identify the in-situ concrete production practices on sites, to establish the compressive strength achieved and compare them with target mean strength and finally to determine the relationship between the compressive strength achieved and site practices. Through a check list, quality control practices and adherence to design criterion on sites was documented on all the sampled sites.

The study investigated contractors falling under NCA category NCA5 to NCA8 who are located within Nairobi City county and its environs. Key practices investigated includes site safety, site organisation, availability of design information on site, conditions of equipment, educational level of the site supervisors and adherence to key quality control practices for fresh concrete production. The site supervisor for each site was interviewed and answered a questionnaire (See Appendix 02).

Laboratory compressive strengths (after 28 day) for each of the concrete produced during the site visited were recorded. Two results for each contractor were recorded and an average of the two taken. The observed practices for each contractor were finally correlated with the achieved average bearing strength of Concrete so produced. The study specifically dealt with Building projects ranging from Flats, industrial buildings, institutional buildings and single dwellings. Data was collected for class 25 concrete works mainly form substructure concrete, columns, beams, and suspended slabs. The data collected was analysed using descriptive and inferential statistical analysis method using SPSS.

4.2 Data Presentation and Analysis of Results

One hundred and twenty four contractors were originally sampled with 116 responding to questions and giving the required information and availing their cube strength records after 28 days. This gave a 93.55% response rate. The high response rate was attributed to the fact that the researcher visited the sites and had the questionnaire answered to during the visits. Appendix 03 gives the summary of all key observations and average compressive strengths for each contractor sampled.

4.2.1 Identifying the In-Situ Concrete Production Practices on Site

The following table summarised observation in regard to quality control practices.

Table 4.1: % of contractors performing critical quality control measures.

		% Age	Importance
Type of batching	Volume	96	Design mix call for weight batching
	Weight	4	
Cubes	Taken	84	Cubes are mandatory quality control requirements
	Not taken	16	
Water cement Ratio	Recorded	3	Water cement ratio is a major strength determinant in fresh concrete
	Not recorded	97	
Slump test	Taken	0.42	Slump test is a good indicator of workability
	Not taken	99.59	
Batching containers	Calibrated	0.2	Calibration is mandatory for batching accuracy
	Not calibrated	98	
Weighing scale	Available	0	Weighing is necessary to achieve accurate Batching
	Not available	100	
Curing tank on site	Available	78	A curing tank is necessary on site if sample is not transferred to the lab. Within 12 hours
	Not available	21	

From the above summary, it is observed that most of the batching is being done by volume as opposed to weight. Volume batching requires adjustment of quantities to account for the varying densities for the ingredients. Where the same size of batching container (mostly 20 litre plastic paint tins) instruments is used as observed in the majority of the sites, there is an assumption that the materials have the same density, which is technically incorrect and can lead to errors. This clearly is in conflict with the principles of mix design.

Measurement of **Water- cements ratio and Slump which were important test parameters being sought for were not being done by most of the contractors, which is a major indicator to poor quality control** of in-situ concrete production. Generally many critical factors in quality control were not being practiced by majority of the contractors. This is a clear signal of compromise in quality of concrete being produced (Neville, 1981). Where there is no control of amount of water being added, workers will tend to go for easy flowing mixes which are easier to handle. This will mean higher water- Cement ratios which ultimately lead to weak concrete. According to Jackson and Dhir (1988), the connection between water-concrete proportion and solid quality is non-direct and varieties in water concrete proportion will influence solid quality.

Due to the above shortcomings, the researcher therefore narrowed on concrete compressive strength as the main quality aspect criteria. Observed practices were then correlated to the achieved strength.

Majority of the contractors were found to be using uncalibrated containers for batching, with the 20 litre plastic and/or metallic paint tins being the most commonly used. This is mostly due to their availability and their cost. No evidence was visible of any attempt to calibrate these containers to ensure uniformity in ingredient quantities when batching. This results in workers feeding differing proportions of ingredients into the concrete mixer. The consequence of such practice is poor quality control as a result of inconsistences within a batch and from batch to batch leading to inconsistencies in strength. This practice was observed to be more of the norm among majority of the contractors and hence a matter of concern. This is an area that needs urgent addressing in order to ensure improved quality control and adherence to standards.

4.2.2 Site Organisation

Based on the key considerations in section 3.5 of research methodology contractors were rated (graded) as either Good fair or poor. The figure below shows the distribution of performance of the contractors.

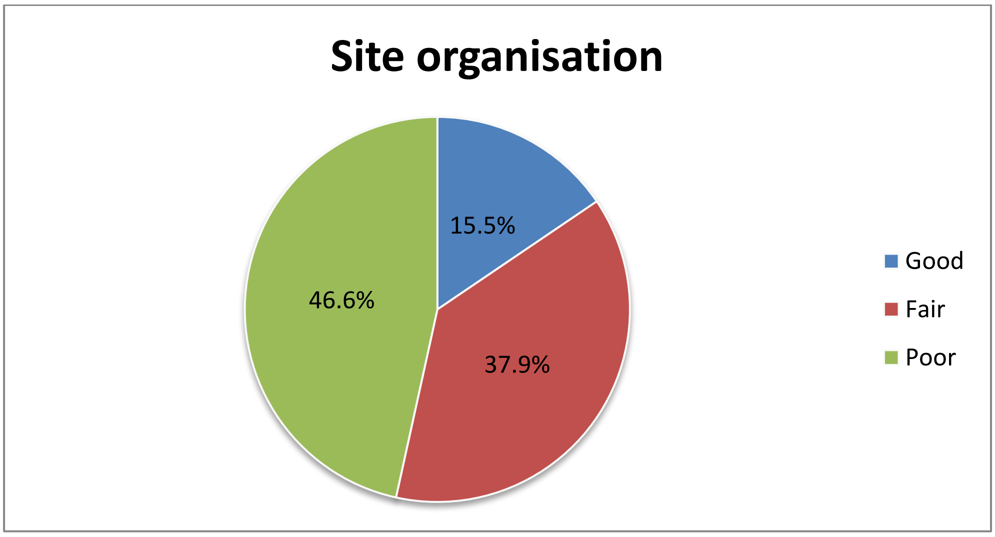

Figure 4.1: Contractors performance on Site organisation

It is noted that 46.6% of the contractors scored poorly in regard to site organisation. As discussed earlier, site layout affects the overall concrete production flow process. Poorly laid out sites will lead to poor control, loss of time, and unnecessary wastages. Workers safety is compromised where sites are not properly planned. Disorganised sites lead to congestion; increases risk of collisions, affect lighting and leads to workers lifting beyond their ability over distances. This also leads to dangerous handling manoeuvres that can lead to injuries. All this is in contravention of the Occupational Safety and Health Act 2007, (OSHA 3, 2(2007) which sets objectives to promote and improve the occupational safety and health standards. In the workplace

4.2.3 Site safety

Similarly, based on a similar rating criterion as good, fair or poor, formulated in section 3.5 of the preceding chapter, the following figure 6 below summarises the performance in regard to safety for the Contractors sampled.

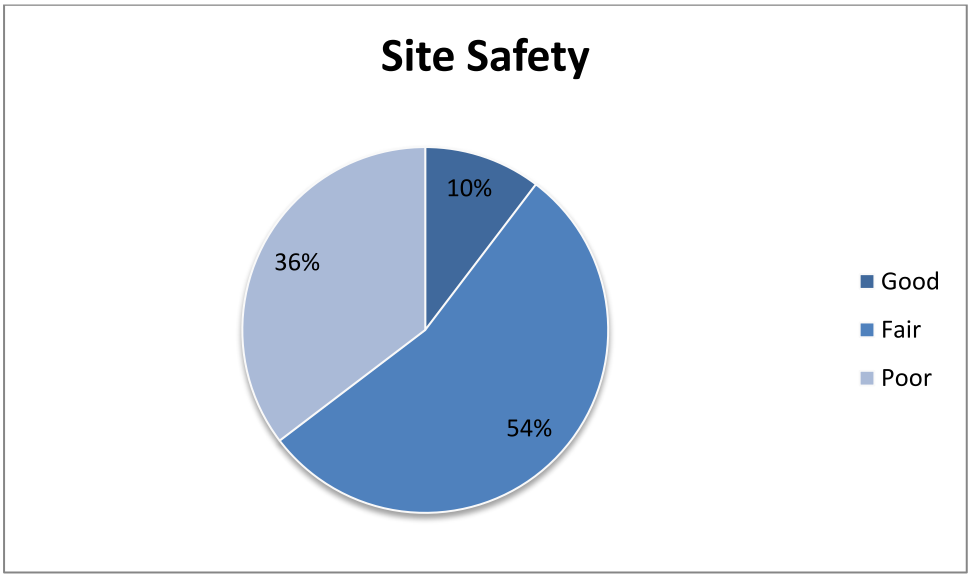

Figure 4.2: Contractors performance on Site Safety

It is observed that majority (54%) of the sites fared poorly in respects to Site Safety. Compromised site safety leads to accidents, near misses and at times fatalities. This results in lost time, lost productivity and at times loss of human life. These factors are likely to have negative effects on the quality of concrete being produced.

Some of the unsafe practices observed includes, overcrowding leading to frequent collisions by workers, working very close to moving equipment, luck of protective gear and exposure to fumes from concrete mixers and poker vibrators. This compromised safety, affects workers wellbeing, concentration and state of alertness. This is likely to affect the accuracy of batching. Compromised batching is a precursor to poor quality of concrete.

Observance of the requirement of Occupation Health and Safety (OSHA) Act 2007, No 15 is meant to ensure health, safety and welfare of workers at the workplace. This is not being observed. It is apparent that in regard to safety, a large number of sites are unsafe. In their study Kinyanjui and Mitulla (1999) noted that most of the workers in construction sites are employed as casual workers and work under troublesome and perilous conditions without any advantages.

A common practice in manual concrete production operations is the manual lifting of concrete ingredients to feed into the mixer. ISO Standard 11228 part1 gives the recommended lifting limits for workers. This standard stipulates the mass for two handed lifting under ideal conditions at, 25kg for 95% of males and 15Kg for 99% of females. In our construction sites (where we now have increasing number of females being involved) the female workers are expected to lift the same 20kg tin as men which is beyond what is stipulated by the above ISO Standards.

4.2.4 Condition of Equipment

The criteria for grading the contractor's performance on equipment was laid out in the chapter on methodology, which took in account factors such as age of the machinery and state of repair. On the Condition of equipment, it was observed that majority (82%) are using equipment in poor to fair condition; while 18% have good equipment (see Figure 7 below). Poor condition of equipment is a contributor to inefficiency and accuracy and ultimately quality of fresh Concrete being produced. A concrete mixer and/or vibrator in poor condition will tend to cause stoppages, and lead to uneven mixing of ingredients and inconsistencies in the mix. Stoppages will also lead to premature setting which results in poor quality of concrete. Unserviced equipment will tend to emit smoke which is detrimental to both personnel and the environment due to smoke emissions.

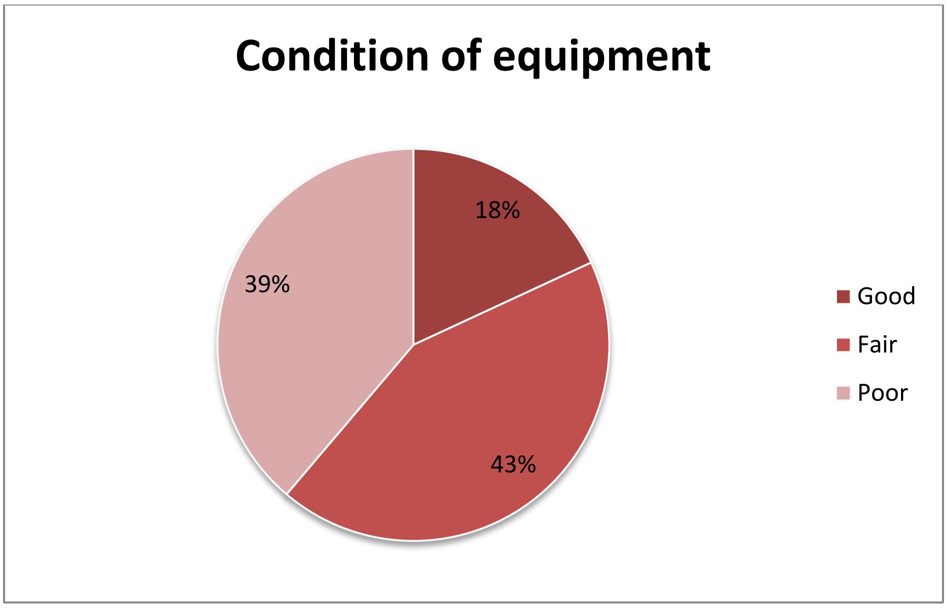

Figure 4.3: Contractors performance on Condition of Equipment

4.2.5 Qualification of Supervisory Staff

Majority of Sites are supervised by personnel with Certificate and Diploma qualifications. While a small proportion being supervised by university graduates (Figure 8). Certificate holders are less likely to strictly adhere to appropriate site practises as they are less certain on its implications on the quality of concrete.

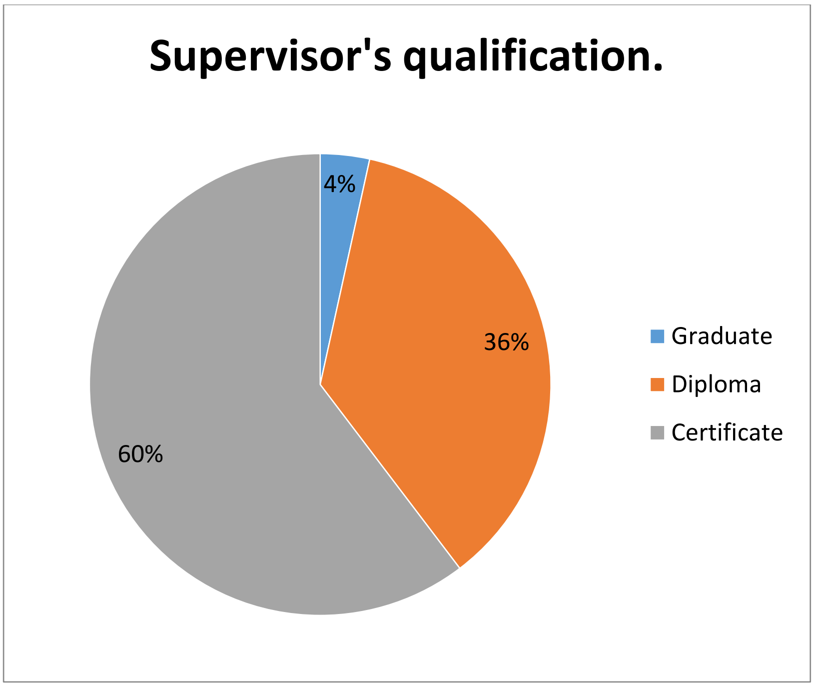

Figure 4.4: Distribution of supervisors' qualification

4.2.6 Design information availability

Table 4.2: Design information available on site

	No of Sites		
Design information	**Availability**	**Not available.**	**Remarks**
Project Mix Design information on site	8	108	Control is compromised
Knowledge of Class of concrete	110	6	
Type of cement as per mix design	110	6	
Grading curves for Aggregates	6	110	
Type/Source of aggregates	89	27	No adherence to design mix criteria
Source of water	72	44	Water quality may affect quality of Concrete
Data on Quality of water	Nil	116	Ditto
Actual design Water Cement Ratio	6	110	Control is compromised hence quality is in doubt
Aggregate to Cement Ratio	6	110	Ditto

It was observed that very little design information is maintained on project sites. Good quality control of concrete requires observance of design regimes on site. This data is necessary for continuous frequent comparison with achieved parameters as work progresses. Factors such as water cement ratio, water quality and grading of aggregates requires displaying so that site supervisors can constantly compare with achieved data. It is also important that control data is understood and correctly interpreted by site supervisory staff. This is the responsibility mainly lies with the consulting team who oversee project implementation. Some of the data expected to be readily available (displayed) on site includes grading curves and mix design information.

Table 4.3: Critical Field quality control measures

	% of Contractors
Cubes being taken	94%
Slump being Measured	3%
Water cement ratio adhered to	0.4%

Majority of contractors are observed to be taking concrete cubes for compressive strength tests. It was also observed that Slump was taken by only 3% of the contractors sampled. Water cement ratio is not recorded by majority of the contractors. This is an indication that workability is not being critically monitored. Without control of water – Cement ratio, it is very likely that workers will tend to add more water than required to make mixing, and handling of the concrete easier for them. This definitely compromises strength. Cubes tests, slump measurement and adherence to design water – cement ratios are critical site quality control requirements for any concrete production.

4.3 Compressive Strength Achieved and Comparison with the Target Mean Strength

In line with the objectives of the research, Correlation analysis was done to determine whether there was significant relationship between average strength achieved and NCA category, Site Organization, Site Safety, and Equipment Condition. Since the characteristics were described qualitatively, the researcher developed coding to convert the variables into numerical data. NCA categories were coded 1, 2, 3, and 4 for categories 5, 6, 7, and 8 respectively. For the other characteristic variables, poor, fair, and good were assigned the values 1, 2, and 3 respectively.

4.4 Determining the Relationship between Compressive Strength Achieved and Site Practices

It was observed that there is a slight increase in average compressive strength as the category of contractor increases (improves).

Table 4.4: Average Compressive Strength and NCA Category

		Average Strength	NCA Category
Average Strength	Pearson Correlation	1	-.154
	Sig. (2-tailed)		.098
	N	116	116
NCA Category	Pearson Correlation	-.154	1
	Sig. (2-tailed)	.098	
	N	116	116

Correlation analysis between NCA Category and Contractor's average strength indicated a negative relationship. This implies that increase in NCA category (lowering of category) results in reduction in contractor's concrete average strength. However, the results are not statistically significant since the obtained p-value (0.098) was greater than the alpha value (0.05).

4.4.1 Site Organization and Average Compressive Strength

More organized sites recorded a very slight increase in average Compressive strength achieved.

Table 4.5: Average Strength and Site Organisation

		Average Strength	Site Organisation
Average Strength	Pearson Correlation	1	.087
	Sig. (2-tailed)		.352
	N	116	116
Site Organisation	Pearson Correlation	.087	1
	Sig. (2-tailed)	.352	
	N	116	116

Correlation analysis between contractors sampled cubes average strength and Site organization showed a weak positive relationship. This indicates that increase in site organization rating leads to slight increase in contractor's concrete average strength. However, the findings are not statistically significant since the p-value obtained (0.352) was greater than the applied alpha level (0.05). The following figure illustrates a typical site operations and organisation in Nairobi during concreting.

Plate 4.1: Concreting operation in progress at a site in Nairobi.

[Notice the batching tools in use.]

4.4.2 Site Safety and Average Compressive Strength.

From the observed rating for site Safety, it was observed that there is a slight increase in achieved Compressive strength for those Contractors exhibiting better site safety rating.

Table 4.6: Average strength and Site Safety

		Average Strength	Site Safety
Average Strength	Pearson Correlation	1	.163
	Sig. (2-tailed)		.081
	N	116	116
Site Safety	Pearson Correlation	.163	1
	Sig. (2-tailed)	.081	
	N	116	116

Correlation analysis between contractor's average strength and site safety showed a weak positive relationship. Though the results were not statistically significant, they imply that an increase in site safety rating impacts a slight increase in the contractor's average compressive strength.

4.4.3 Equipment Condition and Average Compressive Strength

On account of Equipment Condition, significantly Better strengths were observed where the Contractor's rating on equipment was is higher.

Table 4.7: Average Strength and Condition of Equipment

		Average Strength	Equipment Condition
Average Strength	Pearson Correlation	1	.215*
	Sig. (2-tailed)		.021
	N	116	116
Equipment Condition	Pearson Correlation	.215*	1
	Sig. (2-tailed)	.021	
	N	116	116

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation analysis between contractor's average strength and equipment condition indicated an average positive relationship. The results indicate that an increase in equipment condition rating indicates an increase in contractor's average strength. Additionally, the results were statistically significant since the obtained p-value (0.021) was less than the used confidence interval (0.05).

Table 4.8: Test of Normality- Descriptive

			Statistic	Std. Error
estimated 28-day strength	Mean		24.2295	.27203
	95% Confidence Interval for Mean	Lower Bound	23.6936	
		Upper Bound	24.7653	
	5% Trimmed Mean		24.2678	
	Median		25.3000	
	Variance		18.056	
	Std. Deviation		4.24924	
	Minimum		12.50	
	Maximum		36.50	
	Range		24.00	
	Interquartile Range		6.34	
	Skewness		-.193	.156
	Kurtosis		.140	.310

Table 4.9: Tests of Normality- Shapiro-wilk test of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
estimated 28-day strength	.104	244	.150	.969	244	.203

a. Lilliefors Significance Correction

Inferential tests like t-test requires that the data used is normally distributed. The above test was conducted to ensure that this assumption is not violated in succeeding tests. Given the study involves a small dataset use Shapiro-Wilk test for normality is most appropriate. Since the p-value (0.203) is greater than the alpha value (0.05) it is concluded that the data comes from a normal distribution. Data normality confirmation allowed the researcher to use the data in conducting inferential analysis and using the results obtained from such analysis to develop conclusions.

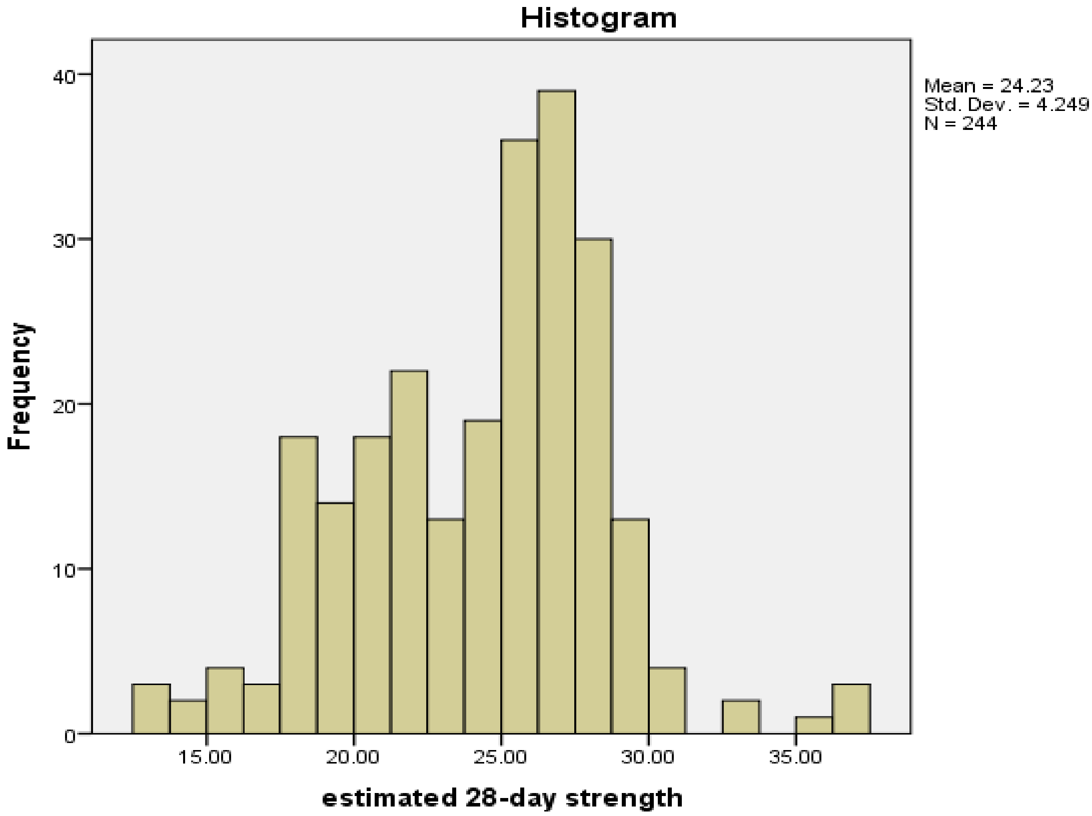

Figure 4.5: Plot of the distribution of 28day strengths for sampled cubes

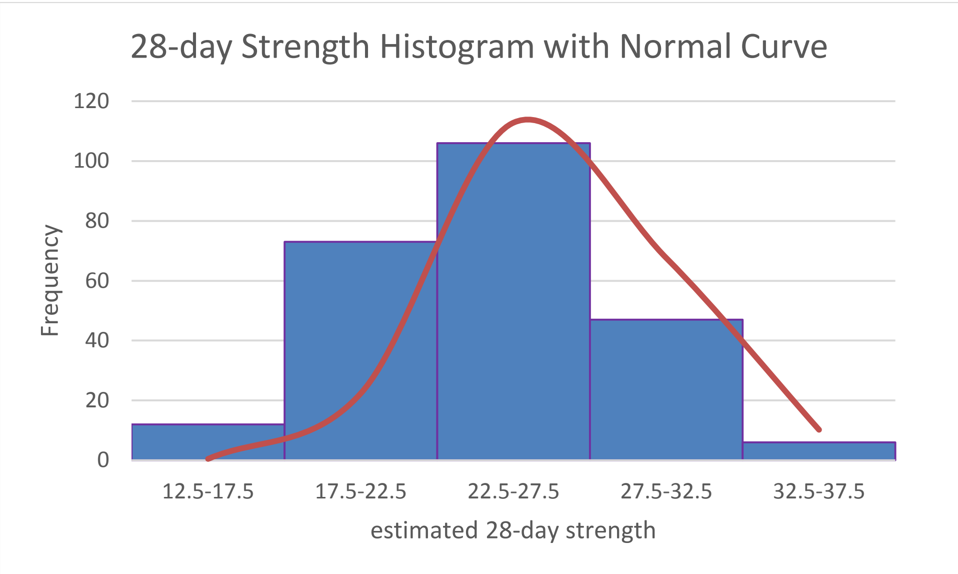

Figure 4.6: Plot of deviation from the normal for observed values

As can be seen in figures 9 and 10 above, the concrete cube samples tested show a normal distribution. This indicates that the samples taken represent a real field occurrence as is expected when sampling many contractors. It is therefore an indication that the sampling was not biased. The use of t-test was also appropriate in this case.

4.5 Hypothesis Testing

Table 4.10: One Sample T-Test

	Test Value = 25					
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
estimated 28-day strength	-2.833	243	.005	-.77053	-1.3064	-.2347

One sample t-test compares the sample mean strength with the hypothesized population mean strength of 25N/mm2 (the test value). The test, therefore, evaluates whether the sample mean is significantly different from the hypothesized mean (test value, 25). The null hypothesis is that the samples mean and the hypothesized mean are equal. The alternate hypothesis is that the two means are different (not equal). ***The obtained p-value (0.005) is less than the alpha value 0.05 (95% CI). Therefore, we reject the null hypothesis that the sample mean is equal to the hypothesized population mean of 25. We conclude that the mean strength of the sampled cubes is significantly different (lower) than the average expected strength of 25 N/mm2.***

The control chart in Figure 11, shows how the observed values deviated from the mean (average 24.2295), the lower control limit (LCL) and the upper control limit (UCL). From this figure the outliers can be clearly observed. The strength requirements of concrete are generally specified in terms of a characteristic strength as per BS 8110- Part 1, coupled with requirements that the strength falling below this shall not exceed a certain value. Typically, this may be 5% or 1 in 20 chances of a strength falling below the specified characteristic strength for 28-day strength. (Refer to Table 4)***. This variation in strength indicates poor quality control of concrete production in our sites. It further indicates inconsistencies which may be attributed to the observed shortcomings in regard to site practices. Concrete strengths that are significantly lower that the target mean strength are an indicator of some of the reasons that could lead to collapse of buildings reduced durability, and high porosity of concrete in use. Strength values higher than the target mean strength may be an indication of materials wastage and poor batching control.***

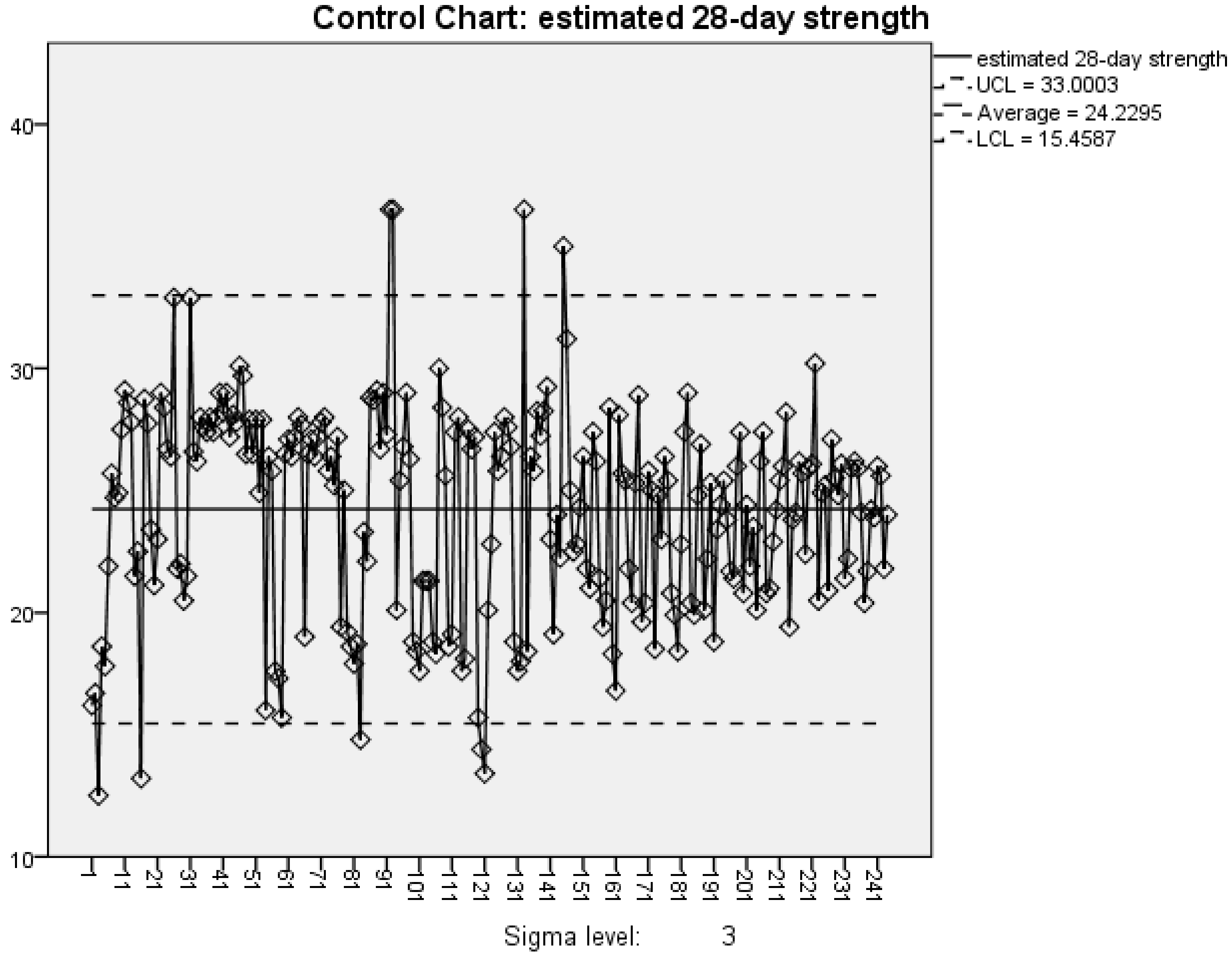

Figure 4.7: Control chart for the estimated 28-day strength

4.6 Chapter Summary

It is observed that for the average contractor under the category in consideration, significant level of non-adherence to quality control practices is prevalent. This is evident in;

i) Poorly organised sites (46% poor, 37% fair and 15.5% good)

ii) Poor condition of equipment (39% poor, 43% fair and 18% good)

iii) Unsafe working conditions (11% good, 54% fair and 35% poor)

iv) Poor site quality control practices for fresh concrete production.

v) Sizeable number of cases where Concrete is not meeting the required target mean strength

Overall, a high prevalence (90 %) of batching is by volume using various types of un-calibrated containers which compromise batching accuracy. Quality control procedures for fresh concrete are not being adhered to, including weight batching, recording of water-cement ratio, slump measurement and display of design data on site.

From the analysis of Compressive strengths of concrete sampled, it is concluded that there is a significant variation of concrete being produced (mean of 24.222N/mm2) against the target mean strength of 25 N/mm2. This is significant in that concrete is a critical component in most buildings.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall aim of this research was to investigate key site practices with a view to assessing their effects on in-situ concrete production in construction sites in Nairobi City County and its environs. The specific objectives of the study were to identify the key in-situ concrete production practices on sites; to establish the compressive strength achieved under these conditions and compare this with target mean strength; and to determine the relationship between the compressive strength achieved and site practices.

The following are findings from the exercise.

1. **Critical site practices and their relationship to the strength of concrete**

- ***Site safety:*** 11% of the sampled sites were safe, 54% fair and 35% recorded poor safety practices. It can therefore be concluded that majority of this category of contractors are producing in-situ concrete under fair to poor conditions which potentially compromise site safety and can lead to accidents and can result in in loss of productive time and even loss of lives.
- ***Site organisation:*** 46% of the sampled sites were poorly organised, 37% fairly organised and 15.5% well organised. This can generally be categorised overall as poor performance. Poorly organised sites tend to lead to congestions, loss of time, obstructed movements and compromised batching control that possibly resulted in poor quality control of the in-situ concrete production. Good site organization rating leads to slight increase in contractor's average concrete strength.
- ***Condition of Equipment:*** 39% of the sampled sites were using equipment in poor conditions, 43% had theirs in fair condition while 18% had equipment in good condition. An increase in equipment condition rating indicates an increase in contractor's average strength.
- ***Supervisors' Qualification:*** Majority of sites were supervised by certificate holders (60%), 36% by diploma holders and 4% by university graduates. There was no notable change in the average compressive that could be attributed to any category of supervisor.

2. **Achieved Average compressive strength.**

The range of compressive strength achieved is very wide, ranging from a minimum of 12.50 N/msm2 to a high of 36.50 N/mm2. The average compressive strength achieved was **24.22 N/mm2**. This is found to be lower than the target mean strength of 25N/mm2. This can be attributed to site practices and quality control shortcomings.

3. **Concrete production quality control practices**

As can be seen in the check list (appendix 01) majority of sites are producing concrete in complete disregards to several critical site quality control requirements from the design information such as measurement of water cement ratio, slump measurements and accuracy of batching. Moreover, poor site practices (site safety, site organisation, condition of equipment) were prevalent on the samples sites further exacerbating the situation because although their individual impact was small, together they significant. Accordingly, the Null hypothesis is rejected, and the Alternative hypothesis is adopted that 'In-situ concrete production site practices have a significant effect on the quality of concrete produced'.

5.2 Importance of this study to quality control practices

The process of Concrete mix Design as stipulated by various methods is a stringent procedure which when followed, should result in quality concrete being produced in our sites.

This study has brought out the following important matters.

1. The principles of mix design are not being adhered to and site quality control practices are wanting in majority of sites. The Kenya building industry should review the mix design process with a view to aligning them with our current practices, capacity and material sources.
2. The mix design process is not well understood by the people responsible for actual production of concrete namely site agents or supervisors. This is detrimental to growth of the industry in terms of quality control and points to need for training.
3. Occupation Safety and Health requirements are not adhered to. There is need to ask why this is the case despite the presence of many regulatory agencies.
4. Ongoing review of planning and building legislation should bring together of all the regulatory organs under one umbrella to improve effectiveness of policing adherence to standards in the built environment.

5.3 Recommendations

This research brings to the fore the shortcomings in site in-situ concrete production practices for the sampled category of contractors. The research further amplifies the disconnect between the design mix requirements and the actual practices on site. The following Specific recommendations are hereby outlined.

1. Supervision

Conditions of contract be reviewed to enforce stricter control of site concrete production practices by obligating both contractors and supervising engineers to be more accountable in quality control of in-situ concrete production. Critical quality control practices could include; Measurement of water – Cement ratio and Aggregate- Cement ratio; Measurement of slumps; Regular grading of aggregates as sources change of after certain pre-agreed duration; and Enforcement of minimum education levels for contractor's site agent.

2. Capacity Building and Training for Contractors

Ways should be explored to empower contractors to access basic concreting equipment including availability of affordable and friendly hire facilities. Structured training and monitoring of work supervisors (e.g. by clerks of works) should be more strictly enforced. All supervisors should be knowledgeable on the design mix process and requirements as well as the provisions of Occupation Health and Safety Act (OSHA).

Mandatory preliminary items in the costing of every projects should be provided for, so that the contractors provide adequate facilities and plans to ensure safe and organised sites. The consultants too should be empowered to enforce acceptable levels of compliance.

3. Batching Equipment and quality Control

The construction industry in Kenya should consider standardisation of batching equipment making them mandatory checklist items for approvals before and during execution of structural concrete works. Since design is based on weight batching it should be adopted in the site practice.

5.4 Area of Further Study

i) Weight vs Volume Batching

The findings indicate that most of the Contractors use Volume batching in in-situ concrete production while in most of the literature Weight batching is the recommended method. There is need to explore the difference in strength between these two methods of batching.

ii) Site Safety and Site organisation.

Site Safety and Site organisation are very crucial aspects of site operations. Further research should be carried out to evaluate the effectiveness of existing training in our technical institutions with a view to enhance site supervisor's effectiveness in maintaining organised and safe sites.

References

Adewole, K. K., Ajagbe, W. O., & Arasi, I. A. (2015). Determination of appropriate mix ratios for concrete grades using Nigerian Portland-limestone grades 32.5 and 42.5. *Leonardo Electronic Journal of Practices and Technologies*, *26*, 79-88.

AlKalbani, A., Deng, H., & Kam, B. (2016). Investigating the role of socio-organizational factors in the information security compliance in organizations. *arXiv preprint arXiv:1606.00875*.

Alvi, M. (2016). A manual for selecting sampling techniques in research. [online] Munich *Personal RePEc Archive*. Available at: https://mpra.ub.uni-muenchen.de/70218/ (Accessed May 9 2019)

Batterchajee, B. (2012). *Batching and Mixing of Concrete: General Principles*. [ebook] Delhi: Indian Institute of Technology. Available at: http://textofvideo.nptel.ac.in/105102012/lec19.pdf [Accessed 9 May 2019].

Boyle, G. (2017). *Design project management*. London: Routledge.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks: Sage publications.

Goel, A. K., & Syal, I. C. (2009). *Reinforced Concrete Structures*. New Delhi: S. Chand & Company.

Hedidor, D., & Bondinuba, F. (2017). Exploring Concrete Materials Batching Behaviour of Artisans in Ghana's Informal Construction Sector. *Journal of Civil Engineering and Construction Technology*, Vol. 8(5), pp. 35-52.

Hughes, B. P. (1971). The economic utilization of concrete materials. In *Proceedings of the Symposium on Advances in Concrete, Birmingham 1971*. London: Concrete Society.

Jackson, N., & Dhir, R. K. (1988). *Civil engineering materials*. London: Macmillan.

Kerzner, H. (2017). *Project management: a systems approach to planning, scheduling, and controlling*. Hoboken, N.J.: John Wiley & Sons.

Kong, F. and Evans, R. (1987). *Reinforced and Pre-stressed Concrete, Third Edition*. 3rd ed. CRC Press. Trevor, Y. (1994). *Implementing projects*. Kuala Lumpur: Pelanduk Publications.

Koteng, D. O. (2013, May). Concrete use for sustainable development. In *The 20th Engineers International Conference, Kisumu* (pp. 8-10).

Kumar, P., & Morawska, L. (2014). Recycling concrete: an undiscovered source of ultrafine particles. *Atmospheric Environment*, *90*, 51-58.

Lamka, B. H. V. (2015). *Investigation of factors influencing construction site labour productivity in Nairobi County, Kenya* (Doctoral dissertation, JKUAT).

Larsen, J. K., Shen, G. Q., Lindhard, S. M., & Brunoe, T. D. (2015). Factors affecting schedule delay, cost overrun, and quality level in public construction projects. *Journal of Management in Engineering*, *32*(1), 04015032.

Lockyer, K. G. (1983). *Production management*. Pitman.

Marzouk, M. M., & El-Rasas, T. I. (2014). Analysing delay causes in Egyptian construction projects. *Journal of advanced research*, *5*(1), 49-55.

McCormac, J. C. (2001). *Design of reinforced concrete*. Michigan; John & Wiley.

Method123 (2003). *METHOD 1 2 3 Project Management Guidebook about this e-book*. [ebook] Method123. Available at: https://www.academia.edu/11134148/METHOD_1_2_3_Project_Management_Guidebook_bout_this_e-book [Accessed 9 May 2019].

Murdock, L. J., & Brook, K. M. (1979). *Concrete materials and practice*. London: E. Arnold.

Neville, A. M. (1981). *Properties of concrete*. London: Pitman Pub.

Neville, A. M., & Brooks, J. J. (1987). *Concrete technology* (pp. 242-246). England: Longman Scientific & Technical.

Okumu, V. A., Shitote, S. M., & Oyawa, W. O. (2017). Determination of Appropriate Mix Proportions for the Kenyan Blended Portland Cement Concrete Production. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, *31*(1), 265-286.

Okumu, V., Oyawa, W. O., & Shitote, S. M. (2016, June). The Effect of the Properties of Constituent Materials on the Quality of Concrete in Kenya. In *Proceedings of Sustainable Research and Innovation Conference* (pp. 225-230).

Olusola, K. O., Babafemi, A. J., Umoh, A. A., & Olawuyi, B. J. (2012). Effect of batching methods on the fresh and hardened properties of concrete. *IJRRAS*, 13(13), 773-779.

Parsons, N. R., Teare, M. D., & Sitch, A. J. (2018). Science Forum: Unit of analysis issues in laboratory-based research. *Elife*, *7*, e32486.

PMBOK (2000). A guide to the project management body of knowledge. *Project Management Institute.* Newton Square: PA.

Punmia, D., Jain, A. and Jain, A. (1992). *Reinforced Concrete Structures, Volume 1*. New Delhi: Laxmi Publications (P) Ltd.

Quinlan, C., Babin, B., Carr, J., & Griffin, M. (2019). *Business research methods*. Andover, UK: South Western Cengage.

Rosengaus, E., Levy, A., & Bhaskar, K. (2015). *U.S. Patent No. 9,222,771*. Washington, DC: U.S. Patent and Trademark Office.

Rukwaro, R. (2016). *Ergonomics for Construction Management*.

Sedgwick, P. (2015). Multistage sampling. *BMJ*, *351*, h4155.

Seeley, I. H. (1996). *Building economics: appraisal and control of building design cost and efficiency*. UK: Macmillan International Higher Education.

Setia, M. S. (2016). Methodology series module 5: Sampling strategies. *Indian Journal of Dermatology*, *61*(5), 505-509.

Sinha, S. N. (2014). *Reinforced concrete design*. New York: Tata McGraw-Hill Education.

Taherdoost, H. (2016). Sampling methods in research methodology; how to choose a sampling technique for research. *How to Choose a Sampling Technique for Research (April 10, 2016)*.

Thomas, H. R.,. (2004). Demotivating Factors Influencing The Productivity In The Construction Industry, *International Journal Of Project Managers*. 22(2).

Walker, A. (2015). *Project management in construction*. Chichester, West Sussex, United Kingdom: John Wiley & Sons.

Appendices

Appendix 01: Field observation Check List

	Required Information	Specific Observation (information)Required	Remarks/Findings/
A	**Contractor's Information**		
	Name of Contractor		
	NCA Category		For NCA Category verification
	Physical location of office		County verification
B	**Project Information**		
	Type of Project	Building/ Civil/ water	
C	**Site Safety Information**		
	Safety Signage	Available, and adequate or not	
	Availability of adequate PPEs'	Adequacy of suitable PPEs'	
	Presence of trained safety officer on site	Available/Not available	
	Level of Hoarding	Adequate/ not adequate/None	
D	**Site Organisation**		
	Materials storage	Organised/disorganised	
	Ease of movement	Efficiency and Safety	
	Possibility of Contamination		
E	**Equipment Condition**		
	Condition of Mixer, buckets, wheelbarrows etc.	Conditions and State of repair etc.	
	Level of maintenance	Smoke emittance	
	Noise levels from equipment		
F	**Materials Quality Information**		
	Sand	Quality (grading, silt content), Source	
	Course Aggregates	Quality (grading, ACV)	
	Cement		
	Water	Clean / Tepid /dirty	
	Site Organisation		
	Materials storage	Organized/Dis-organized	
G	**Quality Control Practices**		
	Class of Concrete	Is it Class 25?	

	Water Cement Ratio	Recorded /Not recorded	
	Cubes Samples	Taken/ Not taken	
	Sand Quality	Grading, Silt content tests	
	Course aggregates Quality	Grading, ACV, Sulphate content	
H	**Batching Information**		
	Apparatus		
	Cube mould(s)	Present/Absent	
	Weighing scale	„	
	Slump Measurement apparatus	„	
	Sand Containers	Calibrated/Not calibrated	
	Aggregate Containers	„	
	Cement containers	„	
	Water Container	„	
J	**Curing Information**		
	Curing tank	Present/Absent	
	Curing Location	Site/ Lab	
K	**Site supervisory staff qualification**		
	Graduate (Degree level)		
	Diploma		
	Certificate		
	Craft		
	On the job trained		

Appendix 02: Field Questionnaires

i) What is your level of training (Craft, certificate, diploma or Graduate)? If other please explain here

ii) What site safety measures do you have in place?

iii) Do you carry volume or weight batching?

iv) How do you rations the various proportions?

v) Do you record your water to cement ratios for all of your concreting works?

vi) Do you carry out slump tests? (Please tick)

Yes No

vii) What material quality control tests do you carry on your sand?

(Please tick)

Sieve analysis

Clay and Silt Content

Others (specify)

Viii) What quality control tests do you do on your Course aggregates?

(Pleases tick)

Aggregate crushing value

Grading

Flakiness index

Others (specify)

viii) Which lab do you have your concrete cubes tested?

Appendix 03: Summary of findings

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	Diploma -D	W = Weight			
		Not Available	Certificate- C	V= Volume	N/mm2	N/mm2	N/mm2
			Craft -CR				
			Mason-M				
NAIROBI	NCA5	Not available	D	V	28	26.4	27.2
NAIROBI	NCA5	Not available	D	V	21.3	25.4	23.35
NAIROBI	NCA5	Not available	GR	V	23	29	26
NAIROBI	NCA5	Not available	C	V	29.1	20.1	24.6
NAIROBI	NCA5	Not available	D	W	29.1	20.4	24.75
NAIROBI	NCA5	Available	D	v	21.9	25.5	23.7
NAIROBI	NCA5	Not available	D	v	20.8	21.4	21.1
NAIROBI	NCA5	Not available	D	v	23.4	27.6	25.5
NAIROBI	NCA6	Not available	CR	v	13.2	30	21.6
NAIROBI	NCA6	Not available	CR	v	23.8	26.8	25.3
NAIROBI	NCA6	Not available	C	v	26.8	28	27.4
NAIROBI	NCA6	Not available	D	v	25.7	24	24.85
NAIROBI	NCA6	Not available	CR	-	26.2	22.2	24.2

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
NAIROBI	NCA6	Not available	C	v	27.1	22.4	24.75
NAIROBI	NCA6	Not available	C	v	17.6	18.8	18.2
NAIROBI	NCA6	Not available	CR	v	24.9	25.8	25.35
NAIROBI	NCA6	Not available	C	v	27.2	22.5	24.85
NAIROBI	NCA6	Not available	D	v	18.8	27.9	23.35
NAIROBI	NCA6	Not available	C	v	24.1	26.3	25.2
NAIROBI	NCA7	Not available	CR	v	24.4	25.9	25.15
KIAMBU	NCA7	Not available	CR	v	27.2	28.2	27.7
NAIROBI	NCA7	Not available	CR	v	28.2	27.3	27.75
NAIROBI	NCA7	Not available	C	v	21	19.4	20.2
NAIROBI	NCA7	Not available	C	v	27.4	22.8	25.1
NAIROBI	NCA5	Not available	D	W	18.4	35	26.7
NAIROBI	NCA5	Not available	GR	v	26.7	28.7	27.7
NAIROBI	NCA6	Available	CR	v	27.1	28	27.55
NAIROBI	NCA6	Available	CR	v	25.8	24.2	25

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
NAIROBI	NCA6	Not available	D	v	21.5	26.2	23.85
NAIROBI	NCA6	Not available	D	v	28.1	27.2	27.65
NAIROBI	NCA7	Not available	D	v	24.8	26.4	25.6
KIAMBU	NCA8	Not available	C	v	28.25	27.4	27.825
NAIROBI	NCA5	Not available	D	V	28	27.4	27.7
NAIROBI	NCA5	Not available	C	-	20.8	21.3	21.05
MACHAKOS	NCA6	Not available	C	v	26.1	23.9	25
MACHAKOS	NCA7	Not available	D	v	27.9	19.1	23.5
NAIROBI	NCA7	Not available	C	v	18.1	25.9	22
NAIROBI	NCA7	Not available	D	v	20.5	25	22.75
NAIROBI	NCA7	Not available	CR	v	26	24.9	25.45
NAIROBI	NCA7	Not available	CR	v	18.4	32.9	25.65
NAIROBI	NCA7	Not available	C	v	24.7	26.4	25.55
22-KIAMBU	NCA8	Not available	C	v			0
NAIROBI	NCA5	Not available	D	W	28.4	27.4	27.9
NAIROBI	NCA5	Not available	D	V	26.4	28.4	27.4

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
KIAMBU	NCA5	Not available	D	V	22.9	27.4	25.15
NAIROBI	NCA5	Not available	C	V	22.25	36.5	29.375
NAIROBI	NCA5	Available	C	v	20.4	29.25	24.825
NAIROBI	NCA6	Not available	C	v	21.4	20.8	21.1
NAIROBI	NCA6	Not available	CR	v	28	26.7	27.35
NAIROBI	NCA6	Not available	CR	v	21.5	26.2	23.85
NAIROBI	NCA6	Not available	C	v	28.8	26.9	27.85
NAIROBI	NCA6	Not available	CR	v	17.6	15.7	16.65
NAIROBI	NCA6	Available	CR	-	16.7	17.9	17.3
NAIROBI	NCA7	Available	C	v	24.8	25.9	25.35
NAIROBI	NCA7	Not available	C	v	22.8	28.9	25.85
NAIROBI	NCA7	Available	D	v	25.2	26	25.6
NAIROBI	NCA5	Available	C	V	21.8	20.5	21.15
NAIROBI	NCA6	Available	CR	v	28.1	27.1	27.6
NAIROBI	NCA7	Not available	C	v	26.4	24.1	25.25
NAIROBI	NCA6	Not available	C	v	21.8	25.6	23.7
NAIROBI	NCA6	Available	C	v	22.2	25.7	23.95
NAIROBI	NCA5	Not available	D	V	25.3	26.5	25.9
NAIROBI	NCA5	Not available	C	V	20.1	18.6	19.35
NAIROBI	NCA5	Not available	GR	V	27.4	28.4	27.9
NAIROBI	NCA5	Not available	CR	V	25.4	18.6	22

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
NAIROBI	NCA5	Not available	C	-	12.5	26.5	19.5
NAIROBI	NCA5	Not available	C	V	25.4	22	23.7
NAIROBI	NCA5	Not available	D	V	23.3	27.5	25.4
NAIROBI	NCA5	Not available	C	V	25.4	21.3	23.35
NAIROBI	NCA5	Not available	C	-	28	26.7	27.35
NAIROBI	NCA6	Not available	D	v	27.7	28.75	28.225
NAIROBI	NCA6	Not available	C	v	13.4	30.1	21.75
MACHAKOS	NCA6	Not available	C	v	18.7	27.8	23.25
NAIROBI	NCA6	Not available	D	v	17.6	15.7	16.65
NAIROBI	NCA6	Not available	C	v	24	26.2	25.1
NAIROBI	NCA6	Not available	D	v	18.8	27.8	23.3
NAIROBI	NCA6	Not available	C	v	25.8	21.9	23.85
NAIROBI	NCA6	Not available	D	v	26.2	21.8	24
NAIROBI	NCA6	Not available	D	v	17.8	16.2	17
NAIROBI	NCA6	Not available	CR	v	27.9	19	23.45
NAIROBI	NCA7	Not available	C	v	22.5	27.2	24.85
NAIROBI	NCA7	Not available	CR	v	26.4	24.3	25.35
NAIROBI	NCA7	Not available	D	vivo	18.3	21.13	19.715
NAIROBI	NCA7	Not available	C	v	26.4	24.8	25.6
NAIROBI	NCA7	Not available	D	v	20.5	25	22.75
NAIROBI	NCA7	Not available	D	v	25	26.4	25.7

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
NAIROBI	NCA5	Not available	D	V	27.4	22.8	25.1
NAIROBI	NCA5	Not available	D	V	19	29	24
NAIROBI	NCA5	Not available	D	V	29	19.9	24.45
KIAMBU	NCA5	Not available	C	V	29	23	26
NAIROBI	NCA5	Not available	CR	V	25.3	26.5	25.9
NAIROBI	NCA5	Not available	D	V	22.1	20.1	21.1
NAIROBI	NCA5	Not available	C	V	26.6	28.6	27.6
NAIROBI	NCA5	Not available	C	v	27.5	23.4	25.45
NAIROBI	NCA5	Not available	D	v	29.7	20.4	25.05
NAIROBI	NCA6	Not available	D	-	25.6	21.7	23.65
NAIROBI	NCA6	Not available	CR	v	27.6	23.5	25.55
NAIROBI	NCA6	Not available	D	v	26.1	21.4	23.75
NAIROBI	NCA6	Not available	GR	v	23.8	27.75	25.775
NAIROBI	NCA6	Not available	D	v	30.2	14.4	22.3
NAIROBI	NCA6	Not available	C	v	27.8	23.9	25.85
NAIROBI	NCA6	Not available	D	v	14.8	17.3	16.05
NAIROBI	NCA6	Not available	D	v	24.2	25.7	24.95
NAIROBI	NCA6	Not available	C	v	16	18.6	17.3
NAIROBI	NCA6	Not available	C	v	25.8	21.7	23.75
NAIROBI	NCA7	Not available	CR	v	19.1	29	24.05

Location of Contractor	NCA Category	Design Information	Supervisors Qualification	Batching Method	Cube Strengths		Mean Strength
		Available	**Diploma -D**	**W = Weight**			
		Not Available	**Certificate- C**	**V= Volume**	**N/mm2**	**N/mm2**	**N/mm2**
			Craft -CR				
			Mason-M				
NAIROBI	NCA7	Not available	C	v	27.25	19.2	23.225
NAIROBI	NCA7	Not available	C	v	31.2	18.3	24.75
NAIROBI	NCA7	Not available	CR	v	19.4	21	20.2
NAIROBI	NCA8	Not available	C	v	32.9	18.4	25.65
NAIROBI	NCA8	Not available	C	v	24.4	28.26	26.33
NAIROBI	NCA8	Not available	C	v	36.5	18.5	27.5
KIAMBU	NCA8	Not available	D	v	24.8	25	24.9
NAIROBI	NCA8	Not available	C	v	23	23.8	23.4
NAIROBI	NCA7	Not available	D	v	16.8	18	17.4
NAIROBI	NCA8	Not available	D	v	20.9	19.6	20.25

Appendix 04: Current NCA Contractors Classification

Categories	Classes					
	Roads	Water	Buildings	Electrical	Mechanical	**Total**
NCA1	118	70	182	90	53	**513**
NCA2	83	47	143	21	22	**316**
NCA3	189	110	231	47	21	**598**
NCA4	699	419	728	195	74	**2115**
NCA5	652	344	797	201	55	**2049**
NCA6	1438	488	1808	378	86	**4198**
NCA7	2681	566	2587	320	84	**6238**
NAC8	1054	266	1094	65	45	**2524**
Total	**6914**	**2310**	**7570**	**1317**	**456**	**18,551**

Appendix 05: Analysis of Distribution of Estimated 28-day Strength

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	12.50	1	.4	.4	.4
	13.20	1	.4	.4	.8
	13.40	1	.4	.4	1.2
	14.40	1	.4	.4	1.6
	14.80	1	.4	.4	2.0
	15.70	2	.8	.8	2.9
	16.00	1	.4	.4	3.3
	16.20	1	.4	.4	3.7
	16.70	1	.4	.4	4.1
	16.80	1	.4	.4	4.5
	17.30	1	.4	.4	4.9
	17.60	4	1.6	1.6	6.6
	17.80	1	.4	.4	7.0
	17.90	1	.4	.4	7.4
	18.00	1	.4	.4	7.8
	18.10	1	.4	.4	8.2
	18.30	2	.8	.8	9.0
	18.40	3	1.2	1.2	10.2
	18.50	1	.4	.4	10.7
	18.60	3	1.2	1.2	11.9
	18.70	1	.4	.4	12.3
	18.80	4	1.6	1.6	13.9
	19.00	1	.4	.4	14.3
	19.10	2	.8	.8	15.2
	19.20	1	.4	.4	15.6
	19.40	3	1.2	1.2	16.8
	19.60	1	.4	.4	17.2
	19.90	2	.8	.8	18.0
	20.10	4	1.6	1.6	19.7
	20.40	4	1.6	1.6	21.3
	20.50	3	1.2	1.2	22.5
	20.80	3	1.2	1.2	23.8
	20.90	1	.4	.4	24.2
	21.00	2	.8	.8	25.0

	Frequency	Percent	Valid Percent	Cumulative Percent
21.13	1	.4	.4	25.4
21.30	3	1.2	1.2	26.6
21.40	3	1.2	1.2	27.9
21.50	2	.8	.8	28.7
21.70	2	.8	.8	29.5
21.80	4	1.6	1.6	31.1
21.90	2	.8	.8	32.0
22.00	1	.4	.4	32.4
22.10	1	.4	.4	32.8
22.20	2	.8	.8	33.6
22.25	1	.4	.4	34.0
22.40	1	.4	.4	34.4
22.50	2	.8	.8	35.2
22.80	3	1.2	1.2	36.5
22.90	1	.4	.4	36.9
23.00	3	1.2	1.2	38.1
23.30	1	.4	.4	38.5
23.40	2	.8	.8	39.3
23.50	1	.4	.4	39.8
23.80	2	.8	.8	40.6
23.90	1	.4	.4	41.0
24.00	2	.8	.8	41.8
24.10	2	.8	.8	42.6
24.20	2	.8	.8	43.4
24.30	1	.4	.4	43.9
24.40	2	.8	.8	44.7
24.70	1	.4	.4	45.1
24.80	3	1.2	1.2	46.3
24.90	3	1.2	1.2	47.5
25.00	3	1.2	1.2	48.8
25.20	2	.8	.8	49.6
25.30	2	.8	.8	50.4
25.40	5	2.0	2.0	52.5
25.50	1	.4	.4	52.9
25.60	2	.8	.8	53.7
25.70	3	1.2	1.2	54.9

	Frequency	Percent	Valid Percent	Cumulative Percent
25.80	5	2.0	2.0	57.0
25.90	3	1.2	1.2	58.2
26.00	3	1.2	1.2	59.4
26.10	2	.8	.8	60.2
26.20	5	2.0	2.0	62.3
26.30	1	.4	.4	62.7
26.40	9	3.7	3.7	66.4
26.50	4	1.6	1.6	68.0
26.60	1	.4	.4	68.4
26.70	3	1.2	1.2	69.7
26.80	2	.8	.8	70.5
26.90	1	.4	.4	70.9
27.10	3	1.2	1.2	72.1
27.20	5	2.0	2.0	74.2
27.25	1	.4	.4	74.6
27.30	1	.4	.4	75.0
27.40	8	3.3	3.3	78.3
27.50	2	.8	.8	79.1
27.60	2	.8	.8	79.9
27.70	1	.4	.4	80.3
27.75	1	.4	.4	80.7
27.80	3	1.2	1.2	82.0
27.90	3	1.2	1.2	83.2
28.00	7	2.9	2.9	86.1
28.10	2	.8	.8	86.9
28.20	2	.8	.8	87.7
28.25	1	.4	.4	88.1
28.26	1	.4	.4	88.5
28.40	3	1.2	1.2	89.8
28.60	1	.4	.4	90.2
28.70	1	.4	.4	90.6
28.75	1	.4	.4	91.0
28.80	1	.4	.4	91.4
28.90	1	.4	.4	91.8
29.00	6	2.5	2.5	94.3
29.10	2	.8	.8	95.1

	Frequency	Percent	Valid Percent	Cumulative Percent
29.25	1	.4	.4	95.5
29.70	1	.4	.4	95.9
30.00	1	.4	.4	96.3
30.10	1	.4	.4	96.7
30.20	1	.4	.4	97.1
31.20	1	.4	.4	97.5
32.90	2	.8	.8	98.4
35.00	1	.4	.4	98.8
36.50	3	1.2	1.2	100.0
Total	244	100.0	100.0	