ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

CONCRETE PRODUCTION AND QUALITY CONTROL IN BUILDING CONSTRUCTION INDUSTRY OF ETHIOPIA

By

ABEBE ESHETU TESSEMA

Addis Ababa, November 2005

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A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the degree of Master of Science in Construction Technology and Management

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November 2005

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ABSTRACT

Concrete is a construction material produced from three main ingredients namely, cement, mineral aggregates and water. The production process goes through various phases. Batching, mixing, transporting, placing compacting, finishing and curing are the main ones. In order to get quality concrete product, which satisfies both the strength and durability requirement, great care has to be given for concreting work starting from ingredient selection. The ingredient selected has to fulfill the requirement stated on standards. Every production process should follow the proper scientific procedures to get the desired quality concrete products. For this, quality control plays a significant role.

Quality control is all the measures that are taken during material selection, concrete production processes and on finished concrete products to ensure the compliance of works with the specification.

Concrete as a major building material, which is useful for the construction of the structural part, and as a non-factory product, which is susceptible to variation, proper control is utmost important in ensuring the desired quality product. Therefore, concrete quality affects the overall quality of buildings to a higher extent. But in Ethiopia there hasn't been any study made on this area yet.

Considering this, investigations focusing on concrete production and its quality are undertaken in the year 2005 on forty three building construction projects found in various parts of Ethiopia namely, Addis Ababa, Nazreth Debrezeith, Jimma, Awassa and Bahirdar

The research is carried out by collecting sample compressive strength test result data and information on qualities of concrete ingredients and methods of concrete production through questionnaire and site observation. The findings of the investigation have shown that in most of the projects sufficient tests are not conducted both for the coarse and fine aggregate. This indicates that a lot has to be done to improve concrete quality in the building construction industry. From the statistical analysis of test results, the computed standard deviation shows 51.23 % of the projects` quality control is not good from which 19.51% fall in the “fair” classification range and 31.72% in the “poor” range; and that of the coefficient of variation shows 53.67 % of the projects` quality control is not good from which 39.02% fall in the “fair” classification range and 14.65 % in the “poor” range as per the classification of ACI 214. This is an indication that the test results among a significant portion of the investigated projects have shown large variability implying the quality control is unsatisfactory on those projects. It is also observed that, more than half, 52.17% of the projects have got defective lots, which fail to satisfy the compliance requirement set on the Ethiopian building codes and standards.

Key words:- Cement, mineral aggregates, water, bathing, mixing, transporting, placing, compacting, finishing, curing, quality control, standard deviation and coefficient of variation.

1.INTRODUCTION

1.1 Quality of Concrete

Concrete is one of the major construction materials in building construction industry and it is produced from three basic ingredients; namely, cement, aggregate and water. In addition admixture is sometimes used to improve some properties of concretes like workability and setting times. The ingredients of concrete should be of good quality that satisfies the requirements set in standards.

It is not enough to have only good quality concrete ingredients; the production processes also have the most important influences on concrete quality. These production processes are batching, mixing, transporting, placing compacting and curing which requires proper and scientific approaches. A good and a bad concrete may be made of exactly the same ingredients if there is a difference on the quality control of the production.

Quality control is a means of checking that concrete ingredients and production processes are in compliance with the requirements stated in code of practices. It is done by the contractor who must ensure that the quality of materials and workman ship is as per the contract document in the contract agreement. The quality control work undertaken by the contractor is assured by the quality assurance agency, which is the consulting engineer.

The consultant is given the responsibility of assuring the work. There is no direct in put in the quality of work by the quality assurance team but it oversees the work and assures the owner that work is being done in accordance with the provision of the contract document.

Quality has cost in it; however, if the contractor is not willing to pay the controlled cost of quality during construction, he will pay the uncontrolled cost of correcting the defective materials and redoing of the unacceptable works later by the quality assurer or the consultant.

To get quality concrete products, proper care and control has to be done during ingredient selection and production processes. It should also be reminded that all professionals and firms involved in the construction industry have to give special emphasis to quality control.

It is observed that building constructions in Ethiopia is currently flourishing here and there in various parts of the country, especially in major cities and towns. Most of these buildings are reinforced concrete structures in which concrete takes the major proportion.

Those parts of buildings made with reinforced concrete such as beams, columns, slabs and foundations are load bearing as opposed to other non-load bearing elements which are rather loads to be carried by reinforced concrete structural parts. This is an indication as how much the quality of concrete is important for the overall quality of a building.

In addition, concrete is a non-factory product which is mostly produced on site; hence, there are various factors that bring variations on concrete quality. These factors are quality of ingredients, variation in concrete production processes and quality of work man ship. As a result, proper quality control is extremely necessitated, particularly to concrete which forms the critical part of a building.

Hence, the fact that concrete forms the load bearing parts of a building and the variabilities in concrete product became leading motivational factors to undertake research on this area so that to identify the problems associated with the quality of concrete production in the newly flourishing building construction industry and at the end to suggest ways of improving it.

1.2 Objective of the research

As it is pin pointed in the preceding part of this introductory section, the objective of the research is to undertake qualitative and quantitative assessment on the quality of concrete in the building construction industry of Ethiopia. This objective is achieved through;

1. Investigating the current practices of concrete production in building construction sites and looking at whether or not there is a gap between the existing practice on site and the recommended scientific approaches stipulated on literatures and code of standards.

2. Assessing the level of quality control being undertaken after performing statistical analysis on sample test results collected from construction sites and after checking the compliance of these compressive strength test results with the Ethiopian, the British and the American standards.

Finally; after making the above qualitative and quantitative assessment on the quality of concrete, conclusions and recommendations are drawn out.

2. LITERATURE REVIEW

2.1 Composition of Concretes.

Concrete is a composite material which consists essentially of a binding medium within which are embedded particles or fragments of relatively inert mineral fillers. In concrete the binder or matrix is a combination of cement and water; it is commonly called the "cement paste. The filler material, called "aggregate," is generally graded in size from fine sand to pebbles or fragments of stone. In addition to aggregates and binders, there is another material called additive which may be used in concretes to improve certain of its properties [1].

In concretes, the proportions of these principal components, the binder and the aggregate are controlled by the requirement that;

1. When freshly mixed, the mass be workable or placeable
2. When the mass has hardened, it possesses strength and durability adequate to the purpose for which it is intended.
3. The cost of the final product is a minimum consistent with acceptable quality.

A Diagrammatic representation of the composition of concrete of the proportions used is shown in fig. 2.1

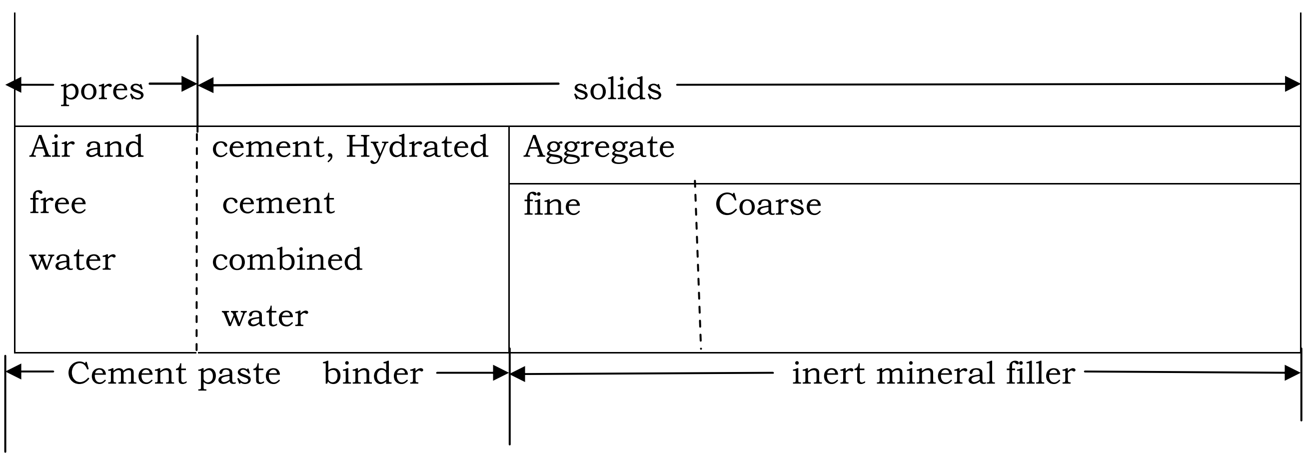


Fig. 2.1 composition of concrete

The aggregates occupy about 3/4 of the space within a given mass. The space which is not occupied by aggregate, roughly one-quarter of the entire volume of an average, is filled with cement paste and air voids. After concrete has been placed, even though it has been compacted with considerable thoroughness, some entrapped air remains with in the mass. In a well compacted concrete of suitable proportions, the volume of unavoidable entrapped air is comparatively small, usually not over 1 or 2 percent [1].

For particular purposes, however, there has developed starting from years before the practice of incorporating in the mixture special air entraining agents, the purpose of entertaining air in concrete are to increase the workability and to improve the resistance of concrete to weathering. The voids left in concrete due to air entertaining agents are discontinuous and very small size with an average diameter of less than 0.05mm. Hence entertained air is not significant problem as compared to the entrapped air, which forms continuous channels and increases the concrete's permeability [2].

The solid portion of hardened concrete is composed of the mineral aggregate and the hardened cement paste, which may include some of the original cement, and a new product formed, by combination of the remainder of the cement with some of the water. After any period, the amount of free water left depends upon the extent of combination of cement and water, and upon possible loss of water from the mass due to evaporation under drying conditions [2].

2.1.1 Portland cement

2.1.1.1 Portland cement and its production process

Cement in general can be described as a material with adhesive and cohesive prosperities which make it capable of bonding mineral fragments into a hard continuous compact mass [3, 4].

Though there are various types of cements used for concrete production, Portland cement is the one which is commonly used in Ethiopia for concrete production.

Portland cement is one of the Hydraulic cements which are capable of setting and hardening under water.

The principal raw materials used in the manufacture of cement are:-

1. Argillaceous or silicates of alumina in the form of clays and shales.
2. Calcareous, or calcium carbonate, in the form of limestone, chalk and marl- which is a mixture of clay and calcium carbonate [5].

Two processes of manufacture are employed, the dry process and the wet process. In the dry process the materials are crushed, dried, and then ground in ball mills to a powder, which is burnt in its dry condition. In wet process the materials are first crushed and then ground to form slurry in wash mills. After passing through the wash mills and the slurry silos, the slurry passes to the slurry tanks. The slurry is next pumped to a kiln and made to clinker at clinkering temperature of about 1400 to 1500^{o}c. The cement clinker then passes through clinker coolers. Having cooled sufficiently, the clinker is ground to the required degree of fineness. During grinding, gypsum, which acts as "a retarder" is incorporated [6].

2.1.1.2 Chemical composition of Portland cement

The major constituents of raw materials used in Portland cement production; mainly, lime, silica, alumina and iron oxide compounds interact with one another in the kiln to form a series of more complex products. Which are usually regarded as the major constituents of cement. These are the tricalcium silicate (C_3S), Dicalcium silicate (C_2S), tricalciu aluminate (C_3A) and tetracalcium alumino ferite or iron compound (C_4AF). Table 2.1 gives approximate oxide composition limits of Portland cement [3].

Table 2.1 Approximate oxide composition limits of Portland cement.

Oxide	Content in percent
CaO	60 -67
SiO_2	17-25
Al_2O_3	3 - 8
Fe_2O_3	0.5 - 6
MgO	0.1 - 4.0
A1kalis	0.2 - 1.3
SO_3	1-3

2.1.1.3 Hydration of cement

Hydration is the reaction in which cement becomes a bonding agent takes place in a water cement paste or the process in which in the presence of water, the silicates and aluminate compounds of cement form products of hydration, which in time produce a firm and hard mass [3].

Hydration is fast during the first few minutes of mixing and decreases continuously with time. Because of reduction in rate of hydration even after a long time there remains an appreciated amount of unhydrated cement. Hence there is hydration at any time after hardening of concrete though it is at a very lower rate [3].

The various compounds of cements mentioned previously has different rate of hydration, the rate of hydrations of C_4AF is higher than the three major compounds of cement. C_3A has higher rate than C_3S and C_2S; and C_3S has higher rate of hydration than C_2S [3].

The hydration products of the major cement compounds, C_3S and C_2S, gives calcium silicate hydrates which is commonly designated as C-S-H. This hydrate product determines the basic physical properties of concrete such as setting and strength gain [3].

The hydration of C_3A cement is fast and violent in comparison to the other cement compounds and it leads to immediate stiffening of the paste, known as flash set. To prevent this from happening gypsum is used which reacts with C_3A and forms in soluble calcium sulphoaluminate by protecting the direct reaction of water and C_3A [3].

The presence of C_3A in cement is undesirable, it contributes little or nothing to the strength of cement at early ages, and when hardened cement paste is attacked by sulphates, expansion due to the formation of calcium sulphoaluminates from C_3A may result in a disruption of the hardened paste. However, C_3A & C_4AF acts as a flux and thus reduces the temperature of burning of clinker and facilitates the combination of lime & silica, hence they are useful in the production of cement [3].

As per the Ethiopian standard, the percentage by mass of SO_3 in port land cement is limited to 3% if the C_3A content is limited to 8% or less and to 3.5%

when C_3A exceeds 8 percent. However; it's content in Portland pozzolana cement is 3 percent which is independent of the C_3A content [7].

2.1.1.4. Heat of hydration of cement

The hydration of cement compound is exothermic, and hence there is significant amount of heat energy evolved during hydration, which may reach up to 500 joules per gram (120 cal/ gram). Since the conductivity of concrete is comparatively low, it acts as insulator, and in the interior of a large concrete mass, hydration can result in a large rise in temperature. At the same time the exterior of the concrete mass loses some heat so that a steep temperature gradient may be established, and during subsequent cooling of the interior serious cracking may result [3]. Due to the presence of various climatic zones in Ethiopia where both the lowland hot areas and the high land cold areas are found, selection of cements needs to be given emphasis. Hence the use of low heat Portland cement such as PPC in hot areas of Ethiopia like Afar and Gambela should be better preferred than OPC for cement.

At the other extreme, the heat produced by the hydration of cement may prevent freezing of the water in the capillaries of freshly placed concrete in cold weather, and a high evolution of heat is therefore advantageous. It is clear, then, that it is advisable to know the heat producing properties of different cements in order to choose the most suitable cement for a given purpose or environment [3].

The heat of hydration depends on the chemical composition of the cement and in one of its physical properties, which is fineness. This heat of hydration of cement is very nearly a sum of the heats of hydration of the individual compounds when hydrated separately [3].

2.1.1.5. Tests on physical and chemical properties of cement

The manufacture of cement requires stringent control, and a number of tests are performed in the cement works laboratory to ensure that the cement is of the desired quality and that it conforms to the requirements of the relevant national codes and standards. These tests are; consistency test, fineness test, setting time test, soundness test, strength test etc [5, 8].

The loss on ignition test is a test, which is carried out to determine the loss in weight when the sample is heated from 900 to 1000^{0}C. The loss in weight occurs when the moisture and carbon dioxide, which are present in combination with free lime or magnesia, evaporate. Since the hydroxides and carbonates of lime have no cementing property, they are termed inert substance. The less the loss on ignition, the less is the quantity of these inert substances and better cement [4].

2.1.1.6. Ordinary Portland and Portland pozzolana cement

There are various types of Portland cements. The two, namely, Ordinary and pozzolanic Portland cements, are cements which are mostly produced by the cement factories in Ethiopia and used for concrete production. Hence the properties of these two cements are discussed in detail here.

Ordinary Portland cement is admirably suitable for use in general concerte construction when there is no exposure to sulphates in the soil or in ground water. However; in urban and near urban areas, underground water has higher tendency of getting spoiled with chemicals due to the possibility of percolation of wastes discharged from factories and various chemicals which has been used for domestic purposes. Therefore, the placing of sub structural reinforced concrete elements like footing, mats or piles generally concrete foundations are subject to these chemicals.

Portland pozzolana cement is produced by partially replacing a certain percentage of the Portland cement by prozzolanic material obtained from volcanic ash. The pozzolana added varies commonly between 10 and 30 %[1]. Pozzolanas aren't reactive by themselves but becomes reactive when it gets in contact with Portland cement. It reacts with the calcium hydroxide liberated from portland cement at ordinary temperatures to form compounds possessing cementitious properties. Portland pozzolana cements gain strength slowly and require, therefore, curing over comparatively long period, but their ultimate strength is approximately the same as that of ordinary Portland cement alone[3].

Low heat Portland cement such as Portland pozzolana cement has approximately half the strength of ordinary Portland cement at 7 days, two-thirds at 28 days and is approximately equal in strength at 3 months [2].

Pozzolanas are cheaper than Portland cement. Its slow hydration and the resulting slow rate of heat development make it important in mass concrete construction. It also shows good resistance to sulphate attack and to some other destructive agents. This is so because the pozzolanic reaction leaves less lime to be leached out and also reduces the permeability of concrete [3].

2.1.1.7. Transport, storage and Batching

The storage of cement is entirely a matter of keeping it dry, and it is necessary to stack the bags in a shed or under whatever cover is available. On small projects where storage without a shed is required for a few days, the cement should be placed on a raised platform and covered with transpaulins, polyethylene film (0.2mm thick) or water proof building paper [6, 9].

Even when stored under good conditions bagged cement may lose 20 percent of its strength after 2 months of storage, and 40 percent after 6 months of storage [3]. Cement can be stored in air tight bins indefinitely without deteriorating in any way, but this is not practicable for site use. Cement which is 4 months old should be classified as "aged" and be retested for use [9].

Air set cement results from storage in a damp atmosphere. This is due to the moisture present in the air being absorbed by the cement and causing a partial set. Preventing the movement of air in to the store as far as practicable reduces the absorption of moisture from a damp atmosphere. As a rough guide, lumpy cement, which cannot be easily crumbled in the fingers, is unsatisfactory for general use [6, 9].Cement should be stacked in such a way that the cement first delivered can be used first.

2.1.2. Aggregates

2.1.2.1. General

Aggregate represent the major proportion of concrete by volume. Hence it has significant importance on the quality of concrete, especially on strength. This is because good aggregate are known to have better crushing strength and better resistance to impact. Not only that aggregates affect the strength of concrete, but the proper ties of aggregates such as its size and shape affect the durability and structural performance of concrete [3,4].

Aggregate is cheaper than cement. It is, therefore, economical to put in to the mix in as much proportion as possible.

Aggregate may be defined as a relatively inert mineral filler used in the construction of concrete. This aggregate consists of uncrushed or crushed gravel, crushed stone or rock, sand, or artificially produced inorganic materials.

2.1.2.2. Physical properties of Aggregates

The physical properties of aggregates such as size shape, texture, porosity, absorption, moisture content, bulking of fine materials, presence of deleterious substances etc affects significantly the resulting concrete quality produced as briefly explained under

2.1.2.2.1. Aggregate size, shape and texture

The size of aggregates used in concrete ranges from tens of millimeters down to a tenth of millimeter in cross section. In accordance with the Ethiopian standard aggregates are classified as coarse and fine depending on their size [10]. The Ethiopian standard has adopted the requirement set on the parts of the American standard (ASTM C-33) [11]. In the size classification of aggregates by the British Standard (BS 882), there is an additional size group called all-in aggregate that contains mixed coarse and fine aggregate [12]. But all- in aggregate is recommended for the production of low grade concrete [5].

Shape of aggregates has an effect on the degree of packing particles and on the surface area to volume ratio of particles. Well-packed aggregates have less void content. This is important in concretes as it reduces the void content of concrete resulting in better strength concrete. Particles with high ratio of surface area to volume lower the workability of the mix; however, it has an advantage of providing larger bond surface area. Flaky and elongated particles affect the durability of concrete in that, as they tend to be oriented in one plan, with water and air voids forming underneath. As a result, the presence of elongated or flaky particles in excess of 10 to 15% of the weight of course aggregate is undesirable [3, 4].

The physical properties of aggregates have a significant impact on the properties of concretes.

The rounded aggregate requires lesser amount of water and cement paste for a given workability. The amount of mixing water could be reduced by 5 to 10 percent, and the sand content by 3 to 5 percent by the use of rounded aggregate. On the other hand, the use of crushed aggregate may result in 10 to 20 percent higher compressive strength due to the development of stronger aggregate-mortar bond. This increase in strength may be up to 38 percent for a concrete having a water-cement ratio below 0.4. The elongated and flaky particles, having a higher ratio of surface area to volume reduce the workability appreciably. These particles tend to be oriented in one plane with water and air voids underneath. An aggregate with a rough and porous texture is preferred to one with a smooth surface as the former can increase the aggregate-cement bond by 75 percent, which may increase the compressive and flexural strength up to 20 percent [4].

2.1.2.2.2. Porosity and Absorption of Aggregate

Due to the presence of air bubbles, which are entrapped in a rock during its formation or on account of the decomposition of certain constituent minerals by atmospheric action, minute holes or cavities are formed in it that is commonly known as pores [3,4].

As mentioned at the beginning of this chapter, since aggregate constitutes about 75% by volume of concrete, the porosity of aggregate contributes to the overall porosity of concrete. The porosity and absorption affect the bond between aggregate and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion, and the specific gravity of the aggregate [3,4].

2.1.2.2.3. Moisture content of Aggregates

Aggregate exposed to rain collects a considerable amount of moisture on the surface of the particles, and, except at the surface of the stockpile, keeps this moisture over long periods. This is particularly true of fine aggregate, and hence the surface or free moisture (in excess of that held by aggregate in a saturated and surface dry condition) must be allowed for in the calculation of batch quantities. The surface moisture is expressed as a percentage of the weight of the saturated and surface dry aggregate, and is termed the moisture content [3,4].

Since absorption represents the water contained in aggregates in a saturated and surface-dry condition, and the moisture content is the water in excess of that state, the total water content of a moist aggregate is equal to the sum of absorption and moisture content [3,4].

The determination of moisture content of an aggregate is necessary in order to determine the net water-cement ratio for a batch of concrete [3,4].Otherwise; if the moisture content and absorption of aggregates is not properly determined, the water added during preparing the mix becomes variable. This results in either high or low water to cement ratio. Higher water to cement ratio may affect the properties of concrete like workability in which concretes with lower water content becomes less workable as a result it makes difficult to attain full compaction and leave excessive void in the concrete mass.

2.1.2.2.4. Bulking of fine Aggregate

The presence of free moisture on the surface of sand results in a phenomenon known as bulking. This is the increase in the volume of a given mass of fine aggregate caused by the films of water pushing sand particles apart [3,4]. The extent of bulking depends on the percentage of moisture present on the sand and on its fineness. The increase in volume relative to that occupied by saturated and surface dry sand increases with an increase in the moisture content of the sand up to a value of some 5 to 8 percent, when bulking of 20 to 30 percent occurs. Upon further addition of water, the films merge and the water moves in to the voids between the particles so that the total volume of the sand decreases until, when fully saturated or flooded, its volume is approximately the same as the volume of dry sand for the same method of filling the container. Finer sand bulks considerably more and the maximum bulking is obtained at higher water content than the coarse sand. In the case of coarse aggregate, the increase in volume is negligible due to the presence of free water as the thickness of the moisture film is very small compared with particle size [3,4].

Bulking doesn't affect the proportion of materials by weight. In the case of volume batching, bulking results in a smaller weight of sand occupying the fixed volume of the measuring. This results in a mix deficient sand hence the concrete is prone to segregation and honeycombing. Therefore allowance for bulking of sand has to be considered during proportioning of sand [3,4].

2.1.2.2.5. Deleterious substances in Aggregates

Materials in aggregates, which may affect adversely the strength or durability of concrete, or reinforcement in concrete are termed deleterious materials. There are three broad categories of deleterious substances, these are: -

i. Impurities interfering with the process of hydration of cement.
ii. Coatings preventing the development of good bond between aggregate and the cement paste, and
iii. Unsound particles which are weak or bring about chemical reaction

The impurities in the form of organic matter interfere with the chemical reactions of hydration. These impurities are generally consisting of decayed vegetable matter (mainly tannic acid and its derivatives) and appearing in the form of humus or organic loam are more likely to be present in fine aggregate than coarse aggregate, which is easily washed [4].

Clay and other fine materials in aggregate may affect the quality of concrete if present in excess amount. Clay may be present in the from of surface coatings which interfere with the bond between aggregate and the cement paste. Since good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of clay coating is an important one. The other two fine materials which can be present in aggregate are silt and crusher dust. Silt is a material between 2μm and 60 μm reduced to this size by natural process of weathering; silt may thus be found in aggregate obtained from natural deposits. On the other hand, crusher dust is a fine material formed during the process of crushing rock into crushed coarse and fine aggregate. The soft or loosely adherent coatings can be removed by washing. The well-bonded chemically stable coatings have no harmful effect except that the shrinkage may be increased. However, aggregates with chemically reactive coatings, even if physically stable, can lead to serious trouble. Silt and fine dust, if present in excessive amount, increases the surface area of the aggregate and hence the amount of water required to wet all particles in the mix, thereby reducing the strength and durability of concrete [4].

Hence it is necessary to control the clay, silt and fine dust contents of aggregate as per the limitations set by the standards specified in the technical specification of the contract document.

The other deleterious material is salt. The sand obtained from seashore or a river estuary may sometimes contain salt, which may be significant in amount. The salt can be removed from the sand by washing it with fresh water before use. If salt is not removed, it absorbs moisture from air and may cause efflorescence; and corrosion of reinforcement may also occur if soluble chloride salts are present [4].

2.1.2.2.6. Soundness of aggregates

Soundness is the resistance of aggregates changes in volume as a result of changes in physical or environmental conditions such as freezing and thawing, thermal changes at temperatures above freezing, and alternating wetting and drying. The aggregate is said to be unsound when volume changes result in deterioration of the concrete. This may range from local scaling and so-called pop-outs to extensive surface cracking and to disintegration over a considerable depth, and can thus vary from no more than impaired appearance to structurally dangerous situation [4]. Aggregates used for concrete production are tested for its soundness and it should comply with the requirement set in the specification.

2.1.2.2.7. Reactions between active aggregates and alkalis that affect concrete quality

One of these reactions is the deleterious chemical reaction which takes place between the active silica of aggregate and the alkalis in cement that is called the alkali-aggregate reaction (AAR). The reactive forms of silica occur in opaline chalcedonic cherts, siliceous limestone, rhyolites and rhyolitic tuffs, andesite and andesite tuffs, phyllites, etc. The reaction between the siliceous mineral of the aggregate and the alkaline hydroxide of the cement results in an alkali silicate gel. The gel is confined by the surrounding cement paste and an internal pressure is developed leading to expansion resulting in cracks and disruption of cement paste [4].

There is another reaction that takes place between alkalis of the cement and carbonate of aggregates known as alkali carbonate reaction (ACR). This results in expansive material that deteriorates concrete. Humid condition is required for the reaction to take place [3]. Hence the amount and type of the mineralogical content of aggregates used in concrete production is essential for determining the resulting quality of concrete.

2.1.2.2.8. Grading of Aggregates

The particle size distribution of an aggregate as determined by sieve analysis is termed grading of the aggregate. If an aggregate is composed of all uniform size, the compacted mass will contain more voids, whereas an aggregate comprising particle of various sizes will give a mass containing lesser voids. The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement paste. Hence it is essential that the coarse and fine aggregate be well graded to produce quality concrete. [4]

The grading of aggregates affects the workability which, in turn, controls the water and cement requirements, segregation, and influence the placing and finishing of concrete. These factors represent the placing and finishing of concrete. These factors represent the important characteristics of fresh concrete and affect properties in the hardened state [4]. Therefore aggregate has to conform with the grading requirement of standards specified on the technical specification.

2.1.2.2.9. Strength of aggregate

Aggregates contribute the significant proportion of strength possessed by concrete due to its higher modulus of elasticity as compared to the cement paste. To have a strong concrete, the aggregate should have high load bearing capacity and resistant to wearing and abrasion effects. To assess the strength of aggregates, a number of strength tests are undertaken in laboratories. Some of these are; aggregate crushing value, aggregate impact value, losangeles abrasion test, ten percent fines values etc. Therefore, aggregates in use for concrete production have to be strong that satisfy standards requirement [2, 6].

2.1.2.2.10 Handling and storing of Aggregates

Unless care is taken in handling and storing of aggregates, there is a marked tendency for segregation of the fine and coarse particles to occur that affects the gradation. In addition to segregation, contamination of stockpiles could also occur due to poor handling and storage.

When dry sand is dropped from the end of an elevating conveyor, a chute or chimney (with exit opening) should be installed so as to prevent segregation of sizes by wind action. The segregation of aggregate moving down a sloping surface can be prevented by a retaining baffle. The bottom 0.5m of wet sand in a stockpile is best allowed to serve as a drainage layer for the upper part.

Bulk storage should be on hard ground or a thin slab of weak concrete that is graded for drainage. A space or dwarf walls should be placed between different materials [3]. Placing of various material sizes separately is useful in avoiding segregation. For instance, aggregate sizes that range from 5 to 10mm, 10 to 20 mm, and 20 to 40 mm could be stock piled separately on sites.

2.1.3. Water

2.1.3.1. Introduction

Water is the most important and least expensive ingredient of concrete. A part of mixing water is used in the hydration of cement to form the binding matrix. The remaining serves as a lubricant between fine and coarse aggregate and makes concrete workable.

Cement requires around 30% of its weight of water for hydration. But concrete containing water in this proportion will be very harsh and difficult to place.

Hence additional water is required for workability. However; if this additional water is present in excess, will pose a problem. Therefore it must be kept to the minimum. The problems associated with too much water in the mix are, reduction in strength, formation of laitance on surfaces of concrete through bleeding. The excess water may also leak through the joints of the formwork and make the concrete honeycombed [4].

2.1.3.2 Quality of mixing water

The water used for mixing and curing of concrete should be free of materials that significantly affect concrete quality like rate of hardening, strength and durability of concrete, or which promote efflorescence or the rusting of steel reinforcement. Potable water is generally considered satisfactory for mixing concrete. In the case of doubt about the suitability of water particularly in remote areas, where water is derived from sources of normally utilized for domestic purpose, water should be tested [4].

2.1.3.3 Impurities in water which affect concrete Properties

The effects of impurities present in mixing water are mainly expressed in terms of the difference of the setting times and strength of cement mixes containing impure mixing water as compared to clean fresh water or distilled water. The effluents from sewerage works, gas works, and from paint, textile, sugar and fertilizer industry are harmful to concrete. Tests show that water containing excessive amounts of dissolved salts reduces compressive strength by 10 to 30 percent of that obtained using fresh water [4].

Deleterious substances which affect both the fresh and hardened quality of concrete that could possibly be found in impure water like silt, clay, acids, alkalis, algae, inorganic salts and sugars should be with in the permissible limits so that concrete quality shouldn't be adversely affected.

Generally, the PH value of water which is suitable for concrete construction has to be in the range of 6 to 8. The water which is fit for drinking purposes is fit for concrete production. Table 2.2 shows the limits set for impurities in mixing water [4].

Table 2.2 limits of permissible impurities in water [4]

<table>
<tr><td colspan="2">Type of impurities</td><td>Permissible percentage of solids by weight of water</td></tr>
<tr><td colspan="2">Organic</td><td>0.02</td></tr>
<tr><td colspan="2">Inorganic</td><td>0.3</td></tr>
<tr><td colspan="2">Sulphates</td><td>0.05</td></tr>
<tr><td rowspan="2">Alkali chlorides</td><td>a. For plain concrete</td><td>0.2</td></tr>
<tr><td>b. For reinforced concrete</td><td>0.1</td></tr>
</table>

2.1.3.4. Curing Water

The water which is satisfactory for mixing purpose can also be used for curing. Curing water should not produce any objectionable stain or unsightly deposit on the surface. Iron and organic matter in the water are chiefly responsible for staining or discoloration and especially when concrete is subjected to prolonged wetting, even a very low concentration of these can cause staining [4].

2.1.4. Admixtures

These are substances or chemicals used in concrete for the purpose of improving or imparting particular properties. The use of admixture should offer an improvement not economically attainable by adjusting the proportions of cement and concrete, and should not adversely affect any property of the concrete. Admixtures are not substitute for good concreting practice. An admixture should be employed only after an appropriate evaluation of its effects on the concrete that is intended to be used is made. It is often necessary to conduct tests on the representative samples of the materials for a particular job under simulated job conditions in order to obtain reliable information on the properties of concrete containing admixtures [3,4].

The properties of concrete commonly modified are workability, rate of hydration or setting time i.e. either accelerating or retarding the setting time, and air entertainment. Admixture is generally added in a relatively small quantity. A degree of control must be exercised to ensure proper quantity of admixture, as an excess quantity may be detrimental to the properties of concrete. In using any admixture, careful attention should be given to the instructions provided by the manufacturer of the product [3,4].

2.3. Specification of Concrete

In concrete production the proportioning of ingredient materials has to be in such a way that the resulting concrete shows good performance both in the fresh and hardened state. To attain this goal, various national standards have set mix design procedures. The American (ACI) and the British method of mix design, commonly called DOE method, are the two most common [3].

There are three different ways of specifying concrete. These are the designed, prescribed and standard or nominal mixes [4, 7].

In the designed mix the compressive strength is specified with other limits such as aggregate size, minimum cement content and workability. The designer is made to take all responsibility for designing the mix in prescribed mix since the mix proportion is stipulated by the designer and given to the producer. The third type of mix, standard mix, is rich in its cement content and recommended mainly for low-grade concrete where the cost of trial mixes or of acceptance cure testing is not justified. Standard concrete mix may be used without verification of compressive strength by testing [7].

The minimum cement content specified in designed concrete mix is in order to assure durability. The Ethiopian building code of standards has specified minimum cement content as shown on table 2.3, which is found out to be higher than the requirement set on other literatures (4, 7].

Table 2.3 Minimum cement content in kilogram per m^3 of Concrete to ensure Durability under Specified Conditions of Exposure [7]

	Reinforced Concrete					Plain Concrete				
	Nominal maximum size of Aggregate				Max W/C	Nominal Maximum Size of Aggregate				Max W/C
Exposure	40	30	20	10		40	30	20	10	
Mild: E.g. Completely protected against weather, or aggressive conditions, except for a brief period of exposure to normal weather conditions during construction	230	260	280	300	0.65	220	230	260	280	0.7
Moderate: E.g sheltered from sever rain. Buried concrete and concrete continuous under water	270	300	330	350	0.55	230	260	290	310	0.6
Sever: Exposed to sea water, driving main alternate wetting and drying. Subject to heavy condensation of corrosive fumes	330	370	400	420	0.45	280	320	340	370	0.5

2.4. Concrete production

2.4.1. Introduction

Only a good concrete mix design is not sufficient in getting the intended concrete quality product, rather the concrete placed in a structure must be of uniform quality, free of voids and discontinuities, and adequately cured [2, 6]. Hence, the proper execution of the operations in the production process, namely, batching, mixing, transportation, placing, compaction, finishing and curing are important in attaining the desired quality.

Concrete production is a scientific process that is based on some established principles and governs the properties of concrete mixes in fresh as well as in hardened state [3,4]. The various phases of the production processes stated above will be discussed in detail in the succeeding section with the consequent impact on concrete quality.

2.4.2. Batching

For solid granular materials, such as aggregates and cements, batching is best done by weight. Only water and liquid admixtures can be measured accurately by volume. Batching by weight also follows rapid and convenient adjustments aggregates and water contents when changes in aggregates moisture contents occur [2, 4, 13].

In volume batching, solid ingredients are measured by loose volume using measuring boxes, wheel barrows, etc. In batching by volume allowances has to be made for the moisture present in sand which results in its bulking and adjustments to the amount of water depending on the absorption capacity and the free moisture content of the sand and the coarse aggregate [13].

In volume batching, it is generally advisable to set the volumes in terms of whole bags of cement. Fractional bags lead to variable proportions, resulting in concretes of non-uniform strength in successive batches. Before the batching operations are started; the engineer-in-charge should check the batch box volumes. When filling the boxes, the material should be thrown loosely in to the box and struck off, and no compaction is to be allowed [13].

During batching, batching quantities should be measured with a high degree of accuracy.

The batching equipment falls into three general categories. These are manual, semiautomatic and fully automatic.

Manual batching is acceptable for small jobs of up to $400m^3$ and having low batching rates up to $15m^3/hr$; otherwise, semiautomatic or automatic batching should be used.

2.4.3. Mixing

The main objective of mixing is that the materials be uniformly distributed throughout the mixture and that all aggregate surfaces be well coated with the cement-water paste. Equipments called mixers normally do concrete mixing, but some times the mixing of concrete is done by hand. Machine mixing is more efficient, economical and results in better quality concrete compared to hand mixing [3,4,13].

When mixers are used for mixing purposes, the mixer must be clean and in good condition, properly designed, particularly as to type and numbers of blades, not overloaded or under loaded, charged correctly, and operated at the optimum speed as recommended by the manufacturers. The valves controlling the mixing water should not allow leakage in to the mixer [3].

In the occasions when concrete has to be mixed by hand, it has to be done thoroughly. A clean surface should be selected for mixing. If this is not available, a wooden platform with close joints to prevent loss of mortar should be obtained. It is usually specified that the concrete shall be mixed three times dry and three times wet, turning over from one spot to another [6].

Hand mixing usually results in poor concretes of lower strength. Hence to compensate for the lower strength, it is advisable to allow an extra 10 percent of cement above that normally required [6].

There are two observed stages in the mixing process. In the first stage, the cement paste is formed with simultaneous absorption of water by aggregates. In the second stage the cement paste coats the aggregate particles. The mixing process should be continued till a thoroughly and properly mixed concrete is obtained. At the end of this stage the concrete appears to be of uniform color and grading. The uniformity must be maintained while discharging the concrete from the mixer [3,4].

2.4.3.1. Mixing time and its impact on concrete quality

On a site, there is often a tendency to mix concrete as rapidly as possible, and it is, therefore, important to know what the minimum mixing time necessary to produce a concrete uniform in composition and of satisfactory strength. The mixing time varies with the type of mixer and also on its size. On some researches made previously, it appears that it is not the mixing time but the number of revolutions of the mixer that is the criterion of adequate mixing. Generally, about 20 revolutions are sufficient. Since, however, there is optimum speed of rotation recommended by the manufacturer of the mixer; the numbers of revolutions and the time of mixing are interdependent [4, 6].

The average strength of concrete increases with an increase in mixing time up to about 5 minutes. The rate of increase in strength falls rapidly beyond about one minute and is not significant beyond two minutes. Within the first minute, however, the influence of mixing time on strength is of considerable importance. The minimum mixing time in relation to capacity of mixer is indicated in table 2.4. A mixing time of not less than one minute after all the materials have been added in the mixer drum is generally recognized as a satisfactory period for mixers up to capacity of 750 liters [4].

Table 2.4 Recommended minimum mixing times [3]

Capacity of mixer (m^3)	Mixing times, min American concrete institute and ASTM standard C94-78a
0.8	1
1.5	$1^{1/4}$
2.3	$1^{1/2}$
3.1	$1^{3/4}$
3.8	2
4.6	$2^{1/4}$
7.6	$3\ ^{1/4}$

The mixing time is counted from the time when all the solid materials have been put in the mixer, and it is usual to specify that all the water has to be added not later than after one quarter of the mixing time. The figure quoted above refers to the usual mixers but there are many modern large mixers, which, perform satisfactorily with a mixing of 1 to 1 and 1/2 min. In high-speed pan mixers, the mixing time is as short as 35 seconds. On the other hand, when light weight aggregate is used, the mixing time should not be less than five minutes, sometimes divided in to two minutes of mixing the aggregate with water, followed by 3minutes with cement added. For mixers of larger capacity than shown in the table above, the mixing time should be increased at the rate of 20 seconds more for each cubic meter or fraction thereof; however, this is not applicable to light weight aggregate concrete [3,4].

If mixing is done over a long period, evaporation of water from the mix takes place, with a consequent decrease in workability. A secondary effect is that of grinding of the aggregate, particularly if soft, the grading of the aggregate thus becomes finer, and the workability lower. The friction effect also produces an increase in the temperature of the mix.

No general rules on the order of feeding the ingredients into the mixer can be given as they depend on the properties of the mix and of the mixer. Generally, a small amount of water should be fed first, followed by all the solid materials, preferably fed uniformly and simultaneously in to the mixer. If possible, the greater part of the water should also be fed during the same time, the remainder of water being added after the solids [4].

The choice of mixer depends on the size, extent, and the nature of work. The choice between central and site mixing will be governed by factors such as accessibility, water supply, transport routes, availability of working space, etc [4].

2.4.4. Transport of Concrete

Concrete from mixer should be transported to the point where it has to be placed as rapidly as possible by a method, which prevents segregation or loss of ingredients. The concrete has to be placed before setting has commenced. A maximum of two hours between mixing and discharge of concrete is permitted, if the concrete is transported in a truck mixer or agitator. In the absence of agitator, the time is reduced to one hour only. This maximum permitted time lapse between mixing and discharging holds if the concrete temperature is between 5^{o}c and 32^{0}c [3]. Delayed concrete transportation may result in the formation of pour planes, cold joints or construction joints between the interfaces of previously placed and newly placed concrete. Such joints are susceptible to water leakage and leave weak structural parts [14].

In case when the mixing and placing locations are far apart or transportation of concrete takes longer time, the use of retarding admixture could help in increasing the setting time by two to four hours and reducing water requirement by 5 to 10 percent [4].

The prevention of segregation is the most important consideration in handling and transporting concrete. The segregation should be prevented and corrected before its occurrence. The concrete being a non-homogenous composite material of widely differing particle sizes and specific gravities is subjected to internal and external forces during transportation and placing tending to separate the dissimilar constituents [4]. The other point that needs to be considered in handling and transporting of concrete is that the method should protect concrete from the effects of the weather like heat or cold that has an impact on the performance of concrete.

Segregation can be prevented by ensuring that the direction of fall during the damping or dropping of concrete is vertical. When the discharge is at an angle, the larger aggregate is thrown at the far side of the container being charged and the mortar is collected at the near side, thus resulting in segregation.

2.4.5. Placement of Concrete

The methods used in placing concrete in its final position have an important effect on its homogeneity, density and behavior in service. The same care which has been used to secure homogeneity in mixing and the avoidance of segregation in transporting must be exercised to preserve homogeneity in placing.

The concrete should be placed in its final position rapidly so that it is not too stiff to work. Water should not be added after the concrete has left the mixer. The concrete must be placed and as close as possible to its final position. It

should never be moved by vibrating it and allowing it to flow, as this may result in segregation which will show on the surface of the finished work. When placing the concrete, care should be taken to drop the concrete vertically and from not too great height [4]. As per the Ethiopian building code, the free fall height of concrete mass is restricted to a maximum of three meters [14].

The surfaces against which the fresh concrete is to be placed must be examined as to their possible effect in absorbing mixing water. For example, sub grade should be compacted and thoroughly dampened to prevent loss of moisture from concrete.

Mixes placed in deep lifts should be designed in such away that the risk of segregation and bleeding are lowered. The concrete should be introduced into the forms through trunkling, as this reduces impact damage to the forms and reinforcement, and enables the layer of concrete to be built up evenly [4].

During concreting slab, the batches of concrete should be placed against or towards preceding ones, not away from them. Batches should not be dumped in separate individual piles [4].

2.4.5.1. Effect of delay in placing concrete

The effect of delay in placement of concrete varies with the richness of the mix and the initial slump [3, 4]. As an example Brook (6) suggests different delay times for various temperatures, a maximum of half hour for placing at 20^{o}C, three-fourth of an hour for temprature that ranges 15°C to 20°C and 1hr if the temperature is about 15°C.

When concrete in a lift hardens before the next lift can be placed, a weak layer called cold joint or construction joint is formed. This is one of the serious problems of extreme delay of concrete placement. In case when such a joint is formed either because of delay in concrete placement or for another reasons, the following measures are recommended to be taken during construction time.

The surface of the last lift should be left in a roughened state to provide a good mechanical bond. Before placement of the next lift, the surface should be scarified to remove any laitance. Air-water jets, wire brooming, or even sand blasting are useful techniques. The concrete should be dampened and a layer of mortar worked well into the surface [13].

The mortar layer placed should be about 15 mm thick, and have the same water cement ratio as the concrete. The surface can be cleaned by a steal broom a few hours after placement when the concrete is still soft enough to allow removal of scum but hardened enough not to permit loosening of aggregate particles [4]. The Ethiopian building code of standard recommends construction joints to be at right angle to the general direction of the member and shall take due account of shear and other stresses [14].

2.4.6. Compaction of Concrete

This is one of the most important concrete production phases that determines both the strength and durability of concretes. For good quality concrete, after placement, the concrete should be worked to eliminate voids and entrapped air and to consolidate the concrete into the corners of the forms and around the reinforcing steel. Most concrete is compacted by vibration. Proper vibration allows stiffer mixes to be used and generally leads to better consolidation and a superior finish [13].

However; over vibration brings excess paste to the surface, enhances bleeding, and causes loss of entrained air [13].

Compaction has a significant effect on the strength and durability of concrete. The presence of 5 percent of voids in improperly or insufficiently compacted concrete reduces the strength by as much as 30 percent [3].

The two methods of compacting concrete are using mechanial vibration and hand rodding. Hand roding; however, better than no compaction, cannot assure thoroughly dense and compacted concretes free of air pockets [4].

Mechanical vibrators are the most commonly used for compaction of concrete [3, 4, 13]. There are various types of mechanical vibrators. The two widely used of these are the external and internal vibrators. Internal vibrators have a steel tube called poker connected to a motor or diesel engine through a flexible tube. It is this steel poker which is immersed in the concrete to compact. The poker is applied in the concrete mass at center to center interval of 0.5m to 1m for 5 seconds to 30 seconds, depending on the consistence of the mix, but with some mixes up to 2min is required [3]. But it is limited on some literatures that the poker immersion location shouldn't be more than 600mm or 8 to 10 times the diameter of the poker. The concrete should be placed in layers not more than 600mm high [4].

2.4.6.1. Revibration of Concrete

In order to ensure good bonds between lifts the upper part of the underlying lift should be revibrated provided the lower lift can still regain a plastic state. Such revirbration eliminates settlement cracks and the internal effects of bleeding.

Experiments have shown that concrete can be revibrated up to about four hours from the time of mixing. Revibration at 1 to 2 hours after placing was found to result in an increase in 28-days compressive strength. This increase in strength is due to the expulsion of air and water from the concrete. As a result, the bond between the concrete and the reinforcement is improved [4].

2.4.7 Curing Of Concrete

Theoretically; there is enough water in concrete to ensure complete hydration without additional water being supplied only with the water added during mixing [13]. However, in practice a significant loss of water due to evaporation or by absorption of water by aggregates, form work or sub grade [6]. Hence, in order to obtain good concrete the placing of an appropriate mix must be followed by curing in a suitable environment during the early sages of hardening [3]. In addition, evaporation can cause early and rapid drying shrinkage, resulting in tensile stresses which are likely to cause cracking unless the concrete has achieved sufficient strength to withstand these stresses [6].

Evaporation of water from concrete after placing depends on the temperature, relative humidity of the surrounding air and the velocity of wind which affects change of air over the surface of the concrete.

There are various methods adopted for curing. These are direct provision of water or moisture, preventing evaporation by providing impervious cover or by spraying chemical compounds forming membrane and the method which accelerates strength gain by providing heat and moisture. The last technique of curing, i.e. curing with heat and moisture is mainly used with the production of prefabricated element and some times for testing concretes on production sites. Since the 28 day strength could be obtained in hours or few days.

To develop design strength, the concrete has to be cured for up to 28 days with the normal curing techniques that is with direct supply of water. As the rate of hydration, and hence the rate of development of strength, reduces with time, it is not worthwhile to cure for the full period of 28 days [4].

Exposed surfaces of concrete containing ordinary or standard Portland cement be kept continually moist cured for at least 7 days. Concretes containing high early strength cements require less time, about half the time required for OPC.

For pozzolana or blast furnace slag cements [slow hardening cements], two to three times more than OPC [4, 15].

2.5. Quality control

2.5.1. Introduction

Due to the various factors involved in concrete production, such as materials, proportioning and production process, the concrete obtained at the end has shown variability from batch to batch [4,13]. Therefore, this variability in properties must be considered when preparing concrete specifications.

Factors that contribute to variability of concretes may be grouped in to the following three general categories [13].

1.Materials: - these include variability in the cement; in the grading, moisture content, mineral composition, physical properties, and particle shape of the aggregates; and in the admixture used.

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

3.Testing: - this includes the sampling procedures, the making and curing of test specimens, and the test procedures used.

The variability in concrete properties due to the factors mentioned above makes significant the importance of quality control. Quality control is defined as an action and decisions taken to ensure the compliance of works with the specification. It contains two parts, namely, production control and compliance control. Production control is a measure taken during production to obtain a reasonable assurance that the specifications will be satisfied. And compliance control is a check made to ensure the compliance of the product with the specification [14].

Though quality control incurs extra cost, the advantage due to quality control offset the extra cost. Some of these advantages are: -

a. Quality control is used for the rational use of the available resources after testing their characteristics and for reducing the material cost.

b. In the absence of quality control at the site, the designer is tempted to over design, so as to minimize the risks. This adds to the overall costs.

c. Checks at every stage of the production of concrete and rectification of the faults at the right time expedite completion and reduces delay.

d. Quality control reduces the maintenance costs

e. In the absence of quality control there is no guarantee that overspending in one area will compensate for the weakness in another, e.g. an extra bag of cement will not compensate for incomplete compaction or inadequate curing. Proper control at all the stages is the only guarantee [4,13].

The variation observed in concrete which indicates the degree of quality control exercised during concrete production could be quantitatively computed from compressive strength test results with variability measuring statistical parameters like standard deviations and coefficient of variation as shown below.

2.5.2. Measurements of variability

It has been found that the distribution of concrete strengths can best be approximated by the normal or Gaussian distribution. Such a distribution is defined by two parameters; the mean $\overline{X}$ and the standard deviation, S [19].

The mean is give by

$$\overline{X} = \frac{\sum x}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

And the standard deviation or the root-mean-square deviation, which is the measure of dispersion or variability of the values, is given by:

$$S = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n-1}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

Wherex_i =is the values of strength of a given sample

n =is the number of samples tested

$\overline{X}$ = Arithmetic mean strength of all the samples

The variation of results about the mean can also be expressed by the coefficient of variations which is a non-dimensional measure of variation and is given by:-

$$V = \frac{S}{\overline{X}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.\ 3)$$

2.5.3. Application of measure of variability to concrete

The above statistical parameters; namely, standard deviation and coefficient of variation are useful in the design and quality control of concrete assuming that variations in concrete properties is to be described by normal distribution.

Following the statistical normal distribution assumption a number of important implications are observed:-

a. We can't design on the basis of mean strength or average strength. If we did, this would mean that about one half of the concrete would have strengths that fall below the design value, which would be unacceptable. On the other hand, we cannot insist that all concrete strengths be above the design value; since concrete strengths are approximately normally distributed, this is impossibility. Therefore, we must arbitrarily decide what constitutes an acceptable percentage of specimens falling below the "minimum" design values. The Ethiopian building code and standards specifies a 5% defective or fall below the design values [14]. Using this percentage, and knowing or assuming the standard deviation in strength that can be expected, we can then determine the required mean strength for which to design the concrete mix.

b. When carrying out tests on concrete, we are trying to evaluate the distribution in strength of all the concrete in the structure, based upon a limited sample size. Clearly enough test data must be collected so that the tests are truly representative of the concrete in the structure. However it has to be known that, the test results are only estimates of the strength of concrete in the structures.

c. Because variations in concrete strengths are due not only to mix variations, but also to sampling variations, there are two risks that must be balanced. The "producer's risk" that satisfactory concrete will be rejected and the "consumer's risk" that bad concrete will be accepted. This consumer's risk can be large indeed if insufficient testing is carried out [13].

d. There must be some plan of action that can be followed if the concrete is considered not to have complied with the specification. This is stated well in the succeeding section [13].

Depending on the quality of control measures taken in construction sites or in laboratories, there are values of standard deviation and coefficient of variation assigned to each class of activities (ACI 214) as shown in table 2.5 a & b.

Table 2.5 ACI standard of concrete quality control

a. Using standard deviation [16]

Class of Operation, Over all variations	Standard deviation for different control standards, MPa (lb/in2)				
	Excellent	Very good	Good	Fair	poor
General construction testing	Below 2.8 (400)	2.8-3.5 (400-500)	3.5-4.2 (500-600)	4.2-4.9 (600-700)	Above4.9 (700)
Laboratory trial batches	Below 1.4 (220)	1.4-1.8 (220-250)	1.8-2.1 (200-300)	2.1-2.5 (300-350)	Above 2.5 (350)

b. Using coefficient of variations [17]

Class of Operation Over all variations	Coefficient of variation for different control standards (%)			
	Excellent	Good	Fair	Poor
Field control testing	Below 10	10-15	15 - 20	Above 20
Laboratory trial batches	Below 5	5-7	7-10	Above 10

2.5.4. Approaches of the Ethiopian (EBCS), the American (ACI) and the British (BS) codes to variability of concrete strength and their Acceptance criteria

Due to the variability inherent and the normal distribution assumed in concrete strength, we should require a strength which is higher than the specified strength. Various codes have their own approaches or criteria set for the required strength in such a way that to ensure low probability of the compressive strength obtained below the design strength. In this paper the EBCS, ACI and BS codes approaches and acceptance criteria of test results are discussed.

After testing concrete, the strength has to be checked whether the specified strength, f_c`, is obtained or the probability of compressive strength falling below $f_c$` is small enough. For this ACI 318 provides two acceptance criteria.

For laboratory cured specimens of job concrete

1. Every arithmetic average of any three consecutive strength tests must equal or exceed f_c`; and
2. No individual tests (average of two cylinders) may fall below f_c` by more than 3.5 Mpa when $f_c$` is less than or equal to 35 Mpa or by more than o.1 f_c` if $f_c$` is greater than 35 Mpa.

Failure to satisfy either of the acceptance criteria requires changes in the mix proportions and construction procedures to increase concrete strength. Failure to meet the second criterion requires an investigation of the strength of the concrete in the structure [13].

The Ethiopian standard has also set the requirement for characteristic compressive strength or specified strength. In accordance with (EBCS 2, 1995) the characteristics compressive strength is defined as the strength below which 5% of all possible strength measurements may be expected to fall. Acceptance criteria are also stated as follows.

Two acceptance criteria are envisaged [14].

Criterion 1: this criterion may be applied in all cases but is less suited to large scale sampling each lot is represented by three samples, the strength of which are $x_1 < x_2 < x_3$.

The lot is accepted if the following conditions are satisfied simultaneously.

$$\overline{m_3} \geq f_{ck} + k_1 \text{ ....}(2.4)$$

$$\overline{X_1} \geq f_{ck} - k_2 \text{ ....}(2.5)$$

Where, $\overline{m_3}$ is the mean value

f_{ck} is the specified characteristic strength

k_1& k_2 are the margins of strength given in the table 2.6 below

$\overline{X_1}$ is the average strength of the minimum strengths for the several lots.

Table 2.6 margins of strengths in MPa

Margin of strength	First two lots	Third and fourth lot	Fifth lot and above
K_1	5	4	3
K_2	1	2	3

Criterion 2:- this is suitable for large lots.

Each lot is represented by a lot less than 15 test specimens (No)

The lot is accepted if the following conditions are satisfied simultaneously.

$$\overline{m_n} - \lambda S_n \geq f_{ck} \text{ -----------------------(2.6)}$$

$$\overline{X_1} \geq f_{ck} - k_2 \text{---------------------------------(2.7)}$$

Where, $\overline{m_n}$ is the mean value

S_n is the standard deviation of the set of sample results.

f_{ck} is the characteristics cylindrical strength.

λ is the coefficient (may be taken as 1.4)

k_2 is the margin of strength (may be taken as 4MPa)

n is the member of specimens

The lot could be defined as the quantity of concrete produced in the same essential conditions and subjected to individual assessment. There is a minimum requirement set on the size of lot and frequency of sampling (EBCS-2, 1995) as given hereunder.

(a) No individual sampling can represent, on the average, more than 100 mixes or 100 m^3.

(b) For each grade of concrete, at least one sample shall be taken every week.

(c) For each grade of concrete, at least two lots shall be made.

If the test results do not satisfy the requirements of the above acceptance criteria, there are recommended measures to be taken. The measures includes checking the strength using non-destructive tests, rechecking the structural safety by making new calculation or design with the non-complying compressive strength and so on [14].

The non-destructive tests that could be used to check the quality of hardened insitu concrete are like ultrasonic and Schmidt hammer test. However; those tests have their own drawbacks and hence accurate results are not expected. Schmidt hammer test is the very common test used, but it provides sufficient information only for a surface layer of concrete up to 30mm deep [3].

2.5.5. Acceptance and compliance according to British standard

According BS 5328: 1990, compliance with the characteristics strength is based on groups of consecutive test results, as well as on single test results. Each result is the average of two cubes, made in the specified manner from concrete which is sampled at a prescribed rate, and normally tested at 28 days. Compliance is assumed if both of the following requirements are satisfied:

(a)The mean strength determined from the first two, three or four consecutive test results or from any group of four consecutive results complies with the limits of table 2.7 below.

(b)No individual test result falls short of the specified characteristics strength by more than the value given in table 2.7

Table 2.7: compliance requirements for compressive strength according to BS 5328: 1990 [18]

Specific characteristics strength (grade)[MPa]	Group of results	Minimum value by which the mean strength of the group of test results should exceed the grade strength [MPa]	Maximum value by which any individual test result falls short of the grade strength [Mpa]
7.5 to 15	First two	0	2
	First three	1	2
	Any consecutive four	2	2
20 and above	First two	1	3
	First three	2	3
	Any consecutive four	3	3

If only one result (average of two cubes) fails to meet the second requirement, we can assume that the result represents only the particular batch of concrete from which the cubes were made, provided that the average strength of the group satisfies the first requirement. If the average strength of any group of four consecutive test results fails to meet the first requirement, then all the concrete in all the batches represented by the test cubes is deemed not to comply with the strength requirements. In such a case, the mix proportions of subsequent batches of concrete should be modified to increase the strength [18].

3. METHODOLOGY

The methods adopted in conducting the research are:-

1. Designing questionnaire and distribute it to resident Engineers and Supervisors working on investigated projects. There are about thirty-three questions included in the questionnaire. The questions are both open and closed ended having contents which mainly focus on the quality of material and methods of concrete productions. In addition to collecting information with questionnaire, observation on site activities related with concrete construction is made on active building projects.

2. Collecting compressive strength test results of structural grade concrete used in building construction from the consultant`s test data files and data kept in laboratory

3. Analyzing information gathered through questionnaire from test results and observations. Then make a subjective assessment on the current concrete construction practices with respect to the recommended scientific approaches of literatures and also to make a quantitative evaluation of the level of concrete quality control on building construction sites of the investigated projects

4. Draw out conclusion and recommendations

Investigation is undertaken on randomly selected forty-three projects located in the central, the western, the southern and the northern parts of Ethiopia to assure the representativeness of the sample with respect to its spatial distribution. The cities and towns in which the research is conducted are Addis Ababa, Debrezeith, Nazreth, Awassa, Wolyita Sodo, Arbaminch, Dilla, Jimma, Mizanteferi, Bahirdar, Gonder and Mertolemariam. Those cities and towns are places where currently extensive building construction projects has been executed. The projects investigated are owned by different Federal and Regional government bodies and institutions such as the Ministry of Education, the Ministry of Agriculture, the Ministry of Defence, the Ethiopian Telecommunication Corporation and the Oromyia Regional State. The types of constructions are; expansion works in existing universities and new constructions of technical colleges, office buildings, research centers, hospitals etc. The majority of the firms involved in the construction work are among the leading building construction companies in Ethiopia.

4. RESULTS AND DISCUSSIONS

The research is carried out by analyzing the data and information gathered through questionnaires and observations on building construction sites. Twenty-six questionnaires are collected from active projects which are among the total forty-three projects investigated. Test results are obtained from forty-three projects located in various parts of the country. Nine questionnaires are distributed and collected from building projects in Addis, two from Debrezeit, four from Nazreth, three from Awassa, five from Jimma and the last three are from Bahirdar. Four hundred sixty seven (467) lots are obtained for the study from the forty-three project areas. Each lot represents three cubes (15cm x 15cm x 15cm), which makes the total number of cubes investigated 1401. The projects included in the research are listed on table 4.10 with the analysis of compressive strength test results.

The information gathered through questionnaire, site observations and compressive strength test results are briefly discussed here. The practices of concrete production in the building construction industry are evaluated against the recommended scientific practices. As the concrete quality is affected both by the quality of concrete making materials and the production processes, each concrete ingredient and every production processes are thoroughly seen. Finally, test results are analyzed and the level of concrete quality control is assessed from the observed variability in the test results. The compliance of the collected test results with the requirement of various codes and standards is also evaluated. The questionnaires and the collected test results are attached on the annex part of this paper.

4.1. Quality of Concrete Ingredients

4.1.1. Aggregates

Aggregates are the major component of concrete making materials. It contributes the higher strength possessed by concrete due to its higher modulus of elasticity. Because of these facts, aggregate quality affects the overall concrete quality significantly as compared to cement and water.

Table 4.1 Types of fine aggregates

Type of fine aggregate	**Projects in percent**
Natural sand only	76.92
Crushed fine aggregate only	11.54
Natural sand or Crushed fine aggregate	3.85
Mixed crushed fine aggregate and natural sand	7.69

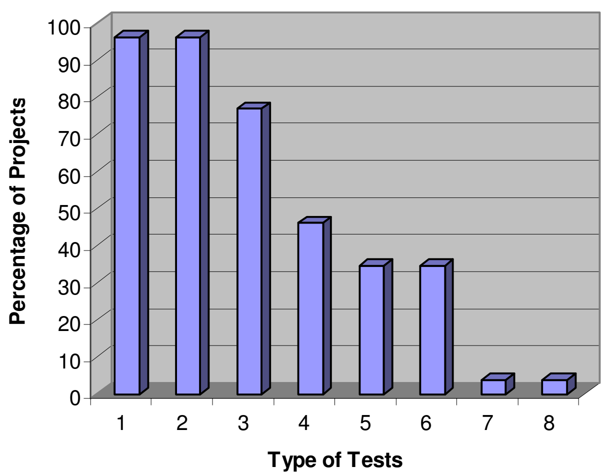
Even though aggregates represent higher proportion and strength possessed by concretes, the variability in characteristics of aggregates have an impact on the properties of concrete if careful consideration is not given for aggregates during production of concretes. As aggregates, unlike cements, are non-factory products which goes through less controlled production processes; the variation in the physical and chemical features like shape, size, texture, mineral content and other properties contributes a lot to the variability of concretes. Therefore aggregates need to be carefully tested and inspected.

Various aggregate sources are observed for the investigated projects. Most of these projects have used materials which can be obtained nearer to the location of the projects. However; when aggregates are brought from different quarry sites and river deposits, the mineralogic contents of aggregates and the presence of other deleterious substances like salts and sulphates are not tested.

There is an observation that the coarse aggregate used for concrete production is crushed whereas the fine aggregate is either crushed, natural sand, or a mixture of crushed and natural sand. But the use of natural sand as a fine aggregate is found out to be very common as shown on table 4.1.The higher consumption of natural sand, in 76.92 percent of the projects, for concrete production is due to the easiness of obtaining these materials economically. However, 11.54 percent and 7.69 percent of the projects used crushed aggregate and a mix of natural sand and crushed aggregates respectively as a fine aggregate. Those projects which include crushed fine aggregate as a part of their mix ingredient is to improve the compressive strength of their concrete. For example, on the building project of Addis Ababa University, faculty of Business and Economics blended natural sand and crushed aggregate has resulted in an improved compressive strength as witnessed by the project supervisor. It is, in fact, possible to obtain higher compressive strength concrete due to the stronger *aggregate mortar bond* developed by the use of crushed aggregate than natural sand as described in the literature review [3].

Aggregates, both fine and coarse, have passed through a number of tests. The tests conducted in all the projects under investigation are sieve analysis, aggregate crushing values, losangeles abrasion test, flakiness index, clay lump and friable particles content, dust content, unit weight, specific gravity, water absorption and soundness test for coarse aggregate; and sieve analysis, silt and clay content, organic impurity, unit weight, specific gravity, water absorption and chloride content tests for fine aggregate.

Sieve analysis is conducted and checked to comply with the requirements of standards specified in the technical specification (ASTM C-33, 1992 & ES C D3.201, 1990) on 100 % and 96.15 % of the projects for fine and coarse aggregate respectively as observed on table 4.2 & 4.3. Fig. 4.1& fig. 4.2 also show these. Since gradation or particle size distribution significantly affects the compactability of aggregates, it generally determines the quality of concrete. Because a well-graded aggregate has lesser voids, concretes having such an aggregate as its ingredient becomes denser, having higher strength and lower permeability and porosity. The grading of aggregates has influence on the properties of fresh concrete that is on workability and on the placing and finishing properties of concrete [4]. Hence tests of gradation have to be seriously taken in all projects to make sure that the distribution of aggregate size complies with the requirement of standards.

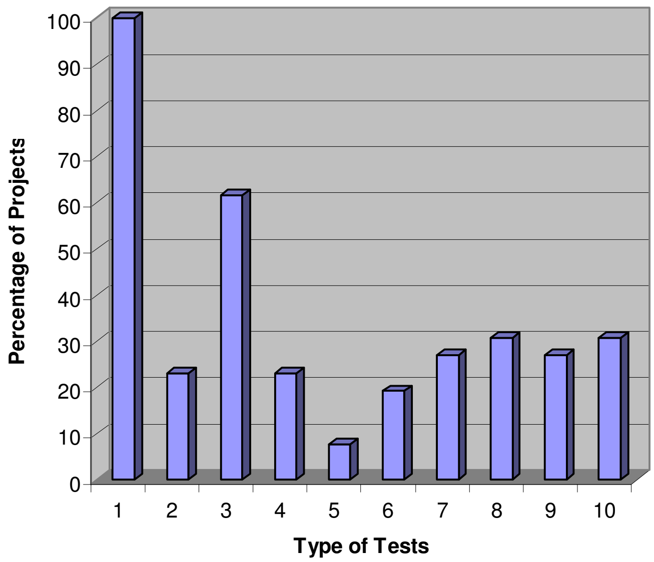


LEGEND

1- Sieve analysis
2- Silt and clay content
3- Organic impurity
4- Unit weight
5- Specific gravity
6- Water absorption
7- Soundness test
8- Chloride test

Fig. 4.1 Percentages of Projects conducting Various Tests on Fine Aggregates

A number of conducted tests are observed during investigating projects which assess the strength of aggregates in bearing various loads and showing resistance of aggregates to weathering. These are aggregate crushing value (ACV) and losangeles abrasion test (LAV) for coarse aggregate and soundness test for both coarse and fine aggregate. As observed on table 4.2 and 4.3, only 23.08 % of the projects conduct ACV test and around 61.54 % of the projects conduct LAV test. Projects which has made soundness test for coarse and fine aggregate are 30.77 % and 3.85% respectively. This is an indication that strength tests for aggregate used in concrete production are not being done satisfactorily which in effect put the over all quality of concrete under question.



LEGEND

1- Sieve analysis

2-ACV

3- LAV

4-Flakiness index

5-Clay lump & friable particles

6- Dust content

7- Unit weight

8- Specific gravity

9- Water absorption

10-Soundness

Fig. 4.2 Percentages of Projects Doing Various Tests on Coarse Aggregates

Flakiness index test is conducted only for 23.08% of the projects. Flakiness is one of the characteristics of defective aggregates. The presence of such an aggregate leaves significant amount of void in concretes with a consequent decrease in the compressive strength. Hence, it has to be limited as per the allowable values stated on standards.

In order to determine the quantity and availability of unwanted deleterious materials, the following tests are conducted. Clay lump and friable particles content, dust content, silt and clay content and tests for organic impurities are made for fine and coarse aggregate. Determination of the amount of clay lump and friable particles, and dust content is made only on 7.69 % of the projects for coarse aggregate. Clay coating in aggregate interfere with the bond between cement paste and aggregate, which inhibits the development of satisfactory strength and durability of concrete and also it may result in disruptive expansion on freezing or during exposure to water [4]. Excessive amount of dust and silt increases the water consumption, there by reducing the strength and durability of concrete. For fine aggregates, the silt and clay content test is made on 96.15 percent of the projects and organic impurity test is conducted on 76.92 percent. When organic impurities are available in significant amount in concrete aggregates, it interferes with the chemical hydration reaction, which is determinant to the strength gain in concretes [4].

Table 4.2 Tests Conducted for Coarse Aggregates

Types of tests conducted for coarse aggregate	Projects in percent
Sieve analysis	100
Aggregate crushing value, ACV	23.08
Losangeles abrasion test, LAV	61.54
Flakiness index	23.08
Clay lump & friable particles	7.69
Dust content	19.23
Unit weight	26.92
Specific gravity	30.77
Water absorption	26.92
Soundness test	30.77

Table 4.3 Tests Conducted for Fine Aggregates

Types of tests conducted for Fine aggregate	Projects in percent
Sieve analysis	96.15
Silt and clay content	96.15
Organic impurity	76.92
Unit weight	46.15
Specific gravity	34.61
Water absorption	34.61
Soundness test	3.85
Chloride test	3.85

However; it is found out that chloride test is conducted only in one project among the twenty-six investigated projects from which information are gathered through questionnaires. Investigation of the historical data kept for the thirty-nine building projects has also revealed that there is no chloride test undertaken on the other projects. The presence of soluble chloride salts in aggregates of concretes causes corrosion of reinforcement and efflorescence [4]. There has not been any project which has made test to check the presence of sulphates and other unwanted chemicals that has a potential to deteriorate concretes as a result of the formation of expansive compound due to the reaction which takes place between sulphates and C_3A of cements.

During investigation it is also observed that the three tests namely unit weight, specific gravity and water absorption are conducted on 26.92 percent, 30.77 percent and 26.92 percent of the projects respectively for coarse aggregates; and on 46.15 percent, 34.61 percent and 34.61 percent of the projects respectively for fine aggregate as shown on table 4.2 & 4.3. The values of these tests help in assessing the quality of aggregates and also in determining the proportion of materials during mixing. Aggregates showing high water absorption capacity requires lots of water in excess of that needed for hydrating the cement.

It was observed from the investigation that all tests listed on table 4.2 & 4.3, both for coarse and fine aggregates, fulfill the requirement of the technical specification. In case when aggregates brought to the construction sites are out of the limits of the specified requirements, the contractor is obliged to clear or change the source if the defective material is with in its source. The technical specification of the investigated projects commonly requires tests to satisfy ASTM and BS standards.

Tests for aggregate discussed in the preceding parts are carried out either once or more than once for a source. The percentages of those projects which take samples of aggregates to be tested once are 3.85 percent. The remaining, 96.15 percent, conduct tests more than a time as indicated on table 4.4. However, it is only in the first test that the tests shown on table 4.2 and table 4.3 are fully made in the consultant's laboratory or on sites under the supervision of the resident engineer or the supervisor. The subsequent tests are based on the quality of aggregate, which is visually observed, and hence it mainly focuses on the silt, clay and dust content which can be easily detected visually.

Table 4.4 Test Frequencies on Construction Sites

Testing frequencies	Projects in percent
Only once when it comes from the source	3.85
Once when it comes from the source and then depending on the visually observed quality defects	96.15

It was observed on some sites that aggregates aren't stored properly till the time of usage. They are placed where they easily get dust due to the work on site by moving loaders, dump trucks, truck mixers, dumpers etc or; they might be kept under trees where leaves drop on the stock piles and increases the amount of organic content of aggregates after decay. Such negligence in aggregate handling affects or degrades the quality of aggregate.

There is a thought among respondents of the twenty-four (92.31%) of the projects that defective aggregates should automatically be rejected. However; on two (7.69 %) of the projects, before rejecting the aggregates, mechanisms, if any, to improve the quality should be sought. The improving mechanisms may be washing if the defect is solely due to the presence of excessive silt, clay or dust content. Whereas, one of the respondents argues that aggregates shouldn't satisfy hundred percent of the requirements hence a small amount of deviation has to be tolerated as it could be economically impossible to ensure the satisfaction of all requirements.

Nevertheless, aggregates that are out of specification limit shouldn't be used just only for the sake of maintaining economy. Making productions Economical at the expense of quality results in poor work. However, there are circumstances in which it is possible to keep quality and economy simultaneously by sacrificing neither of them. For instance, aggregates which doesn't satisfy gradation requirement, may be corrected by blending it with other size of aggregates than rejecting it.

In order to get better quality of aggregates, the following important points are recommended by respondents.

a. Select good quality providing sources
b. Sources of good aggregates has to be used consistently
c. It must be made sure by frequent inspection that the supplying source doesn't show significant variation of quality
d. To obtain well graded aggregate or aggregate of the required size, crusher plants should be closely inspected and adjusted or maintained incase when there are problems affecting the quality of aggregate product
e. Aggregate should satisfy specification requirements
f. Samples taken for test should be representative of the source
g. Aggregates of different sizes should be separately piled to protect it from being mixed
h. Tests on aggregates shouldn't be limited to one time only; it has to be conducted a number of times either periodically or depending on the visually observed quality of aggregates

i. Investigate, identify and locate potential aggregate sources. Then control and advice contractors or investors involved in the sector to use these best sources
j. The location of the deposit of river sand along the river course has to be inspected and tested
k. Seasonal flooding may disturb the quality of natural sand imported from rivers; hence care has to be given when using natural sand
l. There must be strict quality control at the production spot

4.1.2. Cements

There are two common cement types used in construction projects under analysis. These are OPC and PPC. Their source is from the three factories located in different parts of the country. These are Mugher, Messebo and Addis Ababa cement factories. When the usage of these two cements is observed, which is shown on table 4.5, OPC`s consumption is higher in which 57.69 percent of the projects have been using OPC cement for concrete production, 15.38 percent PPC and the rest 26.92 percent of the projects used either OPC or PPC cement after making trial mixes and setting the appropriate mix proportions which could provide the required concrete quality. Due to the higher calcium oxide content of OPC, which results in higher C_3S content, the rate of strength gain or the rate of hydration is accelerated in the early ages of concretes containing this cement. However, there is an advantage obtained by using PPC cement. The pozzolana in PPC undergoes pozzolanic reaction and leaves less free lime to be leached out which reduces the permeability of concrete and makes concrete resistant to attack against chemicals [3]. The reason for most projects using OPC cement as explained by resident engineers of the projects is the faster strength gain capability and the thought that generally concrete produced with OPC is of better quality than PPC. However, such a thought doesn't have any scientific ground. PPC is better cement particularly when durability is of special interest. The only problem with the use of PPC is its lower rate of strength gain.

Table 4.5 Usages of Portland Cements on Building Construction

Type of cement	Percent of Projects using the specified cement
OPC	57.69
PPC	15.38
Either PPC or OPC	26.92

The date of production of cements produced in Ethiopia is not specified and written on the packing paper; hence the age of cement used for concrete production on construction sites is not exactly known. But when cements are stored even under good conditions, bagged cements may loose its 20 percent strength after two months and forty percent after six months of storage [6] and Cement which is four months old has to be classified as aged and be retested for use [9]. But in all the projects investigated there is no test conducted to check the quality of cement. Therefore, this is considered as one of the problems that could seriously affect the quality of concrete. In the quality control of concrete, the packing slip or bin card of cement explaining its date of packing is required when delivering cements to construction sites as per DIN 1084[20].

On 26.92 percent of the projects, minimum cement content is not specified. As long as it is possible to get the required strength, it seems there is an understanding that concrete could be produced with any cement amount. However, the need for limiting minimum cement content is to assure the long-term serviceability of concrete exposed to various environmental conditions. In projects where minimum cement content is specified, it is observed that the amount of minimum cement content is found out to be in excess of that is recommended by standards and literatures. For C-25 and C-30 concrete 360 and 400 Kg of cement per m^3 of concrete is mentioned respectively. But even for a concrete exposed to severe environmental conditions as shown in table 2.3 of the literature review, such a high minimum cement content is not mentioned for 40 mm nominal maximum size aggregates (commonly used on projects under investigation) to ensure durability. This has an impact on the client as it has the possibility of increasing the total project cost.

Thus, instead of specifying a high amount of cement to compensate for the poor concrete construction techniques, it would be better if measures are taken to improve the quality control work in concrete production.

Transport and storage of cements influences to a higher degree the quality of concrete. Hence; it requires proper care, otherwise there is a higher tendency that the cement may get moisture and consequently loose its significant amount of strength. In Ethiopia, it is common that cements are transported a long distance by trucks and trailers that makes cements susceptible to moisture contact unless attention is given. The other serious problem is with storage of cement. Cements after brought from factories, they are stored in room or shops that are not properly constructed. Therefore its impact on concrete quality is not simple.

4.1.3. Water for concrete mixing

Drinking or potable water is the commonly used mixing water in most of the projects. Ground water and river water are also rarely used when there is no supply of drinking water. Table 4.6 shows that 80.77 percent of the projects use only drinking water for concrete mixing, 7.69 percent use ground water and the rest 11.54 percent use river water when there is a shortage in the supply of drinking water. In all the projects investigated, there is no test conducted for water except visual inspection on non drinking water. Of course drinking water could be used for mixing purpose without any test; however, when this water is brought from other sources like river and drilled well of the ground, it should be tested. Because non-visually observed dissolved salts and other impurities, which could possibly be present in it, have a negative impact on both fresh and hardened concrete quality [3].

In urban and near urban areas the ground water has higher tendency to be polluted with domestic wastes and chemicals discharged out of factories. Even though this water is not mostly used as part of mixing water, sub structural parts a building made with reinforced concrete has higher possibility of getting in contact with such water. This water contains significant amount of deleterious substances like sulphates and other soluble salts that deteriorate concrete. Therefore ground water should be tested before using it for concrete mixing and as well as before placing concrete structures in it.

Table 4.6 Types of Mixing Water

Type of water	Percent of Projects using the specified water type for mixing purposes
Drinking water	80.77
Drinking & ground water	7.69
Drinking & river water	11.54

4.1.4. Admixtures

Admixtures haven't been commonly used in projects under investigation. Only 13.33 percent of the projects use admixtures. These projects are among those which complete the mixing operation out of the construction sites.

Two types of admixtures are employed to improve the workability and to retard the setting of concretes. The dosage of these chemicals is in accordance with the instruction manual of the manufacturers. Concrete producers have to be careful in using admixtures. Because usage of both excessive and quantities below the limit set by manufacturers affect the properties of concrete [3].

4.2. Production of concretes

4.2.1. Types of concrete grades

The grade or strength of concrete used in buildings are tested with a standard cube size of 15cm x 15cm x 15cm. The two common structural Concrete grades observed on the investigated building projects are C-25 and C-30 concrete. C-20 and C-35 are also used rarely. 53.85% of the projects use C-25 concrete only, 19.23% use only C-30 concrete, 15.39% use both C-25 & C-30 concrete grades and 11.53% use C-20 to C-30 concrete grades. Only one project used C-35 concrete grade. This indicates that C-25 and C-30 are the widely used concretes grades on the investigated building projects. This is also shown on fig 4.3. In order to produce these concrete grades, two types of mixes are used. These are designed and nominal or standard mixes which are stated on the literature review section. Table 4.8 shows that 69.23 percent of the projects have used designed mixes and the remaining 30.77 percent nominal or standard mixes in concrete production. There is no project, which has employed the prescribed method of specifying concrete mix. This shows that the consultant or the designer is not involved in preparing concrete mixes. But it would have been better if consultants have shown their in depth knowledge and experience during the stage of preparing the mix design than complaining at the end about the quality of concrete.

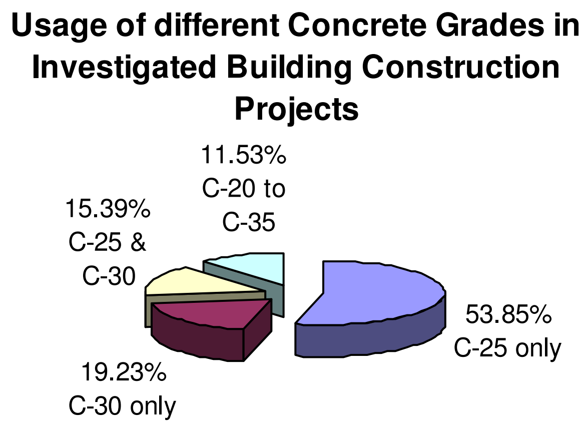


Fig. 4.3 Percent of Various Grades of Concretes Used on Investigated Projects

Table 4.7 Types of Concrete Mixes

Type of mixes	Percent of Projects using the mix type
Designed mix	69.23
Prescribed mix	0
Nominal or standard mix	30.77

4.2.2 Batching of concretes

Concrete ingredients on sites are batched either using volume or weight. In volume batching, boxes of the given capacity are constructed manually on sites for coarse and fine aggregates per 50Kg or one sack of cement in accordance with the proportion specified in mix design.

In weight batching, automatic batching plants weigh and feed to the mixing plant each ingredient as per the mass set by mix design. On 88.46% of the projects studied, volume batching is used and on the remaining, 11.54 %, weight batching is adopted as indicated on table 4.8.

Table 4.8 Concrete Mix Batching Techniques

Batching Techniques	Percent of Projects
By volume	88.46
By weight	11.54

Batching could be done best by weight. It allows rapid and convenient adjustment of aggregates and water when a change in aggregates moisture content has occurred. The other important advantage of weight batching is that there is no adjustment required for bulking of sand, which has to be carefully handled in volume batching [13].

There is a negligence observed on adjusting the quantities of ingredients on construction sites, especially on aggregates. During rainy times aggregates have excess water or free moisture on its surface and during dry season aggregate needs additional water to saturate itself since proportioning of ingredients is made on the basis of saturated surface dry condition. In volume batching, in addition to adjusting the amount of water because of free surface moisture, bulking of sand should also be considered. It is found out from the the respondent that among projects adopting volume batching techniques, 34.78% of building construction sites don't make any adjustment, 56.52 % adjust only the moisture content in aggregates and the remaining 8.7 % have been making adjustments to both sand bulking and the moisture content in aggregates. If there is significant bulking and allowance is not given to compensate for it, the concrete will be deficient in sand and prone to segregation and honey combing. In addition, sand deficient mix lacks sufficient mortar to fill the void system, resulting in a loss of cohesion and mobility that ends up with a harsh mix. This concrete requires a greater effort to compact [4]. The water in aggregate, if not adjusted, affects the water cement ratio with the subsequent impact on the properties of fresh concrete and the ultimate compressive strength. The increase in the amount of water in the mix increases the w/c ratio. However; it is known that compressive strength is inversely related with the w/c ratio. Therefore, a decrease in strength results from an increase in w/c ratio.

Generally improper batching affects the reheology of concrete that is the stability, mobility, and compactability of concretes, which finally affects the quality of hardened concretes.

4.2.3. Mixing of concretes

Mixing is an important stage of concrete production which needs to be carefully executed to get the desired concrete quality. It is observed that all investigated projects use machineries or mixers for mixing purposes.

Around 88.46 percent of the projects have mixing equipment plant on construction sites, 7.69% of the projects mix the concrete in plants located out of the site and 3.85% prepare their concrete both with mixers available on site and with plants far from the construction sites as shown on table 4.9. It is on those projects where concrete is prepared out of the construction sites that admixtures, which improve workability and setting time of fresh concrete, have been used. It is important to use admixtures in projects where concrete mixing and placing spots are relatively far apart to prevent setting of concretes prior to placing and to add or maintain workability [4].

Various mixer types are observed on building construction projects. Small to medium size mixers with capacity ranging from 300litres stationary mixers to 3.6m^3 mobile truck mixers are used. But around 73.33 percent of the projects commonly undertake the mixing operations with the 500litres and 750 liters mixers. Fig. 4.4 a & b shows concrete batching, mixing and discharging operation on the building project of faculty of veterinary medicine, Addis Ababa University. There are projects in which the concrete mixing time is not given attention, instead concretes are evaluated visually whether to attain sufficient mixing or not. However, it is important to know the minimum mixing time or the number of revolution with the optimum speed of rotation for mixers as strength is significantly affected by mixing time. It is noticed on two construction sites where 750 liters capacity stationary mixers are used for mixing purpose; a response on the mixing time is obtained to be in the range of 7 to 10 minutes. This is a longer duration that could affect concrete quality. One minute of mixing is a satisfactory period for mixers up to capacity of 750litres [4]. If mixing is done over a long period, evaporation causes decrease in workability.

Table 4.9 Concrete Mixing Location

Place of mixing	Percent of Projects
On site	88.46
Out of the site (ready mix)	7.69
Both on site & out of the site mix	3.85

One of the properties of fresh concrete is its workability that is assessed by the slump value. During the investigation, it was observed as how the required workability is achieved on construction sites. Accordingly, the following findings are obtained. Regarding the measures taken to adjust the slump of concrete when it is higher or lower than the required limits, 84.62 percent of the respondents have said that the adjustment is carried out by simply adding or reducing water. But the difficulty of attaining the specified slump may not be corrected always with water. The problem may be attached with the grain size distribution of aggregates or may be with the amount of either or both fine and/or coarse aggregate in the mixed concrete. In order to correct the slump value, adding water may have a negative impact on the compressive strength of concretes. Increasing the amount of water increases the water-cement ratio which in turn decreases the compressive strength and durability. Therefore, always before starting concrete mixing it has to be properly checked and supervised to make sure that materials are in conformity with standards.

a. Picture of 250 liters stationary concrete mixer being batched

b. Picture of 750 liters concrete mixer discharging the mixed concrete

Fig 4.4 batching & mixing of concretes on different sizes of mixers on the building project of Addis Ababa University Faculty of veterinary medicine, Debrezeit:

a. Picture of 250 liters stationary concrete mixer being batched

b. Picture of 750 liters concrete mixer discharging the mixed concrete

On three of the projects investigated, concrete mixing is done out of the construction sites. It is observed that an average time of twenty minutes for transporting concrete by a project and one and a half hour by the other project is taken. This is in agreement with the maximum permitted time of two hours between mixing and discharging concretes if the concrete is transported in a truck mixer or agitator in the temperature range of 5^{o}C to 32^{o}C[4]. In the third project where mixing is done out of the construction site, it was explained that there is no control over the time between mixing and placing of concrete. The concrete could arrive to the pouring station at any time from its mixing place. The main factor limiting the transportation time, in accordance with the respondent from this project, is the traffic density on the road.

4.2.4. Placing, Compaction and curing

The most important production processes which have a significant influence both on the strength and durability of concrete are compaction and curing. The problems associated with placing, compaction and curing are not manifested on the compressive strength of samples which are kept under controlled laboratory condition after taking of discharged concrete from mixing plants. Hence if these processes aren't appropriately undertaken, those concretes showing higher compressive strength in laboratory may have a cast-in-situ concrete which is weak with very small compressive strength.

Improper placing of concrete may segregate the concrete and undermine its quality. Delay in placing of concrete forms a joint between hardened and newly placed fresh concrete which is commonly called construction or cold joints. These joints are weak planes, hence, has to be avoided during concrete constructions. However; it may not be practical to avoid cold joint formation completely, but it is possible to minimize and reduce its effect by properly implementing the right construction techniques [4]. The study made on projects has proved that there is a good understanding on construction sites as how to eliminate and minimize formation of construction joint. The work procedures followed to avoid or significantly reduce cold joint formation in almost all of the investigated projects are the following:

a. When it is obligatory to stop concrete casting, it has to be stopped at non-critical structural sections where shear and other stresses are minimal and that is at about one-third from the support.

b. Before pouring fresh concrete over the hardened one, first clean the surface from all foreign matters and then remove the laitance or scum.

c. Make the concrete receiving surface rough by chiseling, wet the surface with water, add rich mortar and finally pour the fresh concrete on the wet surface.

Fig 4.5 300liters stationary concrete mixer used on the building project of Oromyia Regional State President Office, Adama

Fig 4.6 Compaction of concrete on ground column of Nazareth Technical college building project

To assess the proper execution and the degree of importance paid for compaction and curing of concrete, queries related with these two production processes are included in the questionnaire. As observed on the results, on 34.62 percent of the projects there is no attention paid both for the time of compaction and the spacing of vibrators poker during compaction. Respondents on 7.69 percent of the projects don't show any care for the time of compaction but paying due attention only for the spacing of poker's immersion location. Again also 7.69 percent of the respondents has mentioned that attention is given only to the compaction spacing but not for the time of compaction. It is only in the response of five respondents (19.23%) that a time of 1 to 5 minutes is observed to be the time of compaction. In the rest 38.46 percent, the compaction time is under one minute.

The study shows, 7.69 percent of the respondent explained that the spacing of vibrators poker on fresh concrete surface is approximately in the range of 1 to 2 meters, 50 percent of the respondent have mentioned a spacing which varies between 10cms and 80cms. It is also observed on the finding that 7.69 percent of the respondents don't worry about the compaction depth in each layer. Fig. 4.6, 4.7 and 4.9 show the photograph of concrete placing and compaction operations on columns and slabs of different investigated projects

When the maximum depth of compaction is observed, 23.08 percent of the respondents have mentioned that there is no specific depth of compaction considered for each compaction layer, 69.23 percent have given compaction depth in the range of 20 to 60 Centimeters and 7.69 percent of respondents have explained that there is a compaction depth between 50 and 80 Cms.

On 19.23 percent of the projects, no response is obtained all in all on the time, spacing, and depth of compaction. This indicates that either there is no attention given for those works or the competency of professionals responsible for the concreting work on the site is under question. However; to efficiently utilize the compaction effort obtained from vibrators, it is recommended that the poker immersion location shouldn't be more than 600mm or 8 to 10 times the diameter of the poker for five to thirty seconds depending on the consistence of the mix but with some mixes up to 2 minutes is required and the concrete should be placed in layers not more than 600mm high [4]. If the compaction effort of vibrator is not appropriately used, it might result either to over vibration or under vibration. Over vibration enhances bleeding and segregation and under vibration leave excessive voids in concrete which contains entrapped air. The presence of 5% voids reduces the strength by as much as 30 percent [3, 13].

Fig 4.7 concrete placing &compaction on ground column of Nazareth Technical college building project

When the curing practice on the investigated projects are observed, twelve of the respondents have given equal curing period for both OPC and PPC concrete. Eleven of the twenty four (45.83%) respondents that have given a response on OPC concrete curing time, the concrete is cured for seven days; respondents on twelve projects (50%) have mentioned curing time for OPC cement containing concrete to be in the range of 7 to 21 days; in one project

(4.17%), the curing time is from three to seven days and in four projects (16.67%), the curing time is for 28 days.

Fig 4.8 Concrete mixing & discharging operation with a self loading tractor on Nazareth Technical college building project

Respondents on twenty-one projects have given their response on PPC concrete. Among them 33.33 percent of the respondents cure PPC cement containing concrete for less than fourteen days which is considered to be insufficient as per the recommendation of the literatures whereas the remaining 66.67 percent cure for a time of 14 to 35 days.

Fig 4.9 Placing of concrete on the slab of the building project of Addis Ababa University, Faculty of Veterinary medicine, Debrezeit.

PPC cement concrete is a slow hardening concrete due to the pozzolanas in it as compared to OPC concrete. Hence it gains strength slowly requiring longer curing duration. Literatures recommended that a minimum of seven continuously moist curing days are required for concretes containing OPC concrete and two to three times of OPC for pozzolana or slag cement concretes [4,15]. Therefore, except in one of the projects mentioned above, the curing of OPC concrete is in conformity with the recommended practice. However, equal curing duration observed in twelve of the projects both for OPC and PPC concrete is an indication that there is no clear understanding about the behavior of concretes made of different cement types among professionals who play the supervisory and advisory role on building project site.

Fig 4.10 Compaction of second floor slab concrete on the building project of Addis Ababa University, Faculty of Veterinary medicine, Debrezeit.

Generally, in order to have good quality concrete, all concrete ingredients has to be of the proper quality and each production phase should be carefully done and the technology used in concrete production has to be updated. The use of automatic batching plants and proper types of mixers need to be given due consideration.

4.2.5. Compliance of 28th day compressive strength test results with the requirements of standards

One of the most important methods of assuring that concrete is of the required quality is to take representative samples during concrete casting and analyze whether the results are satisfactory or not. Since the design of reinforced concrete structures of buildings or other concrete elements are based on the strength of concretes, the testing of sampled concretes should be given a special emphasis than the quality of the ingredient or the production processes. In addition as the attention given on all quality assuring activities or operations are reflected on the strength test, the importance of testing is immense. Therefore, the sample should be representative of the mass, the testing should follow the right procedures specified by codes and standards starting from casting concretes to molds up to testing it. Otherwise, the results obtained will be misleading and unreliable. The main objectives of making quality tests for concrete ingredients and carefully undertaking the production processes is at the end to obtain good quality concrete that satisfies both the strength and durability required. These facts make concrete testing an invaluable phase of concrete quality determining.

Therefore; noting the importance of test result in assessing the quality of concrete, compressive strength test results from a number of lots in all projects are analyzed and their compliance is checked.

The level of quality control is also quantitatively assessed with the use of statistical parameters measuring variability after undertaking statistical analysis as shown on table 4.10.

The concept of statistics and probability nowadays is applied in lots of industrial products so that to make productions or outputs has better quality and at the same time less costly [22]. Therefore, construction as an industry, utilizes the basics of statistics and probability as a tool in improving quality and costs of productions.

To perform the analysis shown on table 4.10, the following points are considered.

In the Ethiopian building codes of standards, the values of K_1 and K_2 shown in table 2.6 are variable for various lots. But for analysis of test results in this thesis paper, both the values of K_1 and K_2 are taken to be 3MPa assuming that the lots considered in all the projects are above the fifth lot. This assumption requires the least acceptance criterion indicating that we are assessing the test results on the basis of this minimal requirement.

In order to convert the cube strength to cylindrical strength and carry out the analysis as per the American standard, a conversion factor of 0.8 is used [i.e cylindrical strength = 0.8* cubic strength][14].

In accordance with the British and American standard a test result is represented by two sample tests. However, the Ethiopian building code of standard requires one cube to represent one test result and a lot to have three samples or cubes. Hence, in the analysis, this single test result is used both in the American and British standards by assuming that as if it were an average of two sample tests.

To carry out the statistical analysis shown below, eq. (2.1), eq. (2.2) and eq. (2.3) are used for the determination of the mean, the standard deviation and the coefficient of variation respectively. The standard deviation is computed first with the cube test results then converted to the cylindrical strength with the conversion factor of 0.8 so that to label the level of quality control as per the ACI 214.

The compliance of test results is made in accordance with the requirement set on standards. The Ethiopian standard has set two criteria. But the first one with eq. (2.4) and eq. (2.5) which suited for small number of samples is used.

Table 4.10 compressive strength test results on investigated projects and their analysis.

Table 4.10 compressive strength test results on investigated projects and their analysis

No	Name of projects investigated & grade of concrete	Total mean compre-ssive strength	Sample Standard Deviation in Mpa (cubic strength)	Sample Standard Deviation in Mpa (cylinderical strength)	Coefficient of Variation	Ethiopian Standard (EBCS-2,1995)			American Standard (ACI 318)			British Standard (BS 5328:1990)		
						Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defectiv e lots	Number of defective lots	Number of Non-defective lots	% of defective lots
1	National museum conservation research & analytical laboratory; C-25	37.01	6.5	5.20	17.55	1	5	16.67	0	6	0.00	0	6	0.00
2	Bole Aircraft Maintenance Hangar;C-30	35.37	3.37	2.70	9.52	1	3	25.00	0	4	0.00	0	4	0.00
3	AAU, Debrezeit faculty of veternary medicine, project-1; C-25	32.07	3.36	2.69	10.46	0	7	0.00	0	7	0.00	0	7	0.00
4	AAU, Debrezeit faculty of veternary medicine, project-2; C-25	36.47	4.63	3.70	12.69	0	4	0.00	0	4	0.00	0	4	0.00
5	AAU, faculty of Science; C-25	39.39	5.38	4.30	13.66	0	5	0.00	0	5	0.00	0	5	0.00
6	AAU, FBE/SISA building; C-25	34.03	6.05	4.84	17.77	0	7	0.00	0	7	0.00	0	7	0.00
7	AAU, FBE/SISA building; C-30	32.53	2.11	1.69	6.5	3	3	50.00	0	6	0.00	3	3	50.00
8	Adama Oromyia Regional State President Office; C-30	40.8	0.91	0.73	2.23	0	2	0.00	0	2	0.00	0	2	0.00
9	Gurd Sholla, Management Institute Head office extension; C-25	29.77	5.51	4.41	18.52	1	1	50.00	1	1	50.00	1	1	50.00
10	Megenagna, Adari School Class room construction; C-25	48.6	0.87	0.70	1.78	0	1	0.00	0	1	0.00	0	1	0.00

No	Name of projects investigated & grade of concrete	Total mean compre-ssive strength	Sample Standard Deviation in Mpa (cubic strength)	Sample Standard Deviation in Mpa (cylinderical strength)	Coefficient of Variation	Ethiopian Standard (EBCS-2,1995)			American Standard (ACI 318)			British Standard (BS 5328:1990)		
						Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defectiv e lots	Number of defective lots	Number of Non-defective lots	% of defective lots
11	Adama TV & Radio Station; C-30	40.3	6.5	5.2	16.1	1	2	33.3	0	3	0.0	0	3	0.0
12	Adama, Oromyia State Council building complex (Geda Hall); C-25	32.2	4.2	3.3	12.9	0	10	0.0	0	10	0.0	0	10	0.0
13	Nazreth Technique College; C-25	28.7	1.2	1.0	4.2	0	2	0.0	0	2	0.0	0	2	0.0
14	Kality Tse-Tse eradiation center phase-II; C-30	40.3	3.0	2.4	7.3	0	2	0.0	0	2	0.0	0	2	0.0
15	Kebena Apartement 2nd phase; C-25	40.0	4.3	3.4	10.8	0	1	0.0	0	1	0.0	0	1	0.0
16	AAU, Faculty of Medicne; C-25	26.9	4.7	3.8	18.2	1	4	20.0	0	5	0.0	1	4	20.0
17	Jimma University phase-I; C-25	29.6	2.0	1.6	6.7	0	2	0.0	0	2	0.0	0	2	0.0
18	Jimma University phase-II; C-25	27.6	2.0	1.6	7.2	1	0	100.0	1	0	100.0	1	0	100.0
19	Jimma University phase-III; C-25	29.3	3.1	2.4	10.5	2	3	40.0	0	5	0.0	2	3	40.0
20	Miza Teferi Agricultural College Package-I; C-25	38.0	5.8	4.6	15.3	0	1	0.0	0	1	0.0	0	1	0.0
21	Miza Teferi Agricultural College Package-II; C-25	29.2	7.2	5.8	24.7	3	5	37.5	1	7	12.5	3	5	37.5
22	Jimma University President Office; C-25	26.2	0.7	0.6	2.7	1	0	100.0	0	1	0.0	1	0	100.0
23	Bahirdar University Expansion Building; C-25	37.6	6.4	5.1	17.1	0	28	0.0	0	28	0.0	0	28	0.0
24	Bahirdar University Phase-II; C-25	30.4	4.5	3.6	14.7	1	41	2.4	0	42	0.0	0	42	0.0

No	Name of projects investigated & grade of concrete	Total mean compre-ssive strength	Sample Standard Deviation in Mpa (cubic strength)	Sample Standard Deviation in Mpa (cylinderical strength)	Coefficient of Variation	Ethiopian Standard (EBCS-2,1995)			American Standard (ACI 318)			British Standard (BS 5328:1990)		
						Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defective lots
25	Bahirdar University Phase-III; C-25	35.4	7.0	5.6	19.7	4	50	7.4	2	52	3.7	4	50	7.4
26	Bahirdar Regional Hospital; C-25	35.7	6.5	5.2	18.2	0	8	0.0	0	8	0.0	0	8	0.0
27	Bahirdar Technical & Voational Training Center (TVET); C-25	33.3	4.7	3.8	14.2	0	5	0.0	0	5	0.0	0	5	0.0
28	Gonder University Phase-II, Medical Science faculty; C-25	30.2	4.8	3.8	15.9	6	11	35.3	0	17	0.0	6	11	35.3
29	Gonder University Phase-III, Medical Science faculty; C-25	48.6	5.2	4.2	10.7	1	51	1.9	1	51	1.9	1	51	1.9
30	Gonder University Phase-III, Social Science faculty; C-25	36.0	7.6	6.1	21.2	1	28	3.4	1	28	3.4	1	28	3.4
31	MertolemariamTechnical & Voational Training Center (TVET); C-25	32.8	4.3	3.5	13.2	0	9	0.0	0	9	0.0	0	9	0.0
32	Dilla Technical & Voational Training Center (TVET) Package-I; C-25	36.0	4.1	3.3	11.4	0	3	0.0	0	3	0.0	0	3	0.0
33	Dilla Technical & Voational Training Center (TVET) Package-II; C-25	39.4	6.4	5.1	16.1	1	9	10.0	0	10	0.0	0	10	0.0
34	Dilla Technical & Voational Training Center (TVET) Package-III; C-25	32.7	6.8	5.4	20.8	1	3	25.0	0	4	0.0	1	3	25.0
35	Dilla Technical & Voational Training Center (TVET) Package-III; C-30	42.1	7.7	6.2	18.3	0	2	0.0	0	2	0.0	0	2	0.0
36	Arbaminch Water Technology Institute (AWTI), Phase-II; C-25	35.1	8.4	6.7	24.0	2	17	10.5	1	18	5.3	2	17	10.5

No	Name of projects investigated & grade of concrete	Total mean compre-ssive strength	Sample Standard Deviation in Mpa (cubic strength)	Sample Standard Deviation in Mpa (cylinderical strength)	Coefficient of Variation	Ethiopian Standard (EBCS-2,1995)			American Standard (ACI 318)			British Standard (BS 5328:1990)		
						Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defetive lots	Number of defective lots	Number of Non-defective lots	% of defective lots
37	Arbaminch Water Technology Institute (AWTI), Phase-III; C-25	33.4	5.8	4.6	17.4	8	38	17.4	6	40	13.0	7	39	15.2
38	Wolyita Technical & Voational Training Center (TVET) Package-I; C-25	34.4	4.2	3.4	12.2	0	3	0.0	0	3	0.0	0	3	0.0
39	Wolyita Technical & Voational Training Center (TVET) Package-II; C-25	29.0	6.3	5.0	21.7	1	2	33.3	1	2	33.3	1	2	33.3
40	Wolyita Technical & Voational Training Center (TVET) Package-III; C-25	33.7	4.0	3.2	11.9	0	3	0.0	0	3	0.0	0	3	0.0
41	Wolyita Technical & Voational Training Center (TVET) Package-IV; C-25	32.4	5.5	4.4	17.0	2	3	40.0	0	5	0.0	2	3	40.0
42	Wolyita Technical & Voational Training Center (TVET) Package-V; C-25	30.9	5.9	4.7	19.1	1	3	25.0	1	3	25.0	1	3	25.0
43	Awassa, Debub University Additional Blocks Phase-III; C-25	30.8	5.5	4.4	17.8	4	21	16.0	2	23	8.0	2	23	8.0
44	Awassa, Debub University Additional Blocks Phase-III; C-30	30.8	5.4	4.3	17.5	5	3	62.5	4	4	50.0	5	3	62.5
45	Awassa Referal Hospital Phase-III; C-30	51.4	15.0	12.0	29.2	0	2	0.0	0	2	0.0	0	2	0.0
46	Awassa, Ethiopian Telecommunication Corporation Southern Branh Office building; C-25	38.1	3.6	2.9	9.5	0	2	0.0	0	2	0.0	0	2	0.0

As shown on table 4.11, 52.17 % of the projects contain defective or non-complying lots for tests made on samples taken for compressive strength test results in accordance with the requirement set on the Ethiopian building codes and standards which is used as part of the specification of the contract document [14]. However; as per the American and British standard, only 26.09 % and 41.30% of the projects respectively have got defective lots.

Where there are defective lots, non-destructive test commonly schimidt hammer test is ordered for the structural part of the building in which unsatisfactory test results are obtained. During investigating the project, mostly it is found out that the result of this hammer test satisfies the compliance criteria. However; as hammer test provides reliable result only at shallow depth on the surface of the structure up to around 30 mm as explained on the literature review, it is difficult to determine with certainty the insitu strength of deeper slab and column or beam sections.

The variation observed among test results of the investigated projects is shown on the statistical analysis of table 4.10. In accordance with the classification of ACI 214, there is a quality control standard which is determined based on the variation of compressive strength test results [16, 20]. Table 4.11 shows percentage of investigated projects which belongs to the various level of control standards. Fig. 4.11 & 4.12 have also shown in pie chart the level of quality control of thirty-nine projects whose test results are analyzed. These control standards are determined from the observed variability of test results. The two variability measuring statistical parameters used in assessing the level of control standards are standard deviation and coefficient of variation.

Table 4.11 assessment of the level of quality control

a) Classification of the level of quality control using standard deviations

Standard deviation	No of projects & grade of concrete	Percentage of projects	Control standards
< 2.8	8	19.51	Excellent
2.8 - 3.5	6	14.63	Very good
3.5 - 4.2	6	14.63	Good
4.2 - 4.9	8	19.51	Fair
> 4.9	13	31.72	Poor

b). Classification of the level of quality control using Coefficient of variations

Coefficient of variations	No of projects & grade of concrete	Percentage of projects	Control standards
< 10	7	17.07	excellent
10-15	12	29.26	good
15-20	16	39.02	fair
>20	6	14.65	poor

NB thirty-nine projects having more than one lot are considered and analyzed to determine the level of quality control standards.

In projects where there are defective lots, non-destructive test commonly Schmidt hammer test is ordered for the structural part of the building in which unsatisfactory results of tests are obtained. Mostly the rechecking test is found to satisfy the compliance criteria. However; as Schmidt hammer test gives reliable results for the surface of the structure to a depth of only about 30mm, it is difficult to tell the strength of deeper slab, column, beam or any load bearing structural element.

When the structural safety of a building is observed, it is obvious that defective concrete definitely have a significant impact on it. But concrete structures are designed with higher safety factors. For instance a C-25 concrete is assumed to have design strength of 11.33MPa i.e,

f_{cd} = 0.85*(f_{ck}/1.5) (EBCS-2, 1995)

Where f_{ck} is the cylindrical characteristic compressive strength, and

f_{cd} = is the design strength

Hence for C-20, fcd = 9.07MPa. Similarly for C-25, f_{cd} =11.33MPa and for C-30, f_{cd} =13.6 MPa

Therefore, a minor deviation from compliance requirement may not have as such a big impact on the safety of the building. However; poor quality concrete that results in lower compressive strength than the required are not durable though it seems that there is no problem of the structural safety for the time being. Strength and durability are directly related. Strong concrete is obtained from dense concretes having less porosity and permeability that affects concrete durability.

As observed on table 4.10, for the same concrete grade, some projects which have higher mean compressive strength, have shown higher variablity i.e. higher standard deviation and coefficient of variation. Hence indicating that the quality control is unsatisfactory.

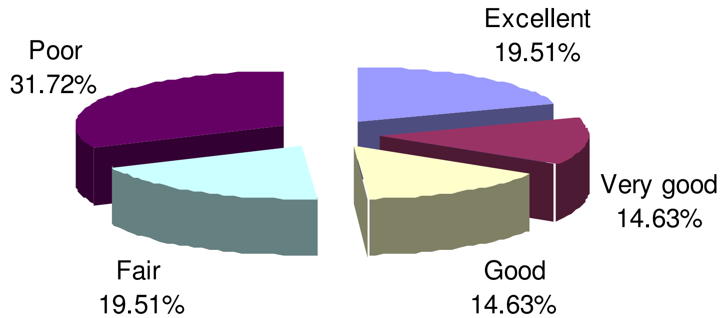


Fig. 4.11 level of quality control of projects based on standard deviation

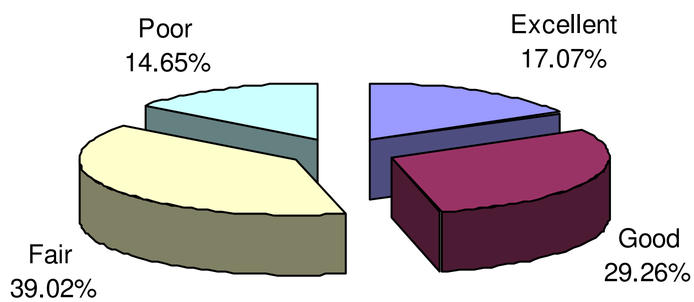


Fig. 4.12 level of quality control of projects based on coefficient of variations

For instance on the project of National museum conservation research & analytical laboratory where C-25 structural concrete is produced, the cube mean compressive strength test result is 37.01 MPa with a standard deviation of 5.2Mpa indicating that there is poor quality control.

However, on the project of Addis Abeba University, Debrezeit faculty of veternary medicine at which the same concrete grade is used the mean cube compressive strength is found out to be 32.07MPa with the corresponding standard deviation of 2.69 which shows that the standard of concrete quality work is excellent.

Since, the mix design of concrete is prepared considering the expected variation in concrete production in which a concrete with higher variability is designed to attain higher required mean strength than a concrete with lower variability for the same concrete grade [13]. This higher mean strength which results due to larger variability consumes much cement that makes the production uneconomical.

On some of the projects it seems that there is an intention to offset the problem tied with quality control by preparing a mix with a very high compressive strength than that required. However, this has a disadvantage of making the concrete produced uneconomical as higher compressive strength consumes much cement. It is not always possible to remedy the defects of quality control by increasing the cement content. Quality concrete doesn't only mean a concrete with higher compressive strength. Durability is also vital to determine quality. Due to the higher cement content of concrete, a concrete which is honey combed and porous that is an indication of poor durability, may show higher compressive strength due to the lower w/c ratio at the early age of the structure. Hence, there should be a strict follow up of the production process to assure the overall quality of concrete.

One of the observations made during investigating concrete test results is on the testing time of concrete samples. The projects listed on table 4.12 that accounts 25.58% of the thirty-nine investigated projects, concretes are not tested on the proper time.

Table 4.12 Projects having lots tested above 28th day

No	Name of projects investigated projects	Number of lots tested on 28th day	No of lots tested above 28th day					
			28-40 days	40 - 50 days	50 - 60 days	> 60 days	% Of lots tested above 28 days	Maximum observed testing time in days
1	Bahirdar University Phase-II	42	2	1	1	0	8.70	60
2	Bahirdar University Phase-III	54	2	0	0	0	3.57	35
3	Bahirdar TVET	5	1	0	0	0	16.67	31
4	Gonder University Phase-III, Social Science faculty	52	18	15	10	4	47.47	68
5	Dilla (TVET) Package-II	10	1	0	0	0	9.09	31
6	Dilla TVET Package-III	6	1	0	0	0	14.29	31
7	Arbaminch Water Technology Institute (AWTI), Phase-II	19	2	0	0	1	13.64	65
8	AWTI phase-III	46	1	0	0	0	2.13	32
9	Wolyita TVET Package-I	3	3	0	0	0	50.00	38
10	Wolyita (TVET) Package-V	4	0	0	1	1	33.33	61
11	Debub university phase-III	8	2	0	0	0	20.00	34

On some projects that are listed on table 4.13, Samples which are intended to be tested on 28th day were sometimes observed to stay up to two months and even longer. In Gonder university phase III project of the social science faculty, one lot is found to stay up to 68 days.

Design of concrete structure is based on the 28th day strength that concrete attains. Hence, concrete strength test result should be taken on time to assure its compliance. If it doesn't satisfy specified requirements, the insitu strength is rechecked with non-destructive tests and finally a decision whether to demolish or not to is given before proceeding to construction works on top of the defective one. However; if concrete is tested beyond the standard testing time and the result becomes unacceptable, the removal of such a poor quality concrete may have a possibility of damaging the erected superstructure over it. In such a circumstance, demolishing the unaccepted part brings damage to the structure on top of it. As a result; this has an impact on the quality of the overall structure. If defects are not rectified on time and construction work continues on top of such a poor concrete, the removal of the unsatisfactory part brings damage to the remaining work which in effect lead to additional maintenance cost. Therefore this results in both time and cost overrun of the project. It is known that the objective of taking the 3rd , 7th and 14th day compressive strength test result is to priorly forecast the 28th day strength and take on time measures so that to proceed with the subsequent work without incurring any delay.

It is observed that on some of the lots tested after the 28th day, higher compressive strength is obtained. Even if concretes having longer age showed higher strength, it is not possible to be certain about the quality of concrete since concrete gain strength with time as explained on the literature review.

Therefore; testing of concrete, from which the quality of concrete is assessed quantitatively, need to be seriously considered on construction sites. Representative samples should be taken and tests have to be conducted on time and measures have to be taken to rectify defects at the earliest possible time to assure both quality and economy.

5. CONCLUSIONS AND RECOMMENDATIONS

The research carried out has shown some of the problems associated with concrete construction practice of the investigated building construction sites and attempt is made to show the impact of improper concrete construction practice on the quality of concrete. The following conclusions and recommendations are drawn out from the investigation undertaken on the building construction projects.

5.1. Conclusions

1. Sufficient tests are not undertaken both on fine and coarse aggr egate. For coarse aggregate; tests which are useful to check the strength of aggregate that includes aggregate crushing value (ACV), losangeles abrasion test (LAV) and soundeness test are observed only in a few number of the projects. For fine aggregate; only sieve analysis, and silt and clay content tests are conducted in a great number of the projects (on 96.15%). However, the remaining tests such as organic impurity, specific gravity, and water absorption is conducted in small number of the projects.

2. It is only in the national museum building project that the presence of chloride is checked in the fine aggregate. There is no other project that conducts tests to check the presence of deleterious chemicals like sulphate and chloride both for the fine and coarse aggregate.

3. Batching of concrete ingredient is made by weight only in 11.54% of the projects.

4. Bulking of sand during batching is not considered in 91.3 % of the projects either due to negligence or poor understanding. This results in sand deficient concrete mix.

5. The moisture content of aggregates is not carefully considered and adjusted during mixing. Therefore the water cement ratio, which has significant impact both on strength and durability, is affected.

6. The date of production of cements is not known as factories donot specify it on their product. This has an impact on the concrete quality, as there is a possibility that aged cements can be used for concrete production.

7. Attention is not given to the mixing and compaction of concrete. On most of investigated projects, only visual inspection is a measure to assure quality at these production stages.

8. Statistical analysis made on compressive strength test results indicated that the quality control on significant portion of the projects is not good. As per the classification of ACI 214, the standard deviation of 51.23 % of the projects compressive strength has shown that the quality control is not good from which 19.51% fall in the “fair” classification range and 31.72% in the “poor” range; and the coefficient of variation of 53.67 % of the projects compressive strength has shown that the quality control is not good from which 39.02% fall in the “fair” classification range and 14.65 % in the “poor” range.

9. Compressive strength test results were not conducted on time on 25.58% of the projects and it is observed that there was a test result taken at the 68th day.

10. From the analysis of the forty-three investigated projects` compressive strength test result, 52.17%, 26.09% and 41.3% of the projects has shown defective lots as per the Ethiopian, the American and the British codes compliance requirement respectively.

11. The compliance requirement set by the Ethiopian building codes and standards is tight as compared to the American and British Standard. However, each test result is represented by two samples in the American and British Standard but only one sample represents one test result in accordance with the Ethiopian practice. Hence it is better if a lot is represented by larger number of samples and a less stringent compliance criteria is used so that to reduce producer's risk and to make the samples more representative.

5.2. Recommendations

1. Aggregate sources have to be identified and studied. The mineralogical contents of quarry sites should be known and made available to any concrete producer, contractors or consultants by the responsible government bodies or institutes.

2. By giving emphasis to concrete quality control system, which reduces variation in concretes, it is possible to minimize cement consumption and make concrete production economical. Hence quality control is important to maintain both quality and economy simultaneously

3. Cement producing factories should specify the date of production of cement so that concrete producers know whether the cement is aged or not.

4. When slump fails there is a tendency to correct the slump by adding or reducing water. However, it is required to investigate and identify the cause than trying to adjust the slump by varying the water content only.

5. The specification prepared has to include important tests for concrete materials and all specified tests have to be done in accordance with standard procedures.

6. It is better if concrete is produced by specialist subcontractors to improve the quality in large towns and cities.

7. Both contractors and consultants have to conduct their work in accordance with their professional ethics.

8. There must be well-experienced professionals both on the contractor and the consultant staff to improve quality.

9. Training should be given to the semi-skilled laborers on concreting work.

10.As concrete is a major construction material forming the structural part of buildings manual on concrete production has to be separately prepared and used as a guide on construction sites.

11. Quality management plan has to be prepared and properly implemented during concrete production processes that identifies the critical activities and helps in taking the appropriate measures at any stages during concrete production.

12. Systematic and Well-organized quality control by an independent body is useful in improving concrete quality on construction projects.

13. The provision of Ethiopian building code of standards on concrete production and its quality control is insufficient. Therefore, it is recommended to be comprehensive enough to address key problems related with concrete production and its quality control considering its importance.

14. The following areas could be investigated in the future as part of the extension of this research work.

- The quality of workmanship involved in the building construction industry of Ethiopia and its impact on concrete quality
- The impact of aggregate quality on the overall quality of concrete
- Concrete quality and costs associated with quality in the building construction industry of Ethiopia.

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7. APPENDIX-A

QUESTIONNAIRE

Please give response to the following questions either by putting an `x` mark at your choice on the rectangles shown for questions having choices or by writing your answers in the space provided.

1. What is the structural grade of concrete that is used for this project (cubic strength in MPa)?

2. Where is the source(s) of your coarse and fine aggregate?

Coarse aggregate: ____

Fine aggregate: ____

3. What kind of fine aggregate do you use for concrete production?

☐ Natural sand
☐ Crushed aggregate

4. What are the tests made for coarse aggregates? Please write down the corresponding values obtained.

Physical tests:

____
____
____
____

Chemical tests:

____
____
____
____
____

5. What are the tests made for fine aggregate with specified values? Please write down the corresponding values obtained.

Physical tests:

____
____

Chemical tests:

____
____

____

____

6. How frequent do you take samples when testing aggregates?

☐ Only once for one source
☐ Once when it came from the source and then after depending on conditions (that is when the aggregate seems defective, test may be ordered.)
If any other sampling procedure to be followed, please specify

7. Are you satisfied with the quality of aggregate? What would you do if test result fails?

8. What do you propose to maintain the quality of aggregate?

9. What would you do with the aggregates if it doesn't satisfy the requirement on the specification?

10. What type of cement do you use for the concrete production?

☐ OPC
☐ PPC
If any other, please specify

11. Where is the source of cement used in concrete production?

12. What is the minimum cement content specified in the specification of the contract document of this specific contract?

____

13. Is there any test made for the cement that you are using? If any, please specify.

____

14. How old is the age of the cement until casting date? (Starting from the time of its production)

____

15. What quality of water do you use for concrete mixing?

☐ Drinking water
<u>If non-drinking water;</u>
☐ From river
☐ Ground water from drilled well

16. Is there any test that was made for the water? If any, please specify

____
____
____
____

17. Do you use admixture in concrete production? If it is used, please specify the type and dosage the admixture.

____
____
____
____

18. What kind of concrete mixing procedures do you follow?

☐ Designed mixes
☐ Prescribed mixes
☐ Standard (or nominal) mixes

19. In case when you aren't able to get the type of cement specified on the specification of the contract document, for instance if OPC is specified and PPC is the only cement available on the market, what adjustments do you make?

____
____
____
____

20. Which batching techniques do you use?

□ By weight
□ By volume

21. What are the adjustments that you make to ingredients when using;

a)Weight batching:

____
____
____
____

b) Volume batching:

____
____
____
____

22. How do you mix your concrete?

□ Manually
□ Using mixing plant
□ Both of them (both manually and using mixing plant)

23. If you are using mixing plant, what type of mixing plant do you use?

□ On site mixing
□ Ready mix; mixing out of the construction site and transported to the site by trucks.

24. What is the capacity of your mixing plant?

____

25. For how long do you mix the ingredients?

____

26. If the concrete is mixed out of the site, how long is taken for the concrete to be placed on the forms? (The time between the start of mixing and placing)

____

27. What is the corrective measure that you take in case when you aren't able to attain the required slump?

____
____
____
____

28. How do you compact concrete?

□ using hand compaction (rodding)
□ using mechanical vibration
If any other, please specify
____
____
____
____

29. If you use mechanical compaction (i.e. compaction using vibrators)

a)For how long do you compact at an immersion place?
____

b) What is the center to center spacing of vibrators tube on the fresh concrete surface being compacted?
____

b)In case of compacting thicker concrete sections, what is the maximum compaction depth that you use?
____

30. During concrete placing what are the measures that you take to prevent formation of cold joint?
____
____
____

31. After casting your concrete, for how long do you cure it if

a) OPC is used in your concrete production?

b) PPC is used in your concrete production?

c) Another type of cement is used? Please specify the cement.

32. What would you do with the concrete if not?

33. What do you propose to produce good quality concrete?

Thank you for your cooperation!

8. APPENDIX-B

TEST RESULT DATA AND THEIR ANALYSIS

Project number & concrete grade	Compressive strength[MPa]		mean compressive strength	mean strength of each lot	standard deviation	coefficient of variation	compliance of compressive strength to the various standards for each lots		
							Ethiopian standard	American standard	British standard
	27.50		37.01	27.90	6.50	17.55	failed	complied	complied
	27.80								
National museum conservation research & analytical laboratory	28.40								
	33.80			33.70			complied	"	"
	33.10								
	34.20								
	31.00			32.89			"	"	"
	34.12								
	33.56								
	44.30			44.30			"	"	"
C-25	43.90								
	44.70								
	40.50			39.07			"	"	"
	40.60								
	36.10								
	46.90			44.20			"	"	"
	46.50								
	39.20								
	35.70		35.37	37.10	3.37	9.52	complied	complied	complied
Bole Aircraft Maintenance Hangar	37.90								
	37.70								
	31.00			31.23			failed	"	failed
	29.70								
	33.00								
	39.20			39.03			complied	"	complied
C-30	40.10								
	37.80								
	34.50			34.10			"	"	"
	35.90								
	31.90								

AAU, Debrezeit faculty of veternary medicine, project-1	32.00 36.20 36.50		32.07	34.90	3.36	10.46	complied	complied	complied
	29.60 31.40 26.80			29.27			"	"	"
C-25	29.60 29.10 29.90			29.53			"	"	"
	32.90 31.80 32.50			32.40			"	"	"
	28.10 32.50 27.40			29.33			"	"	"
	32.70 32.50 29.50			31.57			"	"	"
	37.80 37.50 37.20			37.50			"	"	"
AAU, faculty of Science	37.00 36.60 35.60		39.39	36.40	5.38	13.66	complied	complied	complied
	36.90 40.40 36.60			37.97			"	"	"
C-25	33.60 35.30 35.30			34.73			"	"	"
	43.20 52.70 49.00			48.30			"	"	"
	40.60 36.80 41.20			39.53			"	"	"

AAU, FBE/SISA building C-30	**33.00** **32.40** **34.00**		32.53	**33.13**	2.11	6.50	complied	complied	complied
	29.70 **31.20** **30.70**			**30.53**			failed	"	failed
	29.80 **31.40** **30.50**			**30.57**			"	"	"
	32.00 **32.40** **31.20**			**31.87**			"	"	"
	32.40 **37.40** **36.70**			**35.50**			complied	"	complied
	33.40 **34.40** **33.00**			**33.60**			"	"	"
AAU, FBE/SISA building C-25	**28.70** **29.60** **28.30**		34.03	**28.87**	6.05	17.77	complied	complied	complied
	27.50 **28.90** **29.80**			**28.73**			"	"	"
	29.90 **29.20** **29.60**			**29.57**			"	"	"
	37.40 **34.60** **37.10**			**36.37**			"	"	"
	34.90 **39.80** **39.40**			**38.03**			"	"	"
	31.70 **32.50** **29.80**			**31.33**			"	"	"
	45.40 **47.60** **43.00**			**45.33**			"	"	"
Adama Oromyia Regional State President Office C-30	***39.67*** ***40.81*** ***40.38***		***40.80***	**40.29**	***0.91***	***2.23***	***complied***	complied	complied
	40.19 ***42.04*** ***41.68***			**41.30**			"	"	"
Gurd Sholla, Management Institute Head office extension C-25	***24.50*** ***24.30*** ***25.90***		***29.77***	**24.90**	***5.51***	***18.52***	***failed***	failed	failed
	35.10 ***36.40*** ***32.40***			**34.63**			***complied***	complied	complied

Megenagna, Adari School Class room construction, C-25	*49.10* *47.60* *49.10*		*48.60*	48.60	*0.87*	*1.78*	*complied*	complied	complied
Adama TV & Radio Station	*39.00* *41.10* *42.00*		*40.34*	40.70	*6.50*	*16.11*	*complied*	complied	complied
	44.30 *49.60* *48.40*			47.43			"	"	"
C-30	*32.80* *32.60* *33.30*			32.90			failed	"	"
AAU, Debrezeit faculty of veternary medicine, project-2	*34.70* *36.90* *37.80*		36.47	36.47	4.63	12.69	complied	complied	complied
	43.60 *40.40* *39.10*			41.03			"	"	"
	29.40 *28.90* *30.50*			29.60			"	"	"
C-25	*37.30* *38.50* *39.60*			38.47			"	"	"

Adama, Oromyia State Council building complex (Geda Hall)	*31.11* *32.44* *30.67*		32.22	31.41	4.16	12.92	complied	complied	complied
	32.00 *36.89* *28.44*			32.44			"	"	"
C-25	*32.44* *33.78* *30.22*			32.15			"	"	"
	32.48 *26.47* *28.86*			29.27			"	"	"
	28.42 *33.39* *31.25*			31.02			"	"	"
	29.38 *26.30*			29.24			"	"	"

	32.03								
	35.13			39.25			"	"	"
	41.07								
	41.55								
	38.19			36.54			"	"	"
	39.84								
	31.60								
	28.20			32.13			"	"	"
	34.50								
	33.70								
	28.90			28.77			"	"	"
	32.20								
	25.20								

	30.30		28.67	28.67	1.19	4.15	complied	complied	complied
Nazreth Technique College	28.30								
	27.40								
	30.00			28.67			"	"	"
	28.10								
C-25	27.90								
	40.30		40.28	40.28	2.96	7.34	complied	complied	complied
Kality Tse-Tse eradiation center phase-II	38.30								
	35.70								
	42.90						"	"	"
	40.80								
C-30	43.70								
Kebena Apartement 2nd phase	41.70		40.00	40.00	4.31	10.77	complied	"	"
	35.10								
C-25	43.20								
	25.50		26.07	26.07	4.74	18.18	failed	complied	failed
AAU, Faculty of Medicne	26.40								
	26.30								
	32.70			32.73			complied	"	complied
	31.30								
	34.20								
	31.20			31.77			"	"	"
	33.50								
C-25	30.60								
	39.20			39.73			"	"	"
	40.80								
	39.20								

	29.00 31.20 29.40			29.87			"	"	"

jimma university phase-III C-25	29.10 28.08 22.18		29.25	26.45	3.06	10.45	failed	complied	failed
	33.53 27.98 32.68			31.40			complied	"	complied
	26.92 26.34 27.01			26.76			failed	"	failed
	30.96 29.97 33.81			31.58			complied	"	complied
	28.74 30.76 30.68			30.06			"	"	"
jimma university phase-I C-25	30.10 30.90 29.30		29.62	30.10	1.98	6.70	complied	complied	complied
	28.80 32.20 26.40			29.13			"	"	"
jimma university phase-II C-25	26.40 26.50 29.90		27.60	27.60	1.99	7.22	failed	complied	complied
mizan Teferi agricultural college pack-I C-25	36.16 33.28 44.45		37.96	37.96	5.80	15.28	complied	complied	complied
mizan Teferi agricultural college pack-II C-25	34.70 32.90 32.00		29.16	33.20	7.21	24.72	complied	complied	complied
	34.50 32.20 34.70			33.80			"	"	"
	37.90 36.20 38.10			37.40			"	"	"
	30.70 30.90 29.30			30.30			"	"	"

	40.70 29.60 29.60			33.30			"	"	"
	25.90 25.50 25.20			25.53			failed	"	failed
	14.70 14.30 14.60			14.53			"	failed	"
	25.10 25.70 24.80			25.20			"	complied	"

jimma univ- ersity President office C-25	25.50 26.90 26.30		26.23	26.23	0.70	2.68	failed	complied	failed
bahirdar univer- sity expansion building C-25	37.25 34.07 40.96		37.59	37.43	6.43	17.11	complied	complied	complied
	30.22 47.78 45.78			41.26			"	"	"
	52.56 55.43 52.39			53.46			"	"	"
	33.97 35.49 32.07			33.84			"	"	"
	43.30 39.26 38.98			40.51			"	"	"
	36.84 42.60 42.67			40.70			"	"	"
	34.57 33.66 34.59			34.27			"	"	"
	34.80 35.14 36.31			35.42			"	"	"
	31.34 31.04 32.44			31.61			"	"	"

	35.52 31.07 36.34			34.31			"	"	"
	41.71 40.50 41.22			41.14			"	"	"
	35.29 30.47 33.84			33.20			"	"	"

	33.80 41.62 32.48			35.97			"	"	"
	28.27 32.29 30.05			30.20			"	"	"
	36.41 37.01 34.25			35.89			"	"	"
	36.39 37.15 36.22			36.59			"	"	"
	39.56 28.22 25.56			31.11			"	"	"
	35.56 40.89 40.00			38.82			"	"	"
	42.00 42.22 45.78			43.33			"	"	"
	35.11 41.33 40.67			39.04			"	"	"
	27.33 36.67 33.11			32.37			"	"	"
	50.00 48.22 49.33			49.18			"	"	"
	54.22 48.00			44.96			"	"	"

	32.67								
	31.56			32.89			"	"	"
	35.11								
	32.00								
	39.11			37.41			"	"	"
	39.11								
	34.00								
	37.78			41.19			"	"	"
	48.00								
	37.78								
	32.67			33.19			"	"	"
	30.67								
	36.22								
	36.44			33.18			"	"	"
	36.22								
	26.89								

bahirdar univer-	36.89		35.45	34.82	6.98	19.69	complied	complied	complied
sity phase-III	32.00								
C-25	35.56								
	40.22			37.93			"	"	"
	36.89								
	36.67								
	32.44			30.37			"	"	"
	27.33								
	31.33								
	50.89			48.89			"	"	"
	52.22								
	43.56								
	38.89			38.82			"	"	"
	39.78								
	37.78								
	33.78			34.89			"	"	"
	31.78								
	39.11								
	37.11			34.52			"	"	"
	34.44								
	32.00								
	31.33			33.92			"	"	"
	34.22								
	36.22								
	39.33			35.11			"	"	"

	32.00 34.00								
	30.44 37.33 36.44			34.74			"	"	"
	45.56 48.22 47.33			47.04			"	"	"
	36.89 32.00 35.56			34.82			"	"	"
	40.41 40.11 38.31			39.61			"	"	"
	48.23 55.94 42.10			48.76			"	"	"
	48.93 42.43 46.84			46.07			"	"	"
	32.00 30.00 32.22			31.41			"	"	"
	23.56 19.33 27.33			23.41			failed	failed	failed
	33.33 33.78 33.56			33.56			complied	complied	complied
	40.89 30.67 31.33			34.30			"	"	"
	29.78 29.33 30.44			29.85			"	"	"
	30.22 28.67 31.78			30.22			"	"	"
	27.56 26.22 32.22			28.67			"	"	"
	36.22			36.59			"	"	"

	32.44 41.11								
	26.22 29.78 33.11			29.70			"	"	"
	23.56 23.78 23.56			23.63			failed	failed	failed
	26.44 27.11 24.89	24.89		26.15			"	complied	"
	30.89 33.11 30.44			31.48			complied	"	complied
	32.67 27.11 28.00			29.26			"	"	"
	43.33 34.07 48.67			42.02			"	"	"
	27.56 36.00 31.11			31.56			"	"	"
	30.89 30.89 36.44			32.74			"	"	"
	40.00 47.78 38.44			42.07			"	"	"
	48.00 44.00 44.89			45.63			"	"	"
	29.11 24.89 33.33			29.11			"	"	"
	44.44 44.00 45.11			44.52			"	"	"
	33.87 32.74 33.20			33.27			"	"	"
	46.00 49.56 47.11			47.56			"	"	"
	36.44 34.22 40.00			36.89			"	"	"

	40.67 36.00 34.89			37.19			"	"	"
	27.11 35.56 30.00			30.89			"	"	"
	47.73 39.90 48.69			45.44			"	"	"
	39.11 40.22 34.00			37.78			"	"	"
	31.56 29.11 31.78			30.82			"	"	"
	52.22 48.00 48.00			49.41			"	"	"
	33.78 33.42 27.78			31.66			"	"	"
	27.56 32.27 33.96			31.26			"	"	"

	35.87 37.69 40.89			38.15			"	"	"
	39.11 40.22 34.00			37.78			"	"	"
	31.56 29.11 31.78			30.82			"	"	"
	34.24 32.06 33.03			33.11			"	"	"
	33.98 32.19 33.34			33.17			"	"	"
	26.48 28.66 25.39			26.84			failed	"	failed
	36.55			35.09			complied	"	complied

	34.23 34.50								
	28.76 31.73 33.34			31.28			"	"	"
Gonder univer- sity phase-III C-25 social science faculty	30.22 30.89 32.44		36.00	31.18	7.63	21.20	complied	complied	complied
	42.67 38.00 33.33			38.00			"	"	"
	56.89 32.44 33.11			40.81			"	"	"
	47.72 42.89 49.33			46.65			"	"	"
	31.11 38.89 27.33			32.44			"	"	"
	35.80 38.89 27.33			34.01			"	"	"
	38.88 31.50 33.85			34.74			"	"	"
	39.99 39.26 33.75			37.67			"	"	"
	38.70 46.83 43.46			43.00			"	"	"
	37.44 43.69 40.66			40.60			"	"	"
	21.24 17.19 18.83			19.09			failed	failed	failed
	33.40 32.51 32.63			32.85			complied	complied	complied
	35.34 29.94 39.07			34.78			"	"	"
	35.34 29.94 39.07			34.78			"	"	"

	27.33 23.50 29.76			26.86			"	"	"
	32.40 25.90 30.52			29.61			"	"	"
	31.53 33.71 30.02			31.75			"	"	"
	31.97 28.37 31.31			30.55			"	"	"
	32.05 34.85 32.36			33.09			"	"	"
	32.40 25.90 30.52			29.61			"	"	"
	34.20 48.50 43.18			41.96			"	"	"
	47.56 44.92 45.81			46.10			"	"	"
	39.00 43.04 37.61			39.88			"	"	"
	44.54 39.10 46.88			43.51			"	"	"
	50.76 41.52 50.55			47.61			"	"	"
	48.00 46.11 44.20			46.10			"	"	"
	29.40 30.67 33.18			31.08			"	"	"
	31.09 32.86 32.89			32.28			"	"	"
	27.85			33.56			"	"	"

	30.94 41.88								

Gonder univer- sity phase-III C-25 medical science faculty	48.63 52.02 47.73		48.63	49.46	5.20	10.69	complied	complied	complied
	45.09 40.24 36.62			40.65			"	"	"
	31.33 32.00 27.33			30.22			"	"	"
	30.00 32.44 35.33			32.59			"	"	"
	35.44 28.51 28.29			30.75			"	"	"
	29.82 32.90 36.08			32.93			"	"	"
	42.73 36.90 31.90			37.18			"	"	"
	30.36 34.58 37.70			34.21			"	"	"
	28.65 35.74 25.51			29.97			"	"	"
	42.47 40.59 42.68			41.91			"	"	"
	39.74 40.99 35.41			38.71			"	"	"
	32.73 33.71 32.08			32.84			"	"	"
	43.30 43.30 41.30			42.63			"	"	"
	40.70 41.80			41.57			"	"	"

	42.20								

	31.33 32.00 27.33			30.22			"	"	"
	30.00 32.44 35.33			32.59			"	"	"
	27.95 35.74 39.33			34.34			"	"	"
	35.44 28.51 28.29			30.75			"	"	"
	29.82 32.90 36.08			32.93			"	"	"
	42.73 36.90 31.90			37.18			"	"	"
	30.36 34.58 37.70			34.21			"	"	"
	28.65 35.74 25.51			29.97			"	"	"
	28.44 30.44 35.11			31.33			"	"	"
	32.67 29.11 30.22			30.67			"	"	"
	28.90 34.22 30.67			31.26			"	"	"
	35.33 31.11 37.11			34.52			"	"	"
	42.47 40.59 42.68			41.91			"	"	"
	39.74 40.99 35.41			38.71			"	"	"

	32.73 33.71 32.08			32.84			"	"	"
	28.44 30.44 35.11			31.33			"	"	"
	32.67 29.11 30.22			30.67			"	"	"
	43.30 43.30 41.30			42.63			"	"	"
	40.70 41.80 42.20			41.57			"	"	"
	39.52 36.51 34.49			36.84			"	"	"
	36.19 35.48 35.84			35.84			"	"	"
	35.11 32.89 36.00			34.67			"	"	"
	39.11 41.33 44.89			41.78			"	"	"
	41.33 33.78 42.22			39.11			"	"	"
	29.11 31.56 34.89			31.85			"	"	"
	36.89 33.78 35.56			35.41			"	"	"
	35.33 36.89 20.22			30.81			failed	failed	failed
	39.56 36.89 29.78			35.41			complied	complied	complied
	32.00			33.04			"	"	"

	35.78 31.33								
	24.44 27.56 32.00			28.00			"	"	"
	38.22 32.67 31.78			34.22			"	"	"
	35.56 36.66 30.00			34.07			"	"	"
	26.67 32.22 38.89			32.59			"	"	"
	32.96 39.63 34.45			35.68			"	"	"
	34.89 34.22 36.22			35.11			"	"	"
	39.56 37.11 37.33			38.00			"	"	"
	39.52 36.51 36.49			37.51			"	"	"
	36.99 35.48 35.84			36.10			"	"	"
Gonder univer-sity phase-III C-30 medical science faculty	36.97 32.44 36.96		36.97	35.46	3.74	10.12	complied	complied	complied
	27.95 35.74 39.33			34.34			"	"	"
	36.97 32.44 36.96			35.46			"	"	"
	45.09 40.24 36.02			40.45			"	"	"
	39.52 36.51 36.49			37.51			"	"	"
	33.68 31.86 36.02			33.85			"	"	"

	30.57 33.01 34.33			32.64			failed	"	"

bahirdar univer-sity phase-II C-25	30.36 29.70 30.50		30.36	30.19	4.47	14.73	complied	complied	complied
	30.55 36.74 34.87			34.05			"	"	"
	33.98 34.72 36.93			35.21			"	"	"
	45.43 47.18 55.50			49.37			"	"	"
	31.58 32.57 36.48			33.54			"	"	"
	42.33 33.09 39.07			38.16			"	"	"
	35.30 33.98 28.60			32.63			"	"	"
	35.20 36.77 37.20			36.39			"	"	"
	37.60 36.48 32.17			35.42			"	"	"
	35.20 36.77 32.20			34.72			"	"	"
	38.49 38.25 36.39			37.71			"	"	"
	34.11 28.36 33.21			31.89			"	"	"
	33.37 37.45 38.93			36.58			"	"	"
	41.62			41.56			"	"	"

	42.45								
	40.60								
	29.24			28.06			"	"	"
	26.70								
	28.25								
	28.59			32.14			"	"	"
	32.28								
	35.54								
	35.34			33.68			"	"	"
	29.58								
	36.12								
	33.81			34.67			"	"	"
	33.34								
	36.87								
	46.33			43.18			"	"	"
	42.14								
	41.06								
	34.60			36.23			"	"	"
	37.35								
	36.73								
	29.13			33.47			"	"	"
	36.16								
	35.11								

	34.55			35.31			"	"	"
	33.16								
	38.22								
	34.68			35.01			"	"	"
	35.68								
	34.68								
	27.60			28.97			"	"	"
	28.70								
	30.62								
	35.93			37.22			"	"	"
	37.03								
	38.70								
	35.52			34.00			"	"	"
	30.90								
	35.57								
	31.32			33.83			"	"	"
	36.26								
	33.92								
	36.03			34.71			"	"	"
	34.90								

	33.19								
	37.82 30.92 35.06			34.60			"	"	"
	33.77 28.40 35.97			32.71			"	"	"
	33.67 34.28 38.48			35.48			"	"	"
	28.40 33.30 33.30			31.67			"	"	"
	38.00 40.00 43.10			40.37			"	"	"
	31.24 31.30 34.34	43.10 31.24		32.29			"	"	"
	35.82 32.93 34.73			34.49			"	"	"
	32.80 36.00 32.22			33.67			"	"	"
	33.00 26.70 30.56			30.09			"	"	"
	35.82 32.93 34.73			34.49			"	"	"
	31.24 31.30 34.34			32.29			"	"	"
	28.31 26.10 29.13	34.34		27.85			failed	"	"
	29.07 30.91 30.69			30.22			complied	"	"
	32.19 36.35 29.92			32.82			"	"	"

bahirdar Regional hospital C-25	36.00 33.11 38.67		35.66	35.93	6.49	18.21	complied	complied	complied
	27.33 28.00 29.56			28.30			"	"	"
	48.00 45.33 48.00			47.11			"	"	"
	36.67 34.22 34.67			35.19			"	"	"
	26.67 35.78 32.00			31.48			"	"	"
	31.56 28.89 30.00			30.15			"	"	"
	34.67 32.44 34.44			33.85			"	"	"
	40.89 45.78 43.11			43.26			"	"	"
Mertolemariam Technical and Vocational Training center C-25	30.07 31.83 33.16		32.83	31.69	4.33	13.20	complied	complied	complied
	40.06 38.70 39.92			39.56			"	"	"
	30.07 31.83 33.16			31.69			"	"	"
	32.06 28.90 27.48			29.48			"	"	"
	30.60 29.86 27.13			29.20			"	"	"
	27.67 27.35 30.60			28.54			"	"	"
	29.31 29.35 30.55			29.74			"	"	"
	37.89 37.95			38.07			"	"	"

	38.38								
	38.84 37.46 36.23			37.51			"	"	"

Gonder university Phase II (gonder college of medical science C-25	33.06 33.46 32.63		30.18	33.05	4.81	15.94	complied	complied	complied
	32.24 28.30 32.53			31.02			"	"	"
	30.56 31.61 33.71			31.96			"	"	"
	25.40 25.00 24.52			24.97			failed	"	failed
	26.76 24.16 26.35			25.76			"	"	"
	32.73 32.87 35.62			33.74			complied	"	complied
	25.67 28.06 25.10			26.28			failed	"	failed
	26.76 24.16 26.35			25.76			"	"	"
	36.07 32.46 29.65			32.73			complied	"	complied
	24.67 27.50 38.80			30.32			"	"	"
	21.12 29.85 26.53			25.83			failed	"	failed
	25.90 25.90 27.43			26.41			"	"	"
	31.45 28.14 27.06			28.88			complied	"	complied

	30.32 30.02 30.05			30.13			"	"	"
	29.01 32.05 28.05			29.70			"	"	"
	35.11 32.89 36.00			34.67			"	"	"
	39.11 41.33 44.89			41.78			"	"	"

Bahirdar techni- cal and vocational Training center	38.44 33.11 39.33		33.31	36.96	4.74	14.23	complied	complied	complied
	35.11 34.22 28.67			32.67			"	"	"
	38.51 26.35 32.45			32.44			"	"	"
	34.57 32.98 37.18			34.91			"	"	"
	31.22 22.13 35.31			29.55			"	"	"
dilla TVET package III C-25	41.00 41.50 42.50		32.69	41.67	6.80	20.81	complied	complied	complied
	30.10 29.80 30.70			30.20			"	"	"
	33.10 19.30 24.60			25.67			failed	"	failed
	33.20 34.10 32.40			33.23			complied	"	complied
dilla TVET package III C-30	41.30 37.70 30.10		42.12	36.37	7.70	18.28	complied	complied	complied
	46.50			47.87			"	"	"

	52.40 44.70								
dilla TVET package II C-25	37.10 35.50 36.30		39.39	36.30	6.35	16.11	complied	complied	complied
	24.40 29.90 27.30			27.20			failed	"	"
	48.20 42.40 40.30			43.63			complied	"	"
	42.00 41.20 40.00			41.07			"	"	"
	44.70 35.60 48.30			42.87			"	"	"
	38.00 38.20 39.10			38.43			"	"	"
	41.20 39.10 42.30			40.87			"	"	"
	38.80 36.80 37.80			37.80			"	"	"
	35.00 36.20 34.80			35.33			"	"	"
	47.10 53.40 50.60			50.37			"	"	"

AWTI phase-II Arbaminch C-25	38.50 39.30 36.60		35.05	38.13	8.42	24.02	complied	complied	complied
	36.90 43.50 50.20			43.53			"	"	"
	30.70 31.00 31.10			30.93			"	"	"
	31.40 28.60			30.93			"	"	"

	32.80								
	28.50 26.50 29.30			28.10			"	"	"
	29.00 25.00 36.60			30.20			"	"	"
	25.20 26.90 23.80			25.30			failed	"	failed
	28.80 31.00 31.80			30.53			complied	"	complied
	42.60 40.00 38.10			40.23			"	"	"
	41.20 35.00 34.90			37.03			"	"	"
	41.10 32.00 41.00			38.03			"	"	"
	44.00 43.00 43.60			43.53			"	"	"
	33.00 32.20 31.80			32.33			"	"	"
	27.30 22.30 22.70			24.10			failed	failed	failed
	30.10 30.90 29.80			30.27			complied	complied	complied
	59.40 58.90 61.80			60.03			"	"	
	30.00 30.80 29.20			30.00			"	"	
	38.10 35.00 35.40			36.17			"	"	
	34.20 38.70 36.80			36.57			"	"	"

TVET package II Wolyita Sodo C-25	30.80 31.50 32.10		28.96	31.47	6.27	21.66	complied	complied	complied
	22.40 21.30 19.20			20.97			failed	failed	failed
	35.00 36.10 32.20			34.43			complied	complied	complied
TVET package I Wolyita Sodo C-25	37.87 35.00 31.60		34.41	34.82	4.19	12.17	complied	complied	complied
	37.30 37.00 39.20			37.83			"	"	"
	32.40 25.60 33.70			30.57			"	"	"
TVET package III Wolyita Sodo C-25	30.90 31.60 32.00		33.71	31.50	4.02	11.93	complied	complied	complied
	37.70 39.20 40.00			38.97			"	"	"
	30.00 30.80 31.20			30.67			"	"	"
dilla TVET package I C-25	37.70 37.50 33.20		36.04	36.13	4.11	11.39	complied	complied	complied
	41.40 39.40 40.60			40.47			"	"	"
	31.50 31.30 31.80			31.53			"	"	"

Debub University Additional Blocks Phase III	33.70 31.60 33.40		30.80	32.90	5.47	17.75	complied	complied	complied
C-25	30.80			29.80			"	"	"

	28.90 29.70								
	22.90 28.70 29.70			27.10			failed	"	"
	30.70 30.40 29.80			30.30			complied	"	"
	34.60 33.50 35.20			34.43			"	"	"
	30.70 31.00 29.80			30.50			"	"	"
	34.50 27.90 35.00			32.47			"	"	"
	28.30 28.60 32.80			29.90			"	"	"
	38.70 40.00 39.00			39.23			"	"	"
	30.80 31.20 30.90			30.97			"	"	"
	15.00 14.60 18.70			16.10			failed	failed	failed
	30.50 31.20 30.90			30.87			complied	complied	complied
	34.20 33.80 32.40			33.47			"	"	"
	37.50 34.80 33.50			35.27			"	"	"
	31.10 30.80 31.20			31.03			"	"	"
	25.40 24.40 33.70			27.83			failed	"	"
	38.20 37.50 36.20			37.30			complied	"	"

	30.80 31.20 32.40			31.47			"	"	"
	32.70 33.80 33.70			33.40			"	"	"
	33.80 34.23 35.80			34.61			"	"	"
	31.20 31.40 30.80			31.13			"	"	"
	33.30 34.00 32.10			33.13			complied	complied	complied
	14.60 15.90 14.10			14.87			failed	failed	failed
	31.50 30.80 31.10			31.13			complied	complied	complied
	30.80 30.10 31.20			30.70			"	"	"

Debub University Additional Blocks Phase III C-30	36.20 35.30 38.40		30.80	36.63	5.40	17.54	complied	complied	complied
	35.60 34.20 35.80			35.20			"	"	"
	24.00 23.30 22.10			23.13			failed	failed	failed
	28.50 27.90 26.00			27.47			"	"	"
	23.00 25.50 24.00			24.17			"	"	"
	33.80 35.20 34.80			34.60			complied	complied	complied
	26.50			25.37			failed	failed	failed

	21.50								
	28.10								
	35.00			31.67			"	complied	"
	28.60								
	31.40								
Awassa referal	38.60		51.42	37.73	15.00	29.17	complied	complied	complied
hoaspital phase III	37.40								
C-30	37.20								
	64.80			65.10			"	"	"
	65.30								
	65.20								
TVET package IV	36.70		32.41	37.30	5.52	17.04	complied	complied	complied
Wolyita Sodo	37.10								
C-25	38.10								
	22.80			26.30			failed	"	failed
	27.80								
	28.30								
	27.40			27.93			"	"	complied
	28.90								
	27.50								
	32.50			31.17			complied	"	"
	31.60								
	29.40								
	37.00			39.33			"	"	"
	40.80								
	40.20								
TVET package V	30.00		30.90	30.20	5.89	19.06	complied	complied	complied
Wolyita Sodo	30.10								
C-25	30.50								
	24.00			23.37			failed	failed	failed
	24.10								
	22.00								
	30.30			29.20			complied	complied	complied
	28.30								
	29.00								
	41.70			40.83			"	"	"
	40.80								
	40.00								

AWTTI phase-III	30.50		33.41	30.90	5.80	17.38	complied	complied	complied
Arbaminch	31.00								
C-25	31.20								
	30.60			30.87			"	"	"
	30.80								

	31.20								
	31.50 30.70 29.80			30.67			"	"	"
	28.20 26.00 24.20			26.13			failed	"	failed
	36.00 35.00 32.00			34.33			complied		complied
	31.50 29.80 35.40			32.23			"	"	"
	37.50 38.10 37.80			37.80			"	"	"
	31.80 34.10 36.20			34.03			"	"	"
	22.50 24.20 26.40			24.37			failed	failed	failed
	29.60 27.00 29.00			28.53			complied	complied	complied
	30.60 28.50 29.60			29.57			"	"	"
	37.50 38.50 39.60			38.53			"	"	"
	38.00 33.60 35.80			35.80			"	"	"
	36.00 36.80 37.20			36.67			"	"	"
	35.20 34.80 40.30			36.77			"	"	"
	30.50 29.90 22.10			27.50			failed	"	"
	33.00 34.20 33.80			33.67			complied	"	"
	50.00			48.93			"	"	"

	48.20 48.60								
	23.00 23.60 24.20			23.60			failed	failed	failed
	20.40 20.10 21.10			20.53			"	"	"
	23.60 23.80 24.20			23.87			"	"	"
	32.10 31.80 31.60			31.83			complied	complied	complied
	25.00 23.20 22.80			23.67			failed	failed	failed
	43.60 42.00 45.20			43.60			complied	complied	complied
	23.10 23.10 23.20			23.13			failed	failed	failed
	34.50 33.70 32.90			33.70			complied	complied	complied
	36.20 37.20 36.00			36.47			"	"	"
	38.30 39.40 37.50			38.40			"	"	"
	37.60 37.80 39.00			38.13			"	"	"
	35.70 31.20 32.60			33.17			"	"	"
	40.00 38.60 38.20			38.93			"	"	"
	33.00 34.50			34.57			"	"	"

	36.20								
	30.40 30.80 31.20			30.80			"	"	"
	31.20 30.00 30.80			30.67			"	"	"
	42.00 39.00 39.20			40.07			"	"	"
	39.20 40.20 37.60			39.00			"	"	"
	32.00 32.80 33.50			32.77			"	"	"
	35.70 35.90 34.20			35.27			"	"	"
	35.00 36.20 38.60			36.60			"	"	"
	34.20 36.30 35.40			35.30			"	"	"
	34.80 35.60 35.20			35.20			"	"	"
	38.20 37.60 36.40			37.40			"	"	"
	40.50 34.00 38.00			37.50			"	"	"
	38.00 36.20 37.50			37.23			"	"	"
	30.30 32.70 31.80			31.60			"	"	"
	38.20 36.20 34.80			36.40			"	"	"
Ethiopian telecom- munication Office building	33.00 41.30 34.20		38.12	36.17	3.61	9.47	complied	complied	complied
C-25	39.20			40.07			"	"	"

	41.20 39.80								