ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRUMENTAL ENGINEERING

A study on assessment and comparison of Schmidt rebound hammer test result against uniaxial and core test of concrete

(A case study on some selected building projects in Addis Ababa)

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

(Construction Technology and Management)

SOLOMON TIBEBU

ADVISOR: PROF (DR. – ING) ABEBE DINKU

JUNE, 2022

ADDIS ABABA

UNDERTAKING

I certify that this research work titled "Astudy on assessment and Comparison of Schmidt Rebound Hammer Test Result against Uniaxial and Core Test of Concrete **(**A Case Study on Some Selected Building Projects in Addis Ababa)" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

____

Solomon Tibebu

A study on assessment and comparison of Schmidt rebound hammer test result against uniaxial and core test of concrete - a case study on some selected building projects in Addis Ababa.

The undersigned have examined this thesis entitled **"A study on assessment and comparison of Schmidt rebound hammer test result against uniaxial and core test of concrete (A case study on some selected building projects in Addis Ababa)"** presented by **Solomon Tibebu**, a candidate for degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Approved by: Board of Examiners

1. Prof. Abebe Dinku (Dr-Ing) Advisor — Signature — 13. July 2022 Date

2. Adil Zekaria (Dr.-Ing.) Internal examiner — Signature — 13/07/2022 Date

3. Denamo Addisse (PhD) External examiner — Signature — July 13, 2022 Date

Mebruk Mohammed (Dr.-Ing.)
Dean, School of Civil & Environmental Engineering

4. ____________ Chairperson — Signature — Date

Addis Ababa University, Addis Ababa Institute of Technology, Director of Postgraduate Program

ACKNOWLEDGMENTS

First of all, I praise to the Almighty God for giving me endurance, patience and grace to cope up with all ups and downs throughout the thesis study and work period.

My deepest gratitude goes to my advisor, Prof. Dr.-Ing. Abebe Dinku; for his continuous support, encouragement, and guidance during this research work. I have learnt a lot from his prestigious academic career and construction industry experience during the course of the master's program.

I would also like to thank Ethiopian Roads Authority for financing my postgraduate studies and for giving me this special opportunity to continue my MSc degree.

I dearly appreciate Addis Ababa Institute of Technology's construction materials laboratory staff members for allowing me to conduct laboratory test. They have always given me their heartfelt cooperation and assistance during research work period. SM Engineering PLC and its staff also provided their unlimited support in various tasks related to this thesis work.

I am also thankful to all my friends, especially Simeneh Abate, Samueal Mekonen and Esubalew Kitaw for their material, moral and technical support which they provided to me.

Finally, I am blessed to have an understanding and cooperative family, my wife and our beloved children, in all the situations during my research work.

Solomon Tibebu

Addis Ababa, Ethiopia

June, 2022

Table of Contents

ACKNOWLEDGMENTS .... **ii**

LIST OF TABLES .... **v**

LIST OF FIGURES .... **vii**

LIST OF ABBREVIATIONS .... **ix**

ABSTRACT .... **x**

1 CHAPTER ONE: GENERAL **1**

1.1 Introduction 1

1.2 Statement of the Problem 2

1.3 Objectives and the research questions Objective 2

1.4 Scope and Limitation of the Research 3

2 CHAPTER TWO: LITERATURE REVIEW **5**

2.1 Non-destructive test (NDT) 5

2.2 Rebound hammer / Surface hardness method 5

2.2.1 Types of rebound hammer 7

2.2.2 Operating principle of the rebound hammer 8

2.2.3 Measuring Equipment and Handling 9

2.2.4 Calibration & Interpretation of results 10

2.2.5 Limitations of rebound hammer 12

2.2.6 Factors influencing the test hammer (rebound hammer) 13

2.2.7 Advantages of using Schmidt rebound hammers: 14

2.2.8 Calculation 14

2.3 Destructive Testing (DT) of Concrete Compressive strength using the Compression Machine/ Uniaxial compression test: 14

2.4 Concrete Core Test 15

2.4.1 Core Drilling 16

2.4.2 Number of test locations 17

2.4.3 Cores for Compressive Strength 17

2.4.4 Moisture Conditioning 17

2.4.5 Advantage and Drawback of core drilling 17

2.4.6 Calculation 18

2.5 Current local practice of applying and interpretation of rebound hammer test result. 19

2.6 Summary of literature review 19

2.7 Research gaps identified 20

3 CHAPTER THREE: RESEARCH METHODOLOGY AND DESIGN 21
3.1 Introduction 21
3.2 Research Design 21
3.3 Laboratory work 21
3.4 Field work 22
3.5 Selection of Aggregate sources and project sites 22
4 CHAPTER FOUR: MIX DESIGN AND PHYSICAL PROPERTIES OF AGGREGATE 23
4.1 Material preparation 23
4.2 Materials test results 23
4.2.1 Coarse Aggregate material test results 23
4.2.2 Fine aggregate test results 27
4.3 Concrete Mix Design and Materials Proportion 30
4.4 Compressive strength and rebound hammer reading on UTM machine 31
5 CHAPTER FIVE: DATA COLLECTION AND ANALYSIS 33
5.1 Data collection 33
5.2 Computation of compressive strength 38
5.3 Compressive strength ratio computation 48
5.4 Data analysis and interpretation 50
5.4.1 Normal distribution of strength 50
5.4.2 Mean X 51
5.4.3 Standard Deviation 51
5.4.4 Abnormal Results 60
5.4.5 Results and Discussion 63
5.4.6 Relation between Core Compressive Strength and Cube Strength 64
5.4.7 Relation between Hammer Compressive Strength and Cube Strength 64
6 CHAPTER FIVE: SUMMARY, CONCLUSION, AND RECOMMENDATIONS 65
6.1 Conclusion 65
6.2 Recommendations 66
6.3 Suggestions for future work 66
7 REFERENCES 67

LIST OF TABLES

Table 2.1. Correction factors [2] 18

Table 4.1. Sieve analysis for coarse aggregate/S2 23

Table 4.3. Summary of coarse aggregate quality test 27

Table 4.4. Specific gravity and water absorption coarse aggregate 27

Table 4.5. Sieve analysis for Fine aggregate 28

Table 4.6. Summary of Sand quality test / Langano sand 30

Table 4.7. Specific gravity and water absorption of sand 30

Table 4.8. Mix proportion for C-30 concrete 30

Table 4.9. Results of trial mix specimen 31

Table 5.1. Sample size 33

Table 5.2. Rebound Hammer results of slab at Ever grand site 39

By applying the uniform pressure in a vertical direction, three cores were extracted from the marked concrete slabs. 39

The drilled cores from the slab were observed, the aggregates are not equally distributed and there are no cracks was caused to the drilled cores. From the recovered core samples, it was observed the slab thickness is not uniform. 39

The drilled cores were marked at suitable heights and diameter. The marked cores are trimmed with three different height/diameter ratios. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test as shown in the figure 5.13. 39

Table 5.3 Drilled Cores Compressive Strength of Concrete from Ever grand site at 45 days. 40

Table 5.4 Cube Compressive Strength of Concrete from Ever grand site 40

Table 5.5 Rebound Hammer results of slab at MKB site 41

Table 5.6 Drilled Cores Compressive Strength of Concrete from MKB site at 45 days. 42

Table 5.7 Cube Compressive Strength of Concrete from MKB site 42

Table 5.8 Rebound Hammer results of slab at Fedengua site 42

Table 5.9 Drilled Cores Compressive Strength of Concrete from Fedengua site at 45 days 43

Table 5.10 Cube Compressive Strength of Concrete from Fedengua site 43

Table 5.11 Rebound Hammer results of slab at GAF site 44

Table 5.12 Drilled Cores Compressive Strength of Concrete from GAF site 45
Table 5.13 Cube Compressive Strength of Concrete from GAF site at 45 days 45
Table 5.14 Rebound Hammer results of slab at 2nd control mix with W/C=0.42 45
Table 5.15. Drilled cores compressive strength of concrete from 2nd control mix with W/C=0.42 46
Table 5.16 Cube compressive strength of concrete cube 2nd control mix 46
Table 5.17 Rebound Hammer results of slab at 1st control mix with W/C=0.47 47
Table 5.18 Drilled cores compressive strength of concrete from 1st control mix 47
Table 5.19 Cube compressive strength of concrete cube 1st control mix 48
Table 5.20 Corrections for height/ diameter ratio 48
Table 5.21; 28th day cube, Schmidt rebound hammer and core and test results Evergrand site 49
Table 5.22; 28th day cube, Schmidt rebound hammer and core and test results MKB site 49
Table 5.23; 28th day cube, Schmidt rebound hammer and core and test results Fedengua site 49
Table 5.24; 28th day cube, Schmidt rebound hammer and core and test results GAF site 49
Table 5.25; 28th day cube, Schmidt rebound hammer and core and test results control mix with W/C=0.42 50
Table 5.26;28th day cube, Schmidt rebound hammer and core and test results control mix with W/C=0.47 50
Table 5.27; Mean, Standard deviation and Normal distribution for HR/CU 52
Table 5.28; Computed HR/CU and Normal distribution 53
Table 5.29; Mean and Standard deviation CO/CU 55
Table 5.30; Computed Co/Cu and Normal distribution 56
Table 5.31; Mean and Standard deviation HR/C0 58
Table 5.32; Computed Co/Cu and Normal distribution 59
Table 5.33; The table Removing an outliner 61
Table 5.34. Corrected core, cube and hammer compressive strength (N/mm2) 62

LIST OF FIGURES

Figure 2.1. Rebound hammer for nondestructive evaluation of hardened concrete 6
Figure 2.2: Original Schmidt type N/L [14] 7
Figure 2.3: Original Schmidt type NR/LR [15] 7
Figure 2.4: Digi-Schmidt type ND/LD [14] 8
Figure 2.5: Silver Schmidt type ST [14].. 8
Figure 2.6: Schmidt rebound hammer [7] 9
Figure 2.7: Schematic diagram illustrating the operation of the rebound hammer (After ACI
Figure 2.8: Conversion curve for the average compressive strength measured On cylinders (f 150, H300mm) [14] 11
Figure 2.9. The cube specimen placed in the testing machine 12
Figure 2.10. Schmidt Hammer test before the execution of the cores in an existing building. 12
Figure 2.11. Core drilling rig (Maitham Fadhil Abbas Alwash,2017) [26] 16
Figure 4.1. Gradation of coarse aggregate/S2.. 24
Table 4.2. Sieve analysis for coarse aggregate/S1 24
Figure 4.2. Gradation of coarse aggregate/S1.. 25
Figure 4.3. Gradation of fine aggregate 28
Figure 5.1. Concrete pad caste for core test (Pictured by researcher) 33
Figure 5.2. Sample preparation for coring (Pictured by researcher) 34
Figure 5.3. Cylindrical cored Samples (Pictured by researcher)... 34
Figure 5.4. Hammer reading from slab and column (Pictured by researcher) 34
Figure 5.5. Core sampling (Pictured by researcher) 35
Figure 5.6. Surface preparation for hammer test on basement floor slab Fedengua site 35
Figure 5.7. Conducting hammer test for basement floor slab Fedengua site 35
Figure 5.8. Concrete Soaked in water for curing until the age of testing 36
Figure 5.9. Laboratory Schmidt hammer rebound reading.. 36
Figure 5.10. Cored sample trimmed and capped and ready for crushing from GAF site 36
Figure 5.11. Cut face of concrete from a single point from top and bottom of the slab.................. 37
Figure 5.12. Compressive strength test on trimmed bottom part of the core.................................... 37
Figure 5.13. Core samples after Trimming from Ever grand site 39
Figure 5.14. Core samples after Testing from Ever grand site... 40

Figure 5.15. Core samples after Trimming from MKB site......41
Figure 5.16. Core samples after Trimming from Fedengua site......43
Figure 5.17. Core samples after trimming from GAF site......44
Figure 5.18. Core samples after Trimming from 1st control mix site......47
Figure 5.19. Illustration of concrete strength distribution from [37]......51
Figure 5.20. Illustration of concrete strength distribution hammer vs cube......54
Figure 5.21. Illustration of concrete strength distribution core vs cube......57
Figure 5.22. Illustration of concrete strength distribution hammer vs core......60
Figure 5.23. Drawing of concrete strength distribution showing outliner data......61
Figure 5.24. correlation between estimated cube strength from core and rebound number of slabs......62
Figure 5.25. correlation between estimated cube strength from rebound number of slabs......63
Figure 5.26. correlation between estimated cube strength from and core strength......63

LIST OF ABBREVIATIONS

A	Air, percent content
ACI	American Concrete Institute
ASTM	American Society for testing and Materials
BS	British Standard
CM	Cement requirement
Co	Core
Cu	Cube
DT	Destructive test
Ga	Weighted average specific gravity of combined fine and coarse aggregate
GC	Specific gravity of cement
MPa	Mega Pascal
NDT	Nondestructive test
OPC	Ordinary Portland Cement
HR	Rebound hammer
S/A	Sand Coarse aggregate ratio
S1	Sample source 1
S2	Sample source 2
UM	Unit mass of fresh concrete
UTM	Uniaxial Testing Machine
W/C	Water cement ratio
WM	Mixing water requirement

ABSTRACT

Concrete is a mixture of cement, coarse aggregate, sand and water. This mixture is expected to form a homogeneous material with predictable strength behavior. However, it is very difficult to develop a model to correctly evaluate its onsite strength properties. Common methods used in evaluating and estimating concrete structures are uniaxial compressive strength; core test; and rebound hammer test.

This research presents the assessment of compressive strength of cocnrete using rebound hammer, core test and uniaxial compressive strength test to develop relationship between these methods. In this study, cube samples, rebound hammer reading and core samples were extracted from the concrete slabs casted both from two control mix slabs and from four selected project sites for this analysis. Rebound hammer reading and core drilling operations were performed from the casted slabs the same data were collected from rebound hammer versus the project sites under investigation. Descriptive statistical data analysis such as the mean and standard deviation were computed between hammer versus cube and core versus cube strength.

The relationship obtained from the variables is expressed as compressive strength of core is 0.732844 times cube strength and compressive strength of rebound hammer 1.11612321 times cube strength and compressive strength estimated from rebound hammer is 1.5241 times compressive strength of core.

Key words: Compressive strength, Core test, correlations coefficient, destructive tests, DT, non-destructive tests, NDT, Rebound hammer,

1 CHAPTER ONE: GENERAL

1.1 Introduction

The compressive strength test is the test most commonly performed on hardened concrete. Compressive strength is one of the main structural design requirements to ensure that the structure will be able to carry the intended load [1].

The strength of concrete is most important property (especially when needed for structural purposes) alongside its durability. Consequently, it is very important to ascertain the compressive strength of concrete before subjecting it to its anticipated loads which can be determined using uniaxial compressive strength, core test or non-destructive testing (NDT) methods.

Destructive testing (DT) method is carried out on a test specimen taken from actual concrete in a standard cube or cylinder molds and checking its strength to failure under crushing loads while **non-destructive** methods will be carried out without destroying the concrete specimens. The main disadvantage of the destructive testing methods is the length of time it takes for the results to be ready, the equipment and the power required.

Core test specimens are obtained when doubt exists about the in-place concrete quality due either to low strength test results during construction or signs of distress in the structure. Additionally, this method may be used to provide strength information on older structures.

There is no universal relationship between the compressive strength of a core and the corresponding compressive strength of standard-cured molded cylinders [2]. The relationship is affected by many factors such as the strength level of the concrete, the in-place temperature and moisture history, and the strength gain characteristics of the concrete. Historically, it has been assumed that core strengths are generally 85 % of the corresponding standard-cured cylinder strengths, but this is not applicable to all situation. The acceptance criteria for core strength are to be established by the specifying authority. ACI 318 provides core strength acceptance criteria for new construction.

The rebound hammer is one of the most popular nondestructive testing (NDT) methods used to test strength of concrete. This is due to its relatively low cost and simplicity in use. Although non-destructive tests (NDT) are much quicker compared to destructive methods, they are more of an approximation than telling exact compressive strength values.

1.2 Statement of the Problem

The acceptance and rejection of concrete work is possible through reliable test results. Due to biased results recorded, it is controversial to relay on test results between rebound hammer, uniaxial and core compressive strength test results. Therefore, the following problems initiated the researcher to study the topic.

1. Absence of a correlation factor between core compressive strength test and rebound hammer tests to make evaluations on concrete structures tested in local buildings; where destructive tests show low strength or non-conformance to strength requirements which creates a major bias and, in some cases, a real risk of structural safety.
2. Against the international practice in the use of NDT as also described on ASTM 805 “Because of the inherent uncertainty in the estimated strength, rebound hammer test method is not intended as the basis for acceptance or rejection of concrete” [3]. While the regulatory body or municipality considers and orders hammer test for any concrete structural modification works for acceptances and rejection.
3. In Ethiopia, Schmidt hammer test is being used as acceptance criteria for concrete structures which fail to satisfy cube compressive strength test criteria.
4. The Schmidt hammer test results are not verified using internationally accepted concrete cube and core tests specific to local materials.
5. Unusual confidence of most contractors and engineers that almost all concrete hammer tests compute to target strength in contrary to cube/core test results
6. Taking core test from every point in doubt is very difficult because it makes the structure weak at the point of test. It is also expensive and time consuming.
7. The relationship between the three test methods has not been studied on local materials to date.

1.3 Objectives and the research questions Objective

The objective of this research is to establish a relationship among the test methods between concrete rebound hammer test, the uniaxial and core compressive strength tests and establishing a correlation coefficient among the test methods on the selected building projects.

List of objectives to be achieved in doing this study includes:

- To evaluate the reliability of concrete rebound hammer test result against core and uniaxial compressive strength and develop correlation coefficient among the test methods in our local practice.
- To develop a relationship between core compressive strength and cube compressive strength
- To develop a relationship between compressive strength obtained from core and strength from concrete cube samples.
- To assess the possibility of using rebound hammer for quick control of concrete structures and adopt with local practice
- To study the possibility of using Schmidt hammer test in place of concrete core test and recommend future application method.

Hence, the research should address the following questions:

i. How does the quality of concrete structures evaluate? Are there methods to measure the quality of the concrete structures?
ii. Is there any test method to check the quality of concrete structures? Which is more practiced destructive or nondestructive test methods?
iii. Which test method is more applicable in Ethiopia for concrete evaluation? rebound hammer test or core test?
iv. Which test method is more applicable for structural modification purpose in municipality? Rebound hammer test or core test?
v. Is there a possibility to use core test and rebound hammer for structural evaluation? Is there a correlation developed with local materials between the two methods?

1.4 Scope and Limitation of the Research

This research is intended to assess the dependability on the test result of concrete rebound hammer and compare the results against uniaxial compressive strength and core compressive strength test which was limited to some selected building projects in Addis Ababa. Cube compressive tests and core are only considered for comparison against the rebound hammer test. As it was stated in the previous section, there are several nondestructive techniques that can be used to assess the concrete compressive strength. However, in this work, only the rebound hammer test method is considered because it is the most widely used method on existing reinforced concrete structures in our current practice.

Since concrete core test is expensive test method, it was difficult to cover large number of projects in this study. Core compressive strength test is destructive and it weakens the structure under investigation;

due to this, it was difficult to get volunteer clients who allow their structure for core test. Hence, two 1.0m by 1.0m C 30 MPa concrete slabs were casted and core samples were recovered for the test to get sufficient number of core sample.

2 CHAPTER TWO: LITERATURE REVIEW

The strength of concrete is the most important property (especially when needed for structural purposes) alongside its durability. Therefore, it is very important to ascertain the compressive strength of concrete before subjecting it to its anticipated loads. Compressive strength of hardened concrete can be determined using destructive and non-destructive test (NDT) methods. The destructive testing (DT) method is carried out by core test and uniaxial compression test by crushing the cast and or the cored specimen to failure while the non-destructive is carried out without destroying the concrete specimen.

2.1 Non-destructive test (NDT)

Non-destructive testing (NDT) is defined as the course of inspecting, testing, or evaluating materials, components or assemblies without destroying the serviceability of the part or system; [4][5].

Nondestructive testing causes no significant structural damage to concrete [6].

The purpose of NDT is to determine the quality and integrity of materials, components or assemblies without affecting the ability to perform their intended functions [4].

From the above definition, It is possible to generalize that non-destructive test are preferred not only by their easiness but also, they enable to provide strength information of a structure with out or with little effect on the structure.

NDT methods explore indications of properties without reaching component or assembly failures. Extensive attempts and advancements have been made to develop NDT methods capable of indicating mechanical, acoustical, chemical, electrical, magnetic, and physical properties of materials [4].

Workman & Moor listed common type of non-destructive test methods; [5].

- Rebound hammer/Surface hardness method;
- Penetration resistance method;[8].
- Pull-out resistance methods;[9].
- Pull-off resistance method and [10].
- Ultrasonic pulse velocity method [11].

2.2 Rebound hammer / Surface hardness method

The rebound hammer test, also known as the Schmidt hammer test, is a nondestructive test performed on hardened concrete to determine the hardness of the surface (Figure 2.1). The hardness of the surface can be correlated, to some extent, with the concrete strength. The rebound hammer is commonly used to get an indication of the concrete strength. The device is about 0.3 m long and encloses a mass and a spring. The spring-loaded mass is released to hit the surface of the concrete. The mass rebounds, and the amount of rebound is read on a scale attached to the device. The larger the rebound, the harder is the concrete surface and, therefore, the greater is the strength. The device usually comes with graphs prepared by the manufacturer to relate rebound to strength. The test can also be used to check uniformity of the concrete surface [1].

The fundamental understanding of impact and rebound relates to the theory of wave propagation. A compression wave is propagated when the surface of the concrete is disturbed by the plunger (σ_i). The reaction force propagates a reflected compression wave through the plunger (σr). The ratio of the wave amplitudes (σ_r / σ_i) is found to be proportional to the rebound number which could be empirically correlated to compressive and flexural strength [12].

Malhotra, 2004 describe about conducting procedure for Schmidt hammer test. According to his explanation, to prepare the instrument for a test, release the plunger from its locked position by pushing the plunger against the concrete and slowly moving the body away from the concrete [7].

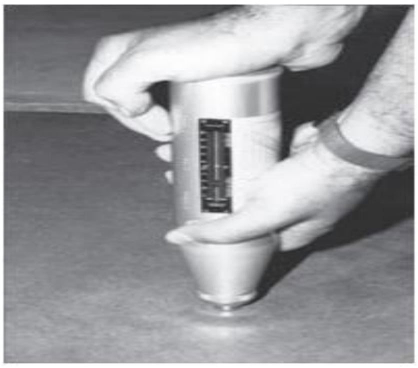


Figure 2.1. ***Rebound hammer for nondestructive evaluation of hardened concrete***

The test can be conducted horizontally, vertically upward/downward, or at any intermediate angle. Due to different effects of gravity on the rebound number as the test angle is changed, the rebound number will be different for the same concrete and will require separate calibration or correction charts.

Empirical correlations are provided by the manufacturer to relate the rebound number to concrete strength properties. The following publications present standard guidelines for the application and interpretation that govern the standard rebound test:

- ASTM C 805: Standard Test Method for Rebound Number of Hardened Concrete; [3].
- BS EN 12504-2:2012: Testing Concrete in Structures- Non-destructive Testing – determination of rebound number [13].

The standard rebound hammer provides a simple, easy and inexpensive method to estimate concrete strength properties. However, the results of the test on concrete are affected by various factors such as smoothness of the surface, geometric properties of the test specimen, age of the test specimen, surface and internal moisture conditions of the concrete, type of coarse aggregate, type of cement, type of mold and carbonation of the concrete surface [7].

2.2.1 Types of rebound hammer

Nowadays, the most widely used method for measuring the surface hardness of the concrete test is hammer (Schmidt rebound hammer). There are different types of rebound hammer used for different type of structures. The following are type of rebound hammers applied which are invented each with additional features. To mention them:

- Schmidt type N/L

The Original Schmidt type L is the ideal option for testing thin-walled elements with a thickness between 50 and 100 mm or to analyze small parts.

Figure 2.2: Original Schmidt type N/L [14]

- Schmidt type NR/LR

The measuring ranges: 10 to 70 MPa. Values rebound are recorded as a bar graph on the registered paper

Figure 2.3: Original Schmidt type NR/LR [15]

- Digi- Schmidt type ND/LD

The first digital rebound hammer in the world with data storage, correcting the angle of impact and direct display of the compressive strength. Also corrects the carbonation ratio. It is accompanied by a number of preprogrammed correlation curves, allowing the user to select the one that best suits the tested concrete.

Figure 2.4: Digi-Schmidt type ND/LD [14]

- Schmidt type ST/PC(N/L)

Silver Schmidt facilitates the creation of customized conversion curves specific to the composition of the concrete tested, thereby increasing significantly the reliability of estimated of compressive strength.

Figure 2.5: Silver Schmidt type ST [14]

2.2.2 Operating principle of the rebound hammer

Physical Principle

The Schmidt rebound hammer is intended to measure the surface hardness of concrete. There is an empirical relationship between the compressive strength of concrete and the rebound index which is a code consisting of a letter (giving an indication of the quality of the concrete) and a number (giving indication on the compressive strength). The hammer has an approximate mass of 1.8 kg and is suitable for laboratory tests at the test site.

The surface on which the test is conducted can be horizontal, vertical, or at any other angle. A correction must be made to the readings to account for the angle of the strike. The correction to be made depends on the model of hammer requires only that the device is calibrated to the position where it will be used.

2.2.3 Measuring Equipment and Handling

The hammer, consisting of a steel hammer with a compressed spring which, when released, projects a striker rod steel in contact with the concrete surface. The moving speed of the hammer produced by the spring must be constant and reproducible. The steel hammer rebounding from the percussion rod or other steel rebound values must be measured on a linear scale secured to the frame of the instrument. The hammer is a cylindrical device composed of various elements illustration below (Figure 2.2):

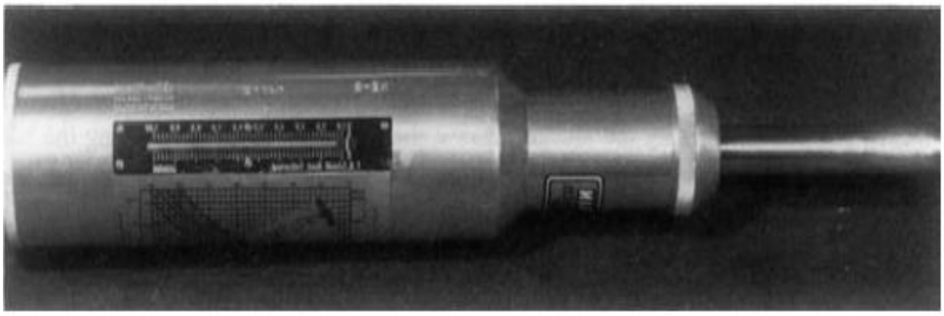
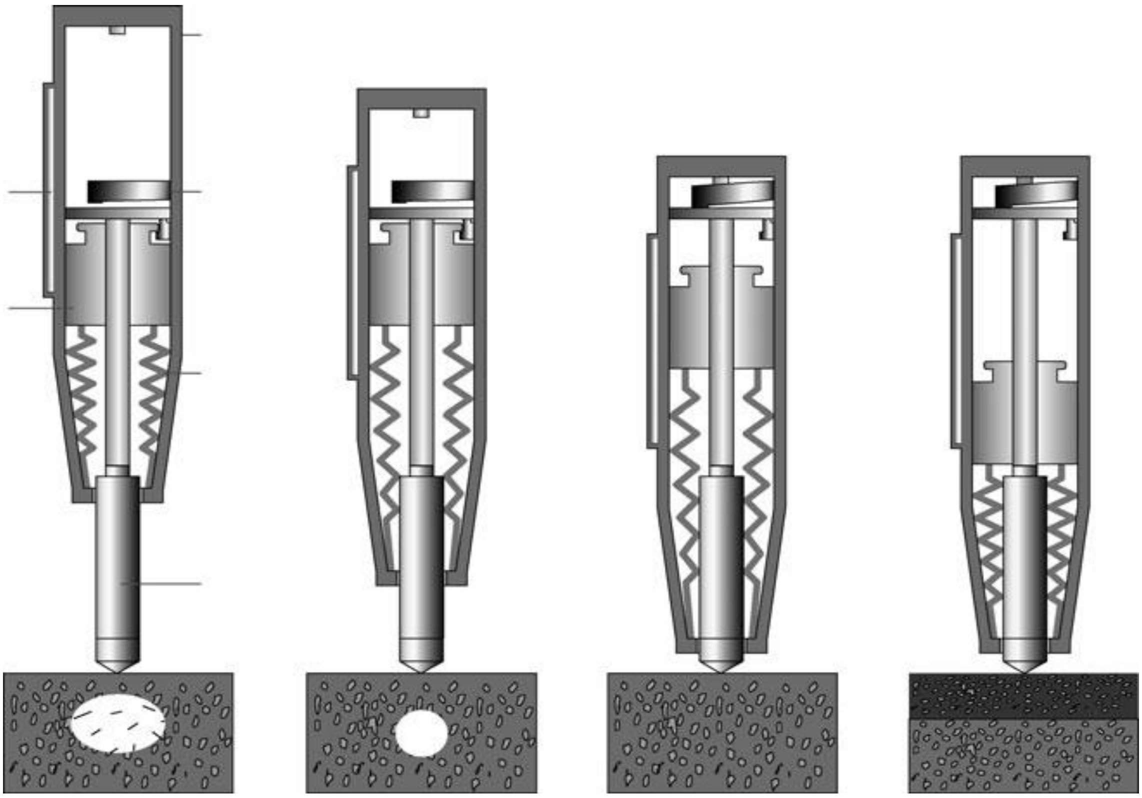


Figure 2.6: Schmidt rebound hammer [7]

Handling

The most commonly used method employs the Schmidt rebound hammer, which consists of a spring-controlled hammer that imparts a load on a plunger. At the beginning of the test, the extended plunger is placed in contact with the concrete surface (Figure 2.3(a)). Next, the outer body of the instrument is pressed against the surface of the concrete making the spring to extend (Figure 2.3 (b). The handle is released when the spring is fully extended and the hammer moves toward the concrete surface (Figure 2.3 (c)). The hammer impacts upon the plunger, and the spring-controlled mass rebounds taking a rider with it along a guide scale, which is then used to obtain the hammer rebound number (Figure 2.3 (d)). This number depends on the stiffness of the spring and on the selected mass, and therefore a standard procedure has been established and is described in detail in ASTM C 805[3].



Instrument ready for test | Body pushed toward test object | Hammer is released | Hammer rebounds

(a) **(b)** **(c)** **(d)**

Figure 2.7: Schematic diagram illustrating the operation of the rebound hammer (After ACI 228.1R-95, In-Place Methods to Estimate Concrete Strength); ACI Manual of Concrete Practice, American Concrete Institute, 2002) [7][16].

2.2.4 Calibration & Interpretation of results

The new method of non-destructive concrete testing was acclaimed throughout the world. DIN 4240 was published in 1962 dealing with the Schmidt Hammer and its use.

However, as other investigators began to develop correlations between strength and rebound number, it became evident that there was not a unique relationship between strength and rebound number. This lead to the often-stated recommendation that a correlation should be developed using the same concrete and forming materials as used in construction. Without such a correlation, the rebound hammer is useful only for detecting gross changes in concrete quality throughout a structure. The issues of reliability of the rebound measurement and of calibration are key issues.

The first correction corresponds to the direction of impact (horizontal, vertical up and down), for which the calibration curve (which expresses the estimated compressive strength as a function of rebound number) must be shifted. The test hammer symbols in the diagram indicate the impact direction and the respective conversion curve. In many countries' cylinders of 150x300 mm are used as test specimens for whom conversion curves are available as well; Figure (2.8).

A common factor that influences the reading is the carbonation of the concrete which starts from the surface and penetrates into the structure.

Correction factors have been proposed by Tanigawa et al. and in Japanese and Chinese guidelines (AIJ,1983, JGJ/T 23-2001), but their values are very different and the more efficient way to compensate for this effect remains the calibration of the rebound values against the strength of core specimens taken from the structure.

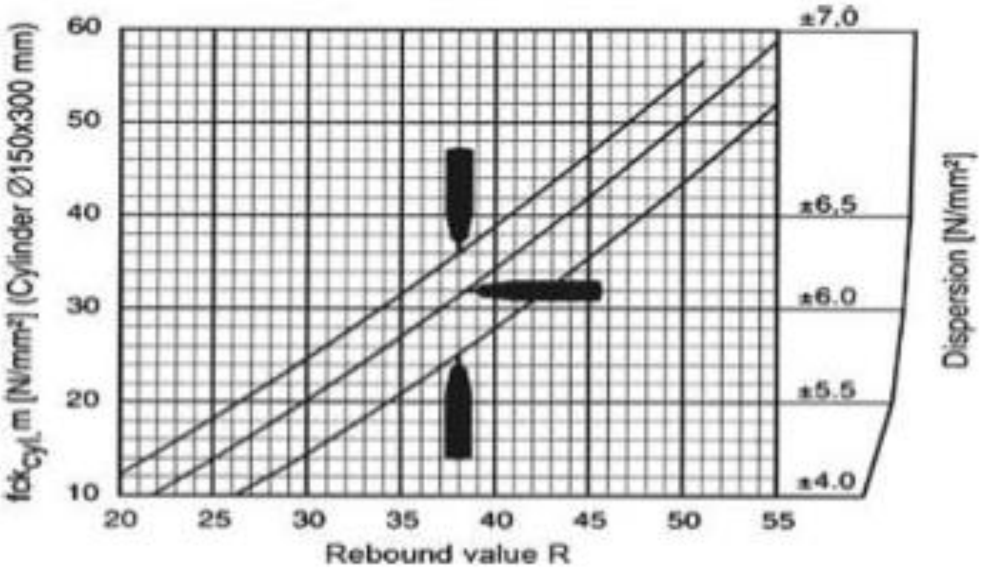


Figure 2.8: Conversion curve for the average compressive strength measured On cylinders (f 150, H300mm) [14]

Standard cube specimen 15*15*15 were prepared in laboratory and used to be placed on compressive strength machine and hammer reading was taken to compare with the manufacturer calibration curve as shown in figure (2.9).

Figure 2.9. The cube specimen placed in the testing machine

Ferhat Aydin & Mehamet Saribiyik,2010 [17]

The concrete element was tested using Schmidt hammer for the calculation of rebound values before the execution of the concrete core test as shown in figure 2.10.

Figure 2.10. Schmidt Hammer test before the execution of the cores in an existing building.

2.2.5 Limitations of rebound hammer

Although the rebound hammer provides a quick, inexpensive means of checking the uniformity of concrete by taking rebound number, it has serious limitations and these must be recognized [3]: The results of the Schmidt rebound hammer are affected by

- Surface smoothness
- Age of concrete;
- Moisture content.
- Surface carbonation.
- Aggregate, air voids, and steel reinforcement
- Calibration of the rebound hammer

2.2.6 Factors influencing the test hammer (rebound hammer)

The following are some of the factors that influence the test result of rebound hammer test; [7]

- **Surface smoothness** – The surface texture significantly affects the R-number obtained. Tests performed on a rough-textured finish will typically result in crushing of the surface paste, resulting in a lower number [18] states: "Past research has also shown that troweled surfaces or surfaces formed by metal forms yield rebound numbers 5 to 25 percent higher than surfaces cast against wooden forms.".
- **Age of concrete** – Concrete continues to develop strength with age due to cement hydration. This is the reason behind the development of data relating rebound numbers to the compressive strength of the concrete mixture or cores from the structure. Testing of concrete less than 14 days old is not recommended. This is because the R-numbers will be too low for an accurate reading, and the testing will be more destructive to the concrete surface [3].
- **Moisture content** – This has a profound effect on the test results. Dry concrete surfaces result in higher rebound numbers than wet surfaces.
- **Surface carbonation** – Surface carbonation of concrete significantly affects the Schmidt rebound hammer test results. The carbonation effects are more severe in older concretes when the carbonated layer can be several milli meters thick and in extreme cases up to 20 mm thick. In such cases, the rebound numbers can be up to 50% higher than those obtained on an uncarbonated concrete surface. Suitable correction factors should be established in such cases, otherwise overestimation of concrete strength will result.
- **Aggregate, air voids, and steel reinforcement** – The presence of materials in the immediate area where plunger comes into contact with the concrete will have an obviously profound effect as well. If the test is performed over a hard-aggregate particle or a section of steel reinforcement, the result may be an unusually high rebound number. ASTM C805 states that tests directly over reinforcing bars with cover less than 0.75 inches should not be conducted [3].
- **Calibration of the rebound hammer** – Carrying out periodic calibration of rebound hammer using standard anvil is desirable. However, for new and retrofit concrete construction, rebound hammer is calibrated on concrete test cubes for a given source of constituent materials (viz. cement, sand and stone aggregate), this calibration data can be used with reasonable accuracy in arriving at equivalent in-situ cube strength of relatively new concrete.

The influences of the above-mentioned factors are so great that it is very unlikely that a general calibration curve relating rebound hammer to strength, as provided by the equipment manufacturers, will be of any practical values.

A calibration curve for each concrete under testing have to be performed, taking into account the specimen condition, as well as a frequent check on a standard steel mass to verify spring performance or friction problem between the impacting mass and the plunger. EN 12504-2 standard recommends that calibration have to be performed on samples properly clamped between the plate of testing equipment under a compressive load of about 15% of concrete strength and in any case higher than 7 N/mm2.

Estimation of strength of concrete by the rebound hammer within an accuracy of ±15 to ±20% may be possible only for specimens cast, cured, and tested under conditions similar to those from which the correlation curves are established [7].

2.2.7 Advantages of using Schmidt rebound hammers:

Rebound hammer **test** method is applicable for the following uses [19]:

- A small amount of structure damage occurs in testing, usually negligible.
- It makes possibility of testing concrete strength in structures where cores cannot be drilled.
- It has an application of less expensive testing equipment, Low power consumption.
- Simple operation doesn’t need high consumption of labor, or intensive training.

2.2.8 Calculation

Rebound readings differing from the average of 10 readings by more than 6 units are discarded and the average of the remaining readings were determining. If more than 2 readings differ from the average by 6 units, the entire set of readings are discarded and rebound numbers at 10 new locations within the test area are determined [3].

2.3 Destructive Testing (DT) of Concrete Compressive strength using the Compression Machine/ Uniaxial compression test:

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform and partly because the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

Compression test is carried out on specimen cubical or cylindrical in shape. The compression strength test method is carried out using compression machine that will be done in accordance with BS 1881:1970 [20].

Destructive testing explores failure mechanisms to determine the mechanical properties of material such as yield strength, compressive strength, tensile strength, ductility and fracture toughness.

The DT of concrete is not always appropriate method to find compressive strength of concrete and concrete structures because it affects the durability and lifespan of concrete.

According to Abebe [22], the results obtained from compression test on hardened concrete cubes are used to check that its strength is above the minimum specified and to assess the control exercised over the production of concrete.
The strength of concrete specimen is affected by factors like water cement ratio, degree of compaction and curing temperature. Care to be taken, therefore, in preparing samples for testing [22].

Factors affecting result of hammer test includes effect of specimen ends condition, effect of specimen size, effect of specimen moisture condition, effect of loading direction verses casting condition and effect of loading rate [23].

2.4 Concrete Core Test

Concrete core test is commonly required in the area of concrete industry to evaluate the concrete strength and sometimes it becomes the unique tool for safety assessment of existing concrete structures. Core test is therefore, introduced in most codes.

In preparation of core test specimens, samples of hardened concrete shall not be taken until the concrete is strong enough to permit sample removal without disturbing the bond between the mortar and the coarse aggregate. When preparing strength test specimens from samples of hardened concrete, samples that show defects or samples that have been damaged in the process of removal shall not be used.

It is not possible to specify a minimum age when concrete is strong enough to withstand damage during removal, because the strength at any age depends on the curing history and strength grade of the concrete. If time permits, the concrete should not be removed before it is 14 days old. If this is not practical, removal of concrete can proceed if the cut surfaces do not display erosion of the mortar and the exposed coarse aggregate particles are embedded firmly in the mortar. In-place test methods may be used to estimate the level of strength development prior to attempting removal of concrete samples [2] [24].

2.4.1 Core Drilling

A core specimen taken perpendicular to a horizontal surface shall be located, when possible, so that its axis is perpendicular to the bed of the concrete as originally placed and not near formed joints or obvious edges of a unit of deposit. A specimen taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit when possible and not near formed joints or obvious edges of a unit of deposit.

Core specimen is extracted from the structural member using a cutting tool having diamond bits attached to the core barrel, see a core drilling equipment in Figure 2.11. Since any movement during drilling may lead to damaged core so the rig should be firmly anchored to the concrete member. Moreover, it should be perpendicular to the surface from which the core is taken off in order to avoid cutting a distorted core. The drill bit is usually lubricated or cooled with water.

Since the correction factor is derived from an empirical formula so applying this factor to the core strength will add some uncertainty. The other possibility to avoid using the correction factor is to drill a core with sufficient length and to remove the portion containing the reinforcement (of course if the remaining portion has accepted length to diameter ratio). Finally, the produced hole in the member after the drilling process should be filled with concrete or epoxy or other suitable fillers.

Figure 2.11. Core drilling rig (Maitham Fadhil Abbas Alwash,2017) [26]

From above it is obvious that a skilled operator is mandatory in order to obtain a core specimen that is undamaged and representative of the in-situ concrete.

2.4.2 Number of test locations

To determine the number of core and selecting test location depends on the size of the test region needed to be determined and reliability of the final results [26].

The number of core test required to develop correlation varies standard to standard to see a few BS EN 13791, 2007 requires at least 15 cores (with minimum nominal diameter 100 mm) for strength assessment. The same code also sates minimum number of cores required by standards (18 for regression approach and 9 for calibration approach and ACI 228.1R, 2003 cited requirement of minimum of six to nine test location should be selected for obtaining the correlation data. Generally, from the above codes we can understand the minimum number of cores required should not be less than nine [27].

2.4.3 Cores for Compressive Strength

Test Specimen—The nominal diameter of core specimens for the determination of compressive strength shall be at least 3.75 in. [95 mm]. Core diameters less than 3.75 in. [95mm] are permitted when it is impossible to obtain cores with length to diameter (L/D) ratio of 1 for compressive strength evaluations in cases other than load bearing situations. The preferred length of the capped specimen is between 1.9 and 2.1 times the diameter. If the ratio of the length to the diameter of the core specimen exceeds 2.1 reduce the length of the specimen so that the ratio is between 2.1 and 1.9. Core specimens with length-to-diameter ratios less than 1.8 require corrections to the measured compressive strength. A core having a maximum length of less than 95 % of its diameter before capping or a length less than its diameter after capping shall not be tested [2].

2.4.4 Moisture Conditioning

Since compressive strength test results are usually used for the evaluation of the in-place concrete strength; therefore, the cores shall be conditioned in a moisture condition most representative of the in-place strength. If the concrete service condition is dry, the cores can be tested in either an “as received condition” after allowing the drilling moisture to evaporate.

After drilling, transport the cores to the testing laboratory within 24 h. Dry the cores for 12 to 24 hours in air at a temperature between 60 and 80°F [16 to 27°C] and at less than 50 % relative humidity. Cap or grind the cores, and test them within 48 hours of receipt [2].

2.4.5 Advantage and Drawback of core drilling

Core test is the most direct method to evaluate the concrete strength in the existing structure. However, it has many draw backs [26].

a) The number of cores required by the standards is large which leads to high investigation cost,

b) When planning the core locations in the structures, we are not fully free in selecting these locations due to: structural considerations because drilling excessive cores in the high stressed members can weaken the structure and consequently affect its capacity to bear the applied loads; drilling considerations because the access of large and heavy drilling machine may be difficult (or impossible) in several situations,

c) Drilling is a complicated process because it includes setting up the machine, checking the perpendicularity and extracting core and for each step the standards provide several requirements to be respected. Consequently, a skilled operator is mandatory in order to obtain a core specimen that is undamaged and representative of the in-situ concrete.

d) Before the compressive testing, it is required to follow several preparation and storage conditions and the shortening in any of these conditions leads to misleading core strength. Therefore, this is another reason for the expensive cost of core test.

e) Core test takes a lot of time as compared with the other tests due to drilling, preparation, testing processes.

f) The obtained strength of core specimen differs from the true in-situ value existing in the structure at location where the core was extracted.

2.4.5 Calculation

The compressive strength of each specimen is calculated using the computed cross-sectional area based on the average diameter of the specimen using equation [28].

$$Compressive\ strength = \frac{\text{Failur load(KN)}}{Area\ of\ the\ specemen(mm2)}$$

If the ratio of length to diameter (L/D) of the specimen is 1.75 or less, correct the result obtained above by multiplying by the appropriate correction factors.

Table 2.1. Correction factors [2]

Ratio of Length to Diameter(L/D)	Strength Correction Factor
2	1.00
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

Use interpolation to determine correction factors for L/D values not given in the table [2].

If any strength test of laboratory cured cylinder low strength concrete is confirmed and calculation indicate that the load carrying capacity is significantly reduced tests of core drilled from an area in equation according to ASTM C42, in such case three for each strength [2].

Concrete in an area represented by core test should be considered structurally adequate if the average strength of the three cores is equal to at least 85 percent of fc' and if no single core is less than 75 percent of fc' (ACI 318-08). i.e core test having an average of 85 percent of the specified strength are acceptable.

It was found from the result; the compressive strength of cores (75mm diameter) is 0.693 times the compressive strength of cubes (150mm x 150mm x150mm). The compressive strength of cores (75mm diameter) is 0.528 times the compressive strength of cubes (100mm x 100mm x 100mm).The core (48mm diameter) compressive strength is 0.724 times the compressive strength of cubes (150mm x 150mm x 150mm) [38].

2.5 Current local practice of applying and interpretation of rebound hammer test result.

Currently in Ethiopian construction industry the common and the only option applied to evaluate the status of the existing concrete quality using non-distractive test method is rebound hammer and used as final acceptance criteria for concrete quality evaluation which is against the ASTM and ACI standards recommendation which is allowed to use in checking uniformity of concrete and comparing one concrete against another. It can only be used as rough indication of concrete strength. Therefore, this test method is not intended as the basis for acceptance or rejection of concrete because of the inherent uncertainty in the estimated strength. In addition, different hammers vary considerably in performance and need calibration for use in concrete made with the course and fine aggregates from specific sources.

2.6 Summary of literature review

The strength of concrete is most important property (especially when needed for structural purposes) alongside its durability. Therefore, it is very important to ascertain the compressive strength of concrete before subjecting it to its anticipated loads. Compressive strength of the hardened concrete can be determined using the destructive and non-destructive testing (NDT) methods. The destructive testing (DT) method is carried out by crushing the cored and / or cast specimen to failure while the non-destructive is carried out without destroying the concrete specimen.

Concrete cores could also be drilled from the structure following ASTM C42. The standard specimen size is 0.15 m in diameter and 0.30 m high, although other sizes with a height–diameter ratio of two can also be used. The diameter of the specimen must be at least three times the nominal maximum size of the coarse aggregate in the concrete.

The rebound hammer provides an inexpensive and quick method for non-destructive testing of concrete in the laboratory and in the field. This test is conducted to assess the relative strength of concrete based on the hardness at or near its exposed surface. The local practice considers rebound hammer test results as a final acceptance criterion which is becoming a reason for argument. Therefore, the need for a study on relationship between concrete core test and rebound hammer test now a days is unquestionable.

2.7 Research gaps identified

The following research gaps were identified

- Lack of research in the area of the topic of the study with the local material available.
- Lack of understanding and controversy in the application of the Schmidt hammer for structural evaluation.
- The regulatory authority uses Schmidt hammer for final acceptance criteria.

3 CHAPTER THREE: RESEARCH METHODOLOGY AND DESIGN

3.1 Introduction

The aim of this research work is to clearly identify /assess whether rebound hammer test results comply with uniaxial compressive strength and core test result obtained from compressive strength machine and to derive relationship among the test methods.

3.2 Research Design

The methodology used in this research work includes literature survey, find internet web sites to find relevant information related to topics under study, Materials collection, laboratory test and field test, mix design and finally use statistical descriptive analysis method.

3.3 Laboratory work

In laboratory testing the quality of aggregates and preparation of mix design was performed for control concrete mix design because getting the required number of samples at the required age was difficult and on field in situ tests i.e rebound hammers, core test and collection of fresh concrete sample were done.

In Ethiopia the common mix design procedure exercised is ACI therefore, this procedure was adopted for the mix design of the concrete as per [25]; and likewise, ASTM and BS EN test procedures are also common test methods exercised. therefore, this test methods were adopted to check the quality of the aggregates. Generally, the following activities were employed in laboratory .

- The aggregates quality tests and concrete mix design were done; the concrete cubes casted on site and those cored from the project site and casted slabs were trimmed and conditioned until the age reached.
- The concrete cored from project sites were conditioned, trimmed, crushed and values recorded.
- Rebound hammer readings were recorded holding the concrete cube samples firmly on the UTM;
- Concrete cube specimens 15*15*15 cm size were casted from different project sites were cured in water thank until the age reached.

3.4 Field work

The study also includes data collection from the project sites therefore, the following activities were performed on the project sites under study.

- Rebound hammer reading were recorded directly from structures on the project site from where the fresh samples were taken at the edge between 28 to 45 days after casted.
- Fresh concrete specimens were collected from the different project sites using 15*15*15 cm concrete cube mold.
- Concrete core samples were collected from the project sites under investigation and from the control casted slabs using core drilling machine with skilled technician.
- Single-core operator and the same core cutter was used throughout the core cutting process in order to control the large variation between the samples.
- The test results obtained from the two test methods (i.e rebound hammer, cube & core test) were analyzed and interpreted.
- Since the number of cored samples from the project sites were not enough; mix design was adopted and a 1.0 m by 1.0 m having 25 cm thickness slab and 1.0m by 1.0m having 0.50m pad were casted and prepared for further core drilling test.

3.5 Selection of Aggregate sources and project sites

The selection of the project sites for this research was based on the convenience of the sites for data collection and for the follow up of the experimental study and the project sites use the aggregate sources quarried from the sources around Beke and Goro area.

The coarse aggregate materials were collected from two sources. The selection of these quarry sites is based on most of the project under study were using the aggregate quarried from the two sources.

1. From Aleletue – Beke area, Narucon plc Construction Quarry site(S1)
2. From Goro area, Aser Construction plc quarry site(S2)

Sands from different sources were visually identified from stockpiled in AAiT Laboratory and among them the sand collected from around Langano area were selected checked its quality against the standard requirements and sufficient amount of it was collected form the source and was used for mix design analysis. Finally, correlation was developed through regression analysis and formulation of conclusion and recommendations were done based on the results obtained.

4 CHAPTER FOUR: MIX DESIGN AND PHYSICAL PROPERTIES OF AGGREGATE

4.1 Material preparation

In order to produce control mix design concrete ingredients were collected from different sources and the following physical characteristics of the materials were examined.

On coarse aggregate Sieve analysis; Specific gravity and water absorption; Unit weight, rodded and loss; Moisture content; Fakeness index; Elongation index; Soundness test and Aggregate crushing value test were tested and on natural sand sieve analysis; specific gravity and water absorption; unit weight; materials finer than No 200 (Silt and clay content); organic impurities and moisture content. Since in Ethiopia construction industry the common test procedures followed to measure the quality of the materials are ASTM and BS test method the same was applied to check the quality of the aggregates.

4.2 Materials test results

4.2.1 Coarse Aggregate material test results

Aggregates make up the largest volume of material used in concrete. The aggregates must be clean, properly graded, hard, strong, durable, and free from chemicals or coatings of clay or other foreign materials that may inhibit the bond between the cement and aggregate. Testing must be performed to make sure that the aggregate meets all these criteria. The tables 4.1 to 4.7 show the quality tests done on aggregates to measure the competence of aggregate sources for concrete production.

4.2.1.1 Sieve Analysis coarse aggregate

Table 4.1. Sieve analysis for coarse aggregate/S2

Sieve size	Weight retained, gm	Percentage retained	Wt. Passing, gm	% passed	Cum % Retained
37.5	0	0.0	5809.7	100.0	0.0
25	2662.7	45.8	3147.0	54.2	45.8
19.5	2181.8	37.6	965.2	16.6	83.4
12.5	803.2	13.8	162.0	2.8	97.2
9.5	116.8	2.0	45.2	0.8	99.2
4.75	21.2	0.4	24.0	0.4	99.6
2.36	15	0.3	9.0	0.2	99.8
1.18	0	0.0	9.0	0.2	99.8
0.600	0.0	0.0	9.0	0.2	99.8

0.300	0.0	0.0	9.0	0.2	99.8
0.150	0.0	0.0	9.0	0.2	99.8
Pan	9.00	0.2			924.5
total	1840.80	100.0			Fm=7.81

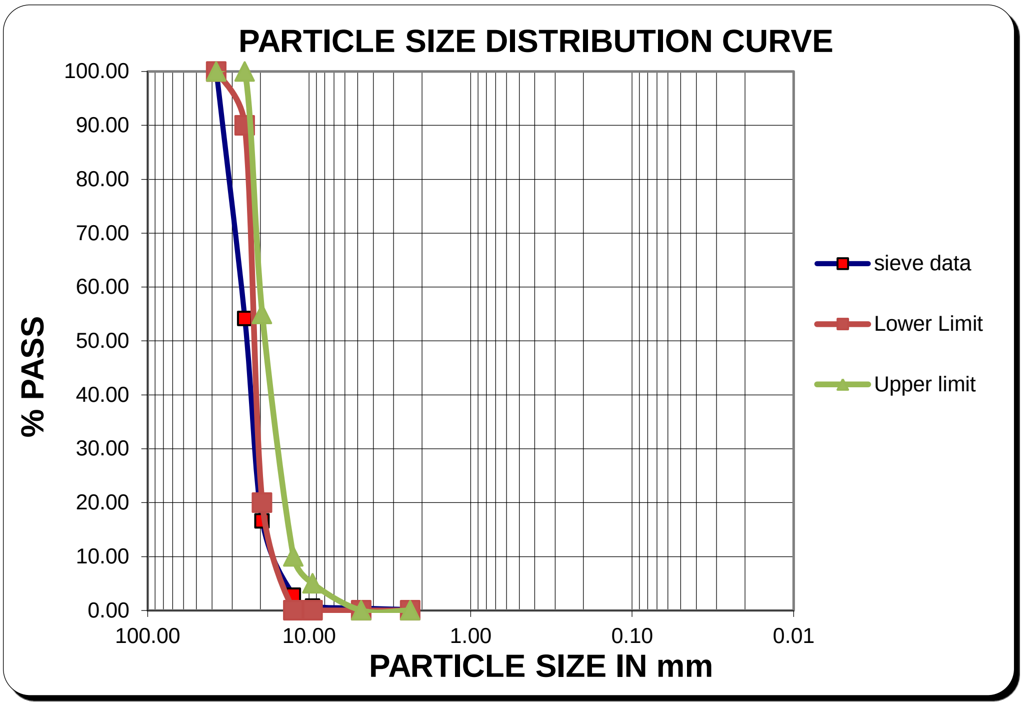


Figure 4.1. Gradation of coarse aggregate/S2

Table 4.2. Sieve analysis for coarse aggregate/S1

Sieve size	Weight retained, gm	Percentage retained	Wt. Passing, gm	% passed	Cum % Retained
50.0					
37.5	0	0.0	3512.0	100.0	3.6
25	127.1	3.6	3384.9	96.4	29.9
19.5	923.6	26.3	2461.3	70.1	46.2
12.5	572.6	16.3	1888.7	53.8	62.5
9.5	572.5	16.3	1316.2	37.5	89.9
4.75	961.3	27.4	354.9	10.1	97.9
2.36	282.5	8.0	72.4	2.1	99.9
1.18	70.3	2.0	2.1	0.1	99.9
0.600	0	0.0	2.1	0.1	99.9
0.300	0.0	0.0	2.1	0.1	99.9
0.150	0.0	0.0	2.1	0.1	99.9
Pan	0.0	0.0			829.8
total	1840.80	100.0			Fm=7.37

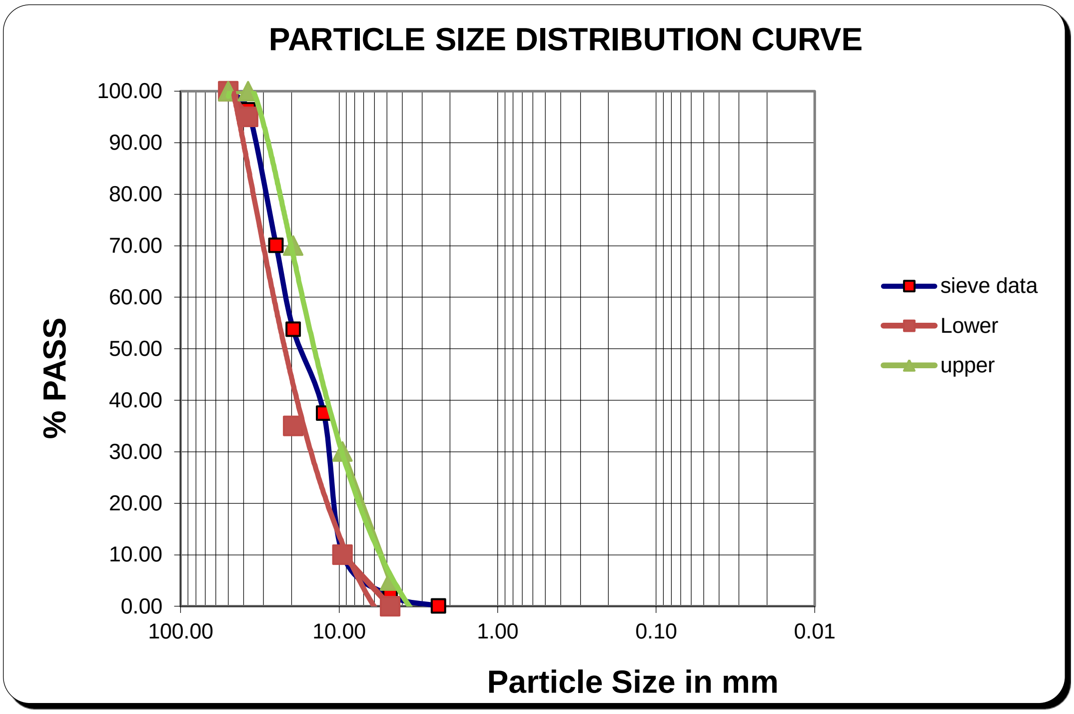


Figure 4.2. Gradation of coarse aggregate/S1

Gradation of aggregates is one of the most important quality parameters that predominantly

influence the properties of a concrete. However, the result of this research shown from of the samples collected from both sources couldn't satisfy the same graduation requirements of ASTM C33. This has an implication that aggregates supplied to the industry have quality problems as far as graduation requirements are concerned the supplies considers the aggregate produced is nominal maximum size of 25.0 mm. The aggregate quarry sites need to cheeked for their production and they should have consistent quality and quality assurance periodically [35].

4.2.1.2 Coarse aggregate quality test

4.2.1.2.1 Compacted Unit Weight

The bulk density unit weight and sometimes called dry-rodded unit weight) of an aggregate is the mass of the aggregate divided by the volume of particles and the voids between particles. the rodded bulk density of aggregates used for normal-weight concrete generally ranges from 1200 to 1760 kg/m3 (75 to 110 lb/ft3) as per ASTM C29 [30].

The compacted unit weight of the aggregates from S1and S2 are 1700 and 1680 kg/m3 which are within the accepted limit of ASTM.

4.2.1.2.2 Flakiness Index and Elongation Index

A maximum flakiness index value of 35% is stated in the ASTM for crushed concrete aggregate (ASTM C33).

The flakiness index and elongation index of the two samples were tested and done as per BS 812 test procedure The flakiness index and elongation index of the two samples were tested and done as per BS 812 test procedure and S2 resulted 33% and 31% for flakiness index and elongation index, while S1 resulted 24% and 28% for flakiness index and elongation index values. From the results the values are within the accepted limit.

4.2.1.2.3 Soundness

Soundness was determined using Sodium Sulphate and the results obtained were 4.6, and 0.6 %. This is a good result as far as the 12% maximum permissible limit stated in the ASTM C33.

4.2.1.2.4 Los Angeles Abrasion

The most common test method for degradation of coarse aggregate by abrasion and impact is the Los Angeles machine method [ASTM C 131 for aggregate smaller than 37.5 mm (1-1/2 in.) but greater than 2.36 mm (No. 8 sieve opening).

ASTM C 33, “Concrete Aggregates,” specifies a maximum mass loss of 50% for gravel, crushed gravel, or crushed stone. The abrasion test on aggregates under study was found 13% for both sources which are within the desired limit of the specification.

4.2.1.2.5 Aggregate Crushing Value (ACV),

These tests are a measure of the crushing properties of aggregate. The ACV test requires a standard load of 400 kN to be applied over a period of 10 minutes.

There are currently no AASHTO or ASTM testing methods to determine aggregate strength directly. However, the British Aggregate Crushing Value Test has been used extensively to determine the relative strength of graded concrete aggregates [33]. This test consists of applying a load to an aggregate sample in a steel cylinder for 10 minutes. After the 10-minute loading period the sample is analyzed for changes in gradation and a value is determined. BS 812 specify the maximum limit for ACV is 30%. The aggregate crushing value of the aggregates were measured and resulted 15% and 11% for S2 and S1 respectively.

4.2.1.3 Coarse aggregate quality test

The quality of concrete produced is highly depends on the quality of ingredient materials. the aggregate quality test under study was summarized as in table 4.3.

Table 4.3. Summary of coarse aggregate quality test

Sr.No	Test Type	Test Method	Test Result/S2	Test Result/S1	Requirement
1	Compacted Unit Weight, kg/m^3	ASTM C29	1680	1700.00	-
2	Flakiness Index, %	BS 812, sec105.1	33.0	24.00	<=*35*
3	Elongation Index, %	BS 812, sec105.2	31.0	28.00	<=*35*
4	Sodium sulphate soundness, %	ASTM C88	4.6	0.60	<=*12*
5	Los Angeles Abrasion, %	AASHTO T96	13.0	13.00	<=*50*
6	Aggregate Crushing Value (ACV), %	BS 812 par 110	15.0	11.00	<=*30*

Concerning the quality, the samples were fit for concrete production as far as their test result values of Compacted Unit Weight, Flakiness Index, Elongation Index, sodium sulphate soundness, Los Angeles Abrasion, Bulk Specific Gravity, Apparent Specific Gravity, Water Absorption, aggregate crushing values.

4.2.1.4 Specific gravity and water absorption (ASTM C127)

The specific gravity and water absorption of aggregated is determined as per ASTM C127 result values as given in table 4.4.

Table 4.4. Specific gravity and water absorption coarse aggregate

Sample source	Bulk specific gravity (SSD)	Apparent specific gravity	Water Absorption (%)
S2	2.81	2.87	1.17
S1	2.82	2.88	2.25

4.2.2 Fine aggregate test results

The quality of concrete produced is highly depends on the quality of ingredients and one of the major ingredients is sand. the quality of the sand source was checked and the test result indicates the sand is fits the standard requirement recommended for concrete production the result presented as below.

4.2.2.1 Sieve Analysis Fine aggregate (Langano sand)

The most desirable fine-aggregate grading depends on the type of work, the richness of the mixture, and the maximum size of coarse aggregate [34]. The sieve analysis of the sand from Langano source was done as per ASTM C136 procedure to check whether it achieves the ASTM C33 requirement and the grading chart presented in table 4.5.

Table 4.5. Sieve analysis for Fine aggregate

Sieve size	Weight retained, gm	Percentage retained	Wt. Passing, gm	% passed	ASTM C-33 Requirement	Cum % Retained
9.50	0.00	0.00	1840.80	100	100	
4.75	97.50	5.30	1743.30	95	95 - 100	5
2.36	141.60	7.69	1601.70	87	80 - 100	13
1.18	163.50	8.88	1438.20	78	50 - 85	22
0.60	800.50	43.49	637.70	35	25 - 60	65
0.30	463.40	25.17	174.30	9	5 - 30	91
0.15	141.90	7.71	32.40	2	0 - 10	98
pan	32.40	1.76				
total	1840.80	100.0				
					Fines modulus (FM)	2.94

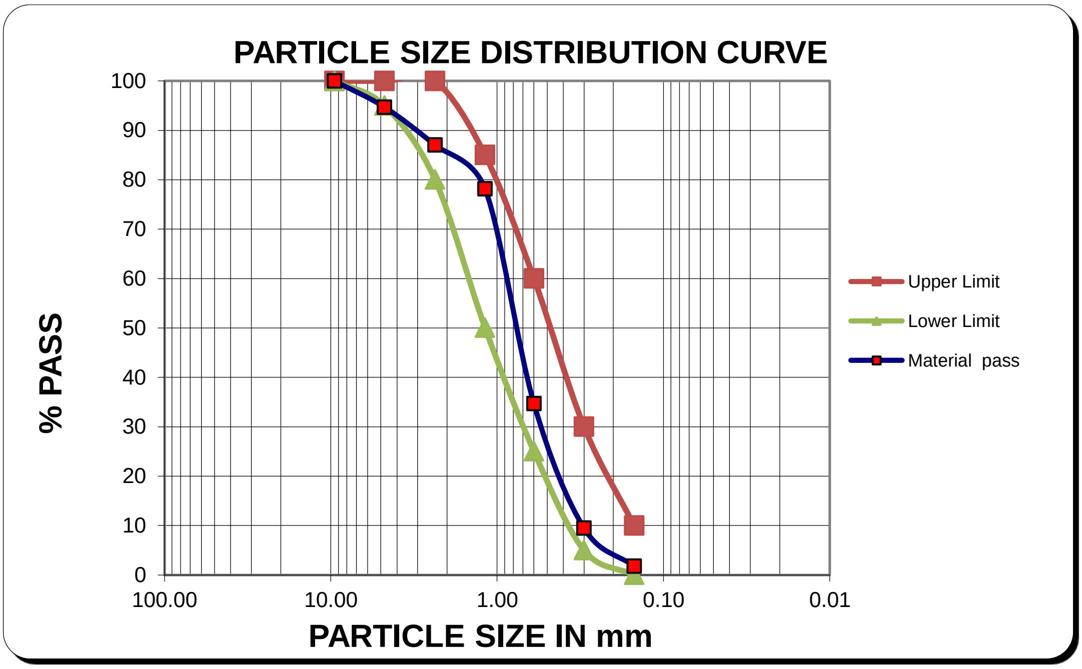


Figure 4.3. Gradation of fine aggregate

4.2.2.2 Fineness modulus

The fine-ness modulus is the sum of the total percentages retained on each of a specified series of sieves, divided by 100. FM is an index of the fineness of an aggregate. the higher the FM, the coarser the aggregate. Sands used in concrete; the fineness modulus generally ranges from 2.3 to 3.1.

The following limits may be taken as guidance [36]:

Fine sand: F.M. 2.2 - 2.6

Medium Sand: F.M. 2.6 - 2.9

Coarse Sand: F.M. 2.9 - 3.2

The fineness modulus of fine aggregate was calculated as per ASTM C125 test procedure and was found 2.94. i.e the sand is classified in the coarse and range.

4.2.2.3 Silt and clay content

The Ethiopian Standard stipulates that the silt and clay contents of a fine aggregate sample should be less than or equal to 3% for concrete subject to abrasion and less than or equal to 6% for all other concrete (ES. C. D3. 201). ASTM C33 specify the maximum silt and clay content 5%.

The silt content of the sand was checked as per ASTM C117 and was found 1.98% which is within the required limit.

4.2.2.4 Organic Impurities

ASTM (C40 – 79) states that plat number 3 is the maximum value allowed for fine aggregates. the organic impurities of the sand under study were recorded plate number 1 which is within limit of ASTM C 40.

4.2.2.5 Bulk density/Unit weight

The bulk density (previously “unit weight” or sometimes “dry-rodded unit weight”) of an aggregate is the mass of the aggregate divided by the volume of particles and the voids between particles [31].

The rodded bulk density of aggregates used for normal-weight concrete generally ranges from 1200 to 1760 kg/m3 [31]. The unit weight of the sand under study is recorded 1400 kg/m^3 which is within the recommended limit.

Table 4.6. Summary of Sand quality test / Langano sand

Sr.No.	Test type	Test method	Test result	Requirement
1	Silt and Clay Content, %	ASTM C117	1.98	6%
2	Organic Impurities	ASTM C40	01	Max. plate No.3
3	Unit Weight, kg/m^3	ASTM C29	1410.00	>=1200

4.2.2.6 Specific gravity and water absorption (ASTM C128)

Table 4.7. Specific gravity and water absorption of sand

Bulk specific gravity (SSD)	Apparent specific gravity	Water Absorption (%)
2.56	2.65	1.98

4.2.2.7 Cement

The cement used for this mix design under this study was from Dangote ordinary Portland cement (OPC). The selection is based on all the project sites under study were using Dangote ordinary Portland cement.

4.3 Concrete Mix Design and Materials Proportion

It is generally understood that mix design is a process in which one determines the relative quantities of the ingredients of concrete prior to mixing to produce concrete of desired properties.

Based on the [24] "Standard Practice for Selecting Proportions for Normal, Heavy weight, and Mass Concrete" and ACI 211[25] procedure mix designs were prepared and the quantities of the ingredient per cubic meter of concrete are shown in table 3.8. The mix design targeted strength was 36 MPa the detail of the mix design is attached in the annex.

Table 4.8. Mix proportion for C-30 concrete

W/C	Quantities (Kg/m^3)			
	Cement	Water	Coarse aggregate	Fine aggregate
0.42/S1	400	168.00	1186.7	711.6
0.47/S2	400	187.00	1186.7	705.6

The concrete cubes of size 150mmx150mmx150mm, after a number of trial mix design finally a total of twelve concrete cubes were cast for determination of compressive strength for water-cement ratio 0.42 for S1 and 0.47 for S2. The concrete cubes were cured for 7 and 28 days in water thank. The cubes were tested in a compression testing machine, load at which the cube specimen ultimately fails is noted. The compressive strength is calculated by dividing the load by area of specimen. The obtained test results are represented in the table 4.9.

Table 4.9. Results of trial mix specimen

	7^{th} day result S1 w/c= 0.42		7^{th} day result S2 w/c= 0.47	
Item No	Load (KN)	Compressive strength (MPa)	Load (KN)	Compressive strength (MPa)
1	676.02	30.63	630.00	28.54
2	651.79	29.53	640.00	29.00
3	592.76	26.86	644.00	29.18
Average		29.00		28.90
	28^{th} day result S1 w/c =0.42		28^{th} day result S2 w/c =0.47	
1	786.58	35.64	825.00	37.38
2	799.77	36.23	840.00	38.06
3	810.81	36.73	861.00	39.01
Average		36.20		38.15

As observed from the above table both trail mix deigns resulted in satisfactory compressive strength value for C-30 grade of concrete at the age of 7 and 28 days because the target mean strength which is 36.0 MPa is achieved. Since most of the concrete batching plants use the aggregate from Aleltu - Beke area S1 with w/c =0.42 and S2 with w/c=0.47 was used to finalize for further casting work.

The cast concrete cube elements were demolded after 24 hours and kept in water tank for 7- and 28-days curing. After that the specimens were tested in a laboratory.

4.4 Compressive strength and rebound hammer reading on UTM machine

Compression tests have been carried out by means of a 3000KN and 2000 KN hydraulic press, with a load rate of 0.5 N.S/mm^2 according to EN 12390-3.

Rebound hammer test has been carried out on concrete specimens soon after their extraction from the water thank in a saturated surface-dry condition.

Tests have been performed by means of analogical N type rebound hammer. According to EN 12504-2 [13] standard a regular check on a standardized steel anvil have been performed at AAiT laboratory, during testing concrete samples were properly clamped between the plates of a UTM and holded under a compressive load of 40 KN axial load. Determinations have been carried out on 12 points, 6 for each of two opposite faces. The mean values of the determination were the rebound number reported in the results.

In situ rebound hammer test was collected from the project sites under investigation from slab, columns and casted controlled slab.

Core specimens were extracted from the structural member using a cutting tool having diamond bits attached to the core barrel.

Analysis of the compressive strength of concrete core test and rebound hammer was carried using regression method and coloration was developed.

When placement direction of sample cube is parallel to the loading direction, the compressive strength is higher than the normal placement perpendicular to the loading direction.

5 CHAPTER FIVE: DATA COLLECTION AND ANALYSIS

5.1 Data collection

Based on the material test results trial mix design was followed as per ACI 211 method [25] for C-30 class concrete and twelve fresh cube samples and socked on water thank until the concrete age; hammer reading and concrete core samples were collected from different project sites under investigation and test was conducted to generate the correlation curves.

- ✓ Dangote OPC cement was used for the mix design
- ✓ Tap water was used for the mix design

Base on the mix design a 1.0 m*1.0 m *0.50 m and 1.0 m* 1.0 m * 0.25 m concrete slab were casted on a panel and form work and cured to set from until gets harder to testing age.

Table 5.1. Sample size

	Total no of sample from laboratory control specimen and casted slab	Total no of sample collected from four project sites
Cube sample	12 (12)	24 (6 from each)
Hammer test	18	36
Core sample	18	12

a) Sample no 1 50cm thick slab b) Sample no 2 25 cm thick slab

Figure 5.1. Concrete pad caste for core test (Pictured by researcher)

Concrete pad casted for core test was prepared for core test after cured to the age of coring as shown in the figure 5.2.

Figure 5.2. Sample preparation for coring (Pictured by researcher)

Cylindrical core sample was recovered from the casted pads as shown in figure 5.3 a and b below

a) Cored sample no trial no 1 ***b) Cored sample no trial no 2***

Figure 5.3. Cylindrical cored Samples (Pictured by researcher)

Rebound hammer readings were taken from the slab and column of a building under the study as shown in the figures 5.4 a and b.

a) Hammer reading from slab b) Hammer reading from column

Figure 5.4. Hammer reading from slab and column (Pictured by researcher)

Coring of concrete sample from mat slab of a building under study as shown in the figure 5.5.

Figure 5.5. Core sampling (Pictured by researcher)

Surface preparation for hammer test reading from mat slab of the building under study as shown in the figure 5.6.

Figure 5.6. Surface preparation for hammer test on basement floor slab Fedengua site

Hammer rebound reading was taken on mat slab of a building under study as shown in the figure 5.7.

Figure 5.7. Conducting hammer test for basement floor slab Fedengua site

Concrete cube specimens were casted from different project sites in water under soaking tanker shown in figure 5.8

Figure 5.8. Concrete Soaked in water for curing until the age of testing

Hammer rebound reading was taken on cube samples fixed on compressive strength machine as shown in figure 5.9.

Figure 5.9. Laboratory Schmidt hammer rebound reading

Concrete cored from the area under study were trimmed and ready for crushing on compressive strength machine as shown in the figure 5.10.

Figure 5.10. Cored sample trimmed and capped and ready for crushing from GAF site

After curing the concrete core samples were trimmed and it was observed the distribution of aggregate particles at cut face of bottom and top are different i.e the top cut face of the concrete contains small size aggregate while the bottom part of the cut contains relatively larger aggregate size as how in the figure 5.11.

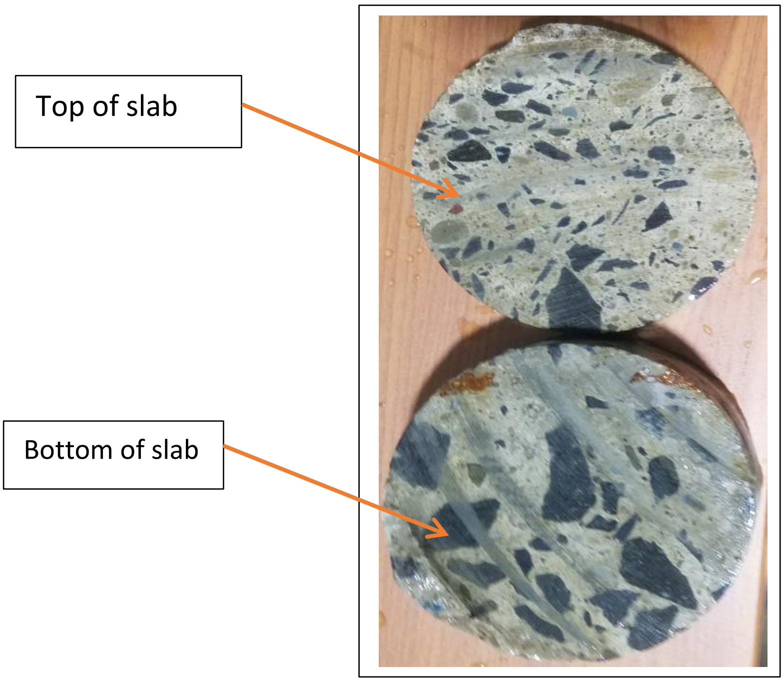


Figure 5.11. Cut face of concrete from a single point from top and bottom of the slab Fedengua site

The drilled cores from the slab elements were observed, the aggregates are not equally distributed and damage caused to the drilled cores.

Compressive strength of the cored concrete was recorded from the trimmed bottom part of the specimen as shown in figure 5.12.

Figure 5.12. Compressive strength test on trimmed bottom part of the core

5.2 Computation of compressive strength

To derive correlation between the test methods both compressive strength and rebound hammer readings of cubes and structures are needed. therefore, compressive strength and rebound hammer reading was conducted at different age specifically at 28 and 45 days on the prepared specimens and structures casted on the same date.

Core test was done according to ASTM C42[2] procedure using Core drill, for obtaining cylindrical core specimens with diamond impregnated bits attached to a core barrel. The samples were covered by water proof plastic sheets and were taken to laboratory. Care was taken in placing the samples to avoid getting exposed to direct sun light. The samples were soaked in water for two days and then ends of the samples were trimmed and capped with sand mortar for tolerance.

Compressive strength test for cored samples was taken from UTM machine at specified age in AAiT material testing laboratory.

Schmidt rebound hammer test was conducted on cube samples as per (BS EN 12504-2:2001) [13] method by keeping the following conditions for cubes using N/NR Type Hammer equivalent compressive strength at ages 14 to 56 day given by the manufactures.

- ✓ Cubes were supported to restrict movement on UTM machine.
- ✓ Care was taken not to hit one place twice using Schmidt rebound hammer
- ✓ Time was taken to dry the samples before conducting the rebound reading.

According to BS EN 12504-2:(2001) [13] the collected data was then analyzed for obvious “off-shots”, that is, those rebound readings that deviate from the mean by more than six units. In this case the reading will be eliminated and/or one additional reading should be taken by further impact test.

The test hammer is calibrated for horizontal impact direction, i.e., for testing vertical surfaces. The correction for non-horizontal impact direction is given by the manufacturer, and the rebound numbers are applied on the mean rebound values of each test point to obtain adjusted mean rebound value.

The rebound number readings were taken from the Ever-grand project site on the slab under investigation and totally nine readings were taken at different places in the slab elements with vertical upward orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.2.

Table 5.2. Rebound Hammer results of slab at Ever grand site

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm^2) 14 to 56 Days
1	40.9	36.49
2	41.4	36.66
3	41.4	36.66
4	40.0	33.68
5	40.7	35.98
6	41.4	36.66
7	42.1	37.51
8	43.0	38.88
9	41.8	37.85

By applying the uniform pressure in a vertical direction, three cores were extracted from the marked concrete slabs.

The drilled cores from the slab were observed, the aggregates are not equally distributed and there are no cracks was caused to the drilled cores. From the recovered core samples, it was observed the slab thickness is not uniform.

The drilled cores were marked at suitable heights and diameter. The marked cores are trimmed with three different height/diameter ratios. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test as shown in the figure 5.13.

Figure 5.13. Core samples after Trimming from Ever grand site

After the concrete core samples were trimmed placed on UTM and load was applied at the rate of 12-24 N/ (mm^2.min), and the load at which core samples fails was recorded. The measured core strength of cores was calculated by dividing the load by the area of cylindrical core sample figure 5.14 shows core samples after load was applied.

Figure 5.14. Core samples after Testing from Ever grand site

The obtained measured core compressive strength results of cores are represented in the table 5.3.

Table 5.3 Drilled Cores Compressive Strength of Concrete from Ever grand site at 45 days.

Item NO	Diameter (Cm)	Height (Cm)	Load (KN)	H/D	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.80	12.30	198.42	1.26	2.28	26.4
2	9.80	11.80	206.69	1.20	2.23	27.5
3	9.80	13.60	184.28	1.39	2.20	24.5
					Average	26.1

Six cube samples were collected during casting for compressive strength and were crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.4.

Table 5.4 Cube Compressive Strength of Concrete from Ever grand site

Item NO	Age	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	28	675.20	2.41	30.59
2	28	652.20	2.42	29.55
3	28	685.50	2.41	31.06
			Average	30.40

The rebound number readings were taken from the MKB project site on the slab under investigation and totally ten readings were taken from nine different test locations on the slab element with vertical upward orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.5.

Table 5.5 Rebound Hammer results of slab at MKB site

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm^2) 14 to 56 Days
1	40.20	34.40
2	40.60	35.64
3	40.80	36.15
4	40.80	36.15
5	40.10	34.04
6	40.70	35.98
7	40.60	35.64
8	40.50	35.30
9	40.30	34.58

By applying the uniform pressure in a vertical direction, three cores were extracted from the marked concrete slabs at MKB site.

The drilled cores from the slab were observed, the aggregates are equally distributed and there were no cracks caused to the drilled cores as seen from the recovered core samples shown the figure 5.15.

The drilled cores are marked at suitable heights and diameter. The marked cores are trimmed with three different height/diameter ratios. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test.

Figure 5.15. Core samples after Trimming from MKB site

The obtained measured core compressive strength results of cores are represented in the table 5.6.

Table 5.6 Drilled Cores Compressive Strength of Concrete from MKB site at 45 days.

Item NO	Diameter (cm)	Height (cm)	H/D	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.8	18	1.84	197.73	2.46	25.7
2	9.8	20	2.04	174.12	2.37	24.5
3	9.8	20	2.04	188.39	2.25	26.5
					Average	25.6

Six cube samples were collected during casting for compressive strength and were crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.7.

Table 5.7 Cube Compressive Strength of Concrete from MKB site

Item NO	Age	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
28-day compressive strength				
1	28	821.22	2.43	37.21
2	28	799.06	2.37	36.20
3	28	830.50	2.37	37.63
Average				37.01
45-day compressive strength				
1	45	858.50	2.42	38.89
2	45	878.90	2.46	39.81
3	45	876.80	2.35	39.72
Average				39.47

The rebound numbers were taken from the Fedengua project site on the slab under investigation and totally ten readings were taken at different places in the slab elements with vertical down ward orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.8.

Table 5.8 Rebound Hammer results of slab at Fedengua site

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm^2) 14 to 56 Days
1	35.4	37.51
2	35.1	37.34
3	35.5	37.68
4	35.7	37.85
5	35.2	37.34
6	36.8	39.78
7	34.5	35.98
8	36.9	39.78
9	36.3	39.24

By applying the uniform pressure in a vertical direction, three cores were extracted from the marked concrete slabs at Fedengua site.

The drilled cores from the slab were observed, the aggregates are not equally distributed and pore voids were identified on the drilled core samples as shown the figure 5.16.

The drilled cores are marked at suitable heights and diameter. The marked cores are trimmed with three different height/diameter ratios. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test.

Figure 5.16. Core samples after Trimming from Fedengua site

The obtained measured core compressive strength results of cores are represented in the table 5.9.

Table 5.9 Drilled Cores Compressive Strength of Concrete from Fedengua site at 45 days

Item NO	Diameter (cm)	Height (cm)	H/D	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.60	18.00	1.88	165.46	2.30	23.30
2	9.60	14.50	1.51	144.46	2.31	20.34
3	9.60	16.20	1.69	133.75	2.38	18.84
					Average	20.83

Six cube samples were collected during casting for compressive strength and were crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.10.

Table 5.10 Cube Compressive Strength of Concrete from Fedengua site

Item NO	Age	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	45	538.89	2.38	24.41
2	45	624.90	2.38	28.31
3	45	555.27	2.37	25.16
			Average	29.29

The rebound numbers were taken from the GAF project site on the slab under investigation and totally ten readings were taken from nine different test locations on the slab element with horizontal orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.11.

Table 5.11 Rebound Hammer results of slab at GAF site

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm^2) 14 to 56 Days
1	36.00	33.5
2	36.00	33.5
3	36.00	33.5
4	36.90	35.1
5	36.40	34.2
6	36.50	34.4
7	38.50	37.9
8	37.00	35.3
9	35.10	32.0

By applying the uniform pressure in a vertical direction, three cores were extracted from the marked concrete slabs at GAF site.

The drilled cores from the slab were observed, the aggregates are equally distributed and pore voids were identified on the drilled core samples as shown figure 5.17.

The drilled cores are marked at suitable heights and diameter. The marked cores are trimmed with three different height/diameter ratios. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test.

Figure 5.17. Core samples after trimming from GAF site

Table 5.12 Drilled Cores Compressive Strength of Concrete from GAF site

Item NO	Diameter (cm)	Height (cm)	H/D	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.8	20	2.04	160.12	2.37	22.50
2	9.8	20	2.04	149.39	2.25	21.00
3	9.8	20	2.04	168.77	2.34	23.80
					Average	23.43

Six cube samples were collected during casting for compressive strength and were crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.13.

Table 5.13 Cube Compressive Strength of Concrete from GAF site at 45 days

Item NO	Age	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	28	725.00	2.43	32.85
2	28	744.00	2.43	33.71
3	28	765.20	2.46	34.67
			Average	33.74

The rebound numbers were taken from the casted 2nd control mix slab under investigation and totally ten readings were taken from nine test locations from slab elements with horizontal orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.14.

Table 5.14 Rebound Hammer results of slab at 2nd control mix with W/C=0.42

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm^2) 14 to 56 Days
1	38.2	37.34
2	37.5	36.15
3	35.7	32.99
4	37.8	36.66
5	32.9	28.34
6	35.2	32.14
7	37.4	35.98
8	38.2	37.34
9	36.9	35.12

By applying the uniform pressure in a vertical direction, nine cores were extracted from the marked casted concrete slabs from the second control mix.

The drilled cores from the casted slab were observed, the aggregates are equally distributed on the drilled core samples and cracks were not identified on the cored samples.

The drilled cores are marked at suitable heights and diameter. The marked cores are trimmed. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test.

Table 5.15. Drilled cores compressive strength of concrete from 2nd control mix with W/C=0.42

Sample code	Diameter (cm)	Height (cm)	H/D	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.8	13.50	1.35	166.80	2.37	23.5
2	9.8	19.50	1.95	163.70	2.55	23.1
3	9.8	19.50	1.95	164.70	2.41	23.2
4	9.8	20.00	2.00	211.70	2.49	29.8
5	9.8	19.50	1.95	251.00	2.52	32.5
6	9.8	19.50	1.95	211.70	2.54	29.8
7	9.8	20.00	2.00	168.77	2.52	23.8
8	9.8	16.80	1.68	181.50	2.46	25.6
9	9.8	20.00	2.00	187.20	2.48	26.4

Six cube samples were collected during casting for compressive strength and were crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.16.

Table 5.16 Cube compressive strength of concrete cube 2nd control mix

Item NO	Age	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	28	705.0	2.27	31.94
2	28	725.0	2.33	32.85
3	28	740.2	2.34	33.53
			Average	32.77
1	45	774.2	2.33	35.08
2	45	788.2	2.35	35.71
3	45	765.2	2.34	34.67
			Average	35.15

The rebound numbers were taken from the 1st control mix slab under investigation and totally ten readings were taken at nine test locations in the slab elements with vertical downward orientation of rebound hammer. Average rebound numbers and equivalent cube compressive strength are presented in table 5.17.

Table 5.17 Rebound Hammer results of slab at 1st control mix with W/C=0.47

Test No	Average rebound no	Equivalent cube compressive strength value (N/mm2) 14 to 56 Days
1	34.5	35.98
2	34.7	36.49
3	34.8	36.66
4	34.8	36.66
5	34.8	36.66
6	34.8	36.66
7	35.4	37.34
8	36.4	39.06
9	36.7	39.42

By applying the uniform pressure in a vertical direction, nine cores were extracted from the marked casted concrete slabs from first control mix with W/C=0.47

The drilled cores from the casted slab were observed, the aggregates are not equally distributed on the drilled core samples and the recovered samples not uniform tallness due to unequal distribution of the aggregates.The drilled cores are marked at suitable heights and diameter. The marked cores are trimmed. The trimmings of cores were done by water lubricated diamond saw. The end surfaces of the trimmed cores were smoothened for compression test.

Figure 5.18. Core samples after Trimming from 1st control mix site

Table 5.18 Drilled cores compressive strength of concrete from 1st control mix

Sample code	Diameter (cm)	Height (cm)	H/D	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	9.8	13.8	13.8	192.81	2.12	23.3
2	9.8	12.5	12.5	192.73	2.43	23.3
3	9.8	12.3	12.3	202.60	2.37	24.5
4	9.8	13.3	13.3	183.65	2.24	22.2
5	9.8	10.0	10.0	201.20	1.62	22.7
6	9.8	14.0	14.0	189.38	2.16	22.9
7	9.8	15.0	15.0	183.71	2.35	22.2
8	9.8	13.3	13.3	193.65	2.71	23.4
9	9.8	12.5	12.5	213.45	2.25	24.9

Six cube compressive strength of samples collected during casting was crushed with UTM and the data was recorded. The measured cube strength was calculated by dividing the load by the area of cube sample and presented in the table 5.19.

Table 5.19 Cube compressive strength of concrete cube 1st control mix

Item NO	Age	Load (KN)	Unit Weight (gm/cc)	Compressive Strength (N/mm^2)
1	28	725.00	2.43	32.85
2	28	744.00	2.43	33.71
3	28	765.20	2.46	34.67
			Average	33.74
1	45	765.20	2.41	34.67
2	45	733.00	2.43	33.21
3	45	751.00	2.44	34.02
			Average	33.97

5.3 Compressive strength ratio computation

The rebound hammer, core and cube compressive strength results from different project sites and control mix are presented in the following tables.

For the analysis of the samples collected the project site the hammer readings are averaged to three and used for the analysis.

Table 5.20 Corrections for height/ diameter ratio

Ratio of Length to Diameter(L/D)	Strength Correction Factor
2	1.00
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

Interpolation was used to determine correction factors for L/D values not given in the table. using the correction factor the corrected core compressive strength obtained and represented in the following tables.

Table 5.21; 28th day cube, Schmidt rebound hammer and core and test results Evergrand site

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	30.59	34.86	26.4	1.140	0.863
2	29.55	33.75	27.5	1.142	0.931
3	31.06	36.27	24.5	1.168	0.789

Table 5.22; 28th day cube, Schmidt rebound hammer and core and test results MKB site

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	37.21	34.90	25.70	0.938	0.691
2	36.20	35.39	24.50	0.978	0.677
3	37.63	34.59	26.50	0.920	0.705

Table 5.23; 28th day cube, Schmidt rebound hammer and core and test results Fedengua site

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	24.41	35.72	23.30	1.463	0.955
2	25.16	36.50	20.34	1.451	0.808
3	25.16	36.51	18.84	1.451	0.749

Table 5.24; 28th day cube, Schmidt rebound hammer and core and test results GAF site

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	32.85	33.50	22.50	1.020	0.672
2	33.71	34.58	21.00	1.026	0.607
3	34.67	35.04	23.80	1.011	0.679

Table 5.25; 28th day cube, Schmidt rebound hammer and core and test results control mix with W/C=0.42

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	31.94	32.38	21.80	1.014	0.683
2	31.94	32.38	22.00	1.014	0.689
3	31.94	34.15	23.10	1.069	0.723
4	32.85	35.49	23.20	1.080	0.706
5	32.85	35.49	23.80	1.080	0.725
6	32.85	36.16	24.00	1.101	0.731
7	33.53	36.16	24.50	1.078	0.731
8	33.53	36.90	26.00	1.101	0.776
9	33.53	37.27	26.40	1.112	0.787

Table 5.26;28th day cube, Schmidt rebound hammer and core and test results control mix with W/C=0.47

Sample No	Cube Compressive (MPa)	Rebound Hammer (MPa)	Core compressive strength (MPa)	Hammer vs cube	core vs cube
1	31.94	35.98	22.17	1.126	0.694
2	32.26	36.49	22.17	1.131	0.687
3	32.26	36.66	22.72	1.136	0.704
4	32.85	36.66	22.86	1.116	0.696
5	33.21	36.66	23.26	1.104	0.700
6	33.53	36.68	23.27	1.094	0.694
7	33.53	37.51	23.37	1.119	0.697
8	34.02	39.20	24.45	1.152	0.719
9	34.67	39.83	24.93	1.149	0.719

5.4 Data analysis and interpretation

5.4.1 Normal distribution of strength

Compressive strength test results tend to follow a normal distribution as showed in Figure 2.12 normal distribution is defined by two parameters, the mean value of the distribution and the standard deviation (σ), which is the measure of the spread of results around the mean value. A low standard deviation means that most strength results will be close to the mean value; a high standard deviation means that the strength of significant proportions of the results will be well below (and above) the mean value. The area under the normal distribution between two values of 'x' represents the probability that a result will fall within this range of values. The term 'tail' is used to mean the area under the normal distribution between a value, e.g. a compressive strength, and where the frequency is effectively zero[37].

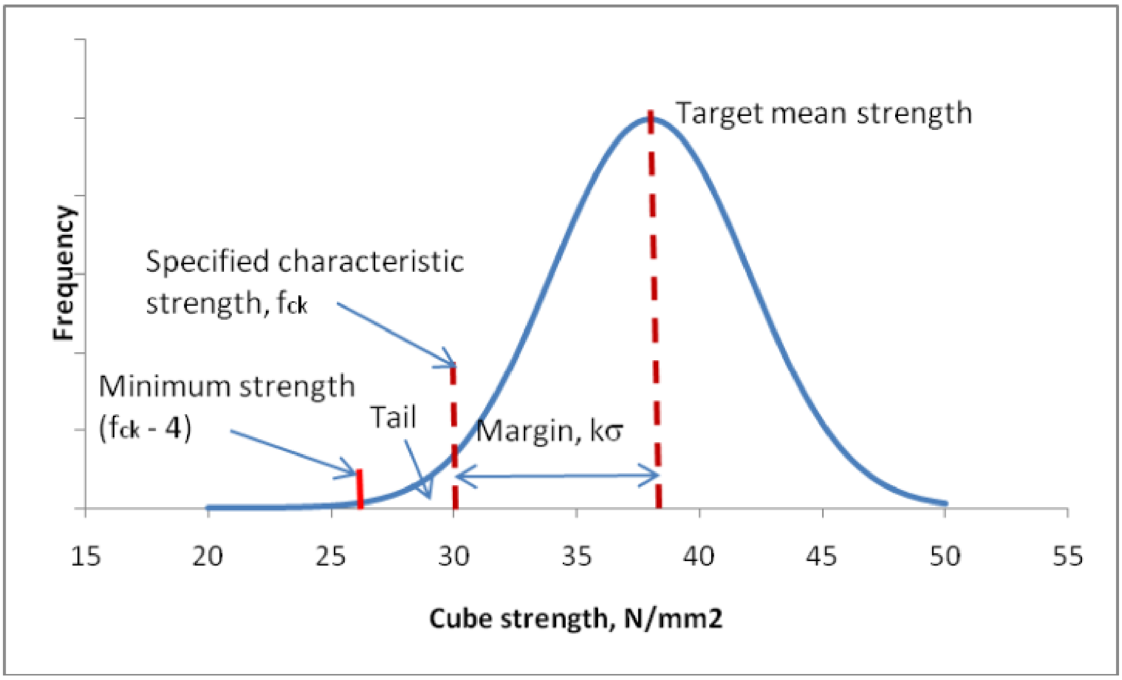


Figure 5.19. Illustration of concrete strength distribution from [37]

5.4.2 Mean X

The average strength tests result X is calculated using Equation 2.1

$$X = \sum_{i=1}^{n} xi/n = (\mathbf{1/n + \Sigma xi}) = 1/n(X1+X2+X3+\ldots Xn) \ \ldots.. \ \textit{Equation 2.1}$$

Where Xi; is the i-th strength test result, the average of at least two cylinder strength tests.

X2 is the second strength test result in the record; **Σ**Xi is the sum of all strength test results and n is the number of tests in the record [38].

5.4.3 Standard Deviation

The standard deviation is the most generally recognized measure of the dispersion of the individual test data from their average. An estimate of the population standard deviation **σ** is the sample standard deviation **S**. The population consists of all possible data, often considered to be an infinite number of data points. The sample is a portion of the population, consisting of a finite amount of data.

$$\text{Standard deviation, } \sigma = \boldsymbol{\Sigma} \frac{\sqrt{\quad (Xi-x}}{(n-1)} \qquad \text{equation 5.2}$$

Alternatively, it can be determined through a range of pairs approach where Mean range of successive pairs = 1.128 x standard deviation ----------------------equation 5.3

or, Standard deviation = 0.886 x mean range of successive pairs of results

Table 5.27; Mean, Standard deviation and Normal distribution for HR/CU

Site	Cube	Hammer	HR/CU
EV1	30.6	34.9	1.139588
EV2	29.6	33.8	1.142132
EV3	31.1	36.3	1.167740
MKB1	37.2	34.9	0.937920
MKB2	36.2	35.4	0.977624
MKB3	37.6	34.6	0.919947
FD1	24.4	35.7	1.463335
FD2	25.2	36.5	1.450715
FD3	25.2	36.5	1.451113
GAF1	32.9	33.5	1.019787
GAF2	33.7	34.6	1.025808
GAF3	34.7	35.0	1.010672
WC0.42-1	31.9	32.4	1.013776
WC0.42-2	31.9	32.4	1.013776
WC0.42-3	31.9	34.2	1.069192
WC0.42-4	32.9	35.5	1.080365
WC0.42-5	32.9	35.5	1.080365
WC0.42-6	32.9	36.2	1.100761
WC0.42-7	33.5	36.2	1.078437
WC0.42-8	33.5	36.9	1.101493
WC0.42-9	33.5	37.3	1.111542
WC0.47-1	31.9	36.0	1.126487
WC0.47-2	32.3	36.5	1.131122
WC0.47-3	32.3	36.7	1.136392
WC0.47-4	32.9	36.7	1.115982
WC0.47-5	33.2	36.7	1.103884
WC0.47-6	33.5	36.7	1.093946
WC0.47-7	33.5	37.5	1.11870
WC0.47-8	34.0	39.2	1.152263
WC0.47-9	34.7	39.8	1.148832
		Mean	1.116123
		STDV	0.131039

The bell curve of the normal distribution graph of the data for hammer and cube was drawn using the data from table 5.28.

Table 5.28; Computed HR/CU and Normal distribution

SITE	HR/CU	NOR. DIS
MK3	0.919947	0.992720
MK1	0.93792	1.207587
MK2	0.977624	1.741545
GA3	1.010672	2.202351
WC0.42-1	1.013776	2.244102
WC0.42-2	1.013776	2.244102
GA 1	1.019787	2.323516
GA 2	1.025808	2.400815
WC0.42-3	1.069192	2.855328
WC0.42-7	1.078437	2.921115
WC0.42-4	1.080365	2.933185
WC0.42-5	1.080365	2.933185
WC0.47-6	1.093946	3.001160
WC0.42-6	1.100761	3.023602
WC0.42-8	1.101493	3.025534
WC0.47-5	1.103884	3.031201
WC0.42-9	1.111542	3.042591
WC0.47-4	1.115982	3.044449
WC0.47-7	1.1187	3.043862
WC0.47-1	1.126487	3.034944
WC0.47-2	1.131122	3.024573
WC0.47-3	1.136392	3.008249
EV1	1.139588	2.996029
EV2	1.142132	2.985070
WC0.47-9	1.148832	2.951071
WC0.47-8	1.152263	2.930839
EV3	1.16774	2.817193
FD2	1.450715	0.116888
FD3	1.451113	0.115985
FD1	1.463335	0.090984

The bell curve of the normal distribution graph co vs cu presented in the figure 5.20.

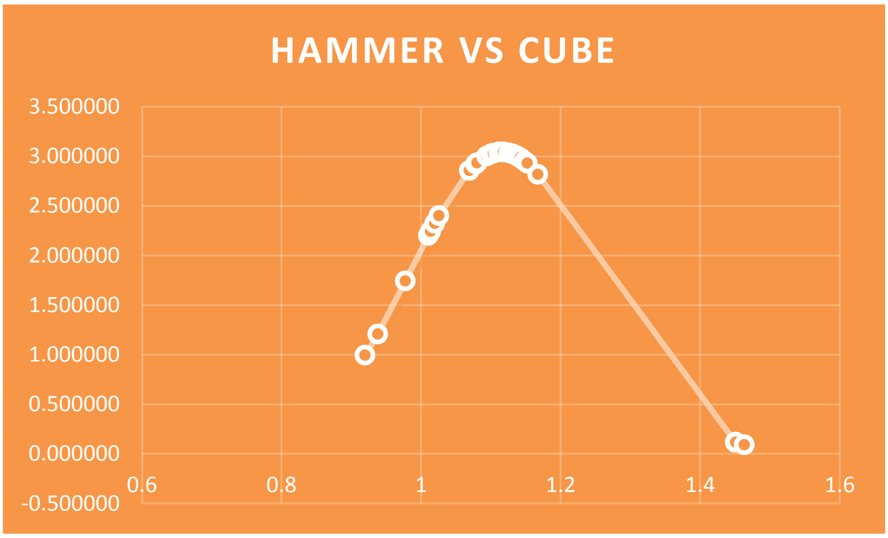


Figure 5.20. Illustration of concrete strength distribution hammer vs cube

The mean and standard deviation of rebound hammer to cube ratio was computed. the mean value =1.116123 the standard deviation =0.131039, 88.9% of the data is between standard deviation was between $\pm 3\sigma$.

Table 5.29; Mean and Standard deviation CO/CU

Site	Cube	Core	CO/CU
Ev1	30.6	26.4	0.863027
Ev2	29.6	27.5	0.930626
Ev3	31.1	24.5	0.788796
MKB1	37.2	25.7	0.690675
MKB2	36.2	24.5	0.676796
MKB3	37.6	26.5	0.704787
FD1	24.4	23.3	0.954527
FD2	25.2	20.3	0.808426
FD3	25.2	18.8	0.748808
GA1	32.9	22.5	0.684932
GA2	33.7	21.0	0.622961
GA3	34.7	23.8	0.686472
WC0.42-1	31.9	21.8	0.682530
WC0.42-2	31.9	22.0	0.688791
WC0.42-3	31.9	23.1	0.723231
WC0.42-4	32.9	23.2	0.706240
WC0.42-5	32.9	23.8	0.724505
WC0.42-6	32.9	24.0	0.730594
WC0.42-7	33.5	24.5	0.730689
WC0.42-8	33.5	26.0	0.776119
WC0.42-9	33.5	26.4	0.787355
WC0.47-1	31.9	22.2	0.694114
WC0.47-2	32.3	22.2	0.687229
WC0.47-3	32.3	22.7	0.704278
WC0.47-4	32.9	22.9	0.695890
WC0.47-5	33.2	23.3	0.700391
WC0.47-6	33.5	23.3	0.694005
WC0.47-7	33.5	23.4	0.696988
WC0.47-8	34.0	24.5	0.718695
WC0.47-8	34.7	24.9	0.719065
		Mean	0.734051
		ST.DV	0.073505

The bell curve of the normal distribution graph of the data for core and cube was drawn using the data from table 5.30.

Table 5.30; Computed Co/Cu and Normal distribution

SITE	CO/CU	NOR DIS
GA2	0.607287	1.306161
GA1	0.671642	3.814903
MK2	0.676796	4.026128
GA3	0.679224	4.122885
WC 0.42-1	0.68253	4.251177
WC 0.47-2	0.687229	4.425556
WC 0.42-2	0.688791	4.481206
MK1	0.690675	4.546563
WC 0.47-6	0.694005	4.657293
WC 0.47-1	0.694114	4.660793
WC 0.47-4	0.69589	4.717012
WC 0.47-7	0.696988	4.750743
WC 0.47-5	0.700391	4.850275
WC 0.47-3	0.704278	4.95394
Mk3	0.704787	4.966702
WC 0.42-4	0.70624	5.002011
WC 0.47-8	0.718695	5.233622
WC 0.47-9	0.719065	5.238455
WC 0.42-3	0.723231	5.284174
WC 0.42-5	0.724505	5.294965
WC 0.42-6	0.730594	5.325497
WC 0.42-7	0.730689	5.325697
FD3	0.748808	5.208192
WC 0.42-8	0.776119	4.508433
WC 0.42-9	0.787355	4.087666
EV3	0.788796	4.03004
FD2	0.808426	3.201163
EV1	0.863027	1.17538
EV2	0.930626	0.162755
FD1	0.954527	0.066565

The bell curve of the normal distribution graph co vs cu presented in the figure 5.21.

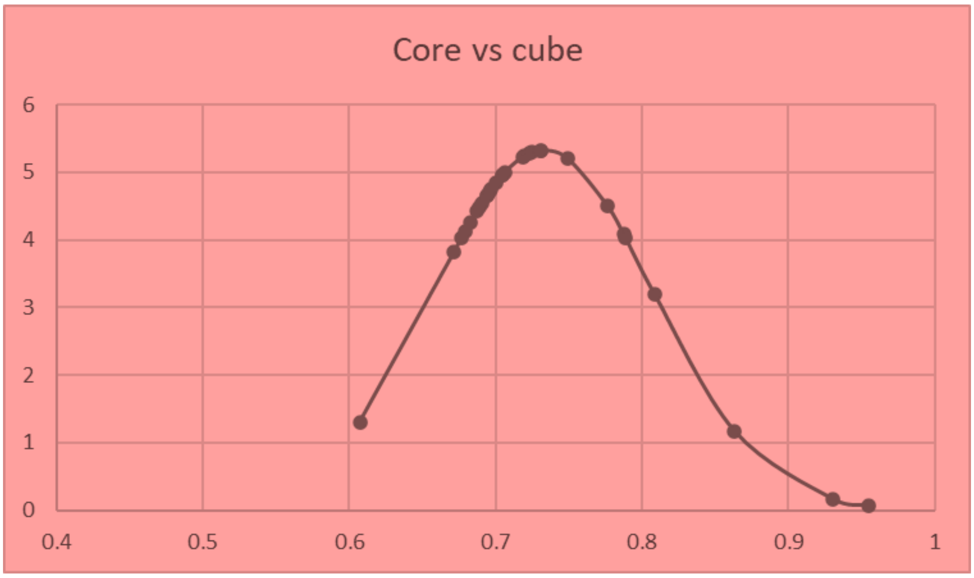


Figure 5.21. Illustration of concrete strength distribution core vs cube

The mean and standard deviation of core to cube ratio was computed. the mean value =0.732844 the standard deviation =0.074878, 88.9% of the data is between the standard deviation was between $\underline{+}3\sigma$.

Table 5.31; Mean and Standard deviation HR/C0

Site	HR	CO	HR/CO
Ev1	34.86	26.4	1.320455
Ev2	33.75	27.5	1.227273
Ev3	36.27	24.5	1.480408
MKB1	34.9	25.7	1.357977
MKB2	35.39	24.5	1.44449
MKB3	34.59	26.5	1.305283
FD1	35.72	23.3	1.533047
FD2	36.5	20.34	1.794494
FD3	36.51	18.84	1.93790
GA1	33.5	22.5	1.488889
GA2	34.58	21	1.646667
GA3	35.04	23.8	1.472269
WC0.42-1	32.38	21.8	1.485321
WC0.42-2	32.38	22	1.471818
WC0.42-3	34.15	23.1	1.478355
WC0.42-4	35.49	23.2	1.529741
WC0.42-5	35.49	23.8	1.491176
WC0.42-6	36.16	24	1.506667
WC0.42-7	36.16	24.5	1.475918
WC0.42-8	36.9	26	1.419231
WC0.42-9	37.27	26.4	1.411742
WC0.47-1	35.98	22.17	1.622914
WC0.47-2	36.49	22.17	1.645918
WC0.47-3	36.66	22.72	1.613556
WC0.47-4	36.66	22.86	1.603675
WC0.47-5	36.66	23.26	1.576096
WC0.47-6	36.68	23.27	1.576278
WC0.47-7	37.51	23.37	1.605049
WC0.47-8	39.2	24.45	1.603272
WC0.47-8	39.83	24.93	1.597673
		Mean	1.524118
		STDV	0.140561

The bell curve of the normal distribution graph of the data for core and cube was drawn using the data from table 5.32.

Table 5.32; Computed Co/Cu and Normal distribution

Site	HR/CO	NOR DIS
EV2	1.2272727	0.3051937
MKB3	1.305283	0.8447213
EV1	1.3204545	0.9934894
MKB1	1.3579767	1.4114604
WC0.42-9	1.4117424	2.0618215
WC0.42-8	1.4192308	2.1484849
MKB2	1.4444898	2.4174448
WC0.42-2	1.4718182	2.6483926
GAF3	1.4722689	2.6515408
WC0.42-7	1.4759184	2.6761552
WC0.42-3	1.478355	2.6917061
EV3	1.4804082	2.7042491
WC0.42-1	1.4853211	2.7321328
GAF1	1.4888889	2.7504552
WC0.42-5	1.4911765	2.7613315
WC0.42-6	1.5066667	2.8164234
WC0.42-4	1.5297414	2.8359448
FD1	1.5330472	2.8324944
WC0.47-5	1.5760963	2.6506457
WC0.47-6	1.5762785	2.6493734
WC0.47-9	1.5976735	2.4750373
WC0.47-8	1.603272	2.4220627
WC0.47-4	1.6036745	2.4181497
WC0.47-7	1.6050492	2.4046865
WC0.47-3	1.6135563	2.3180837
WC0.47-1	1.6229138	2.2170228
WC0.47-2	1.6459179	1.9498313
GAF2	1.6466667	1.9408242
FD2	1.7944936	0.446268
FD3	1.9378981	0.037264

The bell curve of the normal distribution graph HR vs Co presented in the figure 5.22.

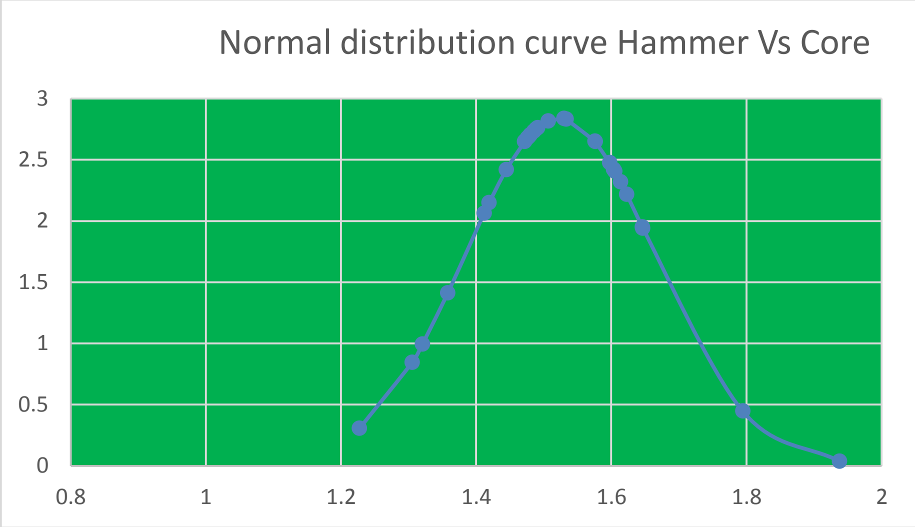


Figure 5.22. Illustration of concrete strength distribution hammer vs core

The mean and standard deviation of core to cube ratio was computed. the mean value = 1.52412 the standard deviation = 0.140561, 92.86% of the data is between the standard deviation was between ±3σ.

5.4.4 Abnormal Results

From time to time, results will occur that are outliers to the bulk of the data. These results could be due to a number of reasons, for example, a testing error or misreporting. If an outlier is included in the main data analysis, it could disproportionately affect the control system and result in actions being taken to adjust the process that are unnecessary (which could increase the risk to the user of the concrete). However, except where it is technically justifiable and documented, each outlier is checked for conformity against the EN 206-1 individual batch criterion [37].

Outlier; is an observation that lies outside the overall pattern of a distribution (moore and McCabe1999)

Outliers occasionally extremely high or extremely low scores that differ from other observations, which can be caused by may be due to in variability in measurement, error in experiment, miss entry. Need to be discarded.

The outliner tests were done two data from Ever grand site and three datas from Fedenga site were identified and removed and the data was tabulated as presented in the table 5.31.

Table 5.33; The table Removing an outliner

Site	co/cu	hr/cu	Hr/Co		co/cu	hr/cu	Hr/co
Ev3	0.788796	1.167739	1.320455				
MKB1	0.690675	0.937919	1.227273	Minimum	0.67164	0.9199	1.2272
MKB2	0.676796	0.977624	1.480408	Q1	0.68973	1.0167	1.4719
MKB3	0.704787	0.919946	1.357977	median	0.70233	1.0973	1.4989
GA1	0.671642	1.019786	1.44449	Q3	0.72323	1.1187	1.6035
GA3	0.679224	1.010672	1.305283	Maximum	0.78735	1.1522	1.9379
WC0.42-1	0.68253	1.013775	1.533047				
WC0.42-2	0.688791	1.013775	1.794494				
WC0.42-3	0.723231	1.069192	1.93790				
WC0.42-4	0.70624	1.080365	1.488889				
WC0.42-5	0.724505	1.080365	1.646667	mean	0.72648	1.0942	1.5241
WC0.42-6	0.730594	1.100761	1.472269	Range	0.11571	0.5311	0.7106
WC0.42-7	0.730689	1.078437	1.485321	IQR	0.03204	0.0885	0.1316
WC0.42-8	0.776119	1.101492	1.471818	IQR*1.5	0.04806	0.1327	0.1974
WC0.42-9	0.787355	1.111541	1.478355	Low Limit	0.64344	0.8993	1.2744
WC0.47-1	0.694114	1.126487	1.529741	Up Limit	0.77161	1.2534	1.8010
WC0.47-2	0.687229	1.131122	1.491176				
WC0.47-3	0.704278	1.136391	1.506667				
WC0.47-4	0.69589	1.115981	1.475918				
WC0.47-5	0.700391	1.103884	1.419231				
WC0.47-6	0.694005	1.093945	1.411742				
WC0.47-7	0.696988	1.118699	1.622914				
WC0.47-8	0.718695	1.152263	1.645918				
WC0.47-9	0.719065	1.1488318	1.613556				

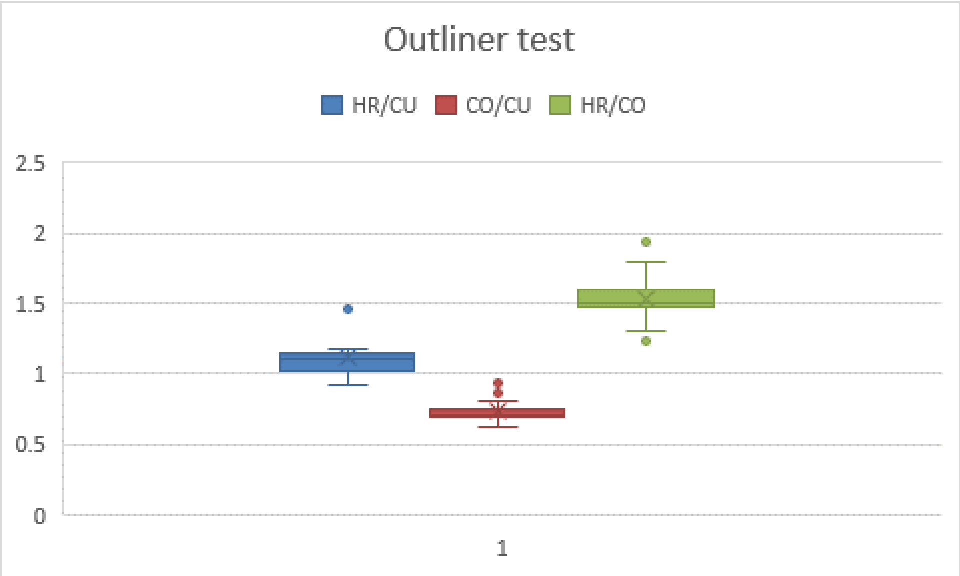


Figure 5.23. Drawing of concrete strength distribution showing outliner data

Concrete from core, rebound hammer and cube compressive strength test is calculated and presented as follows.

Table 5.34. Corrected core, cube and hammer compressive strength (N/mm2)

Cube	Hammer	Core
24.41	32.38	18.84
25.16	32.38	20.34
25.16	33.50	21.00
29.55	33.75	21.80
30.59	34.15	22.00
31.06	34.58	22.17
31.94	34.59	22.17
31.94	34.86	22.50
31.94	34.90	22.72
31.94	35.04	22.86
32.26	35.39	23.10
32.26	35.49	23.20
32.85	35.49	23.26
32.85	35.72	23.27
32.85	35.98	23.30
32.85	36.16	23.37
32.85	36.16	23.80
33.21	36.27	23.80
33.50	36.49	24.00
33.53	36.50	24.45
33.53	36.51	24.50
33.53	36.66	24.50
33.53	36.66	24.50
33.71	36.66	24.93
34.02	36.68	25.70
34.67	36.90	26.00
34.67	37.27	26.40
36.20	37.51	26.40
37.21	39.20	26.50
37.60	39.83	27.50

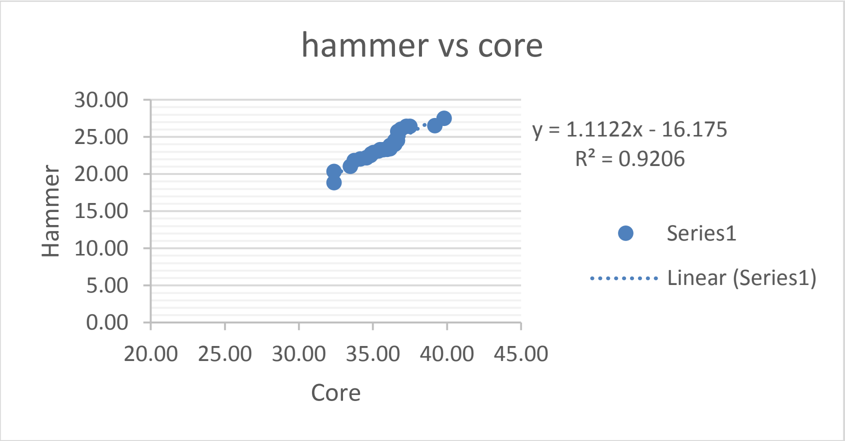


Figure 5.24. correlation between estimated cube strength from core and rebound number of slabs

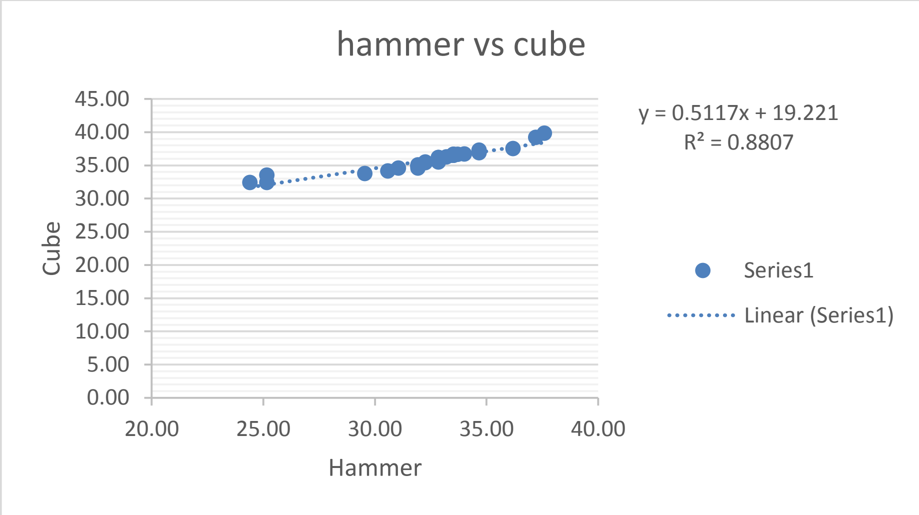


Figure 5.25. correlation between estimated cube strength from rebound number of slabs

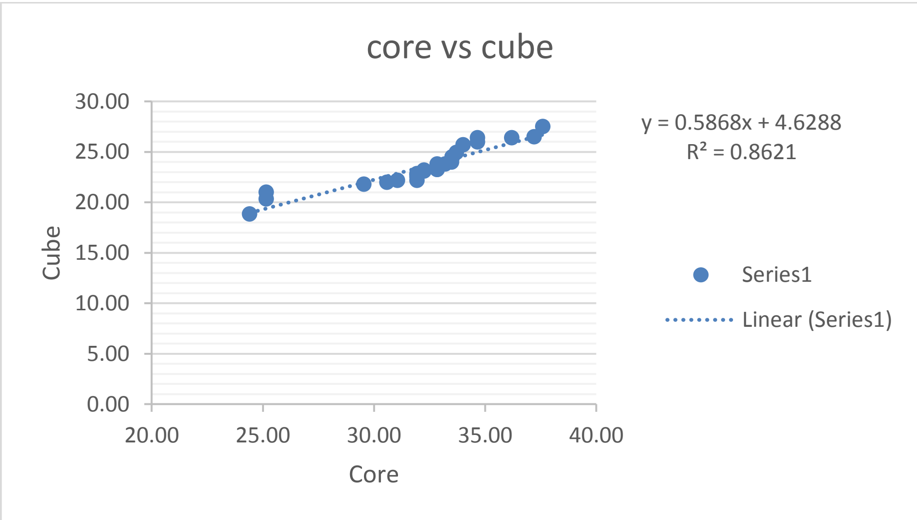


Figure 5.26. correlation between estimated cube strength from and core strength

It is observed from figure 24 to figure 26 the higher value of correlation coefficient is obtained in the range between 0.821 to 0.9206.

5.4.5 Results and Discussion

The rebound hammer compressive strength shows greater compressive strength as compared to cubes and core.

The smaller size cores have smaller cross-sectional area. The compressive strength is load per unit area. Due to smaller size, the strength of smaller diameter cores was greater as compared to the larger size diameter of cores. Similarly, the smaller size cubes give greater strength as compared to larger size cubes.

5.4.6 Relation between Core Compressive Strength and Cube Strength

According to this study it was found from the result; the compressive strength of cores (100mm diameter) is 0.732844 times the compressive strength of cubes (150mm x 150mm x150mm). But on the study done by [8] It was found from the result; the compressive strength of cores (75mm diameter) is 0.693 times the compressive strength of cubes (150mm x 150mm x150mm). The compressive strength of cores (75mm diameter) is 0.528 times the compressive strength of cubes (100mm x 100mm x 100mm).

5.4.7 Relation between Hammer Compressive Strength and Cube Strength

It was found from the result; the compressive strength estimated from rebound hammer is 1.116123 times the compressive strength of cubes (150mm x 150mm x150mm).

5.4.8 Relation between Hammer Compressive Strength and Core Strength

It was found from the result; the compressive strength estimated from rebound hammer is **1.524118** times the compressive strength of core (100mm diameter).

6 CHAPTER FIVE: CONCLUSION, AND RECOMMENDATIONS

6.1 Conclusion

Based on the findings of the research the following conclusion are drawn

1. It was found from the result; the compressive strength of cores is 0.732844 times the compressive strength of cubes and standard deviation of 0.0735.
2. The compressive strength of the compressive strength estimated from rebound hammer is 1.116123 times the compressive strength of cubes and standard deviation of 0.13104.
3. The compressive strength of the compressive strength estimated from rebound hammer is 1.524118 times the compressive strength of cores and standard deviation of 0.1406.
4. The correlation coefficient obtained between hammer strength V/S corrected core; hammer strength V/S actual cube strength and estimated cube strength v/s core strength is R=0.9206, R=8807, R=8621 respectively.
5. The hammer test result of the concrete read directly from the project site is much higher than the core test result obtained from the same project. But the test results obtained from the control mix are close to each other.
6. Using the relationship, it can be conveniently used to predict corrected core strength from rebound number and actual cube strength. This application is limited to materials locally available.
7. If the relationship between rebound index and compressive strength can be found by tests on core samples obtained from the structure or standard specimens made with the same concrete materials and mix proportion, then the accuracy of results and confidence thereon gets greatly increased.
8. Schmidt hammer rebound test can be used to estimate the strength of concrete with calibration curves to reduce the number of cores taken from the structures. As long as this calibration is done properly, there would not be reason to get core test from the structure.
9. High rebound number records were registered with high compressive strength while low rebound number records were registered with in low compressive strength.

6.2 Recommendations

Based on the findings of the research the following recommendations are forwarded

- This research has shown that there is relationship between Schmidt hammer rebound value and core compressive strength for samples obtained from four project sites as well as laboratory control mix. Further study shall be conducted on additional quarry sites to develop correlation between the core compressive test and rebound hammer result. The results from these studies can be compiled to get a general relationship between the test methods.
- During the research work, it is observed that improper workmanship and site management problem may have contributed to data inconsistency. Thus, concrete casting work shall be done in professional manner and properly documented. This shall improve the compressive strength estimate from the correlation developed on this research.
- The Regulatory authority should stick on the use of core test for structural evaluation rather taking Schmidt hammer unless proper correlation is developed with local materials available and should encourage and support the research centers to develop the concept in the area.
- In practice, it is authoritative that the stipulations and guidelines that are stated in the national standards are adhered to for accurate interpretation of results.

6.3 Suggestions for future work

The researcher suggest future works shall be conducted

- On the relationship between Schmidt rebound hammer and other nondestructive tests.
- On the relationship between core test and other nondestructive tests.

7 REFERENCES

[1] Mamlouk, M.S., Zaniewski, J.P. and Hall, P. (2018). *Materials for civil and construction engineers*. Boston: Pearson Education.

[2] American Society for Testing and Materials (2004) ASTM C42 /C 42M–04. *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*. West Conshohocken, PA.

[3] American Society for Testing and Materials (2006) ASTM C805-08. *Standard Test Method for Rebound Number of Hardened Concrete*. West Conshohocken, PA.

[4] Helal, J., Sofi, M., Mendis, P., (2015) Non-Destructive Testing of Concrete: A Review of Methods. *Electronic Journal of Structural Engineering*, 14(1).

[5] Workman, G.L., Moore, P.O., and American Society for Nondestructive Testing (2012) *Nondestructive testing overview*. Columbus, Ohio: American Society for Nondestructive Testing.

[6] American Concrete Institute (1998) ACI 228.2 R-98. *Nondestructive Test Methods for Evaluation of Concrete in Structures*. Farmington Hills, ACI.

[7] Malhotra, V.M. and Carino, N.J. (2004) *CRC handbook on nondestructive testing of concrete*. Boca Raton: Crc Press.

[8] American Society for Testing and Materials (2002) ASTM C 803-02. *Standard Test Method for Penetration Resistance of Hardened Concrete*. West Conshohocken, PA.

[9] American Society for Testing and Materials (2013) ASTM C 900-13a. *Standard Test Method for Pullout Strength of Hardened Concrete*. West Conshohocken, PA.

[10] American Society for Testing and Materials (2009) ASTM D 4541-109e1. Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers. West Conshohocken, PA.

[11] American Society for Testing and Materials (1997) ASTM C 597. Standard Test Method for Pulse Velocity Through Concrete, Testing of Concrete in Structures, 2nd ed., Chapman and Hall, 1989, p. 52. West Conshohocken, PA, United States.

[12] Akashi, T. and Amasaki, S. (1984) Study of the stress waves in the plunger of a rebound hammer at the time of impact. *American Concrete Institute Special Publication*, SP-82, 17.

[13] British Standard European Norm (2012) BS EN 12504-2:2012. *Testing concrete in structures Part 2: Non-destructive Testing - Determination of rebound number*. United Kingdom.

[14] Samia Hannachi1 , and M Nacer Guetteche (2014) Review of the Rebound Hammer Method Estimating Concrete Compressive Strength on Site. International Conference on Architecture and Civil Engineering December 25-26, pp. 118-127, Dubai.

[15] Bui, Q.-B. (2017) Assessing the Rebound Hammer Test for Rammed Earth Material. *Sustainability*, 9(10), 1904.

[16] Mehta, N.K. and Paulo J M Monteiro (2006) *Concrete: microstructure, properties, and materials*. New York, Mcgraw-Hill.

[17] Aydin, F. and Saribiyik, M. (2010) Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings. *Scientific Research and Essays*, 5(13), 1644-1648.

[18] U.S. Department of Transportation Federal Highway Administration (1997) *Guide to Nondestructive Testing of Concrete*. *FHWA-SA-97-105*. Washington, DC.

[19] Pardeep K. Gupta, Niharika Gupta and Amandeep Singh ed., (n.d.). Case study of strength evaluation of structural concrete using rebound hammer test. [online] www.aliexpress.com. Available at: August [Accessed Aug. 21AD].

[20] British Standard (1992) BS 1881-207. *Testing Concrete – Part 207: Recommendations for the assessments of concrete strength by near-to-surface tests*. United Kingdom.

[21] Duna, S. & Omoniyi, T. M. (2014) Correlation between Non-Destructive Testing (NDT) and Destructive Testing (DT) of Compressive Strength of Concrete. *International Journal of Engineering Science Invention*, 3(9), 12-17.

[22] Abebe, D. (2002) *Construction materials laboratory manual*. Faculty of Technology, Addis Ababa University, Ethiopia.

[23] Gashaw, A. (2016) *Schmidt rebound test correlation curve on concrete produced using aggregates in and around Addis Ababa*. MSc Thesis. Addis Ababa Institute of Technology, Ethiopia.

[24] American Concrete Institute (2003) ACI 214.4 R-03. *Guide for Obtaining Cores and Interpreting Compressive Strength Results*. Farmington Hills,

[25] ACI. Standard Practice for Selecting *Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91), Reported by ACI Committee 211, Farmington Hills, 1997.*

[26] Alwash, M. F. A. (2017) Assessment of concrete strength in existing structures using nondestructive tests and cores: analysis of current methodology and recommendations for more reliable assessment. *Mechanics [Physics]*. Université de Bordeaux, 2017. English.

[27] American Concrete Institute (2003) ACI 228.1 R-03. *In-Place Methods to Estimate Concrete Strength*. Farmington Hills, ACI.

[28] American Society for Testing and Materials (2005) ASTM C39/C39M-05. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. West Conshohocken, PA.

[29] American Concrete Institute (2002) ACI 214 R-02. Evaluation of Strength Test Results of Concrete. Farmington Hills, ACI.

[30] Bimas Reskiawan & Hariadi Syam;2019. Exploring the Correlation of Students' ELT Worldwide Volume 6 Number. Indonesia.

[31] ACI Committee E-701, ACI Education Bulletin E1-07, Aggregates for Concrete, August 2007.

[32] American Society for Testing and Materials (ASTM C29). Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate, West Conshohocken, PA.

[33] Richard E. Weyers and Gregory S. Williamson (2005) Testing method to determine long term durability of Wisconsin aggregate resources. Pennsylvania State University.

[34] Kosmatka, Steven H.; Kerkhoff, Beatrix; and Panarese, William C.; Design and Control of Concrete Mixtures,EB001, 14th edition, Portland Cement Association, Skokie, Illinois, USA, 2003.

[35] Denamo Addissie, Handling of Concrete making materials in the Ethiopian construction industry, Addis Ababa University department of civil engineering, school of graduate studies, October 2005

[36] Biruk Negash, The Importance of Standardization of Aggregate in Ethiopian Construction Industry, Addis Ababa University department of civil engineering, school of graduate studies, October 2014.

[37] Ian Gibb and Tom Harrison, Use of control charts in the production of concrete, October 2010.

[38] M. Yaqub, Comparison of Core and Cube Compressive Strength of Hardened Concrete. University of Engineering and Technology Taxila, Pakistan M. Anjum Javed, Concordia University, Canada31stConference on our world in concrete & structures: 16 - 17 august 2006.

[39] Moore,D.S&McCabe G.P,(1999)Introduction to the practice of ststst ics.,Freeman Company

Appendix I

Table A. Rebound values and verification various structural elements Evergrand site

Test No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**9**
Rebound Points on Axis	**1 and 2 b/n B and C**	**3 and 4 b/n C and D**	**3 and 4 b/n C and D**	**4 and 5 b/n B and D**	**5 and 6 b/n A and B**	**6 and 7 b/n A and B**	**7 and 7'' b/n A and B**	**6 and 7 b/n C and B**	**7 and 7' b/n C and D**
1	41	42	42	42	38	40	40	42	42
2	40	40	40	40	40	42	40	44	40
3	39	44	41	42	42	40	42	46	42
4	40	42	44	38	40	41	44	40	42
5	42	39	40	38	41	42	44	42	46
6	40	41	43	39	42	40	42	42	40
7	41	40	42	40	40	42	41	43	42
8	42	42	43	40	44	43	43	46	42
9	44	44	39	42	39	44	44	43	42
10	40	40	40	39	41	40	41	42	40
Average	40.9	41.4	41.4	40.0	40.7	41.4	42.1	43.0	41.8
Expected Minimum	35	35	35	34	35	35	36	37	36
Expected Maximum	47	47	47	46	47	47	48	49	48
Data Minimum	39	39	39	38	38	40	40	40	40
Data Maximum	44	44	44	42	44	44	44	46	46

All tests are conducted on vertical upward direction. All the data are in the range of expected minimum and maximum. Thus, all the data from site are accepted and the average is calculated.

Table B. Cube compressive strength as a function of the average rebound values Evergrand site

Test No	1	2	3	4	5	6	7	8	9
Rebound points Axis	1 and 2 b/n B and C	3 and 4 b/n C and D	3 and 4 b/n C and D	4 and 5 b/n B and D	5 and 6 b/n A and B	6 and 7 b/n A and B	7 and 7" b/n A and B	6 and 7 b/n C and B	7 and 7' b/n C and D
Average Rebound	40.9	41.4	41.4	40.0	40.7	41.4	42.1	43.0	41.8
Correction non-horizontal impact	37.7	37.8	37.8	36.1	37.4	37.8	38.3	39.1	38.5
W_m 14 to 56 Days (MPa)	36.49	36.66	36.66	33.68	35.98	36.66	37.51	38.88	37.85

Table C. Unit weight and drilled cores compressive strength of concrete from Evergrand site

Item No	Sample Code	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	2B1	9.80	12.30	2152.0	198.42	2.28	26.4
2	2B2	9.80	11.80	2018.0	206.69	2.23	27.5
3	2B3	9.80	13.60	2293.0	184.28	2.20	24.5
Average							26.1

Table D. Compressive strength of concrete cube Evergrand site

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	24/03/2020	22/04/2020	28	8124.00	675.20	2.41	30.59
2	24/03/2020	22/04/2020	28	8154.00	652.20	2.42	29.55
3	24/03/2020	22/04/2020	28	8125.00	685.50	2.41	31.06
						Average	30.40

Table E. Rebound values and verification various structural elements MKB site

Test No	1	2	3	4	5	6	7	8	9
Rebound Points Axis	-	-	-	-	-	-	-	-	-
1	40	40	41	42	40	42	41	41	41
2	38	43	39	42	40	40	40	42	44
3	42	42	39	41	38	40	40	40	40
4	37	40	42	44	41	40	40	38	38
5	40	42	44	42	39	40	40	42	42
6	39	40	41	38	39	41	41	42	38
7	42	41	40	42	40	40	40	40	40
8	41	40	41	39	42	42	42	40	40
9	41	39	40	40	40	41	41	42	42
10	42	39	41	38	42	41	41	38	38
Average	40.2	40.6	40.8	40.8	40.1	40.7	40.6	40.5	40.3
Expected Minimum	34	35	35	35	34	35	35	35	34
Expected Maximum	46	47	47	47	46	47	47	47	46
Data Minimum	37	39	39	38	38	40	40	38	38
Data Maximum	42	43	44	44	42	42	42	42	44

All tests are conducted in vertical upward direction. All the data are in the range of expected minimum and maximum. Thus, all the data from site are accepted and the average is calculated.

Table F. Cube compressive strength slab as a function of the average rebound values MKB real estate site

Test No	1	2	3	4	5	6	7	8	9
Rebound points axis	-	-	-	-	-				
Average Rebound	40.2	40.6	40.8	40.8	40.1	40.7	40.6	40.5	40.3
Correction non-horizontal impact	35.7	37.2	36.7	36.7	36.3	36.6	37.3	37.2	36.3
W_m 14 to 56 Days (MPa)	33.0	35.6	34.8	34.8	34.0	34.6	35.8	35.6	34.0

Table G. Unit weight and drilled cores compressive strength of concrete MKB real estate site

Item No	Sample Code	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	1	9.8	18.00	3477.0	197.73	2.46	25.7
2	2	9.8	20.00	3426.0	174.12	2.37	24.5
3	3	9.8	20.00	3250.0	188.39	2.25	26.5

Table H: Compressive strength of concrete cube MKB real estate site

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	23/05/2020	20/06/2020	28	8202.00	821.22	2.43	37.21
2	23/05/2020	20/06/2020	28	8012.00	799.06	2.37	36.20
3	23/05/2020	20/06/2020	28	8010.00	830.50	2.37	37.63
						Average	37.01

Table I: Compressive strength of concrete cube MKB real estate site

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	23/05/2020	07/08/2020	45	8163.00	858.50	2.42	38.89
2	23/05/2020	20/06/2020	45	8303.00	878.90	2.46	39.81
3	23/05/2020	20/06/2020	45	7929.00	876.80	2.35	39.72
						Average	39.47

Table J. Rebound values and verification various structural elements from Fedengua site

Test No	1	2	3	4	5	6	7	8	9
Rebound Points Axis	8-9; AB	9-10; AB (1)	9-10; AB (2)	11-12; AB (2)	9-10 ; CD	10-11; CD (1)	10-11; CD (2)	8-9; DE (1)	8-9; DE (2)
1	34	36	36	36	33	35	36	35	36
2	32	33	35	39	34	37	38	36	35
3	34	36	35	36	37	37	38	38	36
4	36	38	33	34	34	38	33	40	38
5	38	30	37	34	36	35	33	38	35
6	36	33	35	36	36	35	32	34	39
7	38	40	36	35	35	38	32	37	34
8	36	33	36	37	34	37	35	36	34
9	35	37	35	34	38	36	34	40	40
10	35	35	37	36	35	40	34	35	36
Average	35.4	35.1	35.5	35.7	35.2	36.8	34.5	36.9	36.3
Expected Minimum	29	29	30	30	29	31	29	31	30
Expected Maximum	41	41	42	42	41	43	41	43	42
Data Minimum	32	30	33	34	33	35	32	34	34
Data Maximum	38	40	37	39	38	40	38	40	40

All tests are conducted on horizontal direction. All the data are in the range of expected minimum and maximum.

Table K: Cube compressive strength as a function of the average rebound values Fedengua site

Test No	1	2	3	4	5	6	7	8	9
Rebound points Axis	8-9; AB	9-10; AB (1)	9-10; AB (2)	11-12; AB (2)	9-10; CD	10-11; CD (1)	10-11; CD (2)	8-9; DE (1)	8-9; DE (2)
Average Rebound	35.4	35.1	35.5	35.7	35.2	36.8	34.5	36.9	36.3
Correction non-horizontal impact	38.3	38.2	38.4	38.5	38.2	39.6	37.4	39.6	39.3
W_m 14 to 56 Days (MPa)	37.51	37.34	37.68	37.85	37.34	39.78	35.98	39.78	39.24

Table L: Unit Weight and Drilled Cores Compressive Strength of Concrete Fedengua site

Item NO	Sample Code	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	AB and 9/10	9.8	18.00	3000.0	165.46	2.30	23.30
2	AB and 11/12	9.8	14.50	2420.0	144.46	2.31	20.34
3	CD and 8/9	9.8	16.20	2792.0	133.75	2.38	20.84
						Average	21.49

Table M: Compressive Strength of Concrete cube Fedengua site

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	03/06/2020	18/07/2020	45	8021.00	538.89	2.38	24.41
2	03/06/2020	18/07/2020	45	8046.00	845.55	2.38	28.31
3	03/06/2020	18/07/2020	45	7982.00	555.27	2.37	25.16
						Average	25.96

Table N. Rebound values and verification various structural elements GAF site

Test No	1	2	3	4	5	6	7	8	9
Rebound Points Axis	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	35	38	37	35	35	39	39	40	34
2	38	36	35	35	38	36	39	34	34
3	36	36	33	39	39	36	40	36	37
4	36	38	36	34	39	32	38	38	34
5	35	34	38	39	33	38	40	35	35
6	39	36	35	35	38	36	40	36	37
7	33	34	37	35	35	38	38	37	36
8	35	34	38	37	38	34	39	36	34
9	38	36	36	40	35	36	34	38	34
10	35	38	35	40	34	40	38	40	36
Average	36.0	36.0	36	36.9	36.4	36.5	38.5	37.0	35.1
Expected Minimum	30	30	30	31	30	31	33	31	29
Expected Maximum	42	42	42	43	42	43	45	43	41
Data Minimum	33	34	33	34	33	32	34	34	34
Data Maximum	39	38	38	40	39	40	40	40	37

All tests are conducted on horizontal direction. All the data are in the range of expected minimum and maximum. Thus, all the data from site are accepted and the average is calculated.

Table O: Cube compressive strength as a function of the average rebound values GAF site

Test No	1	2	3	4	5	6	7	8	9
Rebound points Axis	C1	C2	C3	C4	C5	C6	C7	C8	C9
Average Rebound	36.0	36.0	36.0	36.9	36.4	36.5	38.5	37.0	35.1
W_m 14 to 56 Days (MPa)	33.5	33.5	33.5	35.1	34.2	34.4	37.9	35.3	32.0

Table P: Unit weight and drilled cores compressive strength of concrete from basement columns GAF site

Item No	Sample Code	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	S1	9.8	20.00	3426.0	160.12	2.37	22.5
2	S2	9.8	20.00	3250.0	149.39	2.25	21.0
3	S3	9.8	20.00	3388.0	168.77	2.34	23.8

Table Q: Compressive strength of concrete cube date collected from GAF site

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	11/05/2020	08/06/2020	28	8201.00	725.00	2.43	32.85
2	11/05/2020	08/06/2020	28	8201.00	744.00	2.43	33.71
3	11/05/2020	08/06/2020	28	8310.00	765.20	2.46	34.67
						Average	33.74

Table R: Compressive strength of concrete cube 1st control mix

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	10/04/2020	08/05/2020	28	7952.00	740.00	2.36	33.53
2	10/04/2020	08/05/2020	28	8012.00	712.00	2.37	32.26
3	10/04/2020	08/05/2020	28	8310.00	712.00	2.46	32.26
						Average	32.68
Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	10/04/2020	25/05/2020	45	8125.00	765.20	2.41	34.67
2	10/04/2020	25/05/2020	45	8205.00	733.00	2.43	33.21
3	10/04/2020	25/05/2020	45	8221.00	751.00	2.44	34.02
						Average	33.97

Table S: Unit weight and drilled cores compressive strength of concrete1st control mix

Item No	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)	Compressive Strength (MPa) after correction
1	9.8	13.8	2300.0	142.81	2.12	18.5	17.2
2	9.8	10.0	1272.0	129.20	1.62	16.8	14.6
3	9.8	13.3	2339.0	153.65	2.71	19.9	18.5
4	9.8	12.5	2384.0	192.73	2.43	25.0	23.3
5	9.8	12.3	2287.0	202.60	2.37	26.3	24.5
6	9.8	15.0	2760.0	183.71	2.35	23.8	22.2
7	9.8	14.0	2370.0	159.38	2.16	20.7	19.2
8	9.8	13.3	2339.0	153.65	2.24	19.9	18.5
9	9.8	12.5	2208.0	213.45	2.25	25.76	24.9

Table W: Rebound values and verification various structural elements of control mix 1

Test No	1	2	3	4	5	6	7	8	9
Rebound Points/Axis	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	34	36	35	36	33	35	36	35	36
2	33	33	35	33	34	37	38	36	35
3	34	36	35	36	36	33	38	37	36
4	36	36	34	34	34	38	35	38	38
5	35	31	33	34	36	35	34	38	36
6	33	33	35	35	36	35	35	34	38
7	36	37	36	35	35	33	35	37	38
8	34	33	36	35	34	35	35	36	36
9	35	37	35	34	35	34	34	38	38
10	35	35	34	36	35	33	34	35	36
Average	34.5	34.7	34.8	34.8	34.8	34.80	35.4	36.4	36.70
Expected Minimum	29	29	29	29	29	29	29	30	31
Expected Maximum	41	41	41	41	41	41	41	42	43
Data Minimum	33	31	33	33	33	33	34	34	35
Data Maximum	36	37	36	36	36	38	38	38	38

All tests are conducted on vertical downward direction. All the data are in the range of expected minimum and maximum.

Table X: Cube compressive strength as a function of the average rebound values of control mix 1

Test No	1	2	3	4	5	6	7	8	9
Average Rebound	34.5	34.7	34.8	34.8	34.8	34.79	35.4	36.40	36.66
Correction non-horizontal impact	37.4	37.7	37.8	37.8	37.8	37.8	38.2	39.2	39.4
Wm 14 to 56 Days (MPa)	35.98	36.49	36.66	36.66	36.66	36.66	37.34	39.06	39.42

Table T: Compressive strength of concrete cubes 2nd control mix design

Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	06/08/2020	13/08/2020	7	7930.00	676.46	2.35	30.65
2	06/08/2020	13/08/2020	7	7930.00	648.47	2.35	29.38
3	06/08/2020	13/08/2020	7	7977.00	660.27	2.36	29.91
						Average	29.98
Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	06/08/2020	03/09/2020	28	7664.00	705.00	2.27	31.94
2	06/08/2020	03/09/2020	28	7880.00	725.00	2.33	32.85
3	06/08/2020	03/09/2020	28	7899.00	740.20	2.34	33.53
						Average	32.77
Sample No	Cast Date	Test Date	Age	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)
1	06/08/2020	18/09/2020	45	7852.00	774.20	2.33	35.08
2	06/08/2020	18/09/2020	45	7921.00	788.20	2.35	35.71
3	06/08/2020	18/09/2020	45	7898.00	765.20	2.34	34.67
						Average	35.15

Table U: Unit weight and drilled cores compressive strength of concrete 2nd control mix

Item No	Diameter (cm)	Height (cm)	Weight (gm)	Load (kN)	Unit Weight (gm/cc)	Compressive Strength (MPa)	Compressive Strength (MPa) after correction
1	9.8	13.50	2318.0	166.80	2.37	23.5	21.8
2	9.8	19.50	3600.0	163.70	2.55	23.1	23.1
3	9.8	19.50	3400.0	164.70	2.41	23.2	23.2
4	9.8	20.00	3608.0	211.70	2.49	29.8	29.8
5	9.8	19.50	3556.0	251.00	2.52	32.5	32.5
6	9.8	19.50	3588.0	211.70	2.54	29.8	29.8
7	9.8	20.00	3646.0	168.77	2.52	23.8	23.8
8	9.8	16.80	2992.0	181.50	2.46	25.6	24.5
9	9.8	20.00	3587.0	187.20	2.48	26.4	26.4

Table W: Rebound values and verification various structural elements of control mix 2

Test No	1	2	3	4	5	6	7	8	9
Rebound Points/Axis	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	36	38	38	38	32	36	36	38	34
2	38	36	34	38	33	36	38	39	36
3	40	40	36	38	34	34	40	40	34
4	38	37	33	36	36	33	36	36	35
5	40	37	36	38	32	34	38	39	37
6	38	40	36	40	32	38	40	40	39
7	38	36	37	36	32	36	37	40	36
8	39	36	36	38	32	38	38	38	40
9	39	36	37	36	32	34	36	34	37
10	36	39	34	40	34	33	35	38	41
Average	38.2	37.5	35.7	37.8	32.9	35.2	37.4	38.2	36.9
Expected Minimum	32	32	30	32	27	29	31	32	31
Expected Maximum	44	44	42	44	39	41	43	44	43
Data Minimum	36	36	33	36	32	33	35	34	34
Data Maximum	40	40	38	40	36	38	40	40	41

All tests are conducted on horizontal direction. All the data are in the range of expected minimum and maximum. Thus, all the data from site are accepted and the average is calculated.

Table X: Cube compressive strength as a function of the average rebound values of control mix 2

Test No	1	2	3	4	5	6	7	8	9
Average Rebound	38.2	37.5	35.7	37.8	32.9	35.2	37.4	38.2	36.9
Wm 14 to 56 Days (MPa)	39.2	38.0	34.6	38.5	29.8	33.7	37.8	39.2	36.9

Table X: Cube compressive strength as a function of the average rebound values of control mix 2

Concrete Mix Design as per ACI 211

1. Required material information

	Coarse Aggregate	Fine Aggregate
SSD	2.81	2.56
NMC	0.5	1.50
W.Ab	1.17	1.98
Dry Rodded (kg/m3)		1680

2. Choice of slump (mm) 25-75

3. Maximum aggregate size - 25 mm

4. Estimation of mixing water and air content

Water 179 kg air content 1%

5. Water/cement ratio 0.47

6. Calculation of cement content, Amount of cement (OPC) 400.00kg

7. Estimation of coarse aggregate content

Amount of coarse aggregate nominal size 25mm 0.68 %

Based on dry rodded bases amount of coarse aggregate 1242.4 kg

Unit mass of fresh concrete kg/m3(UM)=10*Ga(100-A) +CM(1-Ga/Gc) - WM(Ga-1)

UM = 2413.4

8. Estimation of fine aggregate content

Water	**179.00 kg**
Cement	**400.00 kg**
Coarse. aggregate	**1142.4.00 kg**
Total	**1724.40 kg**

The amount of fine aggregate is estimated to be 697.79 kg

Coarse aggregate (wet)	**1155.77kg**
Fine aggregate (wet)	**700.10 kg**

10. Adjustment for moisture in the aggregate

water contributed by Coarse aggregate	**-0.67**
water contributed by Fine aggregate	**0.33**
water added	**184.3704**

Estimated batch masses of cubic meter of concrete

Water	**187.00 kg**
Cement	**400.00 kg**
Coarse aggregate	**1155.78 kg**
Fine aggregate	**700.1 kg**

10.Trial batch

Water	**7.57 kg**
Cement	**16.20 kg**
Coarse aggregate	**48.81 kg**
Fine aggregate	**28.35 kg**

Table: Cube compressive strength as a function of the average rebound values of control mix 1

Concrete Mix Design as per ACI 211

1. **Required material information**

	Coarse Aggregate	Fine Aggregate
SSD	2.82	2.56
NMC	0.5	1.50
W.Ab	2.25	1.98
Dry Rodded (kg/m^3)		1700

2. **Choice of slump (mm)** **25-75**

3. **Maximum aggregate size -** **25 mm**

4. **Estimation of mixing water and air content**

   Water 166 kg air content 1%

5. **Water/cement ratio** **0.42**

6. **Calculation of cement content, Amount of cement (OPC)** **400.00 kg**

7. **Estimation of coarse aggregate content**

Amount of coarse aggregate nominal size 25mm **0.69 %**

Based on dry rodded bases amount of coarse aggregate 1173 kg

Unit mass of fresh concrete kg/m3(UM)=10*Ga(100-A) +CM(1-Ga/Gc) - WM(Ga-1)

UM = 2438.79

8. **Estimation of fine aggregate content**

Water	**168.00 kg**
Cement	**400.00 kg**
Coarse. aggregate	**1173.00 kg**
Total	**1741.00 kg**

The amount of fine aggregate is estimated to be 697.79 kg

Coarse aggregate (wet)	**1186.72 kg**
Fine aggregate (wet)	**711.60 kg**

9. **Adjustment for moisture in the aggregate**

water contributed by Coarse aggregate	**-0.67**
water contributed by Fine aggregate	**-0.48**
water added	**179.21**

Estimated batch masses of cubic meter of concrete

Water	**168.00 kg**
Cement	**400.00 kg**
Coarse aggregate	**1186.7 kg**
Fine aggregate	**711.6 kg**

10. Trial batch

Water	**6.80**	**kg**
Cement	**16.20**	**kg**
Coarse aggregate	**48.06**	**kg**
Fine aggregate	**28.82**	**kg**

Appendix II

Slab surface polishing with grinder prepared for hammer

Rebounder hammer reading on floor slab

Concrete coring from floor slab

concrete cored trimmed and ready for crushing

Cube concrete samples collected from project

Rebound hammer reading from slab

A 1.0m by 1.0m casted slab

Face of trimmed cored concrete

Cut face of trimmed concrete

Coring process from control mix 2

Casted slab and pad prepared for coring

Cored concrete trimming

Cube samples soaked under bath

Extracted core sample

Rebound hammer reading on cube samples

Aggregate sample ready for testing

Appendix III

Certificate of Calibration