



Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies

**PRODUCTION POSSIBILITY OF HYDRAFORM BLOCK AS
WALLING MATERIAL FOR AFFORDABLE HOUSING IN
JIGJIGA**

BY
ABDULKADER BESHIR AHMED

**A Thesis Submitted to the School of Graduate Studies of Addis Ababa
University, Addis Ababa Institute of Technology in partial fulfillment of
the requirements for the Degree of Master of Science in Civil and
Environmental Engineering (Construction Technology and Management)**

April, 2015
Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

**A PRODUCTION POSSIBILITY OF HYDRAFORM BLOCK AS
WALLING MATERIAL FOR AFFORDABLE HOUSING IN JIGJIGA**

BY ABDULKADIR BESHIR AHMED

APPROVED BY THE BOARD OF EXAMINERS

Name	Signature
Prof. -Dr. Ing. - Abebe Dinku _____ ADVISOR	_____
Dr. - Ephraim Senbetta _____ EXAMINER (INTERNAL)	_____
Dr. - Ing. Adil Zekaria _____ EXAMINER (EXTERNAL)	_____
Dr. - Bikila Teklu _____ CHAIRPERSON	_____

DECLARATION

“I declare that this research report entitled *“Potential And Production Possibility Of Hydraform Block As Walling Material for Affordable Housing in Jigjiga”* is original work of my own, has not been presented for a degree of any other university and that all sources of material used for the thesis have been duly acknowledged.”

Signature:

Name of candidate: **Abdulkadir Beshir Ahmed**

Date :

DEDICATION

I dedicate this work for my loving families who supported me all the way.

ACKNOWLEDGEMENTS


First of all, I praise the Almighty Allah, for providing me with the power and grace to carry out this thesis work.

I am very pleased to thank my advisor **Professor Dr.-Ing. Abebe Dinku** for his kind cooperation, constant encouragement and valuable comments at the various stages of this research work. I am also very pleased to thank Ato Abdulkarim Mohammed for his constructive suggestions.

I take this opportunity to express my gratitude to the Addis Ababa University for financing my thesis work. In addition, I am extremely thankful to East-Horizon consultant for providing me to the Hydraform Machine center.

My profound gratitude also goes to the following people for their invaluable material as well as technical support, which was extremely essential to my work.

 Ato Muktar Abib from East-Horizon Consultant, Hydraform Production center.

 W/ro Netsanet form Ethiopian Water Work Design and Supervision Enterprise, Laboratory technician.

Special thanks go to all my family members in general and my mother in particular for her lovely support and encouragement.

Abdulkadir Beshir

Addis Ababa, April, 2015

TABLE OF CONTENTS

Contents

DECLARATION.....	I
DEDICATION.....	II
ACKNOWLEDGEMENTS	III
TABLE OF CONTENTS	IV
ABSTRACT.....	XI
CHAPTER ONE	1
1 INTRODUCTION	1
1.1 Background	1
1.2 Justification for the thesis.....	4
1.3 Objectives of the thesis	5
1.4 Scope of the study	6
1.5 Methodology	6
1.6 Structure of the research.....	8
CHAPTER TWO	9
2 The Literature Reviews on the production of Hydraform blocks.....	9
2.1 Background	9
2.2 Housing Standard and Affordability	9
2.3 Need to improve the building materials	10
2.4 Traditional housing construction in Ethiopia	10
2.5 Traditional Housing construction in Ethiopian Somali region.....	11
2.6 Problems of Traditional Housing Construction Resources	13
2.7 The properties of soil using as building materials	15
2.7.1 Introduction.....	15
2.7.2 Earth as a Sustainable Material.....	15
2.7.3 Cost and Energy efficient.....	15
2.7.4 Efficient Use of Finite Resources	16

2.7.5	Minimizing Pollution	16
2.7.6	Non-Toxic	16
2.8	Other properties of Soils	17
2.8.1	Strength	17
2.8.2	Durability	17
2.8.3	Effect of Weathering and Abrasion	18
2.8.4	Maintenance and Pests	19
2.8.5	Shrinkage	19
2.8.6	Thermal Properties	20
2.8.7	Soil as a Humidity Regulator	20
2.8.8	Soil as a Preservative	20
2.8.9	Fire Resistance	20
2.8.10	Sound Resistance	20
2.8.11	Uses of available and abundant raw materials	21
2.8.12	Aesthetically pleasing	21
2.9	Use of Local Subsoil's	22
2.9.1	Soil Selection for Hydraform Block	22
2.9.2	Soil Characterization	23
2.10	Unified Soil Classification System	24
2.11	Techniques Using Soil as Construction Materials	25
2.11.1	Mud wall	25
2.11.2	Rammed Earth	25
2.11.3	Earth Brick	25
2.11.4	Compressed Earth Block (Hydraform Blocks)	26
2.11.5	Soil Infill in Timber Frame Construction	26
2.12	Hydraform Block	27
2.12.1	Historical background of Hydraform block	27
2.12.2	Hydraform blocks role in development	29
2.13	The future of Hydraform blocks	30
2.14	Social acceptance	31
2.15	Comparison of Hydraform blocks with other building materials	31

2.15.1	Compressive strength of Hydraform Blocks.....	32
2.15.2	Density and Thermal Properties of Hydraform Blocks	33
2.15.3	Moisture contents in Hydraform blocks.....	34
2.15.4	Durability, Maintenance and Appearance of Hydraform blocks	34
2.16	Theoretical Part of Hydraform blocks.....	35
2.16.1	Introduction.....	35
2.17	Properties and Analysis of Soil for Hydraform blocks	35
2.17.1	General properties	35
2.18	Code of practices for Compressed Earth blocks ARS 680:1996 (Houben.H, 1998). 36	
2.18.1	Recommendation soil as building material.....	36
2.19	Soil Classification	39
2.19.1	Soil particles.....	39
2.19.2	Atterberg Limits.....	40
2.20	Suitable Soil for the Hydraform Block Production.....	41
2.21	Soil Selection	41
2.22	Main Constituent Material Used in the Production of Hydraform blocks	42
2.22.1	Cement for Binding the Soil Particles.....	42
2.22.2	Characterization of Soil for Hydraform Block Production.....	42
2.22.3	Quality of Water for Mixing and Curing of Hydraform blocks	43
2.23	Soil Stabilization	43
2.23.1	Mechanical stabilization	44
2.23.2	Physical stabilization	44
2.23.3	Chemical stabilization.....	45
2.23.4	Lime Stabilization:.....	45
2.23.5	Benefits of soil stabilizations	46
CHAPTER THREE	47
3	Properties of materials, mix proportions and test results	47
3.1	Introduction.....	47
3.2	Soil	47

3.3	Cement	50
3.4	Water	52
3.5	Mix proportion	52
3.6	Specimen preparation.....	54
3.7	Curing.....	55
3.8	Tests on blocks	57
3.9	Compressive Strength.....	57
CHAPTER FOUR.....		59
4 LABORATORY TEST RESULTS AND DISCUSSIONS FROM GARAB-ASE AND KARAMARA SOILS JIGJIGA AREA		59
4.1	Introduction.....	59
4.2	Laboratory Tests and Results on Soil Samples	60
4.2.1	Particle size distribution.....	60
4.2.2	Atterburg Limit Criteria (Plasticity)	63
4.2.3	Soil Compaction Test.....	65
4.3	Chemical analysis	66
CHAPTER FIVE		67
5 COMPRESIVE STRENGTH TEST RESULTS AND DISCUSSIONS ON THE PRODUCED HYDRAFORM BLOCKS		67
5.1	Introduction.....	67
5.2	Compressive strength.....	67
5.3	Effects of Cement and Cement Content on The Compressive strength of Hydraform blocks.....	68
5.4	Comparison of compressive strength of Hydraform blocks made of soil from Grab- Ase and Karamara using Dire-Dawa Portland Pozzolana Cement	70
5.5	Effects of compaction pressure on compressive strength of Hydraform blocks .	72
CHAPTER SIX		74
6 ECONOMIC ANALYSIS OF HYDARFORM BLOCKS		74
6.1	Production Cost of Hydraform Blocks	74

6.2	Parameters that influence the production cost of Hydraform blocks	74
6.3	Details for cost calculation.....	75
6.3.1	Variable costs:-	75
6.3.2	Fixed Costs.....	76
6.3.3	Profit Margin.....	76
6.3.4	Comments on how the parameters influence the cost of Hydraform Blocks.	79
6.4	Comparison of Hydraform blocks with hollow concrete blocks per m ² area of wall	82
CHAPTER SEVEN.....		84
7	CONCLUSIONS AND RECOMMENDATIONS	84
7.1	Conclusions	84
7.2	Recommendations	86
REFERENCES.....		87

List of Tables

APPENDICES	91
APPENDIX A	91
Table A1 Natural moisture content Determination for Garab-Ase Soil.....	91
Table A2 Plastic Limit Determination for Garab-Ase soil	91
Table A3 Plastic Limit Determination for Karamara Soil	92
Table A4 Liquid Limit determination for Karamara Soil	92
Fig A1 Flow Curve for moisture content determination for Garab-Ase soil	93
Fig A 2 Flow Curve for moisture content determination for Karamara soil.....	93
Table A5 Hydrometer Analysis/Grain-Size Analysis for Garab-Ase Soil.....	94
Table A6 Hydrometer Analysis/Grain-Size/ For Karamara Soil	96
Table A7 Compaction Test for Garab-Ase Soil	98
Table A8 Compaction Test for Karamara Soil.....	99
Appendix B	100
Table B1 Chemical Composition for Garab-Ase soil at Jigjiga area	100
Appendix C	101
Table C 1 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Contents at age of Seven days	101
Table C 2 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Fourteen days	102
Table C 3 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Twenty Eight days	103
Table C 4 Mean compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven, Fourteen and Twenty Eight days	103

Appendix D	104
Table D 1 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven days	104
Table D 2 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Fourteen days	105
Table D 3 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Twenty Eight days	106
Table D 4 Mean compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven, Fourteen and Twenty Eight days	106
Appendix E	107
Table E 1 Effect of 10MPa Compaction pressure at age of 28 days using Garab-Ase Soil with 6%, 8% and 10% cement contents	107

ABSTRACT

Adequate shelter is a basic human need, while about 75% of the urban populations in developing countries still live in unplanned settlements as they cannot afford the high cost of building materials. The Hydraform block (HFB) has been identified as low-cost building material with its potential and possibility to reverse the housing problem in Somali region especially in Jigjiga area. The main objective of this research was to investigate the potential and production possibility of Hydraform blocks (HFB) in Jigjiga area.

The researcher examines by addressing the traditional housing system in Ethiopian Somali Region in the literature review and the production possibility of Hydraform blocks in Ethiopian Somali Region areas. This can be done by identifying the physical properties of the soil as well as its chemical composition through laboratory experiments, detailed data analysis and determination of soil composition. Its physical, chemical and biological properties, the block properties and behavior are investigated.

According to the African Regional Standard code of practices the Karamara soil composition gives satisfactory result. While Garab-Ase soil does not fulfill the specification of the soil blocks recommended to some extent. This can be solved by clearly sieving the soil by the specified sieve sizes which fulfill the recommended sizes and putting the soil into the specified gradation to produce good quality of Hydraform blocks.

The chemical analysis for the Garab-Ase soil showed that the amount of SiO_2 , CaO , Al_2O_3 and SO_3 were 10%, 33.7%, 0.022% and 0.5% respectively. In the hydration reaction the major components of cement such as dicalcium silicate (C_2S) and tri-calcium silicate (C_3S) form a mono and dicalcium silicate hydrate gels ($\text{C}_3\text{S}_2\text{H}_3$) in the presence of damp soil and removal of free lime from the reaction ($3\text{Ca}(\text{OH})_2$). Then the free lime further react with the clay fraction (pozzolanic reaction) there by removing the silica from the clay minerals and subsequently forms more calcium silicate gel. The calcium silicate gel gradually crystalize in to insoluble interlocking matrix throughout the soil voids binding the soil particles together (Asmamaw.T, Abebe .D, 2008).

The acidic contents of the soil matters the hydration reaction, but the PH (6.5) of the Garab-Ase soil falls in good reactive soil. The Garab-Ase soil has a SO_3 content of 0.5% which reduces the percentage of sulphates to be produced in the reaction that matters overall the strength of the Hydraform block.

The compressive strength results also show that from the blocks produced at the varying cement contents from 6% in increments of 2% up to 10% at constant compaction pressure of 10MPa, all the blocks have 28 day wet compressive strength values well above most of the recommended minimum values for use in nonstructural work as per the literatures.

The thesis result concludes that it is possible to produce Hydraform blocks using Jigjiga soil, so that it fulfills the compressive strength, uses less cement content and adaptable to the environment as walling material for the low-cost housing. The use of hydraulic machine increases more its strength and reduces the air voids through compaction pressure.

The results of this research work have shown that Hydraform block can be used as an alternative wall making material using Jigjiga soil. Significant cost cut can be achieved in low cost housing projects especially town houses. So any concerned body can use this material as an alternative wall making material with proper quality control.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Housing is one of the basic necessities for all human races next to food and clothes. However, despite its importance as a prime production sector with linkages to other productive sectors, housing and related services continue to be accorded low priority in national development.

The housing problems in Ethiopia is a very critical issue that not only its poor condition and level of affordability but also its critical degradation of the environments. Because in the pastoral areas villages as well as most of the towns are using wood for the construction of the houses, which lead to the environmental degradation and for high contribution of global warming. Ethiopia is like in many other developing countries; especially African countries have critical shortage and poor condition of housing which have significant effect on the environment. These problems can be solved through the application of engineering knowledge that the country need to stands for the whole development.

The environmental issue such as global warming which leads to the degradation of ozone layer and melting of ice that affect the human life as whole is simply the contributions of many technological finding (to overcome for the life of human being). The contribution from the deforestation is in the field of engineering which needs a fast solution from engineers.

Wood is used as a building material for house construction in most of African countries. This is mainly due to the bias against non-traditional building construction materials. Many African countries, despite the fact that they are endowed with abundant natural resources that can meet their need for building materials, depend largely on imported building materials and technologies, including green and environmental friendly technologies.

The scarcity of houses, the very low standard of the existing houses, the ever-increasing cost of construction and even the wooden material scarcities for the construction, less quality houses in the pastoral area also demands the need for producing low cost construction materials of acceptable quality. This initiated professionals to seek low cost materials and low cost methods of construction to solve the problems.

In this study Hydraform blocks are considered as an alternative walling material for low

income population in the Ethiopia Somali Regional State especially in Jigjiga area. In this chapter, attempts have been made to sketch out the motivation and objectives for the Study work, and explain more the needs for further studies.

The Ethiopian Somali Regional State is one of the nine regional states that constitute the Federal Democratic Republic of Ethiopia. Geographically, the region occupies a large area and falls in the eastern and Southeastern part of the country with land mass area of about 350,000 km² between 40-110N latitude and 40 -48-0E longitude. It shares borders with Kenya at the South, Somalia South east and East, Djibouti to the north – west and locally Oromia, and Afar Regional States to the west and South –west and North West respectively. The region consists of 9 administrative zones, 67 districts woredas. The zones are Jigjiga (Fafan), Shinile(Siti), Liban, Afder, Gode (Shabbelle), Korahey, Warder (Dollo), Dhagahbour (Jarar) and Fiki (Nogob) (CSA, 2000).

The Region climatically falls in to the arid and semi –arid agro ecological zone with an altitude ranging 500-1800m above the sea level. Its temperature ranges averagely 20-45⁰C with relatively annual average rainfall of about 300-500 mm (CSA, 2000).

According to the 2007 National Census, the Somali Region has a total population of 4,439,147, consisting of 2,468,784 or 55.6% male and 1,970,363 or 44.4% was female gender and population growth rate of 2.6 % as per the census. On the other hand, 86.1 % of the population resides in rural areas while only 13.9 reside in urban areas (Ethiopian Central statistics agency, In the case of Somali region; 2000). Hence, this implies the backbone of the region's economy depends on livestock, as most of the rural dwellers are pastoralists and agro-pastoralists.

Almost throughout the region the climate falls in arid and semi -arid area. Due to this it is a high scarcity of construction materials especially wood, even for a less quality construction for rural areas. This can be initiated me to consider the Hydraform as affordable construction materials with available soil materials to reduces the risk of environmental effects due to use of wooden materials and its modernity for the use of housing in the area.

Hydraform blocks which use soil as the most locally available material in a large amounts. This can be easily made available, affordable and also awareness must be created in the society by the professionals with the help of the government through development of research studies and cooperation of industries that are available in the country. There are

many studies that have been done in this particular case for the contribution to alleviate the housing problems in different countries with affordable and available materials.

The other components of the conventional building system remain largely unchanged. Hydraform system is a largely dry stacked-Interlocking walling system that enables speedier construction of high quality, aesthetic and affordable building. The walls may be left exposed, plastered or finished with cement paint. These construction materials are made using Hydraform Block making machine or with other compressing manual equipment which has an option to make at the site of construction.

Soil requires to be stabilized because the material found in its natural state is not durable for long-term use in buildings. By properly modifying the properties of soil, its long-term performance can be significantly improved (Bureau of Reclamation, 1975; Dunlap, 1975; Herzog & Mitchell, 1963). Soil stabilization processes focus on altering its phase structure, namely the soil-water-air interphase. The general goal is to reduce the volume of interstitial voids, fill empty voids, and improve bonding between the soil grains. In this way better mechanical property, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved (Gooding & Thomas, 1995).

The limitations and the methods to achieve the research objectives are also presented. The final section of the chapter outlines the structure of the thesis and informs the reader certain conventions used throughout the thesis.

1.2 Justification for the thesis

There is an obvious need for adequate and durable housing, especially in the urban and Semi-urban areas of our country specifically in Ethiopian Somali Region. The less income sector of the community is, the most it is affected by the housing shortage, as it is least able to afford construction materials with a qualified techniques. While the land availability is not in question for any society of the country, here the need is to deliver a more durable housing of lower cost with locally available materials.

Building materials accounts for the large portion of the housing construction cost. Production of building components using techniques imported from the developed World is highly costly and energy intensive and using the traditional way is not known considered to this generation as the technology advanced more. By using improved locally available building materials, the construction cost of housing can be reduced significantly (Tomas.T. 1981).

Hydraform blocks are one of those materials which contain soil as the most locally available material in a large amount. This can be easily made available and affordable and also awareness must be created in the society by the professionals with the help of the government through development of research studies and with the cooperation of industries that are available in the country. There are many studies that had been taken place in this particular case for the contribution to alleviate the housing problems in different country especially in our country with affordable and available materials. The other components of the conventional building system remain largely unchanged.

Hydraform system is largely dry stacked-interlocking masonry system that enables speedier construction of high quality, aesthetic and affordable building. The Blocks have an extremely appealing face-brick finish and provide a pre-pointed straight masonry. The walls may be left exposed, plastered or finished with cement paint. These construction materials are made using Hydraform block making machine or with other compressing manual equipment which has an option to make at the site of construction.

Hydraform block in construction of house is very successful in arid areas, but significant stabilization of its soil is required for sufficient performance in humid areas. With controlled production Hydraform block can perform quite enough, but further improvement in material performance will help in meeting the same requirements as other present day building materials.

Hydraform blocks and other soil stabilized materials are building components of growing importance in tropical countries like east African countries and South Africa. Their production possibilities and performances have not been yet studied in different areas of our country, so that its study and introducing to the community is necessary to overcome the poor housing conditions and affordability problems.

A further motivation of this research is that the main raw material soil is the earth which we live on it; on which its availability is not in question. The Hydraform block contains 95% of soil which extracted from the subsoil materials can be the product which is needed. This can be produced by trained labor worker near the construction site or the place where it will be produced for the market thereby using a local resource to help develop technologies that are energy saving, eco-friendly and sustainable. It can be produced on the site which reduces the transportation costs. This technology for the production of such blocks can simplify and made by manually operated mould that reduces the currencies to buy the machines. Currently popular alternatives such as fired bricks and concrete blocks do not have these advantages.

1.3 Objectives of the thesis

The main objective of this thesis was to explore the production possibilities and the durability of Hydraform blocks as an Alternative walling materials using Jigjiga soils, specifically (Garab-Ase and Karamara soils).

The specific objectives are:-

1. The physical and chemical components of the soils around Jigjiga, Garab-Ase and Karamara will be determined using laboratory and properties of binders (Dire-dawa National cement) will be investigated.
2. The specific characteristics of the soil minerals, load resisting ability as an alternative walling materials will be determined.
3. The compressive strength of Hydraform blocks produced from Karamara and Garab-Ase soils will be determined.
4. Economic cost analysis interms of production costs and cost comparison for other wall making materials will be assessed.

1.4 Scope of the study

During the investigation, the study is limited to get soil sample from two sites, because of time and budget constraints. Therefore this research investigation is relied on the soil from Jigjiga at grab-Ase and Karamara areas. These two soils were transported to Addis Ababa and tested for physical composition like: - Grain size using Hydrometer test, Plasticity Index tests, proctor tests, water absorption and shrinkage limit tests and Chemical composition test for only limited to Garab-Ase soil due to Budget constraints. This soil was transported to the East Horizon consultant block production sites and production of the block was conducted at this site using the machine of the East Horizon consultant. The wet compressive strength tests were conducted due to the time and budget constraints.

1.5 Methodology

The research work begins with literature review followed by assessment of the case in Ethiopia and followed the Somali region at Jigjiga. For the development of concepts for the study, the concepts and problems are stated and reviewed. The method to solve the problems requires data that decide on the type and method of data collections and their analysis.

Data collection methods such as experiments, observations, and archival records are examined and used where suitable. Both primary data (collected personally) from the source itself and secondary data from different countries is collected and used for the analysis.

Primary data is collected at controlled environments by testing in laboratories by using electro mechanical equipment's. The collected data is analyzed in qualitative and quantitative methods.

1. The soils from both sites means Karamara and Garab-ase are selected and visualized on the site itself.
2. After on site selection criteria's, both soil samples are taken to the laboratory to investigate its physical and chemical properties.
3. The same soil type will be used for the compressive strength tests by producing a Hydraform blocks using M 7-00-199 pre-installed machine on the site of East-Horizon consultant block production sector.
4. Therefore to produce the Hydraform blocks both soil samples will brought from the site

to the production center and sieved and weighted in to required amount for each types of blocks to be produced.

5. Accordingly the cement amount also weighted and ready for stabilization.
6. The amount of water also calculated and evaluated to be added on the stabilization requirement.
7. Finally soil samples and cement are mixed in dry condition there by sprinkling the required amount of water on it. The mix forms a humid soil –cement mixes ready for the compaction using the Hydraform blocks machine.
8. Every produced Hydraform blocks will be marked on it by the paints or markers which specify their cement percentage, compaction pressure used, the types and percentage of cement and amount of water that has been used.
9. The produced Hydraform blocks should be arranged in one layer and cured for a period of three to five days under shaded area by covering with a plastic sheets that prevents loss of moisture.
10. After five days curing the blocks will be taken to Dire-Dawa Building and Design Share Company to tests for compressive strength of 7th days, 14th days and 28th days.
11. Desk study will be under taken at the East- Horizon consultant block production center to exactly evaluate the economic analysis of Hydraform blocks with the Hollow concrete blocks.
12. Finally discussion will be made based in the test results from physical and chemical compositions, the compressive strength test results for all produced blocks under varying cement contents.

1.6 Structure of the research

The thesis is divided into 7 chapters and each chapter contains a number of sections and further subsections. These three levels are identified by numbers and break down the majority of the text into manageable portions. The first chapter includes the introduction part for the whole thesis. It discusses the background to the research, the methodology part, the objective of the study and lastly the context which the research was based on.

The literature review of Hydraform blocks wall making materials for affordable housing were described in chapter two. The properties of materials, mix proportions and tests are covered in chapter 3. Chapter 4 discusses the laboratory test results of soil and cement. The compressive strength for Hydraform block using Garab-Ase and Karamara soils were discussed in chapter 5. Economic analysis of Hydraform blocks and comparisons with other alternative walling materials were described in chapter 6. Finally chapter 7 summarizes the conclusions made throughout the thesis and makes recommendation for further research to works.

Data's are presented in Graphs, Tables and Appendices formats in this thesis. Graphs are used to show trends and to underline possible relationships. Tables are used to present statistical analysis of the data collected.

These two formats appear in the body of the text close to their point of reference as much as possible, but not necessarily on the same page. The third important data are recorded as appendices for cross- referencing.

CHAPTER TWO

2 The Literature Reviews on the production of Hydraform blocks

2.1 Background

Many research studies have been done on the alternative walling materials. This was dated back to the end of 19th century. These alternative walling materials as compared to the modern hollow concrete block, glass and other recent technologies. As the same as those materials Hydraform, earth bag, adobe bricks, stabilized earth blocks and compressed sand bricks (adobe bricks) are effective on creating and utilizing eco-friendly building systems with low embodied energy. These green systems are cost-effective, labor-intensive, fast to use and equally best for both rural areas and high-density urban areas (Pierre R., and Alex A., 2007).

2.2 Housing Standard and Affordability

Lots of factors affect housing delivery process. e.g legal security and tenure, availability of services, materials and technologies, facilities and infrastructure, affordability, habitability etc.

Focus of paper on two related issues

1. Affordability and availability of low-cost wall making materials and
2. Technologies that used for these materials

The housing standard of the rural and urban area is incompatible with the affordability of the majority residents to build their shelter. However this is beyond the current reality since the price of construction materials is rising rapidly. Data collected by interviewing the Engineers of housing development project office indicates that, the respective price change of the main construction materials that have great role in determining construction cost of a house, before last seven years it was 61%, 37% and 26% for cement, sand and reinforcement bar. So that it is not difficult to understand that the percentage of people who cannot afford to build standard unit could go up (GTZ, (2005).

On the other hand the construction sectors in different regions have been focusing on the previously developed techniques, design, study and construction systems by the national government and the Local Governmental Housing Agency also pushed to implement these developed techniques without consideration of their locality. Due to this many problems may appear to implement this studied systems and different locality have different materials, cultural, environmental, cultural system and needs different study programs.

2.3 Need to improve the building materials

Earthen buildings have been built for thousands of years, and there is a strong tradition of earthen structures on the African Continent. Traditional mud huts were the most common form of building before the advent of modern architecture and planning. Earth buildings shelters are still more than a third of the world's population. Recently there has been a worldwide resurgence of interest in earth building, especially in developing countries where local earth is the most accessible source of building material. However, most soils do not contain the mix of clay, silt and sand required for good brick making. As the technology advanced these original materials were replaced by others, especially made for different purposes as needed. The history of development of house facilities reveals that man has been modeling his environment throughout the ages for more comfortable living standard (Abebe .D, 2007).

Modern stabilization technology has broadened the range of natural soils suitable for making Hydraform blocks (HFBs). Hydraform, Ferro cement and increased their strength and durability through time by studying with different soil types. The soil, raw or stabilized, for Hydraform Blocks was slightly moistened, poured into a steel press (with or without stabilizer) and then compressed either with a manual or motorized.

The soil stabilization techniques allow building higher and thinner walls, which have a better compressive strength and water resistance. The Hydraform block is stabilized with cement and cured for four weeks after manufactured under a shad with plastic sheets and can be dried freely in the air without exposing to rain.

2.4 Traditional housing construction in Ethiopia

In Ethiopia like many countries in the third world, there is a big gap between the income of the majority of the population and the cost of the buildings. Based on Climatic conditions and altitude, traditional house construction in Ethiopia was divided to houses of low lands- Kolla (<1400m); houses of highlands- Woina Dega (1400-2700m) and houses of highlands Dega (2700 above sea level) (Abebe .D, 2007).

2.5 Traditional Housing construction in Ethiopian Somali region

The housing problems in the Somali region is not only its construction costs, availability of construction materials, the defects of construction materials but also its series degradation of the environments by using wooden materials as a main construction constituents. In some areas Somali houses can be constructed by using worn clothes in different colors, which will not with stand rain or sun for even a short time. The following photo show a Somali huts at Awbare area.



Photo .2.1 Somali hut that has been constructed with different color worn clothes (<http://www.Pbase.com/travvelbug/>, accessed on 19/02/2013).

The other traditional building techniques adopted for mud walls in other region cannot be simple to use in Somali region. Because the constituents or binders that mixed in mud walls was not available easily and high shrinkage cracks of the soil type in the region, which weaken the walls. Mud walls can be eroded by rain more in Somali Region than other areas. The practice was to cover mud walls with protective coating consisting of animal dung. This was intended to serve as a wearing surface. The protective surface needed continued maintenance and sometimes renewal almost every year. These entire drawbacks lead most of the people to the misconception that buildings with soil are of inferior quality and should be avoided (Asmamaw .T, 2007).

Sometimes we can see houses that are constructed by the worn out clothes or other materials like that of plastics that are used for the rain on the top of these clothes especially in the rural areas. These types of houses are common in the Somali Region. Almost traditional houses of Somali people are a flexible, moveable and traditionally made homes that have been simply removed and transported to other places and constructed in simple way. But the traditional housing systems of Somali peoples were not the same as with above huts.

It looks beautiful and has withstood different weather for a long time and even better to preserve as heritages. The traditional types of houses will not possible to use at this time anywhere, because its constituent materials will not simple to get it. These types of homes cannot make simple in any cases; this can be made by using grass and spiel of different trees that can be made flexible with different coloring. This type of houses cannot be fire resistance, cannot with stand wind pressure, but the ability to regulate and resist the rain and humidity of the weather conditions was almost good. This types of houses cannot use in the town but it is still used in the rural area of Somali Region.

Photo 2.2 below show a Somali rural woman trying to fix together a roof supports to reconstruct a portable hut after moving to a new location of settlement.



Photo .2.2 a Somali traditional house that has been on starting of construction (<http://shafisaid.wordpress.com/tag/Somali-nomads/>)

The Somali people's uses this type hut to construct their homes in the most rural areas which is its traditional home called (Hori), i.e this hut is easy to break down and reassemble. The constructions of a Somali hut were also very easy when all of its materials are on hand which means the huts are on hand. The women were the one who built the huts and men's are working only on the fabrication of the huts when it takes a lot of time to produce one hut.

These traditional house has been made from the huts and six or more different flexible arched trees which has been made was built in same direction of three and the other three were at the opposite directions were used as frame for the houses. The hut made with a grass and pill of the selected trees are put on the top of the houses to resist from rain and used as a roof. The following picture shows the reconstructing of Somali traditional homes started by putting in place of the arched flexible trees called (hega).



Photo 2.3 -A



Photo 2.3 -B

Photo.2.3 the inside of some traditional hut looks like this (<http://shafisaid.wordpress.com/tag/somali-nomads/>).



Photo 2.3 -C

Photo.2.3.C.the finalized Somali traditional houses (<http://shafisaid.wordpress.com/tag/Somali-nomads/>)

So putting the construction of these houses in mind and the current condition of the trees and grasses what has been used to produce the Somali traditional houses not available at this time in anywhere. We need to solve by using other locally available materials which only not far from the soil which easily available and affordable to these all society by teaching and training their adults to overcome the challenges came to their peoples, traditions and cultures. Therefore these peoples had to be trained and introduced in their locality a soil product which replaced by the former materials to construct a houses.

2.6 Problems of Traditional Housing Construction Resources

The Somali traditional houses were constructed by using specific types of grasses and especial types of wooden materials like long, thin and street which do not have a branch. After cut in its fresh state it was rounded to modify its, so that it fits shape for the purpose it used for. These materials were not found mostly on every site due to the problem of deforestation and overgrazing throughout the region. From this facts the construction materials for traditional houses face shortage of materials.

The Ethiopian highland area uses to construct their houses a wooden material for the skeleton part and reinforced mud as binders. Even this is not applicable in some area of Somali region because the wooden used for the skeleton parts was not available easily.

The traditional housing construction is not flexible in Somali region due to the following reasons:-

1. The wooden materials in most area were not fully functional for housing because the wooden materials were short in length and not easily found.
2. The grass that has been used for the traditional houses was not easily available. Due to these and other problems the society has only the chances to use the soil for the construction of their homes especially in the drought regions.

The following photo shows people using blocks made of silt-sand soils produced manually to construct their houses without stabilizing in the Somali Region, Shinile (Siti) Zone, Adigala woreda.



Photo.2.4 Manual compressed earth block from Silt - Sand Soil to construct houses.

When we analyze these materials for the constructions of houses we can easily say that this house will not functional for even a year. When we analyze that why these peoples uses this materials it is the shortage of other traditionally known construction materials like woods, grasses and the affordability of the peoples to use modern construction materials like cement based materials and the less awareness of the peoples to use the soil that stabilized cements based materials. So a shortage of construction materials, including the traditional one and affordability of modernized one has to be studied in further. The available local materials have to be used for construction of local houses which consider the availability, affordability and modernized (technological) use of these local materials.

2.7 The properties of soil using as building materials

2.7.1 Introduction

This chapter will assess the environmental benefits of using Soil in construction, both locally and nationally. It will also highlight how this could contribute towards reaching established environmental targets and available without any question in any location.

2.7.2 Earth as a Sustainable Material

Materials selection is one of the critical factors in sustainable building design. Soil as a construction material has inherently good environmental characteristics and could make a significant contribution to the improved sustainability of construction (Beckly .L, and Tom .M, 2001).

Using soil as a construction material will make the industry flexible and sustainable because; most of the construction constituents' can be derived from different soil materials which have been modified through application of binding materials in any soil type or conditions.

2.7.3 Cost and Energy efficient

Commonly used construction materials, such as ceramic bricks or those based on cement and gypsum, necessitate mining in a restricted number of geographical locations, significant levels of transportation and high temperature firing (Beckly .L, and Tom .M, 2001).

Energy efficiency can also be realized in the construction process itself. Hydraform blocks are made on-site saving in transportation costs and fuel consumption and require little energy in the block making process (Asmamaw.T, 2007).

In many forms of soil used for construction there is a potential to get the materials on or near the site for every step to use these materials. This can be reduces the energy used in materials transportation, the labor costs and speeder in construction can be result from non - delay of getting the material on the site.

2.7.4 Efficient Use of Finite Resources

In the production of soil materials there are less waste by-products and defective products can be returned to the start of the production cycle and re-used. Other materials are mixed with the soils these are generally the waste products of other industrial or agricultural processes, for example straw or wood chips (Beckly .L, and Tom .M, 2001).

To some extent the wastage of materials was avoided by selecting suitable soil materials in the construction vicinity with good assessment of the areas. Even though the wastage of materials was not completely avoided in some case, but it was not comparable with wooden, block and other construction materials, which have a significant effect on the construction costs.

2.7.5 Minimizing Pollution

When you consider the attributes listed above, the underlying theme is that building with Hydraform blocks is environmental friendly. From the construction of the block itself to the finished product, this is a way to build that benefit everyone (Asmamaw .T, 2007).

Hydraform blocks materials can create minimal pollution. Throughout the entire cycle of production, construction and use, soil building materials require a very low level of processing and create very little polluting waste. At the end of a buildings life, the materials can easily be re-cycled or returned to the ground (Adam .E.A, 2001).

In contrast, many commonly used building materials can cause significant pollution. Such materials require a high level of processing often involving environmental pollution, create waste during construction, cause atmospheric pollution during building use and are an enduring waste material at the end of a buildings life. Even on the human body the hollow block production materials added like cement and other stabilizers can cause some chemical effects, but that of Hydraform causes less than.

2.7.6 Non-Toxic

Block making itself is a non-toxic process; therefore, buildings themselves are clean. Often, man-made ingredients of modern construction set up an environment that is filled with toxic chemicals and gases. Hydraform block is a frequently chosen material for home construction for those people suffering from chemical sensitivity (Cebtex, 2001).

The construction of Hydraform blocks buildings can only include the preparation of the blocks to place on each other with its structural edges, so this cannot include the production of mortar to fill in between each block to strength the building. This can minimize the effects chemicals in cement that cause skin rash due the chemicals and the construction was also a flexible modern if it can be seen in that way.

2.8 Other properties of Soils

2.8.1 Strength

Hydraform block used in building has good strength in compression, but less strength in tension, especially in its damp state (Beckly .L, and Tom .M, 2001).

The technology of the hydraulic press machine has enhanced the fundamentals of using soil materials for construction which is durable, simple for construction and sustainable. Now a day's soil is used as a construction material in most rural and some urban areas which successfully applied without any impact on the environments (Beckly .L, and Tom .M, 2001).

Now days more than half of the world population lives in building constructed with soil materials. Even in Ethiopian Somali Region the people were in need for building that has been constructed using stabilized soil materials.

The strength of the Hydraform blocks can be increased by compaction; hence the density of the blocks can also increase. Now days the technology has been advanced, so that it can be possible to get a manual press machine in every society levels with low costs. This can reduces the relay on the hard currencies of the technology to buy the machines.

2.8.2 Durability

Durability is the ability of the blocks to withstand or resist a heavy weather conditions like rain, winds, rising damp and direct sun lights for a long period of time (Kerali .A.G., 2000).

Hydraform blocks have to be durable and water resistance to some existent to exclude any undesirable influences of the environment such as rain, winds, rising damp or other severe weather conditions of exposure.

When we consider that the oldest structures standing throughout the world today are made of soils, the statement that Hydraform block is durable speaks for itself. Hydraform block have a good resistance for fire and pest. For the purpose of this thesis, Hydraform blocks is defined as a durable material which is produced from a natural or modified soil containing sufficient fines to provide cohesion on densification, to allow unsupported handling or stack curing (Asmamaw .T, 2007).

With these facts I have been no doubt for the durability of Hydraform block in the construction as walling materials for any construction of dwellings.

The lasting qualities of Hydraform block as a construction material are apparent in the traditional buildings that have survived over two centuries of use. If the soil materials can be used with good binding material to the extent it holding the structural stability that have designed for it can last for many years as it can been seen in a century for the heritage structures which in sense amazing as usually in the world.

2.8.3 Effect of Weathering and Abrasion

Soil buildings in cold damp climates need to be protected from prolonged contact with water. This can be done by placing the soil walls on a water-resistant plinth out of reach of groundwater and splashing; by protecting the walls from rain with an overhanging roof; and by protecting exposed surfaces with breathable surface coatings or cladding. Impermeable membranes such as cement floors and renders should be avoided as they can trap water within the walls and encourage rising damp (Becky Little.B. et al, 2001).

As the study cover for the arid and semi-arid area it cannot be expected many rain season that last for half of the year. So the effects of weathering can considered in some times and may avoided using protected coating and cladding materials.

The effect of abrasion can be avoided by using soil that improved by compaction, application of surface coatings, additives and stabilizers are also used to improve wearing qualities. The other effects like deterioration by rains, sun and others weathering condition can be simply avoided by coating with paints of different qualities.

2.8.4 Maintenance and Pests

The durability of soil buildings is due, in part, to the regular maintenance regimes that were integral to traditional practice a change of attitude is necessary if modern soil buildings are to survive similarly well as current construction practice promotes ‘maintenance free’ products such as cement renders and masonry paints. These are incompatible with soil back grounds (Becky Little.B. et al, 2001).

Anxieties that mice and insects might live in earth buildings are largely unfounded in buildings with solid, well-maintained walls. Pests are only likely to have an effect where maintenance of the walls has been neglected and they are suffering from severe erosion. Rodent damage is also associated with un-threshed grain or other foodstuff in the soil mix, which can be easily avoided (Becky Little.B. et al, 2001).

2.8.5 Shrinkage

Soil building materials swell in prolonged contact with water and shrink on drying. The shrinkage and swelling of the soil is also determined by clay type and amount and grading of the soil. Various methods of shrinkage control can be employed depending on the building requirements of the soil. The absorption of humidity from the air does not lead to these physical changes (Becky Little.B. et al, 2001).

The shrinkage crack can be seen in Hydraform blocks building materials than any other materials. But this can be minimized by using proper stabilizers in the production process of Hydraform blocks. While we use the cement as a stabilizer for the production of Hydraform blocks these properties can easily avoided or minimized due to the binding properties of cement. The other thing is that good graded materials for the production of Hydraform blocks can be made easily using materials different size within the allowable range, that can reduces shrinkage cracks with swelling property of the soil.

2.8.6 Thermal Properties

Dense forms of earth construction such as mud wall and rammed earth have high thermal mass and are able to store heat and release it slowly to balance indoor climate. In contrast, light, non-load-bearing forms of earth construction such as earth/fiber panels or blocks are resistant to heat flow and provide good insulation. It is possible, therefore, to alter the thickness and weight of the building material to achieve different thermal effects to satisfy the needs of a particular context (Becky Little.B. et al, 2001).

As far as we are concerning that to satisfy the construction of low-cost building we have been to see more on the sides of affordability and sustainability to satisfy our society.

2.8.7 Soil as a Humidity Regulator

Soil is able to absorb and desorb humidity and thereby balance indoor climate, bathrooms built with soil are particularly effective in this regard as the humidity is absorbed by the walls and slowly released back into the atmosphere, thus reducing condensation and inhibiting fungal growth (Becky Little.B. et al, 2001).

2.8.8 Soil as a Preservative

Timber and natural fibers are conserved in a dry state within soil walls due to soil's low equilibrium moisture content and capillarity. This is apparent in old buildings that contain well-preserved straw and timber within soil walls (Becky Little.B. et al, 2001).

2.8.9 Fire Resistance

Soil block for the building materials have good fire resistance properties unless they contain significant amounts of fiber. According to the German Building Standards, soil, even with a high straw content, is 'not combustible' if the density is higher than 1700kg/m^3 . For light earth/fiber mixes fire resistance can be enhanced with the use of soil or lime renders and plasters (Becky Little.B. et al, 2001).

2.8.10 Sound Resistance

The mechanism of sound balancing or resistance was naturally a gift of soils and it resist the sound more than any other solid materials and in most sounding recording studios can built with a pressed soil blocks to get a good quality of sound recordings (Beckley. L, and Tom .M, 2001).

2.8.11 Uses of available and abundant raw materials

Three ingredients make up the right combination used for soil block: sand, clay and silt materials, which are combined with a small percentage of Portland cement. The only other ingredient needed for wall construction is water, to make the mud slurry that binds the blocks together (Kerali .A.G, 2001).

All the three constituents are available in anywhere with different quality and quantity. To find its quality we won't go kilometers in distances to overcome its types with different properties.

2.8.12 Aesthetically pleasing

Hydraform block buildings can be made to look like any kind of finished structure; however, most people who adopt for this type of construction find they love the look of the block itself and the adobe look of a finish plaster. Exteriors typically are given a weather-resistant skin that can be colored or left natural and interiors plastered with a variety of mixtures or left exposed (Asmamaw .T., 2007).

When the Hydraform blocks are put in different shape and laid in such a way that to make an aesthetical type it has the one come in front of the construction materials. The structure that has been made in a ventilated way is an option that allow for flexibility in design as shown in photo 2.5A and B.



Photo 2.5 - A

Photo 2.5 - B

Photo 2.5 Wall of building constructed with Hydraform block in Jigjiga.

The building also constructed in any shapes, sizes, designs and to fulfill any needs as it can be seen from the fig.2.5 A and B above the aerated or ventilated walls or corridors has been constructed with the help of Hydraform blocks.

2.9 Use of Local Subsoil's

Earth building practice is extremely varied in terms of the soils available, the way they can be used, the functions to which they are applied, and how they perform in different contexts. With a few exceptions, earth suitable for construction is found in the sub-soil layers (Beckley.L.et.al, 2001).

Topsoil and organic soils must not be used because this organic material was not fully stabilized and weaken the bonds between stabilizer and soil particles. Identifying the properties of a soil is essential to perform, at the end, good quality products. Some simple sensitive analysis can be performed. A soil is an earth concrete and a good soil for Hydraform block is more sandy than clayey. The proportion of soil components have been shown in the following diagram.

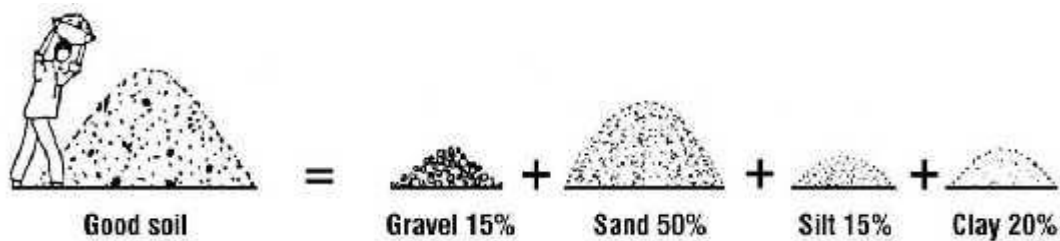


Diagram 2.1 different percent of soil components used for the Hydraform block production (Zami,M.S & Lee, A, 2011).

According to the percentage of these 4 components, a soil with more gravel will be called gravely, another one with more, sand, sandy, others silt or clayey, etc. The aim of the field tests is to identify in which of these four categories the soil is. From the simple classification it will be easy to know what to do with this soil ((Beckley.L.et.al, 2001).

2.9.1 Soil Selection for Hydraform Block





A Hydraform Block is produced from a soil and cement mixture. The soil type is classified as a sandy-loam. Common useable soil examples include Laterite and decomposed granite. The soil should contain more sand than clay and silt. If the clay content is too high, sand will need

to be blended in with the soil (Beckley L.et.al, 2001).

The clay keeps the block together so it is easy to carry the block during block-making. The sandy portion is what bonds with the cement to give the block its ultimate strength. Too little clay will make block handling difficult and too much clay will make the block shrink and crack during curing (Beckley L.et.al, 2001).

2.9.2 Soil Characterization

Soils can be categorized, depending on their composition, by grading the proportions of clay, silt, sand and gravel. The generally accepted decimal grading is:

-  Clay less than 0.002mm
-  Silt between 0.002mm to 0.06mm
-  Sand between 0.06mm to 2.00mm
-  Gravel between 2.00mm to 60.00mm (British Standard Grading).

The grading of a soil is carried out by sieving out the larger grains; silt, sand and gravel; and by sedimentation of the fine clayey materials. Silt, sand and gravel are particles of rock (aggregates) and form the stable body of the earth during construction. Clay acts as the binder for these inert materials and is characterized by its stickiness when damp and by its hardness when dry. Clays are also susceptible to swell and shrinkage (Kerali A.G., 2001).

The type of soil available will usually determine the most appropriate building technique to be used. However, it is possible to modify earth mixes to suit particular circumstances. Balancing the amount of clays and aggregates is essential for most types of earth building.

For example, rammed earth techniques are most suited to soils that have lower proportions of clay (less than 10%) and higher proportions of sand and gravel, while mud wall can be carried out with heavier soils, which contain higher proportions of clay (15%-40%). Moisture content of the soil also influences the nature and workability of the material for any given technique (Kerali .A.G., 2001).

2.10 Unified Soil Classification System

Table .2.1 Unified soil classification system (Holtz, R.D. & Kovacs, W.D.1981)

Major Divisions			Group Symbol	Group Name
Coarse Grained Soils more than 50% retained on No.200(0.075m m) sieve	Gravel >50% of coarse fraction retained on No.4 (4.75mm)	Clean Gravel < 5% smaller than sieve No.200	GW	Well Graded Gravel, Fine To Coarse
		Gravel with >12% fines	GP	Poorly Graded Gravel
			GM	Silty Graded Gravel
		GC	Clayey Gravel	
	Sand: >= 50% of coarse fraction Passes No.4 sieve	Clean sand	SW	Well Graded Sand, Fine to Coarse
			SP	Poorly Graded Sand
		Sand with >12% Fines	SM	Silty Sand
			SC	Clayey Sand
Fine grained soils more than 50% passes No.200 sieve	Silt and Clay Liquid Limit <50	inorganic	ML	Silty
			CL	Clay
		Organic	OL	Organic Silt, Organic Clay
	Silt and Clay Liquid Limit >=50	inorganic	MH	Silt of high Plasticity, Elastic silt
			CH	Clay of high Plasticity, Fat Clay
		Organic	OH	Organic Silt, Organic Clay
Highly Organic Soils		Pt	Peat	

2.11 Techniques Using Soil as Construction Materials

2.11.1 Mud wall

The sub-soil is mixed with straw and water until it reaches a sticky but firm consistency. The mix is then laid in horizontal layers on a stone or brick plinth, trodden down and shaped to form freestanding mass walls (Kerali .A.G., 2001).

Openings are formed as the walls are raised and load-bearing elements such as lintels are inserted directly onto the mud wall. Even when damp, the material has the ability to carry significant loads but account must be taken of minor shrinkage and settlement as the material dries out. Mud wall is a simple, labor intensive form of construction well suited to self-build and community involvement (Kerali .A.G., 2001).

2.11.2 Rammed Earth

Rammed earth, consists of moist, loose sub-soil compacted between shuttering in layers. Coarser soils are sometimes sieved prior to compaction to remove larger aggregate. The shuttering is struck immediately and then moved along or upwards to form the next section of wall. Recent technological advances in rolling and climbing formwork, together with the use of mechanical compaction, have aided this process. The exact composition of the soil and the right amount of water content are critical for the success of this method (Kerali .A.G., 2001).

2.11.3 Earth Brick

This method of construction covers a range of techniques from hand-made mud bricks, known as adobe, to the factory production of unfired clay bricks and the size of individual units varies according to context. Clayey sub soils are mixed with water and/or fiber to a mud-like consistency before being molded or shaped. The bricks are air dried before use and are bedded in earth mortars. Their surfaces may be protected with earth or lime coatings (Kerali .A.G., 2001).

2.11.4 Compressed Earth Block (Hydraform Blocks)

This type of block is produced in a manually operated press, which exerts a large amount of pressure on the soil in the mould. Blocks are thus produced in standard sizes. The soil requirements are similar to those for rammed earth.

The production of Hydraform blocks is not particularly fast (the output per person day is between 150 and 200 blocks) but drying times are speeded up in comparison to wet molded bricks. The blocks can be stacked immediately which eliminates the need for large drying and storage spaces. While some investment in equipment is necessary the amount of mechanization can be tailored to the resources of the particular project. Use of the finished product is ideally suited to skills that are already present in the construction industry and this should facilitate the transfer of the technique to wider applications (Asmamaw .T, 2007).

2.11.5 Soil Infill in Timber Frame Construction

In this technique the timber frame provides the structural support for the roof and the soil is used as a non-structural infill for walls, floors and ceilings. Light earth techniques utilize waste products such as wood chips, straw or hemp chaff as well as porous mineral aggregates in combination with clay rich slurry. The materials are mixed by hand or machine and can be built in situ within shuttering or formed in moulds for use as dry panels or blocks. The density and porosity of the dry mix will determine the thermal properties of the material. These lighter materials are usually clad with timber or protected by wide overhanging eaves due to poor weathering qualities (Asmamaw .T, 2007).

2.12 Hydraform Block

2.12.1 Historical background of Hydraform block

An ancient, traditional method of construction, generally using soil blocks molded by hand, sometimes reinforced using a binder such as straw, and sun-dried can be used. Blocks are laid using mud mortar, and the wall finished with a mud render. Annual maintenance is usually required, by plastering a new-layer of mud, especially in areas of higher rainfall (Rob .F, 2012).

Like adobe, an ancient, traditional method of wall construction, in which a woven lattice of wooden strips (wattle) is daubed by hand with a sticky material, usually made of some combination of wet soil, clay, sand, animal dung and straw. A load-bearing wooden frame is usually constructed first, with wattle-and daub wall panels constructed between the wooden posts (Rob .F., 2012).

In the Andes Mountains in Peru, the shores of Nile in Egypt, in the fertile valley of China and other many mores are examples of places in the world where earth is used as building material. The oldest one can still be seen in Egypt, near Luxor, which was built around 1300 BC: the vaults of Ramasseum, in the "rest" of the Thebes. It has been built with adobes, the sun dried mud bricks (Satprem .M. 2005).

The first machines for compressing soil probably date from the 18th century. In France, Francois Cointeraux, inventor and fervent advocate of "new pise" (rammed earth) designed the "crecise", a device derived from a wine-press. But it was not until the beginning of the 20th century that the first mechanical presses, using heavy lids forced down into moulds, were designed. Some examples of this kind of press were even motor-driven. The fired brick industry went on to use static compression presses in which the earth is compressed between two converging plates. But the turning point in the use of presses and in the way in which Hydraform blocks were used for building and architectural purposes came only with effect from 1952, following the invention of the famous little CINVA-RAM press, designed by engineer Raul Ramirez at the CINVA centre in Bogotá, Columbia. With the 70's and 80's there appeared a new generation of manual, mechanical and motor-driven presses, leading to the emergence today of a genuine market for the production and application of the Hydraform block (Rigassi .V, 1985).



Photo 2.6. The first Manual press, Cinvaram (Satprem .M, 2005)

Instead of being molded by hand in a wooden frame, the blocks are formed by compressing earth, slightly moistened, in a steel press. Compared to the hand-moulded block, the Hydraform block is very regular in size and shape, and much denser as shown in the photo.2.7 below. It has better resistance to compressive strength and to water. Hydraform blocks are blocks of compressed soil that are aesthetically pleasing as well as cost and energy efficient, fire and pest resistant, virtually sound proof, durable and structurally sound. They provide complete architectural freedom and are made from non-toxic readily available natural raw materials (Becky Little.B. et al, 2001).



Photo 2.7A



Photo 2.7B

Photo 2.7 Typical Hydraform blocks produced by the East-Horizon consultant at Jigjiga.

Since the very earliest of times, earth has been used as a major building material and today we can find evidence of this fact over vast areas of our planet. The developments of industrial building materials such as concrete and steel have to a large extent suppressed the use of unfired earth. Today, however, there is a re-awakening of the use of this traditional building material, not only in developing countries, but also in the developed Western world. Earth, the oldest of building materials on our planet, is still today the most commonly used (Becky Little.B. et al, 2001). There is now a worldwide tendency towards using soil as a building material to achieve economy in the final cost of a building (Spon. E.&F.N. 1985).

The technology behind the production of Hydraform blocks is based on a mechanical process. The use of this material in our context cannot be simple in everywhere but developing other techniques manual presses to more make it a simple to use and affordable for local community is easy. But the manual made Hydraform blocks where not be comparable to the mechanically made Hydraform blocks. The machine based made Hydraform blocks ensures a high quality product regular in dimension and of durability consistent with high quality traditional brick building. Earth, as opposed to pure clay, is the raw material used in the production of Hydraform blocks.

2.12.2 Hydraform blocks role in development

Since its emergence in the 50's, Hydraform block (HFB) production technology and its application in building have continued to progress and to prove its scientific as well as its technical worth (Rigassi .V. 1985).

The Hydraform block making technology has become competent due to sophisticated knowledge of Research Institutes, Industrialists, Entrepreneurs and Builders. Hydraform building production meets scientific requirements for the quality control, from selection, extraction and identification of soil used for the production. The quality assessment of finished products has been standardized using test procedures on the materials. The standardized product has leads to the developments of quality materials and contributes the principles and design controls using standards. The Hydraform block production centers has create employment opportunities in its every stages of productions and the use of this blocks for social housing programs, for educational, cultural or medical facilities, and for administrative buildings, helps to develop societies' economies and well-being (Rigassi .V. 1985).

Hydraform block production forms part of development strategies for the public and the private sector, which underline the need for training and new enterprise, and thus contributes to economic and social development (Rigassi .V. 1985).

Housing programs are often integrated into a strategy of development. One must consider not only the direct benefits of the program (number of improved dwellings) but also its effects on the local economy and environmental impact regulation. An organization can produce Hydraform block on the site itself or encourage local entrepreneurship by subcontracting teams. In any case, vocational training provided during a program is a benefit for the community housing programs can provide an opportunity to set up a local industry if appropriate materials such as Hydraform block as preferred to materials based on imported components.

The Hydraform blocks production and using as building materials has its contributions to the society. Especially in the Somali region the housing problems as we have been referring to the standard, susceptibility to different weather and Affordability problem in the society can be considered that Hydraform walling materials has good contribution to the development of these peoples.

2.13 The future of Hydraform blocks

Earth as a building material undoubtedly presents certain outstanding short comings; however, it also has important assets, which compensate any disadvantages, which could be corrected. The shortcomings, principally low mechanical characteristics, unsatisfactory resistance to weathering and danger to volume changes especially in the case of clayey soils, can be corrected by combining chemical and mechanical action. Excellent stabilization results have been obtained on very different materials with various stabilizers (Spon .E. & F.N. 1985). The research centers in India Auroville, CRATerre in France, El Haji Yousif Model School and the Hydraform Company in South Africa have made great progress on Hydraform block. The scientific research, experimentation, and architectural achievements which form the basis of a wide range of technical documents and academic and professional courses can be introduce an effort in development of Hydraform blocks (Rigassi .V. 1985).

Even from mechanical bases the use of Hydraform blocks can be led to the development of manual press that can guarantee the continuity of soil based housing construction materials for the poor community in the future.

2.14 Social acceptance

Another key to success in the Hydraform block building is the social acceptance of the dwellings by their future inhabitants. They generally ask for a ‘modern’ look, i.e. a house made of sand cement blocks. But at the same time, the traditional way of life must be preserved and attention has to be paid to the local climatic conditions, especially in hot countries. The Hydraform block looks modern. Its flexible size and shape allows it to be used to achieve many different types of masonry and so to build houses of any style. In hot countries, and even more in those with a wide thermal variation, a Hydraform block walls creates a truly comfortable living environment compared to sand, cement based materials. Occasionally, a social reluctance to use the Hydraform blocks can be encountered when the Hydraform block has been too strongly associated with low cost or “cheap” building. Social acceptance depends a great deal on how it is presented to the population. Organizations have an active part to play in this respect, as well as political decision makers. The involvement of architects and engineers in this process is also necessary (Rigassi .V. 1985).

2.15 Comparison of Hydraform blocks with other building materials

Hydraform blocks represent a considerable improvement over traditional earth building techniques. When guaranteed by quality control, Hydraform block products can very easily bear comparison with other materials such as the sand-cement block or the fired brick as shown in Table 2.1.

Table 2.1 Properties of Hydraform blocks versus other walling materials (Adam .E.A. 2001).

Property Materials	Hydraform Blocks	Fired Clay Bricks	Calcium Silicate Bricks	Dense concrete Blocks	Aerated concrete Blocks	Lightweight Concrete blocks
Wet Compressive Strength(MPa)	1-40	5-60	10-55	7-50	2-6	2-20
Moisture Content in (%)	0.02-0.2	0.00-0.02	0.01-0.035	0.02-0.5	0.05-0.10	0.04-0.08
Density in (Kg/m ³)	1700-2200	1400-2400	1600-2100	1700-2200	400-950	600-1600
Thermal Conductivity (W/m ⁰ C)	0.81-1.04	0.70-1.30	0.10-1.60	1.00-1.70	0.10-0.20	0.15-0.70
Durability against Rain	Good to Very Poor	Excellent to very poor	Good to Moderate	Good to Poor	Good to moderate	Good to Poor

2.15.1 Compressive strength of Hydraform Blocks

The compressive strength of Hydraform blocks (i.e. the amount of pressure they can resist without collapsing) depends upon the soil type, type and amount of stabilizer, and the compaction pressure and curing conditions used for the block making process. Maximum strengths are obtained by proper mixing of suitable materials and proper compacting and curing. Several different minimum values of 28-day wet compressive strength, all above 1.0MPa are proposed; some of the recommendations by different authors for the minimum compressive strength of Hydraform blocks include 1MPa, 1.4MPa, from 1.4 to 2MPa and 2MPa (.Kerali .A.G. 2000).

In practice, typical wet compressive strengths for Hydraform building blocks may be less than 4MPa. It is strength suitable for many building purposes. It also competes favorably, for example, with the minimum British Standard requirements of 2.8MPa for precast concrete masonry units and load bearing fired clay blocks, and of 5.2MPa for bricks (Adam .E.A. 2001).

The loads on the building or the wall of the building with stands were small as a compressive strength of 1MPa up to 4MPa was sufficient for the building and allowed for many building regulation in the worlds.

2.15.2 Density and Thermal Properties of Hydraform Blocks

Normally Hydraform blocks are denser than a number of concrete masonry products such as aerated and lightweight concrete blocks. While having densities within the range of various types of bricks e.g. clay, calcium silicate and concrete bricks (see Table 2.1). The high density of Hydraform blocks may be considered as a disadvantage due to its dead weight on the structure and when the blocks have to be transported over long distances; however, it is of little consequence when they are produced at or near the construction site. Low density Hydraform blocks have an advantage over high density ones of acting as better thermal insulators. This is particularly advantageous in hot dry climates where extreme temperatures can be moderated inside buildings made of Hydraform blocks (Adam .E.A. 2001).

The density of Hydraform blocks can be reduced by restructuring or molding in other way that it has been a hollow types and has used with different stabilizers to increase its compressive strength. Producing the Hydraform block of hollow type not only decrease the density of the block but also useful for the sound resistance in the building.

Building materials are rated for thermal performance based on measurements known as R and U -values. The R-value indicates the ability of a wall to insulate efficiently. Insulation is nothing more than the resistance of a material to the transference of heat. It makes sense that the higher the R-value, or resistance, the better insulator the material is (asmamaw.T, 2007).

The building made of Hydraform blocks has a low thermal conductivity and advantageous in hot dry climates where extreme temperatures can be moderated inside buildings.

2.15.3 Moisture contents in Hydraform blocks

Building materials with high porosity when used for wall construction may expand slightly in wet and dry conditions. Such movements may result in cracking and other defects to the building. Expansion of Hydraform blocks may vary according to the properties of the soil; some soils expand or shrink more than others.

The addition of a stabilizer will reduce this expansion. In general, however, there may be greater movement in structures built with Hydraform blocks than those using alternative construction materials. Proper block manufacture and construction methods, however, will reduce such movement.

Moisture movement is denoted in terms of linear percentage. It is worth mentioning that moisture movement becomes especially important when two materials with different movement properties are used in a building. Differential movement results in stress, which may break the bond between the materials, or cause other damage. For example, cement renderings often peel off earth walls or Hydraform blocks because of their different expansion properties.

2.15.4 Durability, Maintenance and Appearance of Hydraform blocks

Blocks of the same size, which made of sufficiently, good quality and shape with a high quality finish, can be used for fair-faced walling. Their appearance depends upon soil colors, particle size, and degree of compaction used. With high quality blocks external or even internal rendering should not be necessary. A white wash finish applied directly to the blocks as a render coat could be used to reduce solar gain (Asmamaw .T, 2007).

It should be noted that Hydraform blocks, in common with other types of blocks and bricks, would need adequate steel reinforcement if used in areas where susceptible to earthquakes or cyclones etc. Termites, bacteria, fungi and fire do not present a particular hazard for Hydraform blocks. However, organic material in the soil may weaken the strength of the block.

2.16 Theoretical Part of Hydraform blocks

2.16.1 Introduction

Hydraform blocks are regular in size and shape and can be used for any types of buildings. It can be produced in large or small scale workshops and uses also different techniques to use soil in any locality by changing the types and quantities of stabilizers. The early development of soil based construction techniques has considered the strength of the materials and the availability as well. But the design of this research considers the affordability, soil characterization and stabilization in local areas.

The vocational and training center must develop to create awareness that every locality can use its vicinity soils to overcome the hard currency and build its houses in its local materials. The government in collaboration with the Institutions has to develop the practices codes and put in to practices the outcome of researches in locality.

2.17 Properties and Analysis of Soil for Hydraform blocks

2.17.1 General properties

Soil is the result of the transformation of the underlying rock under the influence of physical, chemical and biological processes related to biological and climatic conditions (Satprem .M, 2006). It is found deposited on the surface of the earth and may consists of many different types. The variation in the soils present at the surface can be attributed to a series of natural effects working on the area over time. On the very surface of the soil one typically finds material with a large amount of organic compounds. This is unsuitable for block manufacture and can usually be distinguished by a musty smell especially on heating (David .E. 2002).

Material underneath this organic layer is much better as it usually contains a cross section of particle sizes and includes a proportion of small soil particles called “fines”. These are usually defined as particles passing a 75µm mesh and consist of silt and clay. Clay is necessary in block production because it aids the workability of the mixture, increasing levels of consolidation and improving green strength. Larger particles “sands” found in soil can generally be assessed as minerals that are silica’s, silicates or limestones. Soil has a proportion of water and air that fill the gaps between adjoining particles in the soil. This gives natural soil a nonhomogeneous and porous nature (Craig .R.F.et al 2002).

Chemical properties are also sometimes of interest particularly when a chemical additive is used. These chemical properties include the composition, mineral content, metallic oxides, PH levels and sulphates in the soils (Craig .R.F.et al 2002).

Soil characteristics and climatic conditions of an area must be evaluated before manufacturing soil building blocks. In a dry climate, for example, needs different soil blocks from those used in temperate, rainy or tropical areas. All soils are not suitable for every building need (Adam .E.A. 2001).

With so many different characteristics that one could discover about a sample of soil, it would be foolhardy to try and discover them all in every situation that soil is to be used for making Hydraform block. Only a small number of characteristics are relevant to the scientist testing the soil. The chemical composition of the soil is of little importance once the absence of unstable compounds and organic matter has been established (Adam .E.A. 2001).

From the literature it is unclear how much a change of say $\pm 5\%$ to the clay content will have on the overall performance of the Hydraform block. Controlling the moisture content in the mixture is also important, but generally the production manuals use a simple drop test to determine an acceptable range. The accuracy of this test is fairly low and what effect the possible variation in the moisture has on the finished product is not clear (Adam .E.A. 2001).

2.18 Code of practices for Compressed Earth blocks ARS 680:1996 (Houben.H, 1998).

The state of art related to the manufacture of Hydraform blocks was described in the code of practice ARS 680:1996. The rule present in this code of practice was that it is applicable in all production enterprise except area where earthquakes, heavy floods and cyclones were attack which requires the application of appropriate techniques to be managed

2.18.1 Recommendation soil as building material

A selection for suitable types of soil can take place in the field using the following parameters:

2.18.1.1 Granular Composition of soils

The granular composition of soil should preferably fall within the limits of the shaded area of on the diagram of texture as which mostly gives satisfactory results. Its approximate limits that recommended were in the shaded area.

If the types of the soil granular composition falls outside the shaded area it may still give acceptable results, but it is recommended that it was subjected to other a series of tests that enables its suitability.

Figure 1 — Diagram of texture

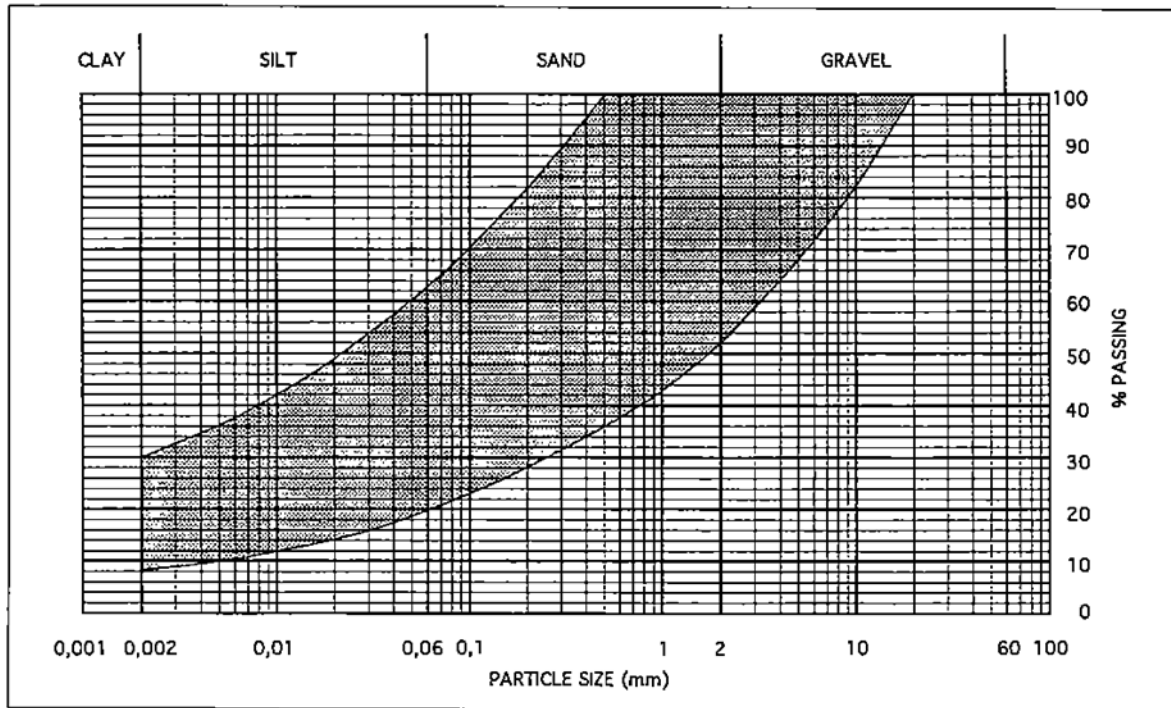


Figure 2.2 Diagram of texture for soils suitable for the production of Hydraform blocks (Houben.H, 1998).

2.18.1.2 Plasticity

The plasticity of soils should preferably fall within the limits of the shaded area of the following diagram of plasticity. Approximately the soil plasticity which recommended should fall in the shaded area gives the satisfactory results. It does not mean that the soils which fall outside the shaded area was not suitable so were recommended to assess its suitability through a series of tests that shows its suitability.

Figure 2 — Diagram of plasticity

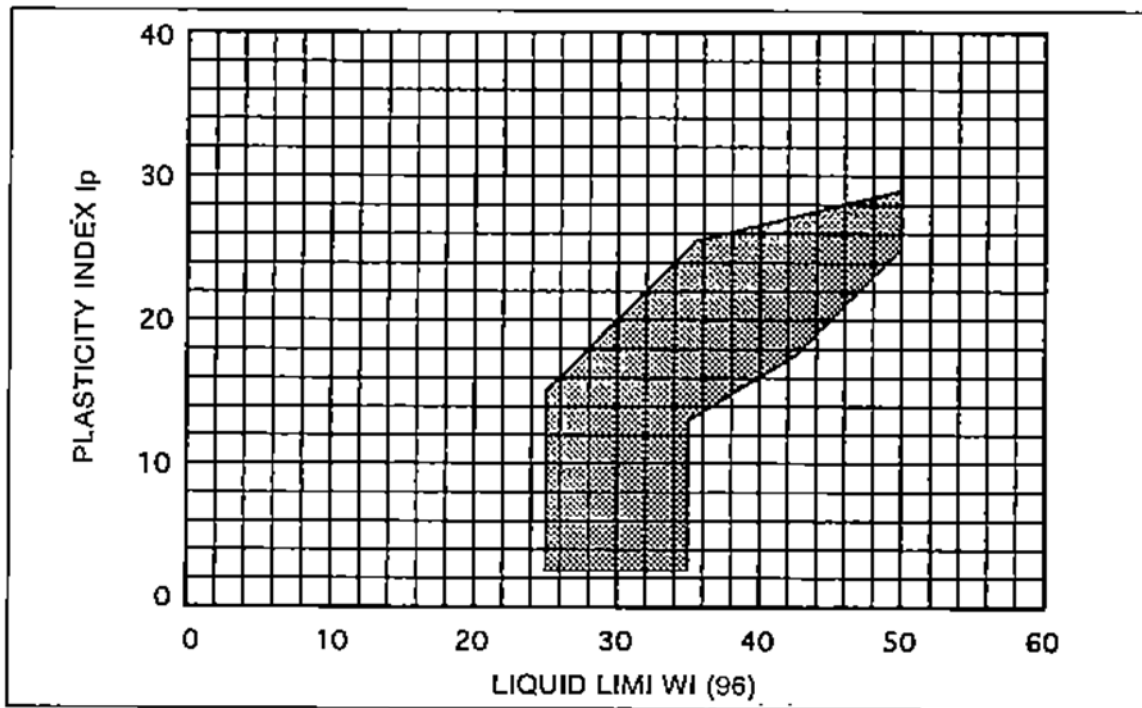


Figure 2.3 Diagram of plasticity for soils suitable for Hydraform blocks (Houben.H, 1998).

Using a suitable soil for Hydraform block production will result in:-

- ❖ Strong blocks, namely those that after curing possess high wet strength and erosion resistance.
- ❖ Hand able blocks that immediately upon demoulding can be transferred to a using area without a high breakage rate.
- ❖ Block that will not seriously distort or crack during curing.
- ❖ Blocks, which will not expand and contract excessively in the building if subjected to wetting and drying cycles.

Specifically disqualified soils are:

- Those containing high excessive organic impurity.
- Those, which are highly expansive.
- Those containing excessive soluble salts e.g. gypsum and chalk.

2.19 Soil Classification

The classification of a soil is the first requirement needed to identify it. Knowledge of the soil type and properties can facilitate the optimization of its use in Hydraform block production. According to the sources of literatures soil classification can be performed on the soil particles less than 60mm in sizes (Dunlap. 1975). Soils are classified based on the following properties:

Particle size distribution, plasticity, compatibility, cohesion, and organic matter content (Vickers. 1983). There are two known soil classification systems that have been used by the engineers based on the particles distributions and Atterberg limits. These two classification systems are:

- American Association of State Highway and Transportation Officials (AASHTO) system.
- Unified Soil Classification System (Preferred by Geotechnical Engineers).

2.19.1 Soil particles

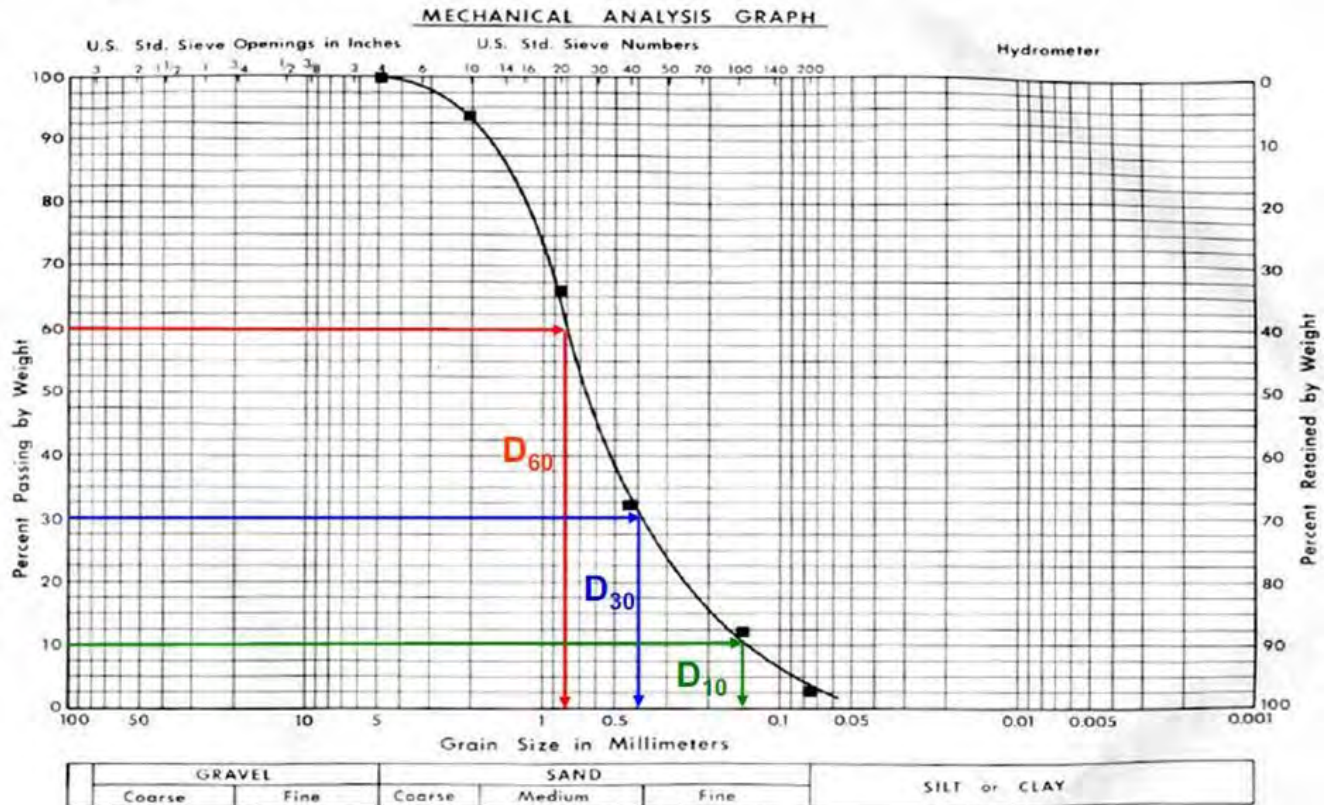
The description of grain size distribution of soil particles according to their texture (particle size, shape, and gradation). Major textural classes According to the Unified Soil Classification system, the following size ranges are given (BS 1377: Part 2, 1990).

Name	Subdivision	Max.Size diameter in (mm)	Min.Size diameter in (mm)
Gravel	Course	60	20
	Medium	20	6
	Fine	6	2
Sand	Course	2	0.6
	Medium	0.6	0.2
	Fine	0.2	0.06
Silt	Course	0.06	0.02
	Medium	0.02	0.006
	Fine	0.006	0.002
Clay			<0.002

Table-2.2. shows soil classification according to particle size distribution (BS 1377 Part 2 1990; ILO, 1987).

Furthermore, gravel and sand can be roughly classified as coarse textured soils, while silt and clay can be classified as fine textures soils.

The graph shown below is mechanical grain analysis of soil according the (AASHTO).



Graph 2.1. Grain size distribution curves for (AASHTO) soil classification (Das, B.M, 1998).

2.19.2 Atterberg Limits

Atterberg limits are the limits of water content used to define soil behavior. The consistency of soils according to atterberge limits gives the following diagram.

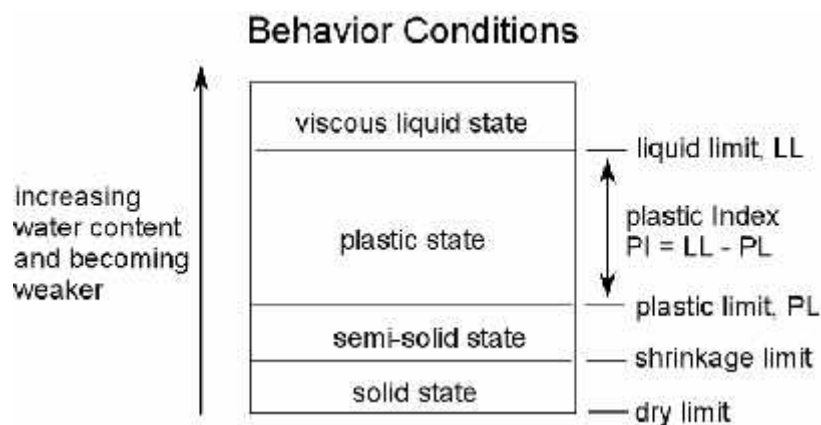



Diagram 2.4 the atterberg limits (Das, Ch.3)


2.20 Suitable Soil for the Hydraform Block Production


The soil is suitable for the production Hydraform blocks where fulfill the following criteria: - Well graded with a continuous or dense gradation. It should be neither gap-graded nor uniformly graded. The size of the maximum soil particle should be less than 6 mm in diameter (ILO, 1987, ILO/UNIDO. (1984).


Particle sizes greater than 6mm in size may easily get dislodged from the block fabric due to poor bonding. The gravel and sandy fraction should be densely packed not only to provide the skeletal structure of the block, but also to take up applied loads. The silt and clay fraction in a soil should be adequate enough to provide sufficient cohesion. (Kerali, A.G., 2001).

2.21 Soil Selection

 **Soil.** This consists principally of sand, clay and silt. Hydraform blocks cannot be moulded from pure sand (which will not compress) or from soil with a very high (>35%) clay content. High-clay soils require the addition of sand, and a higher cement content, to prevent the blocks from cracking. The soil must be free of organic material and must not contain harmful quantities of salts; it should contain just sufficient clay to bind the blocks so that they may be handled immediately after manufacture without disintegrating.

 **Topsoil.** Topsoil is not used because it invariably contains organic matter (roots, leaves and grass) which inhibits the setting of cement. When clearing the area to be dug, barrow the topsoil away from the digging site.

 **Clay.** This is 'plastic' it expands and contracts giving the soil the necessary 'plasticity' for stabilized soil block making and providing cohesion. Excessive clay content (>35%) causes surface cracking when it 'relaxes' after high compression. Most often, these cracks are less than 1 mm deep, but blocks made from soils with very high clay contents can crack right through.

 **Soil Plasticity.** This is a complex subject which is described briefly for interest. The 'plasticity' or 'workability' of a soil is its compressibility, stability and cohesiveness (the property of deforming under load and retaining the deformation after the load is removed). Plasticity is expressed by the 'plasticity index'.

2.22 Main Constituent Material Used in the Production of Hydraform blocks

The three main constituent materials used in the production of Hydraform blocks are:

- ✚ Cement (for binding the soil particles)
- ✚ Soil (for the skeletal structure of the block)
- ✚ Water (for the hydration of cement and lubrication of soil particles)

2.22.1 Cement for Binding the Soil Particles

Cement plays such a critical role in the performance of Hydraform blocks. Without its inclusion, Hydraform blocks would be no different from common sun dried mud blocks and would simply disintegrate on contact with water, or when subjected to moderate impact loads. Compared with concrete products where 12-18% by weight of cement is used, only about half of that amount (5-8% by weight), is required in stabilized blocks (Guillud .H.et al. 1994). Though not commonly recommended, amounts as low as 3% and as high as 10%, have been used depending on the nature of the soil requiring stabilization (Rigassi .V. 1995). The function of OPC is to strongly bind the constituent materials (soil particles) together, in a dense, strong, dimensionally stable and durable unit. Other common binders currently in use include lime, gypsum, pozzolanas, resins and bitumen (Apers .1983; Stulz & Mukerji, 1988).

2.22.2 Characterization of Soil for Hydraform Block Production

Soil alone constitutes over 90 of the bulk of Hydraform blocks. According to BS 1377 Part 1: 1990, soil is an assemblage of discrete particles in the form of a deposit, usually of mineral composition, but sometimes of organic origin, which can be separated by gentle mechanical means, and which include variable amounts of water and air. Soil is also referred to as the loose material that results from the long-term transformation of the underlying parent rock by the simultaneous and evolutionary interaction of climatic factors and other physico-chemical and biological processes (Casagrande, 1947; Das, 1994; Houben & Guillaud, 1994; Craig, 1998). Most of soils consist of disintegrated rocks, decomposed organic matter and water soluble mineral salts. These descriptions confirm that soil is a highly variable and complex material in nature. Although soil properties can be modified to improve their performance, not all soils may be suitable for stabilization as found. The decision on suitability requires the identification of the main constituents in the soil likely to have a direct bearing on its properties and behavior (Head, 1980).

2.22.3 Quality of Water for Mixing and Curing of Hydraform blocks

Water is required in the production of most building construction materials in many stages. In the production of Hydraform blocks there are two critical stages that water has been used:

1. During the mixing of soil with cement and
2. During the wet curing of wet blocks. The quality and quantity of water used for the production of Hydraform ought to be given equal consideration. (Webb & Lockwood, 1987).

The following guidelines for quality are considered useful (BS 3148, 1980; ASTM C 92a, 1992);

- ✚ Water with a high concentration of sodium or potassium should be considered unsuitable for use in cement hydration.
- ✚ Water with pH of between 6.0-8.0, which does not taste saline or brackish, may be suitable for use in cement hydration.
- ✚ Water containing humic acid or other organic acids should not be used (affects hardening of cement paste in the blocks).
- ✚ Use of sea water is not recommended (presence of chlorides >1000 ppm)
- ✚ Water with silt as suspended solids may be used even if concentration of 2000 ppm is found as long as the water is first left to stand in a settling basin or tank for at least 24 hours.

2.23 Soil Stabilization

Soil is one of natural most abundant construction material that all construction can be built from soil or at least upon soils. When the soil condition was unsuitable for the construction system we have to replace the soil types by the suitable one or we have to blend it with other materials that re-establish the soil properties that have been missing in the given soil.

The technique of improving the Engineering properties of soils enough to withstand the needed qualification on the sit (in-situ) is referred to us “Soil Modification” or “Soil stabilization” Current soil stabilization methods can be broadly categorized as follows:

- ✚ Mechanical stabilization (by using a compressor)
- ✚ Physical stabilization (by improving the soil grading)
- ✚ Chemical stabilization (by using a binder to improve bonding between the soils particles)

Normally combinations of all three methods are used (Ingles & Metcalf, 1972). Each method is now discussed in turn to examine the degree of effectiveness in the stabilization of soil.

2.23.1 Mechanical stabilization

Involves compressing the soil particles together to increase density and reduce porosity. Compression leads to the redistribution and rearrangement of soil particles. It is the compaction energy used which forces the particles together and in the process most of the air is eliminated from the soil voids. Compaction is best achieved when the grain size distribution of a soil is continuous, not uniform or gap graded. The presence of grains of different sizes facilitates the occupation of voids left by other soil particles. Unfortunately, the effect of mechanical stabilization when used alone is easily reversed, especially when the soil comes into contact with water (Jagadish. et al. 1981).

Water causes the lubrication the soil grains, forcing them to move about within the otherwise densified but still unbound fabric. It therefore follows that in addition to densification, the use of a binder will normally be required mainly to overcome the reversible effect of contact with a water (Norton . 1986).

2.23.2 Physical stabilization

Physical stabilization involves modification of soil properties by introducing the missing size fractions. The texture of a soil can be altered by calculated and controlled mixing of the different fractions together. When this is done, most of the voids that existed prior to physical stabilization are closed due to closer packing of the grains. An anisotropic network is created limiting the movement of the grains in a soil (Ingles and Metcalf, 1972). Unfortunately, as was the case with mechanical stabilization, the effect of physical stabilization alone is not permanent (Rigassi .V. 1995).

On saturation with water, soil grains are easily dispersed, or washed away. For better results, physical stabilization of soil should therefore be combined with the other two methods (PCA, .1971).

2.23.3 Chemical stabilization

Chemical stabilization involves the addition of a binder or bonding agent to a soil. The binder modifies the soil properties through cementation or linkage of its particles (Houben. H. & Guillaud. H, 1994).

Both cementation and linkage are a result of chemical reactions involving the binder and water. Cementation creates a strong and inert matrix that can appreciably limit movement in a soil. The voids in the soil are also filled with insoluble by-products of the hydration reaction while some soil particles are coated and firmly held together by the binder (Ingles, 1962).

The key binder that acts in this manner is Ordinary Portland Cement. It is generally reported in literatures that the effect of chemical stabilization is more permanent, and may take several years or even decades to partially reverse. For this reason, chemical stabilization is considered to be the superior method of choice. It is also well established that the effect of chemical stabilization is significantly increased by improving the soil grading and compacting the mix together (Gooding, 1994). Combination of the three methods is therefore strongly recommended, and is used in the production of all experimental samples used in the research.

2.23.4 Lime Stabilization:

By adding lime to the soil for stabilization, four basic reactions are believed to occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals of moderate to high plasticity. Stabilization of soil using lime occurs because calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. The reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. Lime can also reduce the degree to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabilizer for clay soils (Adam .E.A. 2001).

Soil stabilization occurs when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay.

The full-term pozzolanic reaction can continue for a very long period of time, even decades - - as long as enough lime is present and the pH remain high (above 10). As a result, lime treatment can produce high and long-lasting strength gains. The key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol, and reliable construction practices (Asmamaw.T, 2007).

2.23.5 Benefits of soil stabilizations

- Very substantial increases in resilient modulus values (by a factor of 10 or more in many cases).
- Very substantial improvements in shear strength (by a factor of 20 or more in some cases).
- Continued strength gain with time, even after periods of environmental or load damage (autogenously healing).
- Long-term durability over decades of service even under severe environmental conditions.

CHAPTER THREE

3 Properties of materials, mix proportions and test results

3.1 Introduction

In this chapter the materials used in the investigation are described with their sources, and their physical and chemical properties. All laboratory investigations on materials are carried out in the Ethiopian Water Works Design and Supervision Enterprise and the production of the blocks were carried out in block yard of East- horizon consultancy, of Jigjiga.

3.2 Soil

The soil used in this investigation was brought from two different sites were called Garab – Ase and far 15km East of Jigjiga town and the other was called Karamara area which were far 20km West of Jigjiga town. It was found out with different substances and Sizes. It was broken to different sizes and sieved to appropriate sizes. The test results are, Grain Size, Atterberg Limit, Free Swell, Proctor and Shrinkage Limit (water Absorption). The soil test is carried out following the appropriate samples preparation and testing procedures. The standard procedure that has been followed in the analysis was shown in table 3.1.

Table.3.1. Standard Procedures for the sample preparations and Soil tests.

S.No	Types of tests	Standard
1	Grain size analysis Hydrometer analysis	BS test 7(B)
2	Atterberg Limit	BS test 2(A) & 2 (B)
3	Proctor Test	BS 1377: 1975, Test 12 & 13
4	Water absorption	ASTM-C-128
5	Linear shrinkage Limit	BS Test 5

Their physical properties and chemical compositions of soils are given in the Tables 3.2 and 3.3 respectively.

Table 3.2 Physical properties of soil

Parameters		Garab-Ase Lab.No 353/05	Karamara Lab.No. 354/05
Hydrometer Analysis			
	Clay %	20	18.75
	Silt%	27.07	57.48
	Sand%	52.93	23.77
	Gravel%		
Atterberg Limit			
	Liquid Limit%	26	26.75
	Plastic Limit%	13.41	17.69
	Plasticity	12.59	9.06
Procter Test			
	MDD gm/cc	1.84	1.84
	OMC %	14.65	15
Water Absorption%		13.43	14.94
Shrinkage Limit %		11.05	12.14

Table 3.3 the chemical composition of the soils

Profile Code	Grab- Ase
CaO%	33.67
MgO%	14.59
MnO%	10.23
SO ₃ %	0.5
Na ₂ O%	16.36
K ₂ O%	17.16
Al ₂ O ₃ %	0.022
Fe ₂ O ₃ %	0.52
SiO ₂ %	10
LOI%	5
PH	6.5

3.3 Cement

In this research the cement data from previous researchers were used and the eight mixes were prepared using Dire-dawa National Cement and soil from two different pits; namely Garab-Ase and Karamara soils around Jigjiga. Dire-dawa Portland Pozzolana cement was produced by the Dire-dawa National Cement factory and complies with the requirement of Ethiopian standards. The chemical compositions of Dire-Dawa National Cements were shown in the Table 3.4 below.

Table 3.4 Composition and properties of cements produced in Ethiopia (Birhanu .B. 2007).

Cement types	Mean chemical Oxides of clinkers in %					
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃
Dre-Dawa	65.81	22.31	4.95	4.03	1.84	0.7
	Mean chemical Compounds of clinkers in %					
Dire-Dawa	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	Total	% of Silicates
	57.4	20.7	6.3	12.3	96.6	78.1
	Mean Chemical Oxides of Pozzolana in %					
Dire-Dawa	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃
	68.1	11.32	4.82	1.5	0.63	0
Cement types	Pozzolana included in % PPC	Gypsum content in cement%	Pozzolana Type	Cement Type Produced	Specific Gravity	
Dire-Dawa	25.05	5	Pumice	PPC	N/A	

3.4 Water

The water used for the production of samples for investigation of compressive strength and water absorption was Jigjiga tap water which is supplied by the Jigjiga town water supply system. The Jigjiga water is a salty.

3.5 Mix proportion

Providing production possibility of Hydraform block and its economic information using Jigjiga soil by assessing the potential of local materials is the purpose of this investigation. Thus Dire-Dawa cement from cement manufacturer and two sites of soil i.e. Garab- Ase and Karamara area were selected and prepared. To this effect the following test programs, the mix proportions are made based on the literature recommendations.

1. The first series of mixes (3 in number) are conducted to compare the difference in compressive strength values with age, rate of strength development of the block produced using Dire-Dawa Portland Pozzolona Cement and soil from Garab-Ase. They are made with 24% of water and cement content of 6%, 8% and 10% by weight of soil. The mix proportions are given in Table 3.5A below.

Table3.5A mix proportion for the Garab-Ase Soils

Mix Code	Cement (Kg)	Water (Kg)	Soil (Kg)
DC-Garab-Ase 6	6	24	100.45
DC-Garab-Ase 8	8	24	100.45
DC-Garab-Ase 10	10	24	100.45

2. The second series of mixes (3 in number) are conducted to compare the difference in compressive strength values with age, rate of strength development of the block produced using Dire-Dawa Portland Pozzolona Cement and soil from Karamara. They are made with 24% of water and cement content of 6%, 8% and 10% by weight of soil. The mix proportions are given in Table 3.5B below.

Table3.5B Mix proportion for the Karamara Soils.

Mix Code	Cement (Kg)	Water (Kg)	Soil (Kg)
DC-Karamara 6	6	24	100.45
DC-Karamara 8	8	24	100.45
DC-Karamara10	10	24	100.45

3. The third series of mixes (3 in number) are conducted to compare the effects of mold pressure on the compressive strength of the sample and on the effectiveness of the cement stabilizer. They are made with 6MPa, 8MPa and 10MPa pressure mold and Dire-Dawa cement contents of 6%, 8% and 10% by weight of soil from Garab-Ase area. The mix proportions are given in Table 3.6A below.

Table 3.6A mix proportion for the third series

Mix Code	Cement Content (Kg)	Mould Pressure (MPa)
C6P6 GS	6	6
C6P8 GS	6	8
C8P6 GS	8	6
C8P8 GS	8	8
C10P6 GS	10	6
C10P8 GS	10	8

4. The forth series of mixes (3 in number) are conducted to compare the effects of mold pressure on the compressive strength of the sample and on the effectiveness of the cement stabilizer.

They are made with 6MPa, 8MPa and 10MPa pressure mold and Dire-Dawa cement contents of 6%, 8% and 10% by weight of soil from Karamara. The mix proportions are given in Table 3.6B below.

Table 3.6B Mix proportion for the fourth series

Mix Code	Cement Content (Kg)	Mould Pressure (MPa)
C6P6 KarS	6	6
C6P8 KarS	6	8
C8P6 karS	8	6
C8P8 karS	8	8
C10P6 karS	10	6
C10P8 KarS	10	8

3.6 Specimen preparation

The preparation of the spacemen's was one of most important stages in handling of the experiments and the soil, cement mix, moisture content, compression, curing and sizing of the samples has need extra cares.

The laboratory tests had to be completed within a limited period of time. The samples preparation describes the raw materials used, mix proportioning, addition moisture or other procedure meant to satisfy only a limited number of tests. For all laboratory tests attempts were made to ensure that the results obtained satisfied three basic conditions: accuracy, reliability and reproducibility. Only the standard methods were used in the production of Hydra form Blocks.

Literature indicates that an ideal soil would have an optimum raw materials composition of:- Sand 75%, fines (silt and clay) 25% of the fines, at least not less than 10% has to be clay (Kerali.A.G. 2000).

The actual mix then used consisted of: Sand 52.93%, Silt 27.07% and Clay 20%. For Garab-Ase soil and Sand 23.77%, Silts 57.48% and Clay 18.75% for the karamara soil which shows somewhat high in silt and clay contents.

Proportioning the mix of the soil raw material with the cement stabilizer was done in varying quantities, by percent weight of cement from 6% by weight in 2% increments up to 10% by weight of the soil as follows: 6%, 8% and 10%.

A total of 170 blocks of average dimension 22.5*22.0*11.5 cm were subsequently made in this manner for three series of tests. The constituent parts of the mixed soil preparations were separately weighed using an accurate and sensitive electronic weighing machine accurate to $\pm 0.05\text{g}$. To improve on the degree of mix, an electro - mechanical mixer had to be used.

To produce the blocks, a pre-installed M7 -00-199 machine designed on the quasi- static compression principal was used for the entire samples see (Photo 3.1) below. Before filling the mould for each compression, the mould lining was slightly oiled with used engine oil. The soil was carefully poured into the mould, all pre-weighed, packed and sealed in light transparent plastic bags. After each pouring, the soil was leveled in the mould. The use of the M7-00-199 machine was based on the operational manual of the machine (Asmamaw .T, 2007)



Photo 3.1 shows M7-00-199 Hydraform block making machine that have been installed in the East-Horizon Consultant block production center.

3.7 Curing

To achieve maximum strength, Hydraform blocks need a period of damp curing, where they are kept moist. This is a common requirement for all cementitious materials. What is important is that the moisture of the soil mix is retained within the body of the block for a few days. If the block is left exposed to hot dry weather conditions, the surface material will lose its moisture and the clay particles tend to shrink. This will cause surface cracks on the block faces.

In practice, various methods are used to ensure proper curing. Such methods include the use of plastic bags, grass, leaves, etc. to prevent moisture from escaping. The required duration of curing varies from soil to soil and, more significantly, which type of stabilizer is used. With cement stabilization, it is recommended to cure blocks for a minimum of three weeks (Adam .E.A., 2001).

After two or three days, depending, on the local temperatures, cement stabilized blocks completes their primary cure. The blocks have been cured for five days under covering of plastic sheets and then be removed from their protective cover and stacked in a pile in the laboratory for thirteen days for more curing to gain its full strength as shown in photo 3.2. As the stack of blocks is built up, the top layer should always be wetted and covered, and the lower layer should be allowed to air-dry to achieve maximum strength. Alternatively, freshly molded blocks can be laid out in a single layer, on a non-absorbent surface, and covered with a sheet to prevent loss of moisture.



Photo 3.2 Curing of the blocks under cover produced in East-Horizon Consultant block production center.

3.8 Tests on blocks

Different separate tests and experiments, all of which have direct bearing with the investigation of the effects of stabilization and molding pressure on the strength and performance of blocks, were selected and conducted. The tests include the wet and dry compressive strength tests and the water absorption test. Although the wet and dry compressive strength tests and the water absorption test are both now standard performance tests widely described and used for stabilized soils, they were originally developed for concrete blocks and fired bricks (Asmamaw .T, 2007).

3.9 Compressive Strength

The wet compressive strength value of blocks is determined using the compressive strength machine. Since the wet compressive strength was lower than the dry compressive strength it is the one that used for the structural design. The compressive strength test done is a standard test based on (ASTM standards, Volume 04.08, Soil and Rock, 1996).

After curing the blocks for a periods of 7, 14 and 28 days, the blocks of average dimension 22.5×22×11.5 cm was measured and weighed. It was tested using a compression test machine of maximum load of 2000KN.

The machine is certified and calibrated for the test duration by Ethiopian Standard and QualityControl Agency. Photo 3.3 shows a photographic record of the compressive strength test taken during the experiment.



Photo 3.3 shows compressive strength test in Construction Design Share Company Dire- Dawa Office.

Three blocks in each category of varying cement content from 6% in increments of 2% up to 10% of the two different soils were tested for wet compressive strength. Each block sample of dimension 22.5×22×11.5cm was soaked for 24 hours or overnight in ordinary water. The samples were removed and kept aside for 20 minutes to dry out the surface water. The samples were then carefully placed within the set marking pins of the compression-testing machine.

The machine applies a continuously without a shocks by a rate of 3.5MPa per minutes until fails and the maximum crushing loads were reads from the machines. The wet compressive strength of the blocks were determined by dividing maximum load by the cross -sectional area of the block and specified in N/mm².

CHAPTER FOUR

4 LABORATORY TEST RESULTS AND DISCUSSIONS FROM GARAB-ASE AND KARAMARA SOILS JIGJIGA AREA

4.1 Introduction

In Hydraform blocks production the use of suitable soil is a fundamental to successful products. We have been using the Jigjiga soil for the production of Hydraform blocks specifically the Karamara and Grab-Ase area was may target for this investigation.

The soil selection for the Hydraform production is a target for the suitability in the production of good block. To get suitable soil we have to check out the following properties of soil.

1. The particle size or grading of particles
2. Plasticity index

The particle size distribution and plasticity was not the only soil tests. There are a number of suitable tests that has been found in the literatures, but further implementation of suitable soil tested for the Hydraform blocks I have considered only few of them which have direct effect on the strength and durability.

A full laboratory analysis including soil grading, plasticity and chemical composition have been discussed and analyzed in the following section. Soil samples from Karamara and Garab-Ase of Jigjiga areas have been checked for the field tests selection process and taken to the Ethiopian Water Work Design and Supervision Enterprise Laboratory Services Sub- Process and relevant laboratory tests were conducted.

Based on the results of both tested soil, trial blocks were produced by using different cement, water and soil proportion and these blocks were tested for 7th day, 14th day and 28th day for constant compressive strength and water absorption capacity.

4.2 Laboratory Tests and Results on Soil Samples

The laboratory tests were conducted and provide detailed information on the soil gradation and plasticity as well. The tests result information helps us to check the suitability of soil based on the literatures. Results have to be compared with criteria in ARS for Granular composition Diagram 2.3.

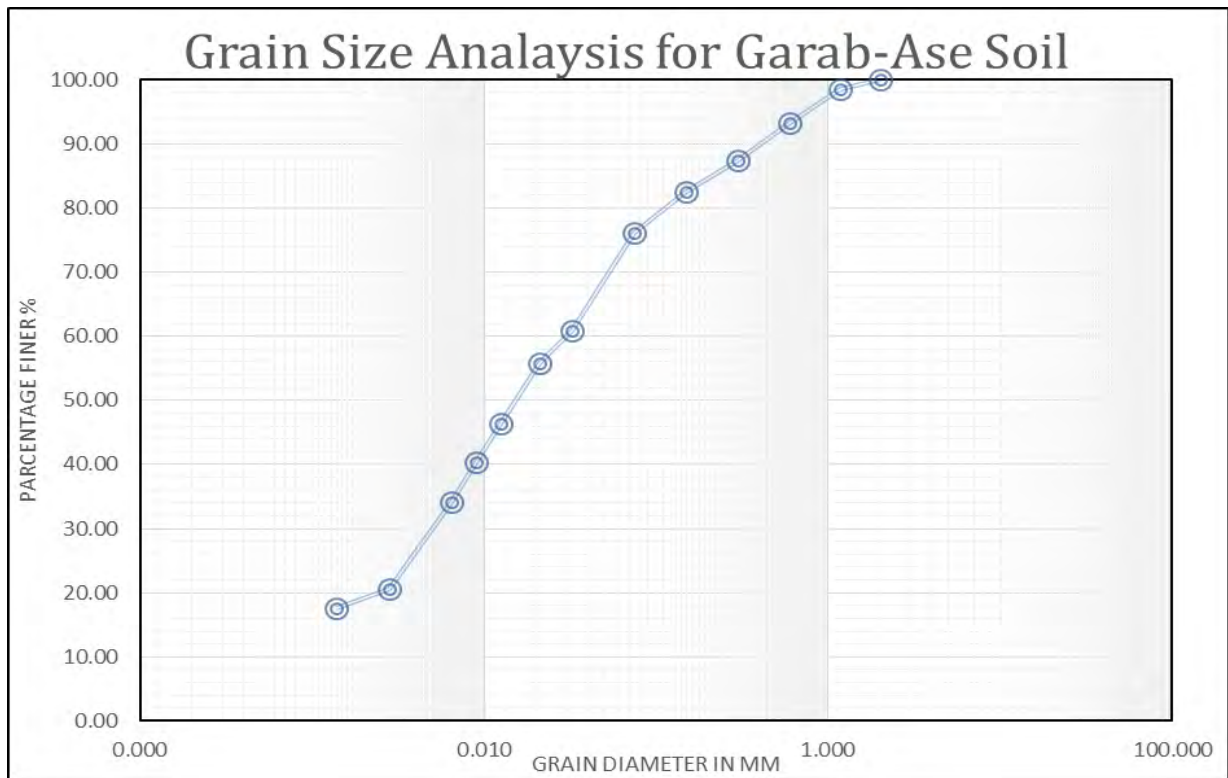
In this research work a number of characteristics that have relevant to production of Hydraform blocks were considered. The physical properties of soils that are more important for the production of Hydraform blocks and that determine mixing, de- moulding, porosity, permeability, shrinkage, dry density, dry strength and apparent bulk density etc., have been determined.

The soil samples are generally characterized by particle size distribution analysis and by plasticity index. The particle size analysis gives information on the soil ability to pack in to a dense structure and the quantity of fines presents in soil, while the plasticity index gives the properties of soil on the cohesion of the fines.

The laboratory tests conducted and establish a numerical values for the soil sample parameter, primarily the percentage distribution of different sizes of the soil particles present and the plasticity limits. These values are subsequently used to determine the suitability of the soil sample for block production.

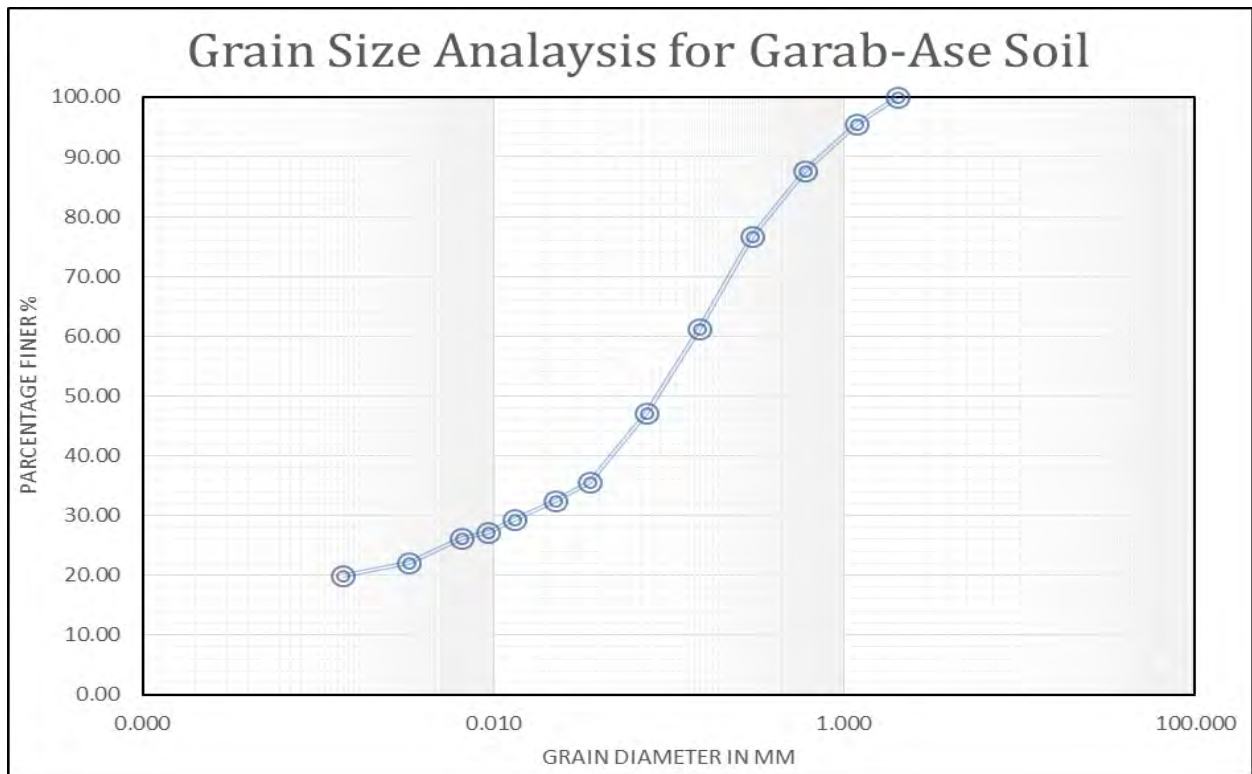
4.2.1 Particle size distribution

The combined sieving and hydrometer tests separated the different size fractions of the soil samples in to discrete parts thereby indicating the soil particle grading. The results of these tests were plotted in graph 4.1A and 4.1B for the Karamara and Grab-Ase soil respectively. Detail raw data's and test results were given in Appendix A. Grain size analysis of both soils form Karamara and Garabase are shown in the next graphs.



Graph 4.1A Particle size distribution of soil from Jigjiga Karamara area.

From the above curve, actual composition of the soil from the Karamara grouped as follows:
 Sand 23.31%, Silt 27.07% and Clay 20.1%.



Graph 4.1B Particle size distribution of soil from Garab-Ase area

From the above curve, actual composition of the soil from the Garab-Ase grouped as follows: Sand 4.8%, Silt 50.6% and Clay 40.52%.

Based on the above two results, now it is possible to check the suitability of the soil by using different techniques as per the literature.

4.2.1.1 Based on African Regional Standard (ARS)

The code of practices ARS : 680: 1996 recommended that granular composition of soil used for the Soil blocks were falls in the shaded area of the graph shown in diagram 2.2, that gives satisfactory result. The gradation curve of the soil sample from the Karamara pit Jigjiga area shown in Fig. 4.1A above falls completely with in the shaded area of the diagram of texture as shown in figure 4.2 below. This shows that the soil sample chosen fulfills the recommended requirements.

The gradation Curve of the soil sample from Garab-Ase shown in the fig 4.1B above will not falls completely in the shaded area of the texture curve shown in the fig 4.2 below. This can show that percentage of silt and clay needed does not fulfill the specification of the soil blocks recommendation in some extent. This can be solved by clearly sieving the soil by the specified sieve sizes which fulfill the recommended sizes and putting the soil into the specified gradation to produce a good quality of Hydraform blocks.

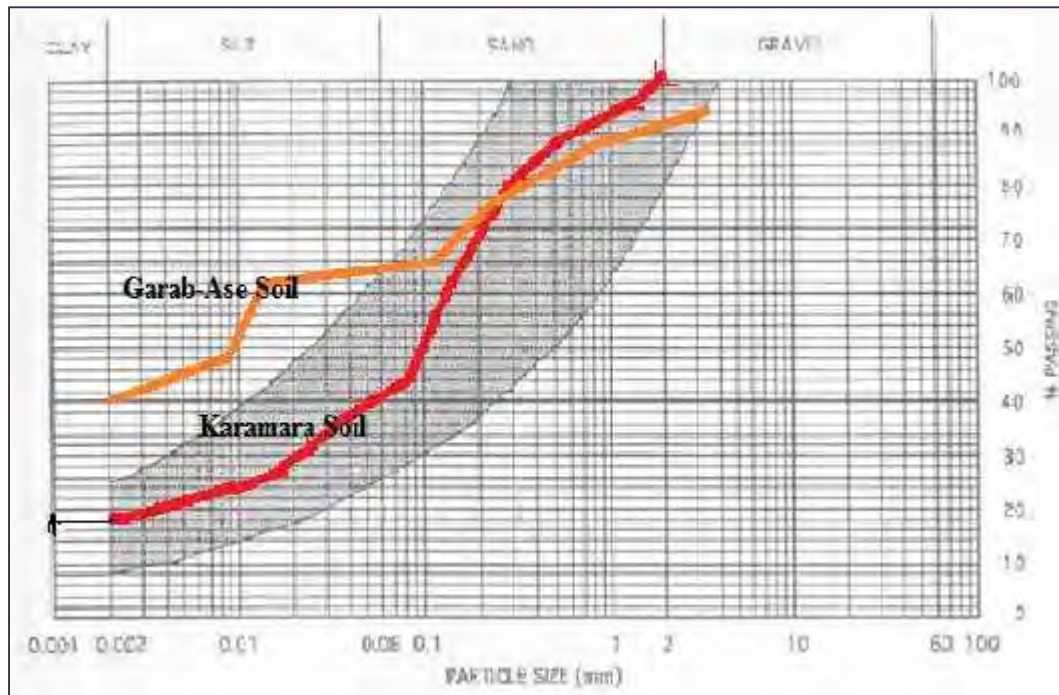


Fig. 4.2 Particle size distribution of the soils sample from Garab-Ase and Karamara on the diagram of texture.

4.2.2 Atterburg Limit Criteria (Plasticity)

The Atterburg limit criteria or plasticity tests define the moisture content at which the soil passes from a liquid state to plastic state and from plastic state to a solid state. This boundary points are the liquid and plastic limits respectively. The suitable criteria for the soil selection in the plasticity characteristics shown in diagram 2.3.

The plastic limit and liquid limit tests described in the appendix one A1.3 and prepared by using method of BS Test 2 (A) & 2(B). The linear shrinkage test which is a test of the soil's contraction on drying and believed to give a combined measure of the soils' particle grading plasticity and clay type is conducted based on (BS 1377-2:1990). It gives an overall idea of the soils behavior and suitability for stabilization. Atterburg limit test results of the soil sample are given in Table 4.1 below but full test measurements and data records are described in appendix one A1.4.

Table 4.2 Atterberg limit test results of soil samples from Karamara and Garab-Ase Jigjiga Area.

Atterberg Limit	Garab-Ase	Karamara
Liquid limit %	26	26.7
Plastic Limit %	13.41	17.69
Plasticity Index %	12.59	9.06

Based on these results we would have to say that both soils are suitable for the production of Hydraform block base on the atterburge limit criteria.

4.2.2.1 Based on African Regional Standard (ARS)

The plasticity index of 12.59 and liquid limit of 26 for the soil of Garab-Ase and plasticity index of 9.06 and Liquid Limit of 26.7 for the Karamara soil respectively both falls in the shaded region of plasticity chart of fig 4.3 below. The plasticity index and liquid limit located in the shaded area, which indicates the suitability of both Gara-Ase and karamara soils for the Hydraform block production.

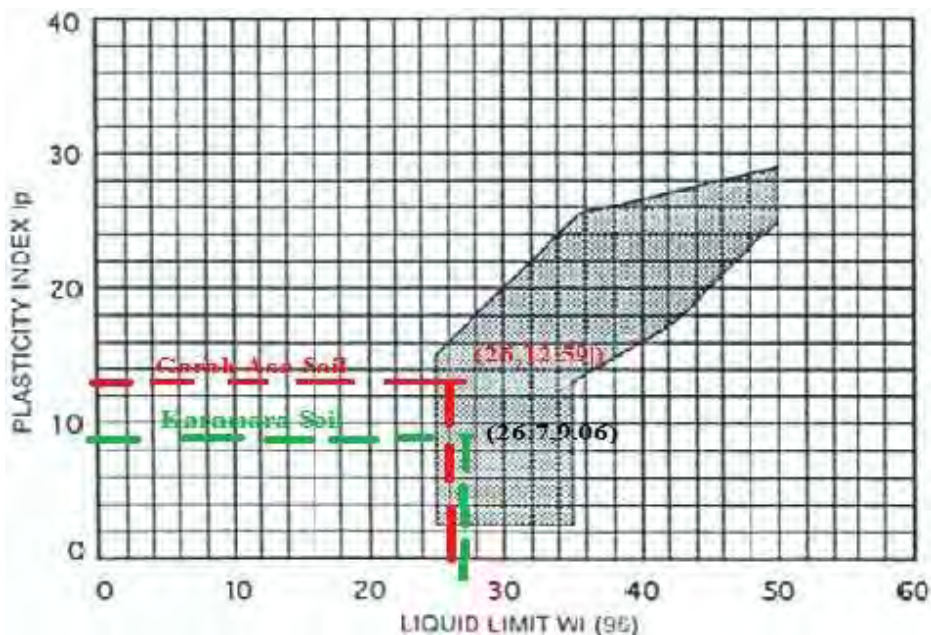


Fig.4.3 plasticity index for the soils of Garab-ase and Karamara in Jigjiga area.

4.2.3 Soil Compaction Test

Both the soil sample has been checked and its suitability for the liquid limits and plasticity index has quantified and the soil considered that it is suitable it will continue for further tests. The soil samples are further tested for a compaction tests. The soil particles can be compressed tightly together that removes the air voids between the soil particles. This is an effective and cheapest way of improving the soil properties. The properties of the soil compacted can be expressed in terms of its dry unit weight (Dry density) of soil.

The common compaction test called standard proctor test performed in the laboratory as usually determined by optimum moisture content and maximum dry density of the soil samples. Standard proctor tests for the soils from Garab-ase and Karamara soil have been determined by using BS1377: 1975 Test 12 & 13 method and the results are plotted in graph 4.3 below. And the detailed measurements and the raw data's are given in the appendix A tables 1.7 and 1.8 respectively.

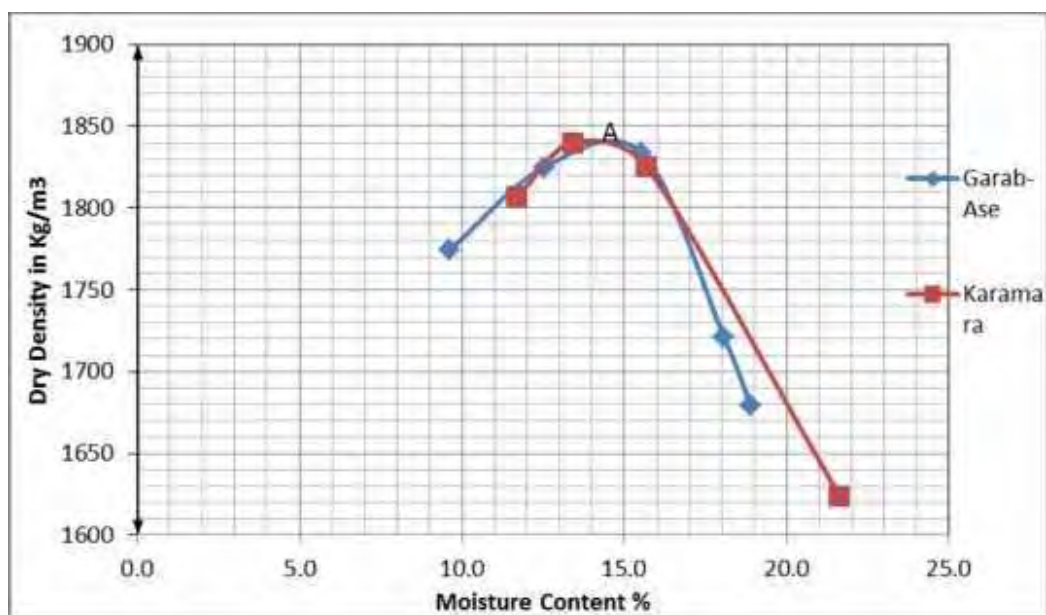


Fig 4.3 Proctor compaction curve for karamara and Garab-ase soil in Jigjiga area

Point “A” in the above curve shows the maximum dry density (MDD) and optimum moisture contents (OMC) of the soil samples. MDD and OMC for both soils were 1840kg/m³ and 1840Kg/m³ and 14.65% and 15% for Garab-Ase and Karamara soils respectively.

The amount of compaction is the primary factor affecting maximum dry density and optimum moisture content for a given soil type. In this particular case compaction of the soil

samples were conducted by using M7-00-199 Hydraform making machine using 10MPa system pressure. The optimum moisture content was determined by using the ideal block length for a given soil type. The amount of moisture content used to produce this ideal block length is taken as optimum moisture content. The ideal block length was nearly 22.5cm and the amount of water required to get this length was 24%.

4.3 Chemical analysis

The chemical properties of soil like composition, mineral contents, metallic contents, Oxides, PH values and sulphates were very crucial particularly when there is chemical additives have to be used. The chemical additives or Stabilizer that have been used for this research case is cement the chemical analysis of one of the soil sample was conducted at the Ethiopian Water Works Design and Supervision Enterprise laboratory sub- section and the results were given in the table 3.3 page 50.

The chemical composition for the Garab-Ase soil which is located in Eastern part of Jigjiga was conducted and the results were expressed in the table 3.3 above page 50 and appendix B Table 2.1.

From table 2.1 in appendix B the amount of SiO_2 (10%), and the CaO (33.7%) from these two results which indicates the composition of sand and calcium Oxides in the soil, that results SiO_2 and Al_2O_3 form the soil react with CaO from the cement and water. But there is CaO high percent that also reduce the required CaO from the cement which implies that less cement gives sufficient strength for the Hydraform block. The more silica found the more reaction with cement and the more CaO the more reaction with silica. The silica from the soil also contributes to the replacement of the CaO from the cement and increase the reaction. The acidic contents of the soil will matters the hydration reaction, but the PH (6.5) of the Garab-Ase soil will fall in good reactive soil. The Garab-Ase soil have a SO_3 content of 0.5% which reduces the percentage of sulphates to be produced in the reaction, that matters overall the strength of the Hydraform block produced from this soil.

CHAPTER FIVE

5 COMPRESIVE STRENGTH TEST RESULTS AND DISCUSSIONS ON THE PRODUCED HYDRAFORM BLOCKS

5.1 Introduction

Any building structures like cement blocks, bricks and Hydraform blocks needs tests that necessitates to measure the block properties of which durability is dependent such as strength, water absorption and to observe the blocks performance in case of deterioration.

The experimental results and data from which has been identified from local and worldwide trends could be identified and is the comparison criteria for the result. The tests would provide the opportunity for currently beliefs checked with the reality and prove the hypothesis of the research and improve the production, performance and awareness of the use with locally available materials in the development of their housing standard, quality and solve the problem of housing system in the Ethiopian Somali Region.

5.2 Compressive strength

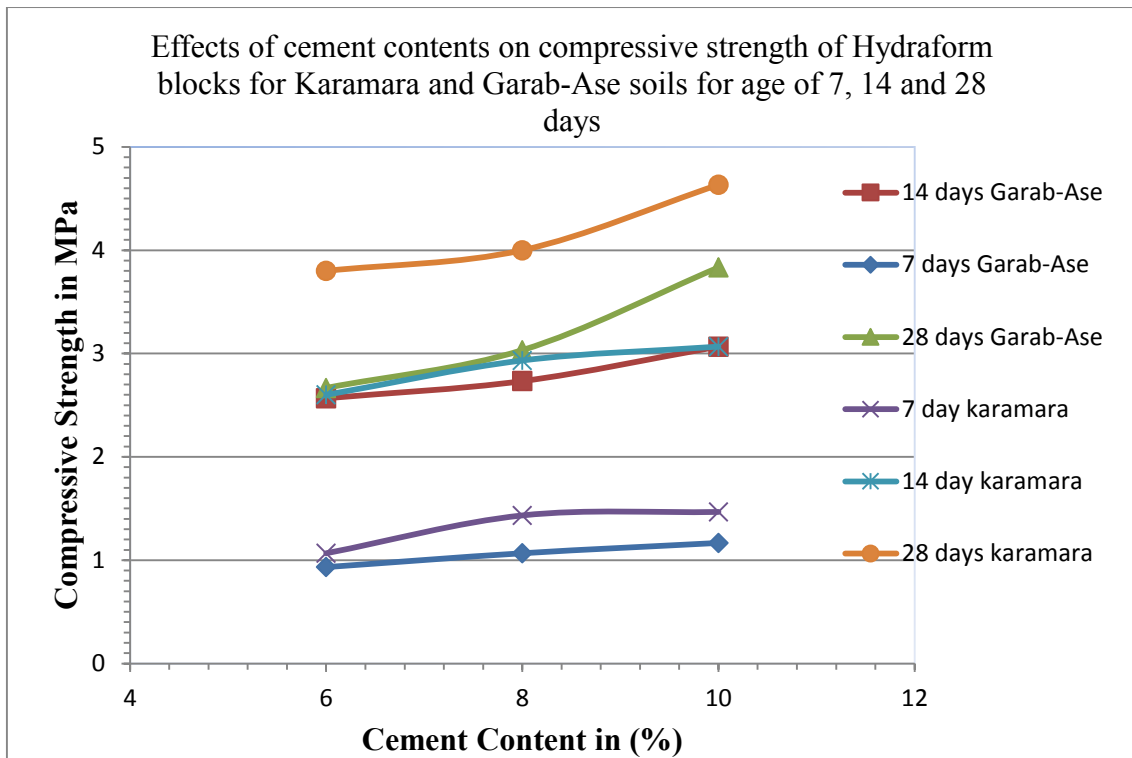
The Hydraform blocks have been produced from the soil stabilized with cement which has been used soil, cement and water. In general this material property affects overall performance of the block produced. The other things that have been affect the block performance was compaction pressure and curing condition. In this experiments all other variables decided to be fixed except the cement contents since it was the stabilizer. According to the literature on stabilized soils, the stabilizer was significantly responsible for the improvement in strength, dimension stability and durability of blocks.

5.3 Effects of Cement and Cement Content on The Compressive strength of Hydraform blocks

The 7th, 14th, and 28th days mean compressive strength values of Hydraform blocks stabilized with Dire-Dawa cement contents of 6%, 8%, and 10% are shown in Table 5.1 below and all the raw data's of cube compressive strength test results are presented in a tabulated form in Appendix C and in a graphical form in Graph 5.1.

Table 5.1 Mean compressive strength of Hydraform block using soils from Grab-Ase and Karamara from Jigjiga area and Dire- Dawa Cement

Days which test have been conducted	Cement Content in (%)	Mean Compressive strength in (MPa)	
		Garab-Ase	Karamara
7 th day	6	0.933	1.067
	8	1.067	1.433
	10	1.167	1.467
14 th day	6	2.567	2.60
	8	2.733	2.933
	10	3.067	3.067
28 th day	6	2.667	3.80
	8	3.033	4.00
	10	3.833	4.633



Graph 5.1 Effects of cement content on the compressive strength of Hydraform block using Grab-Ase and Karamara in Jigjiga soils and Dire- Dawa Cement.

From these test results in general the proposed and locally available trends can be seen and recognized. According to the tabulated results in Appendixes E, F and G, it can be found that for a given constant compaction pressure, an increase in cement content can result in an increase in absolute compressive strength. The cement gel deposit between soil particles and binds together the soil particles and increase strength for the blocks. Increasing thus, cement content means increasing the cement gel between the soil particles which result in an increase in strength. The results also show that from the blocks produced at the varying cement contents from 6% in increments of 2% up to 10% at constant compressive pressure of 10MPa, all the blocks have 28 day wet compressive strength values well above most of the recommended minimum values for use in structural work as per the literature. According to the literature, several different minimum values of 28-day wet compressive strength, all above 1.0MPa are proposed and found to be above the proposed minimum.

5.4 Comparison of compressive strength of Hydraform blocks made of soil from Grab- Ase and Karamara using Dire-Dawa Portland Pozzolana Cement

There are only three operating cement factories in Dire-Dawa area. Dire-Dawa, Ture Cement and Pioner Cement factories are near the study area. The Dire-Dawa and Ture Cement Factories are producing only pozzolana Portland Cement (PPC), while the Pioneer Cement Factory produces both Pozzolana Portland Cement and Ordinary Portland Cement (PPC and OPC).

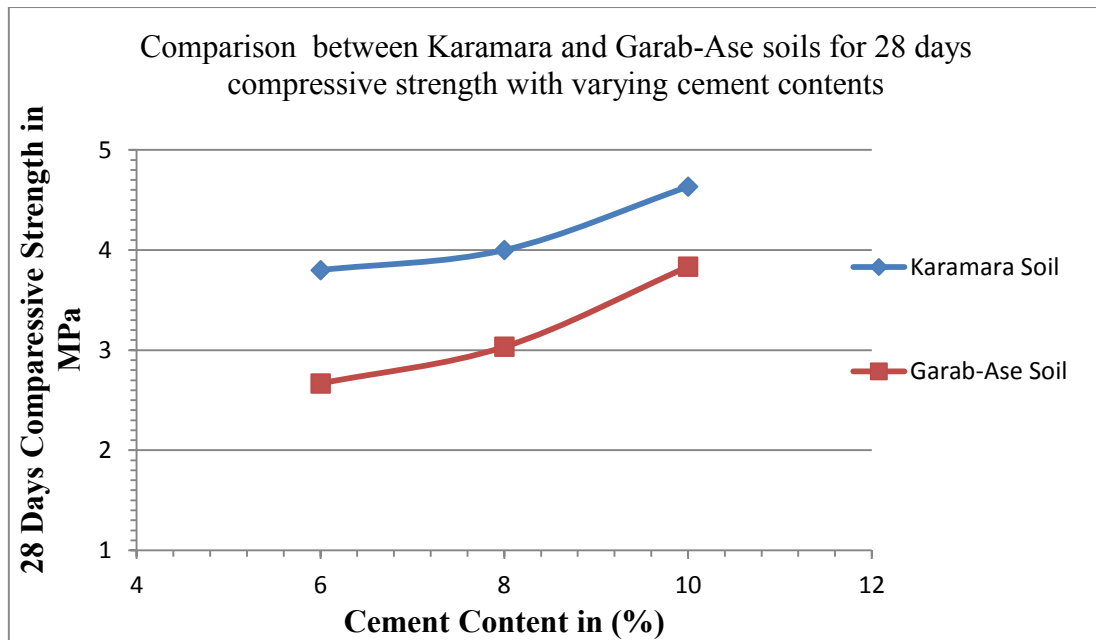
The Dire-Dawa Cement Factory has been producing for long period of time, the other two factories are newly coming factories to the locality and most of local peoples know Dire-Dawa National Cement. So I say that the local peoples can easily accept this cement. The Pioneer Cement Factory has been producing both OPC and PPC which has been widely distributed throughout the region, but as such as Dire-Dawa National Cement.

So the researcher chooses the Dire-Dawa cement for its Known for long period in the region. The availability and cost of transportation will be the two cases that understand by the researcher to use Dire-Dawa cement for stabilization for this work. For the production of Dire-Dawa Portland Pozzolana Cements, the factories used different type and amount of pozzolanic materials as shown in Table 3.4 page 51. Beside the pozzolanic materials in the cement the resaerchers have been considered two different soils from two different locations around the Jigjiga area.

These soils has been put much difference in compressive strength while the cement types and contents remain the same. In this section detailed analysis of the test results is undertaken from the point of view of determining the comparative effect of each soil type on the variable under investigation. To check these effects different trial mixes are prepared as shown in Table 3.5 A and 3.5 B on pages 60 and 61.

The results of tests are shown in Appendixes C and D the 28 day compressive strength comparison curve are shown in Graph 5.2 below.

From Graph 5.2 it is observed that the 28th day compressive strength of the Hydraform blocks by using these two soils revealed that the soil from Karamara have a better compressive strength than soil form Garab-Ase and the percentage differences are given in Table 5.2 below.



Graph 5.2 comparison of the 28th day's compressive strength for Hydraform blocks using Karamara and Garab-Ase soil with varying in cement contents.

Table 5.2 Comparison of the 28th day compressive strength of Hydraform blocks of Soil from Karamara and Garab-Ase area using Dire-Dawa PPC as stabilizers.

Soil type	Cement content by weight of soil and 28 th days compressive strength of Hydraform blocks in MPa		
	6%	8%	10%
Percentage of cement contents	6%	8%	10%
Karamara	3.8	4	4.633
Garab-Ase	2.667	3.033	3.833
Difference %*	30%	24%	17%

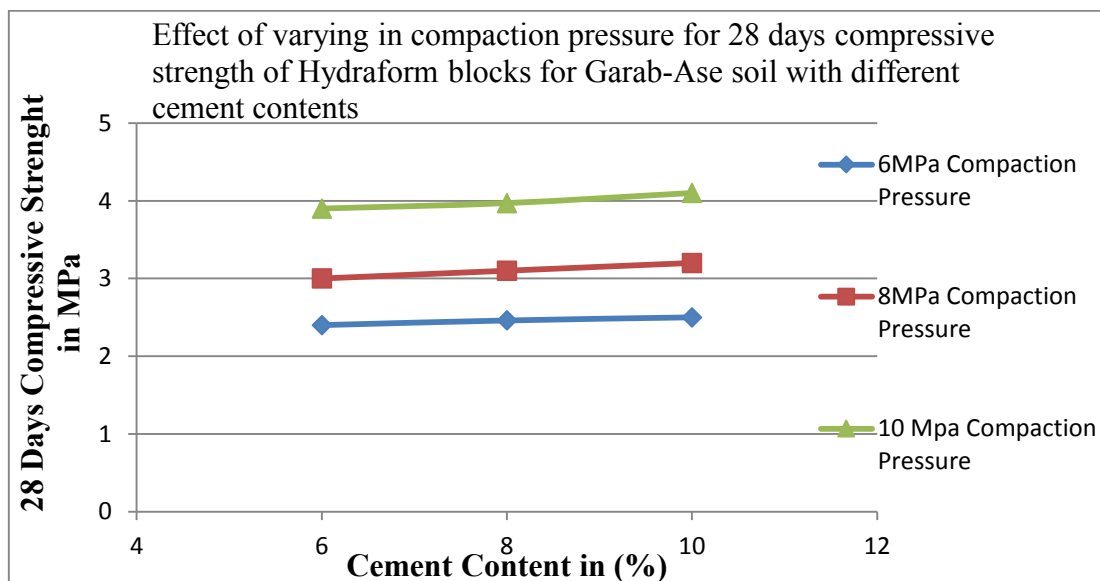
*Taking Karamara soil as reference

5.5 Effects of compaction pressure on compressive strength of Hydraform blocks

The binding, sealing, reinforcing and imparting flexibility of the Hydraform block is due to cement content (stabilizer). Also the compaction pressure can contribute towards increasing density and reduces the void region between the soil particles as well as the cement gels. As we have been determine the stabilizer has increase the compressive strength and improve the resistance of the block weather, thereby reducing swelling and shrinkage properties of soils.

The cracking was reduced by the stabilizer gel there by reinforcing soil particles and reducing excessive expansion and contraction. All the stabilizer effects can be greatly increased by increasing the compaction pressure of soil. In the all previous experiments all the blocks were compacted with a compaction pressure of 10MPa to produce the possible quality blocks. In practices there may not be the same compaction pressure were used for the production of block even in one building construction purposes it may differ. For the next experiment that was conducted only on the Garab-Ase soil, both the cement content and the compaction pressure were varied and the other materials were the same.

The researcher proved that using different compaction pressure and cement content according to the mix design and proportion given in the table 3.6 A and B, Graph 5.3 and table 5.3 below indicate the test results of relations between the cement content and difference in compaction pressures at 28th days compressive strength block of the soil from Garab-Ase area. The full laboratory results are expressed in Appendixes E, F and G.



Graph 5.3 Effects of compaction pressure on compressive strength of Hydraform blocks for Garab-Ase Soil.

Table 5.3 Effects of compaction pressure on the 28th day compressive strength of Hydraform blocks for the soil of Garab –Ase.

Cement Contents in (%)	Compaction pressure and 28 th Days Compressive strength Hydraform blocks for Garab-ase soil (MPa)		
	6MPa	8MPa	10 MPa
6	2.4	3	3.9
8	2.46	3.1	3.97
10	2.5	3.2	4.1

According to the tabulated results in Table 5.3 above the compressive strength of Hydraform block is tested for various cement content samples ranging from 6% to 10% by differing the compaction pressure from 6% to 10% with an interval of 2MPa for all cement content of samples. The results of this test proved that compaction pressure have an effect on the compressive strength of Hydraform blocks. The higher the compaction pressure the higher the compressive strength.

CHAPTER SIX

6 ECONOMIC ANALYSIS OF HYDARFORM BLOCKS

6.1 Production Cost of Hydraform Blocks

In this research work, the production cost of Hydraform blocks are produced using Hydraform M7 -00-199 Machine and relevant data's for working conditions are taken from East- Horizon Consultant Hydraform production center. Prices of raw materials used for the production of the blocks are from the current price indexes of construction materials and the quantity of materials needed were calculated based on the optimum mix design of this research.

Two cases are considered for the cost calculation. These are the production on site and production on the block yard.

1. On Site Production: The production of the Hydraform block has been done in this case on the construction site itself and the store rooms and sheds will be used at the end of the construction by the owner for the other purposes. The soil is extracted from the site which is not applicable for the Jigjiga area and it needs selective materials to produce quality Hydraform block.

2. Block Yard Production: The block yard production is not only for the purpose of constructing an individual construction site, it has been a big block production center for the markets and it is better to locate on the quarry site itself. The types of production can produce a quality blocks and include the work force and materials for the production facilities.

6.2 Parameters that influence the production cost of Hydraform blocks

1. Machine life span:-

This represents the total number of blocks, which can be produced by the machines: About 2.0 million blocks can be produced by using M7-00-199 Hydraform block making machine over a period of 5 years with proper maintenance.

2. Daily Production:-

It varies with the block size. In the case of 22.5×22.0×11.5 cm block the daily production ranges from 1300 to 1500. In this research work 1300 blocks per day is taken as a daily production.

3. Annual Production:-

It is the monthly production (27 days) over a period of 11 months. Every year, one month is deducted for the maintenance of the equipment.

4. Equipment Cost:-

Main equipment's and machineries: Hydraform block making machine (M7-00-199), Pan Mixer, Motor, Soil crusher, Soil sieve, Wheel barrow, Water Can and Plastic sheet.

5. Buildings and Infrastructure

A. **On-Site Production:** It needs simple store room being an area of 15m² and a simple production shed 75m². It could be re-used at the end of the project, for another purpose.

B. **Block Yard:** Moveable office being an area of 10m², moveable store room of 20m², and moveable production shed of 75m² area. They would be moved and re- used at the end of the project.

6. Maintenance:-

This is the total cost of the maintenance during the lifespan of the Hydraform block making machine (M7-00-199). It includes the daily maintenance and the yearly repairs, once in a year. It is a lump sum given according to the experience from East-Horizon Consultant (proper maintenance).

6.3 Details for cost calculation

6.3.1 Variable costs:-


- 1. Labor:** - This includes workers' wages.
- 2. Water:** - It represents, about 24% of the mix. It would vary with the soil quality.
- 3. Cement:** - 6% cement (by weight) is taken as optimum for the cost calculations.
- 4. Soil:** - The cost includes the selected soil type excavation, loading unloading and transportation costs.
- 5. Maintenance /machine/:-** Maintenance cost over the lifespan of the press divided by the total production.


6.3.2 Fixed Costs

1. **Investment cost:** - This corresponds to the 4% interest of the loan taken from a bank (loan) and repaid in a period of five years.

2. **Equipment depreciation:** - This is calculated on the lifespan of the machine (for about 2 million blocks); on average it serves for 5 years. The lifespan depends on the daily productivity with one type of block. Therefore, the depreciation can be estimated as 20% per year.

3. **Buildings depreciation:-**

 **On-site production:** they can be re-used at the end of the project for another purpose. They have only a little value and their depreciation is evaluated to 25%.

 **Block yard:** they would be moved at the end of the exercise and re-used several times. Therefore, their depreciation is evaluated to be 5%.

6.3.3 Profit Margin

1. **On-site production:** -There is no profit margin, as the blocks are not for sale.

2. **Block yard Production:** - This margin should allow some profit, which would be re-invested at the end of the exercise to start another similar enterprise.

6.4 Unit cost

For both production on site and block yard, when fixed and variable costs are added together and this total sum is divided by the number of blocks produced, it gives the unit cost as shown in Table 6.1 and 6.2. This enables the price of the blocks to be set at sensible level, by adding a profit margin to the unit cost.

Table 6.1 On-site /Cost calculation table for (22.5x22.0x11.5 cm) for Hydraform blocks using 6% cement.

COST CALCULATION		ON-SITE PRODUCTION		
Daily block production using M-7 Machine (blocks)				1300
Annual production Hydraform blocks using 27 days/ month				386100
Equipment cost (Hydraform block making machine with Accessories)				300,000
Buildings and infrastructure cost				50,000
1. VARIABLE COSTS	Cost/Units (Birr)	Units	Cost/block (Birr)	%age
Labor per day (Man/day)	100	8	0.615	15%
Soil per day (7.4m ³ per 1300 blocks)	125	7.4	0.712	17.54%
Cement per day (6%=6.69Qt. Per 1300 blocks)	236.7	6.69	1.218	30.03%
Maintenance per block	0.01	1	0.000	0.00%
Total variable Costs/blocks			2.545	62.74%
2. Fixed Costs	Percentage	Total cost(Birr)	Cost/Block (Birr)	% age
Investment cost (interest)	4%	185,000	0.498	12.28%
Equipment depreciation(Press lifespan)	20%	300,000	0.932	22.98%
Building depreciation (site duration)	25%	25,000	0.081	2.00%
Miscellaneous	2%		0.000	0.00%
Total fixed costs/Blocks			1.512	37.26%
Total cost per block			4.057	100%

Note: Factory Dire-Dawa PPC =178birr
VAT+ Transportation cost = 58.7birr
Total = **236.7birr/Qt.**

Table 6.2 Block yard /Cost calculation table for (22.5x22.0x11.5 cm-) block using 6% cement for Karamara Soil.

COST CALCULATION		BLOCK YARD PRODUCTION		
Daily block production using M-7 Machine (blocks)				1300
Annual production Hydraform blocks using 27 days/ month				386100
Equipment cost (Hydraform block making machine with Accessories)				300,000
Buildings and infrastructure cost				100,000
1. VARIABLE COSTS	Cost/ Unit (Birr)	Units	Cost/block (Birr)	%age
Labor per day (Man/day)	100	8	0.615	12%
Soil per day (7.4m ³ per 1300 blocks)	266.67	7.4	1.518	29%
Cement per day (6%=6.69Qt. Per 1300 blocks)	236.7	6.69	1.218	23%
Maintenance per block	0.01	1	0.000	0%
Total variable Costs/blocks			3.351	63.47%
2. Fixed Costs	Percentage	Total cost(Birr)	Cost/Block (Birr)	% age
Investment cost (interest)	4%	185,000	0.641	12.15%
Equipment depreciation(Hydraform machine)	20%	300,000	1.200	22.73%
Building depreciation (site duration)	5%	25,000	0.088	1.66%
Miscellaneous	2%		0.000	0.00%
Total fixed cost/Block			1.929	36.53%
Total cost/Blocks			5.280	100.00%
Profit margin			1.056	
Selling price per blocks			6.336	
<p>The soil cost includes digging and sieving on The Block yard is assumed to be 15 km Site away from the quarry and soil transport cost is taken as 266.67 Birr/m³</p>				

Note: Factory Dire-Dawa PPC =178birr
VAT+ Transportation cost = 58.7birr
Total = **236.7birr/Qt.**

6.3.4 Comments on how the parameters influence the cost of Hydraform Blocks

Two production cases:

A. On-site

On-site production uses small facilities with low overheads. Thus it is a low cost case. The other case has larger physical set-ups. The block yard has the larger overheads and the soil is delivered by trucks. Thus the cost is high. This shows that on-site production is the cheapest but has the disadvantage of scattered production.

B. Daily production

This influences, substantially, the production cost of block. For example, if the productivity of Hydraform blocks could be increased from 1300 to 1500 blocks per day without increasing the man power (without decreasing their quality), the blocks would be 13% cheaper. Which mean that for 1300 blocks per day, the cost per block is 4.057 birr/ block while the production 1500 blocks/ day give us 3.516 birr /block. Note that increasing the given outputs is difficult, since they are near the maximum.

1. Annual production

The number of months worked per year has an influence on the production cost. Working 12 months per year can decrease per block cost from 4.057 to 3.931 Birr/block. From this we can see that a decrease of 3% /block is shown. But the machines cannot work over 11 month per year while it needs once or twice maintenance.

2. Depreciation cost

This also has an influence on the production cost of the block. Doubling the depreciation cost will increase the production cost from 4.057 to 4.989 per block which is more than 19%.

3. Labor cost

This influences more the production cost of the block. An increase of 25% for the labor cost will increase the production cost from 4.057 to 5.143 per block which is more than 21 %.

4. Soil cost

It influences substantially the production cost of the block an increase of 25% for soil will increase the production cost from 4.057 to 5.171 birr/ block which is equal to 21%.

5. Cement cost

This has a high influence on the production cost of the block: an increase of 25% will increase the production cost of the block by more than 26%.

6. Overheads and miscellaneous

This has a little influence on the production cost of the block: doubling the miscellaneous costs will increase the production cost of the block by less than 1%.

7. Profit margin

Its base, for a healthy unit should be determined. For this research work 20% is determined as profit margin.

Table 6.3 Cost calculation for (20x20x40 cm) Hollow Concrete Block “Class C”

COST CALCULATIONS				
Daily production (blocks)				1500
Annual production (blocks)				348,000
Equipment cost with accessories				45,500
Buildings and infrastructure cost				80,000
VARIABLE COSTS	Cost /Unit(Birr)	Unit	Cost/block (Birr)	Percentage
Labor per day (Man/day)	75	12	0.60	9.21%
Sand per day (12m ³ per 1200 blocks)	125	12	1.00	15.34%
Crushed stone 00 per day (2m ³)	500	2	0.67	10.23%
Cement per day (32 Qt. per 1200 blocks)	220	28.6	4.19	64.92%
Maintenance cost per Block	0.01	1	0.00	0.00%
Total Variable Costs/Blocks			6.46	99.70%
Fixed Costs	Percentage	Total Costs	Cost/Block	Percentage
Investment Cost (interest)	4%	150,000	3.43	0.21%
Equipment Depreciation (Press lifespan)	20%	45,500	1.20	0.31%
Building Depreciation (site duration)	5%	80,000	1.85	0.14%
Miscellaneous	2%	1200	0.03	0.20%
Total Fixed costs/Blocks			6.50	0.86%
Total production cost/Block			12.96	100.00%
Profit margin			2.59	
Selling Price/Blocks			15.56	

Note: Factory Dire-Dawa PPC =178birr
 VAT+ Transportation cost = 58.7birr
 Total = **236.7birr/Qt.**

Table 6.4 Cost calculation for (20x20x40 cm) Hollow Concrete Block “Class B”

COST CALCULATIONS				
Daily production (blocks)				1500
Annual production (blocks)				348000
Equipment cost with accessories				45500
Buildings and infrastructure cost				80000
VARIABLE COSTS	Cost / Unit (Birr)	Unit	Cost/block (Birr)	Percentage
Labor per day (Man/day)	125.00	12.000	1.000	7.48%
Sand per day (12m ³ per 1200 blocks)	125.00	12.000	1.000	7.48%
Crushed stone 00 per day (2m ³)	500.00	2.000	0.667	4.99%
Cement per day (32 Qt. per 1200 blocks)	220.00	28.600	4.195	31.39%
Maintenance cost per block	0.01	1.000	0.000	0.00%
Total Variable Costs/Blocks			6.861	51.35%
Fixed Costs		Total Costs	Cost/Block	Percentage
Investment Cost (interest)	4%	150000	3.43	25.66%
Equipment Depreciation (Press lifespan)	20%	45500	1.20	8.98%
Building Depreciation (site duration)	5%	80000	1.85	13.82%
Miscellaneous	2%	1200	0.03	0.20%
Total Fixed costs/Blocks			6.50	48.65%
Total Production cost per block			13.36	100.00%
Profit margin	20%		2.67	
Selling Price /Blocks			16.04	

Note: Factory Dire-Dawa PPC =178birr

VAT+ Transportation cost = 58.7birr

Total = **236.7birr/Qt.**

6.4 Comparison of Hydraform blocks with hollow concrete blocks per m² area of wall

There is question that any nonprofessional men can ask when the idea of construction with different building materials is started. The questions that most users and people ask was which building materials can be more economical than others. To answer these and other related questions we must consider the types of building and its standard.

So we have to consider the low cost housing for the comparison of the Hydraform Blocks and Hollow Concrete Block since the wall cost was the major costs of the buildings.

Due to the high cement content the cost of hollow concrete block production is high. Also the building that built with hollow concrete block requires plastering and rendering so that its appearance and finishing surface to be produced.

To make more accurate evaluation, it is important to consider a complete section of wall including the cost of plastering and structural elements. The researcher has made a comparison of wall made of Hollow Concrete blocks plastered and painted on both sides once and on the other hand compared with dry interlocking Hydraform block walls Varnished on both sides once. Per m² area of wall and cost comparisons are prepared and tabulated in Table 6.5 below.

According to Table 6.5 the cost of Hollow Concrete blocks walls plastered and painted internally and externally costs 347.08 Birr per m² but one m² of Hydraform block walls plastered internally costs 230.17 Birr per m². This implies that the cost of Hydraform block wall is 33.68% cheaper than Hollow Concrete block walls.

Table 6.5 Comparison of Hydraform block with Hollow Concrete block per m² area of wall

No	Description	For Class C HCB	Hollow Concrete blocks (HCB) pointed (inside and outside once) Per m ² (Birr)	Block Yard Production		Hydraform blocks interlocked per m ² (Birr)
		Hollow concrete blocks (HCB) Per m ² Plastered and painted (outside & inside once) (Birr)		Hydraform blocks plastered internally once per m ² (Birr)	Hydraform blocks Plastered and painted (inside and outside) once Per m ² (Birr)	
	Cost/Block	15.56	15.56	6.336	6.336	6.336
1	Block/m2	127.08	127.08	115.97	115.97	115.97
2	Mortar for fixing	39.00	39.00	---	---	---
3	Plastering	94.50	---	47.00	---	---
4	Pointing	---	29.00	---	---	---
5	Painting	37.50	---	18.75	---	---
6	Varnish	--	---	13.00	26.00	---
7	Labor	49.00	35.00	30.00	20.00	26.50
8	Total walling cost	347.08	230.08	224.972	162.222	142.722
	Percentage	0	-33.71	-35.25	-53.33	-58.98

Note:

In this table comparison is made on Hydraform block and Hollow Concrete block walls. The building elements (Hydraform blocks) have a compressive strength of 2MPa or equivalent to Class “C” Hollow Concrete blocks. As per the outcomes of this research, increasing the cement content in the Hydraform blocks yields less increase in compressive strength this show that using less cement means up to 5% also has yield enough strength. So by using proper cement content produce the better strength of the Hydraform block for non-structural walls. Since more increase in cement cannot yield more increase in compressive strength we can’t propose for the structural load bearing wall using Jigjiga soil.

CHAPTER SEVEN

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

1. The production of Hydraform blocks using Jigjiga, Karamara and Garab-Ase soils as alternative wall making materials were shows good properties regarding its physical and chemical compositions.
2. The cost comparison of Hydraform blocks using Garab-ase soil with optimum cement percentage (6% cement) and a class-C hollow concrete block shows that the Hydraform block is less than in terms of production cost.
3. An increase in compaction pressure shows nearly the same effect on an increase in cement contents on compressive strength.
4. An increase in cement content can results increase in compressive strength using the same compaction pressure of 10 MPa. From our findings it shows that, by increasing cement contents to allowable percentage and increasing compaction pressure we can produce a Hydraform blocks that have enough compressive strength.
5. In this research, soil from the Grab-Ase Jigjiga area is grouped as follow: - Sand 52.93%, Silt 27.07% and Clay -20.0% and Soil from Karamara Jigjiga area sand 23.33%, Silt 57.48% and Clay 18.75%. The composition of the first soil (Garab-Ase) yields a good structural characteristics product after mixed with cement. But the Karamara soil cannot produce as much compared to the Garab-Ase soil. Unfortunately, soil with these characteristics will not be found easily near every construction site and so one of the following two things must be done. Either the soil is tested and the required parts added to make the ideal soil, or a compromise is made and a slightly higher percentage of cement or higher compaction pressure is used to ensure a satisfactory outcome whatever the type of soil is used.

6. The Dire-Dawa Pozzolana Portland cement (PPC) cement used for the stabilization shows more or less equal technical performance for the 28th day, regardless of its chemical composition.
7. The thesis result concluded that it is possible to produce Hydraform blocks using Jigjiga soil, so that it fulfills the compressive strength, uses less cement content and adaptable to the environment as walling material for the low-cost housing. The use of hydraulic machine increases more its strength and reduces the air voids through compaction pressure.

7.2 Recommendations

- 1) Any concerned body can use the Hydraform blocks using Jigjiga soils as an alternative wall making material with proper quality control.
- 2) As it was mentioned in the literature the Somali traditional houses was built using a grass and pill of the selected trees. But now a day due to environmental degradation and over grazing the availability of the raw materials has been limited. Accordingly the local community shall use the locally available, affordable and environmental friendly Hydraform blocks as better substitute for construction materials.
- 3) Since the Hydraform block machine was not affordable in the local community, the regional technical and vocational training centers shall contribute through manual press machines modification in terms of preparation and providing there by giving appropriate training to the community so as to improve the housing problem in the region.
- 4) Further research on different type of soils including clay, sandy clay and sandy silt soils is very important due to availability and diversity of soil types especially in the Ethiopia Somali Region.
- 5) Chemical and organic contents of soil that hinder hydration reaction and how to treat these unsuitable soils are further research topics for better understand.

REFERENCES

- A Plan for Accelerated and Sustained development to end poverty (PASDEP), (2005/06-2009/10).Ethiopian Ministry of Finance and Economic Development, Addis Ababa Ethiopia.
- Abebe.D. (2007). A text book of Building Construction. Addis Ababa: Addis Ababa University Press.
- Adam.E.A. (2001). Compressed stabilized Earth Block Manufacturing in Sudan. Paris: UNESCO.
- Akroyd, T.N.W. (1962). Laboratory testing in soil engineering. Soil Mechanics Ltd. London, England.
- Aksa, Z. (1984). A lime stabilised soil building material. Institute of Human Settlements. Bandung, Indonesia.
- Antique, G. & Augusta, D. (1964). Soil Cement: Its Use in Building. United Nations Publications. New York, USA.
- Ashworth, A. (1994). Cost Studies of Buildings. 2nd Edn. Longman Scientific and Technical. Essex England.
- Asmamaw.T. (2007). Study of Compressed Earth Blocks as An Alternative Walling material. Addis Ababa: AAU Printing Press.
- Becky.T. (2001). Cebtex, Compressed Earth Block Construction [Http://Cebtex.Com](http://Cebtex.Com): Scotland: Scottish Executive Central Research Unit, Scotland
- Caroll, R.F. (1992). Bricks and blocks for low-cost housing. Building Research Establishment. OBN 197. March 1992. Garston, England.
- Casagrande, A. (1948). "Classification and identification of soils," Transactions, ASCE, 113, 901-930.
- Cinva-Ram. (1957). Portable Block Making Press. General Information Series No. 4. Scientific and Documentation Exchange Service, Inter-American Housing and Planning Center. Bogota, Colombia.
- CRA-Terre-EAG. (1991). Earth Building Materials and Techniques, Select Bibliography. German Appropriate Technology Exchange. Eschborn, Germany.
- Das, B.M. (1990). Principles of Foundation Engineering. 2nd Ed. PWS Publishing Company. Boston, USA.
- Das, B. M. (1994). Principles of geotechnical engineering, 3rd Edition, PWS Kent Publishers.
- Dunlap, W.A. (1975). US Airforce Soil Stabilisation Index System. Airforce Weapons

- Laboratory. New Mexico, USA.
- Ethiopian Building Code Standard, (1995): Foundations, EBCS-7, Ethiopian Ministry of Works and Urban Development, Addis Ababa.
- Fitzmaurice, R. (1958). Manual on Stabilised Soil Construction for Housing. Technical Assistance Programme. United Nations. New York, USA.
- GATE. (1980). Low-cost self-help housing. German Appropriate Technology Exchange. Eschborn, Germany.
- Gooding, D.E.M. (1993). Soil Testing for Soil-Cement Block Preparation. Working Paper No. 38. Development Technology Unit, University of Warwick, Coventry, England.
- Gooding, D.E.M. (1994). Improved Processes for the Production Soil-Cement Building Blocks. PhD Thesis. University of Warwick. Coventry, England.
- Gooding, D.E.M. (1993). Soil testing for soil cement block preparation, DTU Working paper No.38, <http://www.eng.warwick.ac.uk/DTU/>.
- Guillaud, H., Joffroy, T., Odul, P. (1995). Compressed Earth Blocks: Volume 11. Manual of design and construction. German Appropriate Technology Exchange (GATE) Publications. Eschborn, Germany.
- Herbert, M.R.M. (1974). Some observations on the behaviour of weather protective features on external walls. Techniques and Materials. London, England.
- Herzog, A., Mitchell, J. (1963). Reactions accompanying the stabilisation of clay with cement. 42nd Annual Meeting of the HRB. Washington, USA.
- Holtz, R.D. & Kovacs, W.D. (1981) An introduction to Geotechnical engineering Prentice – Hall
- Houben, H., Guillaud, H. (1994). Earth Construction: A Comprehensive Guide. CRATerre-EAG. Intermediate Technology Publications. London, England.
- Iterbeke, M., Jacobus, P. (1988). Soil-cement Technology for Low-cost Housing in Rural Thailand. An Evaluation Study. PG-CHS-KULeuven. Leuven, Belgium.
- Ingles, O.G., (1972). Metcalf. L.B. Soil Stabilisation. Principles and Practice. Butterworths
- Jagadish, et al., (1981). A Manual of Soil Block Construction, Alternative Building Series-I, Centre for Application of Science and Technology (ASTRA), Indian Institute of Science. Bangalore, India.
- John, W., & Sons, (2002). Mikell P. Groover, Fundamentals of Modern Manufacturing, U.S.A.
- John, W. & Sons, (2003) Callister W.D. Jr., Materials Science & Engineering an Introduction, U.S.A.
- Kerali, A.G, (2001). Working paper, Destructive effects of moisture on Long-Term Durability

of Stabilised Soil Blocks, Development Technology Unit, University of Warwick,
<http://www.eng.warwick.ac.uk/DTU/>

- LAL.A.K., (1995). Hand book of Low Cost Housing. New Age International (p) Ltd.
- Lawson, W. (1991). Materials for Low Cost Building in North Eastern Nigeria. Working Paper No. 35, Development Technology Unit, University of Warwick. Coventry, England.
- Lunt, M.G. (1980). Stabilised Soil Blocks for Building. Overseas Building Note No. 184. Building Research Establishment. February 1980. Garston, England.
- Minke, G. (1983). Low cost housing. Appropriate construction techniques with loam, sand, and plant stabilised earth. In Colloque L'habitat Economique dans les PED. Presses Ponts et Chaussees. Paris, France.
- Montgomery, D.E. (2002). Dynamically-compacted cement stabilised soil blocks for low-cost walling, University of Warwick, School of Engineering, England.
- MoWHPP. (1985). Kenya Low Income Housing Project Report. Ministry of Works, Housing and Physical Planning. Nairobi, Kenya.
- Mukerji, K. (1994). Stabilisers and Mortars for Compressed Earth Blocks. Product Information. German Appropriate Technology Exchange. GATE. Eschborn, Germany.
- Mukerji.K.,(1988). Soil Block Presses. Product Information, German Appropriate Technology Exchange (GATE). Eschborn, Germany.
- Norton. J. (1997). Building with Earth. A Handbook. 2nd Edn. Intermediate Technology Publications Ltd. London, England.
- Okello, W. (1989). Namuwongo Low Cost Housing and Slum Upgrading Project Report. World Bank/Ministry of Housing Project. Kampala, Uganda.
- Riedijk, W. (Ed.) (1984). Appropriate Technology for Developing Countries. Delft University Press. Delft, Netherlands.
- Rigassi, V. (1995). Compressed Earth Blocks: Manual of Production. Vol. 1. CRATerre-EAG. Vilefontaine Cedex, France.
- Rigassi.V. & Craterre-ERG., (1985). Compressed Earth Blocks: Manual of production, A publication of the Deutsches Zentrum fur Entwicklungstechnologien-Gate Volume-1.
- Satprem. M. (2006). Modernity of Earthen Architecture, presentation on National Alternative Building materials workshop Addis Ababa, Ethiopia.
- Satprem,.M.(2006). Production and use of Compressed Stabilized Earth Blocks, Auroville Earth Institute, India.
- Skempton .A. W. (1953).“The colloidal "activity" of clays,” Proceedings, 3rd Int'l Conf. Soil

- Mechanics and Foundation Engineering, Zurich, 1, 57-61.
- Spon.E.&F.N. Ltd, London .(1985). Appropriate Building Materials for Low Cost Housing African region, proceedings of a symposium held in Nairobi Kenya from 7 to 14.
- Suare, T.I. (1974). Stabilised Soil Blocks. Building Research Unit Data Sheet, BRU. Dar es Salaam, Tanzania.
- Terre.C.R.A.(1991). The Basics of Compressed Earth Blocks, A publication of the Deutsches Zentrum fur Entwicklung technologien-Gate.
- Tomas.T., (1981).Institute of Civil Engineers. Appropriate Technology in Civil Engineering. Ltd. London.
- Webb.D.T.J., Lockwood .A.J. (1987). BREPAK Operators Manual. Overseas Development Administration. Building Research Establishment Client Report. Department of the Environment. Garston, England.

APPENDICES

APPENDIX A

Soil Testing Laboratory

Table A1 Natural moisture content
 Determination for Garab-Ase Soil
 Method used ASTM C-128
 Sample no: Lab/No 353/05
 Depth Description of Sample: sandy soil

Tested by: Abdulkadir
 Project: M.Sc. Thesis
 Location: Jijiga, Garab-ase Area
 Date: 29/01/2013

Type of test	LL	LL	LL	LL
Container No.	60	11	157	281
No. of Blows	34	28	22	16
Wt. of sample + Tare wet	40.980	39.500	34.830	38.390
Wt. of sample + Tare dry	36.670	34.990	30.740	32.380
Wt. of water	4.310	4.510	4.090	6.010
Tare	16.470	16.790	14.930	14.930
wt. of dry soil	20.200	18.200	15.810	17.450
Water content %	21.337	24.780	25.870	34.441

Table A2 Plastic Limit Determination for Garab-Ase soil

Method used BS test 2(A) & 2 (B)
 Sample no: Lab. NO 353/05
 Depth Description of Sample: sandy soil

Tested by: Abdulkadir
 Project: M.Sc. Thesis
 Location: Jijiga, Garab-Ase Soil
 Date: 29/01/2013

Type of test	PL	PL	
Container No.	8w	55	
Wt. of sample + Tare wet	28.900	28.280	
Wt. of sample + Tare dry	27.440	26.840	
Wt. of water	1.460	1.440	
Tare	16.340	16.300	
wt. of dry soil	11.100	10.540	
Water content %	13.153	13.662	13.41

Table A3 Plastic Limit Determination for Karamara Soil

Method used BS test 2(A) & 2 (B)
 Sample no:Lab. NO 354/05
 Depth Description of Sample: sandy soil

Tested by: Abdulkadir
 Project:M.Sc.Thesis
 Location:Jijiga, Karamara
 Date:29/01/2013

Type of test	PL	PL
Container No.	52	G1
Wt.of sample + Tare wet	37.480	36.960
Wt.of sample + Tare dry	34.370	33.890
Wt.of water	3.110	3.070
Tare	16.870	16.460
wt.of dry soil	17.500	17.430
Water content %	17.771	17.613
PL content %	17.69	

Table A4 Liquid Limit determination for Karamara Soil

Method used BS test 2(A)& 2 (B)
 Sample no:Lab/No 354/05

Depth Description of Sample:sandy soil

Tested by: Abdulkadir
 Project:M.Sc.Thesis
 Location:Jijiga, Karamara soil
 Date:29/01/2013

Type of test	LL	LL	LL	LL
Container No.	357	330	244	173
No. of Blows	34	28	22	16
Wt.of sample + Tare wet	37.820	44.590	37.250	36.680
Wt.of sample + Tare dry	33.660	38.550	32.170	31.370
Wt.of water	4.160	6.040	5.080	5.310
Tare	14.540	15.180	15.080	14.530
wt.of dry soil	19.120	23.370	17.090	16.840
Water content %	21.757	25.845	29.725	31.532

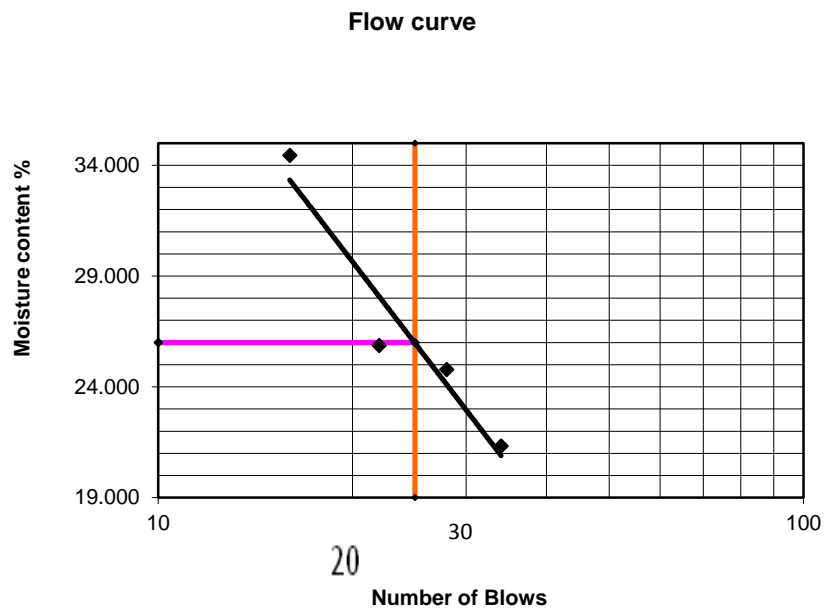


Fig A1 Flow Curve for moisture content determination for Garab-Ase soil

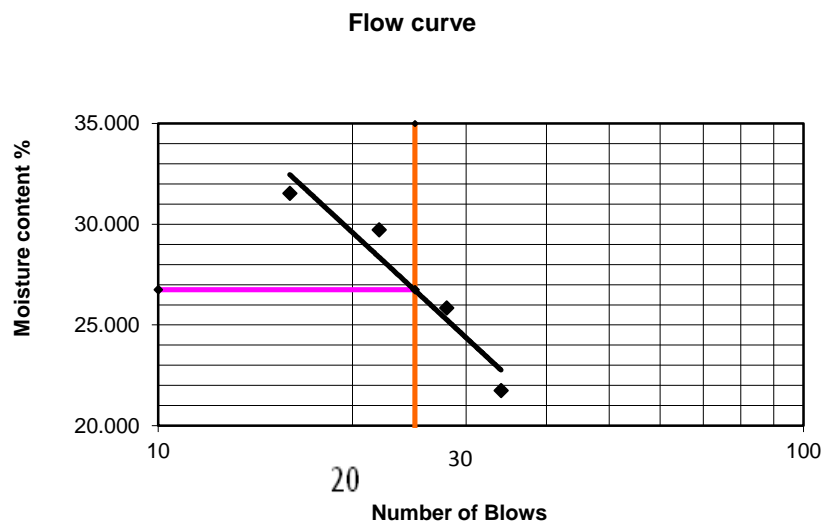


Fig A 2 Flow Curve for moisture content determination for Karamara soil

Table A5 Hydrometer Analysis/Grain-Size Analysis for Garab-Ase Soil
Method used BS 1377: 1975, Test 12 &

13

Project : Thesis
Client : AbdulkadirBeshir
Location Jigjiga Garab-Ase Soil
BH-No. Garab-Ase
Depth(m) : -

Total mass of sample, g 50

Sieve No	Sieve Opening (mm)	Mass of Sieve(g)	Mass of sieve + Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2.00	551.10	551.10	0.00	0.00	0.00	100.00
No 16	1.18	538.90	541.09	2.19	4.52	4.52	95.48
No 30	0.60	516.70	520.46	3.76	7.76	12.29	87.71
No 50	0.30	488.20	493.50	5.30	10.94	23.23	76.77
No 100	0.15	481.90	489.46	7.56	15.61	38.84	61.16
No 200	0.08	459.20	466.02	6.82	14.08	52.92	47.08
pan			0.00	0.00	0.00	0.00	0.00

<i>Specific Gravity of soil</i>		<i>2.59</i>		<i>Test Temperature, deg.c</i>			<i>22.0</i>	
<i>Elapsed Time (min)</i>	<i>Actual Hydrometer Reading</i>	<i>Temperature deg.c</i>	<i>Corrected Hydrometer Reading</i>	<i>Effective Depth (cm)</i>	<i>Coefficient (K)</i>	<i>Grain Size (mm)</i>	<i>Percentage Finer Combined</i>	
2	23.5000	22.0	17.0000	13.50	0.01353	0.0352	35.60	
5	22.0000	22.0	15.5000	13.80	0.01353	0.0225	32.46	
15	20.5000	22.0	14.0000	14.00	0.01353	0.0131	29.32	
30	19.5000	22.0	13.0000	14.20	0.01353	0.0093	27.23	
60	19.0000	22.0	12.5000	14.30	0.01353	0.0066	26.18	
250	17.0000	22.0	10.5000	14.50	0.01353	0.0033	21.99	
1440	16.0000	22.0	9.5000	14.80	0.01353	0.0014	19.90	

Hydrometer Analysis

<i>Specific Gravity of soil</i>		2.59	<i>Test Temperature, deg.c</i>			22.0	
<i>Elapsed Time (min)</i>	<i>Actual Hydrometer Reading</i>	<i>Temperatures deg.c</i>	<i>Corrected Hydrometer Reading</i>	<i>Effective Depth (cm)</i>	<i>Coefficient (K)</i>	<i>Grain Size (mm)</i>	<i>Percentage Finer Combined</i>
2	23.5000	22.0	17.0000	13.50	0.01353	0.0352	68.88
5	22.0000	22.0	15.5000	13.80	0.01353	0.0225	62.80
15	20.5000	22.0	14.0000	14.00	0.01353	0.0131	56.72
30	19.5000	22.0	13.0000	14.20	0.01353	0.0093	52.67
60	19.0000	22.0	12.5000	14.30	0.01353	0.0066	50.65
250	17.0000	22.0	10.5000	14.50	0.01353	0.0033	42.54
1440	16.0000	22.0	9.5000	14.80	0.01353	0.0014	38.49

Table A6 Hydrometer Analysis/Grain-Size/ For Karamara Soil

Method used BS 1377: 1975, Test 12 & 13

Project : Thesis
 Client : Abdulkadir Beshir Ahemed
 Location : Jigjiga Soil Karamara Pit
 BH-No. : Karamara Soil
 Depth(m) :
 :
 Sam. Type : Disturbed
 Test Type : Hydrometer
 Date : 29/01/13
 Lab No: 354/05

Total mass of sample, g 50

Sieve No	Sieve Opening(mm)	Mass of Sieve(g)	Mass of sieve + Ret .soil(g)	Mass of Ret. soil (g)	Percentage Retained	Cumulative % Retained	Percentage Passing
No 10	2.00	551.10	551.10	0.00	0.00	0.00	100.00
No 16	1.18	538.90	539.61	0.71	1.47	1.47	98.53
No 30	0.60	516.70	519.24	2.54	5.24	6.71	93.29
No 50	0.30	488.20	491.01	2.81	5.80	12.51	87.49
No 100	0.15	481.90	484.29	2.39	4.93	17.45	82.55
No 200	0.08	459.20	462.26	3.06	6.32	23.77	76.23
pan			0.00	0.00	0.00	0.00	0.00

Specific Gravity of soil		2.60	Test Temperature, deg.c			22.0	
Elapsed Time (min)	Actual Hydrometer Reading	Temperature deg.c	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient (K)	Grain Size (mm)	Percentage Finer Combined
2	36.0000	22.0	29.5000	11.30	0.01353	0.0322	60.94
5	33.5000	22.0	27.0000	11.90	0.01353	0.0209	55.77
15	29.0000	22.0	22.5000	12.70	0.01353	0.0124	46.48
30	26.0000	22.0	19.5000	13.20	0.01353	0.0090	40.28
60	23.0000	22.0	16.5000	13.70	0.01353	0.0065	34.08
250	16.5000	22.0	10.0000	10.70	0.01353	0.0028	20.66
1440	15.0000	22.0	8.5000	15.00	0.01353	0.0014	17.56

<i>Specific Gravity of soil</i>		Hydrometer Analysis				22.0	
		2.60	<i>Test Temperature, deg.c</i>				
<i>Elapsed Time (min)</i>	<i>Actual Hydrometer Reading</i>	<i>Temperature deg.c</i>	<i>Corrected Hydrometer Reading</i>	<i>Effective Depth (cm)</i>	<i>Coefficient (K)</i>	<i>Grain Size (mm)</i>	<i>Percentage Finer Combined</i>
2	36.0000	22.0	29.5000	11.30	0.01353	0.0322	60.08
5	33.5000	22.0	27.0000	11.90	0.01353	0.0209	54.99
15	29.0000	22.0	22.5000	12.70	0.01353	0.0124	45.83
30	26.0000	22.0	19.5000	13.20	0.01353	0.0090	39.72
60	23.0000	22.0	16.5000	13.70	0.01353	0.0065	33.61
250	16.5000	22.0	10.0000	10.70	0.01353	0.0028	20.37
1440	15.0000	22.0	8.5000	15.00	0.01353	0.0014	17.31

Table A7 Compaction Test for Garab-Ase Soil

Method used BS 1377: 1975, Test 12 & 13

Project: Thesis Project

Client: Abdulkadir Beshir Ahmed

Location: Jigjiga Garab-Ase

Test Pit: Garab-Ase Pit

Depth(m)

Sample type: Disturbed Clay mat'l

Test Type: Standard Proctor Test

Date 29/01/2013

Lab No 353/05

Lab. Test No. 353/05	1	2	3	4	5
Water in cc	180	240	300	360	420
Wt. of mould +Wet sample (g)	3530.23	3632.1	3693.6	3612.3	3578.9
Wt. of mould (g)	1693.8	1693.8	1693.8	1693.8	1693.8
Wt. of wet soil(g)	1836.43	1938.3	1999.8	1918.5	1885.1
Volume of mould cm ³	944	944	944	944	944
Wet Density gm /cm ³	1.95	2.05	2.12	2.03	2
Moisture content	1	2	3	4	5
Tin No.	11	z9	45	b12	5
Wet soil + tin (g)	172.89	154.08	273.13	241.32	231.93
Dry soil + tin (g)	159.18	138.79	238.63	206.97	197.68
Wt of tin (g)	16.77	16.67	16.53	16.8	16.33
Wt of Water (g)	13.71	15.29	34.5	34.35	34.25
Wt of Dry soil (g)	142.41	122.12	222.1	190.17	181.35
Moisture content %	9.63	12.52	15.53	18.06	18.89
Dry Density gm /cm ³	1.775	1.825	1.834	1.721	1.68
ZeroAirVoids100%	2.07	1.96	1.85	1.76	1.74

Table A8 Compaction Test for Karamara Soil

Method used BS 1377: 1975, Test 12 & 13

Project: Thesis Project

Client: Abdulkadir Beshir Ahmed

Sample type: Disturbed Clay mat'l

Location: Jigjiga Karamara

Test Type: Standard Proctor Test

Test Pit: Karamara Pit

Date 29/01/2013

Depth(m)

Lab No 354/05

Lab. Test No. 353/05	1	2	3	4
Water in cc	180	240	300	360
Wt. of mould +Wet sample (g)	3599.1	3663.3	3687.0	3558.6
Wt. of mould (g)	1693.8	1693.8	1693.8	1693.8
Wt. of wet soil(g)	1905.3	1969.5	1993.2	1864.8
Volume of mould cm ³	944	944	944	944
Wet Density gm /cm ³	2.02	2.09	2.11	1.98
Moisture content	1	2	3	4
Tin No.	7	M15	D	AB
Wet soil + tin (g)	163.93	181.36	209.8	259.69
Dry soil + tin (g)	148.49	161.9	183.58	216.42
Wt of tin (g)	16.54	16.61	16.31	16.29
Wt of Water (g)	15.44	19.46	26.22	43.27
Wt of Dry soil (g)	131.95	145.29	167.27	200.13
Moisture content %	11.70	13.39	15.68	21.62
Dry Density gm /cm ³	1.807	1.840	1.825	1.624
ZeroAirVoids100%	1.99	1.84	1.76	1.60

Appendix B

Table B1 Chemical Composition for Garab-Ase soil at Jigjiga area

Profile Code	Grab- Ase
CaO%	33.67
MgO%	14.59
MnO%	10.23
SO ₃ %	0.5
Na ₂ O%	16.36
K ₂ O%	17.16
Al ₂ O ₃ %	0.022
Fe ₂ O ₃ %	0.52
SiO ₂ %	10
LOI%	5
PH	6.5

Appendix C

Table C 1 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Contents at age of Seven days

Marking and Cement Content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	
				L	W	H			
6%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2273	0.9
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2309	1
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2291	0.9
8%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2345	1.1
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2345	1
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2346	1.1
10%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2436	1.2
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2418	1.2
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2418	1.1

Table C 2 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jijjiga Area for 6%, 8% and 10% cement Content at age of Fourteen days

Marking and Cement Content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	
				L	W	H			
6%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2273	2.5
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2309	2.6
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2291	2.6
8%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2284	2.7
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2210	2.8
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2245	2.7
10%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2436	3
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2418	3.1
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2418	3.1

Table C 3 Compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Twenty Eight days

Marking and Cement Content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	
6%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2289	2.6
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2217	2.7
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2261	2.7
8%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2284	3
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2210	3
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2245	3.1
10%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2402	3.8
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2349	3.9
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2381	3.8

Table C 4 Mean compressive strength test results using Dire-Dawa National Cement for the Garab-Ase soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven, Fourteen and Twenty Eight days

Cement Content in (%)	Mean Compressive Strength in (MPa)		
	7 Days	14 Days	28 Days
6%	0.93	2.57	2.67
8%	1.07	2.73	3.03
10%	1.17	3.07	3.83

Appendix D

Table D 1 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven days

Marking and Cement content in (%)		Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)
					L	W	H		
6%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	1964	1.1
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	1964	1
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	1964	1.1
8%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2127	1.5
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2127	1.4
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2127	1.4
10%	1	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2090	1.4
	2	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2090	1.5
	3	25/03/2013	1/4/2013	7	0.25	0.1	0.22	2090	1.5

Table D 2 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Fourteen days

Marking and Cement content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	
				L	W	H			
6%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	1964	2.7
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	1964	2.5
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	1964	2.6
8%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2127	2.9
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2127	2.9
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2127	3
10%	1	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2090	3.1
	2	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2090	3
	3	25/03/2013	8/4/2013	14	0.25	0.1	0.22	2090	3.1

Table D 3 Compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Twenty Eight days

Marking and Cement content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	
				L	W	H			
6%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	1964	3.8
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	1964	3.9
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	1964	3.7
8%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2194	3.9
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2012	4
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2187	4.1
10%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2090	4.6
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2095	4.6
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2098	4.7

Table D 4 Mean compressive strength test results using Dire-Dawa National Cement for the Karamara soil Jigjiga Area for 6%, 8% and 10% cement Content at age of Seven, Fourteen and Twenty Eight days

Cement Content in (%)	Mean Compressive Strength in (MPa)		
	7 Days	14 Days	28 Days
6%	1.07	2.6	3.8
8%	1.43	2.93	4
10%	1.47	3.07	4.63

Appendix E

Table E 1 Effect of 10MPa Compaction pressure at age of 28 days using Garab-Ase Soil with 6%, 8% and 10% cement contents

Marking and Cement content in (%)	Date Casted	Date Tested	Age in Days	Dimension in (m)			Unit Weight in (Kg/m ³)	Compressive Strength in (MPa)	Average Strength in (MPa)	
				L	W	H				
6%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2273	2.5	2.43
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2309	2.4	
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2291	2.4	
8%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2381	3	3.1
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2340	3.1	
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2297	3.2	
10%	1	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2289	3.9	3.97
	2	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2217	3.9	
	3	25/03/2013	22/4/2013	28	0.25	0.1	0.22	2267	4.1	