THE EFFECT OF QUARRY DUST CONCRETE OVER RED SOIL MEDIUM AS SUB-BASE ON THE STRUCTURAL PERFORMANCE OF DWELLING HOUSE GROUND FLOORS

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The Effect of Quarry Dust Concrete over Red Soil Medium as Sub-Base on the Structural Performance of Dwelling House Ground Floors

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DECLARATION

This thesis is my original work and has not been presented for a Degree in any other university

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DEDICATION

This thesis I dedicate to my family who have had to endure loneliness with my several absences from home for this work. And not forgetting my late lovely mum who has been quite an encouragement, always urging me on until Gods will prevailed in may 2016 when she went to be with HIM. May her soul rest in eternal peace.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAC	Autoclaved aerated concrete
ASTM	American standard test measurement
BS	British standards
CH	Clay of high plasticity
CEMs	Concrete-equivalent mortars
CL	Clay of low plasticity
CP	Code of practice
GHG	Green house gases
ID	Identification
ITZ	The interfacial transition zone .
LVDTs	Linear variable displacement transducers
ML	Silt of low plasticity
PSD	Particle size distribution
t PVC	Termiticide-impregnated polyethylene vapour barrier
UCS	Unconfined compression test
USCS	Universal soil classification system

ABSTRACT

This research sought to establish the effect of quarry dust concrete and the underlying subsoil medium on structural performance of dwelling houses ground floors. The research work was geared towards sustainable construction by using locally available materials which are eco-friendly. Housing being one of the basic needs, but its cost is beyond reach of many especially permanent housing. And in conventional construction of the floor bed in this country, even where raising of the levels is not required, hardcore filling is normally done as a sub-base just the same way a paved road would be done, not bearing in mind the difference in loadings between a road and a building floor. The aggregates in use were classified as the conventional 20 mm volcanic rock, graded 5-14 mm, non-graded volcanic rock quarry dust and Nairobi sedimentary rock quarry dust besides river sand and red soil(sandy silty clay with traces of gravel). All the material properties were determined to British and American standards . Concrete slabs class 15 (1:3:6 nominal mix) of one meter squared but in thickness of 150 mm and 100 mm, three each for the various aggregates were cast, cured for 28 days and tested over red soil compacted to maximum dry density by loading on loading jacks for compression and strain on their surfaces through strain gauges attached to a data logger. The hardened concrete from the various aggregates was further tested for compression in a compression machine on concrete cubes cured for 28 days. Another very important parameter of a floor, water seepage was also put to test for the various concrete aggregates. The cured concrete from the various aggregates were subjected to same water heads in special designed containers and water percolating measured by scale rule. All the aggregates were permeable after testing for 28 days, all allowing up to between 16 mm and 20 mm of water passage under the same conditions with the smaller sized aggregates allowing in more water than the single sized 20 mm volcanic rock aggregates which was the largest size used in the research.

For 150 mm thick slabs, the 20 mm ,5-14 mm, non-graded quarry dust and Nairobi sedimentary rock dust crushed at 33,32,22,21 N/mm^2 respectively and for 100 mm thick slabs 20mm, 5-14 mm, non-graded quarry dust and Nairobi sedimentary rock dust crushed at 29,28,12,8 N/mm^2 respectively. Thus 150 mm thick slabs for all aggregates and only 20 mm and graded5-14 mm for 100 mm aggregate slabs crushed above allowable imposed design load 1.5kN/m^2 for dwelling floors. The soil(sandy silty clay) when optimally compacted can safely transmit the loads of a dwelling house floor for graded aggregates from 100 mm thick but for non graded the thickness has to be minimum 150 mm.

CHAPTER ONE

INTRODUCTION

1.1 Background information

The construction industry has received on-going criticism for its lack of innovation (Nam, 1989; Miozzo, 2004; Reichstein et al., 2005; Drejer & Vinding, 2006) and numerous authors have expounded the specific challenges of innovating in the context of the built environment (Blayse & Manley, 2004; Dewick & Miozzo, 2004). One of the unique challenges of innovation in construction is that novel solutions are typically not adopted within organisations, but in the context of one-off projects (Dewick & Miozzo, 2002).

A building concrete ground floor bed can be said to be a concrete slab resting on and supported by the subsoil usually forming the ground floor surface. Concrete slabs (sometimes called over site concrete) are usually cast on a layer of hard-core which is used to make up the reduced level excavation and thus raise the level of the concrete bed to a position above ground level.

Mass concrete class 15/20 (1:3:6 nominal mix) is recommended for use in dwelling ground floors (Chudley et al., 2008) . Thickness for domestic floor slabs is usually 100 mm to 150 mm and the bed is constructed so as provide the structural requirement of transmission of loads to the ground and to prevent the passage of moisture from the ground to the upper surface of the floor, which is usually achieved by incorporating into the design a damp proof membrane. Concrete in the above mix is composed of cement particles, aggregates and water (Chidiac & Mahmoodzadeh, 2009).

This study sought to design the slab by substituting the mass concrete with a quarry dust concrete and laying it on stable compacted subsoil to raise the level of the concrete bed, rather than the hardcore filling, and incorporating the damp-proof membrane. The design was checked against structural soundness and domestic house floor functionality.

1.2 Statement of the Problem

Housing is one of the basic needs for human beings but decent houses are beyond reach for many, especially concrete floored housing. Much research has been taking place on affordable and sustainable construction techniques and materials to make for decent housing. Researchers have come up with innovations for dry walls, wall panels, stabilized blocks, plastic ceilings and many different types of roofing and other techniques. There is no much research on new techniques of construction of the structural ground floor, especially the floor bed which conventionally is done in concrete (cement, sand, ballast, water). Concrete being one of the main components of a permanent structure with quite a substantial cost and not readily available in all places for good concrete is from volcanic rocks and similarly the hardcore used for filling. In conventional construction of the floor slab in this country even where raising of the levels is not required, hardcore filling is normally done as part of substructure filling just the same way a paved road would be done not bearing in mind the difference in loadings between a road and a building floor and the ground conditions. When laying hardcore, red soil is scooped out and replaced. The conventional concrete slab used in Kenya today is an adoption from mainly the British standards code of practice (BS 8110) and it is used indiscriminately almost in all soil type formations. This research sought to establish the effect of quarry dust concrete and the red soil as sub base on the ground floor for structural soundness to meet engineering requirements. In these times of scarce resources, especially natural resources such as stone, it is also important to utilize all the products available such as quarry dust and natural ground formation.

1.3 Justification of the Research

One of the factors that have prompted the research into this area is the local traditional practice. Over time again the practice has been that home owners in the villages have been building floor beds by simply laying a cement /sand screed over the hard-core or stabilised ground and this has somehow been working as the floors have satisfied their functional requirements without any major failures. This has led to the conclusion from the research that the conventional flooring practice is somewhat structurally over designed for domestic housing especially on stable soils (granular) which also have no moisture rise problem since the water table is deeper and their bearing capacity is also good.

Production and transportation of many engineering construction materials requires high amounts of energy and has high levels of GHG (greenhouse gas) emissions associated with it (Anderson 2000) This has a detrimental impact on the environment especially with the recent realization of the severity of climate change and global warming. Concrete is one of the most widely used construction materials and has CO_2 emissions associated not just with the manufacturing process of cement, but also transport of ingredients over long distances. One of the solutions to reduce the environmental impact of concrete is to use more environmentally friendly ingredients and reduce the amount of transportation required in shipping these ingredients and/or the finished material.

1.4 Objectives

1.4.1 General Objective

- To investigate effects of quarry dust concrete over red soil as a sub-base on structural performance of a ground floor slab.

1.4.2 Specific objectives

- To determine the effect of varying depths of quarry dust concrete on the structural soundness and engineering properties of a ground floor slab.
- To establish the effect of different types of quarry dust as coarse aggregate in concrete floor to meet the functional requirements of a ground floor slab.
- To find out the effect of red soil as a sub base on ground floor stability

1.5 Research Questions

- How does varying of depth of quarry dust concrete affect the structural soundness and engineering properties of a ground floor slab?
- What is the effect of different types quarry dust as a coarse aggregate in concrete floor in meeting the functional requirements of a ground floor slab?
- How does the compacted red soil as a sub-base affect the stability of a ground floor slab?

1.6 Scope and Limitations

1.6.1 Scope

While different types of quarry dust are available in Kenya, this research investigated only the volcanic rock and Nairobi sedimentary rock quarry dust. This is as well to the granular soil used for there are various types of granular soils with different properties, the soil investigated in this research was the Juja (Kiambu county) red soil (a sandy silty clay with traces of gravel).Data published regarding domestic quarry dust ground floor slabs structural soundness and functionality is limited to these materials though other materials with similar properties could benefit from the findings.

The floor under research was also limited to domestic housing floors.

1.6.2 Limitations

The concrete slabs were tested for water seepage in improvised moulds because permeability apparatus could not be found. Proper permeability apparatus could have achieved more reliable results.

CHAPTER TWO

LITERATURE REVIEW

2.1. The Floor Slab

Concrete floor beds are the most commonly floors used for both suspended and ground floors. This may be informed by their versatility, availability and as well cost considerations because there are other types such as suspended ground timber floors, and steel sheet floors which are not commonly used. Flooring for ground floors in dwelling housing in normally done in concrete class 15/20 mm nominal mix (1:3:6) is recommended for use on ground floors (Chudley and Greeno, 2008). Thickness for domestic work is usually 100 mm to 150 mm and the bed is constructed so as to prevent the passage of moisture from the ground to the upper surface of the floor, this is usually achieved by incorporating into the design a damp proof membrane. Concrete in the above mix is composed of cement particles, aggregates and water (Chidiac & Mahmoodzadeh, 2009).

Concrete slab floors come in many forms and can be used to provide great thermal comfort and lifestyle advantages. Slabs can be on-ground, suspended, or a mix of both. They can be insulated, both underneath and on the edges. Conventional concrete has high embodied energy. It has been the most common material used in slabs but several new materials are available with dramatically reduced ecological impact. (Chidiac & Mahmoodzadeh 2009).

2.1.1 Different Types of Floor Slabs

Some types of concrete floor slabs may be more suitable to a particular site and climate zone than others. The various types are discussed below.

(i) Slab-on-ground

Slab-on-ground is the most common and has two variants: conventional slabs with deep excavated beams and waffle pot slabs, which sit near ground level and have a grid of expanded polystyrene foam pots as void formers creating a maze of beams in between. Conventional slabs can be insulated beneath the broad floor panels; waffle pods are by definition insulated beneath. Both may benefit from slab edge insulation. (Chidiac & Mahmoodzadeh, 2009).

(ii) Suspended Slab

A suspended concrete floor is a floor slab where its perimeter is, or at least two of its opposite edges are supported on walls, beams or columns that carry its self weight and imposed loading.

Suspended floors can be constructed in three basic forms:- (Chudley & Greeno, 2008).

1. As wholly of reinforced concrete
2. As floor consisting of reinforced or pre-stressed precast concrete units, usually spanning in one direction.
3. As floor comprising reinforced or pre-stressed precast concrete units overlaid by an in-situ concrete layer formed in such a way that it acts compositely with the precast concrete units.

(ii) Pre-cast Slab

Precast slabs are manufactured off site and craned into place, either in finished form or with an additional thin pour of concrete over the top. They can be made from conventional , post-tensioned reinforced concrete, or from autoclaved aerated concrete (AAC). (Chidiac & Mahmoodzadeh, 2009).

2.2 Concrete Aggregates

The mechanical and permeability properties of concretes are influenced by the water–cement ratio, the cement–aggregate ratio, the bond between mortar and aggregate, and the grading, shape, strength, and size of the aggregates (Neville, 2003). The influence of the last parameter, the size of aggregates on strength and permeability, is put in focus in this research because replacing the conventional concrete beds which has aggregates average size 20mm was replaced with quarry dust concrete with aggregate size average 8mm. Aggregate particles influence the microstructure of the cement paste surrounding them (Bentur, 2000). The zone of cement paste that is affected by the aggregate particle has been defined as the interfacial transition zone (ITZ). Moreover, most of the important properties of hardened concrete are related to the quantity and characteristics of various types of pores in the cement paste and aggregate components of the concrete. For example, the engineering properties of concrete, such as strength, durability, shrinkage, and transport, are directly influenced or controlled by the number, type, and size of pores present (Scrivener & Pratt, 1996).

The function of the bed in a floor as seen is mainly to support both live and dead loads as well as protect the surface of the floor from rising moisture. Live loading in a domestic house are relatively low and the dead loading from walls and roof are most of the time transmitted to the foundation through foundation walls. In as much the concrete strength both tensile and compressive was of interest in this research, permeability was also vital because if the aggregate has a very low permeability, its presence reduces the effective area over which flow can take place. Because the flow path has to circumvent the aggregate particles, the effective path becomes considerably longer so that the effect of the aggregate in reducing the permeability may be considerable. It can be concluded that increasing the aggregate size may decrease the permeability of mortar or concrete. (Mehta & Monteiro, 1993) stated that the introduction of low permeability aggregate particles into high permeability cement paste is expected to reduce permeability of the system because the aggregate particles should intercept the channels of flow within the cement paste matrix. Compared with a neat cement paste, therefore, a mortar or a concrete with the same water–cement ratio and degree of maturity should give a lower coefficient of permeability. Mehta &

Monteiro (1993) also stated that in practice, this does not happen. The addition of aggregate to a cement paste or a mortar increased the permeability considerably; in fact, the larger the aggregate size, the greater the coefficient of permeability. These discussions show that the effective area of aggregates has a considerable effect on the transport properties of concrete and mortar.

Aggregates must be suitable for use in concrete. Based on BS882 (1992), the table below indicates the overall grading of sand aggregates per each sieve, to determine suitability for use.

Table 2.1: Extract from BS 882-1992 on overall grading of sand aggregates

Sand overall grading		
% Passing by weight to BS 882		
Sieve sizes	**Lower Limit (LL)**	**Upper Limit(UL)**
10mm	100	-
5mm	89	100
2.36µm	60	100
1.18µm	30	100
600µm	15	100
300µm	5	70
150µm	0	15

2.3 The Subsoil

Construction using Rammed Earth (RE) that includes use of locally available soils stabilized with binders such as lime dates back many centuries.

RE structures utilize locally available materials with lower embodied energy and wasted materials than traditional method (Berg & Ryan et al., 2009).

The soil used for RE building is a widely available resource with little or no side effects associated with harvesting for use in construction. The soils used are typically subsoil, leaving topsoil readily available for agricultural uses. Often soil of reasonable quality can be found close to the location of construction, thus reducing the cost and energy for transportation. Significant cost savings can be achieved when earth (aggregates or soil) is used for construction since the material is generally inexpensive and readily available. If the amount of cement used in RE is carefully controlled, more cost savings can be achieved.

The red soil on which this research was carried out was also be a subject of interest. Floor beds were placed on reduced level red soil's and since subsoil behave differently under loading depending on type, physical properties and this affects the bearing capacity of each subsoil. This research was based on stable ground formations especially the granular soils was to substitute the hardcore filling as a sub base material instead use natural granular soil.

The internal stability of a granular soil mainly depends on three factors: the soil grain-size distribution, the soil relative density and the applied hydraulic gradient. Regarding the grain-size distribution, the concave upward soils, the gap-graded soils, and the broadly graded soils may be generally considered internally unstable. One major criterion that controls the design of shallow foundations on granular soils are the bearing capacity of the soil beneath the foundation and the settlement of the foundation. However, since excessive settlements often lead to serviceability problems, settlement usually governs the footing design process, particularly for shallow foundations wider than 1m (Sargand, 2003; Schmertmann, 1970).

Immediate settlement and consolidation settlement are the main components of shallow foundation settlement. In cohesive soils (silts and clays), as the load is applied the excess pore pressures dissipate slowly because of the low soil permeability. As a result, consolidation settlement may occur over a very long period of time. However, in coarse soils (sands and gravels), the focus of this research , increases in pore pressures are dissipated rapidly owing to the high soil permeability and any settlement resulting from a change in loading occurs more or less immediately. Most of the immediate settlement may be accommodated within the structure during or shortly after its construction by a considerable increase in the internal forces of the structure;

unfortunately, this can result in cracks through structural elements, and may even end in structural failure. (Mohammad & Javadi, 2007).

2.4 Benefits of Concrete Slabs

2.4.1 Thermal comfort

‘Thermal mass’ describes the potential of a material to store and re-release thermal energy. It is sometimes referred to as ‘building conditioning’, which is much more effective than air conditioning. Materials with high thermal mass, such as concrete slabs or heavyweight walls, can help regulate indoor comfort by acting like a temperature flywheel: by radiating or absorbing heat, they create a heating or cooling effect on the human body.

Thermal mass is useful in most climates, and works particularly well in cool climates and climates with a high day–night temperature range. To be effective, thermal mass must be used in conjunction with good passive design and should also consider the inclusion of high mass walls, as they can provide the benefits of ‘building conditioning’ instead of concrete slab floors (Clarke, 2012).

In winter, slabs should be designed so they can absorb heat from the sun (or other low energy sources). This heat is stored by the thermal mass and re-radiated for many hours afterwards (Clarke, 2012).

In summer, slabs must be protected from direct sunlight and exposed to cooling night breezes and night sky radiation so that heat collected during the day can dissipate. (Clarke & Smethurst, 2008).

A slab-on-ground can be ground coupled (uninsulated) or insulated. An uninsulated slab in a good passively designed house has a surface temperature approximately the same as the stable ground temperature at about 3 m depth. Depending upon your location, this may or may not be desirable. A study in Australia found out that ground coupling in mild climate zones allows the floor slab of a well insulated house to achieve the stable temperature of the earth: cooler in summer, warmer in winter. In winter, added solar gain boosts the surface temperature of the slab to a very comfortable level (Clarke, 2012). Locally insulation is not necessary because of the suitable climate thus the floor slabs here are ground coupled.

2.4.2 Durability

2.4.2.1. Long life — Concrete's high embodied energy can be offset by its permanence. If reinforcement is correctly designed and placed, and if the concrete is placed and compacted well so there are no voids or porous areas, concrete slabs can have an almost unlimited life span. (Mehta & Monteiro, 2006).

To ensure longevity of the slab, control cracking with:

- Proper preparation of foundations
- Appropriate water content: excess water causes cracking and weakens the slab
- Appropriate placing and compaction
- Appropriate curing, employing a curing membrane in the first 3–7 days (continuous wetting is a common practice but also consumes large amounts of water)
- Appropriate construction scheduling allowing 28 days, or the duration specified by the structural engineer, for the concrete to reach design strength before placing significant loads. (Chudley & Greeno, 2008).

2.4.3 Termite resistance

For minimum termite risk construction, concrete slabs should be designed and constructed in accordance with British Standards codes of practice (BS8110) to have minimal shrinkage cracking. Joints, penetrations and the edge of the slab should be treated.

- Slab edge treatment can be achieved simply by exposing a minimum 100mm of slab edge above the ground or pavers, forming an inspection zone at ground level.
- Where a brick cavity extends below ground, physical barriers must be installed using sheet materials including stainless steel, a termiticide-impregnated

polyethylene vapour barrier (t PVC) and/or damp course, a fine stainless steel mesh, or finely graded stone.

- Pipe penetrations through concrete slabs require a physical barrier. Options include sheet materials such as t PVC, stainless steel mesh or graded stone.
- Although physical barriers are environmentally preferable, chemical deterrents are also available, which must be reapplied at regular intervals to maintain efficacy. Benign natural deterrents can be applied by permanent reticulation pipe work similar to a drip irrigation system.

2.5 Functions of concrete slabs

The function of the bed in a floor as seen is mainly to support both live and dead loads as well as protect the surface of the floor from rising moisture. Live loading in a domestic house are relatively low and the dead loading from walls and roof are most of the time transmitted to the foundation through foundation walls. Moisture rise is caused by the floor being permeable and this is influenced by the aggregates because if the aggregate has a very low permeability, its presence reduces the effective area over which flow can take place. Because the flow path has to circumvent the aggregate particles, the effective path becomes considerably longer so that the effect of the aggregate in reducing the permeability may be considerable. (Chudley & Greeno, 2008).

2.6 Traditional Practice

It has been observed over the years that floor slabs in the villages are constructed simply by either laying a screed over blinded hardcore fill or over a compacted red soil or murram surface. These floors have functioned well from the early 80s since then, they are still working to date. This has been observed around Nandi and Vihiga counties and the soil formations here are quite stable.

2.7 Concrete

Producing sustainable concrete with a low carbon foot print is a global desire. It is well known that the production of (Ordinary Portland cement) OPC produces a carbon foot print of about 1000 kg/m3 (Malhotra & Mehta, 2008). One solution to reduce the high and unaccepted construction emissions is by reducing the cement in the concrete mix (Elchalakani & Elgaali, 2010). Hence a modified concrete slab on ground floor for residential houses by omitting the conventional slab will reduce the amount of cement in the concrete.

The quality of concrete is a very important subject at the present time. As a result, the importance of quality tests on aggregate, the material with the highest percentage in concrete, has increased. The tests used for determining concrete quality are generally about gradation, water absorption, specific gravity, and the amount of micro fine material passing the 0.063mm sieve. It is also important to determine the organic or humus content of fine aggregate because fine organic or humus material can cause deterioration on strength development and compressive strength of concrete (Neville, 2003).

According to Mehta & Monteiro (2006), increasing the aggregate size may decrease the permeability of mortar or concrete. They further found out that the introduction of low permeability aggregate particles into high permeability cement paste is expected to reduce permeability of the system because the aggregate particles should intercept the channels of flow within the cement paste matrix. compared with a neat cement paste, therefore, a mortar or a concrete with the same water–cement ratio and degree of maturity should give a lower coefficient of permeability. Mehta & Monteiro (2006) also stated that in practice, this does not happen. The addition of aggregate to a cement paste or a mortar increased the permeability considerably; in fact, the larger the aggregate size, the greater the coefficient of permeability

Scrivener & Pratt (1996) in a study found out that compressive and split tensile strengths of concrete and CEMs (concrete-equivalent mortars) increased as the maximum aggregate size increased. The rate of increment was very little between the concrete produced with 22.4 and 16mm maximum aggregate sizes. The same situation was valid for the CEMs produced with maximum aggregate sizes of 8 and 4 mm.

The lowest chloride ion permeability was observed in the concrete produced with maximum aggregate size of 16mm. Decreasing the maximum aggregate size of concrete produced with 22.4 to 16 mm decreased the chloride ion permeability significantly; however, decreasing the maximum aggregate size below 16mm increased the chloride ion permeability drastically.

Water sorptivity values of concrete and CEMs increased while decreasing the maximum aggregate size. The rate of increment was very distinctive at 7days. The highest rate of reduction with the extended curing time was observed at the CEM produced with maximum aggregate size of 4mm.

Water absorption values of concretes produced with maximum aggregate sizes of 22.4 and 16mm were very close to each other at both testing ages. This situation was the same for the CEMs produced with 8 and 4 mm maximum aggregate sizes. Moreover, a significant water absorption increase was observed when decreasing the maximum aggregate size from 16 to mm.

Water permeability values of concrete and CEMs decreased drastically with an increase in the maximum aggregate size at 7 days. However, at 28 days, water permeability values did not change significantly. All of the produced concrete and CEMs can be classified as resistant to chemical attack in aggressive media.

When predicting the service life of a concrete structure, transport parameters such as permeability and diffusivity are the key inputs. Moreover, studies on the coupling effect of ion/gas penetration, freezing–thawing, loading, etc. on the properties of concrete have been found to affect durability of concrete too (Chung et al., 2010; Li et al., 2011). When evaluating these basic concrete parameters, concrete sections having consistent properties were assumed, which, however, always under or overestimate the real values. For example, constants representing the concrete properties of cement-based materials of permeability, diffusivity may vary according to the variations of physical (Djerbi et al., 2008), chemical (Schwotzer et al., 2010) and electrochemical features of the gel, and these are the core features of the real concrete (Schwotzer et al., 2010). Although equations were proposed for obtaining these time and location dependent parameters (Mangat & Molloy, 1994), their relationships with the alteration of the gel properties has been rarely reported.

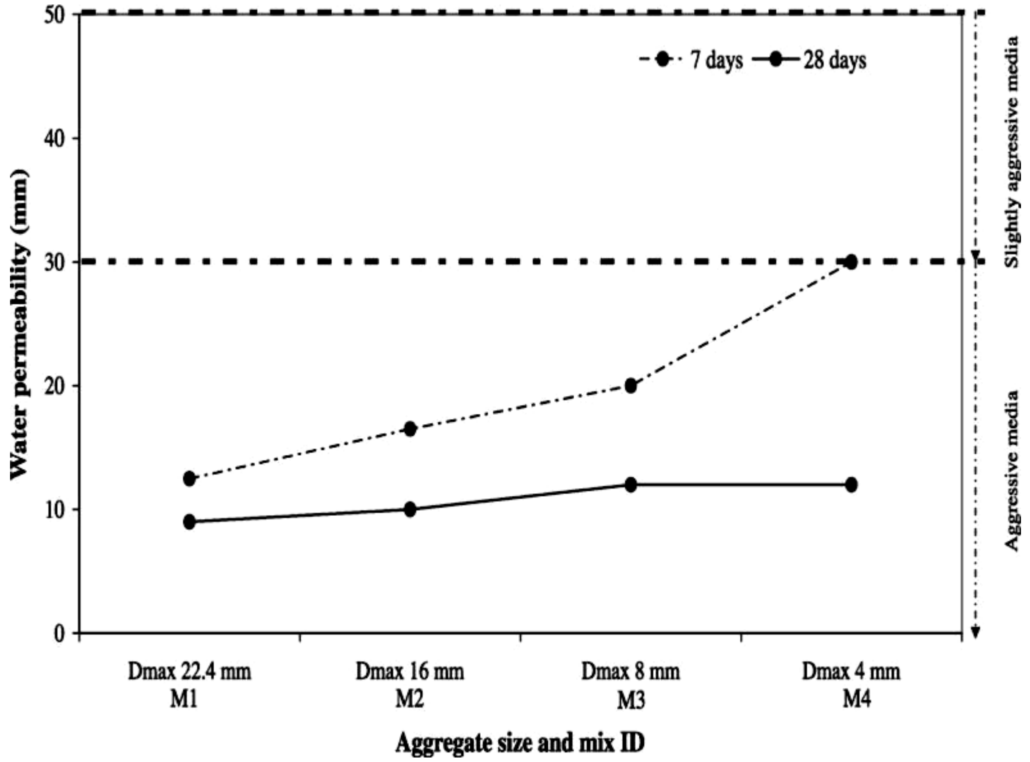

Figure 2.1: Aggregate Size Vs Permeability

(*Source: Effect of coarse aggregate on strength and workability: Canadian Journal of Civil Engineering*)

Large-sized coarse aggregates are increasingly used in concrete for economic and environmental reasons. Large coarse aggregates require less energy for size reduction with increased production rates. Furthermore, large coarse aggregates generate less dust, fines, and waste products. However, there needs to be a balance among economics of production, environmental considerations, and performance of the resulting concrete. (Tumidajski & Gong, 2006).

2.8 Fresh concrete

2.8.1 Concrete workability

This is the relative ease with which a fresh mix can be handled, placed, compacted, and finished without segregation or separation of the individual ingredients. Good workability is required to produce concrete that is both economical and high in quality. Fresh concrete has good workability if it can be formed, compacted, and finished to its final shape and texture with minimal effort and without segregation of the ingredients. Concrete with poor workability does not flow smoothly into forms or properly envelop reinforcing steel and embedded items, and it is difficult to compact and finish. The most common workability method used is the slump test (Musembe, 2009).

2.8.2 The Slump Test

The slump test is a means of assessing the consistency of fresh concrete. It is used indirectly as a means of checking that the correct amount of water has been added to the mix. The test is carried out in accordance with BS EN 12350-2, Testing fresh concrete. Slump test. This replaced BS 1881: Part 102.

A collapsed slump generally means that the mix is too wet or that has a high workability mix (Chudley, 2008).

2.9 Cement and Aggregates

According (BS 1047or 882) two methods of proportioning concrete mixes are permitted; one preferably by weight ,on small jobs, however, where the concrete is mixed on site, it is permissible to use volume batching of the aggregates for nominal mixes.

It is important to note that however good the concrete may be, the subsoil on which it is laid is equally important otherwise the floor will fail. The sub-grade should be firm and able to bear the dead weight of the slab and all other dead and live loads imposed onto the floor .To improve this function, floors are as well laid on other layers including hard-core filling and murram blinding. All these are discussed below

2.10 The Subsoil

2.10.1 Rammed Earth

Construction using Rammed Earth (RE) that includes use of locally available soils stabilized with binders such as lime dates back many centuries. RE structures including walls have been built in numerous countries since the 1800s (Earth Materials Guidelines, 1996). Research indicates that the USA and Australia have been the pioneers in using this sustainable material in building construction (Nelson, 1976). RE structures utilize locally available materials with lower embodied energy and wasted materials than traditional method (Earth Materials Guidelines, 1996). The soil used for RE building is a widely available resource with little or no side effects associated with harvesting for use in construction. The soils used are typically subsoil, leaving topsoil readily available for agricultural uses. Often soil of reasonable quality can be found close to the location of construction, thus reducing the cost and energy for transportation. Significant cost savings can be achieved when earth (aggregates or soil) is used for construction since the material is generally inexpensive and readily available. If the amount of cement used in RE is carefully controlled, more cost savings can be achieved. Today more than 30 percent of the world’s population uses earth as a building material (Anderson, 2000). In addition, RE provides good thermal mass, with inherent good heat retention in buildings and cost-savings.

Floor beds are placed on reduced level subsoil's and it is well known that subsoil behave differently under loading depending on type, physical properties and this affects the bearing capacity of each subsoil. Investigations undertaken in Dallas District in America on observed cracks on jointed concrete pavement (JCP), some of which had occurred on recently reconstructed JCP revealed that the base and the foundation soils had very poor compaction hence poor support to the concrete slab (Dar & Moon, 2007).

2.10.2 Soil properties

Soil properties were also a focus in this study .The internal stability of a granular soil mainly depends on three factors: the soil grain-size distribution, the soil relative density, and the applied hydraulic gradient. One major criterion that controls the design of shallow foundations on granular soils is the bearing capacity of the soil beneath the foundation and the settlement of the foundation. However, since excessive settlements often lead to serviceability problems, settlement usually governs the footing design process, particularly for shallow foundations wider than 1m (Schmertmann, 1970).

Immediate settlement and consolidation settlement are the main components of shallow foundation settlement. In cohesive soils (silts and clays), as the load is applied the excess pore pressures dissipate slowly because of the low soil permeability. As a result, consolidation settlement may occur over a very long period of time. However, in coarse soils (sands and gravels), the focus of this research proposal, increases in pore pressures are dissipated rapidly owing to the high soil permeability and any settlement resulting from a change in loading occurs more or less immediately. Most of the immediate settlement may be accommodated within the structure during or shortly after its construction by a considerable increase in the internal forces of the structure; unfortunately, this can result in cracks through structural elements, and may even end in structural failure. (Rezania & Javadi, 2007).

The subsoil's vary in their bearing capacities to loads but this can also be stabilized by compaction. Soil compaction can offer effective solutions for many foundation problems, and it is especially useful for reducing total and differential settlements in sands. However, efficient use of soil compaction methods requires that the geotechnical engineer understands all of the factors that influence deep soil compaction and plans, designs, and monitors the compaction process carefully. The most useful tool for deciding which soils can be compacted by dynamic methods is the cone penetration test, notably the piezocone.

2.10.3 Bearing capacity

In order to guard against the possibility of shear failure or substantial shear deformation, the foundation pressures used in design should have an adequate factor of safety when compared with the ultimate bearing capacity of the foundation.

With uniform ground conditions, the ultimate bearing capacity will increase with the depth of embedment of the foundation in the ground. this increase is associated not only with the effects of confinement of the ground and the increased overburden pressure at foundation level, but also shear forces that can be mobilized between the sides of the foundation and the ground.

It should however be noted that the existence of an adequate factor of safety against shear failure will not necessarily ensure that foundation settlements will be sufficiently small, in particular, the allowable bearing pressure for a large foundation on granular soil may have to be much smaller than the ultimate bearing capacity divided by a conventional factor of safety of 2 or 3.

2.10.4 Settlement

The magnitude of the settlement that will occur when foundation loads are applied to the ground depends on the rigidity of the structure, the type and duration of loading and deformation characteristics of the ground. In silts and clays consolidation settlements may continue for a long time after the structure is completed, because the rate at which the water can drain from the voids under the influence of applied stresses is slow; allowance will need to be made for this slow consolidation settlement. In beds of organic soils settlement may be prolonged almost indefinitely due to a phenomenon known as creep or secondary consolidation, and will need special consideration. In sands and gravels and most rocks, however, the settlement is likely to be substantially complete by the end of the construction period. (British standard code of practice for foundations (BS 8004:2015).

2.11 Hardcore

Hardcore are the crushed stones put under floors for raising the floor level, take care of drainage or for firm base. It is used as a sub base after building the foundation wall to make up levels before casting the ground floor concrete slab. The recommended is hard stone ballast or quarry waste that should not pass a sieve of more than six inches when broken down. This shall be free of weeds, roots, vegetable soil, clay, black cotton soil or other unsuitable materials. Broken stones or brick cuttings can also be used as hardcore.

To lay hardcore under floor beds well graded smaller pieces mixed with fine materials are normally used. This will give a dense compact mass after consolidation. This shall be laid in layers not exceeding 250mm of consolidated thickness. Sufficient fine materials shall be added to each layer to give a gradation necessary to obtain a solid compact mass after rolling. A ten tone smooth wheeled or two tone vibrating roller should be used to compact each layer.

Each layer is compacted in eight passes of the roller when lying hardcore under floor beds. Sufficient water is added with every pass to obtain maximum compaction. To each layer a fine layer of sand is added or quarry dust forced into the hardcore by a rolling vibrator. All the materials used must always be dry to avoid caking or stickiness. This may allow pockets of air or free spaces. This may sink when the hardcore is loaded with weight. If the sand is absorbed into the holes between hardcore then keep compacting.

The hardcore filling under floor beds should be thoroughly compacted until sand is not absorbed. The top surface should be made level. The levels are done or graded to the required falls. After this is done a blinding layer of similar broken materials is added. This is of at least one inch in thickness. A ten tone roller is used to smoothen the surface. This mass of hardcore is now ready for anti termite, damp proofing and mesh reinforcement material before concreting the ground floor slab.

2.12 Summary

2.12.1 The concrete floor slab

It was established that concrete floor slab is the main type of floor used in construction of floors; hence it will be still with us for quite a while thus improvements are needed so as to make it more affordable and environmentally friendly. There is need to seek alternative materials for this kind of floor for it mainly uses natural resources so as to reduce the impact on the ecology.

The main functions of a floor bed is to support both live and dead load as well protect the surface from moisture rise, thus construction of this element in almost same manner in different ground characteristics is not economical and right thus this research sought to have it done differently for different loading and different ground characteristics. Ground floors for domestic dwelling house are constructed as other ground floors for public and other activities and the loadings are different hence there is need to adopt different and less expensive methods for the domestic ones which have lesser loadings.

2.12.2 Hardcore

From the literature review, hardcore filling is prescribed and this has to be mined and transported to point of use since it is not readily available everywhere. The transportation and mining results into environmental degradation and emissions to the environment. A research that will reduce this is more ideal and this research covered this so as to use readily available materials.

2.12.3 The Sub Soil.

In the literature review, rammed earth has been researched for walling and not as a substructure base. This research sought to fill this gap on rammed earth as a floor slab base thus an environment friendly material and cost effective method of construction of ground floor slab.

2.13 Conceptual frame work

Conceptual framework helps to show the relationship that exist between the different types of quarry dust aggregates used in slabs of different thickness and the end results.

It provides an overview of different aggregates, different depths of concrete slabs of the different aggregates and how this affects the functional requirements and a sound ground floor slab.

Independent Variables

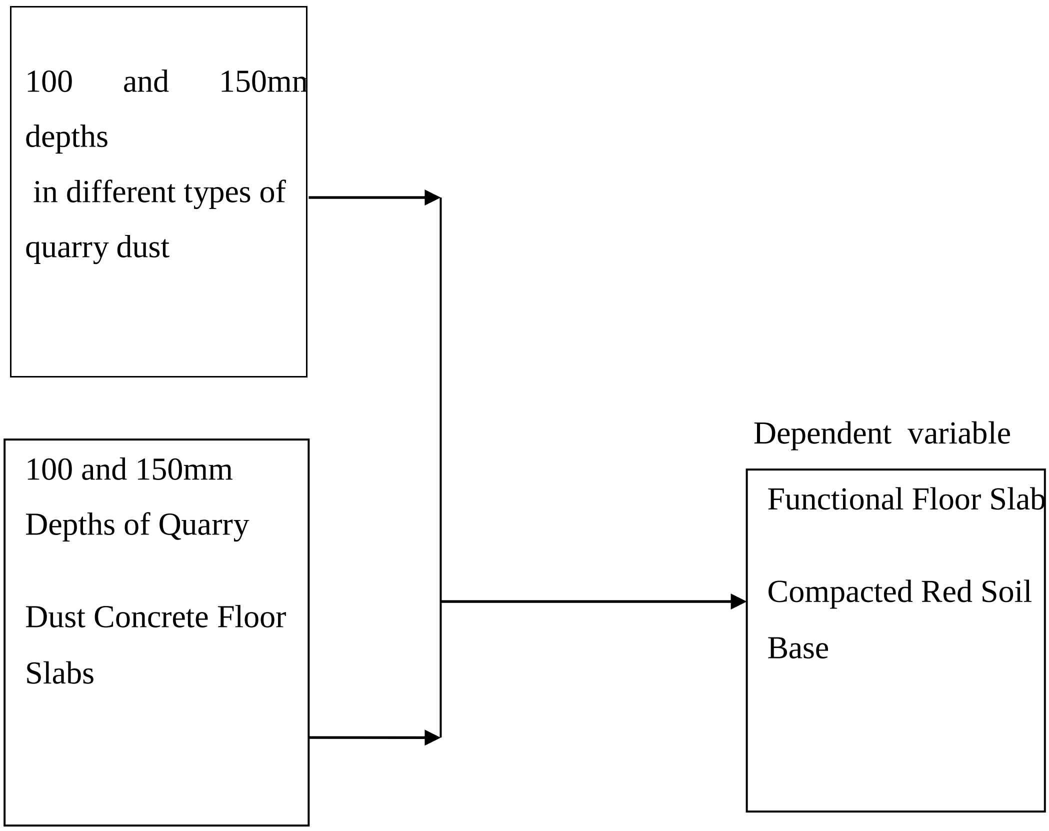

Figure 2.2: Conceptual Framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The research was conducted in the Structures and Materials laboratory of Civil Engineering department at Jomo Kenyatta University of Agriculture and Technology, JKUAT, Kenya. The samples were carefully chosen with coarse aggregates and various volcanic rock quarry dust were sourced from Athi- river crushing plants and sedimentary rocks dust from Nairobi stone quarries. While the granular red soil was sourced from around Juja town in Kiambu county and the river sand was gotten from Konza in Machakos County. Portland cement (CEM I 42.5R) from Bamburi Cement was used in concrete design.

3.1.1 Materials and Testing.

With selected materials, several methods to British and American Codes of practice were used to determine the various properties of materials in the research. The properties enabled decision on suitability of the materials in the tests so as to achieve the specific objectives. The tests on aggregates for their properties were fineness modulus (FM), specific gravity, water absorption and gradation tests (sieve analysis). To achieve the first specific objective of determining the effect of varying depths of quarry dust concrete on structural soundness and engineering properties of a ground floor, concrete slabs of one metre by one meter but in different thickness of 150 and 100mm, three each for the four types of aggregates were cast and tested by loading on loading jacks for compression and strain on their surfaces through strain gauges attached to a data logger. Four different types of quarry dust namely graded 5-14mm volcanic stone, non- graded volcanic stone and Nairobi sedimentary rock dust were cast, cured and crushed as well subjected to water seepage to establish the effect of different types of quarry dust as a coarse aggregate in concrete in meeting the functional requirements of a ground floor slab.

The soil used in the research was compacted by proctor method and tested for unconfined compression strength, atterberg limits, optimum moisture content and gradation test. The soil was further compacted to maximum density and as a base cured slabs tested on top of the soil for stress and strain via loading and strain gauges connected to a data logger to find out the effect of natural sub-base on ground floor stability. The hardened concrete from the various aggregates was further tested for compression in a compression machine to cured cubes at 28 days.

American Concrete Institute (ACI) methods of concrete mix design method ACI 211.1-91 (1997) was used. The method is based on the following;

(i) The strength, at a given age, of fully compacted concrete, cured under standard condition, is governed by water: cement ratio (W/C) and type of cementious material used.
(ii) The amount of water required per unit volume of concrete for a given consistency and with a given material is substantially constant regardless of cement content, W/C or proportions of aggregate and cement. The main factors determining the amount of water are aggregate properties, cement properties and maximum stone size.
(iii) For any particular concrete mix and combination of materials, there is an optimum stone content which depends on size, shape and compacted bulk density of the stone, fineness modulus of sand and desired consistence of concrete.
(iv) The volume of compacted concrete produced by any combination of materials is equal to the sum of the absolute volumes of cement and aggregates plus the volume of water and that of entrapped or entrained air. The absolute volume of material is the total volume of solid matter in all the particles, and is calculated from the mass and the particle relative density

$$V(m^3) = \frac{M(Kg)}{DX100} \tag{3.1}$$

Where :

V is absolute volume.

M is mass of the material

D is the density of the material.

3.2 Determining the effect of varying depths of quarry dust concrete on structural soundness and engineering properties of a ground floor

3.2.1 Experimental set up

3.2.1.1 Tests carried out

To achieve the above objective various tests were carried out towards the objective namely;-aggregates grading, material mass calculations, mix design, batching and casting of concrete slabs and workability

3.2.1.2 The Aggregates properties

Samples were picked from all the aggregates weighed and oven dried at 110^{o} Celsius for twelve (12) hours and weighed again to determine their moisture content. All the aggregates and soil were then subjected to several test analysis to determine their properties. All the sieve analysis was done and classified based on BS882:1992.

The sand and quarry dust samples were tested for particle size distribution, fineness modulus, and specific gravity while coarse aggregates were subjected to specific gravity test and grading test.

(a) Material Fineness (Fineness Modulus FM)

Sand was air dried and about 1kg of representative sample from the batch was taken by riffling. It was then sieved through the following set of sieves: 10 mm, 5.00 mm, 2.36mm, 1.18 mm, 0.6 mm, 0.3 mm and 0.15 mm in that order (i.e., from the most coarse to the finest mesh). Sieving was achieved through hand shaking for a minimum of 2 minutes or when no more particles could pass through a certain sieve. The mass retained in each of the sieve was weighed and recorded. The FM of fine aggregates, which is the weighted average of a sieve on which the material is retained with the sieves being counted from the finest, was calculated from formula given as equation 3.2 below.

$$FM = \sum \frac{\text{cumulative \% retained}}{100}. \tag{3.2}$$

(b) Specific Gravity And Water Absorption(To BS812-2:995).

(i) Fine aggregates

About 500 g of air-dry sand sample passing 5.0 mm sieve and retained on 0.075 mm sieve was washed thoroughly in distilled water to remove all materials finer than 0.075 mm test sieve. The washed sample was then transferred into a shallow tray and fully submerged in water for 24 hours. Water was then carefully drained from the sample by decantation. The wetted aggregates were then exposed to air currents and stirred at frequent intervals in order to evaporate surface moisture completely. Then the mass of the saturated and surface-dry (SSD) aggregates was taken (W3). The aggregates were then placed in a specific gravity bottle and distilled water was poured into it until it was full. Entrapped air was eliminated by rotating the bottle on its side, the hole in the apex of the cone being covered with a finger. The outer surface of specific gravity bottle was wiped and weighed (W1). The contents of the bottle were transferred into a tray. The bottle was then refilled with distilled water to the same level and its mass determined (W2). The sample was then placed in a tray and dried in an oven at a temperature of 100ºC to 110ºC for 24±0.5 hours, cooled and weighed (W4). The procedure was repeated two more times for the purpose of averaging the results. The values of specific gravity and water absorption were obtained from the following calculations.

$$\text{Specific gravity on oven dry condition} = \frac{W4}{W3-(W1-W2)} \tag{3.3}$$

Specific gravity on SSD condition = $\frac{W3}{[W3-(W1-W2)]}$ (3.4)

Apparent specific gravity on oven dry material = $\frac{W4}{\{W4-(W1-W2)\}}$ (3.5)

Water Absorption = $\frac{(W3-W4)}{W4}$ (3.6)

where:

W1 is weight one.

W2 is weight two.

W3 is weight three .

W4 is weight four.

(ii) Coarse Aggregates

About 1 kg sample of air dried coarse aggregates passing 20 mm sieve but retained on 10 mm sieve was obtained through quartering. It was then weighed on a weighing balance and thoroughly washed to remove finer particle and dust and soaked for 24 hours. The specimen was then removed from water, shaken off and rolled in a large absorbent cloth until visible films of water were removed. Large particles were wiped individually and mass of saturated and surface-dry (SSD) aggregates was determined (Ws). The sample was then placed in a wire basket having openings of not more than 3mm and completely immersed in distilled water while ensuring no entrapped air on the surface and between the aggregates by gently tapping the immersed basket. The mass of the sample while totally immersed was measured using a double beam balance of capacity 5 kg x 0.5 g and recorded (W w). The basket was then removed from water and allowed to drain before transferring the aggregates into a tray and oven dried at a temperature of 105^0-110^0C for 24 hours. The samples were then removed from the oven, cooled and its mass determined

(Wd). The procedure was repeated two more times. The values of specific gravity and water absorption were obtained from the following calculations.

$$\text{Specific gravity on SSD} = \frac{Ws}{(Ws - Ww)} \qquad (3.7)$$

$$\text{Specific gravity on oven dry condition} = \frac{Wd}{Ws - Ww} \qquad (3.8)$$

$$\text{Water Absorption} = \frac{(Ws - Wd)}{Wd} \qquad (3.9)$$

where:

Ws = mass of saturated and surface dry aggregates

Ww = mass of sample while totally immersed

Wd = mass of dried and cooled sample

3.2.1.3 Batching and casting of concrete slabs

Weight batching was used.

Class 15 (1:3:6 nominal mix) with water cement ratio of 0.4 was used for aggregates 20 mm average size and the aggregates 8 mm average size. The Nairobi sedimentary rock and the non-graded quarry dust could not meet the properties to be classified as coarse aggregates thus were treated as fines. The mixing was done as: 1:3:3 with water cement ratio of 0.4

The concrete slabs were cast in specially designed detachable moulds of steel plate measuring 1x1x0.6 metre, two each from the four aggregates in thickness of 100 mm and 150 mm measuring 1x1m. The slabs were then cured in water for 28 days .

3.2.1.4 Workability

A slump test was done to check the suitability and workability of the concrete. Only the 20 mm aggregates could give a true slump. The other concrete i.e. the volcanic rock graded 14-5 mm quarry dust aggregates, un-graded volcanic rock quarry dust and the Nairobi sedimentary had shear slump or collapse, an indication of lack of cohesiveness. Three slump tests were done for the aggregates of 20 mm average size and they produced slumps of 126 mm, 129 mm and 131 mm.

3.2.1.5 Material Masses Calculation

The maximum water cement ratio (W/C) and minimum cement content were of interest in mass calculation. Density of concrete and other characteristics were obtained from the design manual (BS 8110) and calculation of the cement content using the following equation;

$$C = \frac{W}{W/C} \tag{3.10}$$

Where :-

C = The cement content in Kgs,

W= The water content also in Kgs.

W/C=Water cement ratio

The next step was to calculate the aggregates content, assuming full compaction of concrete. The volume of concrete is equal to the sum of absolute volumes of cement, aggregates (both coarse and fine) and water.

For 1 m^3 of concrete (ignoring air content)

$$1 = \frac{Mc}{Dcx1000} + \frac{Ms}{Dsx1000} + \frac{Mw}{Dwx1000} \tag{3.11}$$

Where:-

M_c is the mass of cement.

D_c is the density of cement.

M_s is the mass of aggregates.

D_s is the density of aggregates.

M_w is the mass of water.

D_W is the density of water.

Using excel sheets and by iteration masses of all the materials were obtained.

3.2.1.6 Measurement of strain set up

Strain gauges attached to sides of concrete slabs and transmitting results through a data logger and a loading jack were used as shown in Plate 3.1 and were fixed on ball the four faces of the slab in test as illustrated in Plate 3.2.

Strain gauge on all four sides of the concrete slab.

Plate 3.1: The loading of slabs set up with strain gauges on sides of slab

The change in resistance of a strain gauge is normally expressed in terms of an empirically determined parameter called the gauge factor.

For this strain gauge ΔR = RKε

Where R is the resistance = sensitivity = $\frac{1}{2x\,10^{-6}}$ (3.12)

Hence output = 0.5K x 10^{-6} i.e. change in resistance per unit actual strain, necessitating the multiplication of obtained strain values by $\frac{2}{K}$; giving a corrected output of $1/(10^{-6}) = 10^{6}$ machine units per strain Thus 1 unit from machine = 10^{-6} actual strain = 1 u actual strain For deformation, the conversion given by the machine was 500 u=25mm hence

$$1\ u = 0.05\text{mm} \tag{3.13}$$

The main objective of this research was to test the effect of quarry dust concrete and the underlying sub soil to ground floor slabs of dwelling houses thus the testing of the slabs was done on the red soil, which is a common occurrence in the strata of soils in many regions of this country. In this case, red soil from Juja area was used. Soil was compacted to maximum density which from the soil test results was at 23.4% optimum moisture content. This being a lab test, optimum conditions are achievable but in the field it is not possible to achieve optimum conditions thus a slab was also tested on non optimum moisture content to compare the result. A random sample was extracted from the natural strata and its moisture content was determined to be 30% and was compacted lightly and dry density determined as 0.9 g/m^3. The testing for compression and strain was done by loading jacks on loading frame with strain being recorded on a data logger connected to the sample in test via strain gauges. To achieve uniform loading, which was essential for this test loading was done with a thick plate laid on a star like angle line member on top of the sample being tested.

Strain gauges, one each were placed on all the four sides of the sample; a displacement transducer was also placed to measure deformation of the underlying soil. All these with the load cell making readings on a data logger. Cracks appeared randomly on all the four surfaces (see plate 3.2 below), an indication that the loading was uniformly distributed. The loading was done so as to achieve uniform loading. The slab was placed to rest on compacted red soil in a mould 300 mm thick, then a 6 mm thick mild steel plate placed on the slab and another cross member placed so that the applied load is distributed uniformly. The cross member had another 6mm plate placed on top before loading. The strain gauges were attached to all the four sides of the slab and in turn connected to the data logger, a transducer to measure deformation was also placed on the plate to measure the amount of deformation as the slab was loaded.

Plate 3.2: Failure Mode on All Four Faces is illustrated on Face 1 and 2

3.3 Data Collection and Analysis Procedure

3.3.1 Crushing of Hardened Concrete Slabs

The concrete slabs were tested by loading with jacks on a loading frame connected to a data logger. The data generated from the data logger had to be converted to usable data by conversion factors and other formulas given by the manufacturers for load cell, the data logger and the strain gauges. The strain gauge used here was an electrical wire strain gauge type.

The strain gauges gave the strain measured

Where $$\varepsilon = \frac{\Delta \mathrm{L}}{\mathrm{L}} = \frac{\Delta \mathrm{R}/R}{K} \qquad (3.14)$$

R is the resistance of the un-deformed gauge,

ΔR is the change in resistance caused by strain, and

ε is strain

K is the gauge factor which is a term used to describe the sensitivity of output characteristic of the bonded resistance strain gauge. It is the ratio of the change in resistance per unit or original resistance to the applied strain.

3.3. 1.2 Data analysis

The data collected above was analysed by plotting line graphs for stress against strain for the various aggregates. This was further simplified in a chart for better and easy understanding.

3.4 To establish the effect of different types of quarry dust as a coarse aggregate in concrete floor to meet the functional requirements of a ground floor slab

3.4.1 Experimental set up

3.4.1.1 Tests Done

To achieve this objective both the strength of hardened concrete for the various aggregates by cube test and ability of the aggregates to resist water seepage was tested addition to all tests carried out as indicated in section (3.2).

3.4.1.2. Aggregates properties

The aggregate properties were tested for fineness modulus, specific gravity and water absorption and sieve analysis as in objective above

3.4.1.3. Batching of aggregates for concrete cubes

Weight batching was used.

Concrete class 15 (1:3:6 nominal mix) with water cement ratio of 0.4 was used for aggregates 20 mm average size and the aggregates 8mm average size. The Nairobi sedimentary rock and the non-graded quarry dust fell in sand category from the sieve analysis was thus treated as such and the concrete was done as a mortar with the mixing done in: 1:3:3/0.4(cement, sand, quarry dust/water).

concrete cubes 150x150mm two from each concrete aggregates were cast, cured in water for 28 days and crushed to check on compression and strain.

3.4.1.4. Water Seepage Test

Concrete for the various aggregates were cast and cured for 28 days. Concrete was cast in metallic moulds which measured 300 mmx300 mmx450 mm deep. An opening of equal diameter was made at the base of the container and the rest of the container joints made water tight. Concrete 150mm thickness for each aggregate was cast and after curing for 28 days. All the joints between the cured concrete and the wall of the container was treated with silicone, a water proof compound to enable seal any leakage and allow water only through the concrete.

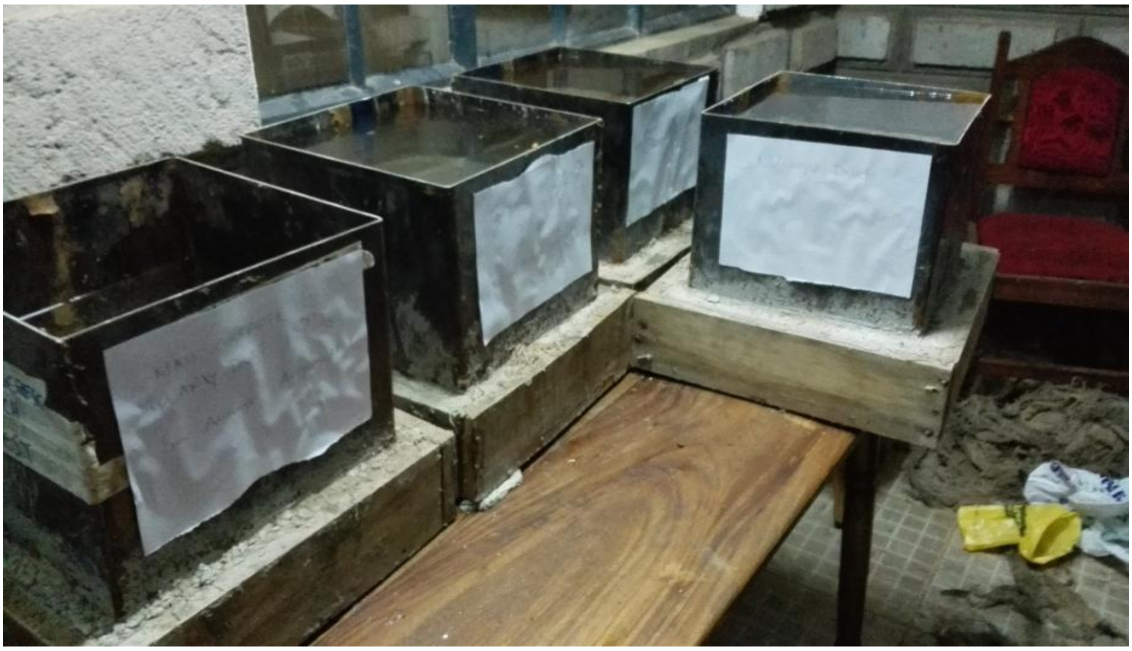

Plate 3.3: Water Seepage Test in Progress.

Resistance to water seepage for concrete is an important parameter because it affects the durability of hardened concrete as well for this case of floors it will affect the functionality of the floor in terms of comfort and aesthetics. The test entailed subjecting the cured concrete specimen of known dimensions, contained in a specially designed cell, to a same hydrostatic pressure from one side, measuring the quantity of water percolating through it during a given interval of time. Scale rulers were stuck on the sides of the containers and water of equal amounts filled at the same time. Water percolating was observed for a month, with recording done after every week. The reduction in water levels equaled water that had percolated through the sample and this was recorded and plotted against time in weeks.

3.5 Data collection and analysis

3.5.1 Crushing of hardened concrete cubes

Two concrete cubes for the each type of aggregates were tested in a compression machine with strain gauges attached laterally and vertically giving the stain against the load being applied. The strain gauges were connected to a data logger which recorded the results.

Plate 3.4: Cube crushing in progress

3.5.3 Data analysis

Data was analyzed by plotting the results on line graphs and summary of the same results in charts and tables. Line graphs for permeability versus time in days was plotted for seepage test on various aggregates as the crushing results were summarized in a chart and table compared to conventionally expected strength for the class of concrete in the test. The concrete Young's modulus was also determined from the stress and strain experienced in the various aggregates.

3.6 To find out the effect of natural sub base on ground floor stability

3.6.1 Experimental set up

3.6.1.1 Tests Carried out

The tests carried out to achieve this objective were:-

- The soil properties (specific gravity, moisture content, liquid limit, plastic limit and linear shrinkage).
- Soil compaction by proctor method to ASTM D-698
- Unconfined compressive strength

3.6.1.2 Soil properties

(a) Specific gravity for red soil

This test was done to determine the specific gravity of fine-grained soil by density bottle method as per BS: 812-2:1995. Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of equal volume of distilled water at the same stated temperature.

(b) Procedure

The procedure as to BS:812-2:1995 was carried out with the sample bottle, stopper and a 50g soil sample.

Two observations were taken.

Then the specific gravity was calculated as:

The specific gravity G of the soil = $\frac{(W2 - W1)}{((W4-1)-(W3-W2))}$ (3.15) where:

W1= The density bottle along with the stopper

W2= Density of the bottles and contents together with the stopper .

W3= Weight of stopper inserted in the density bottle and wiped .

W4= weight of stopper inserted in the bottle, wiped dry from the outside

The specific gravity should be calculated at a temperature of 20^{o}C and reported to the nearest 0.01.

If the room temperature is different from 20^{o}C, the following correction were done:-
G'=kG
where,
G' = Corrected specific gravity at 20^{o}C
k = [Relative density of water at room temperature]/ Relative density of water at 20^{o}C.

(c) Determination of Soils Moisture Content

Procedure:

Weight of the aluminum tin (W1)in grams was recorded.

Then a sample approximately 50 g of moist soil was put into a moisture content tin and weight (W2) taken. Weight of wet soil was now determined using equation 3.16 as

$$M = W2-W1 \quad (3.16)$$

The soil was then dried overnight at 105 °C in an oven and tin removed from oven to cool.

The tin was re-weighed plus the oven dry soil (W3). Now the weight of the dry soil was determined using equation 3.17 as

$$D = W3 - W1 \qquad (3.17)$$

Soil moisture content MC was calculated using the following equation 3.18

$$MC = \frac{\text{weight of moist soil (M)} - \text{weight of dry soil (D)}}{\text{weight of dry soil (D)}} \% \qquad (3.18)$$

where: MC = Moisture content

M = Weight of moist soil

W3 = weight of tin plus oven dry soil

W1= is weight of aluminum tin

W2 is weight of wet soil and tin

D = Weight of dry soil

(d) Atterbeg Limits (To ASTM D 4318)

Liquid Limit

This test was done to determine the minimum amount of water at which soil looses plasticity and becomes brittle.

Cone Penetrometer Method

Procedure:

50g of air dried soil from thoroughly mixed portion of soil was the sample used. the procedure as to ASTM D 4318 was followed through.

Calculations:

A graph was then plotted, with moisture content on the y axis and the cone penetration on the x-axis.

A best fitting straight line was then plotted

The moisture content corresponding to cone penetration of 20 mm was taken as the liquid limit of the soil.

(e) Plastic Limit

This is the minimum amount of water at which soil looses plasticity and becomes brittle.

Sample Preparation

About 30 g of air dried soil from a thoroughly mixed sample of the soil passing through 0.425 mm sieve was mixed with distilled water in an evaporating dish and left to mature for 24 hours.

Procedure:

The procedure as to ASTM D 43183 using 8 g of the sample was followed through.

The pieces of crumbled soil threads were kept in the container used to determine the moisture content. The process was repeated twice with fresh samples of plastic soil. The average water content to the nearest whole number was recorded.

(f) Linear Shrinkage

This test was carried to ASTM D 43183 was to determine the minimum amount of water below which the volume of soil does not change,a mould on length L was used.

Calculations:

Linear shrinkage is give as in equation 3.19

LS (%)= $\frac{Ls}{L\,x100}$ (3.19)

where:

LS= linear shrinkage

Lo = longitudinal shrinkage of the specimen

L = length of mould (mm)

(g) Soil compaction

Procedure:

This was done according to modified Proctor Method (ASTM D-698)

Calculations:

Bulk density was calculated from equation 3.20 below

Bulk weight = (W2-W1) (3.20)

and Moisture content from equation 3.21 as follows

Moisture Content Mc = $\frac{W4-W5}{W5-W3}$ (3.21) hence

$$\text{Dry weight} = \frac{\text{bulk weight}}{1+Mc} \qquad (3.22)$$

Where:

W1= Weight of the proctor mould + base plate (not extension)

W2= The weight of the Proctor Mould + base plate + compacted moist soil and moisture content from equation 3.21

W3= moisture can weight(g)

W4= mass of moist soil + can, (g)

W5= the mass of the moisture cans + soil samples (g)

Mc= moisture content.

A soil compaction curve was then plotted for dry density against moisture content to determine the optimum moisture content..

(i) Unconfined Compressive Strength on the Red Soil

The test was carried out as per(ASTM D-698)

The Unconfined Compressive Strength of a soil(qu) is the load per unit area at which the cylindrical specimen of a cohesive soil falls in compression and is calculated as

$$qu=\frac{P}{A} \qquad (3.23)$$

where :

P = axial load at failure

A = corrected area=Ao/1-ε

Ao = initial area of the specimen

ε = axial strain (change in length/original length.

The un-drained shear strength (s) is equal to half the unconfined compressive strength of

$$s=\frac{qu}{2} \tag{3.24}$$

The unconfined compressive strength ring type of 1KN capacity apparatus was used.

3.7 Data collection and Analysis

3.7.1 Testing of slabs on compacted soil

After determining the soil properties, it was set up at the required mass and moisture content and compacted in a confined specially designed mould. The mould made of timber block-boards and held together tightly measured 1mx1mx0.45 m deep. Slabs were loaded to failure and deformation was recorded with a displacement transducer placed on top of the slab and connected to a data logger. The displacement was read directly on the transducer and recorded. The slabs were spread uniformly on the compacted soil so that the loading was uniform.

3.7.2 Data analysis

Data was analyzed by plotting the values recorded of stress in N/mm^2 against deformation in (mm).This was further simplified in a chart with deformation values against aggregates.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The main objective of this research was to investigate effects of quarry dust concrete and the underlying sub-soil on structural performance of a ground floor. Specifically looking at the effect of varying depths of quarry dust concrete, establishing the effect of different types of quarry dust as coarse aggregate in concrete, and finding out the effect of natural sub base on ground floor.

All geared to check if they can satisfy the structural soundness and engineering properties of a ground floor slab .The results in this chapter address all the objectives of the research as well the properties of the materials used in the research.

4.2 Results and Discussion for Material Properties

4.2.1 Gradation and fineness modulus results for the various aggregates

This was graded based on BS882-1992. A gradation curve / particle size distribution curve (PSD) was plotted. The curve was used to determine if the sample of the aggregates was well graded or poorly graded. If poorly graded it is not recommended for use in the construction .Grading is of importance because it affects workability of concrete (Chandana et al., 2013)**.**

4.2.2 Gradation and fineness modulus for fine aggregates (river sand)

From the sieve analysis for sand (Figure.2.1 literature review) the river sand used in the research was well within the grading envelope for overall grading as to BS 882-(1992) on grading of fine aggregates. Hence this was suitable sand for use in concrete. Fines falling outside this envelope should be blended with other types to ensure it is within this range for it to qualify for use in this method (Gathimba, 2015). It is clear from the graph (Fig4.1) that the sand curve is right in the middle between lower limit and upper limit an indication of well graded sand.

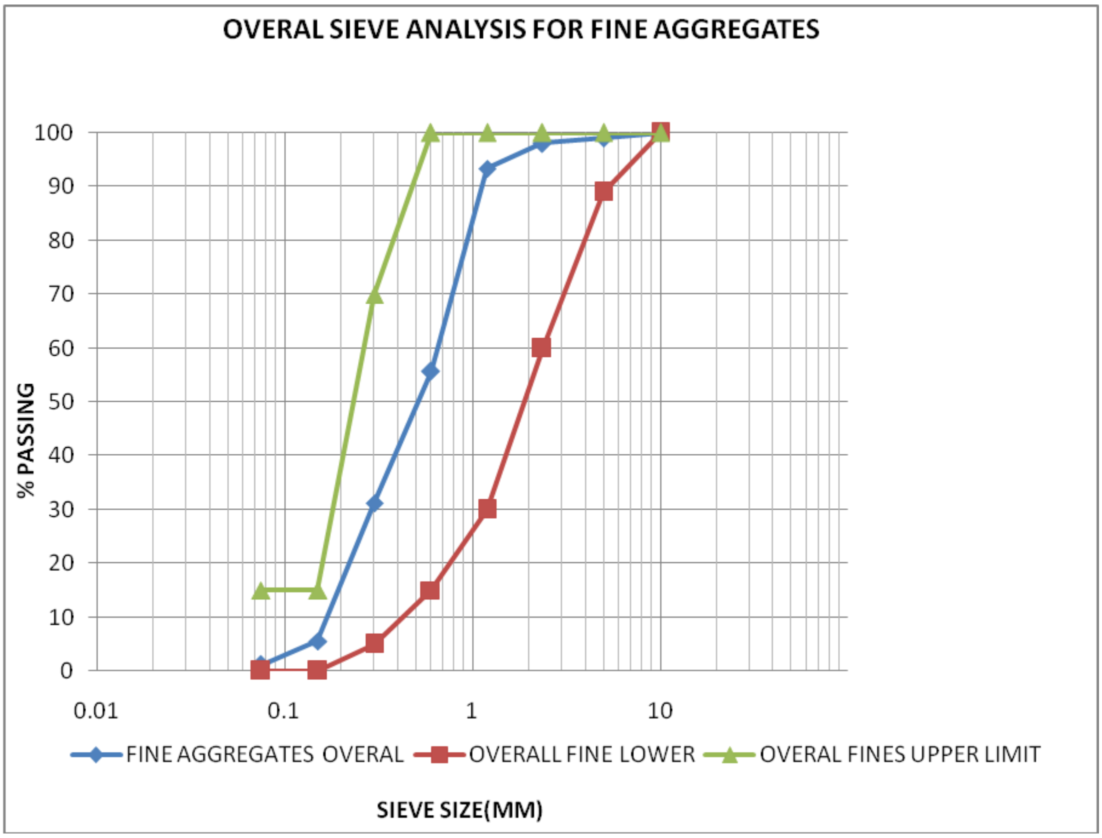

Figure 4.1: (PSD) for fines (river sand)

The fineness modulus (FM) of fine aggregates was calculated using equation 3.2.the value obtained was 3.1. Recommended range is 2.3-3.1(ASTM C33) Smaller particle sizes produce higher concrete strengths because of less severe concentration of stress around particles caused by differences between the elastic moduli of the past and the aggregate.(Cheruiyot, 2015). The higher the FM, the coarser the fine aggregates.

4.2.3 Sieve analysis for coarse aggregates average 20mm volcanic rock

From Figure. 4.2 the aggregates fitted within the grading envelope for 20 mm size for coarse aggregates according to BS 882-1992 on grading of coarse aggregates. The aggregates were poorly graded with more coarser aggregates, however it was within the limits and hence good for use in concrete mix.

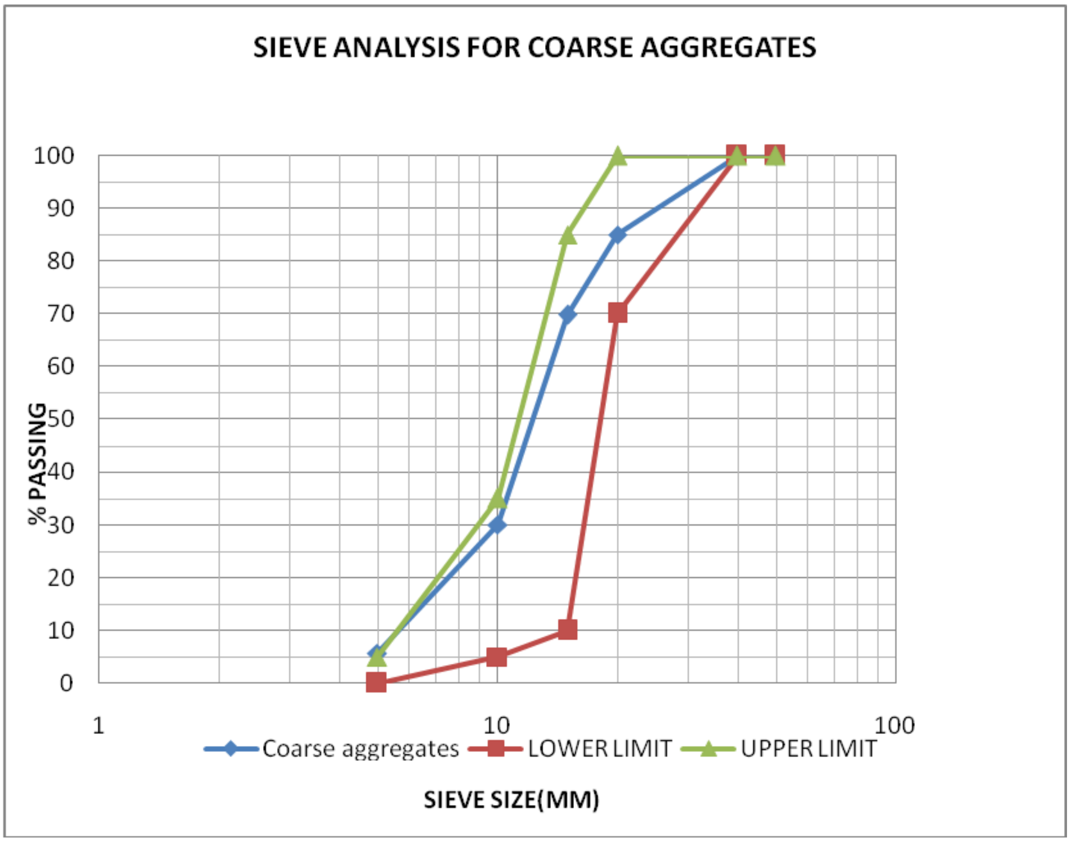

Figure 4.2: PSD for coarse aggregates

4.2.4 Sieve analysis and fineness modulus for Nairobi sedimentary rock quarry dust

From the Figure 4.3 the Nairobi sedimentary rock was found to be fitting within the fines for overall grading as per BS 882-(1992) on grading of sand aggregates Table 4.1 Though compared with PSD for river sand, this can be seen having the curve for the stone dust more towards the upper limit thus means there are much less fines than the river sand. The dust was more coarse than sand, but the resulting concrete would be of more fines and this would affect the strength and other properties such as permeability of the resulting concrete. Such aggregates(much fines) need use of more cement in the concrete to improve strength and permeability properties.

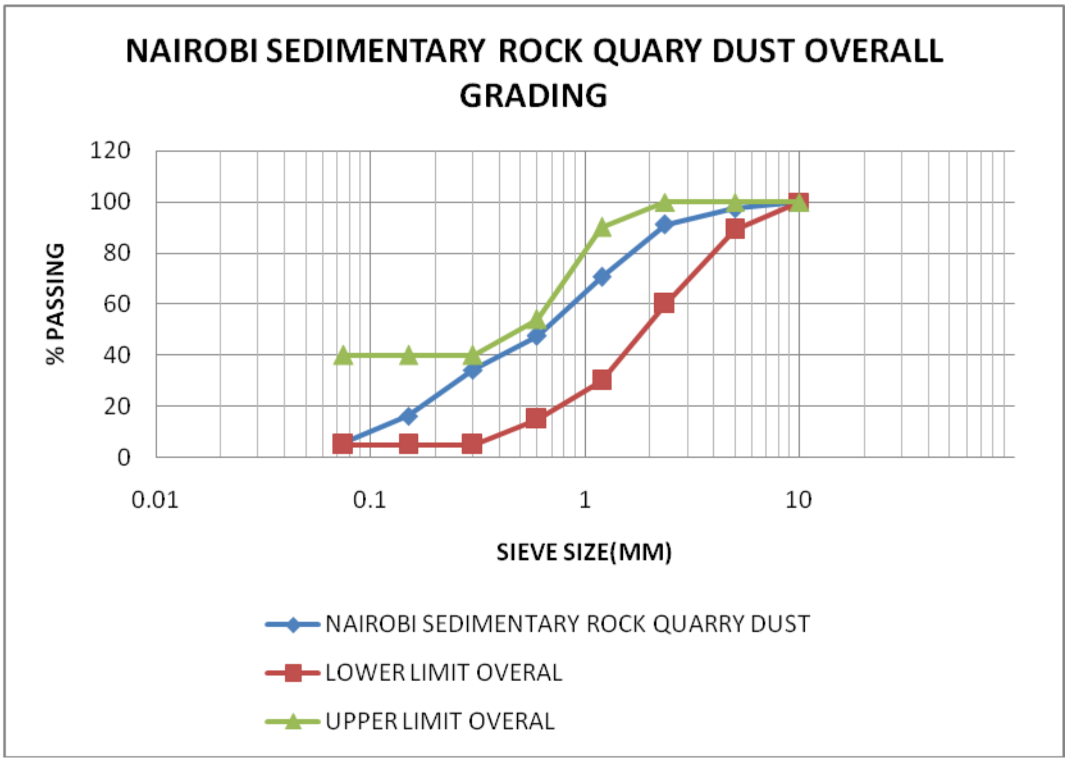

Figure 4.3: PSD for Nairobi sedimentary rock quarry dust fines overall grading limit

The fineness modulus (FM) of fine aggregates was calculated using Equation 3.2 which gave a value of 3.37. This value falls outside the recommended range of between 2.3-3.1(ASTM C33). Thus this aggregates though fine, it is not suitable for use in concrete mix as a fine aggregate. This is because it has more coarse particles than fines thus poorly graded and can affect the strength of concrete if used as a fine for the bonding between aggregates will not be adequate.

4.2.5 Sieve Analysis for Undisturbed Volcanic Rock Quarry Dust

From Figure 4.4 below, this also qualified as a fine, being within the overall grading limits as per BS 882-1992 on grading of sand aggregates Table 4.1 Though compared to stone dust used in this research this had more coarse aggregates than the stone dust.The fineness modulus (FM) of fine aggregates was calculated using

Equation 3.2 and the value 3.5 obtained. The value outside recommended for fines 2.3-3.1(ASTM C33). Thus though a fine, not suitable for use as a fine in concrete mix. This, similarly like the Nairobi sedimentary rock, has more coarse particles and cannot blend well to allow maximum desired bonding in a concrete mix, hence would produce concrete of undesired strength.

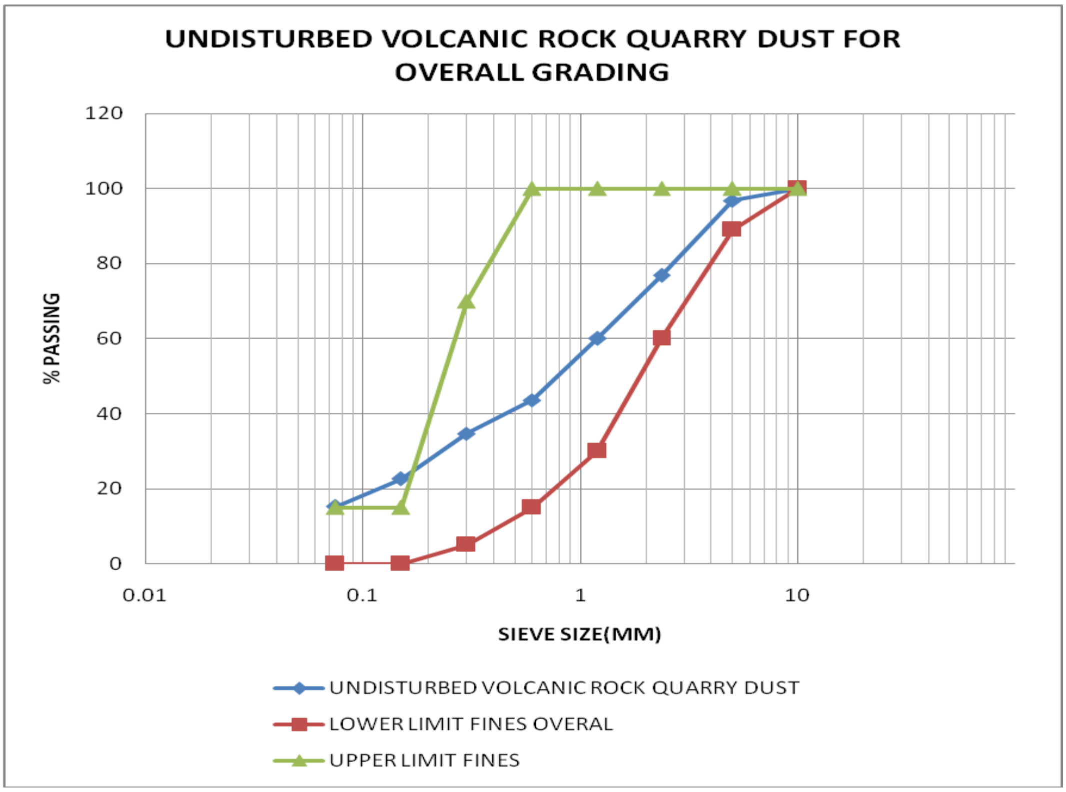

Figure 4.4: PSD for non-graded volcanic rock quarry dust fines overall grading limit

4.2.6 Sieve analysis for Graded volcanic rock quarry dust (5-14mm)

From Figure 4.5 below the aggregates fell within the 5-14mm size limit for coarse aggregates overall grading limit according to BS 882-(1992) on grading of coarse aggregates. This as to this size was well graded. This not being a fine, fineness modulus was not checked.

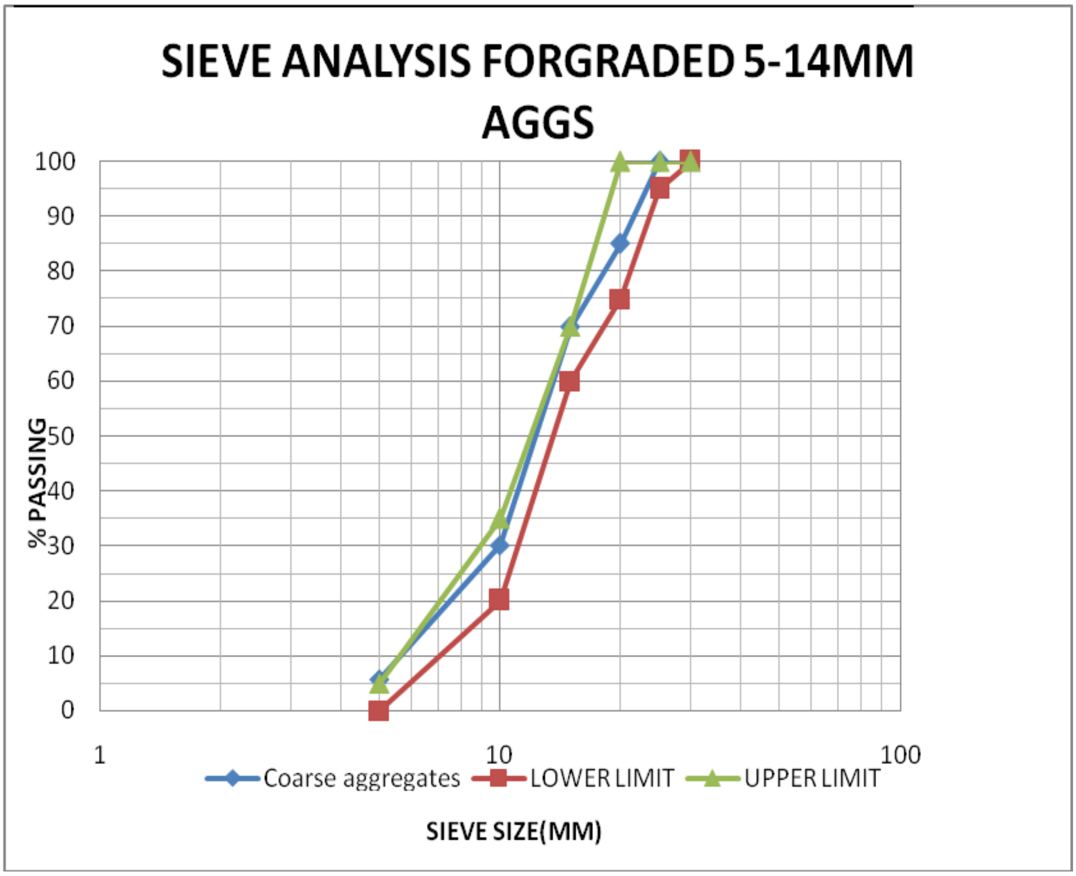

Figure 4.5: PSD for graded volcanic rock aggregates 5-14mm overall grading.

4.3 Specific Gravity and Water Absorption for the various aggregates

The computed values of specific gravity and water absorption for river sand (RS), graded quarry dust (GQD), non graded quarry dust (NGQD), Nairobi sedimentary rock dust (NSRD) and coarse aggregates (CA) were tabulated as shown below. They were computed from Equations 3.3 to 3.9

Table 4.1: Specific Gravity and Water Absorption for the various aggregates

	RS	GQD	NGQD	NRSD	CA
Specific gravity on oven dry basis	2.45	2.56	2.42	2.40	2.55
Specific gravity on saturated surface dry (SSD) basis	2.52	2.44	2.53	2.50	2.45
Apparent specific gravity	2.46	2.60	2.44	2.42	2.61
Water absorption%	0.23	0.1	0.26	0.27	0.94

Calculations with reference to concrete mix design was based on the SSD condition of the aggregate because the water contained in all the pores in the aggregate does not take part in chemical reaction of cement. This water is therefore considered as part of the aggregate. The apparent specific gravities for the aggregates averaged at 2.5, well within the range of apparent specific gravities for different rock groups of between 2.4 and 3.0 (Gathimba, 2015).

4.4 Summary Aggregates Gradation

Quarry dust has a higher fineness modulus than river sand. Safiudin *et al.* (2007) while researching on the performance of quarry dust in concrete reported the fineness modulus of mining sand and quarry dust to be 3.01 and 3.2 respectively. The same values were also quoted by Raman *et al.* (2007) in their study on quarry dust although he used pit sand as opposed to mining sand.

The results have established undisturbed quarry dust (FM of 3.5) and dust from Nairobi sedimentary rock, (FM 3.37) are fines and with fineness modulus not far from that of river sand (3.1) and have properties almost similar to the conventional river sand but are more coarse. The finer the material used for concrete production, the more is the water demand of the concrete hence negatively affect the compressive strength of the concrete (Musembe, 2009).

4.5 Gradation results for the red soil

From the results below, the soil was established to be Sandy silty CLAY with traces of gravel. Clay being the dominant here (at 44%) and clays shrink when dry and swell when wet though the shrinking is affected by a variety of factors but rarely more than 150mm in the horizontal and vertical directions (Clarke, 2008). The soil used in the test was not entirely clay the other properties of sand (20%) and gravel (4%) contributed to improved bearing capacity. Because sand and gravel are usually adequate for strip foundations (Holmes, 2009) but still it is only clays at depth less than 700mm that are really affected by shrinking and swelling, the deeper clays have stable moisture content (Holmes, 2009). The granular property of silt which is 32% in the soil also provided stability and enhanced the bearing capacity of the soil in the research. The soil being a laterite falls within the medium plasticity clay envelope (Kenya Road Design Manual part III,1987).

SILT SAND GRAVEL

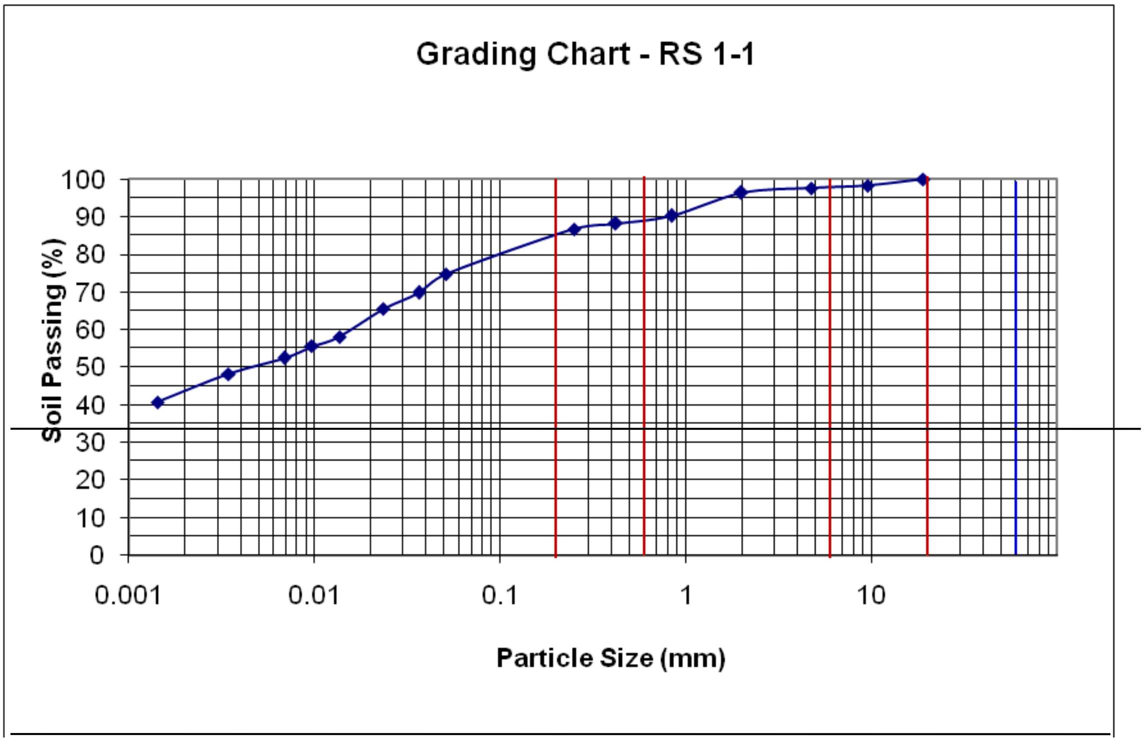

Figure 4.6: Soils grading chart

Table 4.2: Soil Grading Chart Summary

PARTICLE SIZE	SOIL NAME	PERCENTAGE(%)
Particles finer than 60%,D60 (mm)	Gravel	4
particles finer than 30%,D30 (mm)	Sand	20
particles finer than 10%,D10 (mm)	Silt	32
finer particles less than 2%	Clay	32

A Sandy Silty CLAY with traces of Gravel

The moisture content was useful in determining the amount of water to be added when compacting so as to arrive at optimum moisture content at maximum density. Moisture content was computed using Equation 3.16 and using an average of three tests, moisture content for the soil in test was found to be 18.2%. (see Appendix 8) For well graded granular material containing just enough fines to fill small voids. Optimum moisture contents may range from around 5% for granular material to about 35% for elastic silts and clays. BS1377:1990 Part 4:4.

4.6 Specific gravity for red soil

This property which is a weight-volume one is important in classifying soils and for other properties like void ratio, porosity and unit weight. Though in this research only weight and classification of soils were of interest. The results for specific gravity of the soil are tabulated below using Equation (3.15). An average of three tests were done and the average specific gravity found to be 2.56 (see Appendix 9). The value 2.526 was reasonable since specific gravity of soils typically falls in the range of 2.6-2.9. BS1377:1990 Part 4:4.This shows the soil had a good balance of clay, silt and sand hence can achieve good compaction.

4.7 Atterberg limits for the Red Soil.

After determining the soils moisture content (Equation 3.18) the liquid limit, plastic limit and linear shrinkage (Equation 3.19) of the red soil in the research were determined. The plastic limit was helpful in identifying the optimum moisture content for compaction, the plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3.2 mm (about 1/8 inch). A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture. and the liquid limit helped in determining the state of consistency of soil as well for classifying The liquid limit (LL) is conceptually defined as the water content at which the behaviour of a clayey soil changes from plastic to liquid. The shrinkage limit (SL)was the water content where further loss of moisture could not result in any more volume reduction. From the (LL) and (PL) plasticity index (PL) was determined and this is defined as a measure of the plasticity of a soil. The plasticity index was the size of the range of water contents where the soil exhibited plastic properties. The PI was the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay (Das 2006).

Typical ranges (ASTM International D4943) for Plasticity Index

- (0-3)- No plastic
- (3-15) - Slightly plastic
- (15-30) - Medium plastic
- >30 - Highly plastic

Four tests were run for determination of liquid limit, and two tests for plastic limit. (see appendix 10).Determination of various moisture content against penetration is listed and a graph was plotted for cone penetration against moisture content,(fig.4.7).

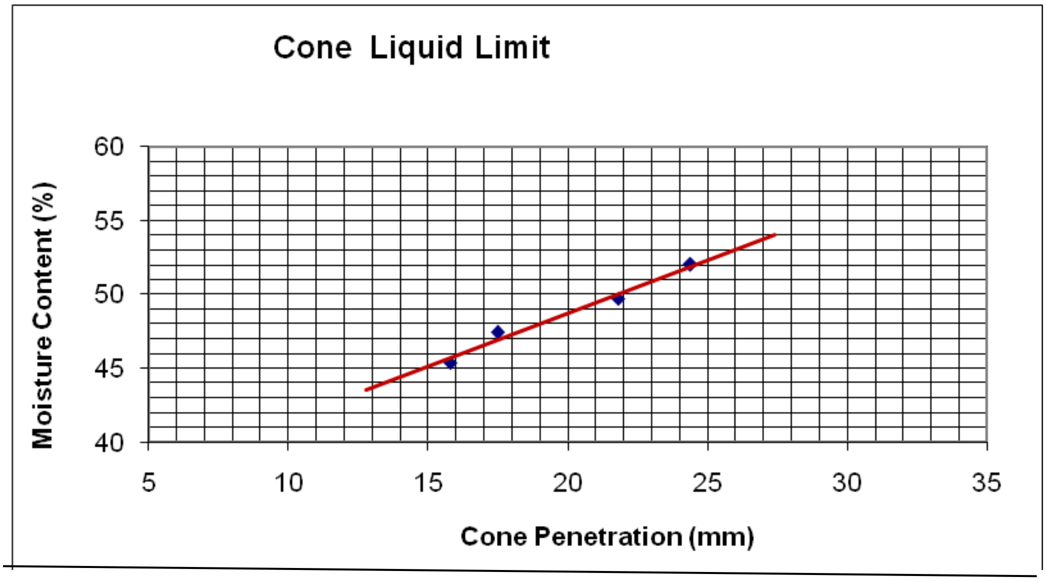

Figure 4.7: Red soil cone liquid limit

4.8 Linear Shrinkage

After running the linear shrinkage test (see appendix 11), linear shrinkage was calculated using Equation 3.19 and found to be 12.85%

Table 4.3: Atterberg limits results

PARAMETER	%
Liquid limit (%)	48.8
plastic limit (%)	30.4
linear shrinkage (%)	12.3
plastic index	18.4

The soil can be classified as a fine soil of intermediate plasticity, for its liquid limit is in the range of 35-50% (CI). This falls in the category of an expansive soil though to the extreme . Thus would not be suitable for heavy structures. (Das, 2006).

The plastic limit of 30.4% percent implies, the soil can soak up to 30.4% saturated with water without affecting the stability of the floor, and it will be unlikely to have this soil saturate with this amount of water unless the structure is built on a wet ground. A linear shrinkage of 12.3 % is not extreme for light weights (Das, 2006).

4.9 The standard compaction test

Proctor method was used to determine the optimum moisture content and the maximum dry unit weight. A total of seven tests were run at different moisture contents and soil density see appendix. 11 using Equations 3.16 to 3.18 at each test run the dry densities to corresponding moisture contents were determined (see Appendix 11) and this was plotted on a compaction curve as shown in Figure.4.8 below.

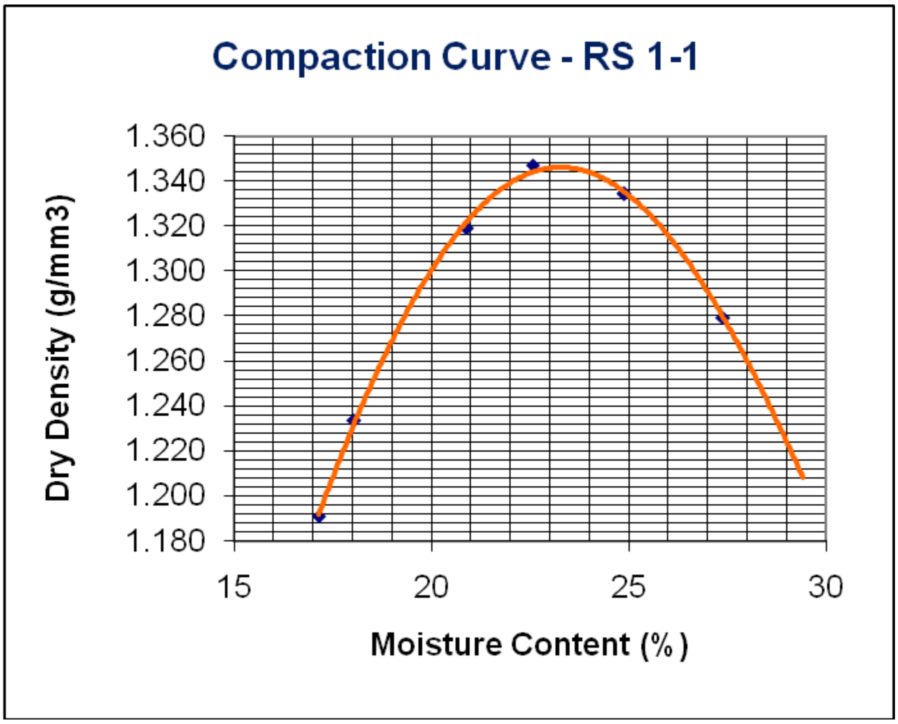

Figure 4.8: The compaction curve

The curve above represented a curvilinear relationship. The optimum moisture content is at the peak of the curve where it turns as well the dry density corresponding to this.

Maximum Dry Density = 1.347 kg/mm^3

Optimum Moisture Content = 23.4%

Hence the soil in research will become most dense and achieve its maximum dry density at moisture content of 23.4% at a density of 1.347kg/mm^3.

4.10 Unconfined compression test

A quick test to obtain the shear strength parameters of cohesive (fine grained) soils either in undisturbed or remolded state the test is not applicable to cohesion less or coarse grained soil. The test results provide an estimate of the relative consistency of the soil Three tests were carried out and the results averaged.

From the Figures 4.9, 4.10 and 4.11 below, this soil can withstand a normal stress bearing of 77.2kN/m^2 (0.772kgf/cm^2) likewise a shear stress of more than 38.7kN/m2 (0.387kgf/m^2)

From figure 4.12 below, the soil young's modulus was found to be 17(stress/strain), this being a clay (Obrzud & Truty, 2012). According to universal soil classification system (USCS). This has the young's modulus falling within ML, CL, CH of stiff to very stiff or hard which have ranges of 7-80 values for modulus of elasticity. Clays are classified as CL (clays of low plasticity, lean clay), CH (clays of high plasticity, fat clays), and ML (silt).

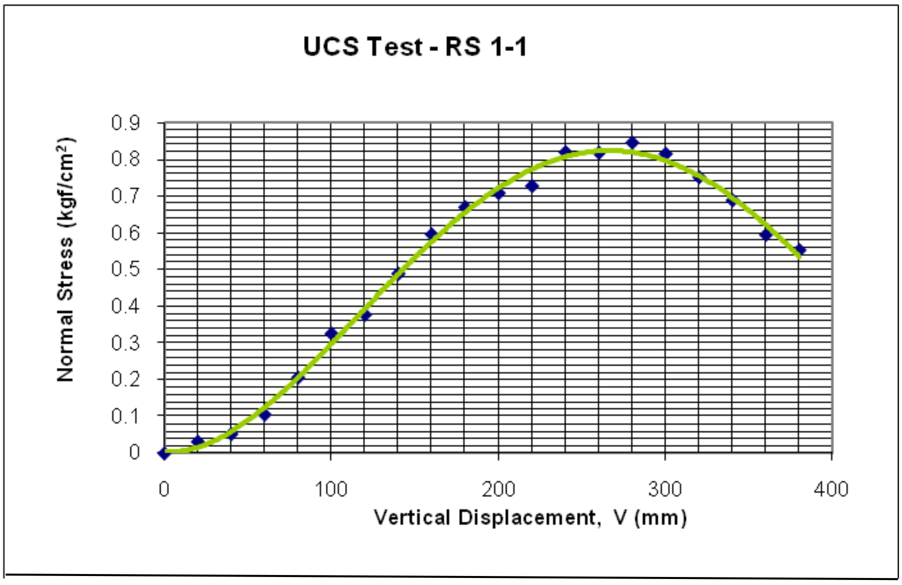

Figure 4.9: Unconfined compression test 1

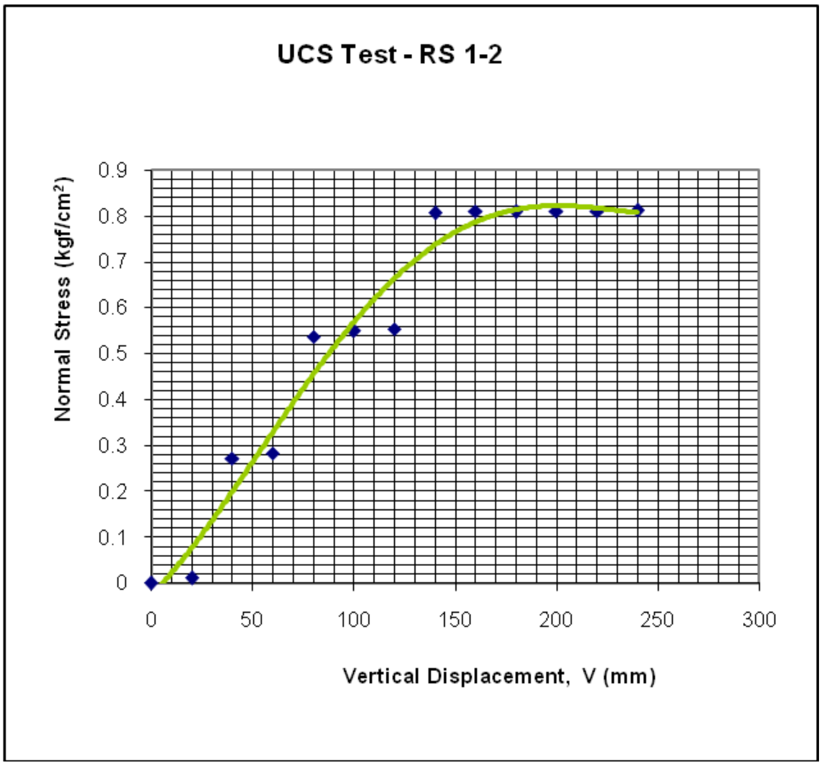

Figure 4.10: unconfined compression test 2

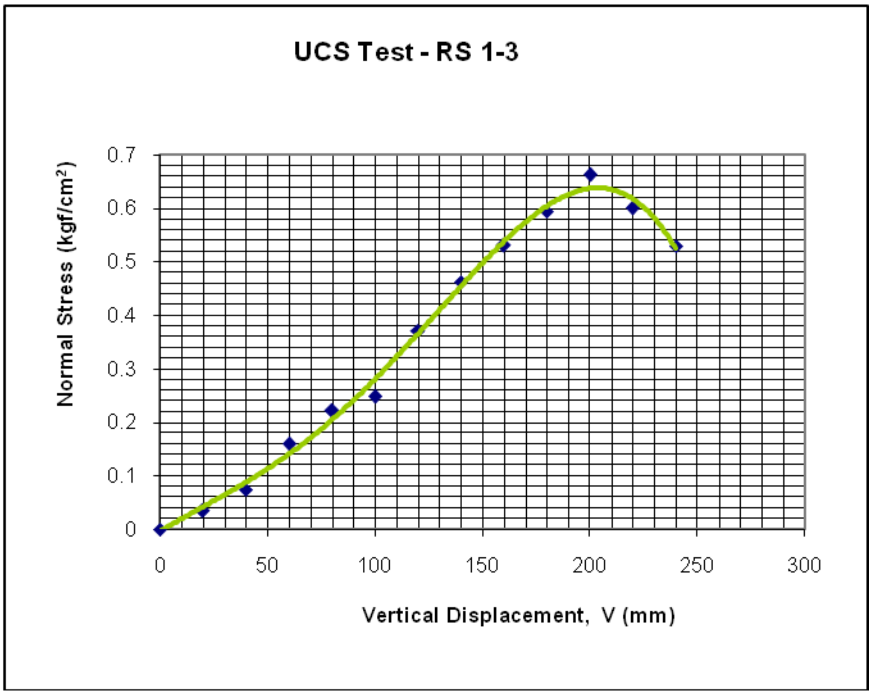

Figure 4.11: Unconfined compression test 3

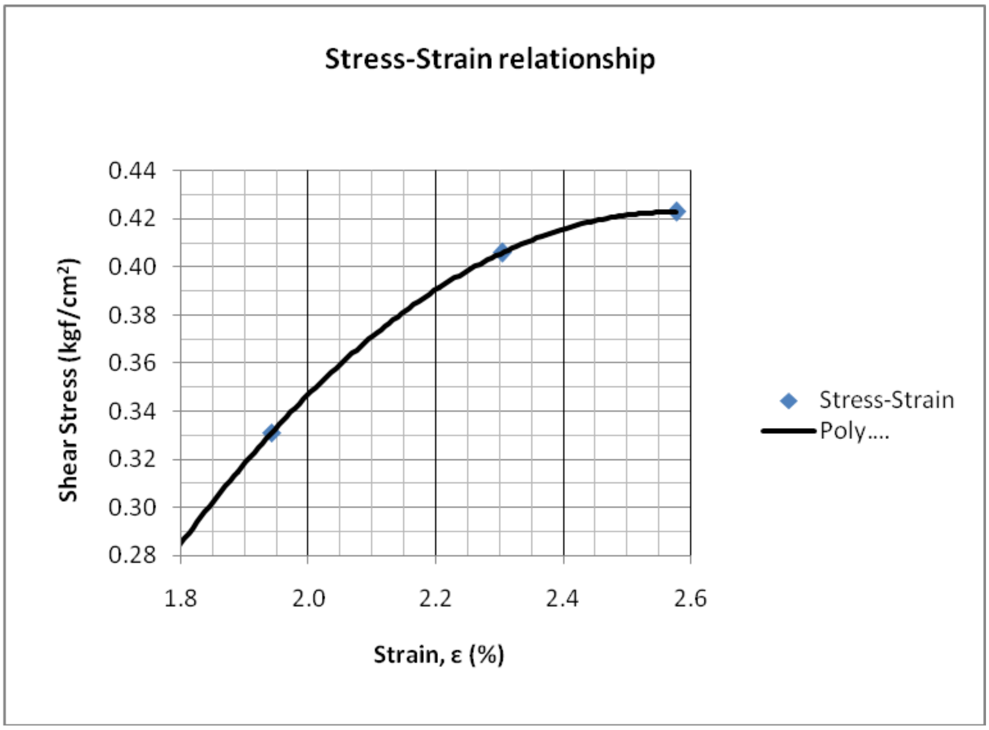

Figure 4.12: Soil shear stress-strain relationship

Applying equations (3.23 and 3. 24).The summary of the three tests were given as in table below;

Table 4.4: Results for unconfined compression test

Results	*RS 1-1*	*RS 1-2*	*RS 1-3*	Av
Dry density,ρ (Kg/mm^3)	0.119	0.137	0.128	***0.128***
Compressive strain, ε (%)	2.58	2.30	1.94	***2.275***
Normal stress, σ N/m^2	0.846	0.812	0.662	***0.773***
Shear stress, q N/m^2	0.423	0.406	0.331	***0.387***

4.11 Summary of Test Soil Properties

The various properties for the soil used in the research can be summarized in the table below:

Table 4.5: Summary of Test Soil Properties

Specific gravity	2.526
Liquid limit	48.8
Plastic limit	30.4
Linear shrinkage	12.3
Plastic index	18.4
Soil classification(USCS)-plasticity	CL
Soil classification by particle size	Sandy Silty CLAY with traces of Gravel
Normal stress (N/m^2)	0.773
Dry density,ρ (N/m^2)	0.128
Compressive strain, ε (%)	2.275
Shear stress, q (N/m^2)	0.387
Maximum Dry Density (N/m^2)	1.347
Optimum Moisture Content (compaction)	23.4%

4.12 Results on Hardened Concrete and Compacted Soil to Specific Objectives

4.11.1 Slabs crushing results

The Plate 4.1 below illustrate the cracking patterns for uniform loading of concrete slab and at crushing. From the plate the cracks appeared all over the slab and cubes, an indication that the loading was uniform. This was important in achieving representative results. For clarity, the cracking of the slab is also illustrated in the Figure 4.11.

Plate 4.1: Cracks appearing all over the slab, an indication of uniform loading

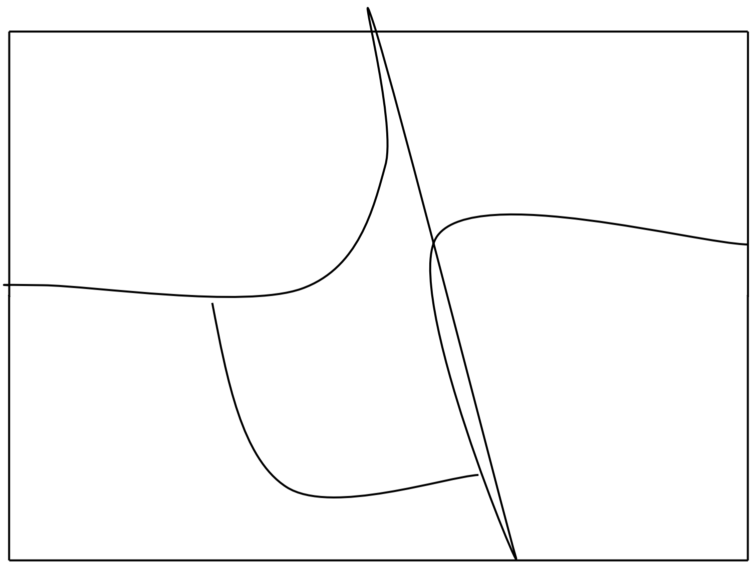

Figure 4.13: Sketch illustrating cracking of the slab under uniform loading

4.11.2 Stress/Strain relationship for 150mm slabs

The following were the findings after crushing of the 150 mm slabs two each of the various aggregates used averaged.From the graph below Fig. 4.14 all the aggregates have a linear stress-strain relationship at the initial of loading. But the curve becomes non linear with large strains being registered for small increments of stress.The non-linearity is primarily a function of the coalescence of micro cracks at the paste-aggregate interface. The ultimate stress is reached when a large crack network is formed within the concrete, consisting of the coalesced micro cracks and the cracks in the cement paste matrix. The strain corresponding to ultimate stress is usually around 0.003 mm for normal strength concrete. The stress-strain behavior in tension is similar to that in compression. For the 20 mm and graded 5-14 mm aggregates, the strain in concrete was within the maximum allowable of 0.003 mm but for the Nairobi sedimentary rock and non graded quarry dust the strain was were far much beyond allowable meaning they are not suitable for use in structural concrete.

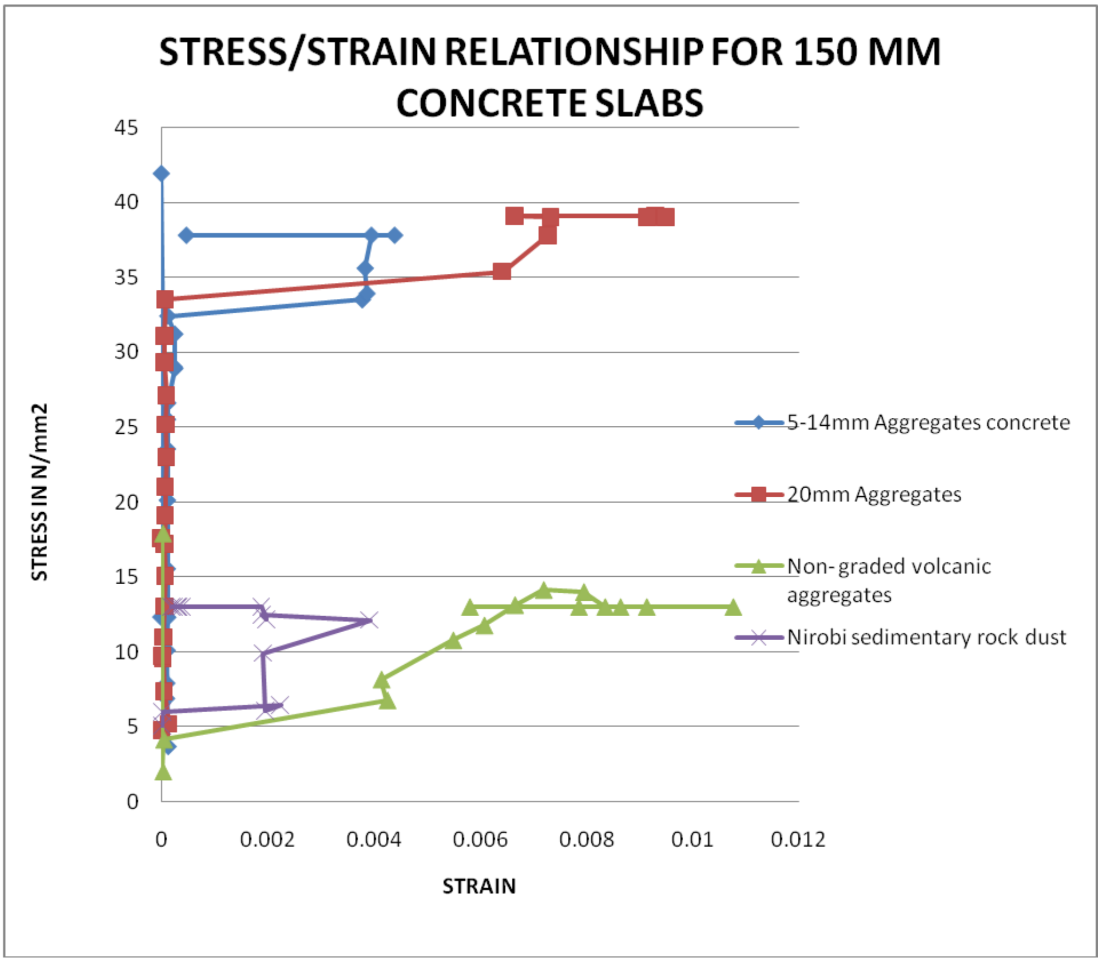

Figure 4.14: Stress/strain relationship for 150 mm concrete slabs

4.11.3 Stress/strain relationship for 100 mm concrete slabs

As in 150 mm slabs, there is a linear relationship for stress strain for all the slabs at initial loading, though in these slabs the cracks appeared earlier, an indication of large strain. The conventional 20 mm and graded 14-5 mm aggregates could bear much load before experiencing much strain than the stone dust and non graded dust. The latter two started having intense strain much earlier in loading an indication of cracking. A sudden failure of the specimen occurs as soon as the maximum load level is reached – the machine gave small increments of load to the specimen and the resultant deformation was measured, as a result, when the incremental load goes over the maximum level, the specimen fractures suddenly (Li, 2016).

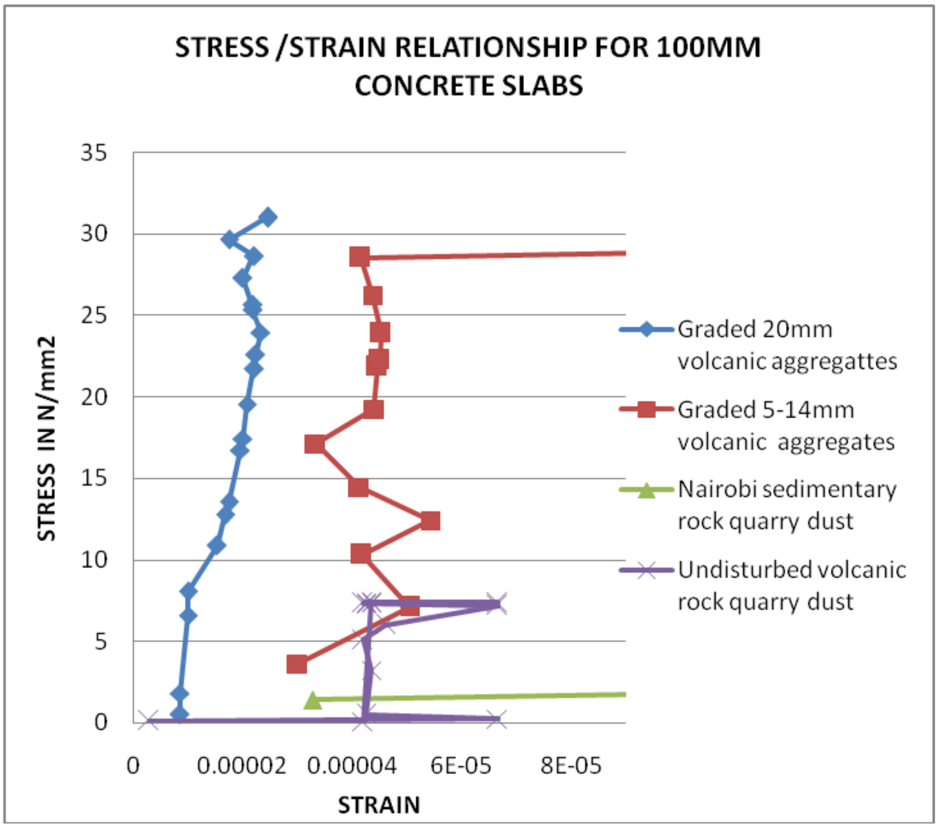

Figure 4.15: Stress/strain relationship graph for 100 mm concrete

From the Table 4.6 it can be seen that all the 150 mm slabs crushed at above 1.5 kN /m^2 minimum allowable imposed loads as per BS6399-1. The slabs of 100 mm thick had two of them crushing below 1.5 kN/m^2. From the stress graphs the loading increased until the samples could not take any more loads meaning the sample had given way. From the stress/strain graphs Figure 4.14 and 4.15 for both 150 mm and 100 mm concrete slabs it can be seen that there is so much strain in quarry dust concretes and as well they crushed at lower stress than the conventional 20 mm aggregates which proves in the literature In a study "the influence of the aggregate size on the mechanical and transport properties of concrete and concrete-equivalent mortars" (Ozbay, 2010) which found out that compressive and split tensile strengths of concrete and CEMs (concrete-equivalent mortars) increased as the maximum aggregate size increased .The thickness of the slab also seems to affect strength. Looking at 150 mm slabs Figure 4.14 above there is very little strain in the conventional 20 mm aggregate slab actually almost none compared to the 100 mm slab Figure 4.16 which shows substantial strain though not as much as in the quarry dust concretes. The use of quarry dust in concrete has been investigated and found to produce good results (Safiudin, 2007) demonstrated that concrete with up to 40% replacement level of sand by laterite attained the designed strength of 20 N/mm.^{2}

Thus it is clear that depth of quarry dust concrete slabs has a great effect on the structural soundness and engineering properties of ground floor slabs. For quarry dust concrete that is not graded, depths of less than 150 mm cannot work for ground floor slabs, as seen from the results they both crushed at below 1.5 KN/m^2 allowable. The graded 5-14 mm and 20 mm aggregates functioned from this depth on loading aspect. The slabs were crushed on top of optimally compacted soil, hence with a factor of safety of 1.5, the expected safe crushing strength would be 2.25 kN/m^2 .Looking at Table 4.6, non graded volcanic dust concrete would fail for 100 mm slabs, the Nairobi quarry dust has both thickness failing but all graded aggregates concrete are safe in both thickness.

Table 4.6: Loadings at Failure Summary

	150MM SLABS IMPOSED LOAD FAILURE IN kN/m^2	100MM SLABS IMPOSED LOAD FAILURE IN kN/m^2	MAXIMUM ALLOWABLE DESIGN LOADS FOR DOMESTIC FLOORS(BS 8110)
20MM VOLCANIC ROCK AGGS.	3.3	2.9	1.5
GRADED 5-14MM VOLCANIC ROCK AGGS	3.2	2.8	1.5
NON GRADED VOLCANIC ROCK QUARRY DUST	2.2	1.2	1.5
NAIROBI SEDIMENTARY ROCK QUARRY DUST	2.1	0.8	1.5

Table 4.7: Deformation at failure

REFERENCE	150MM	100MM
	Deformation in (mm)	Deformation in (mm)
CA	39	63
GQD(5-14MM)	35	29.6
NGQD	23.5	23.95
NSRD	20.5	29.5

4.13 Cube Crushing Test Results

Cubes were tested for failure in compression. In this research apart from compression both lateral and longitudinal strains were measured via strain gauges. It is evident from the line graphs (see Appendix 7) that longitudinal strains were experienced first before lateral ones from all the concrete implying that the specimen crushed first because of compression and the lateral strain come later after the specimen has reduced in volume.

But they all fail at the same point meaning that when failure occurs, be it lateral or longitudinal, the whole thing fails not withstanding which direction. But can also be observed that lateral strain of concrete presents with respect to the longitudinal strain three parts. The first part is linear elastic, the final part is linear, with higher slope than of first part and the intermediate part is a transition curve connecting both parts. The last two parts show an inelastic behaviour so that a residual lateral strain takes place under unloading (Osorio, 2012).

Cubes of (150x150x150) mm were used. Load at the failure divided by area of specimen gives the compressive strength of concrete. Apart from compressive strength the test also sought to establish the strain hence young's modulus for the various aggregates in the research to ascertain their stiffness.

The young's modulus for concrete from various aggregates was established as below:

(ratio of stress to strain)

Non graded quarry dust=3.6 Gpa

Nairobi sedimentary rock=1.4 Gpa

Graded volcanic rock aggregates 5-14mm=16 Gpa

Volcanic rock Aggregates 20mm size average=26.6 Gpa

From the above, the young's modulus for the 20mm aggregates was well within the normal concrete range of 20-30 GPa, all the dusts had very low modulus of rigidity, only the graded quarry dust had a young's modulus close to the concrete range, an indication that the more fine aggregate concrete is less stiff

The results for concrete cubes compression tests were tabulated as shown in Table 4.11

The compression cubes also had all but the Nairobi dust fail above the 15 N/mm2 characteristic compressive strength as per BS6399-1 at 28 days.

Table 4.8: Summary of compressive strength and young's modulus

	Compressive Strength at 28days kN/m^2(class 15)	Young's modulus(GPa)
20mm volcanic rock Aggs.	2.0	26.6
graded 5-14mm volcanic rock Aggs	1.9	16
non graded volcanic rock quarry dust	1.6	3.6
Nairobi sedimentary rock quarry dust	1.4	1.4

4.14 Summary of compressive strength and Young's modulus

All the aggregates concrete, except the Nairobi sedimentary rock quarry dust concrete crushed above the allowable compressive strength at 28 days. The conventional 20 mm aggregates and graded 5-14 mm aggregate concrete cubes has a better factor of safety from the allowable compressive strength and had strengths almost at same values i.e. 20 and 19 respectively. The non graded quarry dust concretes had their compressive strength values as well almost same, with Nairobi sedimentary rock failing marginally to meet the minimum allowable strength but the non graded volcanic rock dust making the cut but with a very small margin, thus a very small factor of safety.

4.15 Water Seepage Test

Another aspect of the test was the rate of water flow through the sample which attempted to define permeability, which had all the concrete comparing fairly for the 28 days they were subjected to the test. The larger aggregates had better resistance to water flow than the smaller size aggregates. Which further gave proof to by (Ozbay, 2010), that water sorptivity values of concrete and CEMs increased while decreasing the maximum aggregate size. This is demonstrated in Figure 3.1 in literature review (aggregate size vs permeability). For the first week, the rate of low was constant and more rapid (Figure 4.16 below), this may have been due to the samples being dry and absorbed water fast as well the hydrostatic pressure being high, but the rapid flow decreased in all the specimen for the remainder of the three weeks which could have been as a result of the reverse of the first condition given that the samples were now saturated with water and there was less hydrostatic pressure.

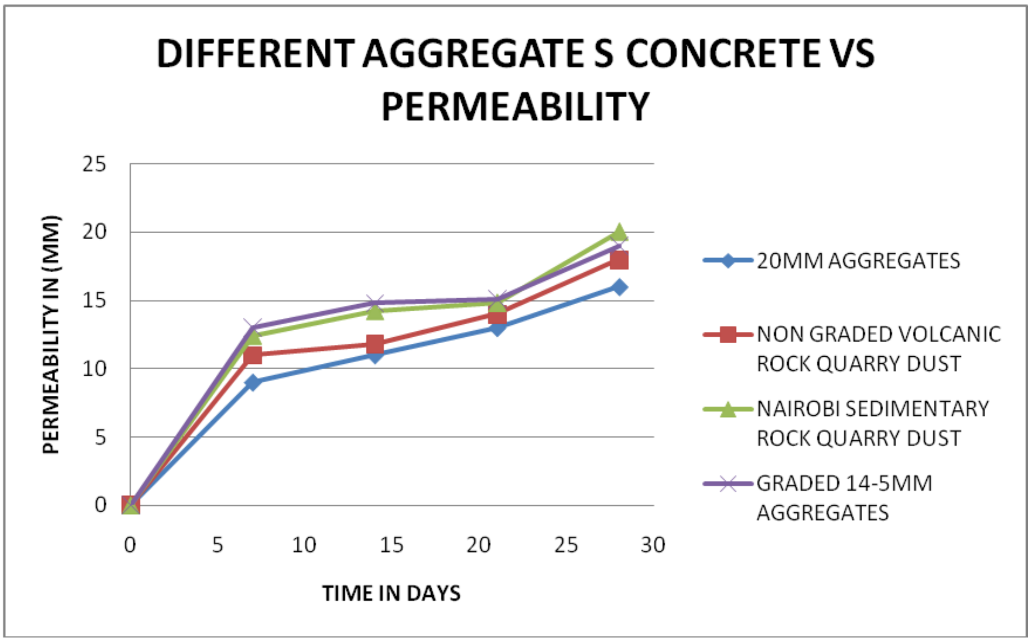

Figure 4.16: Aggregates vs water seepage graph representation

Hence different types of quarry dust as a coarse aggregate has an effect on the functional requirements of a ground floor slab. From the results, the smaller the aggregate is more susceptible to compression and strain. It is also evident from the results that smaller sized aggregates allowed in more water seepage than bigger size.

This is because large size coarse aggregates can decrease the volume of interfacial transition zone in concrete and reduce the content of harmful pores in concrete (Ozbay,2010). Thus small sized aggregates affect ground floor slabs negatively than bigger sized up to 20mm.

4.16 Red soil loading as sub base results.

The soil in the research was established to be a sandy silty CLAY with traces of gravel. The soil achieved maximum dry density compaction at 1.37g/m^3 at optimum moisture content of 23.4% .The results for loading slabs on optimally compacted soil were analyzed of the line graphs below for the various slab thickness.

4.16.1 Deformation in 150 mm slabs

The deformation occurring was due to compressive failure. Though the soil was confined it yielded mainly due to movement of the confining box thus the soil sub base buckled and deformation was recorded. from the graph above, there seems to be less deformation in un-graded quarry dust and the stone dust, an indication of early failure of these materials thus less force being taken in compared to the conventional 20 mm aggregates and graded quarry dust 5-14 mm, indicating that these materials had much more resistance thus took more force hence the significant deformation. The deformation from the Figures 4.17 and 4.18 shows increase and decrease of deformation, this could be due to the mould for confined soil giving way, for by the end of the last test it had given way completely.

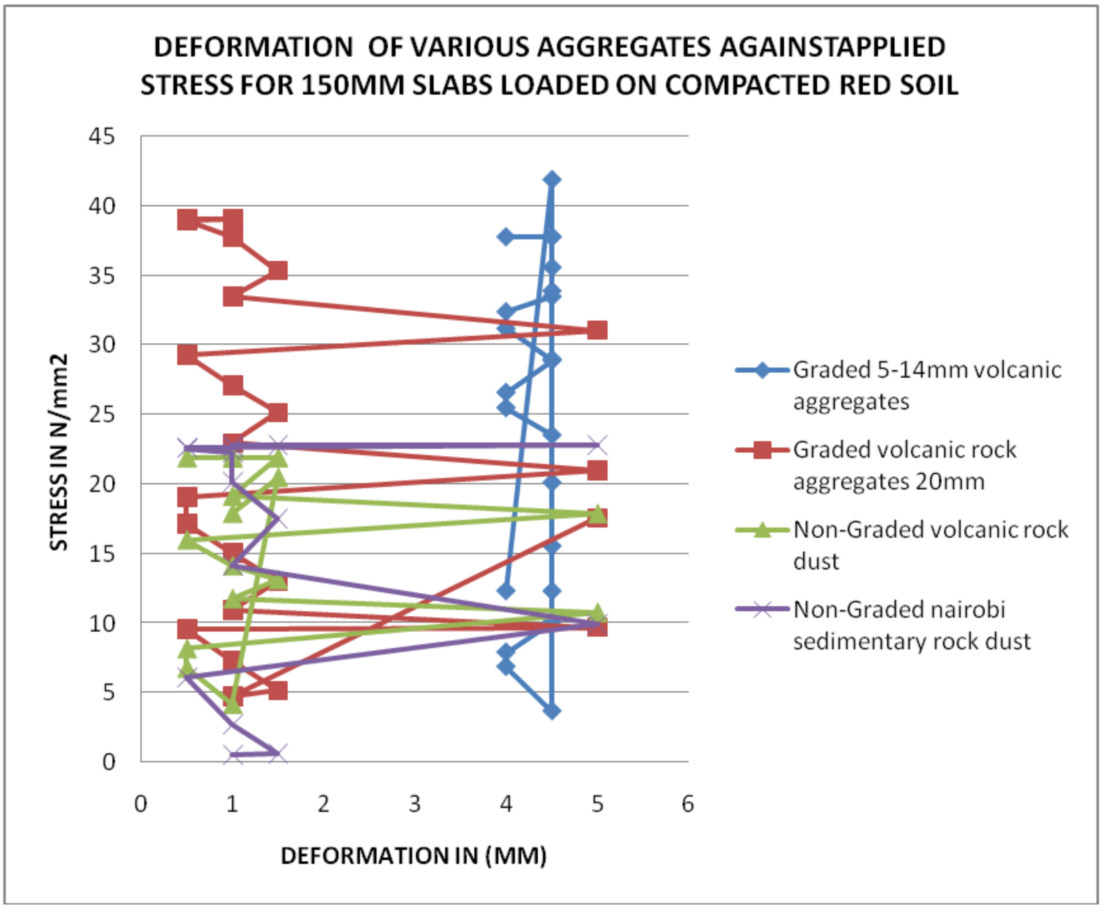

Figure 4.17: Graph Representation for Deformation of Loaded 150 mm Slabs Over Red Soil

4.16.2 Deformation for loading 100mm slabs over compacted red soil

Just as in 150 mm slabs, the much stronger slabs experienced much deformation from higher loads than the weaker slabs. Still due to stone dust and non-graded quarry dust failing earlier hence taking less loads hence no much force for deformation. Though deformation here now was much more than in 150 mm slabs, an indication of the load being transmitted early to the sub base soil than in 150 mm concrete slabs

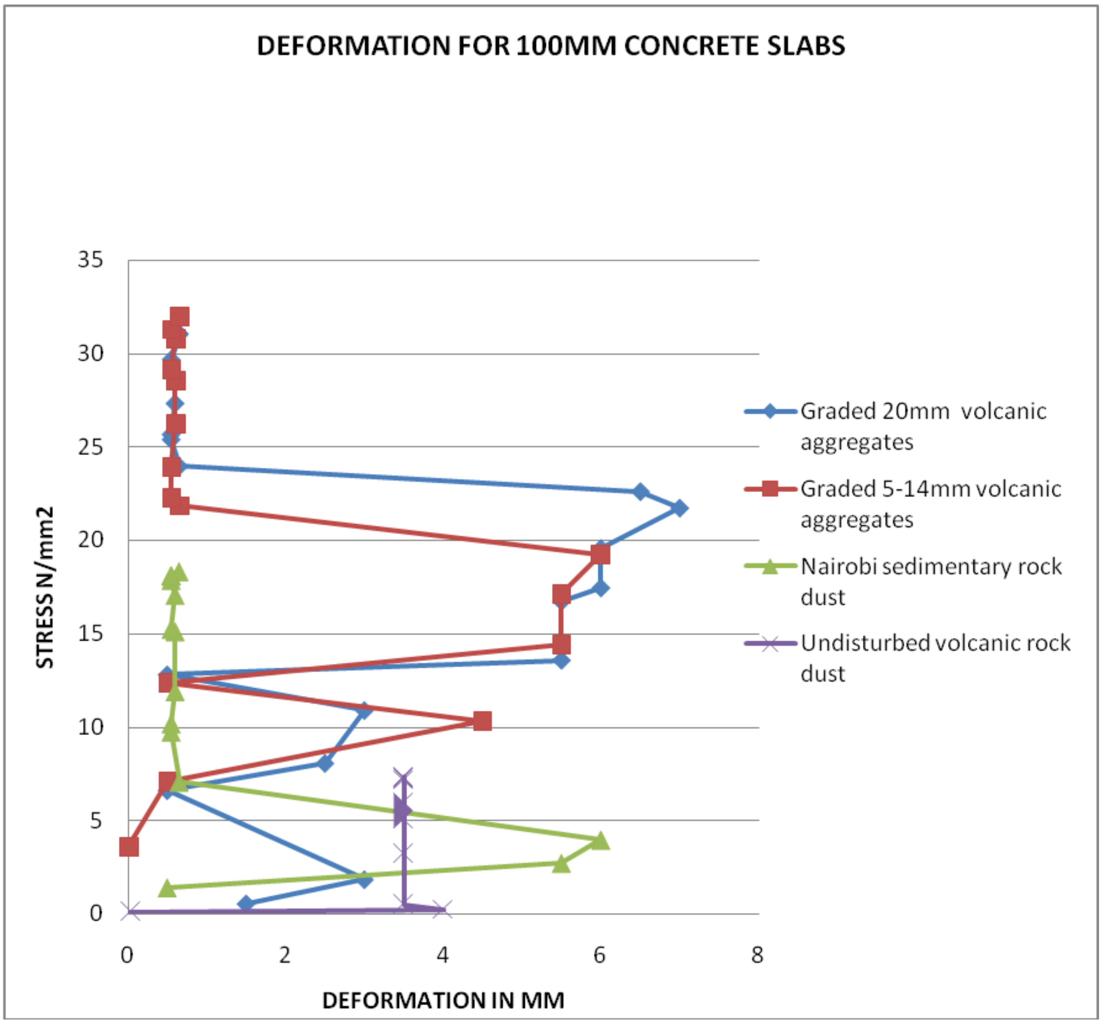

Figure 4.18: Graph representation for deformation of loaded 100mm slabs over red soil

4.16.3 Summary Deformation

The deformation was very significant; the highest being about 43 mm and this could have slightly been caused by disjointing in the process of loading of the mould that contained the red soil. Hence a sandy silty clay with traces of gravel if optimally compacted can meet the functional structural requirement of a ground floor slab. From the properties of the soil e.g. a plastic index of 18.4 it was evident that the soil does not belong to the expansive clays which have higher values of plastic index and need stabilization to meet structural functional requirements (Barasa, 2016).

4.17 Non Optimal Conditions

These tests are done in laboratory set up where all parameters are met for the test conditions such as moisture content, maximum compaction and temperature whereas in the real life situation it is difficult to meet all the parameters thus the slabs were also tested on non optimal conditions to find out the trend. This was done on the soil at 30% moisture content and the result was as below. In the 30 percent and 0.9 g/cm^3 Dry density which were used for non optimum conditions, the conventional slab Figure 4.18 shows sudden strain only after stress of less than 10N/mm$^{2.}$ This could be due to the early failure. The non optimum soil compaction loading gave a deformation of 57 mm, quite a significant deformation (Figure 4.20.)

In view of this it is evident that if soil has to be used as the sub-base then compaction has to be optimum otherwise the results may not be good.

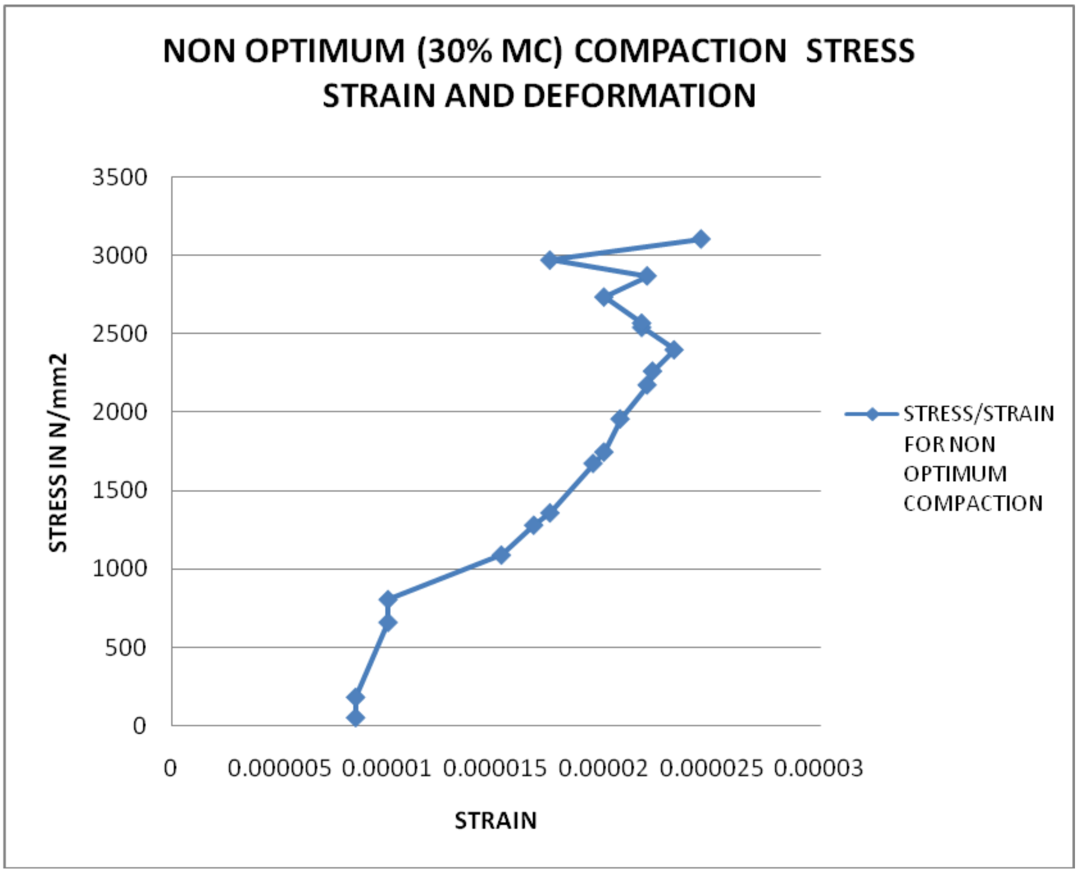

Figure 4.19: Non -optimum compaction loading Stress /strain relationship

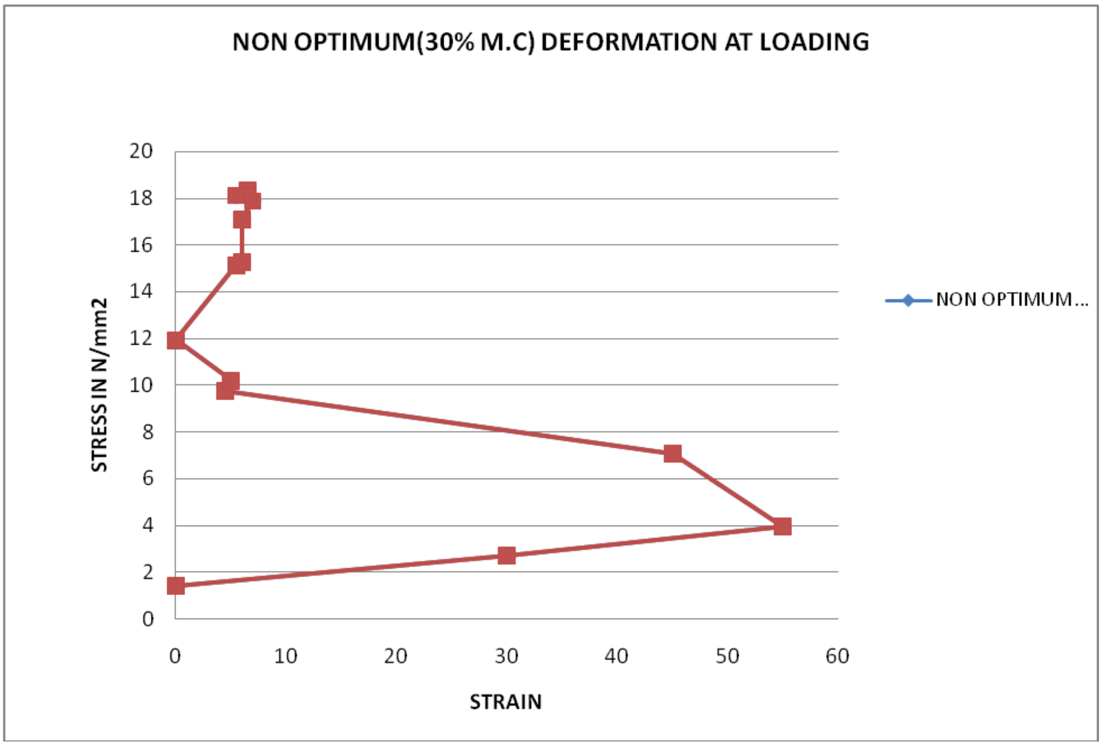

Figure 4.20: Non -optimum compaction loading Deformation

4.18 Point loading

The methods used in this research were aimed at loading uniformly the floor slabs to be able to correctly predict the outcome in a real life situation. In ideal situation it is assumed the slabs shall be loaded uniformly, which is always never the case, furthermore the research wanted also to establish if the methods used in the research achieved uniform loading hence point loading results were as in Fig.4.21 and 4.22 .

The concentrated load, point loading gave way below the allowable 1.4kN/m^2 as per BS6399-1. That is at about 1.0 kN/m^2. The cracking was also not uniform on the slab an indication that if loaded this way the slabs would fail also a proof that the loading of the other slabs achieved uniform loading.

Deformation is also very significant at low stress and failure occurred before even 10N/mm^2

Figure 4.21: Point loading stress/strain Relationship

It can be observed from Plate 4.2 below that failure due to point load was by punching shear failure. punching shear failure in this case could have been affected by the size and geometry of the load, for the concrete was already able to withstand allowable compressive strength of 15N/mm^2 by failing at 20N/mm^2 and the depth was also adequate in compression loading. The slab failed in punching shear at 10N/mm^2

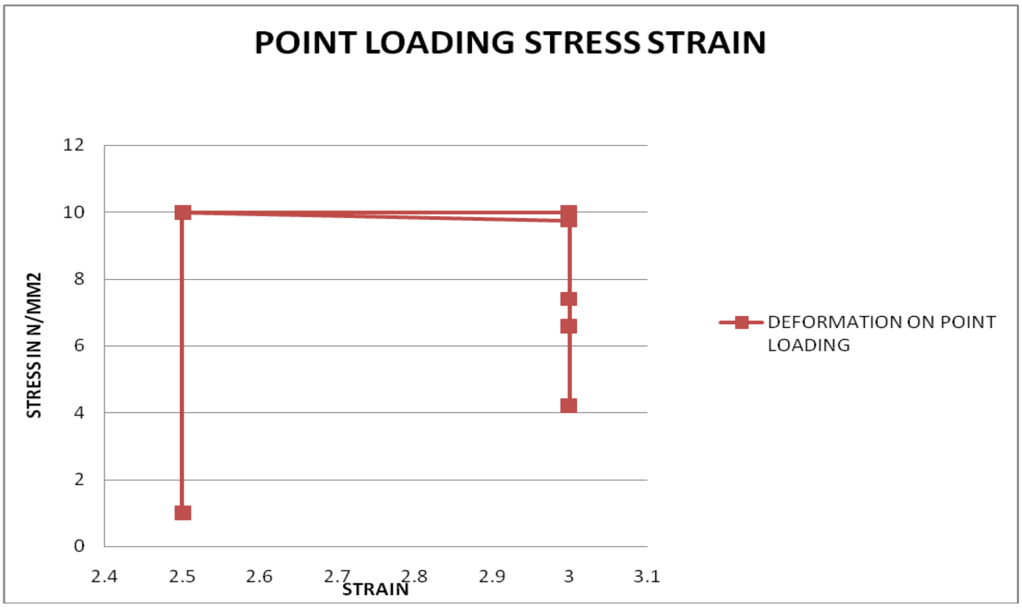

Figure 4.22: Point loading Deformation

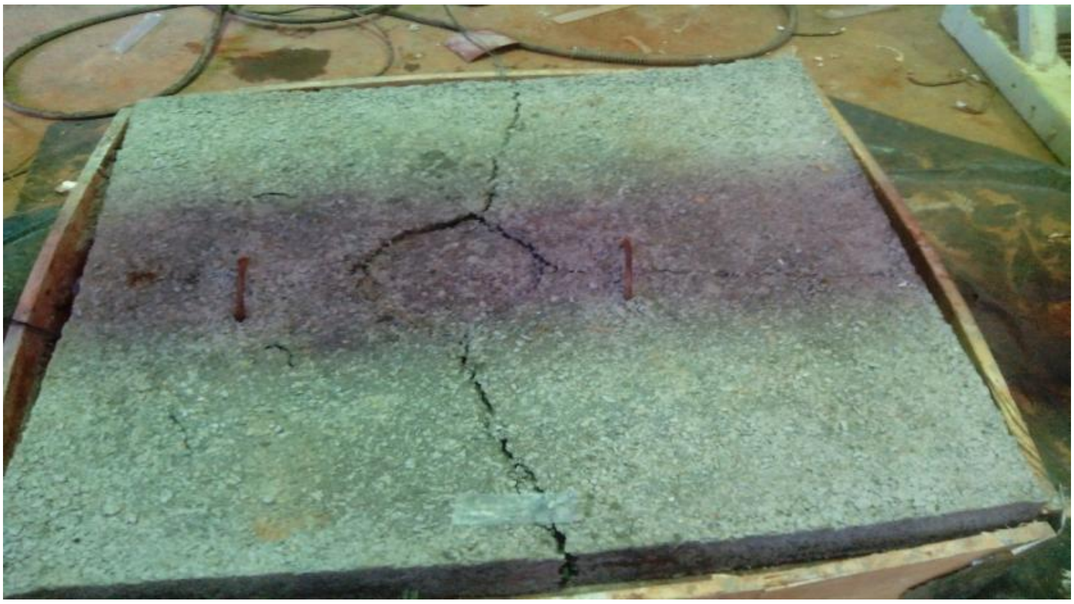

Plate 4.2: Point loading indicating non uniform loading from the cracking

4.19 Summary

The research work was geared towards sustainable construction by using locally available materials which are eco-friendly and reduction in the cost of construction for domestic and residential activity floors.

The tests carried out were to test the strength of quarry dust concrete as an isolated unit (cube crushing) as well the quarry dust concrete together with the supporting soil sub base so as to test real in place conditions. All the quarry dust in research was tested against the conventional aggregates under same conditions and from the results the following was established.

The slabs done in graded aggregates from 5 mm to 20 mm can effectively structurally function on a dwelling house building from as minimum of 100mm thickness. This satisfies the general objective of the research that quarry dust concrete and the underlying sub-soil can effectively perform structurally on domestic dwelling house ground floors. The non graded aggregates, (the quarry dust) can only function structurally on a floor from a minimum of 150 mm on an optimally compacted sandy silty CLAY with traces of gravel. Thus natural sub bases of this soil and other better granular soils if well compacted are stable and can structurally function to carry domestic dwelling ground floors.

Different types of aggregates were used and it was found that the graded aggregates for the volcanic rock perform better structurally than the non- graded. This may be because grading allows proper and determination of sizes for mixing unlike the non-graded which it is difficult to determine the proportions of each for prudent mixing. The sedimentary quarry dust performed poorly due to mainly the fineness the smaller the aggregates the less strong and mainly because it is not possible to batch well with other aggregates.

From the capillarity test all the aggregates are were able to allow passage of water thus a damp proof membrane should always be incorporated where necessary irrespective of the ground conditions

It was also established that hardcore may not be necessary for a ground floor dwelling house unless the ground has drainage issues.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The conclusions made from the study were:

1. Depths of quarry dust concrete slab affects the structural soundness and engineering properties of a ground floor slab. Shallower depths below 150mm thick of non graded quarry dust concrete slabs cannot meet the structural requirements of a ground floor slab, Graded aggregates of quarry dust from 5-20 mm used as coarse aggregates meet the structural soundness of a concrete ground floor slab from depths as low as 100mm thick.
2. The larger the coarse aggregate up to 20mm in ground floor concrete slabs, the more the concrete is able to withstand compressive strength and water percolation. Concretes made in non graded quarry dust can only marginally meet allowable compressive strengths. Graded aggregates from 5 mm to 20 mm when used in concrete the values for compressive strength is higher and they do not allow in much water seepage as the smaller sized aggregates.
3. A sandy silty CLAY with traces of gravel when optimally compacted will safely transmit loads to the ground without necessarily needing to replace them with hard core. Unless there are ground water issues which could be arrested with other methods such as incorporating of a damp proof membrane, natural sub base of granular soils of red soil quality can meet functional requirements of a ground floor slab.

5.1.1 Recommendations

In order to conserve the environment, and use available materials domestic houses built on red soil formations (a sandy silty CLAY with traces of gravel) need no laying of hardcore, the soil can be optimally compacted and floor is cast, especially when the ground has a good drainage. This floor can be done in graded quarry dust 4-20 mm or at minimum 100mm thick floor slab or in undisturbed volcanic rock quarry dust at a minimum of 150 mm thick floor slab.

5.1.2 Further Work

It is recommended that further research be conducted on various soils so as to provide a better guide on sub-soils strengths for the floors for this research only tested the red soil found in Juja, Central Kenya.

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APPENDICES

Appendix 1: Sieve Analysis for Fine Aggregates (River Sand)

							OVERALL	
SIEVE SIZE	WT. OF SIEVE(KG)	WT. OF SIEVE + MASS RETAINED	WT. OF SOIL RETAINED	CUMMULATIVE WT. RETAINED	CUMULATIVE RETAINED %	CUMULATIVE PASSING %	LOWER LIMIT	UPPER LIMIT
10	499.5	499.5	0	0	0	100	100	100
5	468	477.5	9.5	9.5	0.95429	99.045706	89	100
2.36	386	395.5	9.5	19	1.90859	98.091411	60	100
1.2	449.5	496.5	47	66	6.62983	93.370166	30	100
0.6	396	771	375	441	44.2993	55.700653	15	100
0.3	344	587.5	243.5	684.5	68.7594	31.240583	5	70
0.15	362.5	618.5	256	940.5	94.4751	5.5248619	0	15
0.075	342.5	386	43.5	984	98.8448	1.1551984	0	15
PAN	301.5	313	11.5	995.5	100	0	0	5

Appendix 2: Data for Coarse Aggregates Overall Grading Limit

SIEVE ANALYSIS DATA FOR COARSE AGGREGATES								
SIEVE SIZE	**WT. OF SIEVE(KG**	**WT. OF SIEVE + MASS RETAINED**	**WT. OF SOIL RETAINED**	**CUMULATIVE WT. RETAINED**	**CUMULATIVE RETAINED %**	**CUMULATIVE PASSING %**	**LOWER LIMIT**	**UPPER LIMIT**
50	559	559	0	0	0	100	100	100
40	520	520	0	0	0	100	100	100
20	586	875.5	289.5	289.5	15	85	85	100
15	569	865	296	585.5	30	70	0	70
10	493	1263.5	770.5	1356	70	30	0	25
5	482.5	954.5	472	1828	94	6	0	5
PAN	301	412.5	111.5	1939.5	100	0	0	5
				1939.5				

Appendix 3: Sieve Analysis for Nairobi Sedimentary Rock Quarry Dust

SIEVE ANALYSIS DATA FOR NAIROBI SEDIMENTARY ROCK FINES OVERALL GRADING LIMIT								
SIEVE SIZE	**WT. OF SIEVE(KG)**	**WT. OF SIEVE + MASS RETAINED**	**WT. OF SOIL RETAINED**	**CUMULATIVE WT. RETAINED**	**CUMULATIVE RETAINED %**	**CUMULATIVE PASSING %**	**LOWER LIMIT**	**UPPER LIMIT**
10	468.5	468.5	0	0	0	100	100	100
5	463	491	28	28	2.510085	97.48991	89	100
2.36	460.5	531	70.5	98.5	8.830121	91.16988	60	100
1.2	396.5	625	228.5	327	29.31421	70.68579	30	90
0.6	344	601.5	257.5	584.5	52.39803	47.60197	15	54
0.3	344	493	149	733.5	65.75527	34.24473	5	40
0.15	363	564.5	201.5	935	83.81892	16.18108	5	40
0.075	343	459	116	1051	94.21784	5.78216	5	40
PAN	301.5	366	64.5	1115.5	100	0	5	40

Appendix 4: Sieve Analysis Non Graded Volcanic Rock Quarry Dust

NON GRADED VOLCANIC ROCK QUARRY DUST FINES OVERALL GRADING								
SIEVE SIZE	**WT. OF SIEVE(KG)**	**WT. OF SIEVE + MASS RETAINED**	**WT. OF SOIL RETAINED**	**CUMULATIVE WT RETAINED**	**CUMULATIVE RETAINED %**	**CUMULATIVE PASSING %**	**LOWER LIMIT**	**UPPER LIMIT**
10	0	0	0	0	0	100	100	100
5	468	503.5	35.5	35.5	3.1824	96.81757	89	100
2.36	463	686.5	223.5	259	23.218	76.78171	60	100
1.2	449.5	636	186.5	445.5	39.937	60.06275	30	100
0.6	396.5	580	183.5	629	56.387	43.61273	15	100
0.3	344.5	443.5	99	728	65.262	34.73779	5	70
0.15	363	498	135	863	77.364	22.63559	0	15
0.075	343	425.5	82.5	945.5	84.76	15.2398	0	15
PAN	306.5	319.5	13	958.5	85.926	14.07441	0	15

Appendix 5: Sieve Analysis Data for Graded Volcanic Aggregates 14-5mm Size

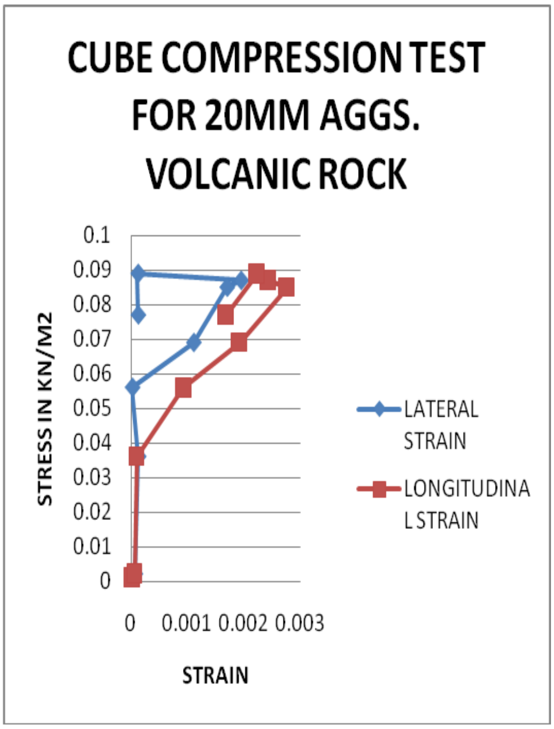
SIEVE SIZE	WT. OF SIEVE(KG)	WT. OF SIEVE + MASS RETAINED	WT. OF SOIL RETAINED	CUMULATIVE WT. RETAINED	CUMULATIVE RETAINED %	CUMULATIVE PASSING %	LOWER LIMIT	UPPER LIMIT
10	499.5	499.5	0	0	0	100	90	100
5	463	1111	648	648	33.609959	66.390041	50	85
2.36	460.5	702.5	242	890	95.905172	4.0948276	0	10
PAN	301.5	339.5	38	928	100	0	0	10

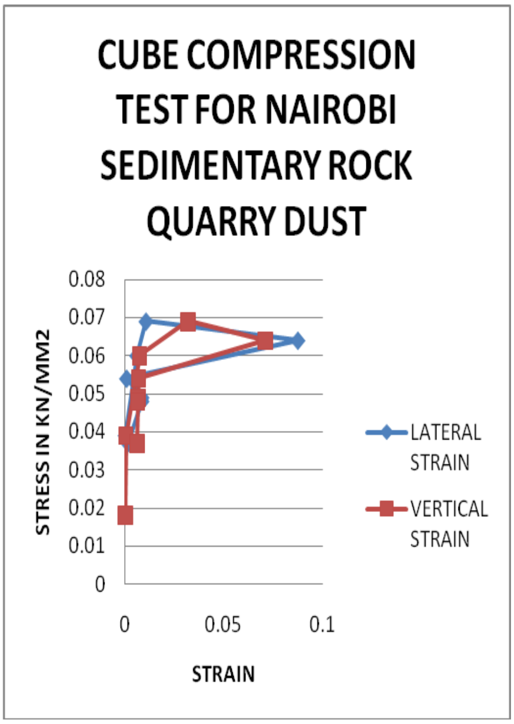
Appendix 6: Red Oil Sieve Analysis Data

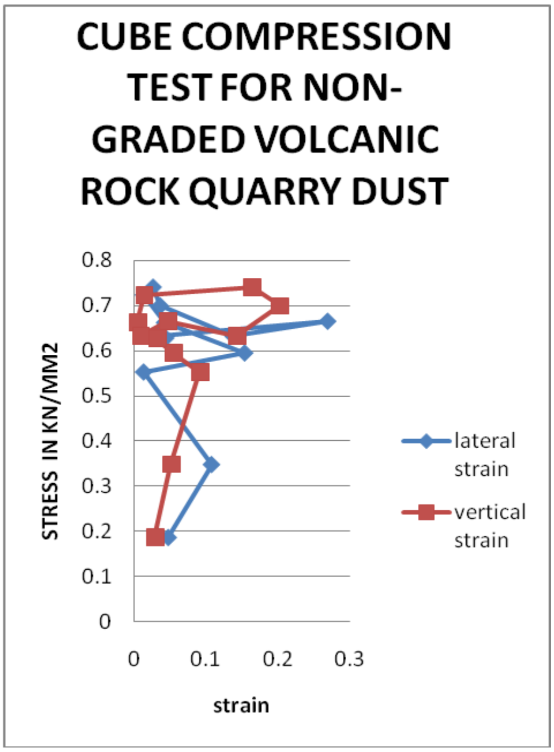
Dry Sieving		***Wet Sieving***
Weigt of Dry Soil + Tray (g)	203.34	Weight of Dry Soil + Tray (g)
Weight of Tray (g)	100.01	Weight of Tray (g)
Weight of Dry Soil Screened (g)	103.33	Weight of Dry Soil retained on 74um (g)

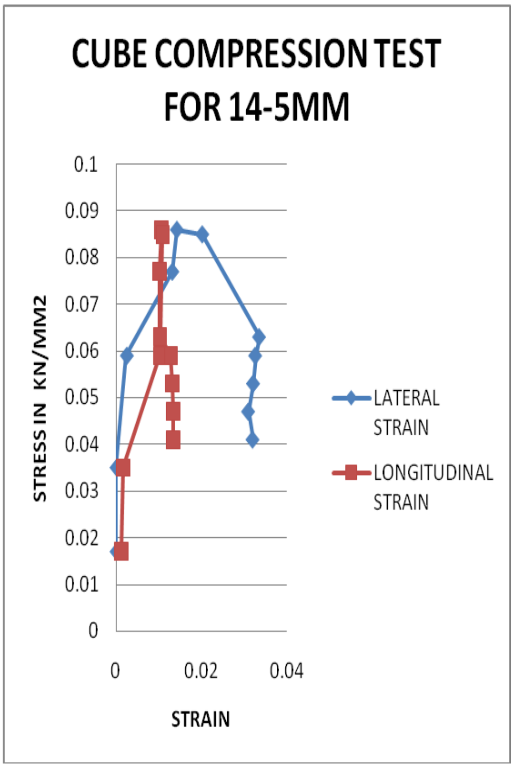
Sieve Size (mm)	**Wt of Sieve and Soil (g)**	**Wt of Sieve only (g)**	**Wt of Soil Retained on sieve (g)**	**Cumulative Wt Retained (g)**	**Soil Retained on Sieve (%)**	**Soil Passing Sieve (%)**
50.8						
38.1						
25.4						
19.1	526.9	526.9	0	0	0.00000	*100.00*
9.52	477.5	475.7	1.8	1.8	1.74199	*98.26*
4.76	434.7	434.1	0.6	2.4	2.32266	*97.68*
2.0	424.4	423.1	1.3	3.7	3.58076	*96.42*
0.84	380.3	379.0	1.3	5	9.68054	*90.32*
0.42	372.1	371.0	1.1	6.1	11.81026	*88.19*
0.25	351.5	350.7	0.8	6.9	13.35915	*86.64*
0.105	330.7	329.1	16.4	23.3	45.11133	*54.89*
0.074	319.5	318.7	0.8	24.1	46.66021	*53.34*
Pan	322.4	322.4	0	24.1	46.66021	*53.34*
				97.4		

Appendix 7: Cube Crushing Results









Appendix 8: Red Soil Moisture Content

	MOISTURE CONTENT		(Red Clay Soil)
	RS 1-1	**RS2-2**	**RS-3-3**
Tin No	1A	2A	3A
Tin + Wet Soil m_a, g	62.79	57.8	61.5
Tin + Dry Soil m_b, g	53.96	49.25	53.34
Tin only m_c, g	5.50	5.51	5.0
Moisture Content %	18.2212	19.54733	16.880

Appendix 9: Specific Gravity Tests

	Gs		
Soil Type	Red Soil - Juja		
Specimen No	RS 1-1	RS 1-2	RS 1-3
Bottle No	30	31	38
Wt of Bottle only m1, (g)	63.00	53.31	47.26
Wt of Bottle + Dry Soil, m2(g)	97.31	93.49	87.78
Wt of Dry Soil = Ws (g)	34.31	40.18	40.52
Wt of Bottle + Soil + Water, m3 (g)	180.23	177.08	172.19
Wt of Bottle + Water, m4 (g)	159.47	152.73	147.78
Wt of water equal to solids, Ww (g)	13.55	15.83	16.11
Specific Gravity	2.53210	2.53822	2.51521
Test water temperature (°C)	24.5	24.5	24.5
Correction Factor to 20°C	0.99895	0.99895	0.99895
Average Specific Gravity at 20°C		2.526	

Appendix 10: Cone Penetrometer Results for Soil Atterberg Limits

ATTERBERG LIMITS						
CONE PENETROMETER METHOD						
Specimen No	RS 1-1			Date		
		Red Soil - Juja				
Type of Test	Liquid Limit			Plastic Limit		
Test Run No	1	2	3	1	2	3
Intial Dial Gauge Reading, mm	0	0	0			
Final Dial Gauge Reading, mm	15.8	17.5	21.8			
Cone Penetration mm	15.8	17.5	21.8	xx	xx	xx
Tin No	2	3	4	4A	6A	7A
Wt of Tin + Wet Soil, ma (g)	13.76	20.47	29.45	7.92	11.4	11.2
Wt of Tin + Dry Soil, mb (g)	12.38	16.87	22.83	7.30	9.99	9.99
Wt of Tin only, mc (g)	9.34	9.28	9.52	5.50	5.46	5.16
Moisture Content, w (%)	45.39	47.43	49.74	34.44	31.3	25.4
				30.42		
		Pen (mm	Moisture (%)			
		15.8	45.39			
		17.5	47.43			
		21.8	49.74			

Appendix 11: Linear Shrinkage Results

Linear Shrinkage

Mould No.	1
Initial Length of Specimen, mm	139.6
Final Length of Specimen, mm	122.45
Change in Length, ΔL, mm	17.15
Linear Shrinkage, %	12.285

Appendix 12: Unconfined Compression Test

RS 1-1				**Date:**	
Test Run No	1				
Specimen Diameter	Top (mm)	Mid (mm)	Bottom (mm)	Average (mm)
	50	50	50	50
Specimen Height	H1 (mm)	H2 (mm)	H3 (mm)	Average (mm)
	120.6	96.6		108.6

X-sectional area, A (cm^2)	19.643
Specimen weight (g)	326.8
Bulk Density (g/cm^3)	0.1531960
Dry Density (g/cm^3)	0.119
Moisture Determination	
Tin No	30
Tin + Wet Soil m_a, g	334.9
Tin + Dry Soil m_b, g	265.1
Tin only m_c, g	22.6
Moisture Content, w %	28.784
Proving ring factor, K (kgf or N)	**0.20855**

READINGS

Vert Displ ΔV(mm)	Comp Strain ε	Proving Ring (Div)	Applied Load (kgf)	Norm Stress, σ (kgf/cm^2)
0	0	0	0	0
20	0.1842	3.0	0.6257	0.0318
40	0.3683	5.0	1.0428	0.0529
60	0.5525	10.0	2.0855	0.1056
80	0.7366	19.6	4.0876	0.2066
100	0.9208	31.0	6.4651	0.3261
120	1.1050	36.0	7.5078	0.3780
140	1.2891	46.7	9.7393	0.4894
160	1.4733	57.0	11.8874	0.5963
180	1.6575	64.2	13.3889	0.6703
200	1.8416	68.0	14.1814	0.7087
220	2.0258	70.0	14.5985	0.7281
240	2.2099	79.0	16.4755	0.8202
260	2.3941	79.0	16.4755	0.8187
280	2.5783	81.8	17.0594	0.8461
300	2.7624	79.0	16.4755	0.8156
320	2.9466	73.0	15.2242	0.7522
340	3.1308	67.0	13.9729	0.6891
360	3.3149	58.0	12.0959	0.5954
380	3.4991	54.0	11.2617	0.5533

RS 1-2 **Date:**

Test Run No	2			
Specimen Diameter	Top (mm)	Mid (mm)	Bottom (mm)	Average (mm)
	50	50	50	50
Specimen Height	H1 (mm)	H2 (mm)	H3 (mm)	Average (mm)
	104.15	104.15		104.15

X-sectional area, A (cm^2)	19.643
Specimen weight (g)	353.3
Bulk Density (g/cm^3)	0.1726950
Dry Density (g/cm^3)	0.137
Moisture Determination	
Tin No	38
Tin + Wet Soil m_a, g	374.3
Tin + Dry Soil m_b, g	300.6
Tin only m_c, g	22.6
Moisture Content, w %	26.511
Proving ring factor, K (kgf or N)	
	0.53191

READINGS

Vert Displ ΔV(mm)	Comp Strain, ε	Proving Rin (Div)	Applied Loa (kgf)	Norm Stress, ((kgf/cm^2)
0	0	0	0	0
20	0.1920	0.4	0.21277	0.0108
40	0.3841	10.1	5.37234	0.2725
60	0.5761	10.5	5.58511	0.2827
80	0.7681	20.0	10.63830	0.5374
100	0.9602	20.5	10.90426	0.5498
120	1.1522	20.7	11.01064	0.5541
140	1.3442	30.2	16.06383	0.8068
160	1.5362	30.4	16.17021	0.8106
180	1.7283	30.4	16.17021	0.8090
200	1.9203	30.5	16.22340	0.8101
220	2.1123	30.6	16.27660	0.8111
240	2.3044	30.7	16.32979	0.8122

RS 1-3

Test Run No	2			
Specimen Diameter	Top (mm)	Mid (mm)	Bottom (mm)	Average (mm)
	50	50	50	50
Specimen Height	H1 (mm)	H2 (mm)	H3 (mm)	Average (mm)
	103	103		103

X-sectional area, A (cm^2	19.643
Specimen weight (g)	325.8
Bulk Density (g/cm^3)	0.1610309
Dry Density (g/cm^3)	0.128

Moisture Determination

Tin No	28
Tin + Wet Soil m_a, g	326.8
Tin + Dry Soil m_b, g	260.9
Tin only m_c, g	9.3
Moisture Content, w %	26.192

Proving ring factor, K (kgf or N)

0.20855

READINGS

Vert Displ ΔV(mm)	Comp Strain, ε	Proving Ring (Div)	Applied Load (kgf)	Norm Stress, σ (kgf/cm^2)
0	0	0	0	0
20	0.19417	3.3	0.688216893	0.0350
40	0.38835	7.0	1.459854015	0.0740
60	0.58252	15.1	3.14911366	0.1594
80	0.77670	21.0	4.379562044	0.2212
100	0.97087	23.6	4.921793535	0.2481
120	1.16505	35.4	7.382690302	0.3715
140	1.35922	44.2	9.217935349	0.4629
160	1.55340	50.8	10.59436913	0.5310
180	1.74757	57.0	11.88738269	0.5946
200	1.94175	63.6	13.26381648	0.6621
220	2.13592	57.8	12.05422315	0.6006
240	2.33010	51.0	10.63607925	0.5289

Appendix 13: Data for Standard Compaction Test

THE STANDARD COMPACTION TEST							
		RS 1-1				Date:	
Diameter of Mould (cm)	10		Weight of Hammer (kg)			2.5	
Height of Mould (cm)	12.7		Free Fall of Hammer (cm)			30	
Volume of Mould (cm3)	997.86		Hammer Blows per Soil Layer			27	
Weight of Mould (g)	4166.80		Number of Layers in Mould			3	
Test Run No.	1	2	3	4	5	6	7
Wt of Mould + Soil (g)	5559.1	5619.8	5758.1	5814.2	5829.5	5793.2	5755.8
Wet Density of Soil (g/cm3)	1.3952899	1.45612	1.59472	1.65094	1.66627058	1.629893	1.59241
Moisture Content (%)	17.15	18.04	20.89	22.56	24.89	27.39	0.00
Dry Density of Soil (g/cm3)	1.191049	1.23362	1.31916	1.34707	1.33423566	1.279483	1.59241
Moisture Determination							
Tin No	20	24	25	28	29	30	
Tin + Wet Soil ma, g	146.45	145.15	177.18	170.77	178.97	182.96	
Tin + Dry Soil mb, g	126.38	124.41	148.19	141.07	145.2	145.64	
Tin only mc, g	9.34	9.42	9.41	9.41	9.50	9.37	
Moisture Content %	17.148	18.036	20.889	22.558	24.886	27.387	
Test Run No.	8	9	10	11	12	13	14
Wt of Mould + Soil (g)							
Wet Density of Soil (g/cm3)						m.cont, %	dry density
Moisture Content (%)						17.15	1.191
Dry Density of Soil (g/cm3)						18.04	1.234
Moisture Determination						20.89	1.319
Tin No						22.56	1.347
Tin + Wet Soil ma, g						24.89	1.334
Tin + Dry Soil mb, g						27.39	1.279
Tin only mc, g							
Moisture Content %							

Appendix 14: Water Permeability Test

Table 4. 1: Permeability Versus Time in 20mm aggregates

PERMEABILITY FOR 20MM VOLCANIC ROCK AGGREGATES	
WATER PERMEABILITY IN(MM)	**TIME IN DAYS**
0	0
9	7
11	14
13	21
16	28

Table 4. 2:Permeability Versus Time in non graded volcanic aggregates

PERMEABILITY FOR NON GRADED VOLCANIC AGGREGATES QUARRY DUST	
WATER PERMEABILITY IN(MM)	**TIME IN DAYS**
0	0
11	7
11.8	14
14	21
18	28

Table 4. 3: Permeability Versus Time in Nairobi Sedimentary Rock aggregates

PERMEABILITY FOR NAIROBI SEDIMENTARY ROCK QUARRY DUST	
WATER PERMEABILITY IN(MM)	**TIME IN DAYS**
0	0
12.4	7
14.2	14
14.8	21
20	28

Table4. 1 Permeability versus Time in graded 5-14mm aggregates

PERMEABILITY FOR GRADED AGGREGATES 14-5MM AGGREGATES	
WATER PERMEABILITY IN(MM)	**TIME IN DAYS**
0	0
13	7
14.8	14
15.1	21
19	28