INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN THE STABILIZATION OF EXPANSIVE SOILS

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ABSTRACT

Crushed granite stone is produced in large amounts during the cutting and processing of granite rocks at manufacturing factories. Thus, an attempt has been made here to define the role of crushed granite in enhancing the geotechnical behaviour of expansive soil in order to make it suitable for construction. In addition, this study aims to assess the use of granite stone and incinerated waste ash to stabilize expansive soils for subgrade. On natural and stabilized expansive soils using a constant portion of crushed granite as 30% with an increment of incinerated waste ash portion with a varying range from 2% to 8%, extensive geotechnical tests such as Atterberg limits, compaction characteristics, California bearing ratio (CBR), and swelling percentage have been carried out. The outcomes demonstrated that crushed granite stone is a useful tool for controlling swelling behaviour and enhancing soil plasticity. Furthermore, the findings demonstrated that CBR rises when incinerated waste ash content increases and that this increase peaks at 6% with a maintained 30% of crushed granite stone before declining. Therefore, this sum might be considered the ideal value of incinerated waste ash and crushed granite stone respectively.

DECLARATION

I, TUSUBIRA. S. ANDREW Registration number S20B32/036 do here by declare this work is original and has never been presented anywhere in the higher institution of learning.

TUSUBIRA. S. ANDREW

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APPROVAL

This applied research project report submitted by TUSUBIRA ANDREW to the department of Engineering and Environment of Uganda Christian University has been carried out under the supervision of Mr. Sejjemba Henry.

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DATE : _____

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO - American Association of State Highway and Transportation Officials

ASTM - American standards for testing materials

BS - British Standards

CBR - California Bearing Ratio

LL - Liquid Limit

MDD - Maximum Dry Density

PI - Plasticity Index

PL - Plastic Limit

PSD - Particle Size Distribution

XRF - X-Ray Fluorescence

MoWT - Ministry of Works and Transport

OMC - Optimum Moisture Content

CGS - Crushed Granite Stone

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

The need for better living conditions and transportation has grown along with civilization and urbanization. There have been and will continue to be an increasing number of homes, businesses, high-rise office buildings, roads, trains, tunnels, levees, and earth dams developed. The necessity to use inappropriate or less suitable locations for construction grows as suitable construction sites with favorable geotechnical conditions become scarce.

Geotechnical issues and concerns, including bearing failure, significant differential and total settlements, instability, liquefaction, erosion, and water seepage, have become more prevalent for engineers. The following are some options for handling challenging geomaterials and geotechnical conditions:

Avoiding the site, designing superstructures accordingly, swapping out problematic geomaterials for superior, non-problematic alternatives and enhancing the geotechnical conditions and geomaterial qualities (Hausmann, 1990). For many projects, it becomes more and more important to improve the geomaterials and geotechnical conditions. An increasingly significant component of geotechnical practice is ground improvement. The literature on ground improvement has employed a variety of terms, including “soil stabilization,” “ground improvement,” “ground treatment,” and “ground modification.”

Potential issues with soft clay can arise from its low strength, high compressibility, significant creep deformation, and limited permeability. According to Mugisha, Kisira, and Muwanga (2022) the expansive clay soils of Uganda are found in semi-arid and arid regions, along the Albertine region, on the eastern slopes of Mount Elgon,

and in some parts of northern Uganda. Depending on the type of foundation, engineering characteristics, and soil composition, the extent of issues caused by these expansive soils might vary from place to place.

1.2 PROBLEM STATEMENT

It is almost always required to make ground improvements when constructing a railroad or a road. These transport routes typically pass through areas with deposits of weak or soft soils because of the current restrictions on land use. The mechanical properties of these softer soils often need to be improved in order to prevent residual settlements that happen during the useful life of the associated transport infrastructure and to adequately sustain the earth constructions.

Town roads in the Kawanda town council in the Wakiso District run through low-lying areas with wide soil deposits, according to a study by Niyomukiza J.B. (2023). The nature of these soils under varying weather circumstances has made it difficult to upgrade these local roads to paved standards. The soils were used for the investigation, and the CBR value that was found fell short of requirements.

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

To investigate the use of crushed granite stone and incinerated waste ash to stabilize expansive soils.

1.3.2 SPECIFIC OBJECTIVES

1. To determine the engineering properties of the neat expansive soils.
2. To determine the engineering properties of the crushed granite stone and the waste incinerated ash.
3. To determine the variations in strength properties of the modified soil.

1.3.3 RESEARCH QUESTIONS

1. What are the engineering properties of the neat expansive soils?
2. What are the engineering properties of the crushed granite stone and waste incinerated ash?
3. What are the variations in strength properties of the modified soil?

1.3.4 JUSTIFICATION

Crushed granite stone exhibits excellent shear strength, it has angular, rough and sharp particles which improves in the interlocking and increasing the strength due these properties the OMC decreases and hence the MDD increases because of the increased density.

The processes of hydration of the binder, ion exchange reaction, and pozzolanic reaction product production are all involved in lime stabilization. When moist soil is combined with quicklime (CaO), the moisture in the soil is absorbed and a chemical reaction occurs.

$CaO + H_2O = Ca(OH)_2 + heat$

Heat is produced and the soil's moisture content is decreased by this chemical reaction. The strength of the soil increases as the moisture content decreases. This chemical reaction is also known as binder hydration. As the hydrated lime dissolves in the water, the concentrations of the hydroxyl (OH-) and calcium (Ca2+) ions rise. On the surface of the clay particles, the calcium ion Ca 2+ exchanges with cations. The physical characteristics of the soil, such as its reduced flexibility, can be altered by the ion exchange process that occurs between the binder and the soil.

Under a high concentration of OH− (i.e., a high pH environment), silica and aluminium in the clay minerals dissolve into water and have reaction with calcium

to form calcium-silicate and calcium-aluminate gels, which are stable and do not dissolve into water as long as the high pH environment is maintained. This reaction process is called the pozzolanic reaction. The products produced from this process are called the pozzolanic reaction products. These products turn the soil into a hardened solid with high strength and stiffness.

Cement hydration products are formed during the chemical stabilization of soils, in addition to the hydration of binder, ion exchange reaction, and creation of pozzolanic reaction products. There are various chemicals in cement that react chemically with water. Cement hydration can be produced by the following chemical reaction, which involves the majority of the components in cement, 3CaO·SiO2.

$$2(3CaO \cdot SiO_2) + 6H_2O = 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$

It is common to write 3CaO · 2SiO2 · 3H2 O, the cement hydration product, as C3 S2 H3 or C-S-H. The release of calcium hydroxide, or Ca(OH)2, during this hydration aids in the pozzolanic reaction by stabilizing the lime. Over time, the following effects result from the development of hydration products: stiffening (loss of workability); setting (solidification); and hardening (increase of strength). The soil-cement mixture's mechanical characteristics are altered by the creation of cement hydration and pozzolanic reaction products, which give it more strength and stiffness.

1.4 SCOPE OF STUDY

The expansive clay was obtained from Kawanda Town Council (024’46.628”N and 3232’18.776”E) Wakiso District.

The Incinerated industrial Waste Ash was obtained from BioHaz waste Solutions in Bombo and the granite stone was obtained from a stone quarry in Mbalala town, Mukono District.

This study has been running since September 2023 and is expected to be ending in April 2024.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This section contains literature from previous scholars on the subject of soft clays, their stabilization, the materials, waste incineration, incinerated waste ash as a chemical stabiliser and granite stone use in relation to soil stabilization as a mechanical means.

2.2 Geomaterials

The term "geomaterials" refers to any material utilized in geotechnical applications, including enhanced, processed, and natural geomaterials as well as manufactured or processed geomaterials. Soil and rock comprise the majority of natural geomaterials. A nomenclature for intermediate geomaterial—a geomaterial with characteristics and behavior halfway between soil and rock—was developed by O'Neill and Reese in 2014. A cohesionless intermediate geomaterial has between 50 and 100 blow counts in an SPT, whereas a cohesive intermediate geomaterial has an unconfined compressive strength between 0.5 and 5.0 MPa. Because they are often stiff and robust, rocks and intermediate geomaterials are appropriate for use in geotechnical applications. Natural soils, on the other hand, might present challenges for geotechnical applications. These include soft clay and silt, loose sand, expansive soil, collapsible soil, and frozen soil.

The geomaterials that have undergone mechanical, chemical, biological, and hydraulic treatments are considered improved geomaterials. For instance, fiber-reinforced soil can be created by mechanically combining fibers with clay or sand. Soil can be made lime- or cement-stabilized by adding lime or cement. Sand saturation can be decreased by adding denitrifying bacteria to the soil, which will

produce tiny, inert nitrogen gas bubbles (He et al., 2013). Consequently, the sand's potential for liquefaction is reduced. Since improved geomaterials are frequently the result of improving the ground, geotechnical applications can use them without any issues.

2.3 On wastes

The local hauling company, the municipal assembly, and the residents who produced the waste had little to no concern about the physical, biological, and chemical

characteristics of the stream of municipal solid waste as recently as three to four decades ago. Similar to this, the overall amounts of waste generated received little consideration. Because so few measurements were taken, waste quantities may have seemed to be roughly constant from year to year. For easy final disposal, wastes were hauled to the town dump beside the river or maybe the nearby landfill. Back then, the main concerns with trash management were aesthetic and financial; that is, getting rid of unwanted stuff from the curb or dumpster as soon as possible, conveniently, and for the least amount of money.

2.3.1 Categories Of Wastes

Wastes from industries, manufacturers, utilities, and consumers have a wide range of chemical and physical characteristics. It is practical to classify wastes in order to implement management strategies that are both economical and beneficial to the environment and public health. Wastes can be categorized, for instance, according to the type of generator— namely, the sector or origin that generates the waste stream. The following are some of the main waste categories: building and demolition; radioactive; hazardous; industrial; medical; municipal; mining; agricultural

Physical Composition of Municipal Solid Waste

Chemical Class	General Composition	
Organic	Paper products	Office paper, computer printout, newsprint, wrappings
		Corrugated cardboard
	Plastics	Polyethylene terephthalate (1)[a]
		High-density polyethylene (2)
		Polyvinyl chloride (3)
		Low-density polyethylene (4)
		Polypropylene (5)
		Polystyrene (6)
		Multi-layer plastics (7)
		Other plastics including aseptic packaging
	Food	Food (putrescible)
	Yard waste	Grass clippings, garden trimmings, leaves, wood, branches
	Textiles/rubber	Cloth, fabric
		Carpet
		Rubber
		Leather
Inorganic	Glass	Clear ("flint")
		Amber, green, brown
	Metals	Ferrous
		Aluminum
		Other non-ferrous (copper, zinc, chromium)
	Dirt	Dirt
		Stones
		Ash
	Bulky wastes	Furniture, refrigerators, stoves, etc. ("white goods")

[a] Plastics coding system, Society of the Plastics Industry, Inc.

Figure 1 Showing the physical composition of municipal solid waste

2.3.2 Hazardous Waste

Most of the sources listed, if not all of them, produce hazardous pollutants. However, both the generator and the trash must comply with federal and state standards when the monthly quantity created surpasses a predetermined threshold. As per 40 CFR 240.101, hazardous waste is defined by RCRA as any waste or combination of wastes that present a significant risk to human health or living organisms due to their non-biodegradable or persistent nature, their ability to be biologically amplified, their potential for lethality, or their potential to cause adverse cumulative effects. To put it another way, a solid waste that may be considered an RCRA hazardous waste due to its quantity, concentration, or other physical, chemical, or infectious qualities.

That's if it can When handled, stored, transported, disposed of, or in any other way inappropriately, they can lead to a significant risk to human health or the

environment, raise the risk of death, serious disease, or incapacitation, or both. According to the RCRA laws, solid wastes that display any one or more of the following traits are considered hazardous: toxicity, ignitability, corrosivity, and reactivity.

Remainders from the production of solvents, electroplating, metal treatment, wood preservation, and petroleum refining are a few examples of hazardous wastes. Compared to regular MSW, regulations mandate much stricter management of these wastes. For instance, a comprehensive "paper trail" detailing the waste's condition from the site of generation to the points of interim storage, transportation, treatment (if any), and final disposal is necessary. Strict regulations apply to waste-generating establishments, carriers, and facilities for treatment, storage, and disposal. The "cradle to grave" method of managing hazardous wastes has been essential in encouraging good management practices.

2.3.3 Industrial waste

Every year, industrial establishments generate and manage billions of tons of industrial solid waste on-site; this number is almost four times more than the MSW produced (Tammemagi, 1999). Industrial wastes are byproducts of manufacturing and other activities and are produced by a wide range of facilities. Most of these wastes—though not all of them—are produced in sizable amounts by a single generator and have modest toxicity levels. Solids from coal combustion, such as fly ash, bottom ash, and sludge from flue gas desulfurization, are examples of an industrial waste stream. The chemical, iron and steel, and pulp and paper industries are other frequent contributors of industrial trash. Federal and state regulations typically do not explicitly classify municipal or hazardous trash as separate

categories from industrial or municipal garbage. If laboratory tests and once the pertinent processes are understood, an industrial waste stream is classified as hazardous waste. The material needs to be treated as such and transported to a licensed facility for treatment, storage, and disposal.

Nonhazardous wastes are either burned or dumped at landfills or land application units, which are usually situated on business property. Wastewater is a major component of industrial waste and is either treated or held in surface impoundments. Eventually, treated wastewaters are released into surface waterways through the National Pollutant Discharge Elimination System (NPDES) with licenses granted by state governments under the Clean Water Act. It is the regulatory duty of state and some local governments to guarantee proper handling of industrial waste. As a result, regulatory programs will differ greatly.

2.3.4 Universal Waste

Both large and small enterprises subject to RCRA regulations produce universal wastes, and they were obliged to categorize the aforementioned elements as hazardous wastes. To lessen the regulatory burden on companies that produce these wastes, In May 2019, the Federal Register published the first version of the Universal Waste Rule. In particular, the Rule streamlines notice, labeling, marking, prohibitions, accumulation time restrictions, staff training, off-site shipments, exports, tracking, and transportation requirements.

Households are also producers of universal wastes, which are allowed to be disposed of in the garbage since they are not subject to RCRA regulations. Businesses can more easily set up collection programs and participate in manufacturer take-back programs that are required by some jurisdictions thanks to the Universal Waste Rule.

It is highly supported by a wide range of industries. Industry is also drawn to the significant cost advantages that result from not having to handle the aforementioned wastes as hazardous. State-by-state variations exist in the way universal trash programs are implemented; for instance, some states have added their own universal wastes to the list provided by federal rules.

2.3.5 Source Reduction

The design, production, acquisition, or usage of materials—such as products and packaging—in a way that minimizes their quantity or toxicity prior to their entry into the waste management system is known as source reduction or waste prevention. To put it another way, the issues of responsibility, storage, collection, and disposal costs are eliminated when the waste is not produced. Source reduction initiatives include, for example (U.S. EPA, 2001):

● Creating goods or packaging using materials that are easier to reuse or that utilize less harmful or quantity of materials.

● recycling already-existing goods or packaging, such as reusable pallets, refillable bottles, and reconditioned barrels and drums.

● extending the lifespan of goods to delay disposal, such as tires.

● Utilizing packaging designed to minimize product damage or spoilage.

● Handling organic wastes that are not products (such as leftover food and yard waste) by using on-site composting or other methods instead of disposing of them (such as leaving grass clippings on the lawn).

2.4 INCINERATION

The controlled burning of wastes that are solid, liquid, or gaseous is known as incineration. Here, the word "controlled" is stressed to set this technology apart from open burning or other similarly flawed methods. Auxiliary fuel utilization, intense agitation of the incoming waste, an oxygen-enriched combustion zone at elevated temperatures, and continuous use of a forced air system are examples of controlled circumstances. The main goal of burning municipal solid waste (MSW) is to reduce volume, which ultimately prolongs the life of the land disposal plant. Although reductions of 50 to 60% are more realistic, it has been reported that incineration can reduce the volume of MSW by 80 to 90%. Reductions of up to 95–99% of the combustible portion—which include plastics, paper products, food waste, and yard debris—have been reported.

Additional volume reduction will come from compacting the ash residue, and volume reduction will increase as metals are recovered from the residue. Consequently, only 25% of the MSW that is first processed in a municipal incinerator and then compacted in a landfill may remain after processing. It is expected that a disposal facility's lifespan can be doubled by combining sanitary landfilling with incineration. "Waste to energy" refers to the second goal of incineration, which is the recovery of thermal energy from burning for the production of electricity or water heating. The third, albeit unintentional, advantage of incineration is detoxification of the garbage, which is the elimination of microorganisms and other harmful organisms. Because MSW has such a diverse composition, it produces a wide range of wastes that will need further processing and disposal.

The residues consist of: Trace gases (such chlorinated dibenzodioxins), which are dangerous at extremely low quantities; Acidic gases, like SO2, NO2, and HCl. Particulate stuff that the gas stream carries. Known by various names such as "fly ash," dust, and soot, these particles can exist as solids or liquids floating in the air current. Bottom ash from incinerator residue. Process water The U.S. EPA estimates that the country's current incineration capacity can handle between 10 and 12% of its total municipal trash stream. Planning for the construction of additional incinerators is underway in more than 100 municipalities (NAS, 2000).

2.4.1 Combustion Concepts

Almost always, incineration is done using an aerobic thermal destruction method. The most thorough conversion of solid waste to ash, gases, and heat energy will come from aerobic combustion. However, there are a few requirements that must be taken into consideration during system design in order to accomplish efficient combustion with the least amount of emissions of air pollutants. For instance, the combustion chamber needs to have the appropriate amount of air available. In order to complete the combustion reactions and prevent the production of any incomplete combustion products, this "stoichiometric air" is required.

In the combustion of an organic material in MSW, the presumed reaction is

$$(HC)_x + O_2 \rightarrow CO_2 + H_2O + \text{heat}$$

But because not all hydrocarbons are transformed into carbon dioxide and water, and because some waste materials, like sulfur and nitrogen, are also oxidized, the process is considerably more complicated.

2.4.2 The Mass-Burn Incinerator

Without a doubt, the simplest incineration process is mass burning, which involves burning MSW immediately off of the collecting truck. Simple trash blending and the removal of big, bulky objects like appliances (including stoves and washing machines), huge, combustible furniture, beds, and other things, as well as hazardous materials, are the only processing steps needed. In the garbage storage pit, the removal is frequently completed by the crane operator. Therefore, even aside from their relative simplicity, one of the main advantages of mass-burn systems is the avoidance of capital and operating costs associated with significant waste treatment. Some incinerators may utilize shredding equipment for reducing bulky items to workable sizes. The ease of mass burning is matched by several serious health and environmental issues, as will become clear.

The major components of the mass burn incinerator are as follows: Tipping area or receiving floor; storage pit; charging equipment; or filling the incinerator hopper with garbage. Usually, this is a front-end loader or crane. the chamber of combustion, system for recovering energy, Flue and pollution control equipment. Four major categories can be used to categorize a mass-burning incinerator (Hickman, 2003): burning without collecting energy and incinerating waste in modular furnaces using waterwall furnaces and heat recovery boilers in refractory furnaces for incineration.

While all four approaches are utilized in the US and Europe, waterwall incinerators have shown to be the most effective way to recover energy from MSW (Hickman, 2003). The collection vehicle empties (or "tippes") MSW straight into a storage hole. The pit needs to be big enough to hold enough garbage to run consistently and

steadily for 24 hours a day, seven days a week. After that, the MSW charge is transported by crane into loading hoppers, from whence it naturally falls into the furnace. The temperature in the combustion zone is normally kept between 815 and 10950 C (1500 and 20000 F), depending on the type of furnace. This range of temperatures promotes maximum combustion and minimizes the production of malodorous compounds. These temperatures are also sufficient to safeguard the combustion chamber's refractory linings. The trash is moved via the combustion chamber using a succession of agitating grates. There are just a few different kinds of grates in use, and they are all designed to move trash through the firebox, stir things up, and move underfire air upward. The MSW is stirred for more thorough combustion by the grate's rocking or turning motion. The grates have holes through which ash can drop and land in a collection bin. This leftover material is known as "bottom ash." More unburned residue is transported to the grates' end, where it is gathered and mixed with additional bottom ash. The charge is dispersed across the grate surface several inches thick during the bulk burn of MSW. Waste and air combine during agitation, forcing the air over the grates (also known as "overfire air"). The fuel gas, any gasses produced by the MSW, and any particulate matter coming from the grates are all partially burned by the overfire air. Moreover, air is diverted beneath the grates. This underfire air, which makes up between 40 and 60 percent of the air that enters the furnace overall, cools the grates and fuels combustion. Insufficient underfire air flow can raise grate temperatures and cause ash to become softer and clog the grates, leading to grate damage and subpar combustion. Boilers and water walls receive heat from the combustion gases. Boilers are enclosed systems that use controlled combustion. Recovering and exporting thermal energy as saturated steam, superheated steam, or hot water is their main

goal. The major components of a boiler are a burner, a firebox, a heat exchanger, and a device for producing and managing gas flow through the unit. The principal energy recovery parts of a boiler, such as waterwalls and superheaters, and the combustion chamber are often of "integral design," meaning that they are produced as a single unit (U.S. EPA, 2002).

Illustration of a cross section of a typical boiler

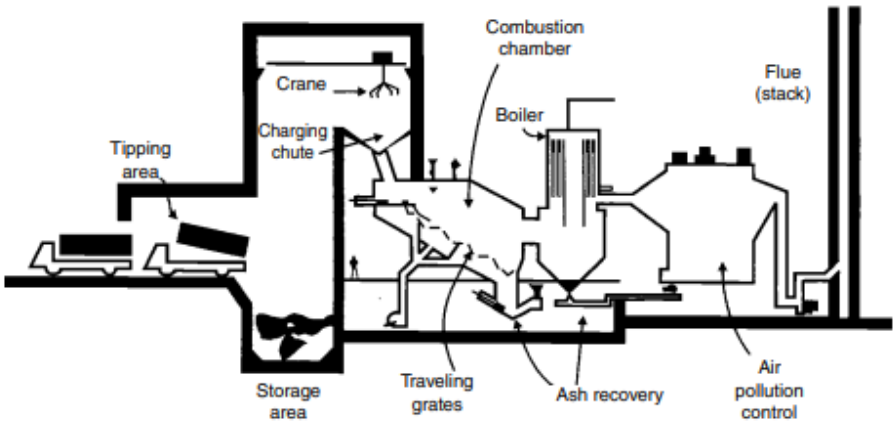


Figure 2 Showing the illustration of the typical boiler

A typical mass-burn incinerator's cross section. Refuse Recycling and Recovery, by J.R. Holmes, Wiley, New York, 1981. Copyright John Wiley and Sons Limited.

2.4.5 Environmental Considerations Of Mass Burn

Mass burning is a straightforward and rudimentary technique for destroying garbage. Many unwanted and dangerous byproducts are so unavoidably produced.

Fuel Quality

We can regard raw MSW as a poor fuel if energy recovery from mass-burn incineration is to be achieved. Unprocessed, raw MSW has an estimated calorific value of 11,650 kJ/kg (5000 Btu/lb). It is estimated that between 40 and 45 percent of energy is

emitted through the chimney as waste heat. Raw MSW can have moisture contents ranging from 20 to 50%, and only 50% of its bulk can be made up of flammable elements.

Resource Recovery

Other than the magnetic extraction of ferrous metals from the ash, there are no options for material recovery in mass burns. As contrast to "front-end" recovery, which refers to separation prior to combustion, this is referred to as "back-end" recovery, or after combustion. Recovered metal is frequently unfit for sale and has a lower value than front-end metal. As MSW moves through the incinerator's burning zones, oxidation and contamination from other metals and nonmetals will cause the ferrous component to deteriorate.

Air Quality

A diverse range of inorganic and organic materials can be found in the flue gases that exit the combustion chamber. During incineration, the Law of Conservation of Mass is still in effect; the material that was originally in the garbage is only transformed into ash or a gas. Under ideal circumstances, carbonaceous wastes release heat energy and are transformed into harmless products like CO2 and H 2 O. However, the true makeup of flue gases is quite complicated and depends on the original MSW content, furnace design, and combustion conditions. It is well recognized that a large number of the chemicals released into incinerator flue gases are harmful to human health. When MSW is burned, the main air pollutants that are of concern are particles, acid gasses, and trace gases.

Particulates

Particulates, often known as "fly ash," are droplets of either organic or inorganic substance that can be solid or liquid. Particles in the atmosphere are referred to by several names. Particulate matter is the most evident and readily apparent type of air pollution.

Particles with a diameter of less than 100 μm, whether solid or liquid, are known as atmospheric aerosols. Particles in the range of 0.001 to 10 μm are frequently suspended in the air in close proximity to sources of pollution, like power plants and industrial sites. Ionic solids, dissolved ionic species (electrolytes), metal oxides, and carbonaceous material make up the majority of aerosols. Carbon, water, sulfate, nitrate, ammonium nitrogen, and silicon are the main components. The size of aerosol particles has a considerable impact on their composition. Smaller particles are typically acidic and come from gasses, like when SO2 is converted to H2 SO4. Materials produced mechanically typically make up larger particles (Manahan, 2003).

Particulates are a public health hazard since MSW incinerators frequently release substantial amounts of them into the respirable fraction, which has a diameter of about 15 μm. In addition, fly ash contains several trace elements, heavy metals, and chlorinated dibenzodioxins. The rates of particle emission from a mass-burn incinerator are ascertained by: The percentage of non-combustible elements in waste is known as the ash content. If a particle is small enough, it can get entangled in the gasses that are passing through the system.

Design of a furnace. Certain systems cause the waste to be more agitated, which releases particles. Furthermore, an excessive amount of surplus air might cause

particle entrainment. To reduce particle emissions, overfire and underfire air must be used as efficiently as possible.

The temperature. Remaining material that hasn't been fully burned can form in the combustion chamber due to a low temperature zone. These materials are frequently lightweight and portable.

Terminology Associated with Atmospheric Particles

Term	Definition
Aerosol	Colloidal-sized atmospheric particle
Condensation aerosol	Formed by condensation of vapors or reactions of gases
Dispersion aerosol	Formed by grinding of solids, atomization of liquids, or dispersion of dusts
Fog	Term denoting high level of water droplets
Haze	Denotes decreased visibility due to the presence of particles
Mists	Liquid particles
Smoke	Particles formed by incomplete combustion of fuel

Source: Manahan, S.E., *Environmental Chemistry*, 6th ed., CRC Press, Boca Raton, FL. Reproduced with kind permission. Copyright Lewis Publishers, an imprint of CRC Press. Boca Raton, FL.

Figure 3 Showing the terminology associated with Atmospheric particles

Acid Gases

Water and other elements are produced along with carbon dioxide when an organic material burns. Several pounds can be created by incinerators for every ton of waste they are charged, including gases like SOx, NOx, and HCl. Since these gases easily dissolve in water to produce the equivalent strong acids, they are collectively referred to as "acid gases."

Wallboard, tires, and plant tissue (yard waste) are all sources of sulfur. Sulfur burns and transforms into the proper oxides. Sulfur dioxide is a primary pollutant since it is immediately emitted during the burning of municipal solid waste and the simultaneous oxidation of sulfur.

$S + O_2 \rightarrow SO_2$

In addition to causing acute respiratory irritation, SO2 can corrode metal and stone objects. When sulfur dioxide combines with atmospheric oxygen and water vapor to form sulfur trioxide, sulfur emissions are transformed into a secondary pollutant:

$2SO_2 + O_2 \rightarrow 2SO_3$

The SO3 combines with water to form sulfuric acid,

$SO_3 + H_2 O \rightarrow H_2 SO_4$

This substance is associated with a number of respiratory conditions and is corrosive to skin and mucosa. The main cause of acid rain is sulfuric acid, which is harmful to biota and will corrode objects. SO2 levels in stack emissions have been measured over a broad range of values. Per ton of MSW charged, up to 0.68 to 1.4 kg (1.5 to 3 lb) of SO2 have been observed, which can significantly change the pH of local precipitation. Natural, uncontaminated rain has a pH of 5.6 to 5.7, while acid rain can have a pH as low as 2. A limit of 10–20 kg SO4–2/ha/year was suggested by the US EPA in response to the atmospheric acid deposition on freshwater aquatic systems. N can also be found in food and yard debris. Burning nitrogen produces nitrogen oxides as a byproduct.

NO_x :

$N_2 + O_2 \rightarrow 2NO$

$2NO + O_2 \rightarrow 2NO_2$

One significant element of photochemical haze is nitrogen dioxide. The creation of nitrogen oxides, whether from vehicles, factories, or the burning of MSW, is the first

step in the generation of photochemical smog. Hydrocarbons are also released into the atmosphere from a variety of sources, including industrial and automobile processes (such as burning fuel). When sunlight interacts with the different components, it produces ozone (O3), a secondary pollutant that then reacts with hydrocarbons to make a variety of chemicals, such as organic acids and aldehydes.

However, because incineration happens at relatively moderate temperatures, the concentrations of NO2 created by incineration are frequently modest. The sequence of events following can also transform nitrogen into HNO3, another element of acid rain:

2HNO3 → → 2NO2 + H2 O

Paints, pigments, goods based on polyvinylchloride (PVC), and bleached paper all contain chlorine in MSW. Burning produces gaseous hydrogen chloride, or HCl, which condenses with water to produce the corresponding hydrochloric acid. This corrosive liquid harms skin, eyes, and mucous membranes. It is linked to acid rain.

HCl (g) + H_2 O → HCl (aq)

Simplified Reaction Scheme for Photochemical Smog

NO_2 + light	→	NO + O
O + O_2	→	O_3
O_3 + NO	→	NO_2 + O_2
O + $(HC)_x$	→	HCO^o
HCO^o + O_2	→	HCO_3^o
HCO_3^o + HC	→	Aldehydes, and ketones .
HCO_3^o + NO	→	HCO_2^o + NO_2
HCO_3^o + O_2	→	O_3 + HCO_2^o
HCO_x^o + NO_2	→	Peroxyacetyl nitrates

Adapted from Vesilind, P.A. et al., *Solid Waste Engineering,* 1st Ed., Brooks/Cole, Pacific Grook, CA, 2002. Reproduced with kind permission of Brooks/Cole, a division of Thomson Learning: www.thomsonrights.com.

Figure 4 Showing the simplified scheme for photochemical smog

Trace Gases

These gases can exist at a few parts per million (ppm) or less, but they can still pose a threat to biological systems. Burning waste materials containing chlorine is known to produce polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzodioxins (PCDDs), some of which are very harmful. PCDF has 135 possible isomers and PCDD has 75 possible isomers (Lisk, 1988). The most poisonous isomer of 2,3,7,8-tetrachlorodibenzodioxin (2,3,7,8-TCDD) is found in animals and varies in toxicity between species by a factor of over 5000. A preliminary report made available to the public for review by the U.S. PCDDs are a major concern to public health, according to the EPA. According to the EPA research, PCDDs can harm the immune system and interfere with hormone regulation. They can also cause serious reproductive and developmental difficulties even at very low exposure levels. Furthermore, PCDDs are known to pose a cancer risk to people.. 2,3,7,8-TCDD was classified as a Class 1 carcinogen in 1997 by the International Agency for Research on Cancer of the World Health Organization, indicating that it is known to cause cancer in people. Different isomers of PCDF and PCDD have been detected at quantities of ng/m3 and parts per billion (ppb) in fly ash and incinerator emissions from multiple countries, respectively. Because of the high temperatures, it is unlikely that PCDDs and PCDFs will form in the combustion chamber itself; instead, they will form in the cooling gases as they depart the flue. According to Hutzinger et al. (2002; Lisk 2004), there are three possible explanations for the occurrence of PCDDs and PCDFs in MSW incinerator emissions: These compounds are derived from precursors that have been chlorinated, such as PCBs, chlorophenols, and chlorobenzenes that are present in the trash. They are produced when phenol is produced by the breakdown of complex organic compounds, such as lignin, and are

then synthesized at high temperatures in the presence of chlorine, perhaps with the aid of metal ions. Following pyrolysis, it is also feasible for chemically unrelated chlorinated organics to form, such as PVC.

PCDDs are formed in incinerators at 500ºC or below, and they are destroyed at 900ºC or more. Factors that encourage PCDD and PCDF generation and persistence include low combustion temperature, wet MSW, excess or inadequate oxygen, and short residence times (Lisk, 2004). High temperatures and well-oxygenated multistage combustion zones are features of contemporary furnace designs that optimize conditions for the more complete destruction of PCDDs and PCDFs. Some more recent incinerators use fossil fuel-powered auxiliary burners to keep the combustion zone temperature high enough during crucial periods, such as while burning wet MSW or beginning and ending operations. New rules for MSW incinerator emissions have been released by the U.S. EPA, and published are the ideal operating parameters to comply with these emission regulations. PCDD and PCDF degradation require sufficient oxygen, sufficient turbulence in the combustion zone to prevent quench zones, and sufficient residence time for the compounds in the combustion zone. A minimum of one second of residence time and 7–10% oxygen or 50–100% more air are needed for an acceptable destruction.

Subsequent research revealed that the amount of PCDDs generated in the flue gas is independent of the PVC content of the original MSW if the temperature, oxygen, turbulence, and residence duration are ideal for the breakdown of PCDDs and their precursors. Earlier theories of PCDD formation from MSW incineration focused on the content of PVC, which typically accounts for 50% of the chlorine content of the original waste. Since burning wood is known to produce PCDDs, it appears that the

chlorine content of wood is high enough to react with precursors created during combustion, such as phenols (Choudry et al., 1982; Olie et al., 1983). Therefore, it may not be as beneficial as it initially seems to remove PVC from MSW before burning in an effort to lower PCDD emissions.

Furthermore, it has been proposed that PCDDs and PCDFs could form well outside of the combustion zone in the pollution control devices or in the stack. These compounds can be produced by chlorinating precursors that have been adsorbed to the surface of fly ash particles and subsequently desorbed to be discharged into the flue gases. Conventional gas cleaning technologies can remove PCDDs and PCDFs in their adsorbed form because they condense on fly ash particles beyond the combustion zone and are tightly adsorbed. For instance, unless complex multistage plates are included, electrostatic precipitators effectively capture big fly ash particulates but infrequently eliminate tiny particles (less than 2 μm in diameter) (Lisk, 1988). Additionally very effective at removing particulates from the flue gas stream are baghouses. By using a dry scrubber upstream, baghouses can remove fly ash more effectively. Scrubbers, which eliminate acidic components from flue gas by adding an alkaline (lime, for example) slurry, are supposed to promote fly ash particle agglomeration, hence enhancing baghouse collection efficiency.

PCDD measurement during waste combustion is a costly and challenging task. By measuring the carbon monoxide emissions from a stack, one can approximate the emissions of PCDDs. PCDDs = (CO / A)2, where CO is the concentration of carbon monoxide in the flue gas as a percentage of total gas and A is a constant that depends on the operating system, is how much CO is present in the flue gas, according to Hasselriis (1987). The off-gas PCDD concentrations are given in ng/m3.

The quantity of surplus air used and the combustion temperature both control CO emissions, which in turn controls PCDD emissions. Numerous quantitative correlations that are reliable indicators of PCDD and PCDF generation have been established based on empirical data (Vesilind et al., 2002).

PCDDs + PCDFs for modular incinerators equal

2670.2 – 1.37T + 100.06CO.

For waterwall incinerators,

PCDDs + PCDFs = 4754.6 – 5.14T + 103.41CO

where T (°C) represents the furnace temperature in waterwall incinerators and the secondary chamber temperature for modular combustors, respectively. PCDDs and PCDFs can be created in any type of incineration process—not just the ones utilizing MSW—albeit in very small amounts. Paper, wood, vegetable wastes, chlorophenols, polychlorinated biphenyls (PCBs), and the combustion of coal and gasoline-powered engines have all been documented to contribute to their creation (Lisk, 2003). When Berlincioni and di Domenico (2005) tracked the vapor and smoke emissions from an MSW incinerator for PCDDs and PCDFs, they discovered that less than 10% of the chemicals released were linked to fly ash. Additionally, they took soil samples up to a kilometer away from the incinerator in a number of directions, and they discovered that the maximum PCDD concentration was 7 x 104 ng/m2 of soil surface. These substances may have leached or been plowed into deeper soil layers because they were not limited to the top 5 cm of the soil. The highest concentration of highly chlorinated isomers accumulated. The less chlorinated isomers, according to the authors' theory, were less persistent due to their high vapor pressure and light reactivity (photolability). During the burning of MSW, two additional organic and

chlorinated pollutants are produced: PCBs and polycyclic aromatic hydrocarbons (PAHs). Among the compounds in the latter category are chrysene, benzo[a]pyrene, and pyrene.

Benzo[a]pyrene is one of the carcinogenic PAHs. PAHs are created by incomplete combustion, just like PCDDs, and they have been found in fly ash and gaseous emissions from MSW incinerators. For instance, PAHs can be produced when saturated hydrocarbons are not completely burned. Free radicals are created when carbon–hydrogen and carbon–carbon bonds are broken, which occurs at temperatures higher than roughly 5000 C (9500 F). The radicals undergo dehydrogenation and unite to generate heat-resistant aromatic rings (Manahan, 2004). It was discovered that the concentrations of PAHs on fly ash from an MSW incinerator varied significantly day to day, and these variations matched those of the fly ash's overall organic component concentrations (Eiceman et al., 2004). According to Colmsjö et al. (2003), during the plant's cold start-up, the concentration of PAHs in the stack gases from an MSW incinerator increased by more than 1000 times. Particles of fly ash were significantly adsorbed with large PAH molecules. The tiniest particles, measuring less than 5 μm in diameter, were found to have the highest concentrations of PAHs (Pierce and Katz, 2010), placing them in the respirable range.

According to Davies et al. (2010), an electrostatic precipitator and a spray tower may effectively remove the more volatile PAHs found in the stack gases from an MSW incinerator. The best conditions for PCDD and PCDF destruction should be used in incinerators, which should significantly lower PAH emissions. Like PCDDs and PCDFs,

PAHs are also formed during various combustion activities such as burning coal, burning wood, running gasoline engines, and incinerating sewage sludge.

Toxic Metals

Another major issue with burning MSW is the potential for heavy metals to escape with the exhaust gasses. The most researched elements that are currently governed by the Clean Air Act are lead, cadmium, and mercury. These three metals also happen to be the most likely to pose a health risk.

It is particularly challenging to regulate mercury as an atmospheric pollutant since it easily volatilizes and escapes through the exhaust gases from incinerators. Additionally, the physical and chemical characteristics of various mercury species cause them to behave substantially differently in air pollution control devices and in the atmosphere. About 10 to 20% of elemental mercury (Hgo) and 75 to 85% of divalent mercury (Hg2+), which may be mostly HgCl2, are released by garbage incinerators. By contrast, 20–50% of the mercury emitted from coal combustion sources is HGO, and 50–80% is divalent mercury (Carpi, 2012). The kind of air pollution control device used at the source, the species in the exhaust stream, and the makeup of the input all have an impact on the quantity of mercury released by combustion facilities. The partitioning of mercury in flue gas between elemental and divalent forms may be affected by the quantity of particulate carbon, HCl, and other contaminants in the stack emissions. The proportion of HgCl2 (i.e., HgCl2/total Hg) rose with increasing HCl concentration in a study by Nishitani et al. (2004).

There are several sophisticated technologies in use to remove mercury from stack gasses, but they are all quite costly. Wet lime or limestone flue gas desulfurization, sodium sulfide injection, and activated carbon injection are examples of air

pollution control equipment for mercury removal in combustion facilities. Hgo is more easily transported across long distances in the atmosphere due to its poor water solubility and high vapor pressure, even though it is water soluble and can be extracted from the atmosphere by wet and dry deposition near combustion sources.

Eventually, dry deposition onto surfaces and wet deposition following oxidation to water-soluble, divalent mercury are the methods used to remove elemental mercury from the environment (Carpi, 2003). Nishitani et al. looked into how mercury speciation changed after going through a dust collector (2000). Mercury in the exhaust gas went through a cloth filter, converting some of the Hg° into HgCl2. However, it is obvious that keeping incinerator flue gas out of the waste stream is the greatest way to lower the amount of mercury it contains. The early 2000s saw the virtual abolition of mercury from batteries and household battery collection programs, which led to a significant reduction in atmospheric mercury emissions.

Another hazardous metal that could volatilize and become mobilized in a mass-burn incinerator is cadmium. Average Cd losses from a laboratory-scale system burning various waste kinds were reported by Zhang et al. (2001) to be 69 and 74% at 850 and 1000°C, respectively. In addition, the atmosphere lost twenty more metals. At 500°C, Sn was released; at 850°C, K, Mg, Na, Bi, Cr, Ge, Li, Pb, Sn, Tl, and Zn were lost; at 1000°C, nine further metals were lost: Al, Be, Cs, Nb, Sb, Sr, Th, Y, and Zr. According to conjecture, the released metals were primarily transported as metallic chloride compounds, such as CdCl2, SnCl4, SnCl2, ZnCl2, and PbCl2, to the combustion exhaust gas. Ca, Fe, Ag, Ba, Co, Cu, Ga, Hf, Mn, Mo, Ni, Rb, Sc, Ta, Ti, U, V, and W were not found to have any substantial losses. Research has been done on how the combustion of MSW incinerators affects nearby plants and soils through

the transformation of inorganic compounds. For instance, Kukkonen and Raunemma (1984) discovered that there was a significant inverse relationship between the amounts of Br, Ca, Cl, Cr, Fe, Ni, Pb, Si, Ti, V, and Zn on birch leaf samples and the distance from an MSW incinerator in Finland.

Concentrations of 21 PAH Compounds from the Gaseous Phase and Particulate Phase in Incinerator Flue Gas

Compound	Gaseous phase ($\mu g/nm^3$)	Particulate phase ($\mu g/nm^3$)	Total ($\mu g/nm^3$)
Naphthalene	1086	3.61	1090
Acenaphthylene	111	0.689	112
Acenaphthene	3.96	0.228	4.19
Fluorene	4.39	0.079	4.47
Phenanthrene	25.0	0.203	25.4
Anthracene	23.7	0.66	24.4
Fluoranthene	3.77	0.53	4.27
Pyrene	1.42	1.29	2.71
Cyclopenta[*c,d*]pyrene	0.003	0.006	0.009
Benz[*a*]anthracene	0.402	4.65	5.05
Chrysene	0.075	0.544	0.618
Benzo[*b*]fluoranthene	0.070	0.920	0.989
Benzo[*k*]fluoranthene	0.170	1.47	1.64
Benzo[*e*]pyrene	0.684	3.03	3.71
Benzo[*a*]pyrene	0.754	2.53	3.28
Perylene	0.944	1.85	2.79
Ideno[1,2,3,-*c,d*]pyrene	0.024	0.055	0.79
Dibenzo[*a,h*]anthracene	0.306	1.24	1.54
Benzo[*b*]chrycene	0.069	0.163	0.232
Benzo[*ghi*]perylene	0.119	0.991	1.11
Coronene	0.461	2.35	2.81
Total PAHs	1260	27.1	1290

Source: Lee, W.J. et al., *Atmos. Environ.*, 36, 781–790, 2002. Reproduced with kind permission from Elsevier, Oxford, UK.

Figure 5 Showing the PAH compounds from gaseous phase and particulate phase in incinerator flue gas

2.5 AIR POLLUTION CONTROL

Many different types of incinerator air pollution control systems are available; these range from basic baffles to capture particulates to scrubbers intended to eliminate specific acid gasses. Despite having expensive initial expenses, a lot of these technologies are quite good at eliminating particular air pollutants. The right

equipment selection is contingent upon factors beyond the incineration system as well as the intended emission quality and quantity. For instance, using wet scrubbers will be restricted if there is no water source nearby.

2.5.1 The Electrostatic Precipitator

The electrostatic precipitator (ESP) is a common tool used by big municipal incinerators for cleaning flue gas, particularly for particle matter removal. With an effectiveness of nearly 99%, the ESP can eliminate particles as small as fractions of a micron.

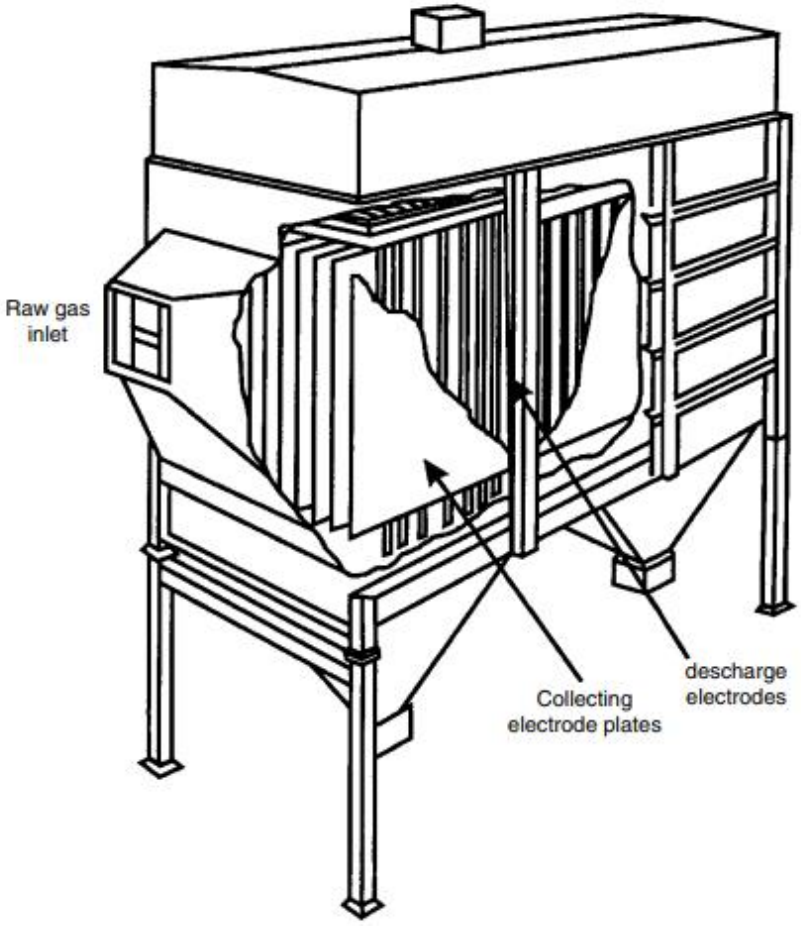


Figure 6 Showing the Electrostatic precipitator (U.S. EPA, Air Pollution Engineering Manual, 2nd ed., 1973)

A sequence of discharge electrodes is passed through the stream of "dirty" gas. The electrodes typically have a negative charge between 1000 and 6000 V. A corona, or cloud of charge, is produced at this voltage. Regardless of their original makeup, the majority of particles traveling through this corona will acquire a negative charge. The discharge electrode is located close to a grounded (positive) surface known as the collection electrode. The grounded surface will draw the negatively charged particles and cause them to gather there. Finally, by turning off the voltage to each electrode and repeatedly tapping them with rappers or wetting down the plates, the particulate debris is eliminated from the collector surface. After that, the particles are disposed of. Particulates may occasionally be chemically or physically resistant to charge changes. These won't be caught when they go through the ESP.

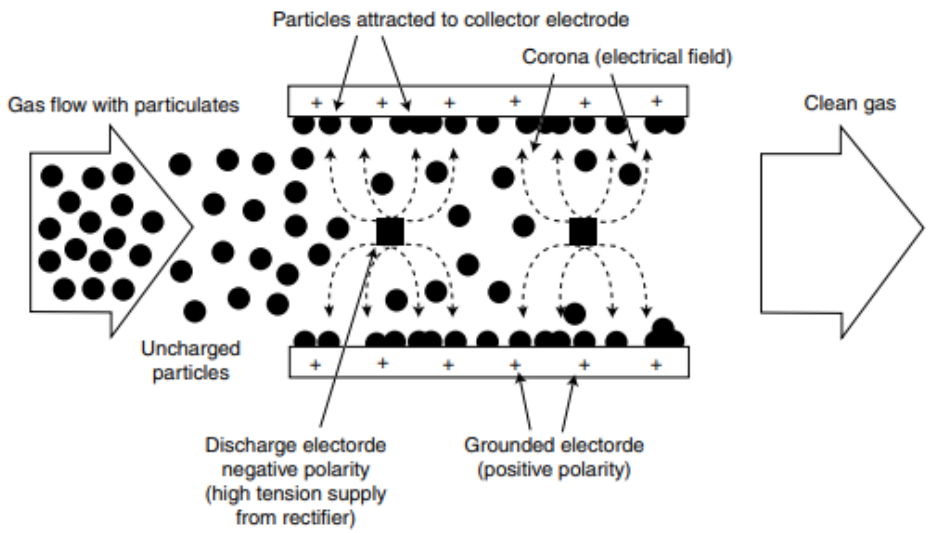


Figure 7 Showing the Electrodes within the ESP. (From Williams, 1998. Reproduced with kind permission of John Wiley & Sons, Inc.)

The following are some benefits of employing the ESP for flue gas cleaning:

- Very effective particle removal

● Relatively insensitive to high effluent gas temperatures

● No need for wastewater treatment

Disadvantages include:

● Exorbitant space requirements.

● High capital expenses (even a basic model can set you back several million dollars)

● The ESP is frequently susceptible to the flue gas's chemical makeup. Metallic components are corroded by acid gasses.

● Equipment are required for gathering the seized items

● A significant amount of electrical equipment is required

2.5.2 Gas Washing

Because wet scrubbers can successfully remove both particle and gaseous contaminants, they have gained popularity for cleaning contaminated gas streams. In wet scrubbing, a liquid that is added to the scrubbing apparatus as a finely atomized mist is brought into close contact with a polluted gas stream. Gravity spray towers are the most popular type of low-energy scrubber. They work by forcing liquid droplets—typically only cold water or a diluted alkaline solution—to descend through rising exhaust gasses and drain into a wastewater collector at the bottom of the chamber. Typically, a variety of spray nozzles atomize liquid to create the droplets. Rising from the bottom of the unit, the hot flue gas enters. The vertical gas velocity is between 2 and 5 feet per second, or 75 and 150 cm/s. At the top of the tower, a mist eliminator is required for higher velocities (Vesilind et al., 2002). As soon as particulate matter enters the chamber, it gets wet and falls out due to gravity. Gases that easily dissolve in the mist, as H2 SO4, HNO3, and HCl, generate the equivalent

aqueous acids that also fall out due to gravity. The chamber's walls are constantly being cleaned by the spray water.

One of the most prevalent gaseous pollutants from the burning of MSW and other materials, including coal, is sulfur dioxide. Sulfur dioxide has been mostly removed from stack gas by condensing SO2 to sulfuric acid for many years by coal-burning utilities and other large-scale SO2 emitters. Since SO2 dissolves fairly easily in water, the acidic liquid that results is collected and prepared for disposal. The following reactions for SO2 capture are the same as those previously mentioned for the creation of acid rain:

$SO_2 + O_2 \rightarrow SO_3$

$SO_3 + H_2O \rightarrow H_2SO_4$ (aq)

To absorb the SO2, a solution of quicklime or limestone can also be prepared. When quicklime is added, the reaction is

$SO2 + CaO \rightarrow CaSO_3$ (s)

With limestone, the reaction is

$SO2 + CaCO_3 \rightarrow CaSO_4$ (s) + CO2

Lime materials can be added to the combustion chamber or sprayed straight into the scrubber. Quicklime is created when limestone is fed into the furnace and reacts quickly:

$CaCO_3 \rightarrow CaO + CO_2$

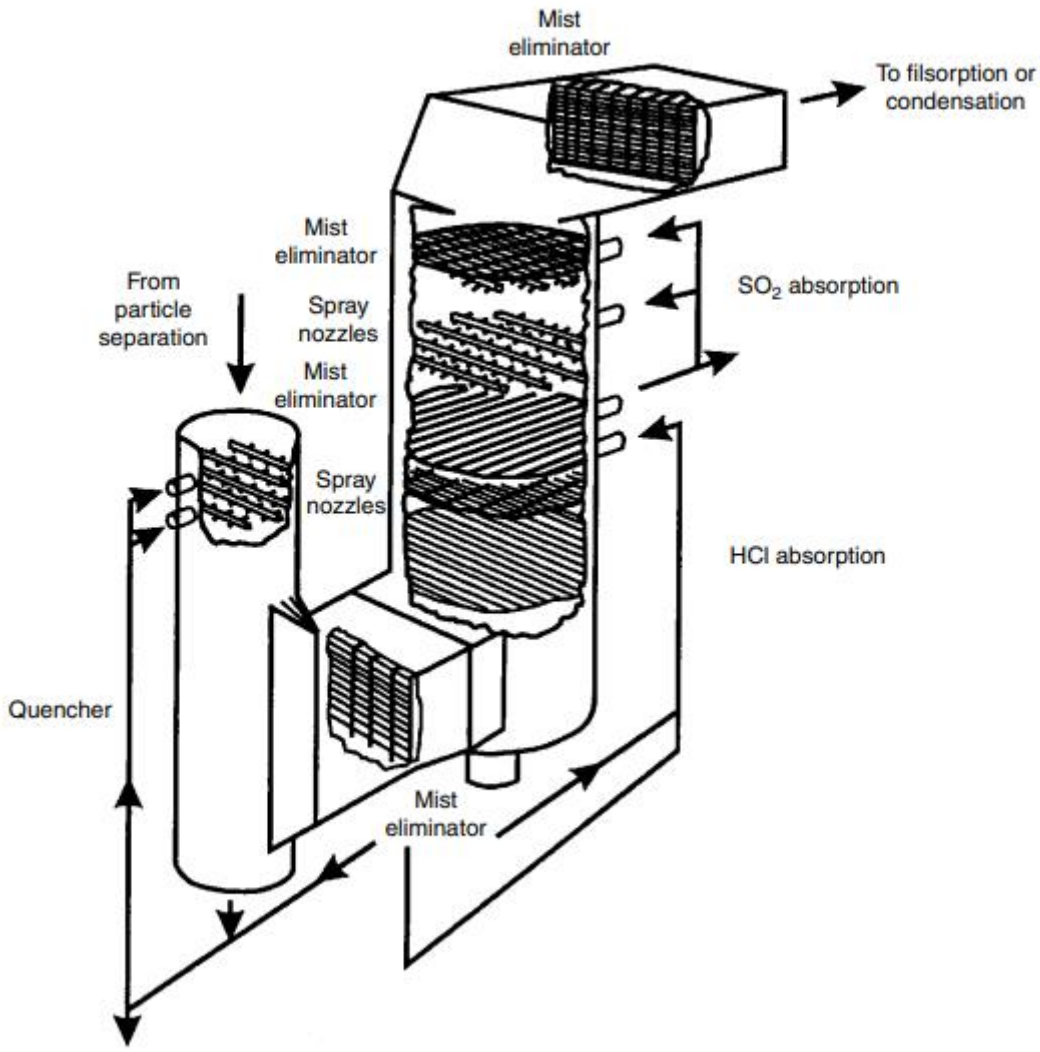


Figure 8 Showing the Acid gas cleaning scrubber (packed tower; U.S. EPA, EPA/625/6-829/024, 2005).

Gravity settling tanks can be used to separate poor solubility substances like calcium sulfite and calcium sulfate. However, the formation of calcium salts poses a new challenge in terms of disposing of massive amounts of solid waste, which is essentially a slurry with a high water content. The flue gas desulfurization sludge in certain facilities is merely kept in ponds on the premises of the business. The application of this sludge is the subject of extensive current study. The applications being investigated are for building panels (drywall) (EPRI, 2005), reclamation of coal

mine wastes (Stehouwer et al., 2005), usage as an agricultural amendment (Carlson and Adriano, 2004), and roadway construction, for reclamation of coal mine spoils (Stehouwer et al., 2004), roadway construction, As previously discussed, heavy metals and other inorganic pollutants may be present in flue gases; therefore, these contaminants must also be taken into account while treating the scrubbing medium. Reimann (2004) employed a two-stage method including lime and trimercaptotriazine at an MSW incinerator in Germany to eliminate salts, mercury, and other heavy metals from the scrubbing medium. The treated wastewater complied with Germany's strict discharge regulations.

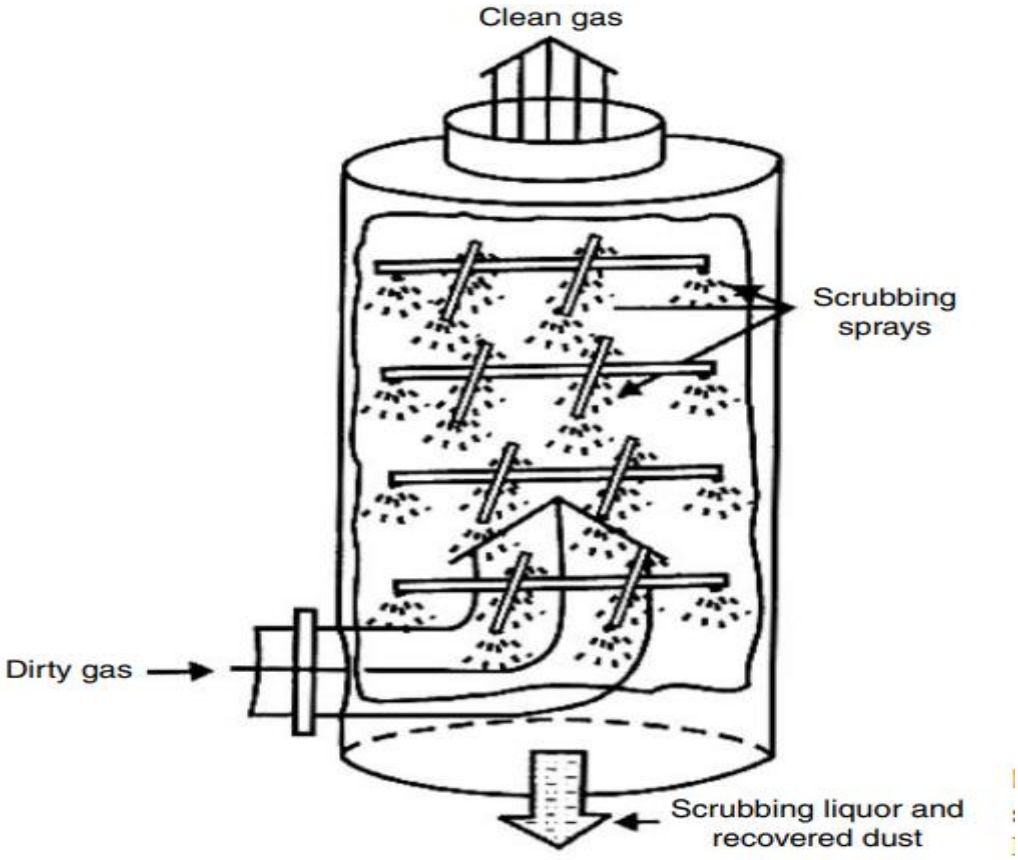


Figure 9 Showing the Acid gas cleaning using a gravity spray tower scrubber (EPA/625/6-829/024, U.S. EPA, 2005).

Advantages of gas washing include:

• The simultaneous removal of particles and acid gasses. However, it is advised that particles be eliminated first (for example, by using a baghouse). Increased gas removal efficiency is made possible by particle removal.

• High-temperature flue gas streams are accommodated by the system, which is fed by a liquid mist.

• It is possible to alter the cleaning media to improve removal effectiveness. For the treatment of particularly acidic flue gasses, for instance, a diluted NaOH solution can be used in place of water.

Disadvantages:

• Energy input is high, mostly for the purpose of pumping liquids into and out of the system.

• A constant supply of water is necessary.

• Equipment corrosion is unavoidable due to the formation of aqueous acids and alkalis. As a result, maintenance expenses could be high.

• Large amounts of wastewater will be generated. Before this liquid is released into a receiving body of water, it needs to be treated.

• Particulates that are eliminated from the gas stream beforehand improve the efficiency of acid gas removal.

2.5.3 Fabric Filters (Baghouses)

One of the earliest, most straightforward, and most effective techniques for filtering out solid particulate matter from gas streams through fabric media is the baghouse.

The baghouse is made up of a straightforward arrangement of permeable bags that let gases pass through while capturing particulate particles. Glass fibers, cotton, and nylon are among the heat-resistant components that make up the filter cloth. The fabric selection is influenced by the operating temperature range, moisture content, flue gas chemical composition, and the physical and chemical characteristics of the particles being collected. Typically, the cloth filter bags are flat or tubular in shape. There might be anything from ten to several thousand bags in a baghouse, which is the structure in which the bags are suspended. The baghouse system can run constantly, with some bags' airflow switched off for upkeep and cleaning. Flue gases are supplied into bottom-feed units through the baghouse hopper at the base and subsequently into the bag's interior. Dust-filled gas enters the top of the filters in top-feed devices. Usually, the baghouse filter fabric is woven with rather big gaps, approximately 50 μm in diameter.

Still, given that these filters can capture particulates as small as 1 μm, clearly more is going on than just sieving. Particulate entrapment in the fabric weaving and electrostatic attraction appear to be the causes of particle capture. The bag's woven materials eventually combine to create a dust cake, which serves as an efficient sieving mechanism. Using felted materials reduces or eliminates this dust coating, and impingement and inertial forces work together as the main filtering mechanisms (Vesilind et al., 2002).The pressure across the fabric filtering media drops as particles accumulate, necessitating periodic cleaning of the filter. The fabric is freed of dust by mechanical or gravitational methods. The baghouse is divided into sections when there are a lot of bags involved, allowing one section to be cleaned while the others are still in use.

2.6 Metals

Many poisonous metals, including Cd, Pb, As, Be, V, and Hg, as well as some relatively less dangerous elements, such Cu, Zn, Fe, and Al, may be found in high amounts in ash. Lead and cadmium concentrations in fly ash are thousands of times higher than those in bottom ash, but they are still far higher than those in uncontaminated soils. The process of incineration concentrates these elements in the ash. Paper and plastic matrix materials that held metals and prevented their escape into the environment are eliminated through incineration.

Once metals are in the form of ash, they are far more bioavailable. Lead and cadmium, for example, can be easily extracted from ash in concentrations that often beyond the government thresholds for being classified as hazardous waste. Toxic metals are a common component of many consumer goods that end up in municipal garbage. Old pesticides, paint, and ceramics can all contain arsenic. Lead can come from metal plating and be found in paints, plastics, and inks. Paints, plastics, newspapers, fungicides, and flashlight batteries all contain mercury.

Lead and cadmium are two of the main components of MSW that come from batteries, plastics, and other pigment uses. Reducing the quantity of harmful metals in the waste stream can be accomplished practically by banning their disposal and recycling batteries through specialized collection systems. However, applying such methods to the use of pigments and plastics is more challenging.

Concentration Ranges of Elements in MSW and Bottom Ash, Fly Ash, and Suspended Particulates from MSW Incineration

Element	MSW (Combustible Fraction)	Bottom Ash	Fly Ash	Suspended Particulates	Possible Carcinogens
Ag	<3–7		52–220	84–2000	
Al(%)	0.54–1.17	2.6–14.2	9.0–14.2	0.58–4.8	
As			9.4–74	81–510	X
Ba	47–447	80–9000	1600–360	40–1700	
Be	<2				X
Bi	<15–30				
C(%)		1.0–28.7	1.7–7.4	1.8–2.2	
Ca(%)	0.59–1.65	3.6–11.2	3.3–8.6	0.66–5.3	
Cd	4—22	3.8–442	<1–477	520–2100	X
Cl		0.2–1.0	0.12–1.12	9.29	
Co	<3–5		25–54	3.8–28	
Cr	22–96		730–1900	122–1800	X
Cu	79–877	630–4281	69–2000	3000	
F	140–200	130–250	1500–3100	990–6800	
Fe(%)	0.10–0.35	2.1–32	2.4–8.7	0.17–1.8	
Hg	1–4.4	0.03–3.5	0.09–25	20–2000	
K(%)	0.09–0.21	0.42–2.41			
Mg(%)	0.09–0.21	0.04–0.86	0.5–2.1	0.31–2.8	
Mn(%)	0.005–0.02	0.08–39	0.20–0.85	0.03–0.57	
Mo					
N(%)		0–0.35	0		
Na(%)	0.18–0.74	2.3–14.2	1.12–1.94	5.1–9.8	
Ni	9–90	110–210	38.6–960	65–440	X
P(%)		0.04–0.83			
Pb(%)	0.01–0.15	0.04–0.80	0.06–0.54	2.5–15.5	X
S(%)		0.27–1.0	1.9–3.6	0.001–0.01	
Sb	20		139–760	610–12000	
Se			1.4–13	7.0–122	
Si(%)		4.7–9.4			
Sn(%)	<0.002–0.004	0.01–0.1	0.12–0.26	0.4–1.51	
Sr	11–35		110–220		
Ti(%)	0.14–.31	0.04–0.90	2.5–4.2	0.13–1.29	
Tl				150	
V			110–166	6–60	
Zn(%)	0.02–0.25	0.35–3.61	0.08–2.6	4.7–24	

Source: Lisk, D.J., *Sci. Total Environ.*, 74, 39–66, 1988. Reproduced with kind permission from Elsevier, Oxford, UK.

Figure 10 Showing the concentration ranges of elements in MSW and bottom ash, fly ash, and suspended particulates from MSW

2.7 Ash Management

The leachability of heavy metals in ash—that is, how rapidly will a specific metal leach from ash and enter the groundwater supply or some other environmental receptor—has been the focus of concerns over ash mobility and toxicity. However, others have criticized the "leachability methods" for being insufficient for determining toxicity. In addition to contaminated groundwater, there are other ways that ash can expose people and the environment, therefore it is important to take

into account the overall amounts of both metals and PCDDs when evaluating the toxicity of ash.

For instance, ash particles can be inhaled by humans, and the poisons on the particles then enter the bloodstream or tissue directly. Furthermore, ash particles could be consumed directly or through tainted food or drink. Data on the entire chemical makeup of ash must be included in a comprehensive evaluation of the risks it poses because these exposure routes can be quite important.

Several steps must be taken to lessen the risk associated with metals and other pollutants in ash (Denison and Rustin, 2000):

• Prevent goods that are contain potentially hazardous metals from reaching the waste stream.

• Keeping metal-containing materials out of incinerators

• Ash can be prepared for disposal either chemically or physically (e.g., by mixing with Portland cement and letting it set).

• ash should be disposed of entirely in safe locations free of other waste (a process known as "monofilling").

• Compacting the ash prior to or during landfilling

The density of noncompacted MSW ash can reach 900 kg/m3 (1500 lb/yd3). The density of the ash can reach 1980 kg/m3 (3300 lb/yd3) if it is compacted. The ash is extremely impermeable at this density; permeability could be as low as 1 x 10-9 cm/sec (Vesilind et al., 2002). Alternative uses for ash are being explored as the amount of ash produced increases and finding landfill space becomes increasingly challenging.

Other applications include capping strip mines, used as road base material, structural fill, gravel drainage ditches, and combining with cement to create building (construction) blocks.

Additionally, recyclable metals, particularly steel and aluminum, can be recovered from the ash left over after MSW is burned.

CHAPTER THREE: METHODOLOGY

This chapter provides a detailed explanation for the laboratory tests and procedures that are to be carried out in this research. These tests are to be carried out to determine the mechanical and engineering properties of the neat expansive soils, crushed granite stone and incinerated hospital waste ash.

3.1 Materials and methods

3.1.1 Materials

Soil sample

The soil sample obtained was one that exhibits the properties of expansive soils ie one that is prone to volume changes which relates to the changing moisture conditions. The cyclic water ingress and removal causes moisture imbalance that triggers the shrink and swell cycle. This was sourced from Kawanda Town council, Wakiso District.

Incinerated hospital waste ash.

The Municipal waste ash was collected from BioHaz waste Solutions in Bombo which burns the inorganic hospital waste at temperatures above 5000C providing the residue with a calcified nature.

3.1.2 Methods

Sample preparation

Collected soil samples were first dried under sunlight, the clods will then be broken to get a unified sample. The organic matters, smal0l aggregates are to be removed carefully from the sample. The sample is to be kept in the oven for drying at a maintained temperature of 1000 c for 24 hours. The prepared sample is then to be divided into 3 clusters that will be tested. The weight of the soil samples to be tested

are to be weighed. The various proportions of bagasse ash and burnt brick are also to be weighed. Four different blends are to be prepared for blending with the soils in varying proportions of 3%, 6%, 9% and 12%.

The following tests are to be carried out to determine the engineering properties of the expansive soils.

Particle size distribution

This experiment was done to determine the predominant soil components in the soil sample obtained to ascertain whether its expansive as reported. The test is to be carried out with BS: 1377- part 2(1990)

For each sieve size

Percentage passing (%) = 100 - percentage retained (%)

$$=100 - (\frac{M}{Ms} \times 100)$$

Cumulative percentage passing = 100 - cumulative percentage retained

$$=100 - (\frac{cummulative\ retained}{dry\ mass} \times 100)$$

$$= 100 - (\frac{M+Mb}{Ms} \times 100)$$

Where;

M and Mb - retained masses for the current and previous sieves respectively

Ms - Dry mass

Soil plasticity index

This is a measure of the soil's ability to undergo irreversible deformation while withstanding an increase in loading. It is established by experimental tests to determine the Atterberg limits.

Plasticity index = Liquid limit – Plastic limit

Sample preparation

A sample of the soil large enough to yield a test specimen was obtained, weighed to about 400 g and then passed through a 425 micron filter. This will be enough material for the liquid test, plastic limit as well as the shrinkage tests. Water will be added to the soil after then it will be put on a glass plate. It will then be vigorously mixed with a palette knife until its thick and has formed a paste. The formed mx will then be placed in an air tight container and then left for 24 hours to allow water to infiltrate the soil.

Liquid limit

This refers to the soil's moisture content at which it transitions from liquid state to the plastic state.

In this study it is aimed at confirming the swelling nature of the expansive soils.

This is carried out in accordance to BS: 1377-part2 (1990)

Calculations

The moisture content, w, of the soil sample on each container is to be calculated as;

$$W=\left(\frac{M1-M2}{M2-M3}\right) \times 100\ (\%)$$

Where;

M1 = mass of wet soil + container

M2 = mass of dry soil + container

M3 = mass of container

Average moisture content is to be calculated as follows for each test

Wave= $(\frac{w1+w2}{2})\%$

The reading of the average penetration and the average moisture content are to be recorded.

Plastic limit

This refers to the moisture content of the soil at which it becomes too dry and it begins to behave as a plastic material. The experiment is to be carried out with reference to BS:1377-part 2(1990)

Calculations

The moisture content of the first, w1 and the second portion w2 are calculated from;

W= $(\frac{m1-m2}{m2-m3})\times 100(\%)$

Where:

M1= mass of wet soil threads + container

M2 = mass of dry soil threads + container

M3 = mass of the container

The plastic limit will be the average moisture content of both portions provided their difference does not exceed 0.5%

Plastic limit= $(\frac{w1+w2}{2})\%$

Linear shrinkage

This is the measure of the amount of shrinkage that is likely to be experienced by the soil if the drying process is prolonged beyond the plastic limit. This experiment is to be done according to BS:1377-part 2(1990)

Calculations

Linear shrinkage (%) = $(1-\frac{LD}{LO})\times 100$

Where;

LD= oven dried length of the soil bar

LO= initial length of the soil bar

Proctor compaction test

This test was carried out to obtain the relationships between compacted dry density and soil moisture content that is the optimum moisture content at which the soil type will become the most dense and attain its maximum dry density. It is to be carried out with accordance to the field compaction.

The experiment was carried out with reference to the procedure in BS:1377-part2(1990)

Sample preparation

Representative samples were generated from the soil that passes through the 20mm filter and then combined with varying quantities of water to provide an appropriate range of moisture levels. The moisture content and the portions are to be sealed in an air tight container and then allowed to cure for approximately 3 hours.

calculations

bulk density, p= ($\frac{m2-m1}{v}$ ×1000) (in kg/m^3)

where;

m1= mass of mold and base plate(g)

m2= mass of mold, base plate and compacted soil(g)

v= volume of the mold (in cm^3)

dry density, pd= $\frac{100p}{100+w}$ where w is the moisture content of the soil (in %)

The readings of the dry densities and the corresponding moisture contents are to be recorded in a table.

California bearing ratio

The CBR test was carried out as specified in BS 1377: part 4(1990). The one point method will be applied. The CBR value is the resistance to 2.5 mm penetration of the conventional cylindrical plunger of 50 mm diameter as a percentage of the plunger's known resistance to 2.5 mm penetration.

Sample preparation

The CBR was performed on a material that passes the 20mm sieve which was of a total weight of 25 kg.

According to the BS heavy compaction test, the sample will be raised to an optimum moisture content of (OMC $\pm$ 0.3%)

Calculation

The matching penetration is to be plotted for each value of the force as ordinated, and a smooth curve is to be created through the points. The normal curve is a convex and does not require modification.

Penetration of 2.5 mm and 5.0 mm is to be used for calculating the CBR value.

At 2. 5 mm penetration, the CBR value is to be calculated from;

CBR value (in %) = $P \times \frac{100}{13.2}$

At 5.0 mm penetration, the CBR will be calculated from;

CBR value (in %) = $P \times \frac{100}{20.0}$

Where P is the plunger force in kN, obtained by multiplying the dial gauge reading at the corresponding penetration by the proving ring factor of 0.113

Unconfined Compressive strength

The unconfined compressive strength test is a laboratory method that is used to determine the shear strength of the soil that does not contain any confinement. This test is carried out to evaluate the properties of cohesive soils.

It will be carried out with accordance to BS 1377: part 4(1990)

Sample preparation

We shall use split type UCS mold to contain 4 kg of similar soil sample. The mass of the air dry sample of the material is to be calculated by taking the moisture content of the dried material.

The weight of the stabilizer is to be determined and mixed with the soil and the bagasse ash. The amount of water required to bring each sample to OMC is to be calculated and added to the soil and mixed thoroughly. The 2 specimens for each percentage from each, the different sets with different quantity of the stabilizer will be cured for a period of 7 days after which they will be compacted in the UCS machine. The specimen will be crushed to total failure on the compaction machine and the load that will be applied will be at a rate of 140kpa/s.

Calculation

The UCS is to be calculated by dividing the maximum axial load that the sample could sustain by the cross sectional area of the sample.

UCS = $\frac{Pmax}{A}$

Where;

UCS = unconfined Compressive strength (in kPa)

Pmax = Maximum axial load sustained by the sample (in N)

A = Cross sectional area of the sample (in m^2)

X Ray Florescence

An equipment called XRF is used to analyze the chemical makeup and elemental content of rocks, minerals, sediments, and fluids. It operates using wavelength

dispersive spectroscopy techniques, which are comparable to those of an electron microbe.

Test procedure

The procedures that are to be taken during the determination of the chemical composition while using the XRF machine are as follow;

1. When all the power sources and UPS are switched on, press the power button on the left side of the XRF machine.
2. Turn on the computer to which the method software is installed.
3. Switch on the x-rays by turning the key on the “HT ENABLED” knob in a clockwise direction. There will be a light beam on the front corners of the instrument indicating that the x- rays have been switched on.

CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSIONS

This chapter presents the laboratory results from tests carried out in this study. The data is analysed and discussed from the results of the tests carried out. So far, the tests carried out were to determine the engineering properties of expansive soils and these tests included sieve analysis, Atterberg limits, California bearing ratio and Proctor test. Other tests were carried out to determine the engineering properties of Crushed granite and Ash from waste incineration and these were sieve analysis and X-Ray Fluorescence test respectively.

4.1. Classification tests.

4.1.1. Neat soil

The neat soil used in this study was greyish-black. The soil was classified using USCS as CH fat clay.

4.1.1.1. Sieve analysis

The neat soil was sieved and it was noted to have 1.28% gravel, 29.57% sand and 69.15% fines. The high percentage of fines contributes to the high plasticity of the soil. The results from the sieve analysis test are shown in the table below.

Table 1 Showing the grading results for the neat soils

Sieve Size (mm)	Passing (%)	Grading Limits (G60 & 80)	
63.0	100	100	100
37.5	100	80	100
20.0	100	60	95
5.0	100	30	65

2.00	99	20	50
0.425	90	10	30
0.075	69	5	15
Grading Modulus	0.42		

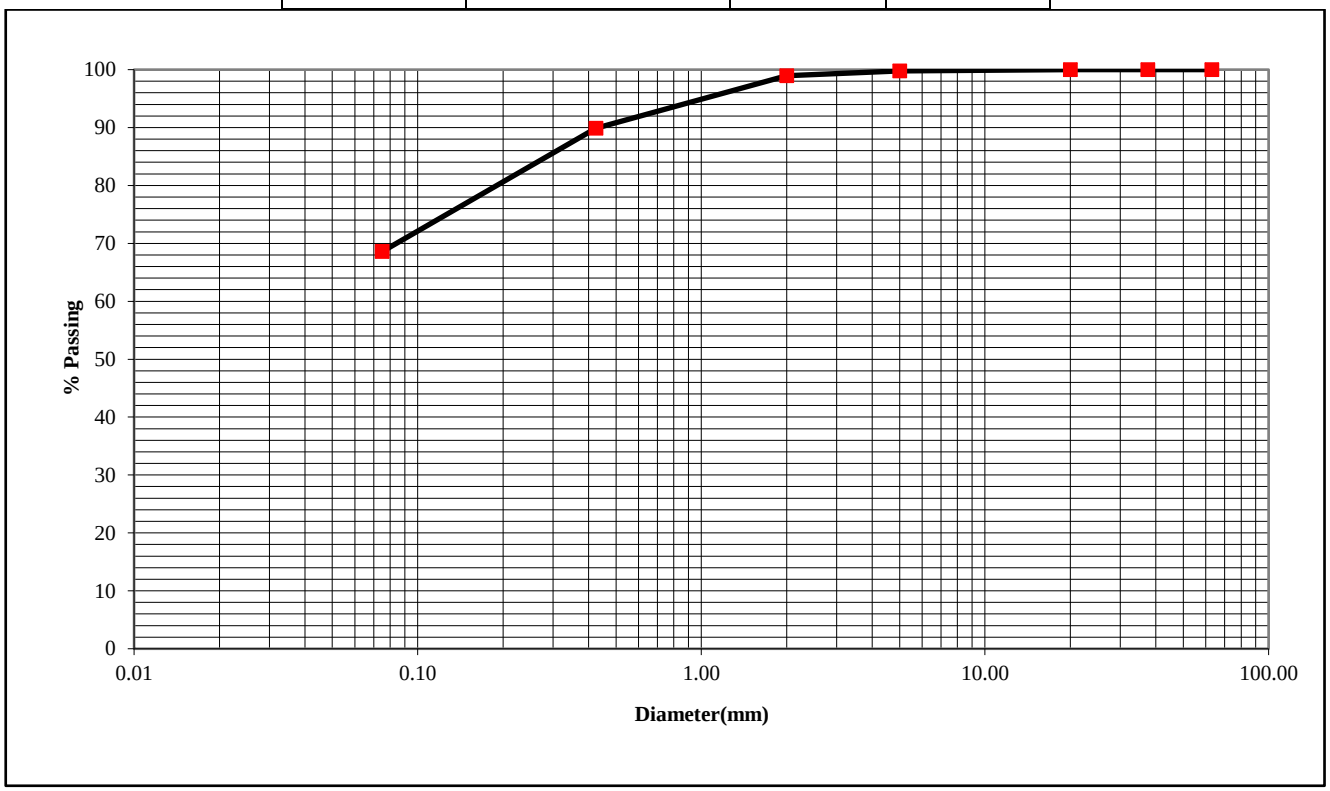


Figure 11 Showing a graph of %age passing against sieve size for neat soils.

4.1.1.2. Atterberg limit tests.

Atterberg limits are a basic measure of the critical water contents of fine-grained soils such as silt and clay as they transition from solid to liquid. They can also be referred to as consistency characteristics of the soil. A summary of test results of the neat soil sample is summarized in table

Table 2 Showing consistency characteristics

Consistency characteristics	
Liquid Limit (%)	57.5
Plastic Limit (%)	27.5
Plasticity Index (%)	30
Linear shrinkage (%)	15.0

The soil had a high liquid limit which implied high compressibility as well as a high shrinkage or swelling potential. Having a high liquid limit directly implied a plasticity index. This indicated an excess of clay material in the neat soil. Linear shrinkage is used to estimate the swell and shrink behaviour of the soils. A shrinkage of 15.0% lies within the range of critical chance for cracking due to swelling and shrinking.

Table 3 Showing linear shrinkage and expansive rating

Category	Linear shrinkage (%)	Expansive rating
Low	0-12	Non-Critical
Medium	12-17	Marginal
High	17-22	Critical
Very High	>22	Very Critical

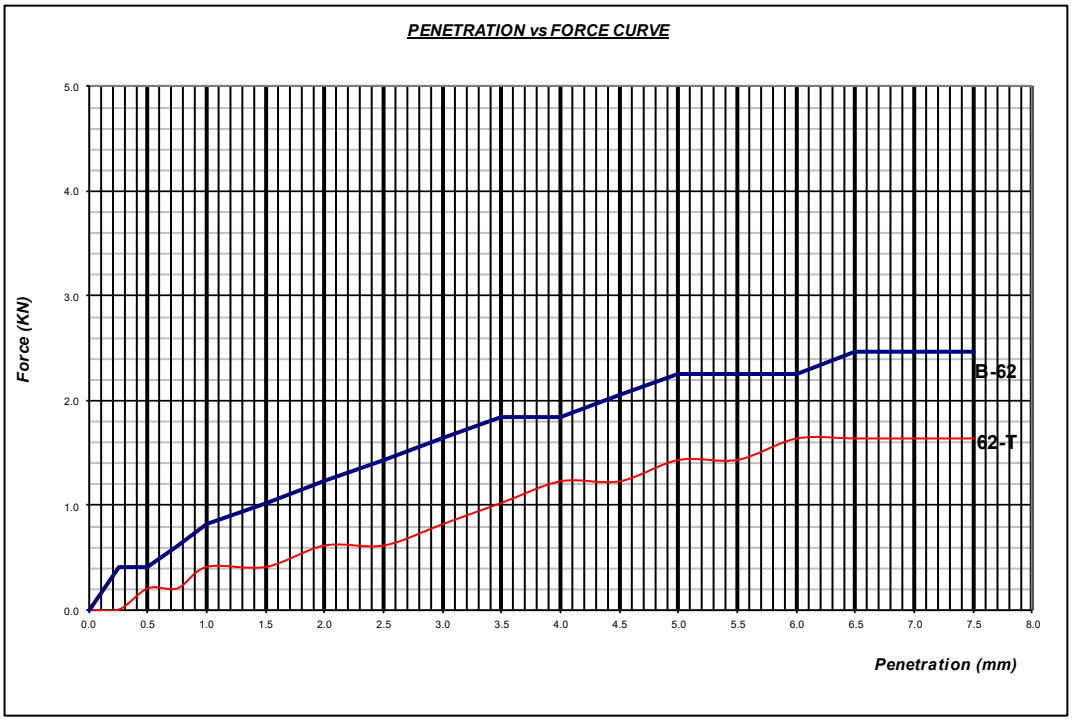
Less than 35% of the liquid limit is typically considered low plasticity, 35% to 50% is considered intermediate plasticity, 50% to 70% is considered high plasticity, and 70% to 90% is considered extremely high plasticity. Thus, the findings demonstrated the extremely high plastic clay content of both soil samples. This indicates that the

subgrade soils have a propensity to cause fractures in the pavement structures because they are readily deformed and swelled and are unable to withstand both internal and exterior stresses. Stabilizing expansive soils before the sub-base, base, and surfacing layers is one way to prevent such failures; different additives are required.

4.1.1.3. California Bearing Ratio.

This test is carried out to evaluate strength of soil as subgrade material. This soil had a CBR value of 11.1% from bottom and 5.1% from top from one point method of determining CBR, so we consider the greater value which is 11.1%.

Table 4 Showing a graph of force against penetration



The CBR test found that the two soil samples had the ideal moisture content at 2.54 and 5.08 penetration at the specified maximum dry density. At a maximum dry density and 0.17% CBR swell, the soil sample had a 0.8% soaked CBR value, but the

soil sample had a 0.91% CBR value and 0.21% CBR swell. Low CBR values were found in the results for the soil samples.

4.1.1.4. Proctor test.

This test was carried out to determine the maximum dry density and optimum moisture content of the neat soil. These parameters are obtained in order to determine the compaction levels of the soil. The soil sample had a maximum dry density of 1.569gm/cm^3 and an optimum moisture content of 22.4%.

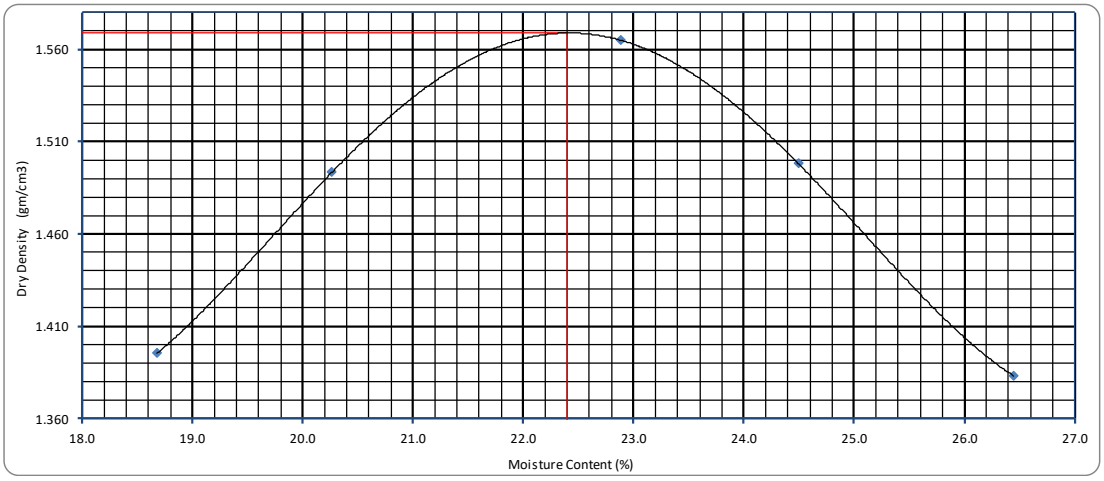


Figure 12 Showing a graph of Dry density against moisture content

4.1.2. Categorization of the waste

Source: The waste used in the incineration process to obtain the ash was got from some hospitals and drug shops within the central region of Uganda. These hospitals include Mukwaya General Hospital along Ggaba road, Marie Stopes Uganda, Bethesda Medical Centre along Makerere hill road among others. It also treats waste from collection companies like Bin it services limited.

Composition: The waste comprises of items such as expired pharmaceuticals(such as drugs), food products, sharps (such as needles and syringes), personal protective equipment (like hand gloves and masks), general waste (non hazardous waste such

as box packaging, paper documents and other office supplies) plastic bottles, plaster, bandages among others.

Category: Medical waste.

Meaning of color codes used in packaging

- Black represents waste that is non infectious such as paper, packaging material or empty containers.
- Red represents biohazardous waste indicating that the contents may be contaminated with potentially infectious materials such as blood, bodily fluids or items used in patients care that have been in contact with those4 substances.
- Yellow represents hazardous waste that requires treatment before disposal.
- These include sharps like needles, syringes or materials contaminated and often signify high level risk.

To categorize the waste used for incineration

Table 5 Showing the methodology for objective 3

Procedure	Standard
Identify the source of the waste. Determine the constituents of the waste. Classify the waste according to the standard	National Environment Management Authority

4.1.2.1. Properties of waste incinerated ash

The ash was a dark-coloured material passed through sieve size 300 micro-meter and assessed for chemical composition.

4.1.2.2. X-Ray Fluorescence Test

XRF test was conducted to examine the chemical properties of fly ash. Figure 13 presents the chemical composition of fly ash obtained from XRF-Spectrometer analysis. It is comparable in composition to geological materials since its main constituents are oxides of Si, Fe, Ca, Al, Na, and K. The results align with earlier studies that have been published, including those conducted by Blanc et al. (2018), Gori et al. (2011), and Lin et al. (2015).

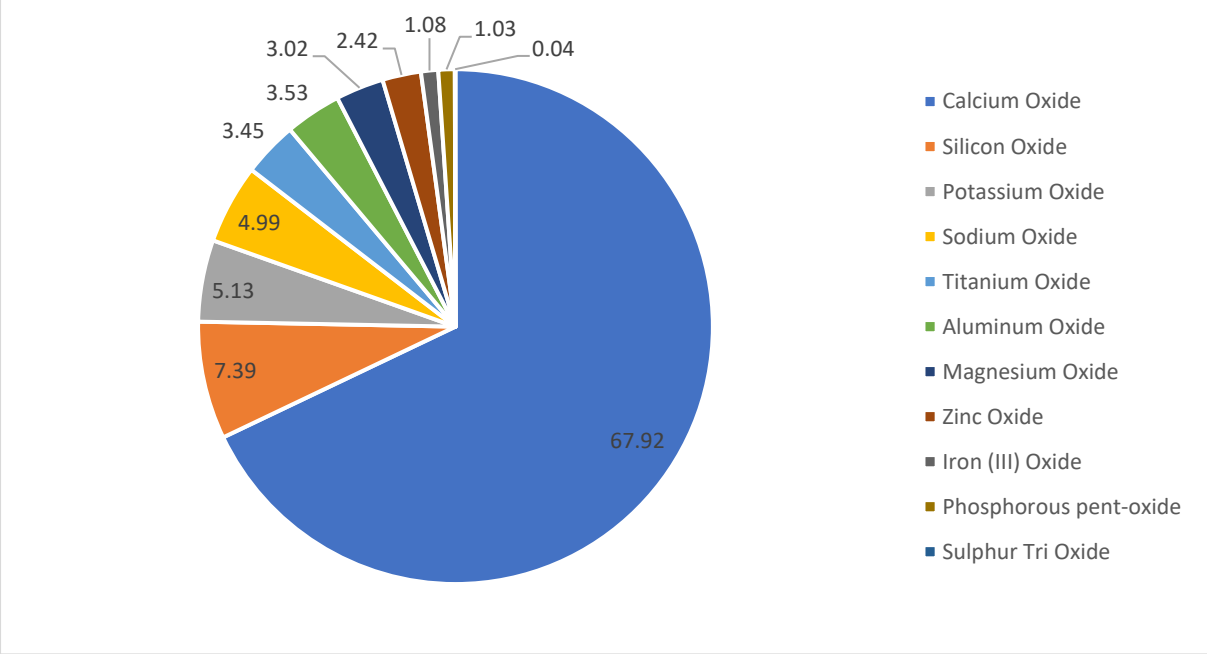


Figure 13 Showing a pie chat of the chemical composition of the incinerated waste ash

4.1.3. Properties of Crushed Granite Stone.

The cost of granite is 70,000 Uganda Shillings per tonne.

The crushed granite stone was greyish in colour and it was majorly gravel.

4.1.3.1. Sieve Analysis

The crushed granite stone was sieved and it was noted to have 74.46% gravel, 25.33% sand and 0.21% fines. The high percentage of gravel will enable in the interlocking of granite particles with soil particles hence filling voids present in the expansive soils, which will increase the Maximum Dry Density of the soil whilst reducing its Optimum Moisture Content. Results from sieve analysis are summarized below.

Table 6 Showing grading results for the crushed granite stone

MAXIMUM SIEVE SIZE (mm)	Cumulative passing (%)	SPECIFIED LIMITS *(spec table 3902/2)*(%)
37.5	100	100
28.0	95	87—97
20.0	88	75 – 90
10.0	63	52 – 68
5.0	43	38 – 55
2.0	31	23 – 40
1.18	24	18 – 33
0.425	16	11 – 24
0.075	7	4 – 12

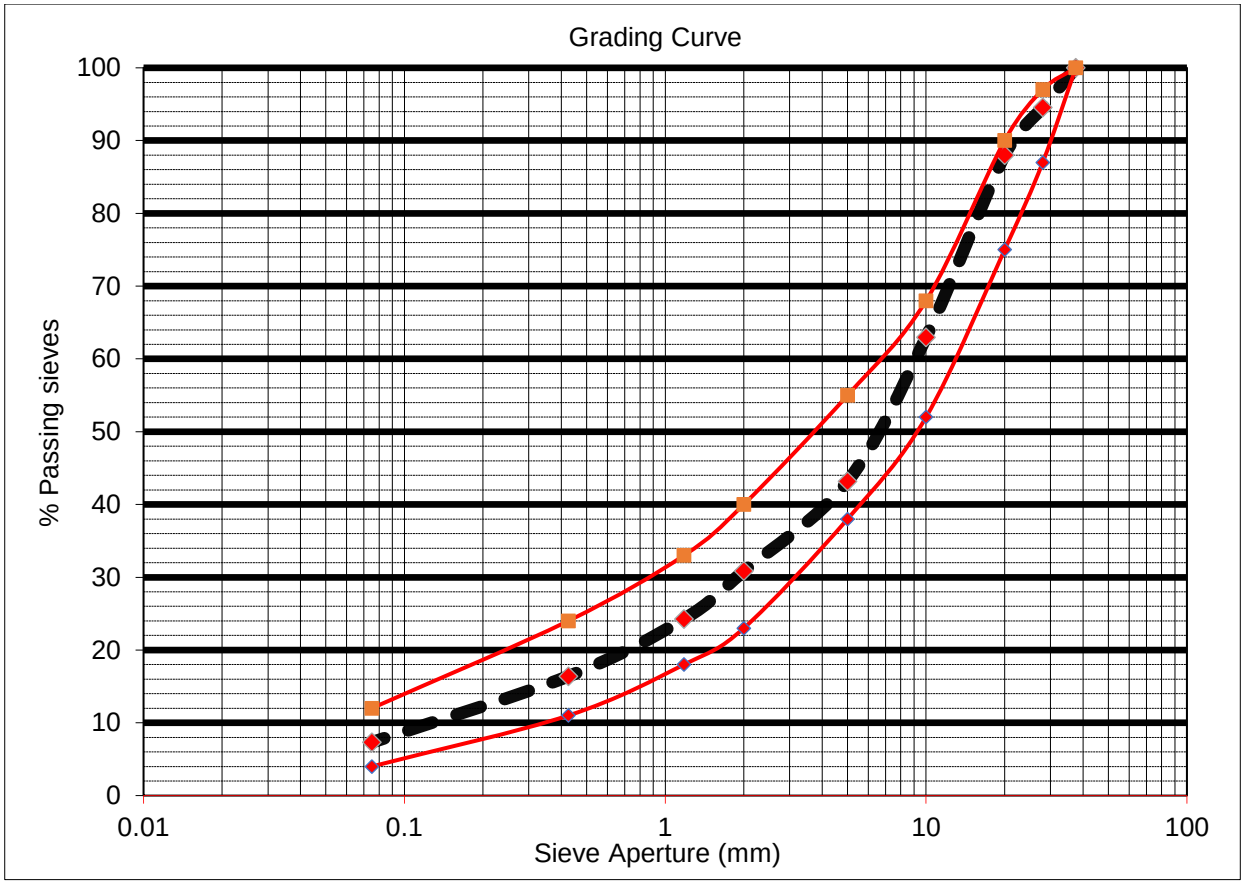


Figure 14 Showing the graph of %age passing against the seive size

The data above shows that the material is mostly coarse.

4.1.4 The Effect Of Waste Incinerated Ash And Crushed Granite Stone On Density And Moisture Content Of The Soil.

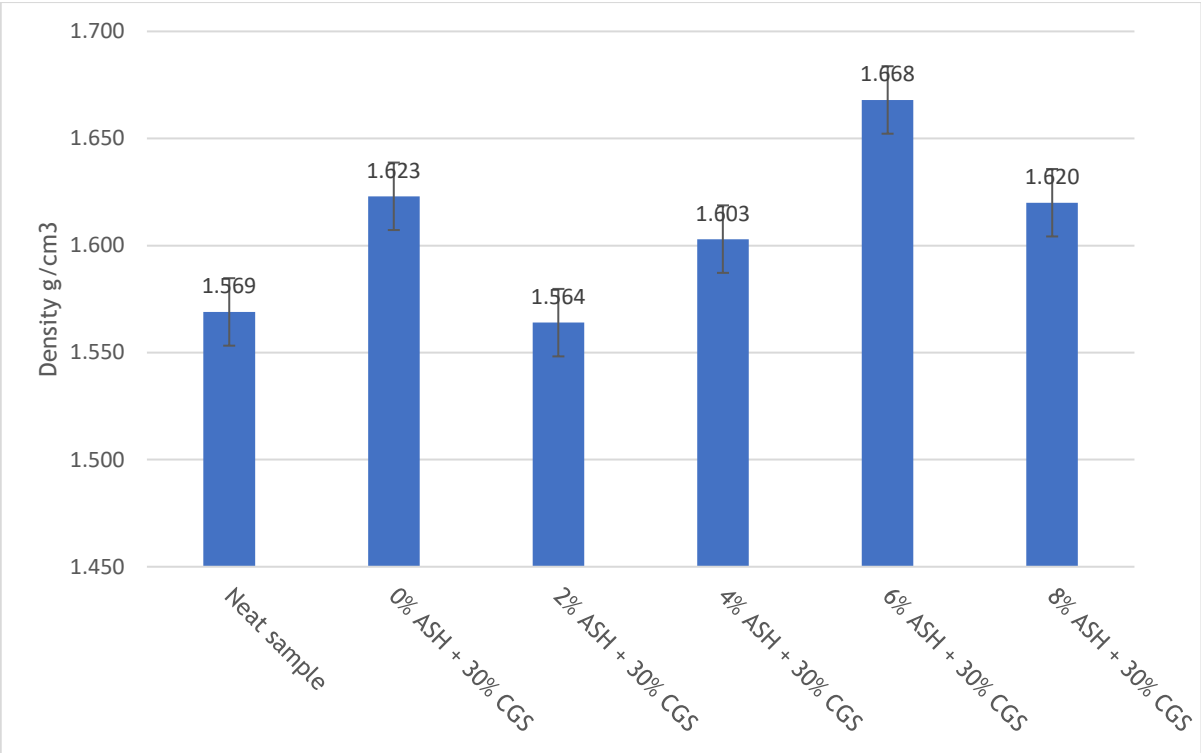


Figure 15 Showing a graph of MDD against percentages of the ash

The variation of the expansive soil's MDD with ash%. As the percentage of ash increases, the MDD of the soil continues to increase. When the ash rose to 4%, the MDD increased from 1.603 g/m3 to 1.668 g/m3.

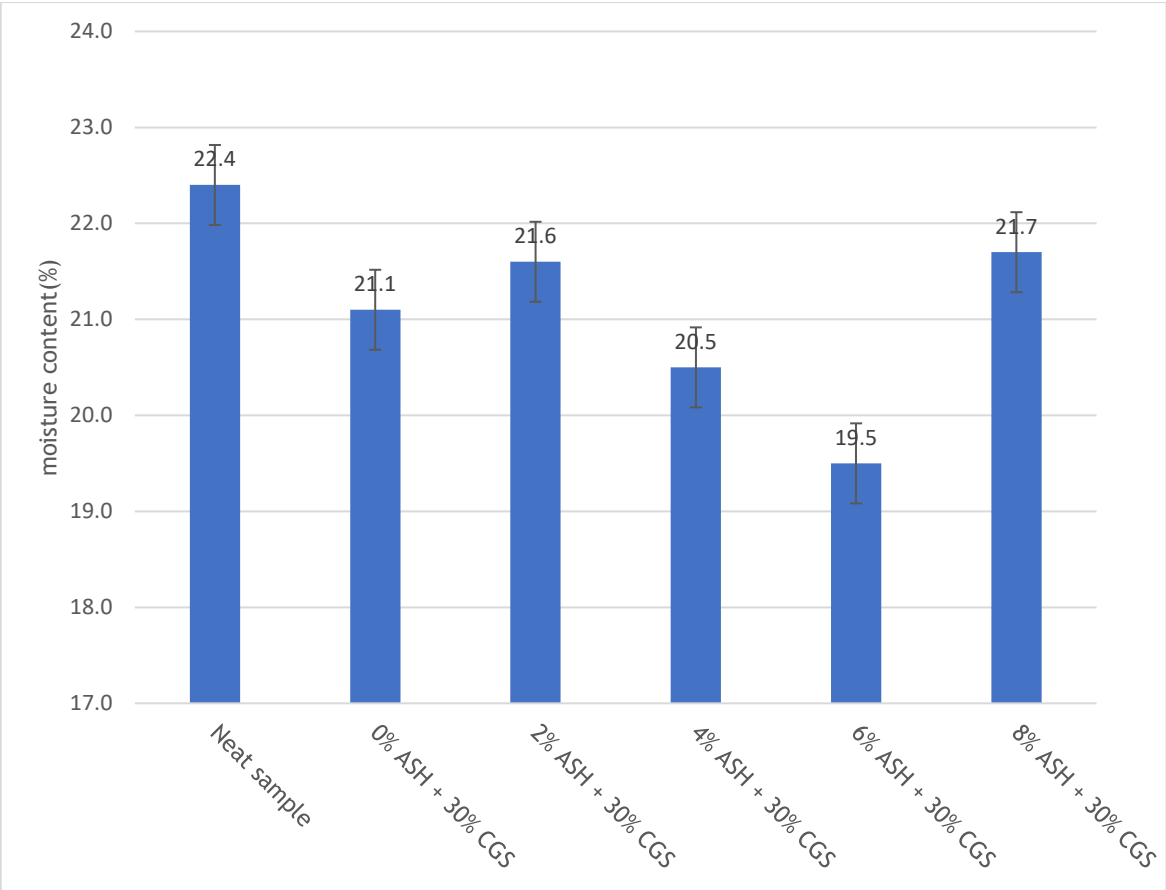


Figure 16 Showing a graph of OMC against percentages of ash and granite

30% CGS improves density of soil and reduces the moisture content due to interlocking properties of the CGS.

There is an increase in density of the soil and a corresponding decrease in moisture content with increase in ash from 2% to 6% because the reaction between ash and the clay properties of the soil creates a strong bond and reduces water intake of the soil.

However, beyond the threshold (6% ash content), the MDD starts to decrease due to excessive addition of ash, which might lead to overcrowding of particles, hindering proper compaction and resulting in reduced density.

4.1.5 The Effect Of Waste Incinerated Ash On The California Bearing Ratio

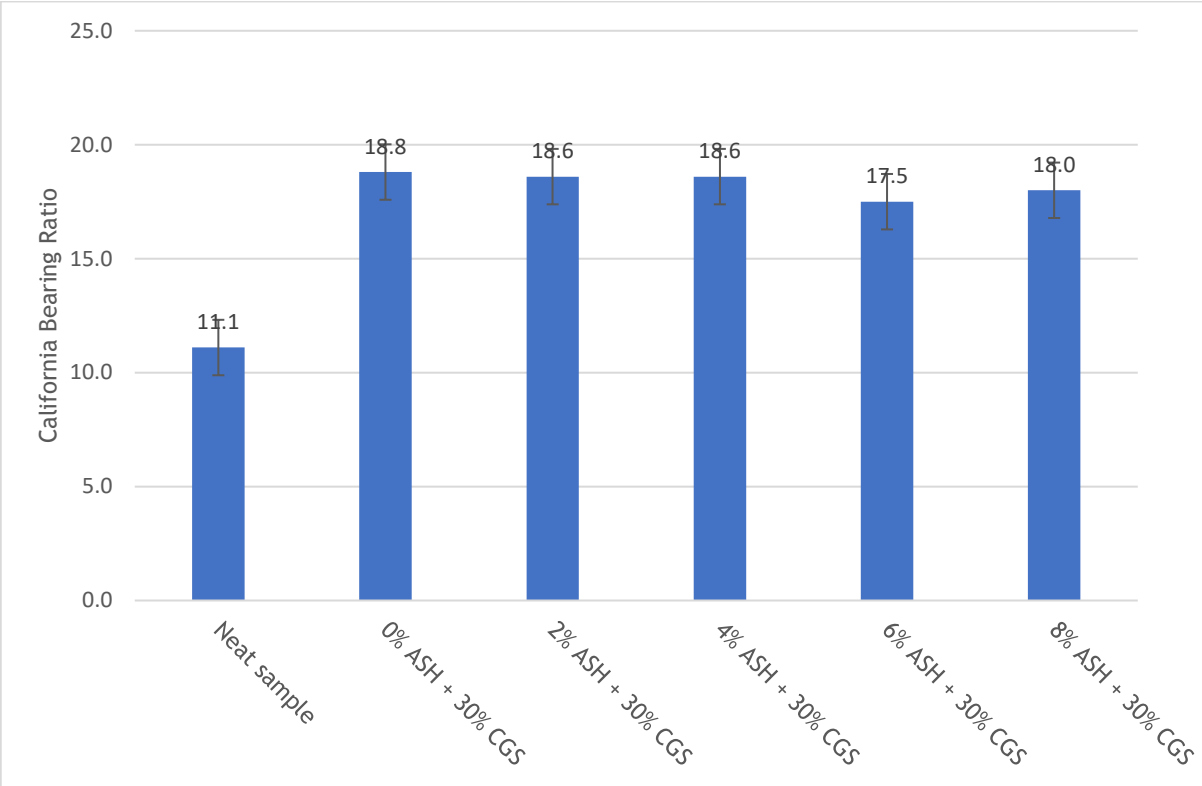


Figure 17 Showing a graph of CBR against percentages of ash and granite

Replacement of 30% of the soil with CGS leads to increase in CBR value of about 7.7%. This is due to the interlocking properties of the CGS .

However, introduction of 2% ash leads to slight decrease in the CBR value by about 0.2%. Further increase in ash percentages leads to further reduction in CBR values up to 6% ash+30% CGS after which the CBR increases again.

4.1.6 Effect Of Waste Incinerated Ash And Crushed Granite On The Atterberg Limits Of The Soil.

4.1.6.1 Plastic index

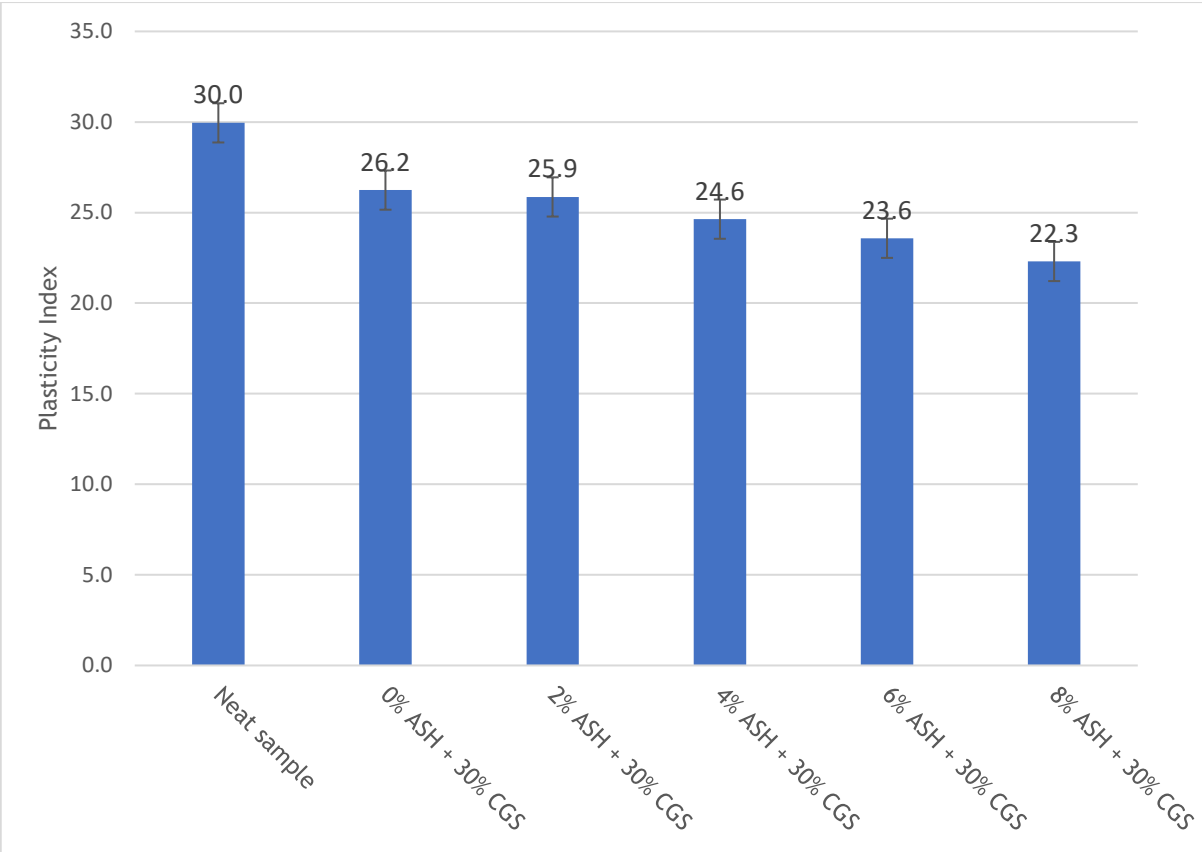


Figure 18 Showing a graph of Plasticity index against the percentages of ash and granite

Modification of the soil with 30% CGS leads to decrease in plasticity index by about 4%. However, introduction of Ash further leads to gradual decrease in values of PI up to 22.3% at 8% ash+30% CGS. This is because the calcium ions in the ash exchange with cations on the surface of the clay particles. The ion exchange reaction between the ash and the soil reduces the PI of the soil.

4.1.6.2 Linear Shrinkage

As observed, the linear shrinkage decreased with introduction of 30% CGS and continued to decrease with 2% addition of Ash at every stage.

Reason: When added to soil, ash binds soil particles together, reducing their ability to move and settle. This binding effect reduces the tendency of the soil to shrink linearly, meaning it will maintain its volume more effectively.

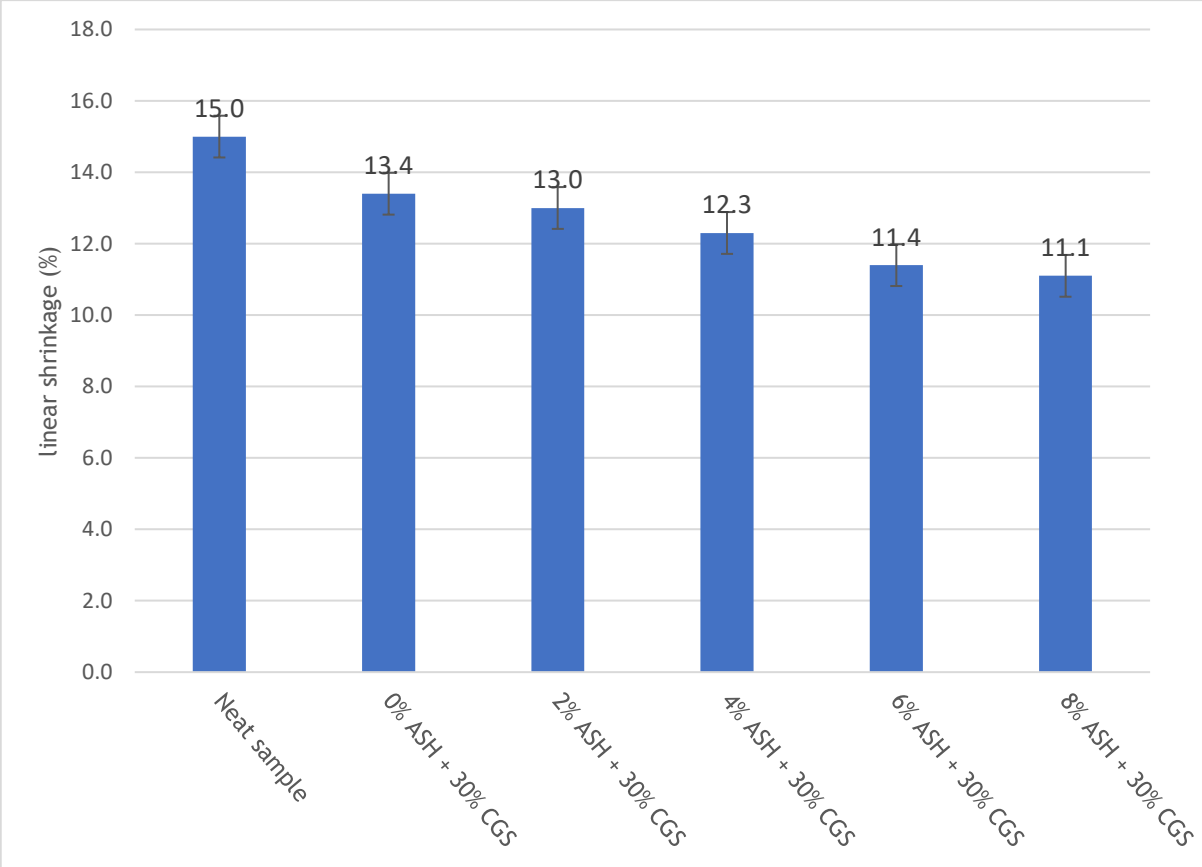


Figure 19 Showing a graph of linear shrinkage against percentages of ash and granite

4.1.7 Final design.

Table 7 Showing the final design

Percentages of materials by mass	TEST RESULTS

Expansive soil (%)	Granite Stone (%)	MWIA (%)	Total percentage	Plasticity Index	Linear Shrinkage(%)	MDD (gm/cm3)	OMC	CBR
100	0	0	100	26.2	13.4	1.623	21.1	18.8
68	30	2	100	25.9	13.0	1.564	21.6	18.6
66	30	4	100	24.6	12.3	1.603	20.5	18.6
64	30	6	100	23.6	11.4	1.668	19.5	17.5
62	30	8	100	22.3	11.1	1.620	21.7	18.0

From the above design in table 6, we note that the optimum ash content that gives a desired result is 6% with a 30% crushed granite content.

The obtained CBR was 17.5 which is above the required 15 for a subgrade soil.

The obtained PI was 23.6 which is also below 25 the maximum PI for a subgrade soil.

The MDD obtained at 6% ash content was 1.668 which was the highest amongst all the varied percentages making it the ideal amongst all of them.

CHAPTER FIVE. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions.

- The neat soil did not meet the requirements for G15 material and therefore they needed to be stabilized so this purpose before its use.
- The chemical constituents of the incinerated waste ash such as Calcium Oxide with a percentage of 67% proved it capable of providing a cementitious material to improve the plasticity of the expansive soils.
- Both the crushed granite stone and the incinerated waste ash when used together with the expansive soils in percentages of 30% for crushed granite and varying percentages of ash by 2% proved to raise the CBR of the expansive soils from 11% to 18% hence the soil was stabilised.

5.2 Recommendations.

- This research could help understand the long-term characteristics and durability of stabilized soil with incinerated waste ash and crushed granite stone.
- Further study should be carried out to determine the various potential uses of the incinerated waste ash and crushed granite stone as a means of waste reduction and management.

REFERENCES

S.N.B. (2014) ‘Effect of Burnt Brick Dust on Engineering Properties on Expansive Soil’, International Journal of Research in Engineering and Technology, 03(04), pp. 433–441. Available at: https://doi.org/10.15623/ijret.2014.0304078.

Afrin, H. (2017) ‘A Review on Different Types Soil Stabilization Techniques’, International Journal of Transportation Engineering and Technology, 3(2), p. 19. Available at: https://doi.org/10.11648/j.ijtet.20170302.12.

El-AzizM.A. and AboHashema, M.. (2013) ‘MeasuredEffectsonEngineeringPropertiesofClayey Subgradeusing Lime-HomraStabiliser’, International Journal of Pavement Engineering [Preprint].

Fondjo, A.A., Theron, E. and Ray, R.P. (2021) ‘Stabilization of Expansive Soils Using Mechanical and Chemical Methods: A Comprehensive Review’, Civil Engineering and Architecture, 9(5), pp. 1289–1294. Available at: https://doi.org/10.13189/cea.2021.090503.

Guyer, J.P. and PE, R.A. (2018) An Introduction to Construction Methods for Soil Stabilized Pavements. Available at: https://books.google.com/books?hl=en&lr=&id=nGVLDwAAQBAJ&oi=fnd&pg=PA1&dq=tank+truck+stability&ots=Tl-l5R-HhW&sig=HIv3VkZCZsnLUaM9j--3dJATwMc%0Ahttps://www.cedengineering.com/userfiles/An Introduction to Soil Stabilization for Pavements R1.pdf.

Mekonnen, E. et al. (2020) ‘Application of Microbial Bioenzymes in Soil Stabilization’, International Journal of Microbiology, 2020. Available at: https://doi.org/10.1155/2020/1725482.

Agamuthu, P., and Chitra, S. (2009). Solidification/stabilization disposal of municipal waste incinerator flyash using cement. Malaysian Journal of Science, 28(3), 241-255.

Akter, N. (2000). Municipal waste management: a review, environmental engineering program, school of environment resources and development. Asian Institute of Technology, Khlongluang, Pathumthani, Thailand.

Al-Mutairi, N., Terro, M., and Al-Khaleefi, A.L. (2004). Effect of recycling hospital ash on the compressive properties of concrete: statistical assessment and predicting model. Building and Environment, 39(5), 557-566.

Al-Rawas, A.A., Hago, A.W., Taha, R., and Al-Kharousi, K. (2005). Use of incinerator ash as a replacement for cement and sand in cement mortars. Building and Environment, 40(9), 1261-1266.

Anastasiadou, K., Christopoulos, K., Mousios, E., and Gidarakos, E. (2012). Solidification/stabilization of fly and bottom ash from municipal waste incineration facility. Journal of hazardous materials, 207, 165-170.

Androjic, I., Kaludjer, G., and Komljen, M. (2013). Usage of the fly ash in hot mix asphalt mixes. In Proceedings of the XXVIII International Baltic Road Conference.

Abusharar, S. and Han, J. (2011). “Two-dimensional deep-seated slope stability analysis of embankments over stone columns.” Eng. Geol., 120: 103–110.

Andrus, R.D. and Stokoe, K.H. (2000). “Liquefaction resistance of soils from shear-wave velocity.” J. Geotech. Geoenviron. Eng.,126(11): 1015–1025.

Baker, R. and Leshchinsky, D. (2001). “Spatial distribution of safety factors.” J. Geotech. Geoenviron. Eng., 127(2): 135–145.

Berg, R.R., Christopher, B.R., and Samtani, N.C. (2009). Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes. FHWA-NHI-10-024, FHWA, Washington, DC.

Bishop, A.W. (1955). “The use of the slip circle in the stability analysis of slopes.” Geotechnique, 5(1): 7–17.

Bjerrum, L. (1972). “Embankments on soft ground.” Proceedings of the Specialty Conference, American Society of Civil Engineers (2): 1–54.

Bonaparte, R., Holtz, R. D., and Giroud, J. P. (1987). “Soil reinforcement design using geotextiles and geogrids.” Geotextile

Testing and the Design Engineer, ASTM, STP No. 952, 69–116.

Bowles, J.E. (1996). Foundation Analysis and Design (5th ed.). McGraw-Hill, New York.

Budhu, M. (2000). Soil Mechanics and Foundations. Wiley,New York.

Conduto, D.P. (2001). Foundation Design: Principles and Practices (2nd ed.).Prentice Hall, Upper Saddle River, NJ.

Cubrinovski, M. and Ishihara, K. (1999).“Empirical correlation between SPT N-value and relative density for sandy soils.” Soilsand Foundations 39(5): 61–71.

Cundall, P.A. (2002). “The replacement of limit equilibrium methods in design with numerical solutions for factor of safety.”

Powerpoint presentation, Itasca Consulting Group. Minneapolis, Minnesota.

Aadland D.M. and Caplan, A.J., Household valuation of curbside recycling. J. Environ. Plann. Manag., 42,

781–799, 2000.

Ackerman F. and Mirza, S., Waste in the inner city: asset or assault? Local Environ., 6, 113–120, 2001.

Benhart J.E. and McCartney, D., Solid waste management in southcentral Pennsylvania, Pennsylvania

Geographer, 22, 1–7, 2000.

Creason J. and Podolsky, M.J., Economic impacts of municipal recycling, Rev. Regional Stud., 31, 149–164,

2002.

Derksen L. and Gartrell, J., The social context of recycling, Am. Sociol. Rev., 58, 434–442, 2000.

Everett J.W. and Peirce, J.J., Curbside recycling in the USA: convenience and mandatory participation, Waste

Manag. Res., 11, 49–61, 2000a.

Everett J.W. and Peirce, J.J., Measuring the success of recycling programs, Resour. Conserv. Recycling, 6,

355–370, 2000b.

Fleschner, E., Crombie, G., and Moreau, T., A city shifts into full-scale recycling, BioCycle, 33, 38–42, 2000.

Gamba R.J. and Oskamp, S., Factors influencing community residents' participation in commingled curbside

recycling programs, Environ. Behav., 26, 587–612, 2000.

Hadjilambrinos, C., The USA plastics recycling industry: A survey of manufacturers and vendors of recycled

plastic products, Environ. Conserv., 26, 125–135, 2000.

Ali Khan, M. and Buney, F., Forecasting solid waste compositions, Resource Conserv. Recycling, 3, 1–17, 1989.

Alter, H., The origins of municipal solid waste: the relations between residues from packaging materials and

food, Waste Manage. Res., 7, 103–114, 1989.

Black, R.J., Muhich, A.J., Klee, A.J., Hickman, H.L., and Vaughn, R.D., The National Solid Wastes Survey:

An Interim Report, National Technical Information Service, NTIS Report PB 260 102, 1968.

Boyd, G. and Hawkins, M., Methods of Predicting Solid Waste Characteristics, U.S. Environmental Protection

Agency, Office of Solid Waste, SW-23c, Washington, DC, 1971.

Cailas, M.D., Kerzee, R., Swager, R., and Anderson, R., Development and Application of a Comprehensive

Approach for Estimating Solid Waste Generation in Illinois, The Center for Solid Waste Management

and Research, University of Illinois, Urbana-Champaign, IM, 1993.

Davidson, G. R., Residential Solid Waste Generation in Low Income Areas, U.S. Environmental Protection

Agency, Office of Solid Waste, Washington, DC, 1972.

Dayal, G., Yadav, A., Singh, R. P., and Upadhyay, R., Impact of climatic conditions and socioeconomic status

on solid waste characteristics: a case study, the Sci. Total Environ., 136, 143–153, 1993.

APPENDICES

Freshly offloaded waste

A typical mass-burn incinerator

Packaged ash

Air drying the ash

ANNEXES

Telephone
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Website: www.mia.go.ug

In any Correspondence on this subject please quote No. GE 057/2024

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O. BOX 105639
Kampala - Uganda

02nd February 2024

MR. TUSUBIRA ANDREW AND MR ASHABA PETER
REG NO. S20B32/036 & S20B32/217
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-778-051449

REPORT OF ANALYSIS

Description of the Samples

One sample in a black polythene bag containing Municipal waste ash sample was submitted by Mr. Tusubira Andrew, on 25th January 2024, and analysed on 31st January 2024. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Municipal waste Ash sample packed in a black polythene bag.	01	Sample "A" GE 057/2024

Analysis Requested

Elemental analysis

Method of Analysis

Elemental analysis was done using the XRF Method.

Results of Analysis

The above sample has been analyzed with the following results as below.

Parameter	Units	Results Municipal waste Ash sample GE 057/2024
Calcium Oxide	% m/m	67.92
Silicon dioxide	% m/m	7.39
Potassium Oxide	% m/m	5.13
Sodium Oxide	% m/m	4.99
Titanium di oxide	% m/m	3.45
Aluminum oxide	% m/m	3.53
Magnesium Oxide	% m/m	3.02
Zinc oxide	% m/m	2.11
Iron (III) Oxide	% m/m	1.08
Phosphorous pent-oxide	% m/m	1.03
Sulphur trioxide	% m/m	0.04

Remarks

1. Results relate to sample analyzed and are reported as on received basis.

02/02/2024

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF ALL THE TEST RESULTS

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD	OMC	CBR			CBR SWELL
			40	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62Blows			42
KABAMBI A TOWN COUNCIL (MASESO DISTRICT)	EXPANSIVE SOIL	11/23/2023	100	100	100	100	99	98	69	0.41	57.5	27.3	30.0	15.0	1.599	22.4	11.1			1.01
			100	100	100	100	99	98	68	0.41	57.4	27.4	29.9	15.0	-	-	-	-	-	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR		100	100	99	75	68	53	33	1.479	53.3	25.8	29.1	13.4	1.623	21.1	18.8			0.91
			100	100	93	76	69	55	34	1.413	52.9	25.0	26.4	13.6	-	-	-	-	-	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH		100	100	91	70	60	53	34	1.441	49.0	25.3	23.5	13.0	1.584	21.6	18.6			0.8
			100	100	80	76	66	55	32	1.460	48.0	23.8	24.8	13.0	-	-	-	-	-	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 4% ASH		100.0	100.0	94.1	79.2	72.7	58.8	37.3	1.530	47.0	22.4	24.6	12.4	1.601	20.5	18.6			0.8
			100.0	100.0	93.1	77.8	70.2	55.8	35.8	1.380	46.7	22.1	24.6	12.3	-	-	-	-	-	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 6% ASH		100.0	100.0	93.1	77.9	70.7	56.6	37.5	1.357	46.2	22.7	23.5	11.4	1.658	18.3	17.5			0.5
			100.0	100.0	95.0	77.3	71.3	58.2	38.9	1.334	46.4	22.7	23.7	11.6	-	-	-	-	-	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH		100.0	100.0	96.1	84.3	78.1	66.0	48.9	1.888	45.4	23.1	22.3	21.1	1.630	21.7	18.8			0.7
			100.0	100.0	95.6	81.9	75.1	59.8	37.1	1.288	45.6	24.1	21.5	21.1	-	-	-	-	-	-

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIED WITH 30%CRR

LOCATION: KAWANDA TOWN COUNCIL, (WAKISO DISTRICT) Depth 0.6m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR		CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC			02	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR	11/29/2023	100	100	90	75	68	53	31	1.48	51.0	25.4	25.1	13.4	1.623	21.1	18.8		0.91	0.91
			100	100	93	76	69	55	34	1.41	52.0	26.6	25.4	13.4	-	-	-	-	-	
			100	100	91.09	75.53	68.81	54.02	32.59	1.45	51.8	25.5	26.2	13.4	1.623	21.1	18.8		0.91	0.91
	AVERAGE		100	100	91	76	69	54	33	1.448	51.8	25.6	26.2	13.4	1.623	21.1	18.8		0.91	0.91

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX 705, KAMPALA (U)

STUDENTS

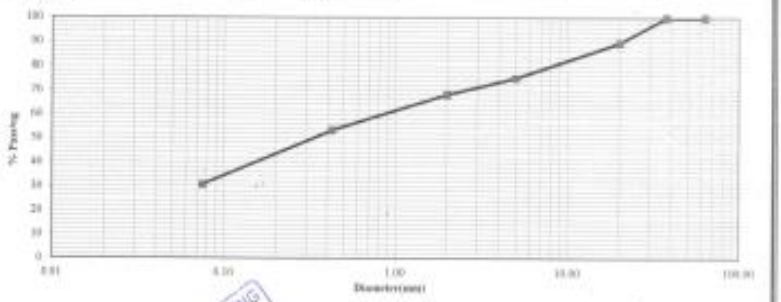
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR	Dry wt. of sample before washing: (g)		3490.5
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		2543.1
Material description	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	360.9	10.3	90	60	95
5.0	510.4	14.6	75	30	65
2.00	240.3	6.9	68	20	50
0.425	519.0	14.9	53	10	30
0.075	788.5	22.6	31	5	15
Total fines	1071.4	30.7			
Bottom Pan	124.0				
Extracted fines	947.4				
Total sample	3490.5				
Grading Modulus		1.48			



Testing Lab

Lab Technician

Materials Engineer

STUDENTS

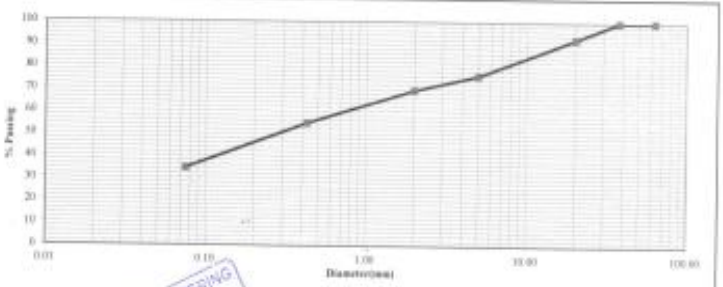
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR	Dry wt. of sample before washing: (g)		4208.1
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		2808.8
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	314.5	7.5	93	60	95
5.0	694.4	16.5	76	30	65
2.00	276.5	6.6	69	20	50
0.425	619.4	14.7	55	10	30
0.075	852.8	20.3	34	5	15
Total fines	1451.5	34.5			
Bottom Pan	51.2				
Extracted fines	1400.3				
Total sample	4209.1				
Grading Modulus		1.41			



Testing Lab

Lab Technician

Materials Engineer

STUDENTS

STIRLING CIVIL ENGINEERING LTD P. O. BOX 798, KAMPALA

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/317 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

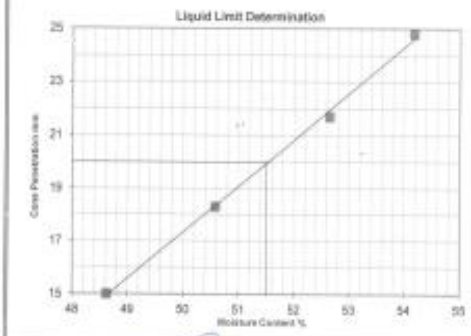
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE	KAWANDA TOWN COUNCIL (WAK/SO	Technician	Lab Team
mix	EXPANSIVE SOIL MODIFIED WITH 30%CRR	Sample Date	29/Nov/2023
Test method	BS 1377: Part 2: 1990 4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No	DT	KK		Average
Mass of wet soil + container (g)		40.44	38.98		39.71
Mass of dry soil + container (g)		36.85	35.6		36.225
Mass of container (g)		22.76	22.24		22.5
Mass of moisture (g)		3.59	3.4		3.495
Mass of dry soil (g)		14.09	13.36		13.725
Moisture content %		25.5	25.3		25.4
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.0	18.3	21.7	24.8
penetration (mm)		15.0	18.3	21.7	24.8
AVERAGE		15.0	18.3	21.7	24.8
Container No.		F00	PP1	P119	P138
Mass of wet soil + container (g)		45.14	43.21	46.46	38.43
Mass of dry soil + container (g)		33.29	30.97	32.84	35.16
Mass of container (g)		6.88	6.77	6.93	6.89
Mass of moisture (g)		12.85	12.24	13.64	15.26
Mass of dry soil (g)		26.43	24.2	25.91	28.17
Moisture content (%)		48.6	50.6	52.6	54.2
AVERAGE		48.6	50.6	52.6	54.2



Liquid limit (%)	51.5
Plastic limit (%)	25.4
Plasticity Index (%)	26.1
Linear shrinkage	
Trough No	R
Trough length (cm)	14.0
Specimen length (cm)	12.1
L shringage =	1.9
% L shrinkage =	13.4

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STUDENTS

STIRLING ENGINEERING P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

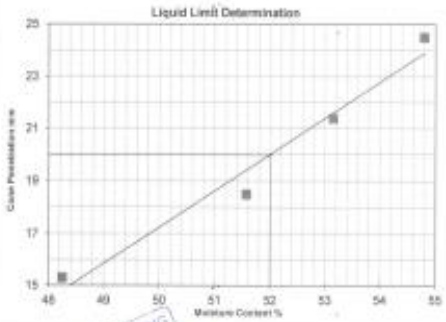
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE	KAWANDA TOWN COUNCIL (WAKISO	Technician:	Lab Team
mix	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR	Sample Date	28/Nov/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth:	0.5m		

PLASTIC LIMIT	Test No	VP	JL		Average
Mass of wet soil + container (g)		39.84	42.98		41.19
Mass of dry soil + container (g)		35.93	39.57		37.25
Mass of container (g)		21.5	22.56		22.03
Mass of moisture (g)		3.71	4.1		3.9
Mass of dry soil (g)		14.43	16.01		15.22
Moisture content %		25.7	25.6		25.6
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.3	18.5	21.4	24.5
(penetration (mm)		15.3	18.5	21.4	24.5
AVERAGE		15.3	18.5	21.4	24.5
Container No.		P2H	P135	P06	P02
Mass of wet soil + container (g)		50.53	40.68	39.09	41.12
Mass of dry soil + container (g)		44.57	29.98	27.95	28.95
Mass of container (g)		11.49	9.27	8.09	6.74
Mass of moisture (g)		15.96	10.68	11.14	12.17
Mass of dry soil (g)		33.08	20.71	20.86	22.21
Moisture content (%)		48.2	51.6	53.1	54.8
AVERAGE		48.2	51.6	53.1	54.8



Liquid limit (%)	52.0
Plastic limit (%)	25.6
Plasticity Index (%)	26.4
Linear shrinkage	
Trough No.	R
Trough length (cm)	14.0
Specimen length (cm)	12.1
L shrinkage =	1.9
% L shrinkage =	13.4

Remarks:

TESTING LAB

Material Engineer

Lab Technician

STUDENTS

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUBUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS				
Test Reference No.		Depth	0.5m	Date Sampled	Date Tested	Technician
Mix	EXPANSIVE SOIL MODIFIED WITH 30%CRR			25/Nov/23	30/Jan/24	Lab team
SOURCE	KKANDA TOWN COUNCIL (NAKISO DISTRICT)					
Material description:	EXPANSIVE SOILS			Natural moisture (%)	11.0	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.5	27	5	457	100	1,000

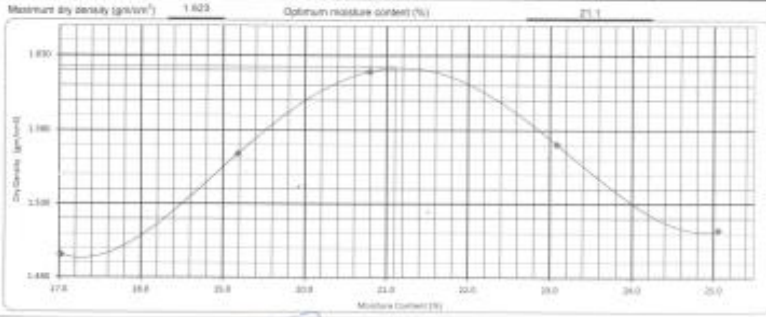
MOISTURE CONTENT DATA

Test No		1	2	3	4	5
Tin No		A	A	A	A	A
Water Added	cm^3	300	360	420	480	540
Mass of Compacted soil + mould	gm	4,979	5,084	5,178	5,153	5,111
Mass of Mould	gm	3,220	3,220	3,220	3,220	3,220
Mass of Compacted soil	gm	1759	1864	1958	1933	1891
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.759	1.864	1.958	1.933	1.891

DATA FOR PROCTOR CURVE

Container No		BAK	FDC	YGY	CRT	MUR
Mass of wet soil + Container	gm	2,410.0	2,291.0	2,340.0	2,279.0	2,377.0
Mass of dry soil + container	gm	2,181.0	2,052.0	1,930.0	1,886.0	2,059.0
Mass of container	gm	806.0	806.0	920.0	770.0	760.0
Mass of water added	gm	234	239	210	283	318
Mass of dry soil	gm	1375	1246	1210	1228	1299
Moisture content	%	17.0	19.2	20.8	23.1	23.1
Dry density	g/cm^3	1.495	1.564	1.618	1.570	1.512

Maximum dry density (gm/cm^3) 1.623 Optimum moisture content (%) 21.1



Remarks:

FOR TESTING LAB		STUDENTS
Lab Technician	Materials Engineer	

STIRLING ENGINEERING LTD P. O. BOX 799, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B12/717 & TUSUBIRA ANDREW S20B12/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Depth: 0.5m	Sampling Date	26/Nov/23
Desc	EXPANSIVE SOIL MODIFIED WITH 10%CRIE	Casting date	31/Jan/23
Source	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Testing Date :	4/Feb/23
Sample Description	EXPANSIVE SOILS	Technician	Lab team
		Volume of Mould used (m^3)	2305

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	NBM		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2085		MDD (Mg/m^3)	1.623
Tin + oven dry soil sample (g)	2081		N.M.C (%)	7.0
Tin (g)	297		OMC (%)	21.1
Dry soil sample	1204		Added OMC (%)	14.1
Water (g)	84		Calculated dry wt of soil (g)	5181.4
N.M.C (%)	7.0		Water added (g)	792
Average (%)	7.0		**Water added (mL)**	792

Number of blows		62					
Number of layer		5					
Water Content Determination		Before Soaking	After Soaking				
Tare No		KAU -	BA -				
Mass of wet sample + Tare	g	2004 -	2168 -				
Mass of dry sample + Tare	g	1791 -	1914 -				
Mass of Tare	g	799 -	768 -				
Mass of water	g	213 -	254 -				
Mass of dry sample	g	992 -	1146 -				
Water content	%	21.5 -	22.2 -				
Average water Content	%	21.8	22.2				
Density determination							
Mould No		-	TX				
Mass of mould + soil	g	10813	10845				
Mass of mould	g	6171	6171				
Mass of soil	g	4642	4674				
Volume of the mould	cm3	2305	2305				
Moist density	g/cm3	2.014	2.028				
Dry density	g/cm3	1.658	1.660				
Swell Determination							
Date		Hour	D.Gauge Reding				
Initial reading		96 hrs	6.23				
Final reading			7.39				
Height of the specimen			127				
Height of swell			1.16				
		Swelling(%)	0.91				

Observation			
For the Lab		**For Students**	
Lab Technician	STIRLING CIVIL ENGINEERING LTD P.O. BOX 795, KAMPALA, UG		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference:	Depth: 0.5m	Sampling Date:	29/Nov/23
Test:	EXPANSIVE SOIL MODIFIED WITH 30%CRB	Penetration Date:	4/Feb/23
Source:	KAWANDA TOWN COUNCIL (KOAKIRO DISTRICT)	Technician:	Lab team
Sample Description:	EXPANSIVE SOILS		

Number of Blows per layer	62		
Number of layers	3	5	7
Mould No	TX		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.001	0.001	0.001

Speed: 1mm/min

Penetration of the plunger (mm)	Time (s)	Top Reading *10⁻³mm	Top Force (KN)	Bottom Reading *10⁻³mm	Bottom Force (KN)				
0	0	0	0.0	0	0.0				
0.25	12	1	0.2	2	0.4				
0.5	24	1	0.2	3	0.6				
0.75	35	1	0.2	5	1.0				
1	47	1	0.2	7	1.4				
1.5	71	2	0.4	8	1.6				
2	94	2	0.4	10	2.1				
2.5	118	3	0.6	11	2.3				
3	142	4	0.8	13	2.7				
3.5	165	5	1.0	15	3.1				
4	189	5	1.0	17	3.5				
4.5	213	7	1.4	19	3.9				
5	236	8	1.6	20	4.1				
5.5	260	9	1.8	21	4.3				
6	283	10	2.1	23	4.7				
6.5	307	10	2.1	24	4.9				
7	331	11	2.3	25	5.1				
7.5	354	11	2.3	26	5.3				

Observations:

For the Contractor		For Students
Lab Technician		

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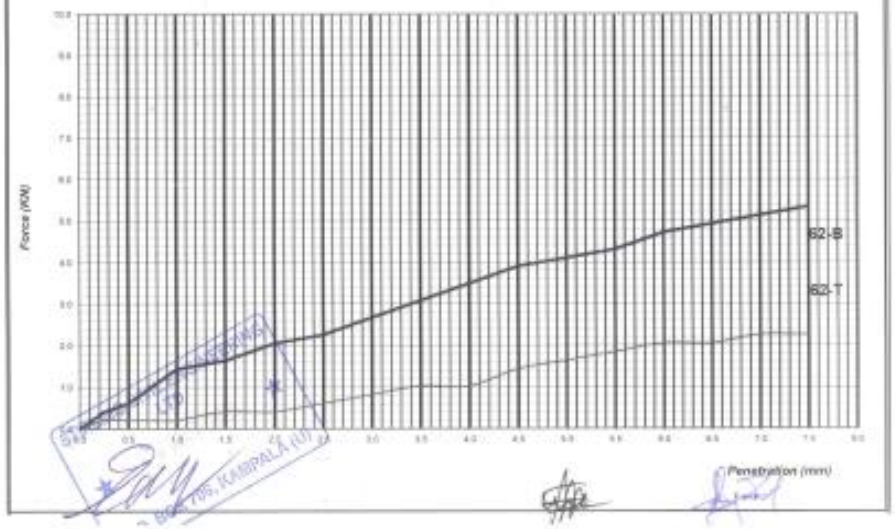
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Depth. 0.5m	Sampling Date :	28/Nov/23
mix:	EXPANSIVE SOIL MODIFIFIED WITH 30%CBR	Testing Date :	4/Feb/23
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT	Technician	: Lab team
Sample Description:	EXPANSIVE SOILS		

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.3	0.6	17	5								
5.0 mm Penetration	4.1	1.6	21	8								
Average	3.2	1.1	18.9	6.4								
Retained CBR	18.8											
Observations	CBR= 18.8											
For the Lab					For Students							
Lab. Technician												

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P. O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 2% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.0m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR			CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 2% ASH	-	100	100	94	76	69	53	34	1.44	49	23.1	25.9	13.0	1.564	21.6	18.6			0.85	0.85
			100	100	90	76	68	53	32	1.46	48.9	23.0	25.9	13.0	-	-	-	-	-	-	
		11/28/2023	100	100	91.95	76.03	68.49	53.28	33.16	1.45	49.0	23.1	25.9	13.0	1.564	21.6	18.6			0.85	0.85
	AVERAGE		100	100	92	76	68	53	33	1.451	49.0	23.0	25.9	13.0	1.564	21.6	18.6			0.85	0.85

FOR LAB

Lab Technician

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STUDENTS

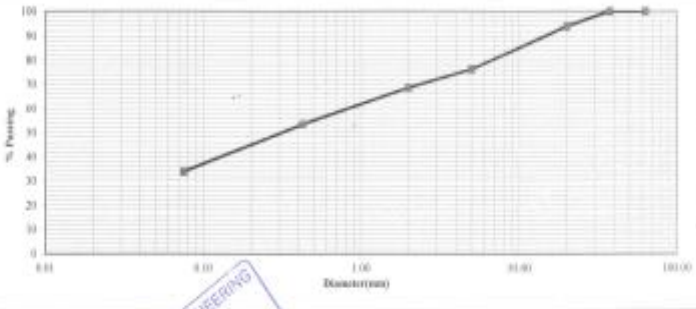
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 2% ASH	Dry wt. of sample before washing: (g)		4653.3
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3165.9
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	278.3	6.0	94	60	95
5.0	826.1	17.8	76	30	65
2.00	359.7	7.7	69	20	50
0.425	701.6	15.1	53	10	30
0.075	909.8	19.6	34	5	15
Total fines	1577.8	33.9			
Bottom Pan	90.4				
Extracted fines	1487.4				
Total sample	4653.3				
Grading Modulus		1.44			



Testing Lab

Lab Technician

Materials Engineer

STUDENTS

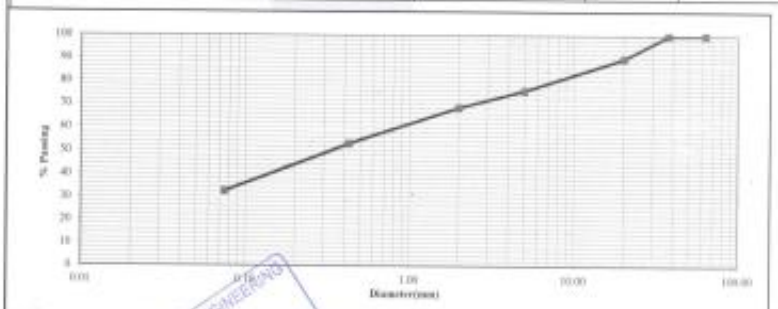
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location (km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 2% ASH	Dry wt. of sample before washing: (g)		4436.3
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3083.4
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	446.8	10.1	90	60	95
5.0	625.4	14.1	76	30	65
2.00	325.3	7.3	68	20	50
0.425	681.5	15.4	53	10	30
0.075	917.2	20.7	32	5	15
Total fines	1438.1	32.4			
Bottom Pan	86.2				
Extracted fines	1352.9				
Total sample	4436.3				
Grading Modulus		1.46			



Testing Lab

Lab Technician Materials Engineer

STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

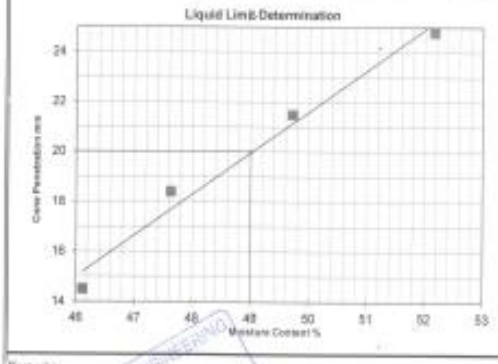
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE	KAWANDA TOWN COUNCIL (WAKISO)	Technician	Lab Team
Mix	XPANSIVE SOIL MODIFIED WITH 35%CRR & 2% AS	Sample Date	25/Nov/2023
Test method	BS 1377 Part 2, 1990 4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No	DG	RAD		Average
Mass of wet soil + container (g)		45.05	30.01		37.53
Mass of dry soil + container (g)		40.62	28.5		34.56
Mass of container (g)		21.39	22		21.695
Mass of moisture (g)		4.43	1.5		2.97
Mass of dry soil (g)		19.23	6.5		12.865
Moisture content %		23.0	23.2		23.1
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		14.5	18.4	21.5	24.8
penetration (mm)		14.5	18.4	21.5	24.8
AVERAGE		14.5	18.4	21.5	24.8
Container No		FORD	PA	PM3	A15
Mass of wet soil + container (g)		47.44	36.07	45.66	34.29
Mass of dry soil + container (g)		34.75	27.22	33.01	24.89
Mass of container (g)		6.90	6.76	6.96	6.97
Mass of moisture (g)		12.69	8.74	12.65	9.4
Mass of dry soil (g)		27.85	20.46	26.05	18.02
Moisture content (%)		46.1	47.8	49.7	52.2
AVERAGE		46.1	47.8	49.7	52.2



Liquid limit (%)	49.0
Plastic limit (%)	23.1
Plasticity index (%)	25.9
Linear shrinkage	
Trough No	2
Trough length (cm)	14.0
Specimen length (cm)	12.2
L shringage =	1.8
% L shrinkage =	15.0

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

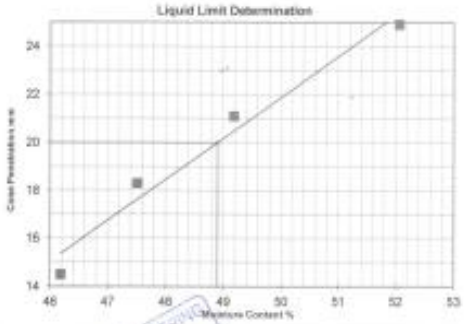
INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE :	KAWANDA TOWN COUNCIL (WAKISO)		Technician		Lab Team
mix	EXPANSIVE SOIL MODIFIFIED WITH 33%CRR, & 2% AS		Sample Date		28/Nov/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4		Test Date		1/Feb/2024
LAYER	EXPANSIVE SOILS				
Depth	0.5m				
PLASTIC LIMIT	Test No.	PNV	⊕		Average
Mass of wet soil + container (g)		32.81	37.33		35.07
Mass of dry soil + container (g)		30.94	34.56		32.75
Mass of container (g)		22.85	22.5		22.675
Mass of moisture (g)		1.87	2.8		2.32
Mass of dry soil (g)		8.09	12.06		10.075
Moisture content %		23.1	23.0		23.0
AVERAGE					
LIQUID LIMIT	Test No.	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		14.5	18.3	21.1	24.9
penetration (mm)		14.5	18.3	21.1	24.9
AVERAGE		14.5	18.3	21.1	24.9
Container No.		KO	FFVP	AO	FBB
Mass of wet soil + container (g)		51.56	40.04	48.84	40.95
Mass of dry soil + container (g)		37.46	29.36	35.02	29.33
Mass of container (g)		6.93	6.88	6.92	7.01
Mass of moisture (g)		14.1	10.68	13.82	11.62
Mass of dry soil (g)		30.53	22.48	28.1	22.32
Moisture content (%)		46.2	47.5	49.2	52.1
AVERAGE		46.2	47.5	49.2	52.1



Liquid limit (%)	48.8
Plastic limit (%)	23.0
Plasticity Index (%)	25.8
Linear shrinkage	
Trough No	2
Trough length (cm)	14.0
Specimen length (cm)	12.2
L shrinkage =	1.8
% L shrinkage =	13.0

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS				
Test Reference No.		Depth	0.5m	Date Sampled	Date Tested	Technician
Mix:	EXPANSIVE SOIL MODIFIED WITH 3%CKR & 2% ASH			29/Nov/23	30/Jan/24	Lab team
SOURCE	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)					
Material description:	EXPANSIVE SOILS			Natural moisture (%)	11.0	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.5	27	5	457	190	1,000

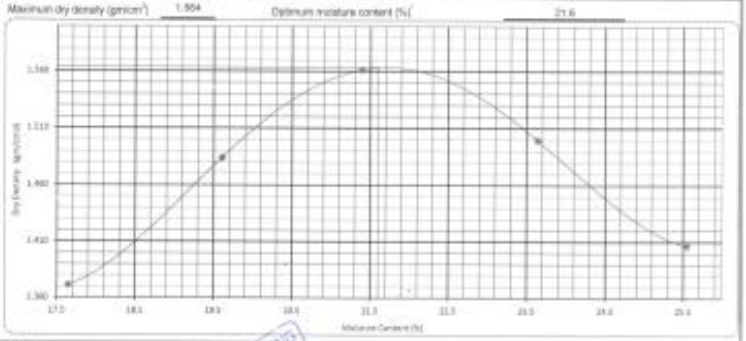
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	380	440	500	560	620
Mass of Compacted soil + mould	gm	4,835	4,995	5,115	5,074	4,988
Mass of Mould	gm	3,220	3,220	3,220	3,220	3,220
Mass of Compacted soil	gm	1615	1775	1895	1854	1768
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.613	1.775	1.899	1.854	1.768

DATA FOR PROCTOR CURVE

Container No.		YMC	EX	BKN	CML	KCR
Mass of wet soil + Container	gm	1,663.0	1,447.0	2,085.0	2,128.0	1,790.0
Mass of dry soil + container	gm	1,476.0	1,297.0	1,887.0	1,887.0	1,502.0
Mass of container	gm	416.0	532.0	801.0	793.0	414.0
Mass of water added	gm	187	150	220	281	270
Mass of dry soil	gm	1060	765	1086	1104	1088
Moisture content	%	17.6	19.6	23.4	25.0	25.4
Dry density	g/cm^3	1.371	1.484	1.551	1.489	1.407

Maximum dry density (gm/cm^3) 1.554 Optimum moisture content (%) 21.6



Remarks:

FOR TESTING LAB		STUDENTS
Lab Technician	Manager	

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER 520032/217 & TUSUBIRA ANDREW 520032/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference:	Depth: 0.5m	Sampling Date:	29/Nov/23
ure:	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH	Casting date:	31/Jan/24
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Testing Date:	4/Feb/24
Sample Description:	EXPANSIVE SOILS	Technician:	Lab team
		Volume of Mould used (m^3)	2305

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	KANI		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1937		MDD (Mg/m^3)	1.564
Tin + oven dry soil sample (g)	1882		N.M.C (%)	6.9
Tin (g)	799		OMC (%)	21.6
Dry soil sample	1083		Added OMC (%)	14.7
Water (g)	75		Calculated dry wt of soil (g)	5584.5
N.M.C (%)	6.9		Water added (g)	823
Average (%)	6.9		**Water added (mL)**	**823**

Number of blows		62					
Number of layer		5					
Water Content Determination		Before Soaking	After Soaking				
Tare No		CR7 -	NN -				
Mass of wet sample + Tare	g	2215 -	2382 -				
Mass of dry sample + Tare	g	1971 -	2091 -				
Mass of Tare	g	770 -	797 -				
Mass of water	g	244 -	289 -				
Mass of dry sample	g	1201 -	1296 -				
Water content	%	20.3 -	22.3 -				
Average water Content	%	20.3	22.3				
Density determination							
Mould No		AST					
Mass of mould + soil	g	11210	11300				
Mass of mould	g	6673	6673				
Mass of soil	g	4537	4627				
Volume of the mould	cm3	2305	2305				
Moist density	g/cm3	1.968	2.007				
Dry density	g/cm3	1.636	1.641				
Swell Determination							
Date		Hour	D.Gauge Reding				
Initial reading		96 hrs	3.1				
Final reading			4.18				
Height of the specimen			127				
Height of swell			1.08				
		Swelling(%)	**0.85**				
Observations							

For the Lab		For Students	
Lab Technician			

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference:	Depth: 0.5m	Sampling Date:	29/Nov/23
Test:	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH	Penetration Date:	4/Feb/24
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Technician:	Lab team
Sample Description:	EXPANSIVE SOILS		

Number of blows per layer	65		
Number of layers	5	5	5
Mould No	A87		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.0892	0.0892	0.0892
Speed ____ mm/min	Top / Bottom		

Penetration of the plunger (mm)	Time (s)	Top Reading *10⁻²mm	Top Force (KN)	Bottom Reading *10⁻²mm	Bottom Force (KN)				
0	0	0	0.0	0	0.0				
0.25	12	1	0.2	3	0.4				
0.5	24	1	0.2	6	0.8				
0.75	35	1	0.2	9	1.2				
1	47	1	0.2	7	1.4				
1.5	71	2	0.4	9	1.8				
2	94	2	0.4	10	2.1				
2.5	118	2	0.4	12	2.5				
3	142	3	0.6	13	2.7				
3.5	165	3	0.6	14	2.9				
4	189	3	0.6	16	3.3				
4.5	213	3	0.6	17	3.5				
5	236	4	0.8	18	3.7				
5.5	260	4	0.8	19	3.9				
6	283	4	0.8	20	4.1				
6.5	307	5	1.0	21	4.3				
7	331	5	1.0	21	4.3				
7.5	354	5	1.0	21	4.3				

Observations

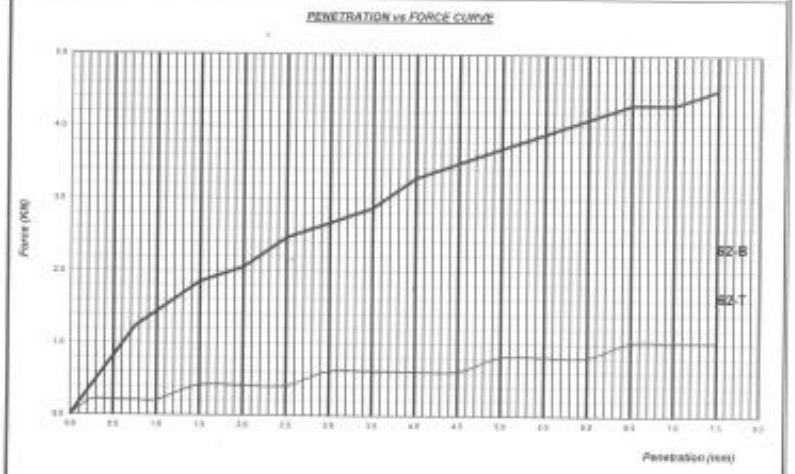
For the Contractor		For Students
Lab Technician	Materials Engineer	

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Depth 0.3m	Sampling Date	29/Nov/23
Type	EXPANSIVE SOIL MODIFIED WITH EPACER &	Testing Date	4/Feb/24
Source	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Technician	Lab team
Sample Description	EXPANSIVE SOILS		



	62 blows											
	Jaws		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.5	0.4	19	3								
5.0 mm Penetration	5.7	0.8	19	4								
Average	5.1	0.6	18.6	3.6								
Retained CBR	18.6											

Observations CBR= 18.6

For the Lab		For Students	
Lab Technician	Head of Department		

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 4% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR			CBR SWELL	
			63	37.5	20	9	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 4% ASH	11/23/2023	100	100	94	79	73	59	37	1.33	47	22.4	24.6	12.5	1.605	20.5	18.6			0.78	0.78
			100	100	93	78	70	56	36	1.38	46.7	22.1	24.6	12.3	-	-	-	-	-	-	
			100	100	93.6	78.38	71.48	57.35	36.63	1.35	46.9	22.2	24.6	12.3	1.603	20.5	18.6			0.78	0.78
	AVERAGE		100	100	94	78	71	57	37	1.343	46.9	22.3	24.6	12.3	1.603	20.5	18.6			0.78	0.78

FOR LAB

Lab Technician

Laboratory Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX 7205, KAMPALA (U)

STUDENTS

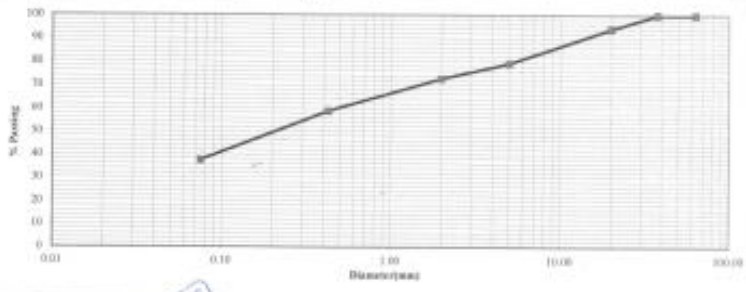
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 4% ASH	Dry wt. of sample before washing: (g):		4835.1
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3119.1
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	285.9	5.9	94	60	95
5.0	720.0	14.9	79	30	65
2.00	313.2	6.5	73	20	50
0.425	674.5	14.0	59	10	30
0.075	1029.7	21.3	37	5	15
Total fines	1811.8	37.5			
Bottom Pan	95.8				
Extracted fines	1716.0				
Total sample	4835.1				
Grading Modulus		1.31			



Testing Lab

Lab Technician: Mwanza Engineer

STUDENTS

STIRLING CIVIL ENGINEERING LTD P. O. BOX 7261, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 4% ASH	Dry wt. of sample before washing: (g)		5436.2
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3565.7
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	373.9	6.9	93	60	85
5.0	846.2	15.6	78	30	65
2.00	397.5	7.3	70	20	50
0.425	778.3	14.3	56	10	30
0.075	1094.6	20.1	36	5	15
Total fines	1945.7	35.8			
Bottom Pan	75.2				
Extracted fines	1870.5				
Total sample	5436.2				
Grading Modulus		1.38			

Testing Lab

Lab Technician — Materials Engineer

STIRLING CIVIL ENGINEERING P.O. BOX 703, KAMPALA (U)

STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER 520B32/217 & TUSUBIRA ANDREW 520B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

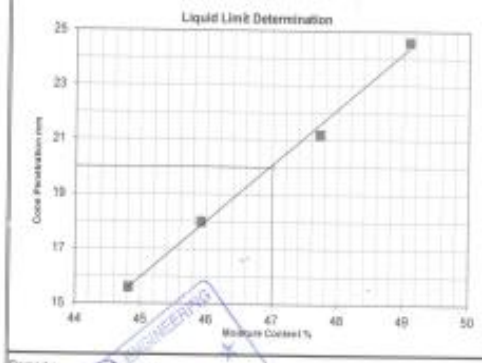
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE	KAWANDA TOWN COUNCIL (WAKISO	Technician	Lab Team
Test	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 4% AS	Sample Date	29/Nov/2023
Test method	BS 1377: Part 2, 1990-4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No.	13	KK		Average
Mass of wet soil + container (g)		50	38.85		44.425
Mass of dry soil + container (g)		45.02	38.78		42.4
Mass of container (g)		22.48	22.21		22.345
Mass of moisture (g)		4.98	3.1		4.025
Mass of dry soil (g)		22.54	16.57		19.555
Moisture content %		22.1	22.8		22.4
AVERAGE					

LIQUID LIMIT	Test No.	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.6	18	21.2	24.6
penetration (mm)		15.6	18.0	21.2	24.6
AVERAGE		15.6	18.0	21.2	24.6
Container No.		P126	KO	P138	P99
Mass of wet soil + container (g)		42.43	45.92	39.04	41.37
Mass of dry soil + container (g)		31.46	32.26	28.69	30.07
Mass of container (g)		6.99	6.93	7.05	7.05
Mass of moisture (g)		10.97	11.64	10.35	11.3
Mass of dry soil (g)		24.46	25.33	21.64	23.02
Moisture content (%)		44.8	45.9	47.7	49.1
AVERAGE		44.8	45.9	47.7	49.1



Liquid limit (%)	47.0
Plastic limit (%)	22.4
Plasticity Index (%)	24.6

Linear shrinkage

Trough No.	J
Trough length (cm)	14.0
Specimen length (cm)	12.3
L shringage =	1.7
% L shrinkage =	12.3

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

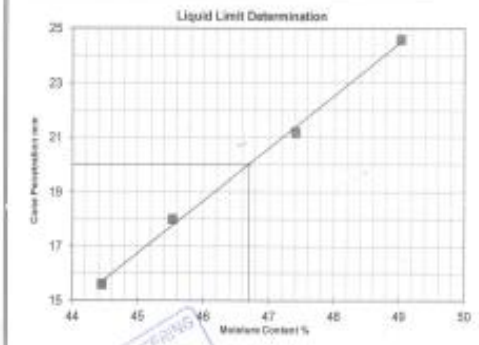
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE :	KAWANDA TOWN COUNCIL (WAKISO)	Technician:	Lab Team
Unit	XPANSIVE SOIL MODIFIED WITH 30%CRR & 4% AS	Sample Date	09Nov2023
Test method	BS 1377: Part 2: 1990 4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth:	0.5m		

PLASTIC LIMIT	Test No.	VPN	J5		Average
Mass of wet soil + container (g)		48.24	41.82		45.03
Mass of dry soil + container (g)		44.45	38.19		41.32
Mass of container (g)		22.84	22.58		22.71
Mass of moisture (g)		4.79	3.4		4.11
Mass of dry soil (g)		21.61	15.61		18.61
Moisture content %		22.2	22.0		22.1
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.6	18	21.2	24.0
penetration (mm)		15.6	18.0	21.2	24.0
AVERAGE		15.8	18.0	21.2	24.0
Container No.		PA	FORD	PA3	PA2
Mass of wet soil + container (g)		35.66	40.77	43.71	42.88
Mass of dry soil + container (g)		26.77	36.32	31.88	31.00
Mass of container (g)		6.77	6.78	6.96	6.77
Mass of moisture (g)		8.89	13.45	11.82	11.88
Mass of dry soil (g)		20	29.54	24.93	24.23
Moisture content (%)		44.5	45.5	47.4	49.0
AVERAGE		44.5	45.5	47.4	49.0



Liquid limit (%)	46.7
Plastic limit (%)	22.1
Plasticity Index (%)	24.6
Linear shrinkage	
Trough No	J
Trough length (cm)	14.3
Specimen length (cm)	12.3
L shringage =	1.7
% L shrinkage =	12.3

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/038	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS				
Test Reference No.		Depth: - 0.5m	Date Sampled: 28/Nov/23	Date Tested: 30/Jan/24	Technician: Lab team
Mix	EXPANSIVE SOIL MODIFIED WITH 30%CRH & 4% ASH				
SOURCE	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)				
Material description:	EXPANSIVE SOILS		Natural moisture (%)	11.8	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No. of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm³)
4.5	27	5	457	100	1,000

MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm³	280	340	400	460	520
Mass of Compacted soil + mould	gm	6,060	6,196	6,249	6,215	6,196
Mass of Mould	gm	4,324	4,324	4,324	4,324	4,324
Mass of Compacted soil	gm	1736	1872	1925	1891	1864
Volume of mould	cm³	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm³	1.736	1.872	1.925	1.891	1.864

DATA FOR PROCTOR CURVE

Container No.		ZXN	ACB	KT	UCU	LDU
Mass of wet soil + Container	gm	2,040.0	2,033.8	2,486.0	2,601.0	2,142.0
Mass of dry soil + container	gm	1,814.0	2,254.0	2,136.0	2,292.0	1,864.0
Mass of container	gm	441.0	781.0	799.0	997.0	417.0
Mass of water added	gm	226	279	270	309	339
Mass of dry soil	gm	1373	1473	1337	1495	1387
Moisture content	%	16.5	18.9	20.2	22.8	24.4
Dry density	g/cm³	1.491	1.574	1.602	1.540	1.499

Maximum dry density (g/cm³) 1.603 Optimum moisture content (%) 20.0

Remarks:

FOR TESTING LAB		STUDENTS	
Lab Technicians	Mr. Kizito Stanley		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASIABA PETER S18B32/017 & TUMUHIRA ANDREW S18B32/026	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Depth 0.5m	Sampling Date	24/Nov/23
Test	EXPANSIVE SOIL MODIFIFIED WITH 10%CRR & 4% ASH	Casting date	4/Feb/24
Source	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Testing Date	8/Feb/24
Sample Description	EXPANSIVE SOILS	Technician	Lab team
		Volume of Mould used (m^3)	2069

Natural moisture of air dried sample			Volume of water added	
Tin No	D1		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1931		MDD (Mg/m^3)	1.603
Tin + oven dry soil sample (g)	1849		N.M.C (%)	6.3
Tin (g)	547		OMC (%)	20.5
Dry soil sample	1302		Added OMC (%)	14.2
Water (g)	82		Calculated dry wt of soil (g)	5622.1
N.M.C (%)	6.3		Water added (g)	802
Average (%)	6.3		Water added (mL)	802

Number of blows		62					
Number of layer		5					
Water Content Determination		Before Soaking	After Soaking				
Tare No		BAK	BH				
Mass of wet sample + Tare	g	2090	2319				
Mass of dry sample + Tare	g	1875	2047				
Mass of Tare	g	805	805				
Mass of water	g	215	268				
Mass of dry sample	g	1070	1242				
Water content	%	20.1	21.6				
Average water Content	%	20.1	21.6				
Density determination							
Mould No		AST					
Mass of mould + soil	g	11265	11333				
Mass of mould	g	6712	6712				
Mass of soil	g	4553	4621				
Volume of the mould	cm^3	2305	2305				
Moist density	g/cm^3	1.975	2.005				
Dry density	g/cm^3	1.645	1.649				
Swell Determination							
Date		Hour	D.Gauge Reding				
Initial reading		96 hrs	2.9				
Final reading			3.89				
Height of the specimen			127				
Height of swell			0.99				
		Swelling(%)	0.78				
Observations							

For the Lab		For Students	
Lab Technician	Manager		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Depth 0.5m	Sampling Date	29/Nov/23
Area	EXPANSIVE SOIL MODIFIED WITH 5%GCSB & 4% ASH	Penetration Date	8/Feb/24
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Technician	Lab team
Sample Description :	EXPANSIVE SOILS		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	A67		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.0032	0.0032	0.0032

Speed : ..... mm/min

Penetration of the plunger (mm)	Time (s)	Top Reading *10⁻²mm	Top Force (KN)	Bottom Reading *10⁻²mm	Bottom Force (KN)				
0	0	0	0.0	0	0.0				
0.25	12	1	0.2	1	0.2				
0.5	24	1	0.2	2	0.4				
0.75	35	2	0.4	3	0.6				
1	47	2	0.4	5	1.0				
1.5	71	2	0.4	8	1.6				
2	94	3	0.6	10	2.0				
2.5	118	3	0.6	13	2.6				
3	142	4	0.8	13	2.7				
3.5	165	5	1.0	14	2.8				
4	189	5	1.0	15	3.1				
4.5	213	6	1.2	17	3.5				
5	236	7	1.4	18	3.7				
5.5	260	7	1.4	20	4.1				
6	283	8	1.6	21	4.3				
6.5	307	9	1.8	22	4.5				
7	331	10	2.1	22	4.5				
7.5	354	10	2.1	23	4.7				

Observations

For the Contractor		For Students	
Lab Technician	*Engineer Supervisor*		

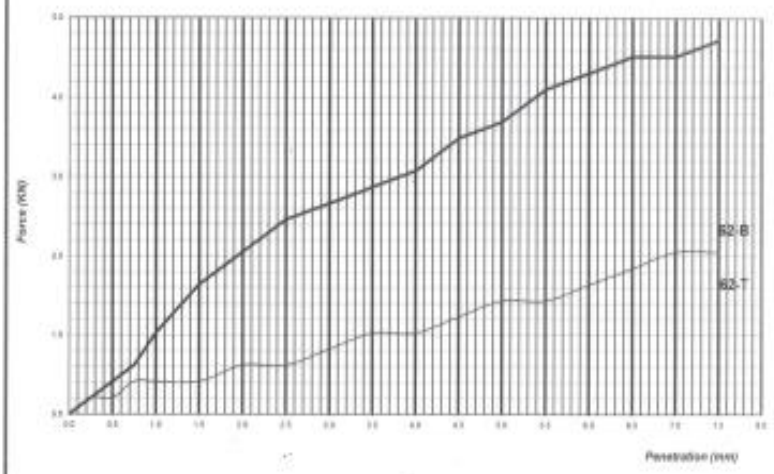
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASIBABA PETER S20B32/017 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Depth: 0.5m	Sampling Date	29/Nov/23
Site	EXPANSIVE SOIL MODIFIED WITH 30%CRB &	Testing Date	8/Feb/24
Source	KAWANDA TOWN COUNCIL (WAKISO DISTRICT	Technician	Lab team
Sample Description	EXPANSIVE SOILS		

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.5	0.8	19	8								
5.0 mm Penetration	3.7	1.4	19	7								
Average	3.1	1.0	18.6	5.9								
Retained CBR	18.6											

Observations: CBR= 18.6

For the Lab		For Students
Lab Technician	Name and Signature	

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 6% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR			CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	DM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 6% ASH	11/10/2023	100	100	63	77	71	57	37	1.16	46.3	22.7	23.5	11.4	1.668	19.5	18			0.62	0.62
			100	100	55	78	71	58	35	1.34	46.4	22.7	23.7	11.4	-	-	-	-	-	-	
			100	100	94.05	77.41	71.11	57.38	36.48	1.35	46.3	22.7	23.6	11.4	1.668	19.5	17.5			0.62	0.62
	AVERAGE		100	100	94.05	77	71	57	36	1.350	46.3	22.7	23.6	11.4	1.668	19.5	17.5			0.62	0.62

FOR LAB

Lab Technician

Laboratory Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX 7130 KAMPALA (U)

STUDENTS

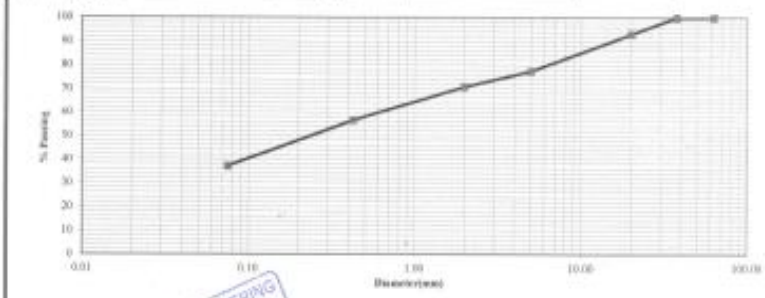
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 6% ASH	Dry wt. of sample before washing: (g)		4846
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3106.7
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	332.2	6.9	93	60	95
5.0	768.5	15.9	77	30	65
2.00	316.8	6.5	71	20	50
0.425	684.8	14.1	57	10	30
0.075	952.4	19.7	37	5	15
Total fines	1791.3	37.0			
Bottom Pan	52.0				
Extracted fines	1739.3				
Total sample	4846.0				
Grading Modulus		1.36			



Testing Lab	STUDENTS
Lab Technician / Materials Engineer	

STIRLING CIVIL ENGINEERING LTD P. O. BOX 733, KAMPALA (U)

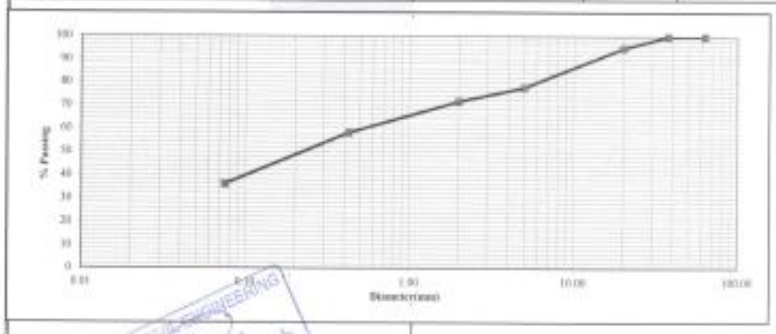
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Refernece No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 6% ASH	Dry wt. of sample before washing: (g)		4455.7
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		2929.8
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	224.4	5.0	95	60	95
5.0	776.7	17.4	78	30	65
2.00	270.2	6.1	71	20	50
0.425	594.2	13.3	58	10	30
0.075	985.4	22.1	36	5	15
Total fines	1603.6	36.0			
Bottom Pan	77.9				
Extracted fines	1525.9				
Total sample	4455.7				
Grading Modulus		1.34			



Testing Lab

Lab Technician | Materials Engineer

STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

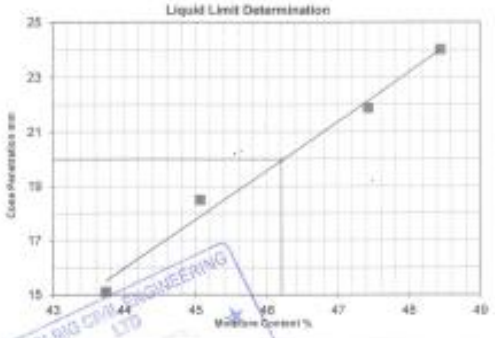
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE	KAWANDA TOWN COUNCIL (WAKISO	Technician:	Lab Team
Mix	EXPANSIVE SOIL MODIFIED WITH 20%CRR & 6% AS	Sample Date	29Nov/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	15Feb/2024
LAYER	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No.	VPN	H		Average
Mass of wet soil + container (g)		27.18	36.1		32.64
Mass of dry soil + container (g)		26.12	35.23		30.675
Mass of container (g)		21.46	22.58		22.02
Mass of moisture (g)		1.06	2.9		1.965
Mass of dry soil (g)		4.66	12.65		8.655
Moisture content %		22.7	22.7		22.7
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.1	18.5	21.9	24.0
penetration (mm)		15.1	18.5	21.9	24.0
AVERAGE		15.1	18.5	21.9	24.0
Container No.		P135	P/H	AD	FDO
Mass of wet soil + container (g)		46.11	45.28	46.71	49.85
Mass of dry soil + container (g)		34.89	33.31	33.91	35.79
Mass of container (g)		9.24	6.79	6.82	6.87
Mass of moisture (g)		11.22	11.95	12.8	14.01
Mass of dry soil (g)		25.65	26.52	26.99	28.92
Moisture content (%)		43.7	45.1	47.4	48.4
AVERAGE		43.7	45.1	47.4	48.4



Liquid limit (%)	46.2
Plastic limit (%)	22.7
Plasticity Index (%)	23.5
Linear shrinkage	
Trough No	Y
Trough length (cm)	14.0
Specimen length (cm)	12.4
L shringage =	1.6
% L shrinkage =	11.4

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

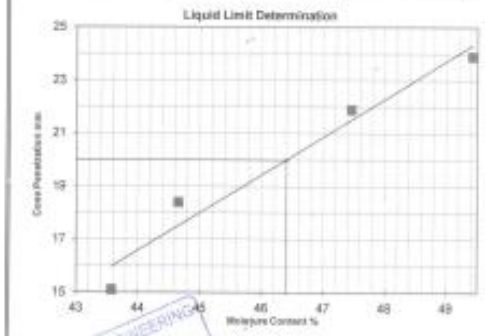
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE :	KAWANDA TOWN COUNCIL (WAKISO	Technician	Lab Team
mix	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 6% ASH	Sample Date	28/Nov/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No	OG	4		Average
Mass of wet soil + container (g)		52.55	38.65		45.1
Mass of dry soil + container (g)		46.75	36.5		41.625
Mass of container (g)		21.34	22.57		21.955
Mass of moisture (g)		5.8	3.2		4.475
Mass of dry soil (g)		25.41	13.93		19.67
Moisture content %		22.8	22.9		22.7
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.1	18.4	21.9	23.9
penetration (mm)		15.1	18.4	21.9	23.9
AVERAGE		15.1	18.4	21.9	23.9
Container No.		A19	P89	P1VPN	P12H
Mass of wet soil + container (g)		40.50	38.19	48.22	57.71
Mass of dry soil + container (g)		30.30	28.05	35.60	42.42
Mass of container (g)		9.89	8.96	8.96	11.46
Mass of moisture (g)		10.2	9.84	13.62	15.29
Mass of dry soil (g)		20.41	21.09	26.7	30.96
Moisture content (%)		43.6	44.7	47.5	49.4
AVERAGE		43.6	44.7	47.5	49.4



Liquid limit (%)	46.4
Plastic limit (%)	22.7
Plasticity index (%)	23.7
Linear shrinkage	
Trough No.	Y
Trough length (cm)	14.0
Specimen length (cm)	12.4
L shringage =	1.6
% L shrinkage =	11.4

Remarks:

TESTING LAB

Mwanda Bridgeer

Lab Technician

STUDENTS

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/038	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILISING OF SUBGRADE EXPANSIVE SOILS				
Test Reference No.		Depth: 0.5m	Date Sampled: 29/Nov/23	Date Tested: 30/Jan/24	Technician: Lab team
Mix:	EXPANSIVE SOIL MODIFIED WITH 25%CKW & 8% ASH				
SOURCE:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)				
Material description:	EXPANSIVE SOILS		Natural moisture (%): 11.0		

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.9	27	5	457	100	1,000

MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	260	320	380	440	500
Mass of Compacted soil + mould	gm	8,280	8,187	8,317	8,271	8,212
Mass of Mould	gm	4,324	4,324	4,324	4,324	4,324
Mass of Compacted soil	gm	1784	1863	1993	1947	1888
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.756	1.863	1.993	1.947	1.888

DATA FOR PROCTOR CURVE

Container No.		YY	ZKT	BA	NMT	BBC
Mass of wet soil + Container	gm	2,366.0	2,371.0	2,229.0	2,255.0	2,284.0
Mass of dry soil + container	gm	2,151.0	2,143.0	1,989.0	1,991.0	2,066.0
Mass of container	gm	783.0	812.0	768.0	758.0	809.0
Mass of water added	gm	215	231	239	262	218
Mass of dry soil	gm	1368	1328	1221	1223	1218
Moisture content	%	15.7	17.4	19.6	21.4	23.3
Dry density	g/cm^3	1.518	1.587	1.667	1.603	1.531

Maximum dry density (gm/cm^3): 1.669 Optimum moisture content (%): 19.6

Remarks:

FOR TESTING LAB		STUDENTS
Lab Technician	Material Engineer	

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASIIARA PETER S20032/217 & TUSUBIRA ANDREW S20032/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference:	Depth: 0.5m	Sampling Date:	29/Nov/23
mix:	EXPANSIVE SOIL MODIFIFIED WITH 30%CKR & 6% ASH	Casting date:	31/Jan/24
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Testing Date:	6/Feb/24
Sample Description	EXPANSIVE SOILS	Technician:	Lab team
		Volume of Mould used (m^3)	2305

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	OPC		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1910		MDD (Mg/m^3)	1.668
Tin + oven dry soil sample (g)	1845		N.M.C (%)	6.3
Tin (g)	808		OMC (%)	19.5
Dry soil sample	1037		Added OMC (%)	13.2
Water (g)	65		Calculated dry wt of soil (g)	5623.4
N.M.C (%)	6.3		Water added (g)	747
Average (%)	6.3		**Water added (mL)**	747

Number of blows		62					
Number of layer		5					
Water Content Determination		Before Soaking	After Soaking				
Tare No		KT -	KAU -				
Mass of wet sample + Tare	g	1989 -	2408 -				
Mass of dry sample + Tare	g	1784 -	2186 -				
Mass of Tare	g	798 -	800 -				
Mass of water	g	205 -	302 -				
Mass of dry sample	g	986 -	1386 -				
Water content	%	20.8 -	21.8 -				
Average water Content	%	20.8	23.8				
Density determination							
Mould No		21					
Mass of mould + soil	g	12114	12160				
Mass of mould	g	7502	7502				
Mass of soil	g	4612	4658				
Volume of the mould	cm3	2305	2305				
Moist density	g/cm3	2.001	2.021				
Dry density	g/cm3	1.656	1.659				
Swell Determination							
Date		Hour	D.Gauge Reding				
Initial reading		96 hrs	14.17				
Final reading			14.96				
Height of the specimen			127				
Height of swell			0.79				
		Swelling(%)	0.62				
Observations							

For the Lab		For Students	
Lab Technician	Lab Supervisor		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Depth: 0.5m	Sampling Date	29/Nov/23
Mix	EXPANSIVE SOIL MODIFIED WITH 35%CRK & 6% ASH	Penetration Date	4/Feb/24
Source	KARANDA TOWN COUNCIL (WAKISO DISTRICT)	Technician	Laboratory
Sample Description	EXPANSIVE SOILS		

Number of blows per layer	92		
Number of layers	5	5	5
Mould No	21		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.0932	0.0932	0.0932

Speed: mm/min		Top		Bottom					
Penetration of Plunger (mm)	Time (s)	Reading *10⁻²mm	Force (KN)	Reading *10⁻²mm	Force (KN)				
0	0	0	0.0	0	0.0				
0.25	12	1	0.2	1	0.2				
0.5	24	1	0.2	2	0.4				
0.75	35	1	0.2	3	0.6				
1	47	2	0.4	4	0.8				
1.5	71	2	0.4	8	1.6				
2	94	3	0.6	10	2.0				
2.5	118	4	0.8	12	2.4				
3	142	4	0.8	13	2.7				
3.5	165	5	1.0	13	2.7				
4	189	5	1.0	14	2.9				
4.5	213	6	1.2	15	3.1				
5	236	6	1.2	16	3.3				
5.5	260	7	1.4	17	3.5				
6	283	7	1.4	17	3.5				
6.5	307	8	1.6	18	3.7				
7	331	8	1.6	18	3.7				
7.5	354	9	1.8	19	3.9				

Observations

For the Contractor		For Students
Lab. Technician		

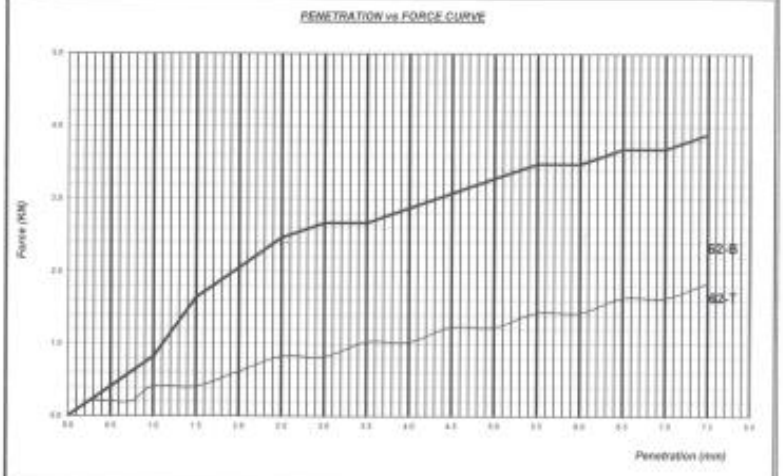
STIRLING CIVIL ENGINEERING LTD P. O. BOX 705, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Depth 0.5m	Sampling Date	29/Nov/23
Test :	EXPANSIVE SOIL MODIFIED WITH 30%CRE &	Testing Date	4/Feb/24
Source :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT	Technician	Lab team
Sample Description	EXPANSIVE SOILS		



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.5	0.8	19	6								
5.0 mm Penetration	3.3	1.2	16	6								
Average	2.9	1.0	17.5	6.2								
Retained CBR	17.5											

Observations CBR= 17.5

For the Lab		For Students	
Lab. Technician	[illegible]		

STIRLING CIVIL ENGINEERING P.O. BOX 799, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 8% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTEMBERG LIMITS				MDD		CBR		CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC			62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH	11/29/2023	100	100	96	84	78	66	48	1.08	45.4	23.1	22.3	11.1	1.620	21.7	18.0		0.65	0.65
			100	100	95	82	75	60	37	1.18	45.4	23.1	22.3	11.1	-	-	-	-	-	
			100	100	95.8	83.1	76.63	62.87	42.53	1.18	45.4	23.1	22.3	11.1	1.620	21.7	18.0		0.65	0.65
	AVERAGE		100	100	96	84	77	63	43	1.100	45.4	23.1	22.3	11.1	1.620	21.7	18.0		0.65	0.65

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX 7051, KAMPALA (U)

STUDENTS

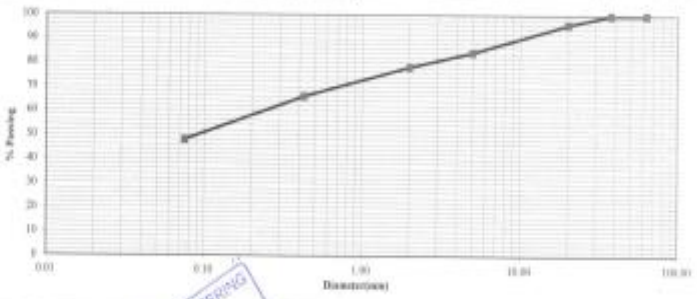
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Refemece No :		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 8% ASH	Dry wt. of sample before washing: (g)		4896.3
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		2651.7
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	191.1	3.9	96	60	95
5.0	579.6	11.8	84	30	65
2.00	300.8	6.1	78	20	50
0.425	596.5	12.2	66	10	30
0.075	881.2	18.0	48	5	15
Total fines	2348.1	48.0			
Bottom Pan	103.5				
Extracted fines	2244.6				
Total sample	4896.3				
Grading Modulus		1.08			



Testing Lab

Lab Technician Materials Engineer

STUDENTS:

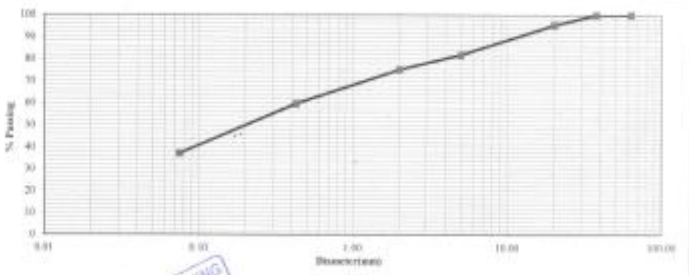
INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT : INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Location :	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Lab. Reference No.:		
Location :(km)	EXPANSIVE SOIL MODIFIFIED WITH 30%CRR & 8% ASH	Dry wt. of sample before washing: (g)		3765.3
Depth: (m)	0.5m	Dry wt. of sample after washing: (g)		3341.3
Material description:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Date Sampled:	Date Tested:	Technician
		29/Nov/2023	1/Feb/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	169.5	4.5	95	60	95
5.0	510.8	13.6	82	30	65
2.00	255.4	6.8	75	20	50
0.425	578.2	15.4	60	10	30
0.075	854.6	22.7	37	5	15
Total fines	1396.8	37.1			
Bottom Pan	972.8				
Extracted fines	424.0				
Total sample	3765.3				
Grading Modulus		1.28			



Testing Lab

Lab Technician Margaret Engineer

STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

ATTERBERG LIMITS

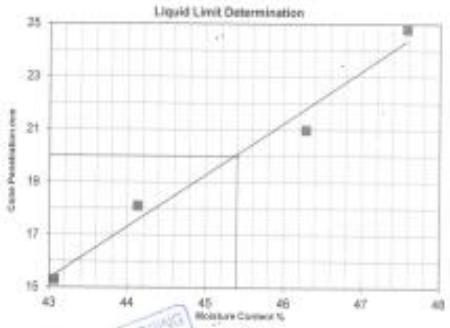
Liquid limit (cone penetrometer) and plastic limit

SOURCE :	KAWANDA TOWN COUNCIL (WAKISO	Technician	Lab Team
mix	XPANSIVE SOIL MODIFIFIED WITH 30%CRR & 8% A/S	Sample Date	29/Nov/2023
Test method	BS 1377: Part 2, 1990:4.3&4.4	Test Date	17/Feb/2024
LAYER :	EXPANSIVE SOILS		
Depth	0.5m		

PLASTIC LIMIT	Test No	RAD	44		Average
Mass of wet soil + container (g)		33.66	27.31		30.43
Mass of dry soil + container (g)		31.57	26.17		28.77
Mass of container (g)		21.66	21.21		21.583
Mass of moisture (g)		2.19	1.1		1.65
Mass of dry soil (g)		9.41	4.96		7.185
Moisture content %		23.2	23.8		23.1
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.3	18.1	21	24.8
penetration (mm)		15.3	18.1	21.0	24.8
AVERAGE		15.3	18.1	21.0	24.8

Container No.	P143	P28	FORD	PH
Mass of wet soil + container (g)	44.84	38.13	34.22	40.02
Mass of dry soil + container (g)	33.44	28.62	29.22	29.31
Mass of container (g)	6.97	7.07	6.91	6.86
Mass of moisture (g)	11.4	9.51	10	10.71
Mass of dry soil (g)	26.47	21.55	22.41	22.51
Moisture content (%)	43.1	44.1	46.3	47.6
AVERAGE	43.1	44.1	46.3	47.6



Liquid limit (%)	45.4
Plastic limit (%)	23.1
Plasticity Index (%)	22.3
Linear shrinkage	
Trough No.	Y
Trough length (cm)	14.0
Specimen length (cm)	12.5
L shrinkage =	1.6
% L shrinkage =	11.1

Remarks

TESTING LAB		STUDENTS
Material Engineer		
Lab Technician		

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

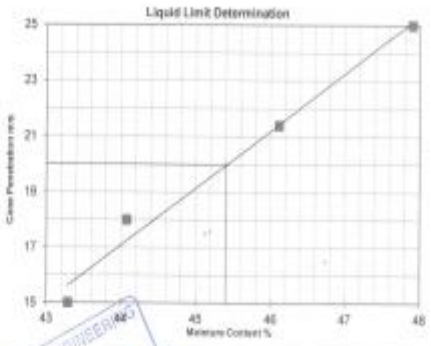
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

SOURCE :	KAWANDA TOWN COUNCIL (WAKISO)	Technician	Lab Team
Fine	XPANSIVE SOIL MODIFIED WITH 30% CRR & 8% AS	Sample Date	29/Nov/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	1/Feb/2024
LAYER	EXPANSIVE SOILS		
Depth:	0.6m		

PLASTIC LIMIT	Test No.	HU	JK		Average
Mass of wet soil + container (g)		46.22	37.81		42.115
Mass of dry soil + container (g)		41.78	34.93		38.345
Mass of container (g)		22.18	21.95		22.065
Mass of moisture (g)		4.50	3.0		3.77
Mass of dry soil (g)		19.59	12.98		16.28
Moisture content %		23.0	23.0		23.1
AVERAGE					

LIQUID LIMIT	Test No.	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.0	18	21.4	25.0
penetration (mm)		15.0	18.0	21.4	25.0
AVERAGE		15.0	18.0	21.4	25.0
Container No.		F00	A15	P88	P02H
Mass of wet soil + container (g)		40.55	36.64	55.88	47.60
Mass of dry soil + container (g)		30.26	27.75	40.48	36.05
Mass of container (g)		6.92	6.90	7.08	11.52
Mass of moisture (g)		10.18	8.19	15.41	11.75
Mass of dry soil (g)		23.47	20.85	33.42	24.53
Moisture content (%)		43.3	44.1	46.1	47.9
AVERAGE		43.3	44.1	46.1	47.9



Liquid limit (%)	45.4
Plastic limit (%)	23.1
Plasticity Index (%)	22.3
Linear shrinkage	
Trough No.	Y
Trough length (cm)	14.0
Specimen length (cm)	12.5
L.shringage =	1.5
% L.shrinkage =	11.1

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/034	Stirling

PROJECT:	INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS			
Test Reference No.	Depth: 0.5m	Date Sampled	Date Tested	Technician
Mix	EXPANSIVE SOIL MODIFIED WITH 20%CKM & 6% ASH	28/Nov/23	30/Jan/24	Lab team
SOURCE	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)			
Material description:	EXPANSIVE SOILS	Natural moisture (%)	11.0	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm³)
4.9	27	5	457	100	1,000

MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm³	330	390	450	510	570
Mass of Compacted soil + mould	gm	5,986	6,124	6,240	6,259	6,119
Mass of Mould	gm	4,282	4,282	4,282	4,282	4,282
Mass of Compacted soil	gm	1704	1822	1958	1927	1837
Volume of mould	cm³	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm³	1,704	1,822	1,958	1,927	1,837

DATA FOR PROCTOR CURVE

Container No.		AFE	MANU	DPD	LP	HP
Mass of wet soil + Container	gm	584.0	1,736.0	1,383.0	640.0	908.0
Mass of dry soil + container	gm	482.0	1,519.0	1,221.0	530.0	658.0
Mass of container	gm	53.0	549.0	553.0	66.0	63.0
Mass of water added	gm	78	155	140	110	150
Mass of dry soil	gm	429	971	668	470	594
Moisture content	%	17.7	19.5	21.5	23.4	25.1
Dry density	g/cm³	1.448	1.525	1.615	1.562	1.468

Maximum dry density (gm/cm³) 1.620 Optimum moisture content (%) 21.7

Remarks:

FOR TESTING LAB		STUDENTS	
Lab Technician	Laboratory Engineer		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHARA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference:	Depth 0.5m	Sampling Date:	29/Nov/23
Mix:	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH	Casting date	31/Jan/24
Source:	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Testing Date:	4/Feb/24
Sample Description:	EXPANSIVE SOILS	Technician:	Lab team
		Volume of Mould used (m^3)	2305

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	HM		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1636		MDD (Mg/m^3)	1.620
Tin + oven dry soil sample (g)	1575		N.M.C (%)	5.9
Tin (g)	544		OMC (%)	21.7
Dry soil sample	1031		Added OMC (%)	15.8
Water (g)	61		Calculated dry wt of soil (g)	5943.0
N.M.C (%)	5.9		Water added (g)	894
Average (%)	5.9		**Water added (mL)**	894

Number of blows		62						
Number of layer		5						
Water Content Determination		Before Soaking		After Soaking				
Tare No		BA	-	CR7	-			
Mass of wet sample + Tare	g	1966	-	2278	-			
Mass of dry sample + Tare	g	1764	-	2008	-			
Mass of Tare	g	768	-	770	-			
Mass of water	g	202	-	270	-			
Mass of dry sample	g	996	-	1238	-			
Water content	%	20.3	-	21.8	-			
Average water Content	%	20.3		21.8				
Density determination								
Mould No		MM						
Mass of mould + soil	g	10660		10730				
Mass of mould	g	6050		6050				
Mass of soil	g	4610		4680				
Volume of the mould	cm3	2305		2305				
Moist density	g/cm3	2.000		2.031				
Dry density	g/cm3	1.663		1.667				
Swell Determination								
Date		Hour		D.Gauge Reding				
Initial reading		96 hrs		7.62				
Final reading				8.45				
Height of the specimen				127				
Height of swell				0.83				
		Swelling(%)		0.65				
Observations								

For the Lab		For Students
Lab Technician	Laboratory Manager	

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Depth: 0.5m	Sampling Date	20/Nov/23
Mix	EXPANSIVE SOIL MODIFIED WITH 30%CRS & 8% ASH	Penetration Date	6/Feb/24
Source	KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	Submission	Lab team
Sample Description	EXPANSIVE SOILS		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	MM		
Capacity of the Proving Ring (KN)	30	30	30
Proving Ring Constant (KN/div.)	0.0011	0.0011	0.0011

Speed ____ mm/min

Penetration of the plunger (mm)	Time (s)	Top Reading *10⁻²mm	Top Force (KN)	Bottom Reading *10⁻²mm	Bottom Force (KN)				
0	0	0	0.0	0	0.0				
0.25	12	1	0.2	1	0.2				
0.5	24	1	0.2	2	0.4				
0.75	35	1	0.2	3	0.6				
1	47	1	0.2	4	0.8				
1.5	71	2	0.4	6	1.2				
2	94	2	0.4	8	1.6				
2.5	118	3	0.6	10	2.1				
3	141	3	0.6	13	2.7				
3.5	165	4	0.8	15	3.1				
4	189	5	1.0	17	3.5				
4.5	213	5	1.0	19	3.9				
5	236	7	1.4	20	4.1				
5.5	260	7	1.4	21	4.3				
6	283	8	1.6	22	4.5				
6.5	307	8	1.6	22	4.5				
7	330	9	1.8	23	4.7				
7.5	354	9	1.8	23	4.7				

Observations

For the Contractor		For Students	
Lab Technician	[illegible]		

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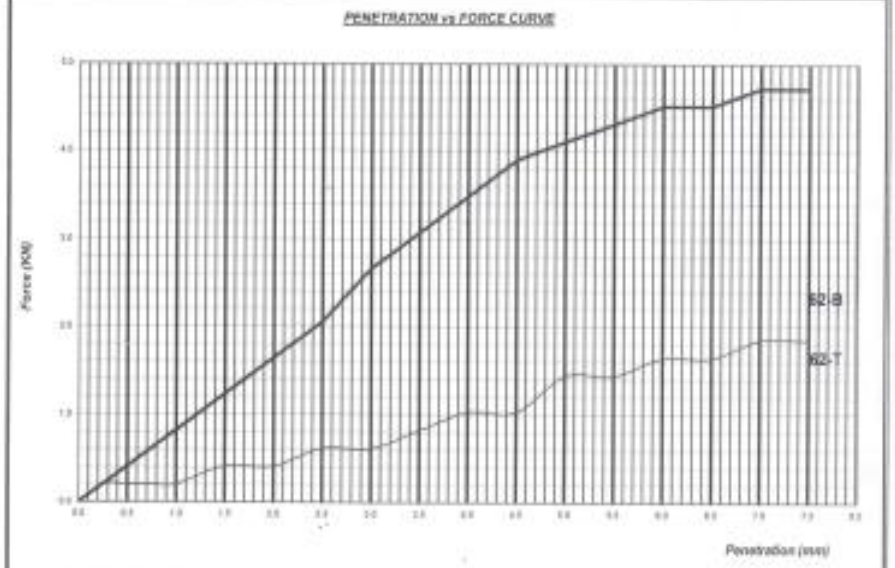
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S18B32/217 & TUSUBIRA ANDREW S18B32/036	Stirling

INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference:	Depth: 0.5m	Sampling Date:	20/Nov/23
Site:	EXPANSIVE SOIL MODIFIED WITH 30%CRR &	Testing Date:	4/Feb/24
Source:	KAWANDA TOWN COUNCIL, WAKISO DISTRICT	Technician:	Lab team
Sample Description:	EXPANSIVE SOILS		



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.1	0.6	15	5								
5.0 mm Penetration	4.1	1.4	21	7								
Average	3.1	1.0	18.0	6.0								
Retained CBR	18.0											

Observations: CBR= 18.0

For the Lab		For Students	
Lab Technician	Materials Engineer		

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