INFLUENCE OF COMPACTION ON COPPER SLAG WHEN ADMIXTURE IS ADDED

PROJECT REPORT

Submitted in partial fulfilment of the
Requirements for the award of the degree of

Bachelor of Technology
In
Civil Engineering

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STUDENT DECLARATION

We hereby declare that the project entitled **"INFLUENCE OF COMPACTION ON COPPER SLAG WHEN ADMIXTURE IS ADDED"** is the work done by us during the academic year 2011-2012 and is submitted in partial fulfilment of the requirements for the award of degree of bachelor of technology in CIVIL ENGINEERING from JNTU, Hyderabad.

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ABSTRACT

Guide: C. Lavanya.

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Objective: To find out the geotechnical properties of cupper slag to replace the soil in constructions.

Industrial waste is a type of waste produced by industrial activity, such that of factories, mills, mines. Copper slag is the one of the industrial waste available. It is a by product of copper production from copper ore. During smelting, a molten pool of copper forms at the bottom of the furnace while a layer of impure metal, which is the slag, is drained off from the top. Copper slag and lime form cementateous material on hydration. Lime is a general term for calcium containing inorganic material, in which carbonates, oxides and hydroxides predominate. Lime provides à comfortable environment. Lime mixes have good workability. Lime binders can be durable and have stood the test of time.

Tests conducted on copper slag with lime

Compaction

Standard proctor test
Modified proctor test

Compaction is the process whereby air is crowded out & its volume decrease due to physical stress. Test is performed to determine the relationship between the optimum moisture content (OMC) and the maximum dry density (MDD) of a soil for a specified compactive effort.

By conducting the above experiments we find the optimum moisture content (OMC) and maximum dry density (MDD) of copper slag with different percentages of admixture and water. Analysis is done by drawing graphs using the values of OMC and MDD

1. INTRODUCTION

Waste is also known as rubbish, trash, refuse, garbage, junk, and is unwanted or useless materials. The compositions of different wastes have varied over time and location, with industrial development and innovation being directly linked to waste materials. Examples of this include plastics and nuclear technology. Some waste components have economic value and can be recycled once correctly recovered. Waste is sometimes a subjective concept, because items that some people discard may have value to others. It is widely recognized that waste materials can be a valuable resource. Such concepts are expressed in culture by such idioms as "One man's trash is another man's treasure”.

Industrial waste is one of the major type of waste coming from industries, factories, mines etc.

1.1 Industrial waste

Many different types of solid, liquid, and gaseous wastes are discharged by industries. Most industrial waste is recycled, treated and discharged, or placed in a landfill. There is no one means of managing industrial wastes because the nature of the wastes varies widely from one industry to another. One company might generate a waste that can be treated readily and discharged to the environment (direct discharge) or to a sewer in which case final treatment might be accomplished at a publicly owned treatment works (POTW). Treatment at the company before discharge to a sewer is referred to as pre treatment. Another company might generate a waste which is regarded as hazardous and therefore requires special management procedures related to storage, transportation and final disposal.

The pertinent legislation governing to what extent waste waters need to be treated before discharge is the 1972 Clean Water Act (CWA). Major amendments to the CWA were passed in 1977 and 1987. The Environmental Protection Agency (EPA) was also charged with the responsibility of regulating the priority pollutants under the CWA. The CWA specifies that toxic and nonconventional pollutants are to be treated with the Best Available Technology (BAT). Gaseous pollutants are regulated under the Clean Air Act (CAA), promulgated in 1970 and amended in 1977 and 1990.

An important part of the CAA consists of measures to attain and maintain National Ambient

Air Quality Standards (NAAQS). Hazardous air pollutant (HAP) emissions are to be controlled through Maximum Achievable Control Technology (MACT) which can include process changes, material substitutions and air pollution control equipment.

In 1990, the United States, through the Pollution Prevention Act, adopted a program designed to reduce the volume and toxicity of waste discharges. Pollution prevention strategies might involve changing process equipment or chemistry, developing new processes, eliminating products, minimizing wastes, recycling water or chemicals, trading wastes with another company, etc. In 1991, the EPA instituted the 33/50 program which was to result in an overall 33% reduction of 17 high priority pollutants by 1992 and a 50% reduction of the pollutants by 1995.

Both goals were surpassed. Not only has this program been successful, but it sets an important precedence because the participating companies volunteered. A Life Cycle Analysis starts with consideration for acquiring raw materials, moves through the stages related to processing, assembly, service and reuse, and ends with retirement/disposal. The LCA therefore reveals to industry the costs and problems versus the benefits for every stage in the life of a product.

In designing a waste management program for an industry, one must think first in terms of opportunities, identify and characterize the various solid, liquid and gaseous waste streams, consider relevant legislation, and then design an appropriate waste management system. Treatment systems that rely on physical (e.g., settling, floatation, screening, sorption, membrane technologies, air stripping) and chemical (e.g., coagulation, precipitation, chemical oxidation and reduction, pH adjustment) operations are referred to as physicochemical, whereas systems in which microbes are cultured to metabolize waste constituents are known as biological processes (e.g., activated sludge, trickling filters, bio towers, aerated lagoons, anaerobic digestion, aerobic digestion, composting). Oftentimes, both physicochemical and biological systems are used to treat solid and liquid waste streams. Biological systems might be used to treat certain gas streams, but most waste gas streams are treated physicochemical (e.g., cyclones, electrostatic precipitators, scrubbers, bag filters, thermal methods). Solids and the sludge or residuals that result from treating the liquid and gaseous waste streams are also treated by means of physical, chemical, and biological methods.

In many cases, the systems used to treat wastes from domestic sources are also used to treat industrial wastes. For example, municipal wastewaters often consist of both domestic and industrial waste. The local POTW therefore may be treating both types of wastes. To avoid potential problems caused by the input of industrial wastes, municipalities commonly have pre treatment programs which require that industrial wastes discharged to the sewer meet certain standards.

The standards generally include limits for various toxic agents such as metals, organic matter measured in terms of biochemical oxygen demand (BOD) or chemical oxygen demand, nutrients such as nitrogen and phosphorus, pH and other contaminants that are recognized as having the potential to impact on the performance of the POTW. At the other end of the spectrum, there are wastes that need to be segregated and managed separately in special systems. For example, an industry might generate a hazardous waste that needs to be placed in barrels and transported to an EPA approved treatment, storage or disposal facility.

Thus, it is not possible to simply use one train of treatment operations for all industrial waste streams, but an effective, generic strategy has been developed in recent years for considering the waste management options available to an industry. The basis for the strategy is to look for opportunities and to consider the life cycle of a product. An awareness of waste stream characteristics and the potential benefits of stream segregation is then melded with the knowledge of regulatory compliance issues and treatment system capabilities/performance to minimize environmental risks and costs.

Types of industrial waste

- Industrial solid waste
- Industrial liquid waste
- Industrial gaseous waste

1.1.1 Industrial solid waste

In general, a 1,000 MW station using coal of 3,500 kilo calories per kg and ash content in the range of 40-50 per cent would need about 500 hectares for disposal of fly ash for about 30 years operation. It is, therefore, necessary that fly ash should be utilised wherever possible to minimize environmental degradation.

The thermal power plant should take into account the capital and operation/maintenance cost of fly ash disposal system as well as the associated environmental protection cost, dry system of collection and its utilisation by the thermal power plant or other industry, in evaluating the feasibility of such system.

The research and development carried out in India for utilisation of fly ash for making building materials has proved that fly ash can be successfully utilised for production of bricks, cement and other building materials. Indigenous technology for construction of building materials utilising fly ash is available and are being practised in a few industries. However, large scale utilisation is yet to take off.

Even if the full potential of fly ash utilisation through manufacture of fly ash bricks and blocks is explored, the quantity of fly ash produced by the thermal power plants is so huge that major portion of it will still remain unutilised. Hence, there is a need to evolve strategies and plans for safe and environmentally sound method of disposal.

Red mud as solid waste is generated in non-ferrous metal extraction industries like aluminium. The red mud at present is disposed in tailing ponds for settling, which more often than not finds its course into the rivers, especially during monsoon. However, red mud has recently been successfully tried and a plant has been set up in the country for making corrugated sheets.

1.1.2 Industrial liquid waste

Management of industrial and commercial liquid wastes is a very open ended topic due to huge variety in types of liquid waste from the wash water at a fast food outlet to the waste water at a uranium mine.

In general terms, when an industry or commercial premises produces a liquid waste (other than basic toilet and kitchen waste water), there is a range of ways that the waste may need to be treated and disposed off.

The business may be able to discharge the waste to the sewer. This means that the business is located in a sewered area and has been given permission to discharge from the water/sewer authority in the area (Sydney Water, Hunter Water or the local council authority). Permission to discharge to the sewer is generally known as a “Trade Waste Agreement” and usually requires that some pre-treatment of the liquid occurs before it is discharged to the sewer.

It is important that sewer authorities regulate what goes into the sewerage system from industries in order to protect their assets for example, sewage pumping stations can easily become clogged with oil and grease, pumps and pipes can be worn away by sediment, toxic substance can cause problems with the biological processes at the sewage treatment plant and very high BOD wastes may overload the plant.

The business may need to store the waste and have it removed by a liquid waste contractor. This might be necessary because there is no sewer connection or because the waste is not suitable for discharge to the sewer. Hazardous liquids need to be collected by a specially licensed waste removal contractor. The waste contractor will take the waste to a treatment plant for further processing and possible recovery for reuse. Some wastes are subject to waste tracking requirements.

Some industries have their own treatment processes and treat their wastes to a standard high enough to discharge into the local environment. This is regulated by the provisions of the Protection of the Environment Operations Act 1997, as you will be aware from your Environmental Law subject. Liquid waste treatment processes will vary for each waste. However, for aqueous wastes, or wastes which are based on water, there are some general principles that do apply and which relate to the treatment processes that you have studied so far in this subject.

Wastes containing solids (such as sediment) will generally be treated with a physical process such as settling (similar to preliminary or primary treatment of sewage) to remove solids. Waste with high carbon loads (high BOD / COD) will often be treated with a biological process either aerobic or anaerobic, depending on the waste.

Once solids and carbon load are reduced, the treatment process can focus on other

Contaminants dissolved metals, nutrients, pathogens etc. by using of physical, chemical and/or biological processes. Non-aqueous waste (that is, wastes that primarily contain a liquid other than water such as oils, coolants, sludge, chemical mixtures) are treated, recovered for re-use or destroyed, depending on the type of waste.

1.1.3 Industrial gaseous waste

Gaseous waste is a perennial problem in every country. The need for national gaseous waste solutions is very eminent now. It seems almost impossible to control the gaseous waste that is emitted from a domestic area, though it is not the same with an industrial area. The gaseous waste disposal systems that are used in the large industries don't seem applicable to the common household. Gaseous waste contributes to the highest amount of carbon dioxide emission which in turn leads to global warming.

As the number of industries and households producing gaseous waste increases, the need for the national gaseous waste solutions becomes more prominent. In industries, the gaseous waste is disposed of in many ways. Incineration is one of them. This kind of gaseous waste disposal method is very prominent in Japan as there are very limited land resources available for landfills and other conventional waste disposal methods.

Incineration is a method that uses combustion of waste material. This is used by both small scale and large industries to dispose of gaseous waste, liquid waste and also solid waste. Incineration is a very controversial method of disposal of waste as it leads to emission of gaseous pollutants.

The problem that one may face while trying to implement national gaseous waste solutions is that it is almost impossible to try and implement a course of action for every household and every industry in the nation, unless of course, the government takes a stand to make it compulsory. While this may seem unpractical, the environment will surely benefit from this.

The gaseous waste that is produced by individual households is not anywhere close to the amount of gaseous waste that the large industries produce. Hence, it would be practical and better if the national gaseous waste solutions could be implemented at least for all industries first. Almost all of these industries produce huge amounts of gaseous waste which gets absorbed into the atmosphere. If the gaseous waste that is emitted by these industries can be controlled, then in turn, global warming can also be controlled and perhaps reversed.

National gaseous waste solutions are necessary now more than ever before. According to statistics with the current rate of global warming, the world may not last very long. There are many things that the government can do to slow down the process of global warming and one of them is ‘national gaseous waste solutions’.

- Hazardous wastes include industrial waste

1.2 Industrial hazardous wastes

A Hazardous waste is waste that posses substantial or potential threats to public health or the environment. In the United States, the treatment, storage and disposal of hazardous waste is regulated under the Resource Conservation and Recovery Act (RCRA). Hazardous wastes are divided into two major categories.

Characteristic wastes

Listed wastes

Characteristic hazardous wastes are materials that are known or tested to exhibit one or more of the following four hazardous traits

- Ignitability (i.e., flammable)
- Reactivity
- Corrosivity
- Toxicity

Listed hazardous wastes are materials specifically listed by regulatory authorities as a hazardous waste which are from non-specific sources, specific sources, or discarded chemical products.

The requirements of RCRA apply to companies that generate hazardous waste as well as those companies that store or dispose of hazardous waste in the United States. Many types of businesses generate hazardous waste. For example, dry cleaners, automobile repair shops, hospitals, exterminators, and photo processing centres may all generate hazardous waste.

Some hazardous waste generators are larger companies such as chemical manufacturers, electroplating companies, and oil refineries.

These wastes may be found in different physical states such as gaseous, liquids, or solids. A hazardous waste is a special type of waste because it cannot be disposed of by common means like other by-products of our everyday lives. Depending on the physical state of the waste, treatment and solidification processes might be required.

Worldwide, The United Nations Environmental Programme estimated that more than 400 million tons of hazardous wastes are produced universally each year, mostly by industrialized countries. About 1- percent of this total is shipped across international boundaries, with the majority of the transfers occurring between countries in the Organization for the Economic Cooperation and Development (OECD). Some of the reasons for industrialized countries to ship the hazardous waste to industrializing countries for disposal are the rising cost of disposing hazardous waste in the home country.

2. INDUSTRIAL SOLID WASTE

The major generators of industrial solid wastes are the thermal power plants Producing coal ash, the integrated Iron and Steel mills producing blast furnace slag and steel melting slag, non-ferrous industries like aluminium, zinc and copper producing red mud and tailings, sugar industries generating press mud, pulp and paper industries producing lime and fertilizer and allied industries producing gypsum.

Table 2.1 Source and quantum of generation of some major industrial waste

S.No	Name	Quantity (million tonnes per annum)	Source/Origin
1.	Steel and Blast Furnace	35.0	Conversion of pig iron to steel and manufacture of Iron
2.	Brine mud	0.02	Caustic soda industry
3.	Copper slag	0.0164	By product from smelting of Copper
4.	Fly ash	70.0	Coal based thermal power Plants
5.	Kiln dust	1.6	Cement plants
6.	Lime sludge	3.0	Sugar, paper, fertilizer tanneries, soda ash, calcium carbide industries
7.	Mica scraper waste	0.005	Mica mining areas
8.	Phosphogypsum	4.5	Phosphoric acid plant, Ammonium phosphate
9.	Red mud/ Bauxite	3.0	Mining and extraction of alumina from Bauxite
10.	Coal washery dust	3.0	Coal mines
11.	Iron tailing	11.25	Iron Ore
12.	Lime stone wastes	50.0	Lime stone quarry

2.1 Some of the important industrial waste

2.1.1 Coal Ash

In general, a 1,000 MW station using coal of 3,500 kilo calories per kg and ash content in the range of 40-50 per cent would need about 500 hectares for disposal of fly ash for about 30 years operation. It is, therefore, necessary that fly ash should be utilised wherever possible to minimize environmental degradation.

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Even if the full potential of fly ash utilisation through manufacture of fly ash bricks and blocks is explored, the quantity of fly ash produced by the thermal power plants are so huge that major portion of it will still remain unutilised. Hence, there is a need to evolve strategies and plans for safe and environmentally sound method of disposal.

2.1.2 Copper slag

Copper slag blasting grit is manufactured of the granulated slag of copper refineries, and used for blast-cleaning of metal surface. In different industries it is called different names abrasive powder, grit, copper slag grit, mineral grit, grinding grains, etc. But its main use is still for surface blast-cleaning.

Copper slag abrasive is suitable for blast cleaning of steel and stone/concrete surfaces, removal of mill scale, rust, old paint, dirt etc.

2.1.3 Integrated Iron & Steel Plant Slag

The Blast Furnace (BF) and Steel Melting Shop (SMS) slags in integrated iron and steel plants are at present dumped in the surrounding areas of the steel plants making hillocks encroaching on the agricultural land. Although, the BF slag has potential for conversion into granulated slag, which is a useful raw material in cement manufacturing, it is yet to be practised in a big way. Even the use of slag as road sub grade or land-filling is also very limited.

2.1.4 Phosphogypsum

Phosphogypsum is the waste generated from the phosphoric acid, ammonium phosphate and hydrofluoric acid plants. This is very useful as a building material. At present very little attention has been paid to its utilisation in making cement, gypsum board, partition panel, ceiling tiles, artificial marble, fibre boards etc.

2.1.5 Red Mud

Red mud as solid waste is generated in non-ferrous metal extraction industries like aluminium. The red mud at present is disposed in tailing ponds for settling, which more often than not finds its course into the rivers, especially during monsoon. However, red mud has recently been successfully tried and a plant has been set up in the country for making corrugated sheets.

Demand for such sheet should be popularised and encouraged for use. This may replace asbestos which is imported and also banned in developed countries for its hazardous effect. Attempts are also made to manufacture polymer and natural fibres composite panel doors from red mud.

2.1.6 Lime Mud

Lime sludge, also known as lime mud, is generated in pulp & paper mills which are not recovered for reclamation of calcium oxide for use except in the large mills. The lime mud disposal by dumping into low-lying areas or into water courses directly or as run-off during monsoon is not only creating serious pollution problem but also wasting the valuable non-renewable resources. The reasons for not reclaiming the calcium oxide in the sludge after recalcination are that it contains high amount of silica. Although a few technologies have been developed to desilicate black liquor before burning, none of the mills in the country are adopting desilication technology.

2.1.7 Waste Sludge and Residues

Treatment of industrial wastes/effluents results in generation of waste sludge/residues which, if not properly disposed, may cause ground and surface water Pollution.

2.2 Potential Reuse of Solid Wastes

Research and Development (R&D) studies conducted by the R&D Institutions like Central Building Research Institute, Roorkee (CBRI) and the National Council for Building Research (NCBR) reveal that the aforesaid solid waste has a very good potential to be utilised in the manufacture of various building materials.

Table 2.2 Area of application of some important industrial wastes

S.No.	Waste	Areas of Application
1.	Fly ash	i. Cement ii. Raw material in Ordinary Portland Cement(OPC) manufacture iii. Manufacture of oil well cement. iv. Making sintered fly ash light-weight aggregates. v. Cement/silicate bonded fly ash/clay binding bricks and insulating bricks. vi. Cellular concrete bricks and blocks, lime and cement fly ash concrete. vii. Precast fly ash concrete building units. viii. Structural fill for roads, construction on sites, Land reclamation etc. ix. As filler in mines, in bituminous concrete x. As plasticiser xi. As water reducer in concrete and sulphate resisting concrete xii. Amendment and stabilisation of soil.
2.	Blast Furnace Slag	i. Manufacture of slag cement, super sulphated cement, Metallurgical cement. ii. Non-Portland cement ii. Making expansive cement, oil well, coloured Cement and high early-strength cement. iv. In refractory and in ceramic as sital v. As a structural fill (air-cooled slag) vi. As aggregates in concrete.
3.	Ferro-alloy and	i. As structural fill ii. In making pozzolana metallurgical cement

	other metallurgical slag.	
4.	By product Gypsum	i. In making of gypsum plaster, plaster boards and slotted tiles ii. As set controller in the manufacture of Portland cement iii. In the manufacture of expensive or non-shrinking cement, super sulphated and anhydrite cement iv. As mineraliser v. Simultaneous manufacture of cement and sulphuric acid
5.	Lime sludge (phosphochalk, paper and sugar sludge)	i. As a sweetener for lime in cement manufacture ii. Manufacture of lime pozzolona bricks/ binders iii. For recycling in parent industry iv. Manufacture of building lime v. Manufacture of masonry cement
6.	Chromium sludge	i. As a raw material component in cement manufacture ii. Manufacture of coloured cement as a chromium bearing material
7.	Red mud	i. As a corrective material ii. As a binder iii. Making construction blocks iv. As a cellular concrete additive v. Coloured composition for concrete vi. Making heavy clay products and red mud bricks vii. In the formation of aggregate viii. In making floor and all tiles ix. Red mud polymer door
8.	Pulp & Paper	i. Lignin

3. COPPER SLAG

3.1 Copper slag

Copper slag blasting grit is manufactured of the granulated slag of copper refineries, and used for blast-cleaning of metal surface. In different industries it is called different names abrasive powder, grit, copper slag grit, mineral grit, grinding grains, etc. but its main use is still for surface blast-cleaning.

Copper slag abrasive is suitable for blast cleaning of steel and stone/concrete surfaces, removal of mill scale, rust, old paint, dirt etc. Contractors may also use copper slag in place of sand during concrete construction. The slag serves as a fine, or binding agent, which helps hold the larger gravel particles within the concrete together. When used in this manner, the slag helps to improve the properties of the concrete, and also serves as a form of recycling.

3.1.1 Health effects

One of the primary advantages to copper slag is the low risk it posses to health and the environment. Silica sand, which represents the most popular blasting medium and concrete fine currently in use, poses serious health risks when inhaled. It may also contribute to pollution and other environmental concerns.

Fig 3.1 Copper Slag

Copper Slag is extracted from Tuticorin, India, one of the largest producers of copper in India. State of the art technology is adopted in their smelter to produce high quality raw material.

3.2 Features of Copper Slag

- Cubical
- Dense
- Fast cutting
- Leaves a good profile
- Inert
- Produces less dust
- Metal-refining industry, waste, by-product
- Shiny or dull, dark brown to black, irregular particles
- Medium performance abrasive
- Tends to be dusty and shatter on impact
- Limited use for ultra hi build coating removal

3.3 Usage

It is used to remove rust, scale, and paint from steel products. These slags are often used by power plants, tank companies, water districts, and waste water transfer plants as blasting abrasives.

- Shipyards
- Fabrication yards
- Blasting cabinet applications
- Tank forms
- Concrete bridge and structures
- Structural steel constructions
- Pipelines
- Offshore and onshore applications
- Chemical and process industries
- Oil refineries and platforms
- Cement industry

4. ADMIXTURES

Over decades, attempts have been made to obtain concrete with certain desired characteristics such as high compressive strength, high workability, and high performance and durability parameters to meet the requirement of complexity of modern structures.

The properties commonly modified are the heat of hydration, accelerate or retard setting time, workability, water reduction, dispersion and air-entrainment, impermeability and durability factors.

4.1 Types of Admixtures

- Chemical admixtures
- Mineral admixtures

4.1.1 Chemical admixtures- Accelerators, Retarders, Water-reducing agents, Super plasticizers, Air entraining agents etc.

4.1.2 Mineral admixtures- Fly-ash Blast-furnace slag, Silica fume, Rice husk Ash and Lime.

4.2 Lime

Fig 4.1 lime extraction

Lime is a general term for calcium-containing inorganic materials, in which carbonates, oxides and hydroxides predominate. Strictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name for a single mineral of the CaO composition, occurring very rarely. The word "lime" originates with its earliest use as building mortar and has the sense of "sticking or adhering." Lime can also refer to a sticky substance (birdlime) smeared on branches to catch small birds.

These materials are still used in large quantities as building and engineering materials (including limestone products, concrete and mortar) and as chemical feed stocks, among other uses. Lime industries and the use of many of the resulting products date from prehistoric periods in both the Old World and the New World.

The rocks and minerals from which these materials are derived, typically limestone or chalk, are composed primarily of calcium carbonate. They may be cut, crushed or pulverized and chemically altered. "Burning" (calcination) converts them into the highly caustic material quicklime (calcium oxide, CaO) and, through subsequent addition of water, into the less caustic (but still strongly alkaline) slaked lime or hydrated lime (calcium hydroxide, $Ca(OH)_2$), the process of which is called slaking of lime.

When the term is encountered in an agricultural context, it probably refers to agricultural lime. Otherwise it most commonly means slaked lime, as the more dangerous form is usually described more specifically as quicklime or burnt lime.

4.2.1 Lime production process

1. Limestone is extracted from quarries or mines.
   Part of the extracted stone, selected according to its chemical composition ,it is calcinated at about 1000°C in different types of kiln, fired by such fuels as natural gas, coal, fuel oil, lignite, etc.
2. Quicklime is produced according to the reaction

$$CO_3 + \text{heat } Ca \rightarrow CaO + CO_2.$$

Lime is used extensively for waste water treatment with ferrous sulphate.
Quicklime can be hydrated, i.e., combined with water.

Hydrated lime, known as slaked lime, is produced according to the reaction.

$$CaO + H_2O \rightarrow Ca\,(OH)_2$$

4.3 Uses of lime

4.3.1 Lime allows buildings to breathe

In the search by architects and conservators for building materials sympathetic to traditional construction, lime was found to be one of the most important. One of the reasons lime binders are promoted by the Society for the Protection of Ancient Buildings for repairs is because the moisture are vapour permeable and allow buildings to breathe. This reduces the risk of trapped.

4.3.2 Lime provides a comfortable environment

Porous and open textured materials such as lime plasters help to stabilize the internal humidity of a building by absorbing and releasing moisture. This makes for a more comfortable environment and reduces surface condensation and mould growth.

4.3.3 The use of lime has ecological benefits

- Lime has less embodied energy than cement.
- Free lime absorbs carbon dioxide in the setting process of carbonation.
- It is possible to produce lime on a small scale.
- The gentle binding properties of lime enable full re-use of other materials.
- A very low proportion of quicklime will stabilize clay soils.
- Small quantities of lime can protect otherwise vulnerable, very low energy materials such as earth construction and straw bales.

4.3.4 Lime binds gently with early adhesion

The fine particle size of lime, far smaller than cement, is linked to the root meaning of the word lime, which is 'sticky material'. Due to the fine particle size, lime mixes penetrate minute voids in the background more deeply than other materials. They bind gently and the stickiness gives good adhesion to other surfaces.

4.3.5 Lime mortar can protect adjacent materials

Lime mortars with high free lime content are porous and permeable. These characteristics allow lime mortars to protect adjacent materials by handling moisture movements through the building fabric and protecting them from harmful salts. Adjacent materials frequently affected this way include timber and iron as well as stone and brick masonry.

4.3.6 Lime renders can assist drying out by evaporation

Dense and impermeable renders can trap moisture within the building fabric. Trapped moisture is often the agent for various decay mechanisms. Dense renders used in conjunction with softer materials or on weaker backgrounds can cause serious problems by creating local stresses. High calcium lime renders allow evaporation and reduce the risk of trapped moisture and decay. In simple terms, the greater the extent of pure lime and permeability the better this is for the building. This needs to be balanced with durability, however, and some reduction in permeability may be necessary to obtain adequate weathering qualities, hence the advantage of feebly hydraulic lime for external use.

4.3.7 Lime mixes have good workability

The ability of a mortar or plaster to remain smooth and mouldable, even against the suction it may experience from porous building materials, is termed workability. Good workability greatly assists good workmanship, helping to achieve full joints with good bonding to the other materials. This is what makes lime based mixes such a pleasure to use. The workability provided by the lime allows the inclusion of widely graded and sharp aggregates in the mix. These enhance both the performance and the aesthetic of the finished work.

4.3.8 Lime binders can be durable and have stood the test of time

When used carefully, lime is exceptionally durable. Caesar's Tower at Warwick Castle has stood the test of time for over 600 years, and many cathedrals have stood longer. An outstanding example is the Pantheon Temple in Rome which has a lime concrete dome Spanning over 43 metres (142 feet). This has survived for nearly 2000 years.

4.3.9 Lime finishes are beautiful

The double refraction of light through calcite crystals give a unique aesthetic combining a soft texture with a lustre that has a liveliness and delight of its own. The graceful softness apparent in lime based materials is a visual indication of their intrinsic permeability, workability and soft binding properties. They can rapidly develop a rich patina which has a glowing translucent quality.

4.3.10 Lime contributes to a healthy environment

Lime is caustic and has been extensively used, often in the form of lime wash, for its disinfectant qualities. Lime is also used for water purification. Lime mortars, plasters, renders and lime wash have been used to create hygienic surfaces and improve comfort conditions within buildings for thousands of years.

4.3.11 Self-healing

The nature of ground conditions and the elements are such that all buildings are subject to varying degrees of movement over time. When buildings made with lime are subject to small movements they are more likely to develop many fine cracks than the individual large cracks which occur in stiffer cement-bound buildings. Water penetration can dissolve the 'free' lime and transport it. As the water evaporates this lime is deposited and begins to heal the cracks. This process is called autogenous or self healing.

4.3.12 Free lime encourages the growth of calcite crystals

Calcite crystals are a different shape to those formed by the more complex compounds in hydraulic limes and cements. The crystals form in voids in lime rich environments. The growth of calcite crystals adds strength over time and generally provides a more open and permeable material than the denser eminently hydraulic and OPC mixes with little or no free lime.

4.3.13 Local limes enhance regional identity and diversity

The diversity of limestone types provides variety and local distinctiveness. Different limes will vary in colour, texture and setting properties. Local limes have a regional identity; they give a sense of place and provide a continuous link with the local aesthetic. Local colour is the obvious example in respect of lime washes.

4.3.14 Disfiguring by cement can be avoided by the use of lime

On site the temptation to use quick and easy solutions for short term gain can lead to long term problems. The attraction of using excess cement to be 'safe' is understandable if not desirable. The fact that it is plentiful, inexpensive and readily available adds to the problem. There is a high probability that over-strong and dense mixes that are not fit for purpose will be used in excess. The physical damage and unsightly aesthetic that results from this can be avoided by the use of lime.

4.3.15 Indefinite shelf life

Non-hydraulic lime has an indefinite shelf life when stored without access to air, usually as putty under water or in sealed containers. In fact the quality of the putty improves the longer it is stored. This is an extract from An Introduction to Building Limes by Stafford Holmes, presented to the Foresight Lime research Conference at Manchester University on 19 November 2002 and revised March 2004.

5. SOIL PROPERTIES

5.1 Soil properties

5.1.1 Soil classification

Geotechnical engineers classify the soil particle types by performing tests on disturbed (dried, passed through sieves, and remoulded) samples of the soil. This provides information about the characteristics of the soil grains themselves. It should be noted that classification of the types of grains present in a soil does not account for important effects of the structure or fabric of the soil, terms that describe compactness of the particles and patterns in the arrangement of particles in a load carrying framework as well as the pore size and pore fluid distributions. Engineering geologists also classify soils based on their genesis and depositional history.

5.1.2 Classification of soil grains

In the US and other countries, the Unified Soil Classification System (USCS) is often used for soil classification. Other classification systems include the British Standard and the AASHTO soil classification system.

5.1.3 Classification of sands and gravels

In the USCS, gravels (given the symbol *G*) and sands (given the symbol *S*) are classified according to their grain size distribution. For the USCS, gravels may be given the classification symbol *GW* (well-graded gravel), *GP* (poorly graded gravel), *GM* (gravel with a large amount of silt), or *GC* (gravel with a large amount of clay). Likewise sands may be classified as being *SW*, *SP*, *SM* or *SC*. Sands and gravels with a small but non-negligible amount of fines (5 % - 12 %) may be given a dual classification such as *SW-SC*.

5.1.4Atterberg limits

Clays and Silts, often called 'fine-grained soils', are classified according to their Atterberg limits; the most commonly used Atterberg limits are the Liquid limit (denoted by *LL*), Plastic Limit (denoted by *PL*), and Shrinkage limit (denoted by *SL*). The shrinkage limit corresponds to a water content below which the soil will not shrink as it dries.

The liquid limit and plastic limit are arbitrary limits determined by tradition and convention. The liquid limit is determined by measuring the water content for which a groove closes after 25 blows in a standard test. Alternatively, a fall cone test apparatus may be used to measure the liquid Limit. The undrained shear strength of remoulded soil at the liquid limit is approximately 2 kPa. The plastic limit is the water content below which it is not possible to roll by hand the soil into 3 mm diameter cylinders. The soil cracks or breaks up as it is rolled down to this diameter. Remoulded soil at the plastic limit is quite stiff, having an undrained shear strength of the order of about 200 kPa.

The Plasticity index of a particular soil specimen is defined as the difference between the Liquid limit and the Plastic limit of the specimen it is an indicator of how much water the soil particles in the specimen can absorb. The plasticity index is the difference in water contents between states when the soil is relatively soft and the soil is relatively brittle when moulded by hand.

5.1.5 Classification of silts and clays

According to the Unified Soil Classification System (USCS), silts and clays are classified by plotting the values of their plasticity index and liquid limit on a plasticity chart. The A-Line on the chart separates clays (given the USCS symbol *C*) from silts (given the symbol *M*). LL=50% separates high plasticity soils (given the modifier symbol *H*) from low plasticity soils (given the modifier symbol *L*). A soil that plots above the A-line and has LL>50% would, for example, be classified as *CH*. Other possible classifications of silts and clays are *ML*, *CL* and *MH*. If the Atterberg limits plot in the “hatched" region on the graph near the origin, the soils are given the dual classification 'CL-ML'.

5.1.6 Indices related to soil strength

Liquidity index

The effects of the water content on the strength of saturated remoulded soils can be quantified by the use of the *liquidity index*, *LI*

$$LI = \frac{w - PL}{LL - PL}$$

When the LI is 1, remoulded soil is at the liquid limit and it has an undrained shear strength of about 2 kPa. When the soil is at the plastic limit, the LI is 0 and the undrained shear strength is about 200 kPa.

Relative density

The density of sands (cohesionless soils) is often characterized by the relative density, D_r

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} 100\%$$

Where

e_{max} is the "maximum void ratio" corresponding to a very loose state, e_{min} is the "minimum void ratio" corresponding to a very dense state and e is the in situ void ratio. Methods used to calculate relative density are defined in ASTM D4254-00(2006).

Thus if D_r =100% the sand or gravel is very dense, and if D_r=60% the soil is extremely loose and unstable.

5.1.7 Bulk density

Bulk density is a property of powders, granules and other "divided" solids, especially used in reference to mineral components (soil, gravel), chemical substances, ingredients, foodstuff or any other masses of corpuscular or particulate matter. It is defined as the mass of many particles of the material divided by the total volume they occupy. The total volume includes particle volume, inter-particle void volume and internal pore volume

Bulk density is not an intrinsic property of a material; it can change depending on how the material is handled. For example, a powder poured in to a cylinder will have a particular bulk density; if the cylinder is disturbed, the powder particles will move and usually settle closer together, resulting in a higher bulk density. For this reason, the bulk density of powders is usually reported both as "freely settled" (or "poured" density) and "tapped" density (where the tapped density refers to the bulk density of the powder after a specified compaction process, usually involving vibration of the container.)

The bulk density of soil depends greatly on the mineral make up of soil and the degree of compaction. The density of quartz is around 2.65g/cm³ but the bulk density of a mineral soil is normally about half that density, between 1.0 and 1.6g/cm³. Soils high in organics and some friable clay may have a bulk density well below 1g/cm³

Bulk density of soil is usually determined on Core samples which are taken by driving a metal corer into the soil at the desired depth and horizon. The samples are then oven dried and weighed.

Bulk density = mass of soil/ volume as a whole

$$\rho = \frac{M_s}{V_t}$$

The bulk density of soil is inversely related to the porosity of the same soil: the more pore space in a soil the lower the value for bulk density. Bulk density of a region in the interior of the earth is also related to the seismic velocity of waves travelling through it for P waves, this has been quantified with Gardner's relation. The higher the density, the faster the velocity.

5.1.8 Effective stress

Effective Stress is a force that keeps a collection of particles rigid. Usually this applies to sand, soil or gravel.

If you pinch a stack of coins between your fingers, the stack stays together. If you then loosen the pressure between your fingers, the coin stack falls apart. Similarly, a pile of sand keeps from spreading out like a liquid because the weight of the sand keeps the grains stuck together in their current arrangement, mostly out of static friction. This weight and pressure is the effective stress.

Effective stress is easy to disrupt by the application of additional forces; every footstep on a sand pile demonstrates this. It is an important factor in the study of slope stability and soil liquefaction, especially from earthquakes**.**

Karl von Terzaghi first proposed the relationship for effective stress in 1936. For him, the term ‘effective’ meant the calculated stress that was effective in moving soil, or causing displacements. It represents the average stress carried by the soil skeleton.

Effective stress (σ') acting on a soil is calculated from two parameters, total stress (σ)
and pore water pressure (u) according to

$$\sigma' = \sigma - u$$

Typically, for simple examples

$$\sigma = H_{soil}\gamma_{soil}$$

$$u = H_w\gamma_w$$

Much like the concept of stress itself, the formula is a construct, for the easier visualization of forces acting on a soil mass, especially simple analysis models for slope stability, involving a slip plane. With these models, it is important to know the total weight of the soil above (including water), and the pore water pressure within the slip plane, assuming it is acting as a confined layer.

5.1.9 Bearing capacity

In geotechnical engineering, bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. *Ultimate bearing capacity* is the theoretical maximum pressure which can be supported without failure; *allowable bearing capacity* is the ultimate bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement.

There are three modes of failure that limit bearing capacity

- general shear failure
- local shear failure
- Punching shear failure.

Spread footings and mat foundations are generally classified as shallow foundations. These foundations distribute the loads from the superstructures to the soil on which they are resting. Failure of a shallow foundation may occur in two ways: (a) by shear failure of the soil supporting the foundation (b) by excessive settlement of the soil supporting the foundation.

5.1.10 Porosity

Porosity or void fraction is a measure of the void (i.e., "empty") spaces in a material, and is a fraction of the volume of voids over the total volume, between 0–1, or as a percentage between 0-100%. The term is used in multiple fields including pharmaceutics, ceramics, metallurgy, materials, manufacturing, earth sciences and construction.

Void fraction in two-phase flow

In gas-liquid two-phase flow, the void fraction is defined as the fraction of the flow-channel volume that is occupied by the gas phase or, alternatively, as the fraction of the cross-sectional area of the channel that is occupied by the gas phase. Void fraction usually varies from location to location in the flow channel (depending on the two-phase flow pattern). It fluctuates with time and its value is usually time averaged. In separated (i.e., non-homogeneous) flow, it is related to volumetric flow rates of the gas and the liquid phase, and to the ratio of the velocity of the two phases (called slip ratio).

Porosity in earth sciences and construction

Used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio

$$\phi = \frac{V_V}{V_T}$$

Where

V_V is the volume of void-space (such as fluids) and V_T is the total or bulk volume of material, including the solid and void components. Both the mathematical symbols ϕ and n are used to denote porosity.

Porosity is a fraction between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay. It may also be represented in percent terms by multiplying the fraction by 100. The porosity of a rock, or sedimentary layer, is an important consideration when attempting to evaluate the potential volume of water or hydrocarbons it may contain. Sedimentary porosity is a complicated function of many factors, including but not limited to rate of burial, depth of burial, the nature of the connate fluids, and the nature of overlying sediments.

A value for porosity can alternatively be calculated from the bulk density ρ_{bulk} and particle density ρ_{particle}

$$\phi = 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}}$$

Normal particle density is assumed to be approximately 2.65 g/cm^3, although a better estimation can be obtained by examining the lithology of the particles.

Porosity and hydraulic conductivity

Porosity can be proportional to hydraulic conductivity; for two similar san3dy aquifers, the one with a higher porosity will typically have a higher hydraulic conductivity (more open area for the flow of water), but there are many complications to this relationship. The principal complication is that there is not a direct proportionality between porosity and hydraulic conductivity but rather an inferred proportionality. There is a clear proportionality between pore throat radii and hydraulic conductivity. Also, there tends to be proportionality between pore throat radii and pore volume.

If the proportionality between pore throat radii and porosity exists then proportionality between porosity and hydraulic conductivity may exist. However, as grain size and/or sorting decreases the proportionality between pore throat radii and porosity begins to fail and therefore so does the proportionality between porosity and hydraulic conductivity. For example clays typically have very low hydraulic conductivity (due to their small pore throat radii) but also have very high porosities (due to the structured nature of clay minerals), which means clays can hold a large volume of water per volume of bulk material, but they do not release water rapidly and therefore have low hydraulic conductivity.

Measuring porosity

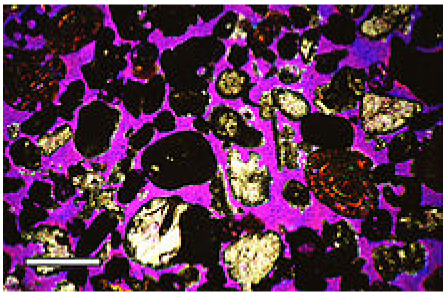


Fig 5.1 porosity measuring

Optical method of measuring porosity thin section under gypsum plate shows porosity as purple colour, contrasted with carbonate grains of other colours.

Several methods can be employed to measure porosity

Direct methods (determining the bulk volume of the porous sample, and then determining the volume of the skeletal material with no pores (pore volume = total volume − material volume).

Optical methods (e.g., determining the area of the material versus the area of the pores visible under the microscope). The "areal" and "volumetric" porosities are equal for porous media with random structure.

Computed topography method (using industrial CT scanning to create a 3D rendering of external and internal geometry, including voids.Then implementing a defect analysis utilizing computer software)

Imbibition methods, i.e., immersion of the porous sample, under vacuum, in a fluid that preferentially wets the pores.

Water saturation method (pore volume = total volume of water − volume of water left after soaking).

Water evaporation method (pore volume = (weight of saturated sample − weight of dried sample)/density of water).

Mercury intrusion porosimetry (several non-mercury intrusion techniques have been developed due to toxicological concerns, and the fact that mercury tends to form amalgams with several metals and alloys).

Gas expansion method a sample of known bulk volume is enclosed in a container of known volume. It is connected to another container with a known volume which is evacuated (i.e., near vacuum pressure). When a valve connecting the two containers is opened, gas passes from the first container to the second until a uniform pressure distribution is attained. Using ideal gas law, the volume of the pores is calculated as

$$V_V = V_T - V_a - V_b \frac{P_2}{P_2 - P_1}$$

Where

V_V is the effective volume of the pores,

V_T is the bulk volume of the sample,

V_a is the volume of the container containing the sample,

V_b is the volume of the evacuated container,

P_1 is the initial pressure in the initial pressure in volume V_a and V_V, and

P_2 is final pressure present in the entire system.

The porosity follows straightforwardly by its proper definition

$$\phi = \frac{V_V}{V_T}.$$

Note that this method assumes that gas communicates between the pores and the surrounding volume. In practice, this means that the pores must not be closed cavities.

A small crystal of a liquid melts at a lower temperature than the bulk liquid, as given by the Gibbs-Thomson equation. Thus if a liquid is imbibed into a porous material, and frozen, the melting temperature will provide information on the pore-size distribution. The detection of the melting can be done by sensing the transient heat flows during phase-changes using differential scanning calorimetry , measuring the quantity of mobile liquid using nuclear magnetic resonance - (NMR cryoporometry) or measuring the amplitude of neutron scattering from the imbibed crystalline or liquid phases.

5.1.11 Void ratio

Void ratio, in materials science, is related to porosity and defined as the ratio

$$e = \frac{V_V}{V_S} = \frac{V_V}{V_T - V_V} = \frac{\phi}{1 - \phi}$$

And

$$\phi = \frac{V_V}{V_T} = \frac{V_V}{V_S + V_V} = \frac{e}{1 + e}$$

Where

e is void ratio, ϕ is porosity, V_V is the volume of void-space (such as fluids), V_S is the volume of solids, and V_T is the total or bulk volume.

$$e = \frac{V_V}{V_S} = \frac{V_V}{V_T - V_V} = \frac{n}{1 - n}$$

$$n = \frac{V_V}{V_T} = \frac{V_V}{V_S + V_V} = \frac{e}{1 + e}$$

Where

e Is void ratio, n is porosity, V_V is the volume of void-space (air and water), V_S is the volume of solids, and V_T is the total or bulk volume.

Engineering applications

Volume change tendency control. If void ratio is high (loose soils) voids in a soil skeleton tend to minimize under loading - adjacent particles contract. The opposite situation, i.e. when void ratio is relatively small (dense soils), indicates that the volume of the soil is vulnerable to increase under loading - particles dilate.

Fluid conductivity control (ability of water movement through the soil). Loose soils show high conductivity, while dense soils are not so permeable.
Particles movement in a loose soil particles can move quite easily, whereas in a dense one finer particles cannot pass through the voids, which leads to clogging.

5.2 Laboratory tests

5.2.1 Soil compaction

In Geotechnical engineering, soil compaction is the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains. When stress is applied that causes densification due to water (or other liquid) being displaced from between the soil grains then Consolidation (soil), not compaction, has occurred. Normally, compaction is the result of heavy machinery compressing the soil, but it can also occur due to the passage of (e.g.) animal feet.

In Soil Science and Agronomy soil compaction is usually a combination of both engineering compaction and consolidation, so may occur due to a lack of water in the soil, the applied stress being internal suction due to water evaporation as well as due to passage of animal feet. Affected soils become less able to absorb rainfall, thus increasing runoff and erosion. Plants have difficulty in compacted soil because the mineral grains are pressed together, leaving little space for air and water, which are essential for root growth. Burrowing animals also find it a hostile environment, because the denser soil is more difficult to penetrate. The ability of a soil to recover from this type of compaction depends on climate, mineralogy and fauna. Soils with high shrink-swell capacity, recover quickly from compaction where moisture conditions are variable (dry spells shrink the soil, causing it to crack). But clays which do not crack as they dry cannot recover from compaction on their own unless they host ground-dwelling animals such as earthworms the Cecil soil series is an example.

Compaction Methods

There are several means of achieving compaction of a material. Some are more appropriate for soil compaction than others, while some techniques are only suitable for particular soils or soils in particular conditions. Some are more suited to compaction of non-soil materials such as asphalt. Generally, those that can apply significant amounts of shear as well as compressive stress are most effective.

The available techniques can be classified as stress is slowly applied to the soil and then released.

Impact - the stress is applied by dropping a large mass onto the surface of the soil.

Vibrating - a stress is applied repeatedly and rapidly via a mechanically driven plate or hammer. Often combined with rolling compaction.

Gyrating - a static stress is applied and Static - a large maintained in one direction while the soil is a subjected to a gyratory motion about the axis of static loading.

Rolling - a heavy cylinder is rolled over the surface of the soil. Commonly used on sports pitches. Roller-compactors are often fitted with vibratory devices to enhance their ability.

Kneading - shear is applied by alternating movement in adjacent positions. An example, combined with rolling compaction, is the 'sheep foot' roller used in waste compaction at landfills.

The construction plant available to achieve compaction is extremely varied and is described elsewhere.

In construction

Soil compaction is a vital part of the construction process. It is used for support of structural entities such as building foundations, roadways, walkways, and earth retaining structures to name a few. For a given soil type certain properties may deem it more or less desirable to perform adequately for a particular circumstance. In general, the preselected soil should have adequate strength, be relatively incompressible so that future settlement is not significant, be stable against volume change as water content or other factors vary, be durable and safe against deterioration, and possess proper permeability.

When an area is to be filled or backfilled the soil is placed in layers called lifts. The ability of the first fill layers to be properly compacted will depend on the condition of the natural material being covered. If poor material is left in place and covered over, it may compress over a long period under the weight of the earth fill, causing settlement cracks in the fill or in any structure supported by the fill. In order to determine if the natural soil will support the first fill layers, an area can be proof rolled. Proof rolling consists of utilizing a piece heavy construction equipment (typically, heavy compaction equipment or hauling equipment) to roll across the fill site and watching for poor areas to be revealed. Poor areas will be indicated by the development of rutting or ground weaving.

To ensure adequate soil compaction is achieved, project specifications will indicate the required soil density or degree of compaction that must be achieved. These specifications are generally recommended by a geotechnical engineer in a geotechnical engineering report.

The soil type that is, grain-size distributions, shape of the soil grains, specific gravity of soil solids, and amount and type of clay minerals present - has a great influence on the maximum dry unit weight and optimum moisture content. It also has a great influence on how the materials should be compacted in given situations. Compaction is accomplished by use of heavy equipment. In sands and gravels, the equipment usually vibrates, to cause re orientation of the soil particles into a denser configuration. In silts and clays, a sheep foot roller is frequently used, to create small zones of intense shearing, which drives air out of the soil.

Determination of adequate compaction is done by determining the in-situ density of the soil and comparing it to the maximum density determined by a laboratory test. The most commonly used laboratory test is called the Proctor compaction test and there are two different methods in obtaining the maximum density. They are the standard Proctor and modified Proctor tests; the modified Proctor is more commonly used.

5.2.2 Consolidation

Consolidation is a process by which soils decrease in volume. According to Karl Terzaghi consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air. In general it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil. The magnitude of consolidation can be predicted by many different methods. In the Classical Method, developed by Terzaghi, soils are tested with an odometers test to determine their compression index. This can be used to predict the amount of consolidation.

When stress is removed from a consolidated soil, the soil will rebound, regaining some of the volume it had lost in the consolidation process. If the stress is reapplied, the soil will consolidate again along a recompression curve, defined by the recompression index. The soil which had its load removed is considered to be over consolidated. This is the case for soils which have previously had glaciers on them. The highest stress that it has been subjected to is termed the pre consolidation stress. The over consolidation ratio is defined as the highest stress experienced divided by the current stress. A soil which is currently experiencing its highest stress is said to be normally consolidated and to have an OCR of one. A soil could be considered under consolidated immediately after a new load is applied but before the excess pore water pressure has had time to dissipate.

Spring analogy

The process of consolidation is often explained with an idealized system composed of a spring, a container with a hole in its cover, and water. In this system, the spring represents the compressibility or the structure itself of the soil, and the water which fills the container represents the pore water in the soil.

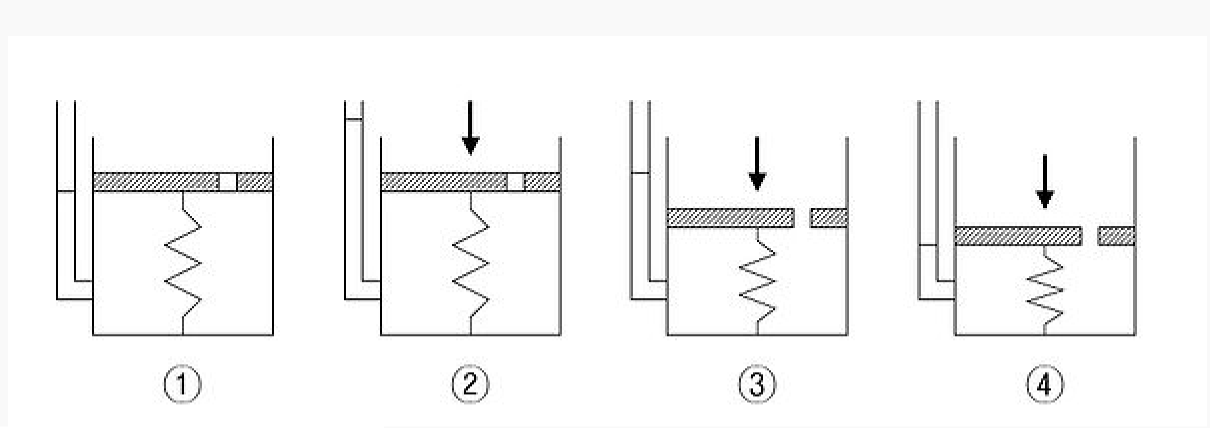


Fig 5.2 consolidation

1. The container is completely filled with water, and the hole is closed. (Fully saturated soil)
2. A load is applied onto the cover, while the hole is still unopened. At this stage, only the water resists the applied load. (Development of excess pore water pressure)
3. As soon as the hole is opened, water starts to drain out through the hole and the spring shortens. (Drainage of excess pore water pressure)

4. After some time, the drainage of water no longer occurs. Now, the spring alone resists the applied load. (Full dissipation of excess pore water pressure. End of consolidation)

Primary consolidation

This method assumes consolidation occurs in only one-dimension. Laboratory data is used to construct a plot of strain or void ratio versus effective stress where the effective stress axis is on algorithmic. The plot's slope is the compression index or recompression index. The equation for consolidation settlement of a normally consolidated soil can then be determined to be

$$\delta_c = \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'_{zf}}{\sigma'_{z0}}\right)$$

Where

δ_c is the settlement due to consolidation.

C_c is the compression index.

e_0 is the initial void ratio.

H is the height of the soil.

σ_{zf} is the final vertical stress.

σ_{z0} is the initial vertical stress.

C_c can be replaced by C_r (the recompression index) for use in over consolidated soils where the final effective stress is less than the pre consolidation stress. When the final effective stress is greater than the pre consolidation stress, the two equations must be used in combination to model both the recompression portion and the virgin compression portion of the consolidation process, as follows

$$\delta_c = \frac{C_r}{1+e_0} H \log\left(\frac{\sigma'_{zc}}{\sigma'_{z0}}\right) + \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'_{zf}}{\sigma'_{zc}}\right)$$

Where σ_{zc} is the pre consolidation stress of the soil.

Secondary compression

Secondary compression is the compression of soil that takes place after primary consolidation. Even after the reduction of hydrostatic pressure some compression of soil takes place at slow rate. This is known as secondary compression. Secondary compression is caused by creep, viscous behaviour of the clay-water system, compression of organic matter, and other processes. In sand, settlement caused by secondary compression is negligible, but in peat, it is very significant. Due to secondary compression some of the highly viscous water between the points of contact is forced out.

5.2.3 Tests on soil

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The sub grade soil and its properties are important in the design of pavement structure. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests.

The tests used to evaluate the strength properties of soils may be broadly divided into three groups

1. Shear tests
2. Bearing tests
3. Penetration tests

5.2.4 Sieve analysis

A sieve analysis (or gradation test) is a practice or procedure used (commonly used in civil engineering) to assess the particle size distribution (also called gradation) of a granular material.

The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, and soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common.

Fig 5.3 Sieves used for gradation test

Fig 5.4 a mechanical shaker used for sieve analysis

A gradation test is performed on a sample of aggregate in a laboratory. A typical sieve analysis involves a nested column of sieves with wire mesh cloth (screen). See the separate Mesh (scale) page for details of sieve sizing.

A representative weighed sample is poured into the top sieve which has the largest screen openings. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver.

The column is typically placed in a mechanical shaker. The shaker shakes the column, usually for some fixed amount of time. After the shaking is complete the material on each sieve is weighed. The weight of the sample of each sieve is then divided by the total weight to give a percentage retained on each sieve.

The size of the average particle on each sieve is then analysed to get a cut-off point or specific size range, which is then captured on a screen.

The results of this test are used to describe the properties of the aggregate and to see if it is appropriate for various civil engineering purposes such as selecting the appropriate aggregate for concrete mixes and asphalt mixes as well as sizing of water production well screens. The results of this test are provided in graphical form to identify the type of gradation of the aggregate.

A suitable sieve size for the aggregate should be selected and placed in order of decreasing size, from top to bottom, in a mechanical sieve shaker. A pan should be placed underneath the nest of sieves to collect the aggregate that passes through the smallest. The entire nest is then agitated, and the material whose diameter is smaller than the mesh opening pass through the sieves. After the aggregate reaches the pan, the amount of material retained in each sieve is then weighed.

Preparation

In order to perform the test, a sample of the aggregate must be obtained from the source. To prepare the sample, the aggregate should be mixed thoroughly and be reduced to a suitable size for testing. The total weight of the sample is also required.

Methods

There are different methods for carrying out sieve analyses, depending on the material to be measured.

Fig 5.5 Throw-Action Sieving

Here a throwing motion acts on the sample. The vertical throwing motion is overlaid with a slight circular motion which results in distribution of the sample amount over the whole sieving surface. The particles are accelerated in the vertical direction (are thrown upwards).

In the air they carry out free rotations and interact with the openings in the mesh of the sieve when they fall back. If the particles are smaller than the openings, they pass through the sieve. If they are larger, they are thrown upwards again. The rotating motion while suspended increases the probability that the particles present a different orientation to the mesh when they fall back again and thus might eventually pass through the mesh.

Modern sieve shakers work with an electro-magnetic drive which moves a spring mass system and transfers the resulting oscillation to the sieve stack. Amplitude and sieving time are set digitally and are continuously observed by an integrated control-unit. Therefore sieving results are reproducible and precise (an important precondition for a significant analysis). Adjustment of parameters like amplitude and sieving time serves to optimize the sieving for different types of material. This method is the most common in the laboratory.

Fig 5.6 Horizontal Sieving

In a horizontal sieve shaker the sieve stack moves in horizontal circles in a plane. Horizontal sieve shakers are preferably used for needle-shaped, flat, long or fibrous samples, as their horizontal orientation means that only a few disoriented particles enter the mesh and the sieve is not blocked so quickly. The large sieving area enables the sieving of large amounts of sample, for example as encountered in the particle-size analysis of construction materials and aggregates.

Fig 5.7 Tapping Sieving

A horizontal circular motion overlies a vertical motion which is created by a tapping impulse. These motional processes are characteristic of hand sieving and produce a higher degree of sieving for denser particles (e.g. abrasives) than throw-action sieve shakers.

Sonic sieving

The particles are lifted and forcibly dropped in a column of oscillating air at a frequency of thousands of cycles per minute. Sonic sievers are able to handle much finer dry powders than woven mesh screens.

Wet sieving

Most sieve analyses are carried out dry. But there are some applications which can only be carried out by wet sieving. This is the case when the sample which has to be analysed is e.g. a suspension which must not be dried; or when the sample is a very fine powder which tends to agglomerate (mostly < 45 µm) – in a dry sieving process this tendency would lead to a clogging of the sieve meshes and this would make a further sieving process impossible. A wet sieving process is set up like a dry process: the sieve stack is clamped onto the sieve shaker and the sample is placed on the top sieve.

Above the top sieve a water-spray nozzle is placed which supports the sieving process additionally to the sieving motion. The rinsing is carried out until the liquid which is discharged through the receiver is clear. Sample residues on the sieves have to be dried and weighed. When it comes to wet sieving it is very important not to change to sample in its volume (no swelling, dissolving or reaction with the liquid).

Air Jet Sieving

Air jet sieving machines are ideally suited for very fine powders which tend to agglomerate and cannot be separated by vibrational sieving. The reason for the effectiveness of this sieving method is based on two components: A rotating slotted nozzle inside the sieving chamber and a powerful industrial vacuum cleaner which is connected to the chamber. The vacuum cleaner generates a vacuum inside the sieving chamber and sucks in fresh air through the slotted nozzle. When passing the narrow slit of the nozzle the air stream is accelerated and blown against the sieve mesh, dispersing the particles. Above the mesh, the air jet is distributed over the complete sieve surface and is sucked in with low speed through the sieve mesh. Thus the finer particles are transported through the mesh openings into the vacuum cleaner.

Types of gradation

Dense gradation

A dense gradation refers to a sample that is approximately of equal amounts of various sizes of aggregate. By having a dense gradation, most of the air voids between the material are filled with particles. A dense gradation will result in an even curve on the gradation graph.

Narrow gradation

Also known as uniform gradation, a narrow gradation is a sample that has aggregate of approximately the same size. The curve on the gradation graph is very steep, and occupies a small range of the aggregate.

Gap gradation

A gap gradation refers to a sample with very little aggregate in the medium size range. This results in only coarse and fine aggregate. The curve is horizontal in the medium size range on the gradation graph.

Open gradation

An open gradation refers an aggregate sample with very little fine aggregate particles. This results in many air voids, because there are no fine particles to fill them. On the gradation graph, it appears as a curve that is horizontal in the small size range.

Rich gradation

A rich gradation refers to a sample of aggregate with a high proportion of particles of small sizes.

Limitations of sieve analysis

Sieve analysis has, in general, been used for decades to monitor material quality based on particle size. For coarse material, sizes that range down to 150µm a sieve analysis and particle size distribution is accurate and consistent.

However, for material that is finer than 100 meshes, dry sieving can be significantly less accurate. This is because the mechanical energy required making particles pass through an opening and the surface attraction effects between the particles themselves and between particles and the screen increase as the particle size decreases.

Wet sieve analysis can be utilized where the material analyzed is not affected by the liquid except to disperse it. Suspending the particles in a suitable liquid transports fine material through the sieve much more efficiently than shaking the dry material.

Sieve analysis assumes that all particle will be round (spherical) or nearly so and will pass through the square openings when the particle diameter is less than the size of the square opening in the screen. For elongated and flat particles a sieve analysis will not yield reliable mass-based results, as the particle size reported will assume that the particles are spherical, where in fact an elongated particle might pass through the screen end-on, but would be prevented from doing so if it presented itself side-on.

Properties

Gradation affects many properties of an aggregate. It affects bulk density, physical stability and permeability. With careful selection of the gradation, it is possible to achieve high bulk density, high physical stability, and low permeability. This is important because in pavement design, a workable, stable mix with resistance to water is important. With an open gradation, the bulk density is relatively low, due to the lack of fine particles, the physical stability is moderate, and the permeability is quite high. With a rich gradation, the bulk density will also be low, the physical stability is low, and the permeability is also low. The gradation can be affected to achieve the desired properties for the particular engineering application.

Engineering applications

Gradation is usually specified for each engineering application it is used for. For example, foundations might only call for coarse aggregates, and therefore an open gradation is needed. Gradation is a primary concern in pavement mix design. Concrete could call for both coarse and fine particles and a dense graded aggregate would be needed. Asphalt design also calls for a dense graded aggregate. Gradation also applies to sub grades in paving, which is the material that a road is paved on. Gradation, in this case, depends on the type of road (i.e. highway, rural, suburban) that is being paved.

Within the last years some methods for particle size distribution measurement were developed which work by means of laser diffraction or digital image processing.

Fig 5.8 Sieving with Digital Image Processing

The scope of information conveyed by sieve analysis is relatively small. It does not allow for a clear statement concerning the exact size of a single particle → it is just classified within a size range which is determined by two sieve sizes ("a particle is < than sieve size x and > than sieve size y"). And there is no additional information concerning other relevant properties like opacity or shape available.

Devices which work with digital image processing enable to recall even this information and a lot more (surface analysis, etc.). The results can be fitted to sieve analysis so that a comparison between measurement results obtained with different methods is possible. Digital image processing is being used to sieve materials in mining, agriculture, and forestry industries on a regular basis.

5.2.5 Water content

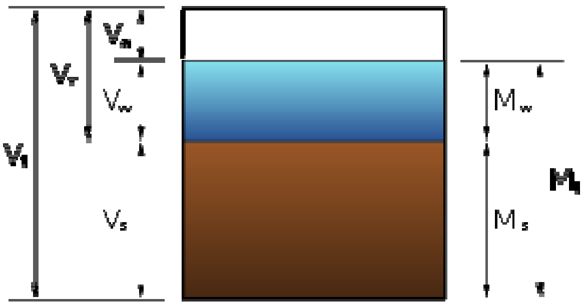


Fig 5.9 water content

Soil composition by phase s-soil (dry), v-void (pores filled with water or air), w-water, a-air. V is volume, M is mass.

Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, fruit, or wood. Water content is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation. It can be given on a volumetric or mass (gravimetric) basis.

Definitions

Volumetric water content, θ, is defined mathematically as

$$\theta = \frac{V_w}{V_T}$$

Where

V_w Is the volume of water and $V_T = V_s + V_v = V_s + V_w + V_a$ is the total volume (that is soil volume + water volume + air space)

Gravimetric water content

Is expressed by mass (weight) as follows

$$u = \frac{m_w}{m_t}$$

The bulk mass is taken as the total mass, except for geotechnical and soil science applications where oven-dried soil (m_s, see the diagram) is conventionally used as m_t.

To convert gravimetric water content to volumetric water, multiply the gravimetric water content by the bulk specific gravity of the material.

In soil mechanics and petroleum engineering, the term water saturation or degree of saturation, **S** is used, defined as

$$S_w = \frac{V_w}{V_v} = \frac{V_w}{V_T \phi} = \frac{\theta}{\phi}$$

Where

$\phi = V_v / V_T$ Is the porosity and

V_v is the volume of void or pore space.

Values of ***S*** can range from 0 (dry) to 1 (saturated). In reality, ***S*** never reaches 0 or 1 - these are idealizations for engineering use.

Direct methods

Water content can be directly measured using a known volume of the material, and a drying oven. Volumetric water content, θ, is calculated using

$$\theta = \frac{m_{\text{wet}} - m_{\text{dry}}}{\rho_w \cdot V_b}$$

Where

m_{wet} and m_{dry} are the masses of the sample before and after drying in the oven

ρ_w is the density of water; and

V_b is the volume of the sample before drying the sample

For materials that change in volume with water content, such as coal, the water content,

u, is expressed in terms of the mass of water per unit mass of the moist specimen.

$$u = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{wet}}}$$

However, geotechnics requires the moisture content to be expressed as a percentage of the sample's dry weight i.e. % moisture content = $u * 100$

Where

$$u = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{dry}}}$$

For wood, the convention is to report moisture content on oven-dry basis (i.e. generally drying sample in an oven set at 105 deg Celsius for 24 hours). In wood drying, this is an important concept.

Other methods that determine water content of a sample include chemical titrations determining mass loss on heating (perhaps in the presence of an inert gas), or after freeze drying. In the food industry the Dean-Stark method is also commonly used.

$$p = \frac{W - D}{D}$$

Where

p is the fraction of total evaporable moisture content of sample,

W is the mass of the original sample, and

D is mass of dried sample.

Geophysical methods

There are several geophysical methods available that can approximate *in situ* soil water content. These methods include: time-domain reflectometry (TDR), neutron probe, frequency domain sensor, capacitance probe, electrical resistivity tomography, ground penetrating radar (GPR), and others that are sensitive to the physical properties of water . Geophysical sensors are often used to monitor soil moisture continuously in agricultural and scientific applications.

Satellite remote sensing method

Satellite microwave remote sensing is used to estimate soil moisture based on the large contrast between the dielectric properties of wet and dry soil. The microwave radiation is not sensitive to atmospheric variables, and can penetrate through clouds. Also, microwave signal can penetrate, to a certain extent, the vegetation canopy and retrieve information from ground surface. The data from microwave remote sensing satellite such as Wind Sat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT are used to estimate surface soil moisture.

Classification and uses

Moisture may be present as adsorbed moisture at internal surfaces and as capillary condensed water in small pores. At low relative humidities, moisture consists mainly of adsorbed water. At higher relative humidities, liquid water becomes more and more important, depending on the pore size. In wood-based materials, however, almost all water is adsorbed at humidities below 98% RH.

In biological applications there can also be a distinction between physisorbed water and "free" water the physisorbed water being that closely associated with and relatively difficult to remove from a biological material. The method used to determine water content may affect whether water present in this form is accounted for. For a better indication of "free" and "bound" water, the water activity of a material should be considered.

Water molecules may also be present in materials closely associated with individual molecules, as "water of crystallization", or as water molecules which are static components of protein structure.

Use of water content in Earth and agricultural sciences

In soil science, hydrology and agricultural sciences, water content has an important role for groundwater recharge, agriculture, and soil chemistry. Many recent scientific research efforts have aimed toward a predictive-understanding of water content over space and time.

Observations have revealed generally that spatial variance in water content tends to increase as overall wetness increases in semiarid regions, to decrease as overall wetness increases in humid regions, and to peak under intermediate wetness conditions in temperate region.

5.2.6 Liquid limit

Fig 5.10 Casagrande cup in action

Casagrande cup

The liquid limit (LL) is the water content at which a soil changes from plastic to liquid behaviour. The original liquid limit test of Atterberg's involved mixing a pat of clay in a round-bottomed porcelain bowl of 10-12cm diameter. A groove was cut through the pat of clay with a spatula, and the bowl was then struck many times against the palm of one hand.

Casagrande subsequently standardized the apparatus and the procedures to make the measurement more repeatable. Soil is placed into the metal cup portion of the device and a groove is made down its centre with a standardized tool of 13.5 millimetres (0.53 in) width. The cup is repeatedly dropped 10mm onto a hard rubber base at a rate of 120 blows per minute, during which the groove closes up gradually as a result of the impact. The number of blows for the groove to close is recorded.

The moisture content at which it takes 25 drops of the cup to cause the groove to close over a distance of 13.5 millimetres is defined as the liquid limit. The test is normally run at several moisture contents, and the moisture content which requires 25 blows to close the groove is interpolated from the test results. the test method also allows running the test at one moisture content where 20 to 30 blows are required to close the groove then a correction factor is applied to obtain the liquid limit from the moisture content.

The following is when you should record the N in number of blows needed to close this 1/2inch gap. The materials needed to do a Liquid limit test are as follows

- Casagrande cup (liquid limit device)
- Grooving tool
- Soil pat before test
- Soil pat after test

Another method for measuring the liquid limit is the fall cone test. It is based on the measurement of penetration into the soil of a standardized cone of specific mass. Although the Casagrande test is widely used across North America, the fall cone test is much more prevalent in Europe due to being less dependent on the operator in determining the Liquid Limit.

Importance of Liquid Limit test

The importance of the liquid limit test is to classify soils. Different soils have varying liquid limits. Also to find the plasticity index of a soil you need to know the liquid limit and the plastic limit.

5.2.7 Shrinkage limit

The shrinkage limit (SL) is the water content where further loss of moisture will not result in any more volume reduction. The shrinkage limit is much less commonly used than the liquid and plastic limits.

5.2.8 Plastic limit

The plastic limit is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. If the soil is plastic, this thread will retain its shape down to a very narrow diameter. The sample can then be re-consolidated and the test repeated.

As the moisture content falls due to evaporation, the thread will begin to break apart at larger diameters. The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3 mm a soil is considered non-plastic if a thread cannot be rolled out down to 3mm at any moisture.

Plasticity index

The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay.

Based on PI the soil is classified as follows

0 – Non plastic
(1-5)- Slightly plastic
(5-10) - Low plasticity
(10-20)- Medium plasticity
(20-40)- High plasticity
>40 Very high plasticity

Liquidity index

The liquidity index (LI) is used for scaling the natural water content of a soil sample to the limits. It can be calculated as a ratio of difference between natural water content, plastic limit, and liquid limit LI= (W-PL)/ (LL-PL) where W is the natural water content.

5.2.9 Permeability

Permeability in fluid mechanics and the earth sciences (commonly symbolized as κ, or k) is a measure of the ability of a porous material (often, a rock or unconsolidated material) to allow fluids to pass through it.

Applications

The concept of permeability is of importance in determining the flow characteristics of hydrocarbons in oil and gas reservoirs, and of groundwater in aquifers.

For a rock to be considered as an exploitable hydrocarbon reservoir without stimulation, its permeability must be greater than approximately 100 mD (depending on the nature of the hydrocarbon - gas reservoirs with lower permeabilities are still exploitable because of the lower viscosity of gas with respect to oil). Rocks with permeabilities significantly lower than 100 mD can form efficient seals. Unconsolidated sands may have permeabilities of over 5000 mD.The concept has also many practical applications outside of geology, for example in chemical engineering (e.g., filtration).

Permeability is part of the proportionality constant in Darcy's law which relates discharge (flow rate) and fluid physical properties (e.g. viscosity), to a pressure gradient applied to the porous media

$$v = \frac{\kappa}{\mu}\frac{\Delta P}{\Delta x}$$

Therefore

$$\kappa = v\frac{\mu\Delta x}{\Delta P}$$

Where

v is the superficial fluid flow velocity through the medium (i.e., the average velocity calculated as if the fluid were the only phase present in the porous medium) (m/s)

κ is the permeability of a medium (m^2)

μ Is the dynamic viscosity of the fluid (Pa·s)

ΔP is the applied pressure difference (Pa)

$\Delta x$is the thickness of the bed of the porous medium (m)

In naturally occurring materials, permeability values range over many orders of magnitude.

Relation to hydraulic conductivity

The proportionality constant specifically for the flow of water through a porous media is called the hydraulic conductivity; permeability is a portion of this, and is a property of the porous media only, not the fluid. Given the value of hydraulic conductivity for a subsurface system, *k*, the permeability can be calculated as

$$\kappa = k\frac{\mu}{\rho g}$$

Where
κ is the permeability, m^2
k is the hydraulic conductivity, m/s
μ is the dynamic viscosity, kg/ (m·s)
ρ is the density of the fluid, kg/m^3
g is the acceleration due to gravity, m/s^2.

Permeability is typically determined in the lab by application of Darcy's law under steady state conditions or, more generally, by application of various solutions to the diffusion equation for unsteady flow conditions. Permeability needs to be measured, either directly (using Darcy's law) or through estimation using empirically derived formulas. However, for some simple models of porous media, permeability can be calculated (e.g., random close packing of identical spheres).

Permeability model based on conduit flow

Based on Hagen Poiseuille equation for viscous flow in a pipe, permeability can be expressed as

$$\kappa_I = C \cdot d^2$$

Where
k is the intrinsic permeability [$length^2$]
C is a dimensionless constant that is related to the configuration of the flow-paths
D is the average, or effective pore diameter [length].

Intrinsic and absolute permeability

The terms intrinsic permeability and absolute permeability states that the permeability value in question is an intensive property (not a spatial average of a heterogeneous block of material), that it is a function of the material structure only (and not of the fluid), and explicitly distinguishes the value from that of relative permeability.

Permeability to gases

Sometimes permeability to gases can be somewhat different that those for liquids in the same media. One difference is attributable to "slippage" of gas at the interface with the solid when the gas mean free path is comparable to the pore size (about 0.01 to 0.1 μm at standard temperature and pressure). See also Knudsen diffusion and constrictivity. For example, measurement of permeability through sandstones and shales yielded values from $9.0\text{x}10^{-19}$ m^2 to $2.4\text{x}10^{-12}$ m^2 for water and between $1.7\text{x}10^{-17}$ m^2 to $2.6\text{x}10^{-12}$ m^2 for nitrogen gas. Gas permeability of reservoir rock and source rock is important in petroleum engineering, when considering the optimal extraction of shale gas, tight gas, or coal bed methane.

Tensor permeability

To model permeability in anisotropic media, a permeability tensor is needed. Pressure can be applied in three directions, and for each direction, permeability can be measured (via

Darcy's law in 3D) in three directions, thus leading to a 3 by 3 tensor. The tensor is realized using a 3 by 3 matrix being both symmetric and positive definite (SPD matrix)

The tensor is symmetric by the Onsager reciprocal relations. The tensor is positive definite as the component of the flow parallel to the pressure drop is always in the same direction as the pressure drop. The permeability tensor is always diagonalizable (being both symmetric and positive definite). The eigenvectors will yield the principal directions of flow, meaning the directions where flow is parallel to the pressure drop, and the eigen values representing the principal permeabilities.

5.3 Field tests

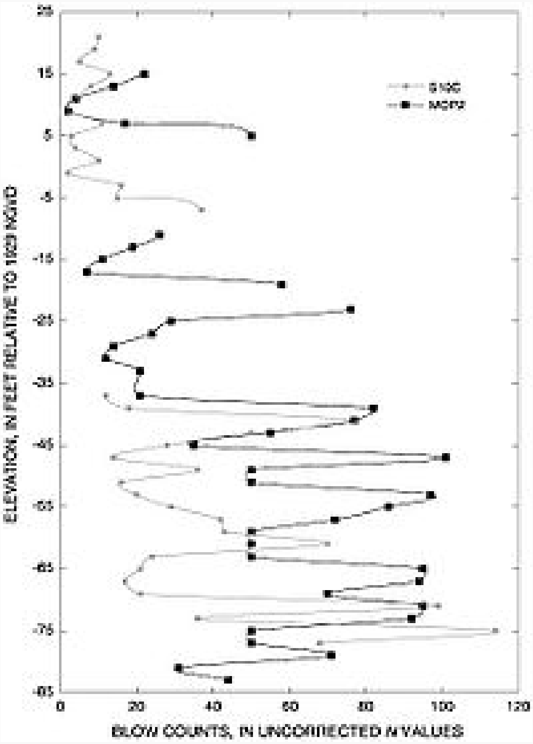
5.3.1 Bearing test

Bearing tests are loading tests carried out on sub grade soils in-situ with a load bearing area. The results of the bearing tests are influenced by variations in the soil properties within the stressed soil mass underneath and hence the overall stability of the part of the soil mass stressed could be studied.

5.3.2 Penetration test

Penetration tests may be considered as small scale bearing tests in which the size of the loaded area is relatively much smaller and ratio of the penetration to the size of the loaded area is much greater than the ratios in bearing tests. The penetration tests are carried out in the field or in the laboratory.

Standard penetration test

- 

The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil.

Fig 5.2 standard penetration test

The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels from which it is virtually impossible to obtain undisturbed samples. The great merit of the test and the main reason for its widespread use is that it is simple and inexpensive. The soil strength parameters which can be inferred are approximate, but may give a useful guide in ground conditions where it may not be possible to obtain borehole samples of adequate quality like gravels, sands, silts, clay containing sand or gravel and weak rock.

In conditions where the quality of the undisturbed sample is suspect, e.g. very silty or very sandy clays, or hard clays, it is often advantageous to alternate the sampling with standard penetration tests to check the strength. If the samples are found to be unacceptably disturbed, it may be necessary to use a different method for measuring strength like the plate test. When the test is carried out in granular soils below groundwater level, the soil may become loosened. In certain circumstances, it can be useful to continue driving the sampler beyond the distance specified, adding further drilling rods as necessary. Although this is not a standard penetration test, and should not be regarded as such, it may at least give an indication as to whether the deposit is really as loose as the standard test may indicate.

The usefulness of SPT results depends on the soil type, with fine-grained sands giving the most useful results, with coarser sands and silty sands giving reasonably useful results, and clays and gravelly soils yielding results which may be very poorly representative of the true soil conditions. Soils in arid areas, such as the Western United States, may exhibit natural cementation. This condition will often increase the standard penetration value.

The SPT is used to provide results for empirical determination of a sand layer's susceptibility to earthquake liquefaction, based on research performed by Harry Seed.

Correlation with Soil Mechanical Properties

Despite its many flaws, it is usual practice to correlate SPT results with soil properties relevant for geotechnical engineering design. The reason being that SPT results are often the only test results available, therefore the use of direct correlations has become common practice in many countries. Different correlations are proposed for granular and cohesive soils.

Cone penetration test

The cone penetration test (CPT) is used to determine the geotechnical engineering properties of soils and delineating soil stratigraphy. It was initially developed in the 1950s at the Dutch Laboratory for Soil Mechanics in Delft to investigate soft soils. Based on this history it has also been called the "Dutch cone test". Today, the CPT is one of the most used and accepted in soil methods for soil investigation worldwide.

The test method consists of pushing an instrumented cone, with the tip facing down, into the ground at a controlled rate (controlled between 1.5 -2.5cm/s Accepted). The resolution of the CPT in delineating stratigraphic layers is related to the size of the cone tip, with typical cone tips having a cross-sectional area of either 10 or 15 cm^2, corresponding to diameters of 3.6 and 4.4 cm.

The early applications of CPT mainly determined the soil geotechnical property of bearing capacity. The original cone penetrometers involved simple mechanical measurements of the total penetration resistance to pushing a tool with a conical tip into the soil. Different methods were employed to separate the total measured resistance into components generated by the conical tip and friction generated by the rod string. A frictionsleeve was added to quantify this component of the friction and aid in determining soil cohesive strength in the 1960s. Electronic measurements began in 1948 and improved further in the early 1970s. Most modern electronic CPT cones now also employ a pressure transducer with a filter to gather pore water pressure data.

The filter is usually located either on the cone tip, immediately behind the cone tip or behind the friction sleeve. Pore water pressure data aids determining stratigraphy and is primarily used to correct tip friction values for those effects. CPT testing which also gathers this piezometer data is called CPTU testing. CPT and CPTU testing equipment generally advances the cone using hydraulic rams mounted on either a heavily ballasted vehicle or using screwed-in anchors as a counter-force. One advantage of CPT over the Standard Penetration Test (SPT) is a more continuous profile of soil parameters, with CPTU data recorded typically at 2cm intervals.

Standards and use

CPT for geotechnical applications was standardized in 1986 by ASTM Standard D 3441 (ASTM, 2004). ISSMGE provides international standards on CPT and CPTU. Later ASTM Standards have addressed the use of CPT for various environmental site characterizations and groundwater monitoring activities .For geotechnical soil investigations, CPT is more popular compared to SPT as a method of geotechnical soil investigation. Its increased accuracy, speed of deployment, more continuous soil profile and reduced cost over other soil testing methods. The ability to advance additional in situ testing tools using the CPT direct push drilling rig, including the seismic tools described above, are accelerating this process.

6. EXPERIMENT

6.1 Compaction

Compaction is the most common and important method of soil improvement. Compaction is the process whereby air is crowded out & its volume decrease due to physical stress. Test is performed to determine the relationship between the optimum moisture content (OMC) and the maximum dry density (MDD) of a soil for a specified compactive effort.

It is the process by which the soil grains get rearranged more closely, the volume of air voids get reduced, and the density of soil increased. it is almost an instantaneous phenomenon. Compaction generally leads to an increase in shear strength and helps to improve the stability and bearing capacity of soil. It also reduces the compressibility and permeability of soil. The densification of soil by the application of mechanical energy is known as compaction.

Smooth wheel roller, pneumatic tyred rollers, sheep foot rollers and vibratory rollers are used in the field for compaction. Vibratory rollers are used mostly for densification of granular soils. The technique of vibration is extensively used for compacting in situ deposits of granular soil up to considerable depths.

The degree of compaction of a soil is measured in terms of dry unit weight, i.e., the amount of soil solids that can be packed in unit volume of the soil.

6.1.1 Factors affecting compaction

Water content

At low water contents, the soil is stiff and the soil grains offer more resistance to compaction. As the water content increases, the particles develop larger and larger water films around them, which tend to lubricate the particles and make them easier to be worked around, to move closer into a denser configuration, resulting in a higher dry unit weight and lower air voids.

Compactive effort

For a given type of compaction, the higher the compactive effort, the higher the maximum dry unit weight and lower the optimum moisture content.

Type of soil

Coarse grained soils, well graded, compact to high dry unit weights, especially if they contain. Some fines however if the quantity of fines is excessive max dry unit weight deceases.

Poorly graded are uniform sands lead to the lowest dry unit weight values. In clay soils the maximum dry unit weight tends to decease as plasticity increases. Cohesive soils have generally high values of OMC. Heavy clays with high plasticity have very low maximum dry unit weight and very high OMC.

Method of compaction

Ideally speaking the laboratory test must reproduce a given field compaction procedure because the mode of compaction does influence somewhat the shape and the position of the dry density verses water content plot. However it does not warrant the devicing of special laboratory tests that can simulate the different field compaction procedures.

6.2 Standard proctor test

In the standard proctor test, a standard volume (944 cc mould) is filled up with soil in three layers. Each layer is compacted by 25 blows of a standard hammer of weight 2.495 kg. Falling through 304.8 mm. knowing the weight of the compacted soil and its water content, the dry unit weight of the soil can be calculated.

Fig 6.1 compaction mould

6.2.1 Procedure

Fig 6.2 mixing of copper slag

1. Weigh 2.5 kg of copper slag and 2% of admixture to the weight of copper slag in a clean tray.

2. Add 2% of water to the weight of copper slag and mix it thoroughly and divide it into 3 equal parts.
3. Now place the first layer of sample into the mould. Make sure that the mould is placed properly on base plate.
4. Then compact the layer by giving 25 blows with the rammer weighing 2.495 falling through 304.8mm.
5. As soon as the first layer is compacted, repeat the same procedure for the other two layers.
6. Use collar to avoid falling of sample on to the ground.
7. Then remove the collar and trim out the excess sample.
8. Weigh the mould (along with base plate) and note the reading as weight of compacted sample.
9. Take 20-30 g of compacted sample in to a container along with lid. Note the reading as wet weight of compacted sample.
10. Note the container number and keep it in oven to know the dry weight of sample.
11. Repeat the same procedure for different percentage of admixture by increasing water percentage.
12. Perform analysis for optimum moisture content (OMC) and maximum dry density (MDD) with the noted values.

6.3 Modified compaction

The modified proctor test was developed during World War II to better stimulate the compaction required for air fields to support heavier air craft. The test employs a heavier hammer (4.54 kg) with a height of fall of 457.2mm and 5 layers tamped 25 times into a standard proctor mould.

Fig 6.3 modified compaction mould

6.3.1 Procedure

1. Weigh 2.5 kg of copper slag and 2% of admixture to the weight of copper slag in a clean tray.
2. Add 2% of water to the weight of copper slag and mix it thoroughly and divide it into 5 equal parts.
3. Now place the first layer of sample into the mould. Make sure that the mould is placed properly on base plate.
4. Then compact the layer by giving 25 blows with the rammer weighing 4.54 falling through 457.2mm.
5. As soon as the first layer is compacted, repeat the same procedure for the other four layers.
6. Use collar to avoid falling of sample on to the ground.
7. Then remove the collar and trim out the excess sample.
8. Weigh the mould (along with base plate) and note the reading as weight of compacted sample.
9. Take 20-30 g of compacted sample in to a container along with lid. Note the reading as wet weight of compacted sample.
10. Note the container number and keep it in oven to know the dry weight of sample.
11. Repeat the same procedure for different percentage of admixture by increasing water percentage.

12. Perform analysis for optimum moisture content (OMC) and maximum dry density (MDD) with the noted values.

6.4 Dry density

Dry density = weight of compacted soil / volume of the mould

$$\surd_d = \surd_t \ /1+w$$

6.5 Optimum moisture content

The moisture content corresponding to the maximum dry unit weight is known as the optimum moisture content.

7. RESULTS

7.1 Standard compaction test results for Copper Slag with lime as admixture

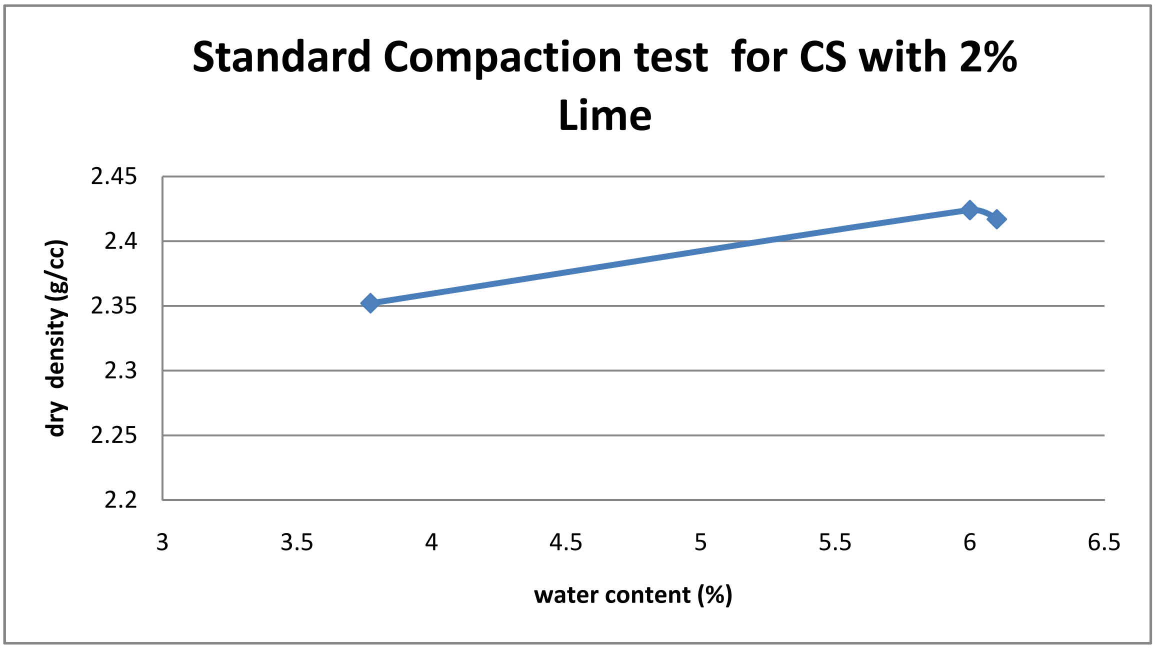


Fig 6.1 copper slag with 2% lime

From the above graph, standard compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.43(g/cc) and optimum moisture content (OMC) at 6%.

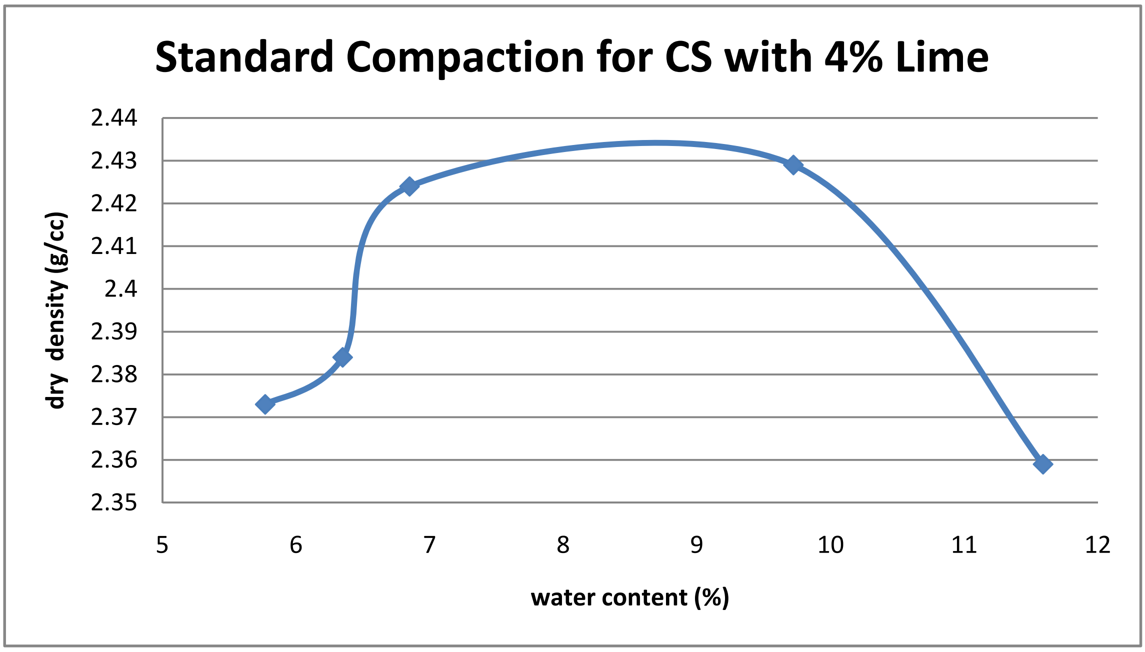


Fig 6.2 copper slag with 4% lime

From the above graph, standard compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.44(g/cc) and optimum moisture content (OMC) at 8.5%.

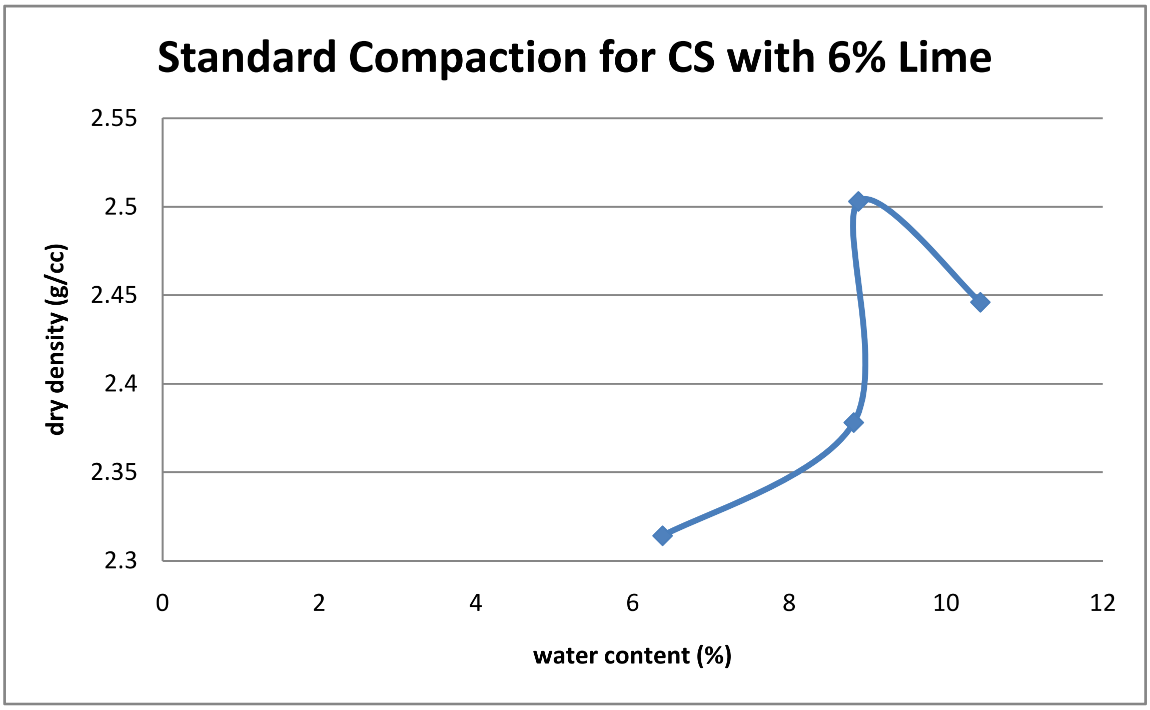


Fig 6.3 copper slag with 6% lime

From the above graph, standard compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.51(g/cc) and optimum moisture content (OMC) at 8.9%.

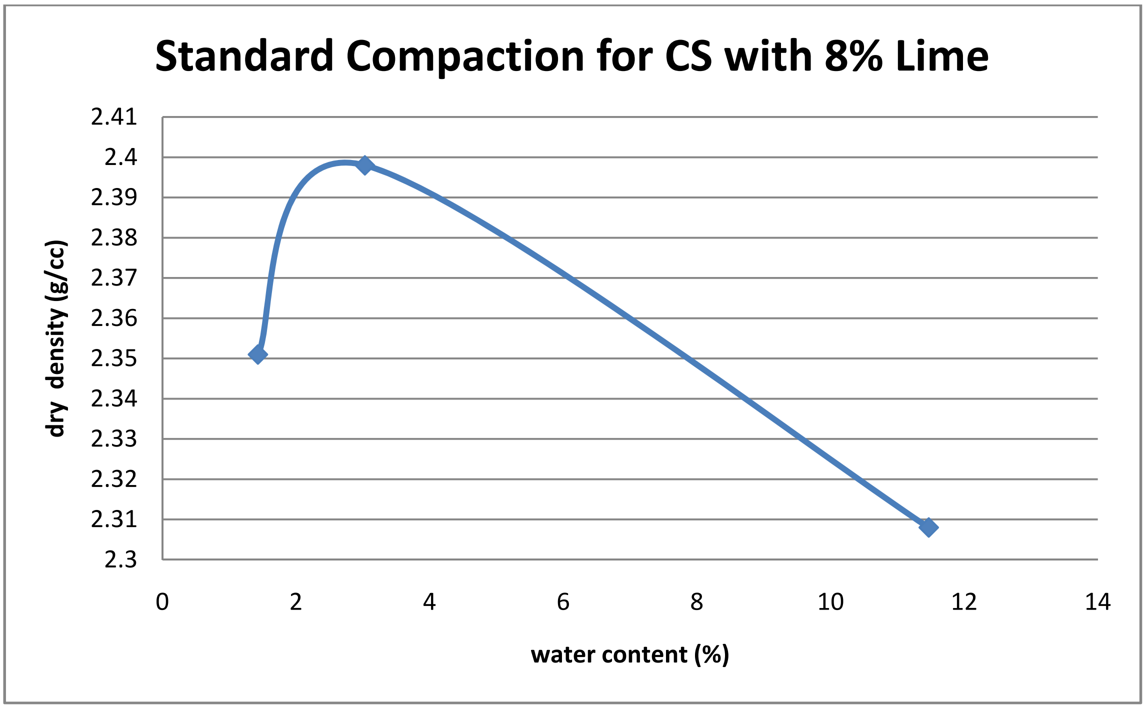


Fig 6.4 copper slag with 8% lime

From the above graph, standard compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.4(g/cc) and optimum moisture content (OMC) at 3.5%.

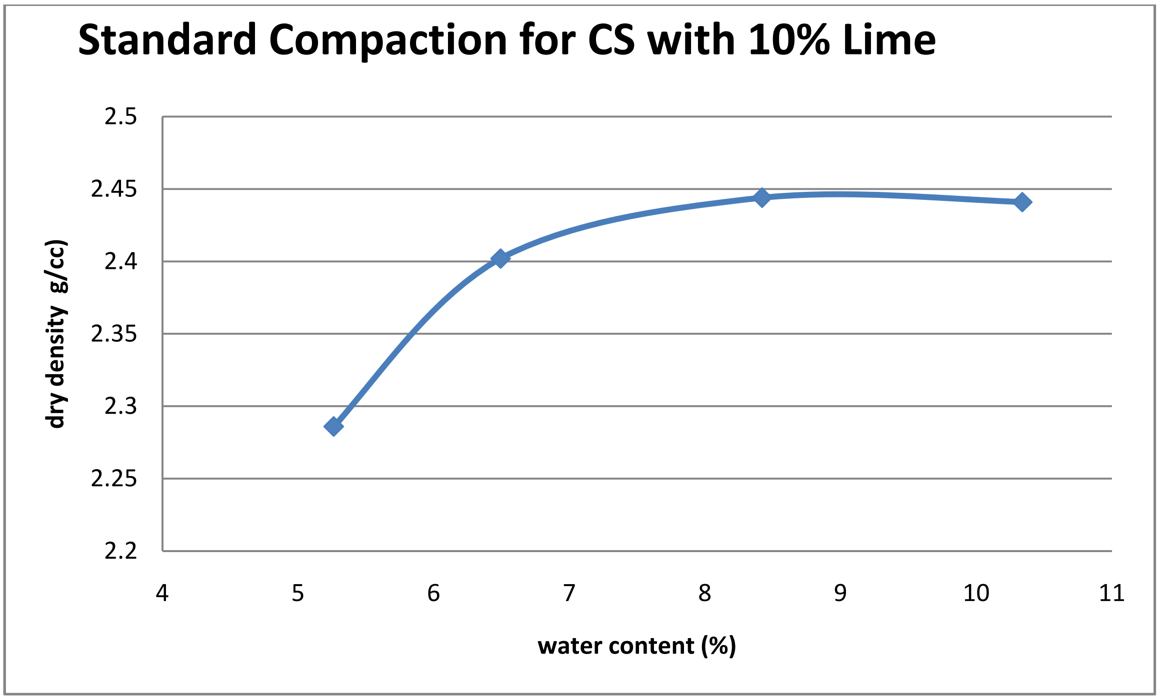


Fig 6.5 copper slag with 10% lime

From the above graph, standard compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.45(g/cc) and optimum moisture content (OMC) at 8.5%.

7.2 Modified compaction test results for Copper Slag with lime as admixture

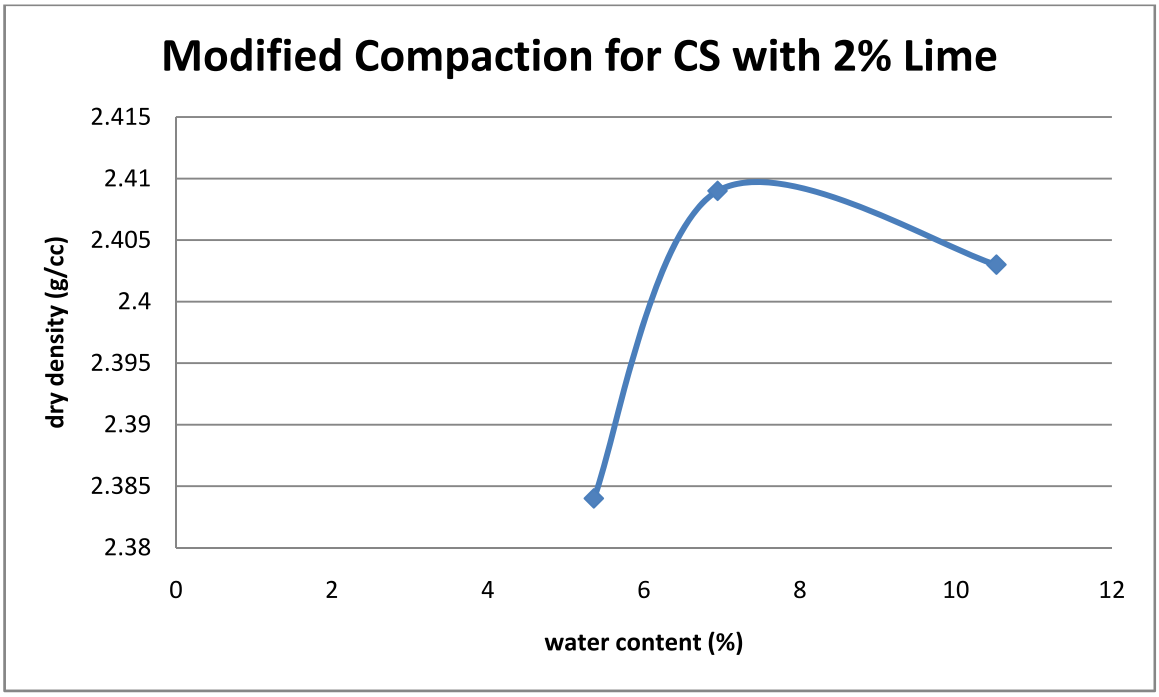


Fig 6.6 copper slag with 2% lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.41(g/cc) and optimum moisture content (OMC) at 7%.

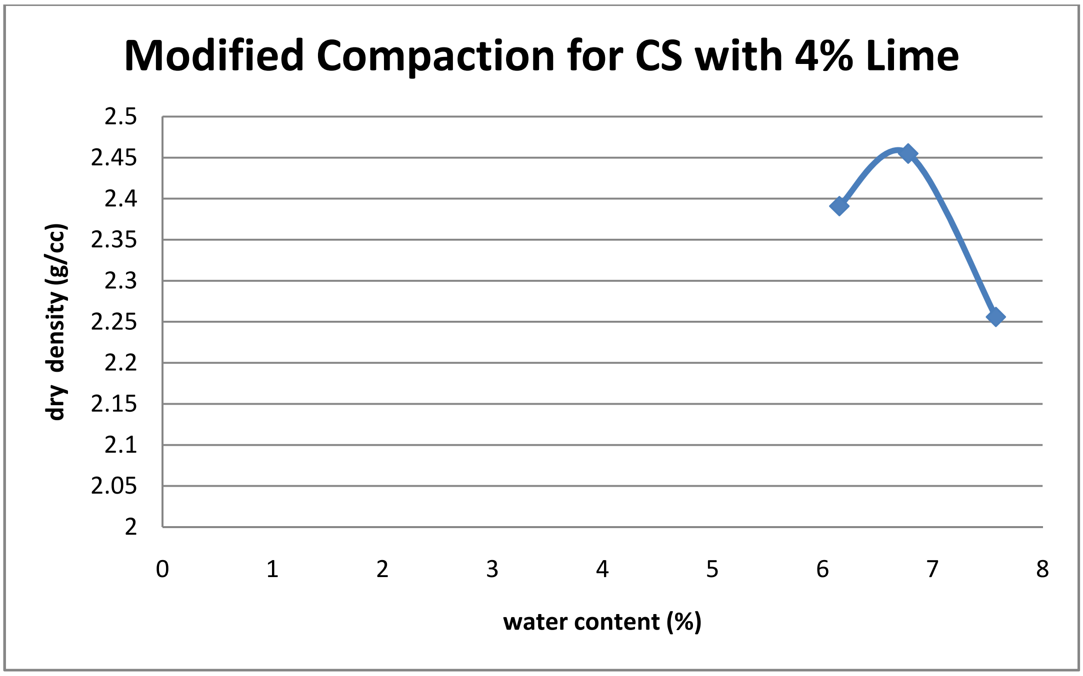


Fig 6.7 copper slag with 4% lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.46(g/cc) and optimum moisture content (OMC) at 7%.

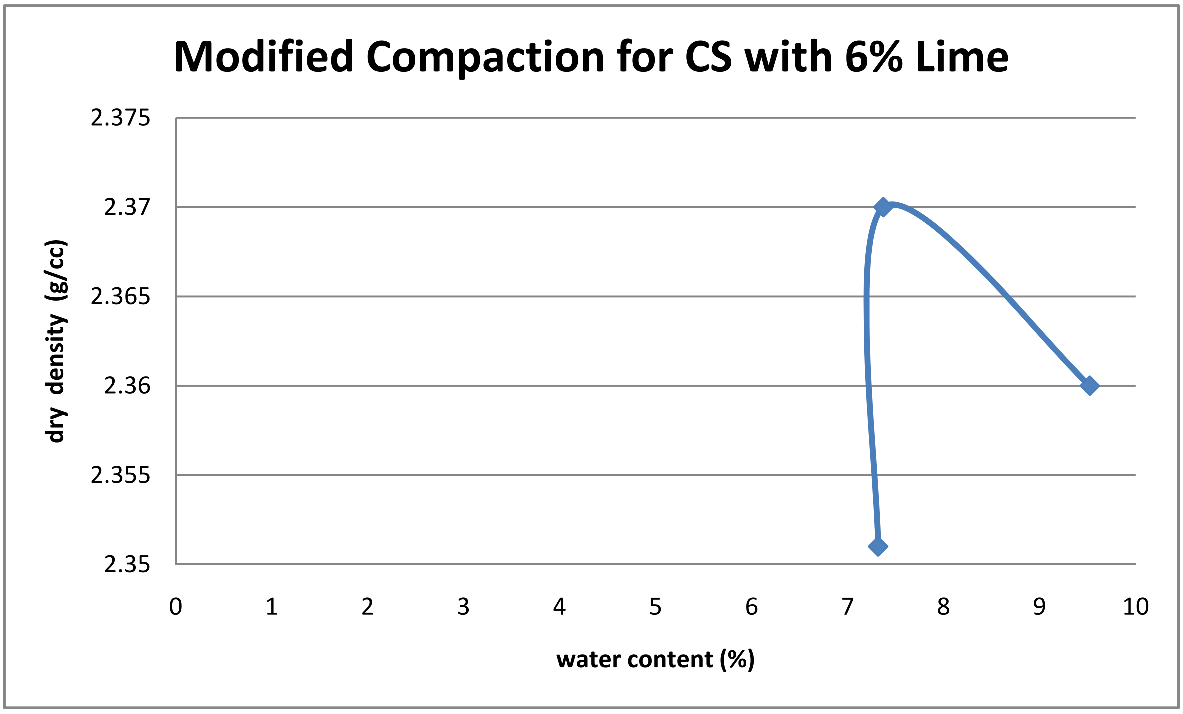


Fig 6.8 copper slag with lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.37(g/cc) and optimum moisture content (OMC) at 7.5%.

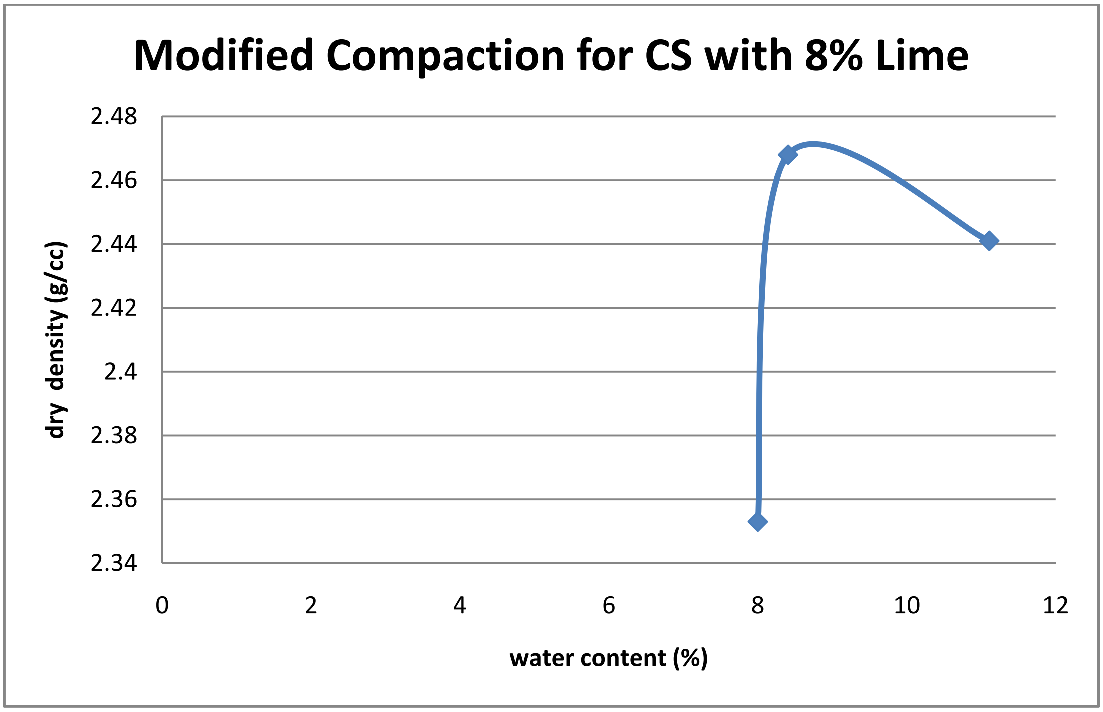


Fig 6.9 copper slag with 8% lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.47(g/cc) and optimum moisture content (OMC) at 8.5%.

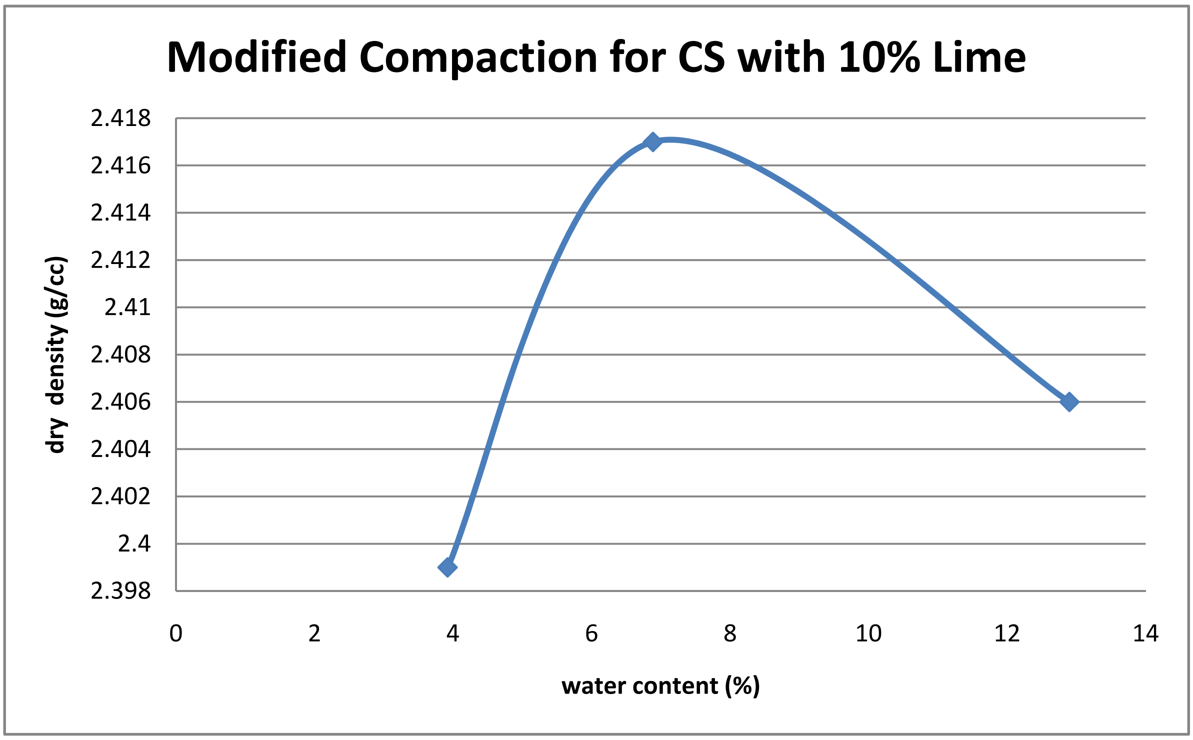


Fig 6.10 copper slag with 10% lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.42(g/cc) and optimum moisture content (OMC) at 7%.

7.3 Compaction test of Copper Slag only

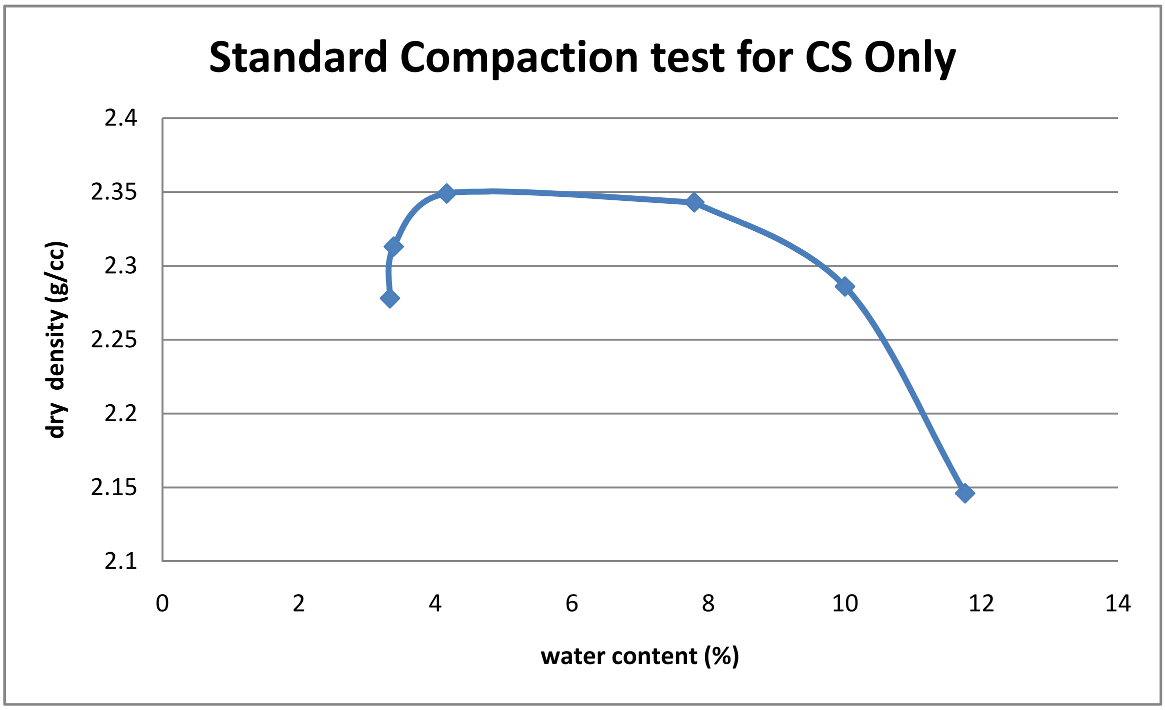


Fig 6.11 copper slag without lime

From the above graph, standard compaction for copper slag only, maximum dry density (MDD) occurs at 2.35(g/cc) and optimum moisture content (OMC) at 6%.

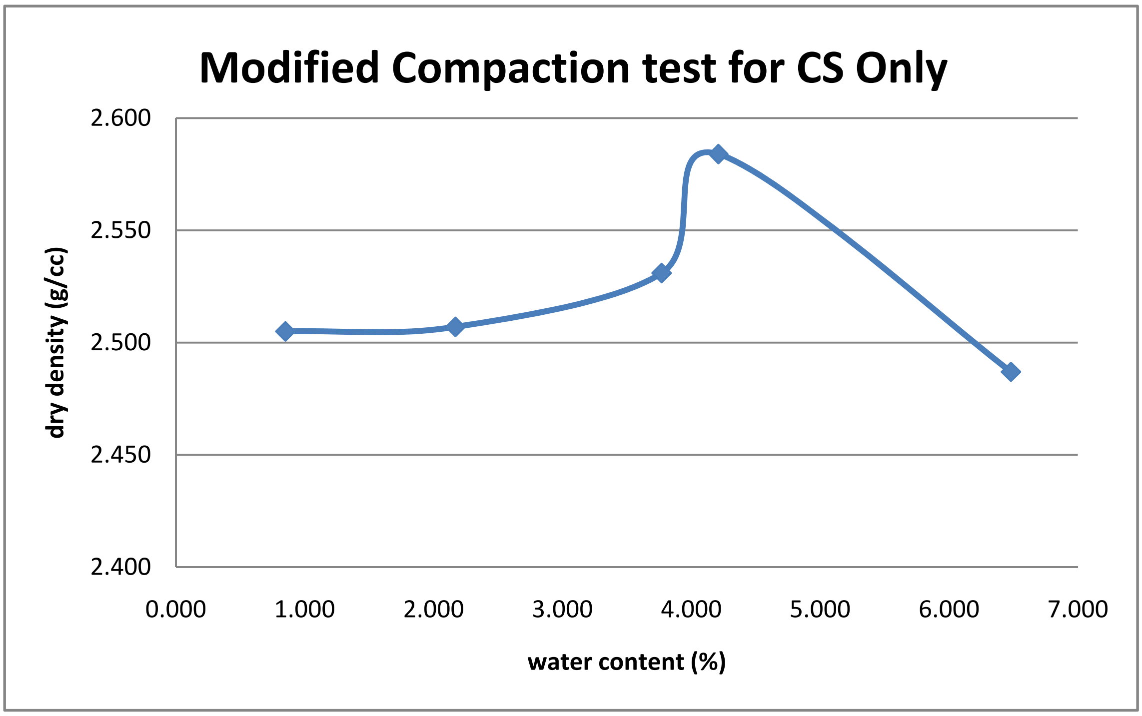


Fig 6.12 copper slag without lime

From the above graph, modified compaction for copper slag with 2% lime, maximum dry density (MDD) occurs at 2.6(g/cc) and optimum moisture content (OMC) at 4.5%.

7.4 Summary

1. Soil stabilization has gained a lot of importance in the construction industry, at the sites where soft or expansive sub grades soils are predominantly present.
2. In the present day, many by products are being in use as soil stabilization agents. Many research outputs are available on fly ash towards soil stabilization.
3. Recently researchers have started conducting studies using copper slag which is being readily available in the copper industry as a waste by product.
4. The present study, the influence of lime on compaction characteristics of copper slag was studied and the results are summarized below.

8. CONCLUSIONS

1. Irrespective of compaction effort, the variation in MDD observed is minimal. And almost the MDD is varying from 2.26g/cc to 2.52g/cc.
2. Up to about 8% of moisture content addition to the CS is not causing liquid condition.
3. Beyond 8% of moisture content for any small increase in moisture content, water is easily coming out of the compacted CS.
4. As the % of lime increases from 2% to 10% the MDD values are slightly increasing where as the OMC values are observed to be increasing and decreasing.
5. From these results it can be noticed that as the % of Lime increases, there is no definite trend in the OMC irrespective of the compactive effort.
6. From the results, it is understand that addition of lime to the CS is not going to benefit in terms of behavior of material.
7. But same lime when mixed with CS along with soils may result in beneficial effects in terms of stabilization of clayey deposits.
8. Hence, as a future study, the combination of CS and lime along the soil can be mixed and relevant geotechnical testing can be carried out to bring out the efficiency of CS along with the lime in the soil stabilization process.