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Analysis of geogrid reinforced pond ash embankment using finite element method

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ABSTRACT

The Pond Ash sample was collected from the ash pond site of Raj ghat thermal power station, Delhi, soil was collected from NIT campus, Srinagar and the lime was procured from the open market in the form of quick lime. This lime was then mixed with pond ash, by weight (= 9%) (Gupta et al, 2013).Further, in the present work an experimental program was carried out to characterize the materials and strength tests were performed to study the behaviour of pond ash mixed with lime; the results shows that in the presence of moisture, pond ash chemically reacts with lime at ordinary temperature and forms cementations material which is attributed to the increase in strength of pond ash. Numerical analysis was performed using the FEM based software PHASE2 (Roc science). Results divulge that use of full length of geogrid covering whole width of embankment increases the critical strength reduction factor (SRF) of embankment at steeper slope inclination. Also, the application of either geogrids layers or pond ash-lime mix layer, results in safer designs in comparison to unreinforced pond ash embankment.

Keywords: *Geogrid, Pond Ash, Geo Grid*

1. INTRODUCTION

Fly ashes are a waste product from thermal power industry; more than 110 million tones of fly ashes are produced annually in India. When pulverized coal is burnt in the boiler of a thermal power station, a part of ash comes down at the bottom of the boiler and is known as bottom ash whereas, the major portion of the ash comes out along with the flue gases and is collected through electro static precipitation or filter bags or other means before allowing the exhaust gases through escape the chimney, this part is generally known as ESP ash. For deposition, the un-utilized ESP ash and bottom ash are taken to ash ponds. The ash deposited in the ash pond is known as pond ash.Present majority of coal ashes generated is disposed of in ash ponds which are harmful for environment. Presently 20,000 hectares of land is occupied by pond ash. Thus this pond ash produced is being regarded as waste material with potential environmental implications.

1.1 Advantages of using Pond Ash for road construction

Pond ash causes lesser settlements as it is lightweight material, therefore, It is preferable for embankment construction over weak sub grade such as alluvial clay or silt where excessive weight could cause failure.

Pond ash embankments can be compacted over a wide range of water content. Therefore, there is less variation in density with change in water content. Pond ash is easily to handle and compact because it is lightweight. It can be compacted using either static or vibratory rollers as there are no big lumps to broken down.

- Pond Ash has high permeability so it ensures free and efficient drainage. Water gets drained out easily after rainfall ensures better workability than soil.
- Pond ash has low compressibility which results in low subsequent settlement.
- Good earth can be conserved, so it can help to protect the environment.
- It has high value of California Bearing Ratio which results in more efficient design of road embankment.
- Self hardening property imparts additional strength to the road embankments.
- Pond ash is pozzolanic in nature. It chemically reacts with lime andcement and forms cementitiousmaterial.

Considering all the above advantages, it is extremely necessary to promote use of pond ash for construction of embankments.

1.2 Economy in use of Pond Ash

Use of Pond ash in embankments results in reduction in construction cost. Typical cost of borrow soil is about Rs.100 to 200 per cu-m. Pond ash is available free of cost at thermal power plant and hence it involves only transportation cost, laying and rolling cost. Hence, when pond ash is used as a construction material, the economy achieved is directly related to transportation cost of pond ash. If lead distance is less, construction cost can be very less. Similarly, the use of pond ash in embankment construction results in significant savings due to reduction in cost of cement and road aggregates. By using large quantity of pond ash for embankment construction, a large area of fertile agricultural land can be saved from ash deposition. Therefore the actual savings achieved will be much higher.

Pandian (2004): The author has presented a review on characterization of the fly ash with reference to geotechnical applications. The study has revealed that the detailed investigations carried out on fly ash elsewhere as well as at the Indian Institute of Science show that fly ash has good potential for use in geotechnical applications. It has low specific gravity, ease of compaction, , good frictional properties, insensitiveness to changes in moisture content,

Freely draining nature, etc. which shows that it can be gainfully employed in the construction of embankments, as a sub-base material, as a backfill material etc.. It can be also used in reinforced concrete construction since the alkaline nature will not corrode steel. The specific gravity is lower leading to lower unit weights resulting in lower earth pressures.

Mohanty (2012): The author has been carried out a study to evaluate geotechnical property of lime stabilized fly ash sample. The following conclusions were drawn:

- Fly ash consists of grains mostly of fine sand to silt size with uniform gradation of Particles.
- Specific gravity of particles is lower than that of the conventional earth materials.
- Fly ash sample responds very poorly to the compaction energy. Maximum dry density increases and optimum moisture content decreases with addition of lime.
- Increase in curing period of lime treated fly ash specimen show improvement in the UCS value of fly ash.
- With increase in compaction energy followed by curing period shows a significant increase in strength due to closer packing of particles.
- Theangleofinternalfrictionandunitcohesionvaryfrom24.84to27.34degreeand
- 10.7 to 13.4 kPa with the change in compaction energy.
- The unsoaked CBR value is more than soaked CBR value.
- Permeability of the lime treated fly ash specimens, reduces with increase in lime content due to the pozzolanic reaction between fly ash and lime which results in blocking of the flow paths thus reducing the value of coefficient of permeability.

2. SLOPE STABILITY ANALYSIS

Slope stability analysis is performed to evaluate the safe design and the equilibrium conditions of a human-made or natural slopes such as embankments, road cuts, open-pit min ay be defined as the resistance offered by the inclined ing, excavations, landfills etc. The term slope stability m surface to failure by collapsing or sliding. Aim of Slope Stability Analysis:

- Investigation of optimal slopes with regard to safety
- Finding endangered areas
- Reliability and economics
- Investigation of the slope sensitivity to different triggering mechanisms
- To investigate the mechanisms of potential failure
- Evaluation of possible remedial measures such as barriers and stabilization

Successful design of the slope necessitates geological information and site characteristics, e.g. slope geometry, groundwater conditions, properties of soil/rock mass, alternation of materials by faulting, movements and tension in joints, joint or discontinuity systems, earthquake activity etc.

The most common methods of slope stability analysis are

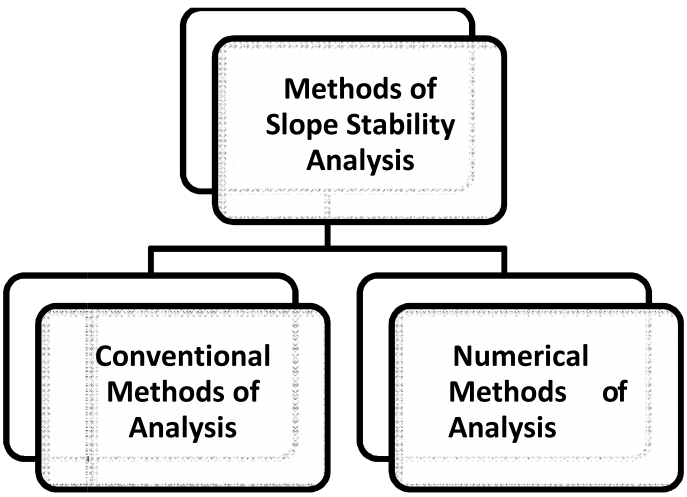


Fig. 1: Methods of Slope Stability

The correct choice of analysis technique depends on both site conditions and the potential mode of failure.

2.1 Conventional Methods of Analysis

Common conventional methods of slope stability analysis are :

- Limit equilibrium method Stereographic and kinematic method
- Rock fall simulators

2.1.1 Limit Equilibrium Method: Limit equilibrium methods are the most popular conventional method of the slope stability analysis. Limit equilibrium methods are used to investigate the equilibrium of the soil mass tending to slide down under the influence of gravity. Rotational or transitional movement is considered on assumed potential slip surface below soil or rock mass. Limit equilibrium methods are based on Mohr- Coulomb criteria in which all the forces (moments or stresses) resisting instability of the mass are compared with those that causing instability (disturbing forces).

In these methods two-dimensional sections are analyzed assuming plain strain conditions. These methods it is assumed that the shear strengths of the materials along the potential failure surface are governed by linear or non-linear relationships between shear strength and the normal stress on the failure surface. Limit equilibrium analysis provides a factor of safety, delineated as a ratio of shear resistance (available) to the shear resistance (required) for equilibrium. The slope is considered unstable if the value of factor of safety is less than 1.0.Sarma and Spencer are called as rigorous methods because they satisfy all three conditions of equilibrium: force equilibrium in horizontal and vertical direction and moment equilibrium condition. These methods can provide more accurate results than non-rigorous methods. Bishop simplified method are non-rigorous methods satisfying only some of the equilibrium conditions. Results (factor of safety) of particular methods can vary because methods differ in assumptions and satisfied equilibrium conditions. Functional slope design considers calculation with the critical slip surface where is the lowest value of factor of safety. Failure surface can be located with the help of computer programs using search optimization techniques. There is wide variety of slope stability software is available which are based on limit equilibrium concept.

In the present study, laboratory investigations have been conducted to evaluate index as well as engineering properties of Pond ash and Soil. The geotechnical behavior of Pond ash+ lime (91:09, by weight), as per the laboratory results by Gupta et al. (2013), was also investigated. The following experiments were performed:

3. SCANNING ELECTRON MICROSCOPY

A scanning electron microscope (SEM) is a type of electron microscope that helps to provide the information about morphology of sample. It produces images of a sample by focusing a beam of electrons on sample and scanning it. These electrons interact with electrons in the sample, and produce various signals.

These signals contain the information about the morphology of sample. By detecting the signals, produced due to interaction of electrons, information about sample's surface topography and composition can be obtained. Characteristic X- rays, which are emitted when the electron beam remove an inner shell electron from the sample, are used to predict the composition and elements in the sample. Due to the shifting of electrons, energy get released. (Liu, F. et al.2010). The SEM instrument is made up of two main components, (i) the electronic console and (ii) the electron column. SEM can attain resolution better than 1 nanometer. Samples can be observed in low vacuum, high vacuum and in Environmental. SEM samples can also be observed in wet condition. A scanning electron microscope (SEM) has been shown in Fig. SEM micrographs of pond ash, soil, and lime and pond ash-lime mixture are shown from Fig. 3.2 to 3.5.

Fig. 3.1: Scanning Electron Microscope

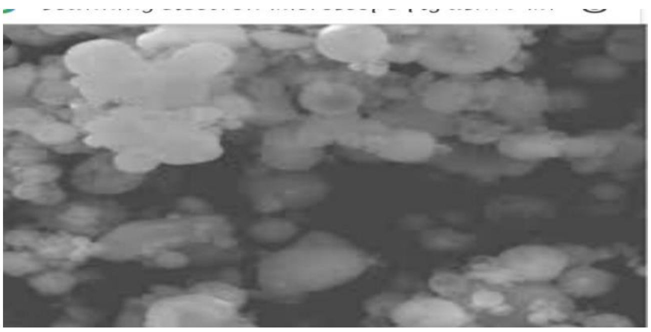


Fig. 3.2: Pond Ash at 10 µm scale

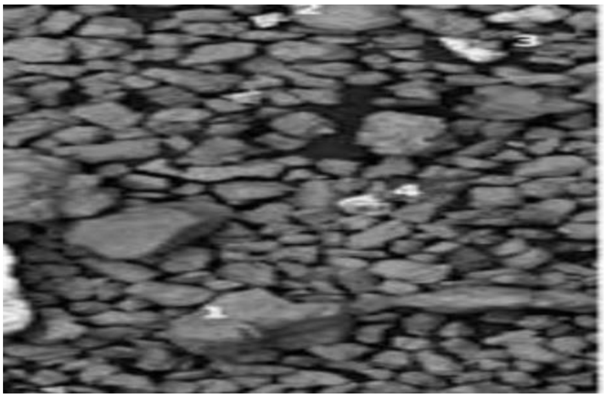


Fig. 3.3: Soil at 1 mm scale

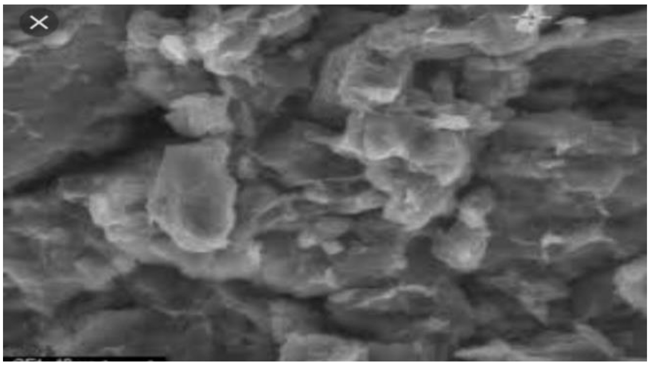


Fig. 3.4: Lime at 10 µm scale

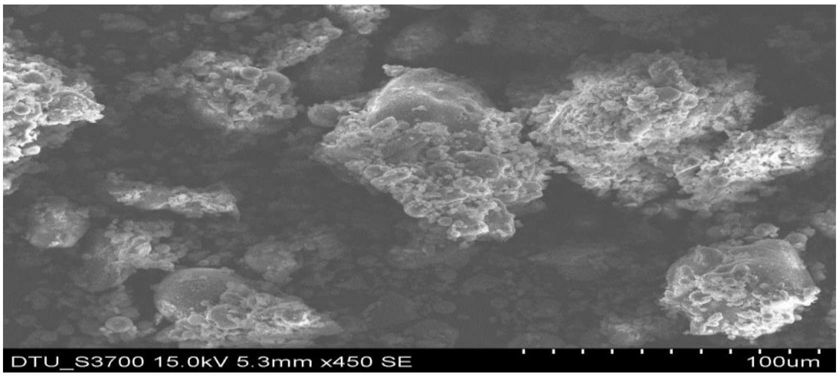


Fig. 3.5: Pond Ash+ Lime at 100 µm scale (after 28 days curing)

An Energy dispersive spectroscopy (EDS) is an analytical technique used for chemical characterization of a sample. Scanning electron microscope (SEM) instrument, shown in Fig.3.1 is used for energy dispersive spectroscopy, if an energy-dispersive spectrometer (or X-ray spectrometer) is added as shown in Fig. 3.6. As in SEM, in energy dispersive spectroscopy (EDS) also, a beam of electrons is focused on the sample. Then, the number and energy of the characteristic X-rays emitted from the sample is measured by an energy- dispersive spectrometer. The energy of the X-rays are characteristic of the atomic structure of the element from which they were emitted and of the difference in energy between the two shells, which allows the elemental composition (chemical composition) of the sample to be measured. EDS spectrum of pond ash, soil, and lime are shown from Fig. 3.7 to 3.9. Chemical compositions of these samples are shown in Table 3.1 to3.3.

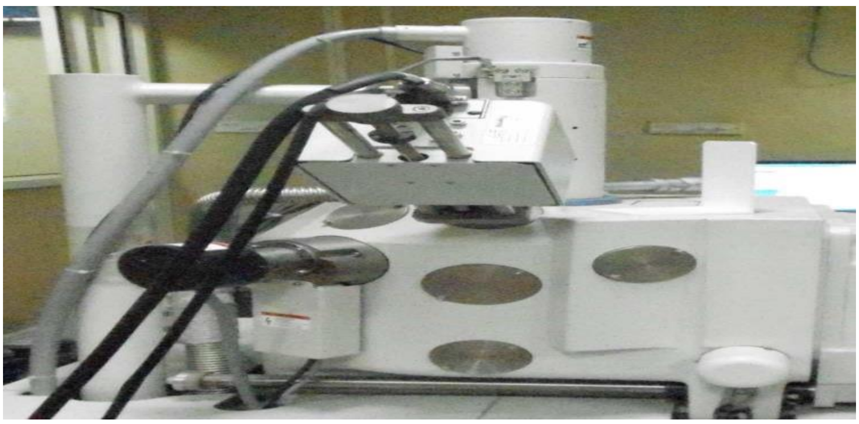


Fig. 3.6: Energy-Dispersive Spectrometer in SEM

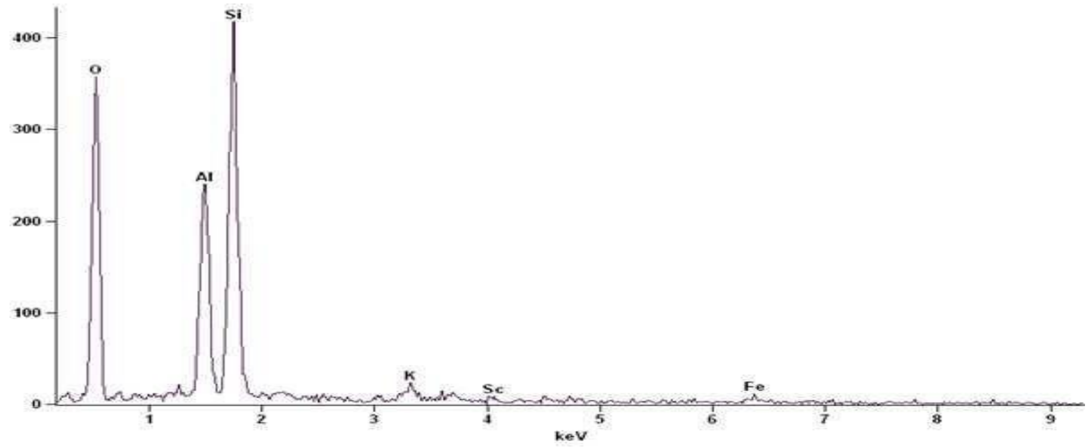
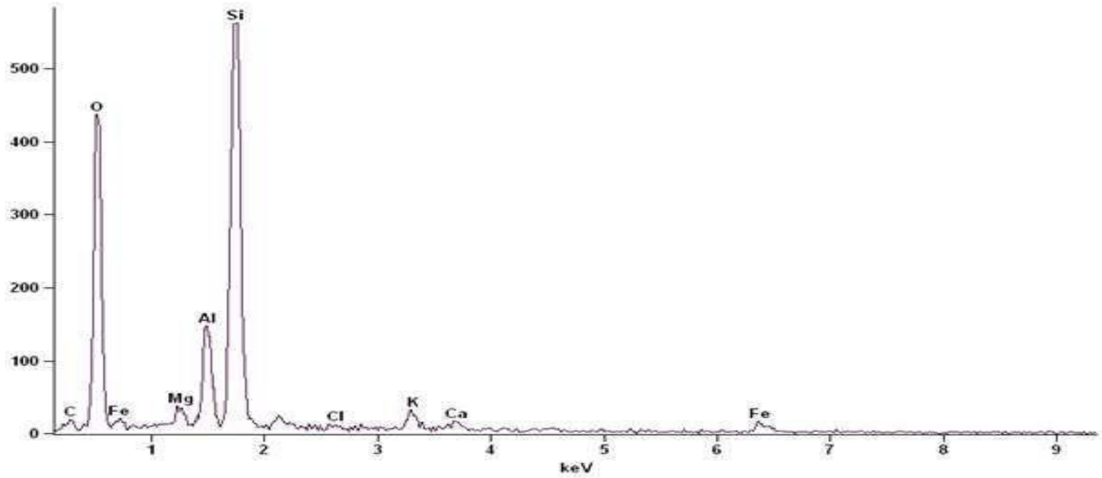


Fig. 3.7: EDS Spectrum of Pond Ash particles



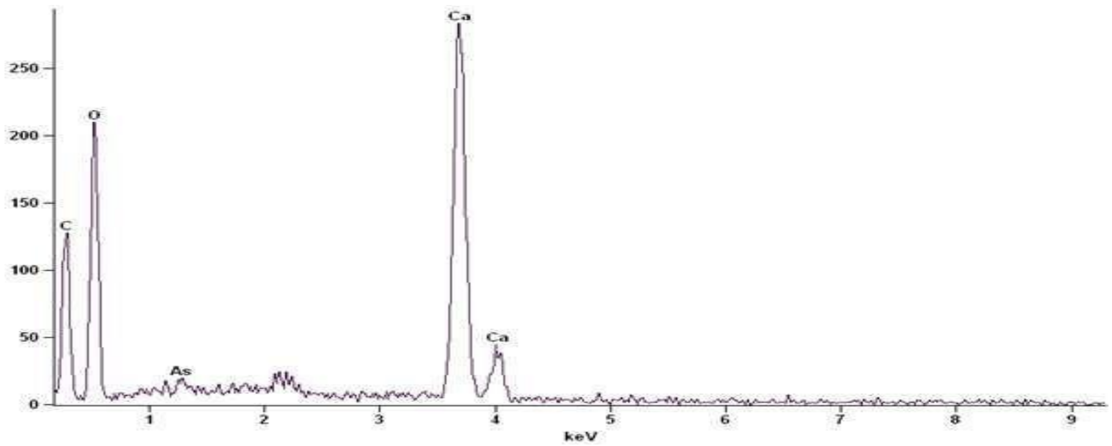


Fig. 3.9: EDS Spectrum of Lime

3.1 Hydrometer Test

To determine the percentage of particles having particle size less than 75µ sieve, hydrometer test is used. The percentage of silt and clay in the soil sample is measured in this test by using a hydrometer, shown in Fig.3.12.

Fig. 3.12: Hydrometer

The Grain size distribution curve for pond ash and soil are shown in Fig. 3.13 and 3.14

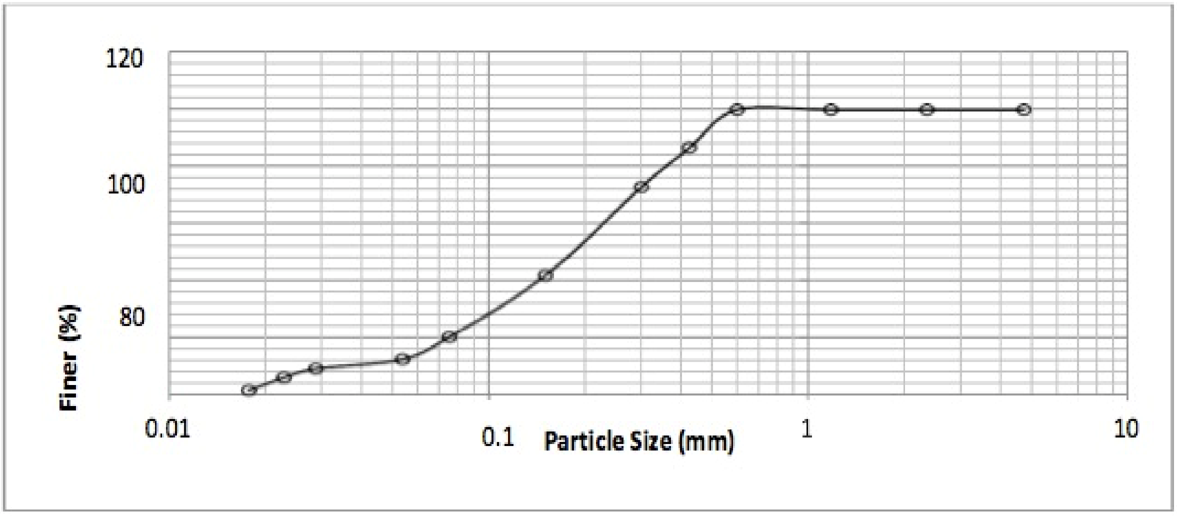


Fig. 3.13: Grain Size Distribution of Pond Ash

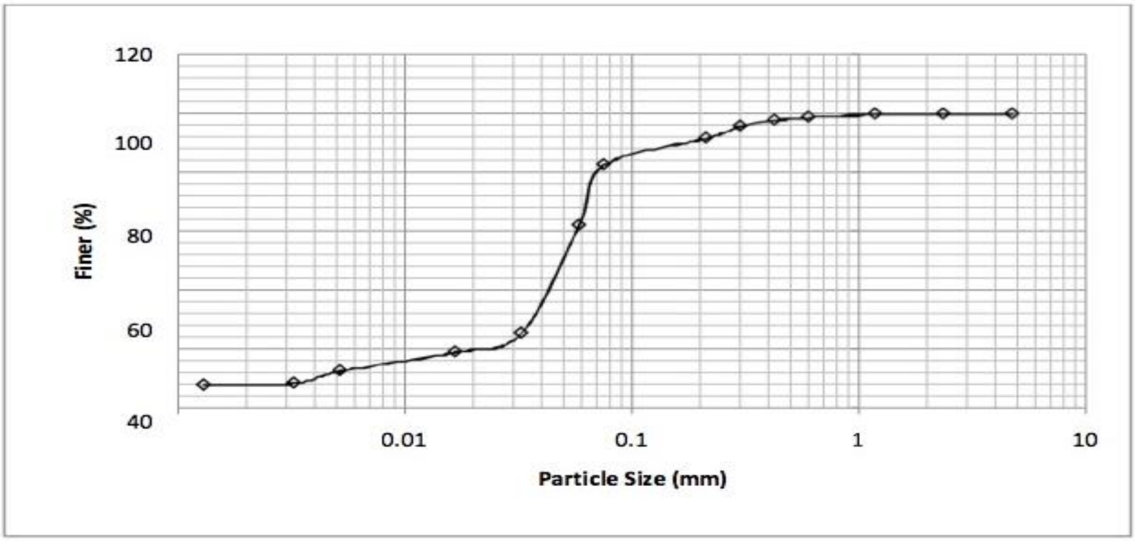


Fig. 3.14: Grain Size Distribution of Soil

3.2 Atterberg Limits IS: 2720 (Part 5)-1985

The Atterberg's limits or consistency limits of a soil are the water content at which the soil changes from one state to other state. The Atterberg's limits, most useful for geotechnical engineering purposes are: Liquid limit, plasticlimit and shrinkage limit.

3.2.1 Liquid Limit: Liquid Limit of a soil is the minimum water content, at which the soil is in liquid state but has a small strength against flowing. The liquid limit soil sample is determined using Casagrade liquid limit apparatus, shown in Fig. 3.15. The Flow curve of soil is shown in Fig. 3.16. Liquid limit of pond ash was tried to be determined with this percussion cup method but was found very difficult to make a groove in pond ash.

Fig. 3.15: Casagrade Apparatus

Fig. 3.15: Flow Curve of Soil

Liquid Limit, w_L = 21.4%

3.2.2 Plastic Limit: Plastic limit of a soil is the minimum water content, at which soil will just start to crumble water rolled into a thread approximately 3mm in diameter. The soil shows the properties of a semi solid, just after the plastic limit. A thread for pond ash was tried to be made but it crumbled very early due toits non-plastic behavior nature. The plastic limit (w_P) of soil is found to be **18.12 %.** The Plasticity index of a soil sample is determined as:

$$I_P = w_L - w_P \qquad (3.6.1)$$

Where, I_P = Plasticity Index
w_L = Liquid Limit w_P = Plastic Limit
The Plasticity index of a soil is = 3.32
Equipments used in Proctor Test:

Fig. 3.16:Mould

Fig. 3.17: Hammer with Collar

The Compaction curves for pond ash, soil and pond and lime mixture areshown in Fig. 3.18 to 3.20

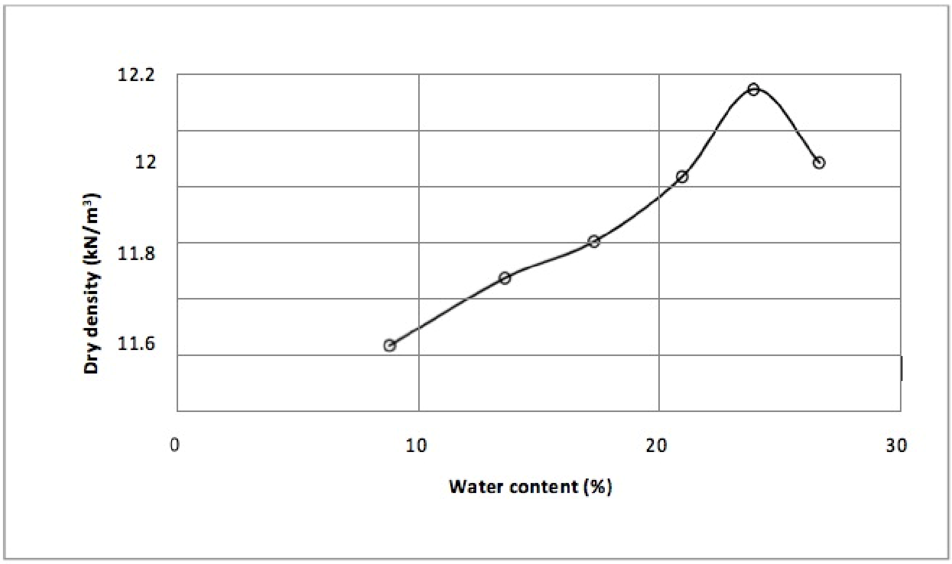


Fig. 3.18: Plot between Moisture Content and Dry Density for Pond Ash Optimum Moisture Content, OMC = 24.07 %
Maximum Dry Density, MDD = 12.14 kN/m^3

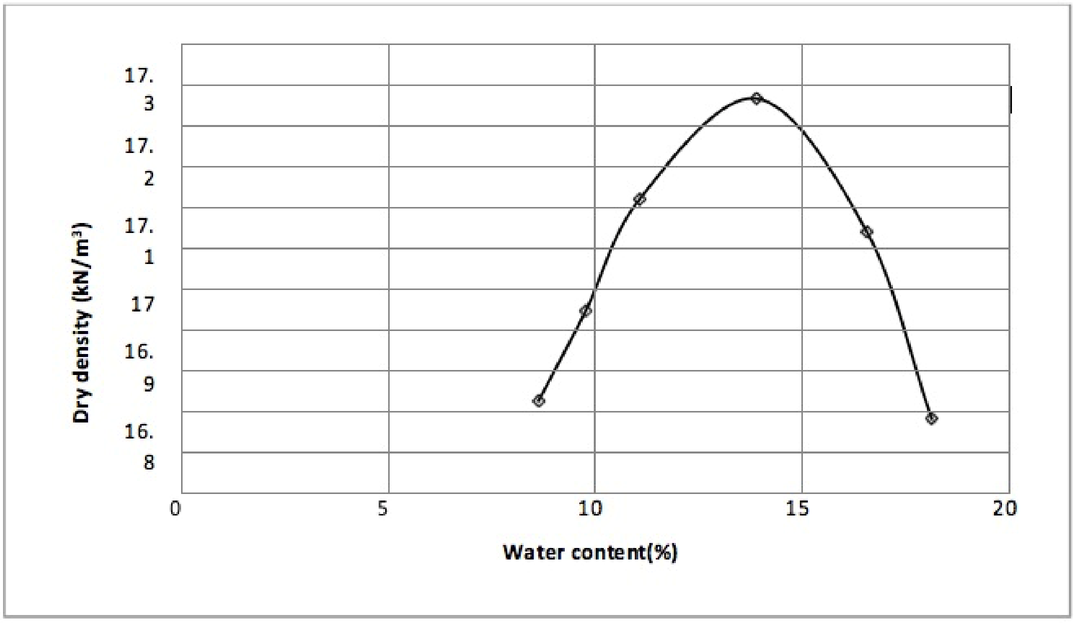


Fig. 3.19: Plot between Moisture Content and Dry Density for Soil

Optimum Moisture Content, OMC = 14.03. % Maximum Dry Density, MDD = 17.23 kN/m^3

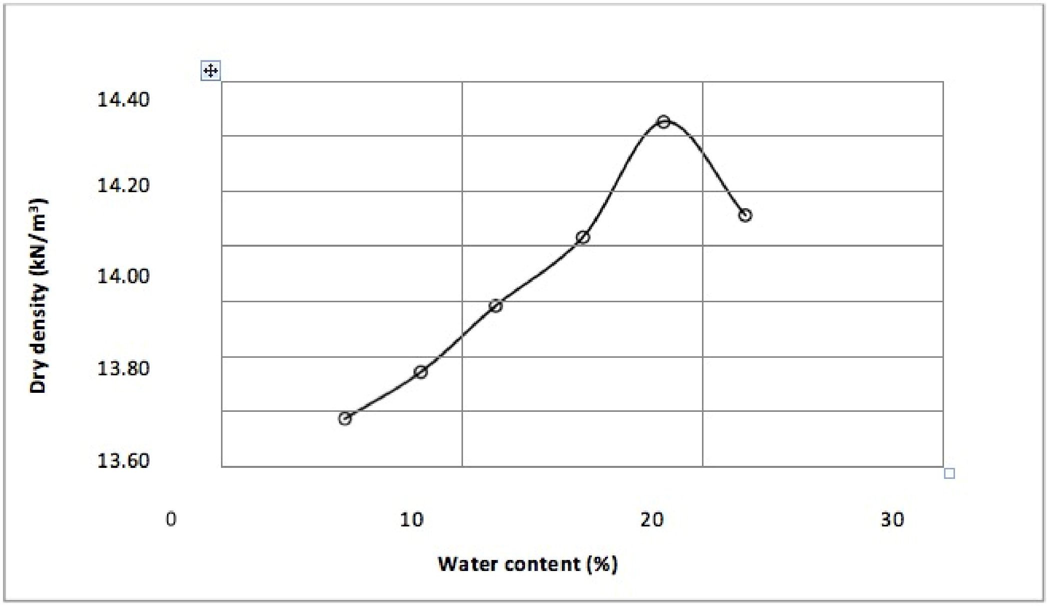


Fig. 3.20: Plot between Moisture Content and Dry Density for Pond Ash +Lime Optimum Moisture Content, OMC = 20.47 % Maximum Dry Density, MDD = 14.31 kN/m^3

3.3 Permeability Test

Permeability (or hydraulic conductivity) is the property of a soil which allows the seepage of water through the voids. This property is very essential for the calculation of seepage through soil structure. The Permeability test apparatus is shown in Fig. 3.21.

In the present study, falling head permeability test is performed for pond ash, soil and pond ash- lime mixture. The Coefficient of permeability of a sample is given as:

K = 2.3 aL/At log10 h1/h2 Where, k = Coefficient of Permeability
a = Area of stand pipe

A = Cross- sectional area of soil sample L = Length of sample

t = Time interval h1 = Initial head h2 = Final head

The Coefficient of permeability of pond ash, soil and pond ash-lime mixture was found to be 7.00×10-6 m/s, 1.53×10-7 m/s and 3.27×10-6 m/s respectively.

Fig. 3.21: Permeability Test Apparatus

4. CONCLUSION

- SEM results of pond ash shows that the pond ash particles are rounded in shape. This shows the spherules of alumina silicates in pond ash. Dark matter presence shows magnetite. SEM results of soil indicates that the soil particles are sub angular particles. SEM results of pond ash and lime, cured sample shows the bonded particles of pond ash and lime.
- The EDS results evidenced the presence of the following components: silica (SiO_2), alumina ($A1_20_3$) and hematite (Fe_2O_3) in pond ash.
- The Compaction curve of pond ash shows that there is a less change in density with variation in water content. Pond ash is also easy to compact as compared to natural soil, as there are no heavy lumps to break down. This property of pond ash is useful for embankment construction.
- The Hydraulic conductivity of pond ash was found to be high which ensures the effective drainage for better workability.
- The Unconfined compressive strength at MDD and OMC, for pond ash + lime with 28 days curing, was found to be 826.33 kPa which very higher than for pond ash.
  Tensile strength at MDD and OMC, of pond ash + lime with 28 days curing, was found to be 137.93 kPa, which very higher than of pond ash.
- Cohesion and angle of internal friction for pond ash + lime with 28 days curing it is found to be 300.35 kPa and 46.4º respectively, which very higher than of pond ash.
- The Strength tests of pond ash and lime mixture evidenced that the unconfined compressive strength, tensile strength as well as shear strength are very high. This is due to the formation of cementitious material. The silica (SiO_2), alumina ($A1_20_3$) and ferrous oxide (Fe_2O_3) present in pond ash and calcium oxide (CaO) present in lime, chemically reacted with each other in presence of water and has been formed cementitious material such as (calcium silicate hydrate (CaO-SiO_2-H_2O), calcium aluminate hydrate (CaO-Al_2O_3-H_2O) and calcium ferro aluminate hydrate (CaO- Al_2O_3-Fe_2O_3-H_2O), which attributed to increase in strength of pond ash and lime mixture. The formation of cementitious material was also evidenced by SEM test, which shows a bonded particle of pond ash and lime.
- The Potential failure surface of embankment slope was found to be circular in shap
- The peak tension in georid reinforcement was found to be within the potential failure surface, due to the generation of tensile forces in the geogrid reinforcement layers as a result of shear strains generated in the pond ash.
- The distribution pattern of tension along the slope was assumed to be triangular with zero at the crest and maximum at the toe. In the present study, the distribution pattern of tension along the slope elevation was found to be different for reinforced embankment. The maximum peak tension in a reinforced slope is always assumed to be at the bottom of the slope in design practice. In present study, it is found somewhere at the mid- height along the potential surface of the slope due to the presence of maximum overburden pressure at that point, which is in good agreement with the results obtained by Zornberg and Arriaga(2003).
- Shear strains within the embankment get reduced by providing geogrid reinforcement along the embankment slope. Shear strains within the embankment get rapidly reduced as the vertical spacing between geogrid layers was decreased, due to the restraining effect of reinforcement which attributed to the reduction in shear stress within the embankment.
- When no geogrid layer was installed in the slope, the shear strains were more concentrated in the middle portion of slope rather than the toe. As geogrid layers were installed in the slope, the shear strains get reduced and shifts towards toe of the slope, due to inement in confinement in the middle of the slope.
- Critical SRF values were increased with the decrease in vertical spacing of geogrid layers. This can be due to generation of more tensile forces in geogrid layers which acts as a resisting force against the driving forces in slopes which is attributed to the increase in critical SRF.
- Shear strains within the embankment slope were reduced with the increase in pond ash + lime layer thickness at the side slope.
- Critical SRF values were increased with the increase in thickness of pond ash +lime layer. It may be occurred due to the additional shear strength provided by this layer, as the shear strength of pond ash + lime is very high as compared to the pond ash alone due to the formation of cementitious material.
- Critical SRF values increased with the increase in thickness of pond ash- lime mix layer at the side slope of embankment, in normal condition as well as in flood condition. Critical SRF values are maximum with thickness of pond ash- lime mix layer is 0.5 m at the top of embankment and 2.0 m thickness at side slope of embankment.
- Critical SRF values are maximum when pond ash + lime (91:09, by weight), is used for embankment construction. And this embankment will also safe in half submerged case.
- Settlement in pond + lime (91:09, by weight), is also very less.
- With the help of geogrid reinforcement, an embankment can be provided a slope inclination of 1H: 4V, which is very steeper

than 1H:1V as used in common practice. Therefore, considering the length and height of the embankment 2000 m and 9m respectively, 13500 m^2 land can be saved, by using 1H: 4V slope inclination.

- The utilization of pond ash for embankment construction with the crest width 20 m and height 9m, approx. 2.88×10^3 to 2.21×10^3 m^3 to pond ash can be utilized which will attributed to reduction in land, which is wasted due to the disposal of pond ash which will also attributed to the reduction in environment pollution.
- By providing pond ash- lime mix layer at the top and side slope of embankment, cost of geogrid reinforcement can be reduced.

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